OPUS

AVON RIVER PRECINCT

YEAR ONE POST REHABILITATION WORK

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1 Executive Summary

The Christchurch City Council (CCC) contracted Opus International Consultants to repeat an ecological survey of the Avon River that had been carried out prior to rehabilitation works undertaken as part of the development of the Avon River Precinct (ARP). The main aim of the repeat study was to determine how rehabilitation works had changed the ecology of the river.

Physical habitat variables, basic water chemistry, macroinvertebrates and fish were assessed at three reference sites and five rehabilitation sites, repeating the methods undertaken in the baseline survey. Comparisons were then made between the reference and rehabilitation sites, and each site was also compared to that recorded during the baseline survey.

Few trends were consistent across study sites and between reference and rehabilitation sites. The most notable change was an improvement in substrate quality at the rehabilitation sites compared to the baseline, as a result of the removal of large amounts of fine sediment. Rehabilitation sites had coarser substrate, significantly less fine sediment and were less embedded than the reference sites. Embeddedness measurements were subjective to surveyor interpretation, and therefore these changes are not considered to be ecologically significant. Other variables, including macrophyte and periphyton coverage, velocity and width demonstrated reach scale changes with individual study sites differing to the baseline data across both individual reference and rehabilitation sites; however, there was no consistent pattern of improvement or degradation across the study area.

Macroinvertebrate communities were significantly different between surveys and between reference and rehabilitation sites however changes were driven by the changes in abundance of a small number of non-sensitive species. Abundance and taxa richness increased for the Year 1 survey however there were no differences in abundance, richness, EPT or QMCI between reference and rehabilitation sites during the Year 1 survey.

There was a significant change in the fish community composition (relative abundance of fish species caught) between surveys and between reference and rehabilitation sites. In addition one new species, the lamprey, was discovered in the rehabilitation area at 'Watermark' (Rehabilitation Site 1). Lampreys have a national threat status of 'Threatened - Nationally Vulnerable' and have only occasionally been recorded in the Avon River catchment. There was no difference in the catch per unit effort (fish abundance) between surveys and there was no statistical interaction between survey year and reference and rehabilitation sites suggesting that there has been no change to fish abundance as a result of the rehabilitation works.

Overall, there are possible trends of improvement at rehabilitation sites in a number of variables including substrate, velocity, fish abundance and macroinvertebrate diversity and macroinvertebrate abundance, and no obvious declines in measured variables. However, there were variable times of completion for the restoration works, with some of the downstream sites only finished four months prior to the Year 1 survey taking place. Therefore, it is considered too early to say definitively if changes have occurred. After the conclusion of the next monitoring survey it will be possible to establish if any trends in the physical and biotic variables are becoming apparent. Until more monitoring has been carried out it is not possible to comment on the relative success of the rehabilitation works in achieving the project objectives.

2 Background

As part of the redevelopment of Christchurch City following the Canterbury earthquake events of 2010 and 2011, a portion of the Avon River (approximately three km of the 14km total length) is undergoing redevelopment and rehabilitation as part of the larger Avon River Precinct (ARP) project. Works include both instream and riparian works with some of the goals being to return the river to a more natural state and to improve the habitat quality that the river provides.

In-river works included removal of fine sediments, creation of riffle/run/pool habitats, river narrowing, and creation of vegetated flood plains within the existing river channel. Riparian work includes planting, landscaping and linking the river with the urban environment but has yet to be completed in most locations.

The Avon River runs through central Christchurch in a predominantly easterly direction before discharging to the coast through the Avon-Heathcote Estuary. It is spring fed with the main tributaries being the Wairarapa Stream, Waimairi Stream, Dudley Creek, Riccarton Stream and Addington Brook.

Prior to rehabilitation works, and in the reaches of river not included in the ARP project, the river is heavily influenced by the surrounding city environment and waterways, through urban runoff, receiving stormwater and most of the banks are maintained as park like grounds with mown lawn and ornamental plants and specimen trees. The river received large inputs of liquefaction silt during the 2010 and 2011 Canterbury earthquakes. This added to the fine sediment already present in much of the river. Cobble habitat was uncommon throughout the river.

A baseline survey conducted by Boffa Miskell carried out post-earthquakes but prior to rehabilitation concluded the Avon River generally had degraded habitat conditions, modified channels and low habitat diversity. The invertebrate community was typical of a highly modified urban catchment and was dominated by non-sensitive taxa. Indices of ecological health based on macroinvertebrate communities indicated a river with poor water quality and low ecological health.

It is expected the rehabilitated section of the Avon River will demonstrate some changes in physical habitat variables due to the rehabilitation works that were carried out. However, whether the works equate to a change in biotic variables such as macroinvertebrate and fish communities is less clear, especially in the early stages following the works. Biotic communities are influenced by a number of catchment wide variables such as landuse, and urban runoff among other things. These aspects have not been altered as part of the rehabilitation works.

3 Scope

CCC contracted Opus International Consultants to carry out a follow up ecological survey of the Avon River repeating the same methodology and site locations as an earlier baseline survey that was carried out by Boffa Miskell in October and November 2013. This earlier survey was done prior to in-river works being carried out to rehabilitate portions of the river. The main purpose of this work was to determine if there have been any changes in ecological values as a result of the instream works. This was to be determined by:

- Describing the current physical habitat;
- Describing the current biology including macroinvertebrates and fish communities;
- Comparing results (a) between reference and rehabilitation sites, and (b) with data from the baseline survey, to determine if any changes have occurred; and
- Discussing any reasons for any observed changes.

4 Methods

4.1 Site Locations

Sampling occurred at eight sites on the Avon River. These sites had been previously determined and encompass the same sites as used in the baseline survey (Boffa Miskell 2014). The sites included three 'reference' sites located upstream of the ARP and five 'rehabilitation' sites within the ARP footprint. The reference sites were selected to be representative of the habitat at the rehabilitation sites prior to instream works being undertaken.

The eight sites and their locations are given in Table 1 and Figure 1.

Table 1: Site name, site number and NZMG coordinates of each site surveyed

Site Name	Site Number	Northing (NZMG)	Easting (NZMG)
Avon River downstream of Mona Vale Weir	Reference Site 1	5742492	2478634
Avon River at Carlton Mill Corner	Reference Site 2	5742834	2479764
Avon River in Hagley Park	Reference Site 3	5742010	2479390
Avon River at Watermark[1]	Rehabilitation Site 1	5741381	2480031
Avon River at Rhododendron Island	Rehabilitation Site 2	5741385	2480253
Avon River at Hereford Street	Rehabilitation Site 3	5741648	2480397
Avon River at Victoria Square	Rehabilitation Site 4	5742085	2480498
Avon River near Kilmore Street	Rehabilitation Site 5	5742329	2481261

It is noted that there was some confusion regarding the location of Rehabilitation Site 1. Based on detailed conversations between the CCC (Belinda Margetts, Waterways Ecologist) and the consultant who undertook the baseline survey (Tanya Blakely at Boffa Miskell Ltd), this site during the baseline study included part of the constructed riffle at the upstream most point of the Watermark Precinct near the Antigua Boatsheds. However, the GPS coordinates provided in the baseline report located the study reach downstream of this riffle. After discussion with CCC, the entire survey site was moved approximately 60 metres upstream to ensure the constructed riffle was encompassed allowing comparisons between the baseline survey and this survey to be conducted. However, caution must be exercised when comparing the data generated by this study with that of the baseline report for Rehabilitation Site 1 due to moving the study site.

For Rehabilitation Site 1 (Watermark), the survey undertaken during the baseline was not technically 'before' data, as instream and riparian works were completed in May 2013 (Martin Ridgway, CERA, personal communication, September 2014) prior to the baseline survey being carried out. This site was still included in the surveys to assess how the site changes as the time since rehabilitation increases. This has been taken into consideration during the analyses (i.e. this site is equivalent to two years post rehabilitation). This site was the first site to undergo restoration

[1] The Baseline survey designates this site as "Avon River near Durham Street" however this site is at a point designated the "Watermark Precinct" and therefore this is considered a more accurate site name.

within the ARP. Table 2 contains a summary detailing when rehabilitation works were carried out and the time between works completion and the Year 1 survey.

Assessments took place between March 25 and April 1 2015, with the exception of Rehabilitation Site 1 which was surveyed on April 17 as a result of re-surveying the site at the more accurate location. In comparison, the baseline survey was conducted in November. The reason for this variation in sampling time was due to the timeframe to complete the instream works and ensuring this survey was one-year post rehabilitation. Any likely influence of these slightly different sampling times are discussed throughout the report.

Table 2: Details for time rehabilitation works occurred, timing of Baseline and Year 1 surveys, and time between rehabilitation works and the Year 1 survey

Site Name	Time of Works	Baseline Survey	Year 1 Survey	Time Since Works
Reference Site 1	NA	October/November 2014	March 2015	NA
Reference Site 2	NA	October/November 2014	March 2015	NA
Reference Site 3	NA	October/November 2014	March 2015	NA
Rehabilitation Site 1	May 2013	October/November 2014	April 2015	23 months
Rehabilitation Site 2	May 2014	October/November 2014	March 2015	11 months
Rehabilitation Site 3	April 2014	October/November 2014	March 2015	12 months
Rehabilitation Site 4	May 2014	October/November 2014	March 2015	11 months
Rehabilitation Site 5	November 2014	October/November 2014	March 2015	4 months

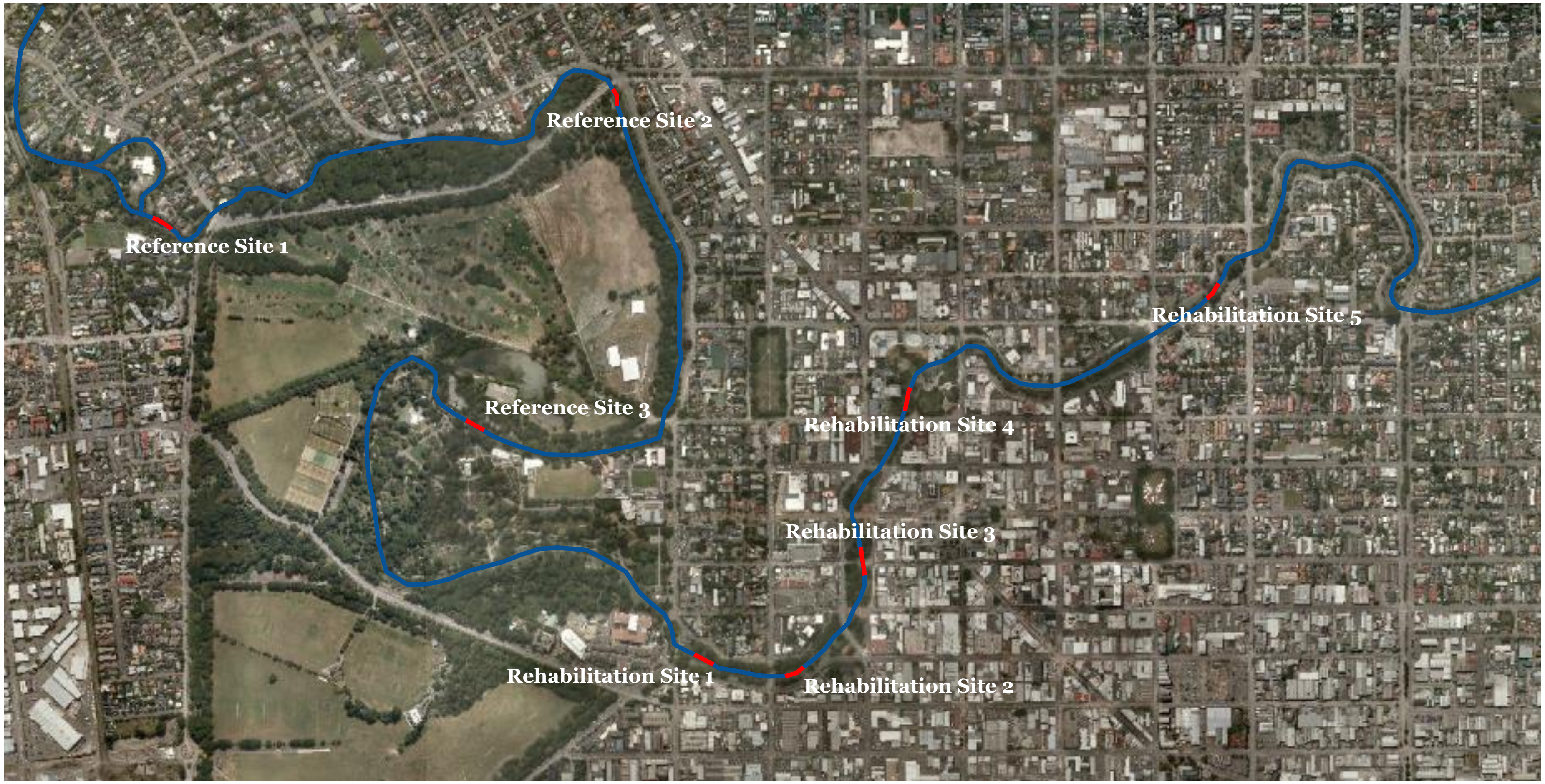

Figure 1: Map of the Avon River (blue line) showing the location of the study sites (red sections)

4.2 Habitat Assessment

At each of the study sites, a number of habitat variables were assessed. Spot measurements of basic water quality parameters were taken. These parameters included water temperature, pH, dissolved oxygen, and conductivity and were measured with a Horiba multi-parameter probe. Velocity was also recorded at three randomly selected locations within the study reach. Random numbers were used to determine a distance downstream from the first transect and a distance from the bank to measure velocity. Velocity measurements were taken using the 'Ruler Method' as described in Drost (1963) and Harding et al. (2009).

Three equally spaced transects, at 10 metre intervals, were established across the full width of the river at each site. The first of these transects was at the location given in Table 1 (more detailed location descriptions are provided in Appendix 1) with the second being 10 metres upstream of this point and the third being 20 metres upstream of the location. This established a 20 metre reach.

At each of the three transects the following variables were measured and recorded on riparian margins of the true left (TL) and true right (TR):

- Total wetted width – distance from the edge of the wetted margin on the TL bank to the edge of the wetted margin on the TR bank (to give an average wetted width for each site)
- Percent canopy cover
- Bank undercutting (if present)
- Overhanging vegetation
- Percent ground cover
- General riparian conditions

The following parameters were measured and recorded on the TL, TR (30cm from the water's edge) and mid channel at each of the three transects:

- Water depth
- Soft sediment depth (measured by gently pushing a metal ruler into the substrate until it hit the harder substrates below)
- Substrate composition (percent sand (<2mm), gravel (3-16mm), pebbles (17-64mm), small cobbles (65-128mm), large cobbles (129-256mm), and boulders(>257mm) within a bathyscope window of approximately 300mm in diameter)
- Macrophyte cover
- Macrophyte depth
- Type (emergent or submerged) and dominant species of macrophyte
- Percent cover of organic material (leaves, coarse wood debris, moss)
- Percent cover and type of periphyton (short filamentous, long filamentous, thin mat or thick mat in either green or brown periphyton) within a bathyscope window

Additional instream and riparian habitat variables were assessed at each of the three reference and five rehabilitation sites using the following standard protocols:

- Protocol 3 (P3) Quantitative Protocol from Harding et al. (2009)

  » P3b: Hydrology and morphology procedure – completed by Environment Canterbury hydrologists[2]
  » P3c: In-stream habitat procedure – completed by Opus ecologists
  » P3d: Riparian procedure – completed by Opus ecologists

- Sediment Assessment Methods from Clapcott et al. (2011)

  » Sediment Assessment Method 2 – instream visual estimate of percent cover
  » Sediment Assessment Method 6 – sediment depth

These assessments measured a range of instream and riparian habitat conditions across either five or six transects in each survey reach. The P3 protocols specify transects should have two transects placed in each of riffle, run and pool habitat. The habitat in the Avon River made this difficult as the majority of the reaches were runs or slow riffles, pools were uncommon and not present at all sites. Therefore the six transects for this protocol were placed at equal 10 metre intervals with the first transect placed at the location given in Table 1 and the remaining five placed at 10 metre intervals upstream (Figure 2). This was the same method utilised for the baseline survey.

It should be noted, the Baseline embeddedness data ranges from 1 to 5, however the methods accompanying this data state a scale of 1 to 4 should be used with 4 indicating substrates are heavily embedded. A scale of 1 to 4 has been used for this survey.

Photographs were taken throughout the reach.

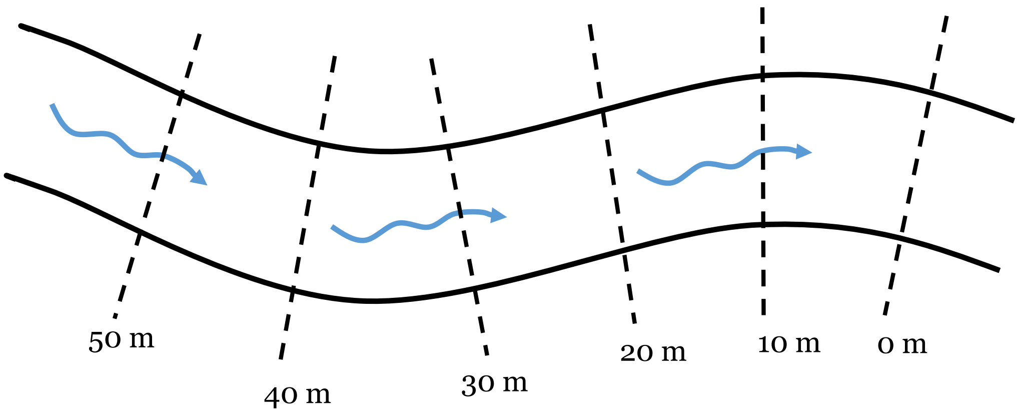

Figure 2: Illustration showing how transects were spaced along the reach

[2] Data was collected by ECan staff members and provided to Opus for inclusion in this report. All width, depth, discharge and velocities measurements were taken and provided by ECan.

4.3 Macroinvertebrate Community Assessment

The use of macroinvertebrates (insects, snails, worms that live in a streams and rivers) for assessing the condition of streams is widespread in New Zealand and overseas. Macroinvertebrates can be present in streams in large numbers and they are an important part of stream food webs and overall habitat function. The structure and composition of macroinvertebrate communities is a good indicator of stream condition as they are found in almost all freshwater environments, are relatively easy to sample and identify, and different taxa show varying degrees of sensitivity to pollution and habitat conditions.

Five surber samples ($0.05m^2$, 500µm mesh) were collected at each of the sites. A surber sample allows the number of invertebrates collected per a specified area to be determined. Samples are taken by disturbing the substrate within the base frame. This frame is a known area allowing the results to be extrapolated to a number of individuals per square metre (or other area). The five samples were collected from randomly selected locations within either a riffle or run. The substrate was disturbed to a depth of approximately 5cm.

In addition, a single kick net sample was collected from each site in accordance with protocols C1 and C2 from Stark et al. (2001). Using these protocols, approximately $0.6m^2$ of the stream bed was sampled including the microhabitats present (e.g. stream margin, mid channel, macrophytes, woody debris etc.) with the unit of effort in proportion to the microhabitat presence in the stream. Sampling in this way maximises the chance of collecting every species of macroinvertebrate present at the site.

All macroinvertebrates were preserved in ethanol in separate, labelled containers before being delivered to Ryder Consulting for identification. Identification was undertaken using protocol P3 from Stark et al. (2001). Further details can be found in Appendix 2.

4.4 Fish Community Assessment

The fish community was assessed at each site between six and seven days following the habitat assessment (with the exception of Reference Site 1 where fishing occurred directly prior to habitat assessment). At each survey reach, the same distance was surveyed that was fished during the baseline survey in order to directly replicate the methods. These distances are given in Table 3. Each reach incorporated various habitat types that were present at each of the sites including, but not limited to, banks, macrophyte beds, mid channel, riffles and runs.

Table 3: Reach lengths fished during electric fishing survey

Site Name	Site Number	Length Fished (m)
Avon River downstream of Mona Vale Weir	Reference Site 1	75
Avon River at Carlton Mill Corner	Reference Site 2	30
Avon River in Hagley Park	Reference Site 3	40
Avon River at Watermark[3]	Rehabilitation Site 1	80
Avon River at Rhododendron Island	Rehabilitation Site 2	80
Avon River at Hereford Street	Rehabilitation Site 3	100
Avon River at Victoria Square	Rehabilitation Site 4	50
Avon River near Kilmore Street	Rehabilitation Site 5	50

Each survey reach was divided into many subsections of between two and five metres depending of the flow velocity. The subsections were then electrofished using multiple passes with a Kainga EFM 300 backpack mounted electrofishing machine (NIWA Instrument Systems). Fish were captured in a downstream push net or a hand net and were held in buckets until fishing had been completed. All fish captured were identified and measured before being returned to the river. The habitat from which the fish were retrieved was also noted.

A portion of Rehabilitation Site 2 was unable to be fished as the river was too deep at this location. Here, the edges of the pool were fished with the hand net being utilised to retrieve fish from the pool where possible.

4.5 Data Analysis

4.5.1 Habitat

Averages were generated for each site for the following parameters to give one value per site:

- Water depth
- Substrate composition
- Percent macrophyte cover
- Percent periphyton
- Soft sediment
- Macrophyte depth
- Percent organic cover

Substrate composition was transformed into a single value using a substrate index (SI). This index was used in the baseline survey and was adapted from Jowett and Richardson (1990). The formula for the SI is as follows:

$$SI = (0.06\ \%boulder) + (0.05\ \%large\ cobble) + (0.04\ \%small\ cobble) + (0.03\ \%pebble) + (0.02\ \%gravel) + (0.01\ \%silt/sand)$$

[3] The Baseline survey designates this site as "Avon River near Durham Street" however this site is at a point designated the "Watermark Precinct" and therefore this is considered a more accurate site name.

The SI value will be between one and six, with an SI of one indicating a substrate consisting of 100% silt/sand and an SI of 12 indicating a boulder substrate. Larger substrates (larger SI value) generally provide better quality habitat for macroinvertebrate and fish species. At two of the sites (Reference Sites 1 and 2) large quantities of macrophytes covered the stream bed and no substrate was visible meaning substrate composition could not be assessed. Where this has occurred, an SI of one has been given as macrophytes are generally associated with finer substrate (Grinberga 2010) and are capable of trapping fine sediments (Riis & Biggs 2003).

Several measures of substrate embeddedness at the rehabilitation sites could not be determined due to extensive macrophyte coverage and depth. As a result of this, embeddedness measurements for the rehabilitation sites during the Year 1 survey have been excluded and therefore comparisons could not be made.

Results from the P3c protocols were computed into percentages of the wetted widths in order to allow for comparison between the two years. For example for on transect 1 at Rehabilitation Site 1, macrophytes covered 670 cm of the 1120 cm wetted width. This equates to macrophytes covering 59.8% of the wetted width at this transect.

The various habitat variables were statistically compared using two-way ANOVA's on the raw data to determine if there was a difference between the results from the baseline and year one surveys, and between reference and rehabilitation sites, and to determine if there was any interaction between the years and the sites. Where an interaction between year and site was significant it indicated there was likely an effect of the rehabilitation works on the specified variable. Response variables included the habitat variables measured during the surveys and the predictor variables included the year (Baseline or Year 1) and site (reference or rehabilitation). Where appropriate, data was log transformed to satisfy the assumptions of normality and homogeneity of variance. ANOVA's were carried out using R version 3.2.0 (The R Foundation for Statistical Computing 2015).

Spearman's rank correlation was carried out on the Year 1 rehabilitation site sediment cover data to determine if there was a relationship between sediment cover and the distance downstream from Rehabilitation Site 1. This data was also graphed.

4.5.2 Macroinvertebrate Community

The following ecological indices were used to assess the biological health of the river:

Macroinvertebrate abundance – the average number of individuals collected in each sample. As the number of individuals fluctuates with water and habitat quality, comparisons between sites and surveys can be useful.

Taxa Richness: This is a measure of the types of invertebrate taxa present in each sample. Generally in streams, the greater the numbers of taxa present, the higher the quality of the environment.

EPT and % EPT (Ephemeroptera-Plecoptera-Trichoptera). This measures the number of pollution sensitive mayfly, stonefly and caddisfly (EPT) taxa in a sample excluding Oxyethira and Paroxyethira (which are pollution-tolerant EPT). A high EPT number is indicative of good water and habitat quality.

Macroinvertebrate Community Index (MCI). The MCI is an index for assessing the water quality and 'health' of a stream using the presence/absence of benthic macroinvertebrates (Stark 1985).

Quantitative MCI (QMCI). The QMCI is similar to the MCI but utilises quantitative data (i.e. takes into consideration abundance of species). The QMCI is designed to be particularly sensitive to changes in the relative abundance of individual taxa within a community (Stark 1993, Stark 1998).

The MCI score was developed for streams with stony substrate. Slow flowing streams with softer substrates typically favour macroinvertebrate communities with lower scores regardless of the water and habitat quality. Alternative versions have been developed for soft bottomed stream called the MCI-sb and QMCI-sb (Stark and Maxted 2007).

The MCI and QMCI reflect the sensitivity of the macroinvertebrate community to pollution and habitat quality, with higher scores indicating better stream health and higher water quality. Quality classes for different MCI and QMCI scores are shown in Table 4.

Table 4: MCI and QMCI scores and associated quality class and descriptions

Quality Class	**Descriptions** (Stark & Maxted 2007)	**MCI**	**QMCI**
Excellent	Clean water	>120	>6.0
Good	Doubtful quality or possible mild pollution	100-120	5.0-6.0
Fair	Probable moderate pollution	80-100	4.0-5.0
Poor	Probable severe pollution	<80	<4.0

Macroinvertebrate indices for Baseline and Year 1 surveys, reference and rehabilitation sites and the interaction between year and site, were statistically compared using two-way ANOVAs. Data was log transformed where appropriate to meet the assumptions of normality and homogeneity of variance.

A non-metric multidimensional scaling (NMDS) ordination with 1000 random permutations was calculated for the Baseline and Year 1 macroinvertebrate community data. Ordinations are particularly useful for identifying differences and similarities between biotic communities. NMDS ordinations arrange data along gradients so that the distance between points on an ordination plot represent community dissimilarity. The Bray-Curtis dissimilarity method was used to determine dissimilarity scores. Data can then be plotted on a scatter plot with those points that are closest together considered to be more similar in community composition when compared to points that are far apart.

Two-way crossed analysis of similarities (ANOSIM) with 100 permutations was then carried out to determine if patterns of dissimilarity in the NMDS data were significant.

If ANOSIM results revealed a significant difference in community composition between surveys or reference or rehabilitation sites, similarity percentages (SIMPER) were calculated. SIMPER calculates the percentage contribution of each taxon to the dissimilarities between pairs of sites and groups. SIMPER results indicate which taxa are responsible for the differences between sites and groups.

NMDS, ANOSIM and SIMPER analyses were carried out using Primer version 7.

4.5.3 Fish Community

A ‘catch per unit effort’ (CPUE) value was calculated for each site. It is calculated using the following formula:

$$CPUE = \frac{Total\ number\ of\ fish\ caught}{Total\ area\ fished\ (m^2)}$$

This value is then extrapolated up to $100m^2$ to give a CPUE value expressed as the number of fish captured per $100m^2$. The time spent actively fishing (i.e. the time displayed on the ‘elapsed time’ display on the fishing machine) and the total distance fished at each site were also recorded.

CPUE results were compared using two-way ANOVA to determine if there was a difference between years and sites, and if there was an interaction between the two. CPUE data included both individual species data and a total CPUE per site.

Results were represented in a number of graphs – CPUE, community composition and species richness.

An NMDS ordination with 1000 random permutations was calculated for the Baseline and Year 1 fish species CPUE data. Two-way crossed ANOSIM with 100 permutations was then carried out to determine if patterns of dissimilarity in the NMDS data were significant.

5 Environmental Conditions

5.1 General Habitat Conditions

The ecological survey of the ARP has now been completed twice. This enables direct comparisons to be generated between Baseline and Year 1 data to determine if there have been any changes following rehabilitation works. With the addition of another survey, trends will begin to be identified.

Two-way ANOVA's were used to determine if there was an effect of the rehabilitation works on the habitat variable associated with the river. This was determined by a significant interaction term between the survey year and site (either reference or rehabilitation). A non-significant interaction suggests the rehabilitation works have had no effect.

As illustrated in Table 5, wetted width, water depth, discharge, substrate embeddedness (the degree substrates are embedded in fine sediment), substrate compactness (the degree to which the substrate is compacted ranging from 1-easily moved, to 4-tightly packed), sediment cover and pH decreased between the Baseline and Year 1 survey (tested with reference and rehabilitation sites combined), while water temperature increased. The changes in the hydrological variables (width, depth and discharge) are likely a result of the Year 1 survey being undertaken following a particularly dry summer when the river was low. This is further discussed in Section 6.3. There were no changes detected for water velocity, substrate index, macrophyte coverage or conductivity. The Year 1 survey found less fine sediment, likely as a result of the works in the rehabilitation reaches. This is discussed further below. The changes in temperature and pH are likely due to the difference in sampling time between the baseline survey and this survey. As they are spot measurements, their differences cannot be interpreted as ecologically significant without a more intensive monitoring regime. Additional detailed comparisons of Baseline data to Year 1 data are presented for each site within Section 5.2 (Individual Site Descriptions and Changes from Baseline).

There were four variables that differed significantly between reference and rehabilitation sites (tested with both years data combined) (Table 6). The SI, discharge and pH were significantly greater at the rehabilitation sites compared to the reference sites, while macrophyte coverage was lower at the rehabilitation sites. The increase in discharge is to be expected as the rehabilitation sites are located downstream of the reference sites and therefore have more inputs of groundwater and runoff. The increase in SI and decrease in macrophyte coverage suggest the in-river works have had some effect however the interaction significance between year and site indicates if these are changes are ecologically significant.

Table 5: Comparisons of Baseline and Year 1 data indicating if any change was detected, Two-way ANOVA F value (with degrees of freedom), and p significance value

	Baseline mean	Year 1 mean	Change	$F_{(df)}$	P
Water Velocity[4]	0.47	0.49	No change	$0.087_{(1,92)}$	0.769
Wetted Width[4]	11.73	10.27	Year 1 lower	$4.809_{(1,92)}$	0.031
Water Depth[4]	0.38	0.32	Year 1 lower	$4.118_{(1,92)}$	0.045
Discharge[4]	1.82	1.35	Year 1 lower	$43.683_{(1,92)}$	<0.001
Embeddedness	2.11	1.42	Year 1 lower	$89.893_{(1,957)}$	<0.001
Substrate Index	2.41	2.53	No change	$0.630_{(1,140)}$	0.429
Substrate Compactness	3.44	2.17	Year 1 lower	$47.943_{(1,92)}$	<0.001
% Macrophyte Coverage	30.72	36.54	No change	$1.015_{(1,92)}$	0.316
% Sediment Cover	30.05	13.41	Year 1 lower	$36.181_{(1,316)}$	<0.001
Water Temperature	10.91	14.6	Year 1 greater	$61.217_{(1,12)}$	<0.001
pH	8.56	7.86	Year 1 lower	$23.014_{(1,12)}$	<0.001
Conductivity	178	188	No change	$1.573_{(1,12)}$	0.234

Table 6: Comparisons of reference and rehabilitation site data indicating if any difference was detected, Two-way ANOVA F value (with degrees of freedom), and p significance value

	Reference mean	Rehabilitation mean	Difference	$F_{(df)}$	P
Water Velocity[4]	0.45	0.50	No difference	$1.456_{(1,92)}$	0.231
Wetted Width[4]	10.36	11.38	No difference	$2.771_{(1,92)}$	0.099
Water Depth[4]	0.35	0.35	No difference	$0.013_{(1,92)}$	0.908
Discharge[4]	1.46	1.66	Rehabilitation greater	$7.274_{(1,92)}$	0.008
Embeddedness	1.79	1.75	No difference	$0.011_{(1,957)}$	0.915
Substrate Index	2.12	2.68	Rehabilitation greater	$10.931_{(1,140)}$	0.001
Substrate Compactness	2.86	2.77	No difference	$0.161_{(1,92)}$	0.689
% Macrophyte Coverage	48.0	25.0	Rehabilitation lower	$14.884_{(1,92)}$	<0.001
% Sediment Cover	25.07	19.72	No difference	$1.685_{(1,316)}$	0.195
Water Temperature	12.37	12.99	No difference	$2.063_{(1,12)}$	0.177
pH	8.04	8.32	Rehabilitation greater	$3.443_{(1,12)}$	0.088
Conductivity	187.6	180.37	No difference	$0.822_{(1,12)}$	0.383

[4] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Table 7: Results from the interaction term of the two-way ANOVA demonstrating if there was a significant interaction between the surveys and between the sites. Two-way ANOVA F values (with degrees of freedom), and p significance values are given.

	Baseline Reference mean	Baseline Rehabilitation mean	Year 1 Reference mean	Year 1 Rehabilitation mean	Significant interaction?	$F_{(df)}$	P
Water Velocity[5]	0.52	0.44	0.38	0.55	Yes	$10.252_{(1,92)}$	0.002
Wetted Width[5]	10.67	12.86	10.85	10.91	No	$2.729_{(1,92)}$	0.102
Water Depth[5]	0.35	0.39	0.35	0.31	No	$2.234_{(1,92)}$	0.138
Discharge[5]	1.69	1.90	1.24	1.42	No	$0.097_{(1,92)}$	0.757
Embeddedness	2.36	1.96	-	1.54	Yes	$31.936_{(1,957)}$	<0.001
Substrate Index	2.47	2.38	1.78	2.99	Yes	$13.426_{(1,140)}$	<0.001
Substrate Compactness	3.72	3.27	2.0	2.27	Yes	$4.959_{(1,92)}$	0.028
% Macrophyte Coverage	39.8	25.28	56.2	24.74	No	$2.026_{(1,92)}$	0.158
% Sediment Cover	30	30.08	20.15	9.36	No	$0.733_{(1,316)}$	0.393
Water Temperature	10.07	11.42	14.67	14.56	No	$2.771_{(1,12)}$	0.122
pH	8.40	8.65	7.67	7.98	No	$0.046_{(1,12)}$	0.834
Conductivity	190.87	170.54	184.33	190.2	No	$2.308_{(1,12)}$	0.155

[5] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

There were a small number of significant interactions between the year of the survey and the site data was collected from (Table 7). Substrate compactness, embeddedness and the SI all presented significant interactions between year and site. This, coupled with significant differences between years or between reference and rehabilitation sites suggest the rehabilitation works have affected these habitat variables. Large amounts of fine sediment were removed from the river during works and coarse substrate was added in some locations which supports the statistical findings. There was also a significant interaction for velocity. Part of the rehabilitation sites involved narrowing the river which in turn increases velocity. Comparisons of reference and rehabilitation sites between the two surveys are given below.

Table 8: Comparisons of results generated from the reference sites for both the Baseline and Year 1 survey. Any changes are indicated along with ANOVA F value (degrees of freedom) and p significance value

	Baseline Reference mean	Year 1 Reference mean	Change	$F_{(df)}$	P
Water Velocity[6]	0.52	0.38	Year 1 lower	$8.80_{(1,34)}$	0.005
Wetted Width[6]	10.67	10.85	No change	$0.11_{(1,34)}$	0.75
Water Depth[6]	0.35	0.35	No change	$0.004_{(1,34)}$	0.95
Discharge[6]	1.69	1.24	Year 1 lower	$26.22_{(1,34)}$	<0.001
Embeddedness	2.36	-	-	-	-
Substrate Index	2.47	1.78	Year 1 lower	$4.53_{(1,52)}$	0.38
Substrate Compactness	3.72	2.0	Year 1 lower	$51.94_{(1,34)}$	<0.001
% Macrophyte Cover	39.8	56.2	No change	$3.11_{(1,34)}$	0.09
% Sediment Cover	30	20.15	Year 1 lower	$7.55_{(1,117)}$	0.007
Water Temperature	10.07	14.67	Year 1 greater	$268.1_{(1,4)}$	<0.001
pH	8.40	7.67	Year 1 lower	$25.41_{(1,4)}$	0.007
Conductivity	190.87	184.33	Year 1 lower	$17.81_{(1,4)}$	0.01

[6] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Table 9: Comparisons of results generated from the rehabilitation sites for both the Baseline and Year 1 survey. Any changes are indicated along with ANOVA F value (degrees of freedom) and p significance value

	Baseline Rehabilitation mean	Year 1 Rehabilitation mean	Change	$F_{(df)}$	P
Water Velocity[7]	0.44	0.55	Rehabilitation greater	$3.95_{(1,58)}$	0.05
Wetted Width[7]	12.86	10.91	Rehabilitation lower	$5.07_{(1,58)}$	0.03
Water Depth[7]	0.39	0.31	Rehabilitation lower	$5.94_{(1,58)}$	0.02
Discharge[7]	1.90	1.42	Rehabilitation lower	$21.59_{(1,58)}$	<0.001
Embeddedness	1.96	1.54	Rehabilitation lower	$15.51_{(1,598)}$	<0.001
Substrate Index	2.38	2.99	Rehabilitation greater	9.90	0.002
Substrate Compactness	3.27	2.27	Rehabilitation lower	$14.32_{(1,58)}$	<0.001
% Macrophyte Cover	25.28	24.74	No change	$0.09_{(1,58)}$	0.77
% Sediment Cover	30.08	9.36	Rehabilitation lower	$31.59_{(1,198)}$	<0.001
Water Temperature	11.42	14.56	Rehabilitation greater	$18.66_{(1,8)}$	0.003
pH	8.65	7.98	Rehabilitation lower	$10.23_{(1,8)}$	0.013
Conductivity	170.54	190.2	No change	$2.47_{(1,8)}$	0.15

The reference sites did demonstrate some significant changes in habitat variables between the two surveys (Table 8) despite no works being carried out in them. This is likely the result of natural variation in the river bought on by climatic and anthropogenic influences. Velocity decreased, possibly due to the low river flows at the time of the Year 1 survey. Physico-chemical measurements also varied, however this is to be expected as the surveys were undertaken during a different time of year.

Several changes were revealed when comparing the rehabilitation site data for the Baseline and Year 1 surveys (Table 9). There was a significant decrease in the width of the rehabilitation sites. This was a direct result of the in-river works where the creation of artificial floodplains narrowed the base flow channel. Decreasing the width of the channel should increase flow velocity as the same volume of water flows through a smaller channel. Increased velocity can reduce fine sediment deposition, macrophyte and periphyton growth and improve habitat quality for macroinvertebrates and fish (Bunn & Arthington 2002). The increase in velocity at the

[7] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

rehabilitation sites in the Year 1 survey compared to the reference sites suggests the narrowing has increased water velocity.

Water depth decreased, again likely due to the particularly dry summer that preceded the Year 1 survey. The SI increased significantly as a result of the rehabilitation works removing large amounts of silt and the addition of course substrates at some sites. A decrease in fine sediment cover supports the increase in SI. Embeddedness and compactness both decreased between the Baseline and Year 1 survey however while statistically significant, this change is not necessarily ecologically significant. Both measurements are subjective and therefore open for interpretation by the surveyor. This is further discussed in Section 6.4. Macrophyte coverage did not change.

There were some changes in the physico-chemical data, however this was not unexpected. Even the most upstream reference site still has a significant part of the Avon Rivers catchment upstream and therefore the measurements downstream are a product of this. In addition, all eight study sites are located within approximately six km of each other and are all within an urban catchment. Results were generally similar to those collected by CCC for their latest surface water quality monitoring report (CCC 2015). Mean results for the site closest to the areas in this study (Avon at Carlton Corner) were: water temperature, mean 13.46°C; pH 7.68; and conductivity, mean 167 µS/cm. Temperature and pH values are below trigger values presented in the Proposed Canterbury Land and Water Regional Plan (ECan 2013).

5.2 Individual Site Descriptions and Changes from Baseline

5.2.1 Reference Site 1: Avon River downstream of Mona Vale weir

Reference Site 1 was the most upstream site in this study. It was located downstream of the Mona Vale weir. At the site, the river was on average 8m wide and 35 cm deep and was not significantly different to the baseline dimensions. Velocity on the day of sampling was slower than baseline velocity. Table 10 presents results comparing Baseline and Year 1 habitat variables.

The TR bank is located on Christchurch Girls' High School grounds and is well vegetated with *Carex secta*, flax (*Phormium tenax*) and various other native plants. Parts of the banks are supported by gabion baskets that are well covered by the existing vegetation. Most of the TL bank contains private residences with the exception of approximately 15 metres where Wood Lane terminates. The TL bank was a mixture of mown grass, garden shrubs and retaining wall. Where Wood Lane terminates, large boulders have been placed at the toe of the bank, likely to protect the bank in high flows.

Emergent monkey musk (*Erythranthe guttata*) was abundant along the length of the reach. Other macrophytes at the site include submerged *Myriophyllum propinquum*, *Elodea canadensis* and *Potamogeton crispus*. *P. crispus* was dominant in the channel. Species composition and dominance had not appeared to change. Macrophyte coverage had not changed significantly since the baseline survey.

Organic cover was largely absent with no change compared to the baseline data ($F_{1,16}$=1, p=0.33). The SI was lower than the baseline data however this is likely the result of the extensive macrophyte coverage leaving little of the substrate exposed and possible variation in the specific siting of the six study transects between the surveys. In the parts of the channel where the substrate was exposed, the substrate was predominantly sand and pebbles. Velocity had also decreased which likely contributed to the increase in fine sediment cover and the lower SI.

Substrates were slightly embedded and this embeddedness had decreased from the previous survey. Where there was no macrophyte coverage, the substrate was predominantly sand. The substrates were moderately compacted and compactness had decreased compared to the baseline survey. There were no leaf packs present on any of the transects and no woody debris, compared with minimal amounts present during the baseline survey. Leaf packs are accumulations of leaves (>10cm^2) within the channel. Further details regarding assessing leaf packs can be found in the P3c protocols of Harding et al. (2009). Boulders and wood jams were present during both surveys, though in very small numbers.

Table 10: Summary statistics for Reference Site 1

Variable		Baseline mean	Year 1 average	Change	F (DF)	P
Width[8]	m	8.17	7.72	No change	$0.42_{(1,10)}$	0.53
Depth[8]	m	0.33	0.35	No change	$0.53_{(1,10)}$	0.48
Velocity[8]	m/s	0.63	0.45	Year 1 lower	$8.06_{(1,10)}$	0.02
Macrophyte Cover	%	63.8	65.8	No change	$0.12_{(1,10)}$	0.73
Periphyton Cover	%	16.27	1.55	Year 1 lower	$7.90_{(1,10)}$	0.02
Substrate Index		2.60	1.59	Year 1 lower	$1_{(1,16)}$	0.03
Sediment Cover	%	9.18	26.75	Year 1 greater	$5.15_{(1,38)}$	0.03
Embeddedness		2.32	1.3	Year 1 lower	$28.98_{(1,118)}$	<0.001
Compactness		3.83	2.5	Year 1 lower	$19.7_{(1,10)}$	<0.001

Photo 1: Reference Site 1 looking upstream towards the Mona Vale weir

[8] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 2: Reference Site 1 looking downstream

5.2.2 Reference Site 2: Avon River at Carlton Corner

Just downstream of the Carlton Corner is the second reference site. This site is located in the north east corner of Hagley Park with the park on the TR of the river. At Reference Site 2 the river is on average 50cm deep and 11.53m wide, with velocity on the day of sampling being 0.28m/s. Depth and width were not significantly different to the baseline measurements but velocity had decreased. The decrease in velocity may be due to the river being low due to a prolonged summer period with no significant rainfall, but this is not supported by the wetted width and water depth, which had not altered significantly from the baseline. Macrophyte coverage had increased significantly though, with in excess of 50% of the bed covered. High percentages of macrophyte coverage often reduce flow velocity (Madsen et al. 2001). Table 11 presents summary habitat comparisons for Reference Site 2 against the baseline.

The TR bank, the park side of the river, was predominantly long grass with some *Carex secta* and fern species. Further back are a number of mature exotic specimens associated with Hagley Park. The TL bank was also predominantly grassed and contained a number of *Carex secta* along with cabbage trees (*Cordyline australis*) and flax. On both banks the grass is obviously maintained to some degree. At the time of the survey there was an obvious line on both banks where grass is regularly mown to.

Macrophytes were extensive at this site covering in excess of 50% of the substrate. Macrophyte coverage had increased since the baseline survey. The dominant species was *P. crispus* with *E. guttata* on the wetted margins. Periphyton was not a major component of this site and coverage had not changed.

Organic cover increased between the baseline and year one survey ($F_{1,16}$=15.25, p=<0.01) however this may be a product of the time of year. The baseline survey was conducted in November while the year one survey was carried out at the end of March when leaves are starting to fall from deciduous trees. Depositional and scouring areas increased ($F_{1,10}$=21.86, p=<0.001).

The SI was lower than the baseline data however again, this is likely the result of the extensive macrophytes, in addition to large areas of fine sediment on the wetted margins. The substrate was almost entirely sand with small areas of pebbles and small cobbles. During the baseline survey, the substrate was predominantly gravels. The substrates were predominantly not embedded and not compacted. Both compactness and embeddedness had decreased compared to the baseline survey.

Table 11: Summary habitat comparisons for Reference Site 2

Variable		Baseline mean	Year 1 average	Change	F (DF)	P
Width[9]	m	10.6	11.53	No change	$2.10_{(1,10)}$	0.18
Depth[9]	m	0.39	0.47	No change	$0.82_{(1,10)}$	0.39
Velocity[9]	m/s	0.49	0.28	Year 1 lower	$9.94_{(1,10)}$	0.01
Macrophyte Cover	%	25.28	59.26	Year 1 greater	$5.99_{(1,10)}$	0.03
Periphyton Cover	%	18.19	13.57	No change	$0.77_{(1,10)}$	0.40
Substrate Index		2.46	1.23	Year 1 lower	$19.9_{(1,16)}$	<0.001
Sediment cover	%	33.63	18.13	Year 1 lower	$14.88_{(1,38)}$	<0.001
Embeddedness		1.92	1.1	Year 1 lower	$35.7_{(1,119)}$	<0.001
Compactness		3.33	1.33	Year 1 lower	$27.15_{(1,10)}$	<0.001

Photo 3: Reference Site 2 looking upstream towards Carlton Bridge

[9] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 4: Reference Site 2 looking downstream

5.2.3 Reference Site 3: Avon River in Hagley Park

The most downstream reference site was located within Hagley Park near the Armagh Footbridge entrance to the Christchurch Botanical Gardens. Wetted width and water depth had both decreased slightly, likely due to the hotter and drier time of sampling compared to the baseline (the summer was also generally drier than previous years), while velocity had not significantly changed. Table 12 presents a summary of the comparisons between habitat variables for Baseline and Year 1 data.

The TL bank is located on the Botanical Gardens side. The bank itself is supported by a brick/stone retaining wall but does have various plantings including *Carex secta*, flax and exotic garden species. The bank is predominantly grassed to the retaining wall with the grass being actively maintained. The TR bank was almost entirely long grass. As with Reference Site 2, this grass appeared to be maintained at least periodically as it was not rank. Both banks had substantial mature trees providing a good level of shade across most of the reach.

Macrophytes were present at the site and were heavily dominated by *P. crispus*. The species dominance, composition and bed coverage had not changed significantly since the baseline survey. Periphyton coverage, predominantly long and short brown filamentous, and long green filamentous had not changed. There was no organic cover present during either of the surveys.

The SI at Reference Site 3 could not be statistically separated from the baseline SI. The SI indicated the substrate was dominated by pebbles, with lesser amounts of small cobbles and sand/silt. Substrates were less embedded and less compacted than the baseline survey possibly due to differences between samplers. This is discussed further in Section 6.4.

Table 12: Summary of comparisons of Baseline and Year 1 habitat variables for Reference Site 3

Variable		Baseline mean	Year 1 average	Change	$F_{(DF)}$	P
Width[10]	m	13.24	12.13	Year 1 lower	$3.57_{(1,10)}$	0.09
Depth[10]	m	0.34	0.23	Year 1 lower	$6.76_{(1,10)}$	0.03
Velocity[10]	m/s	0.43	0.41	No change	$0.01_{(1,10)}$	0.93
Macrophyte Cover	%	30.07	33.5	No change	$0.14_{(1,10)}$	0.72
Periphyton Cover	%	12.89	10.22	No change	$1.01_{(1,10)}$	0.34
Substrate Index		2.34	2.52	No change	$0.4_{(1,16)}$	0.54
Sediment Cover	%	27.63	33.69	No change	$0.95_{(1,38)}$	0.34
Embeddedness		2.85	1.3	Year 1 lower	$54.17_{(1,118)}$	<0.001
Compactness		4	2.17	Year 1 lower	$93.2_{(1,10)}$	<0.001

[10] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 5: Reference Site 3 looking upstream

Photo 6: Reference Site 3 looking downstream

5.2.4 Rehabilitation Site 1: Avon River at Watermark

This site was located at Watermark, just downstream from the Antigua Boat Sheds. Here the river was on average 10.75m wide, 35cm deep and flowed at a velocity of 0.57m/s. These variables were not significantly different to the baseline reflecting the fact that works had already been completed when the baseline survey was carried out. Table 13 presents comparison results against the baseline.

On the TR bank, a number of exotic mature deciduous trees provide good shading. There were some *Carex secta* on the TR and in the upper part of the reach a flood plain has been constructed with boulders and native plantings (*Isolepis distigmatosa* (bristle sedge), *Schoenus pauciflorus* (bog sedge), *Juncus saraphorus, J. pallidus, J. gregiflorus* (wiwi), *Blechnum minus* (swamp kiokio)). The TL bank also had a constructed flood plain across part of the reach with establishing native wetland species. The upper reaches of the TL bank accommodated a board walk. Much of this boardwalk was located over the wetted area of the river providing excellent shading and refuges for native fish.

Macrophtyes were dominated by *P. crispus* with *M. propinquum* and *Nitella hookeri*. Coverage had increased significantly from only small patches of predominantly *M. propinquum*. However it appeared contractors had moved through the site and removed the bulk of the macrophytes prior to the assessment being carried out, meaning coverage was potentially greater prior to this. Higher macrophyte levels were recorded across Christchurch city waterways this summer compared to previous years, due to the drier summer exhibited in 2014/2015 (Belinda Margetts, Christchurch City Council, personal communication, June 2015). Periphyton was mostly long green filamentous however it was not a major component of the substrate, likely due to the ‘cleaning out’ of the water plants. Algal coverage had decreased compared to the baseline results however this may also be attributed to the removal of vegetation by contractors. Organic cover increased ($F_{1,16}$=12.88, p=0.002), however this was likely due to the year one survey being conducted in the autumn, whereas the baseline survey was carried out in spring.

The SI could not be statistically differentiated from the baseline results, however as the baseline survey was conducted after rehabilitation at this site, the SI was not expected to differ significantly with the exception of possible reaccumulation of fine sediment discussed below. The substrate was dominated by pebbles and small cobbles. Both embeddedness and compactness differed to the baseline data.

The baseline survey found on average 11% of the bed was covered in fine sediment compared to 24.8% during the year one survey. The increase in fine sediment was significant, as was the increase in fine sediment depth. This site is the most upstream rehabilitation site and is closest to potentially continuous source of sediment being carried from upstream where rehabilitation has not occurred. This increased sediment is likely a result of continual sediment accumulation over time. This is further discussed in Section 6.2.

Table 13: Comparisons of habitat variables for Baseline and Year 1 data for Rehabilitation Site 1

Variable		Baseline mean	Year 1 average	Change	$F_{(DF)}$	P
Width[11]	m	10.3	10.75	No change	$0.57_{(1,10)}$	0.47
Depth[11]	m	0.37	0.35	No change	$0.07_{(1,10)}$	0.79
Velocity[11]	m/s	0.59	0.57	No change	$0.08_{(1,10)}$	0.78
Macrophyte Cover	%	1.43	76.13	Year 1 greater	$157.01_{(1,10)}$	<0.001
Periphyton Cover	%	78.94	40.91	Year 1 lower	$16.07_{(1,10)}$	0.004
Substrate Index		3.02	2.51	No change	$1.33_{(1,16)}$	0.27
Sediment cover	%	11	24.8	Year 1 greater	$8.88_{(1,38)}$	0.005
Embeddedness		1.62	2.03	Year 1 greater	$7.84_{(1,10)}$	0.01
Compactness		1.5	2.17	Year 1 greater	$5.97_{(1,10)}$	0.04

Photo 7: Rehabilitation Site 1 looking upstream towards the top of the constructed riffle

[11] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 8: Rehabilitation Site 1 looking downstream

5.2.5 Rehabilitation Site 2: Avon River at Rhododendron Island

The second rehabilitated site is located between the Montreal Street bridge and Rhododendron Island. The river was narrower than during the baseline survey and velocity had increased significantly. There was a very deep pool in the upper parts of the survey reach. Comparative results against the baseline are presented in Table 14.

Where the river has been narrowed, flood plains have been constructed on both banks using boulders and fill. They have been planted with native wetland species and weed mat has been installed. The plantings here were significantly smaller than at Rehabilitation Site 2, as they had been planted much more recently (May 2014). Both banks also had a number of exotic mature trees that provided patchy shade across the site.

P. crispus was prevalent at the site with watercress (*Nasturtium officinale*) common at the wetted margins which was similar to the baseline survey. Percent macrophyte coverage was not significantly different from the baseline survey. Periphyton was also very common with large areas of long green filamentous periphyton. However, the algal coverage was no different to coverage during the baseline survey.

The SI for Rehabilitation Site 2 had increased from 1.47 to 3.43 indicating a coarse substrate, in this case, one dominated by small cobbles. Substrate change is also supported by comparisons of fine sediment with significantly less present during the year one survey. The baseline survey yielded an average percent fine sediment cover of 76.75% compared to the year one average coverage of less than 2%. Embeddedness had not changed however compactness had decreased.

Table 14: Results of comparisons between Baseline and Year 1 data for Rehabilitation Site 2

Variable		Baseline mean	Year 1 average	Change	$F_{(DF)}$	P
Width[12]	m	15.09	9.93	Year 1 lower	$25.32_{(1,10)}$	<0.001
Depth[12]	m	0.48	0.38	No change	$1.37_{(1,10)}$	0.27
Velocity[12]	m/s	0.28	0.57	Year 1 greater	$6.11_{(1,10)}$	0.03
Macrophyte Cover	%	11.71	13.65	No change	$0.02_{(1,10)}$	0.89
Periphyton Cover	%	53.12	68.99	No change	$1.08_{(1,10)}$	0.32
Substrate Index		1.47	3.43	Year 1 greater	$47.04_{(1,16)}$	<0.001
Sediment cover	%	76.75	1.44	Year 1 lower	$421.2_{(1,38)}$	<0.001
Embeddedness		1.88	1.6	No change	$0.45_{(1,118)}$	0.5
Compactness		4	2	Year 1 lower	$7.16_{(1,10)}$	<0.001

[12] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 9: Rehabilitation Site 2 looking upstream

Photo 10: Rehabilitation Site 2 looking downstream towards Rhododendron Island

5.2.6 Rehabilitation Site 3: Avon River near Kilmore Street

The third rehabilitation site was located on both sides of the Hereford Street Bridge. On the downstream side of the bridge is Mill Island. The area on both sides of Mill Island was included in the assessment. Downstream of the bridge, the river was on average 11.9m wide, 22cm deep and 0.31m/s velocity. Upstream of the bridge where the river was in a single channel, it was an average of 31cm deep, 8.9m wide and 0.38m/s velocity. There was no change in overall width, depth or velocity. Table 15 presents comparison results against the baseline for Rehabilitation Site 3.

Downstream of the bridge minimal rehabilitation was carried out. The TL bank was predominantly grassed right to the river edge with some *Carex secta* and ferns growing out of the stone wall bank. The TR bank was similar and also included some paved areas providing viewing of the water wheel on Mill Island. On the Island itself, vegetation was a combination of exotic and native shrubs and small trees. Both banks contained several mature exotic trees that provided excellent shading for the reach. Upstream of the bridge, the rehabilitation works were similar to those in the upper reaches (floodplain, plantings, boulders). Both banks contained the same native plantings and were grassed on the upper banks. There were a number of exotic trees here as well.

Macrophytes at the site were predominantly *P. crispus* with some *M. propinquum*, however the total macrophyte coverage and abundance was not significantly different to the baseline survey. *M. propinquum* was not present during the baseline survey. Algal coverage was not different to the baseline either and was dominated by long green filamentous periphyton for both surveys.

The substrate was dominated by small cobbles at the sites assessed, however there was a high proportion of large cobbles and some boulders that were not captured by the transects. The SI was slightly higher for the year one survey. There was less fine sediment cover during the year one survey however the depth of fine sediment did not change ($F_{1,38}$=4.10, p=0.051). Embeddedness and compactness had also decreased since the baseline survey, likely due to the substrate cleaning and addition undertaken during works.

Depositional and scouring zones had increased from the baseline survey ($F_{1,10}$=8.46, p=0.02). Upstream of the bridge there were areas adjacent to the banks where flow was very slow, allowing deposition of fine sediment and other materials.

Table 15: Results of comparisons between Baseline and Year 1 habitat data for Rehabilitation Site 3

Variable		Baseline mean	Year 1 average	Change	$F_{(DF)}$	P
Width[13]	m	12.97	11.11	No change	$0.16_{(1,10)}$	0.69
Depth[13]	m	0.29	0.29	No change	$0.001_{(1,10)}$	0.97
Velocity[13]	m/s	0.48	0.55	No change	$0.55_{(1,10)}$	0.48
Macrophytes Cover	%	19.15	11.94	No change	$0.43_{(1,10)}$	0.53
Periphyton Cover	%	48.10	64.11	No change	$1.33_{(1,10)}$	0.28
Substate Index		2.34	2.41	Year 1 greater	$6.42_{(1,16)}$	0.02
Sediment cover	%	34.94	2.31	Year 1 lower	$29.80_{(1,38)}$	<0.001
Embeddedness		2.5	1.35	Year 1 lower	$27.18_{(1,118)}$	<0.001
Compactness		3.67	1.83	Year 1 lower	$16.35_{(1,10)}$	0.002

Photo 11: Rehabilitation Site 3 downstream of Hereford Street Bridge, on the TL side of Mill Island looking upstream

[13] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 12: Rehabilitation Site 3 downstream of Hereford Street Bridge, on the TR of Mill Island looking downstream

Photo 13: Rehabilitation Site 3 upstream of Hereford Street Bridge, looking upstream

5.2.7 Rehabilitation Site 4: Avon River at Victoria Square

The fourth rehabilitation site was located in Victoria Square. The river was on average 10.7m wide and 31cm deep. There was no change in width or velocity while depth decreased slightly, likely due to the lower water levels exhibited during the preceding dry summer, compared to the spring survey for the baseline. On the TL bank, the majority of the bank had undergone replanting, with the same flood plain development as at other rehabilitation sites. Native wetland vegetation had been planted and weed mat installed, however the plants were still very small and there were large amounts of exposed weed mat. Extensive exotic mature trees provided good canopy coverage.

The upper banks were a mixture of grass and garden species before terminating at the Court buildings. The TR bank had lesser amounts of the flood plains and parts of the reach were contained within the remnant stone wall. Several large *Carex secta* plants were on the bank. There were less mature trees on the TR bank however they were still present. Shading was provided to large portions of the river however areas were still exposed to direct sunlight.

Table 16 presents comparisons of habitat variables for the Baseline and Year 1 data. Macrophyte coverage was reasonable, though not extensive (average of 21% bed coverage). The species assemblage was similar to other sites with *P. crispus* within the main channel, and monkey musk and watercress in the marginal areas on either bank. Again, monkey musk was not present during the baseline survey. Bed coverage was not significantly different from the baseline survey. Periphyton was again predominantly long green filamentous and cover had increased since the baseline survey.

The SI for this site was essentially the same for both the baseline and year one survey. Substrate was dominated by pebbles and small cobbles. Both embeddedness and compactness had decreased slightly from the baseline report, likely due to substrate addition and/or cleaning during instream works. Neither the coverage of fine sediment or the depth of fine sediment ($F_{1,38}$=0.71, p=0.4) had altered significantly compared to the baseline data, supporting the similarity between the SI values.

Table 16: Habitat variable comparisons for Baseline and Year 1 data for Rehabilitation Site 4

Variable		Baseline mean	Year 1 average	Change	$F_{(DF)}$	P
Width[14]	m	10.4	10.67	No change	$0.07_{(1,10)}$	0.79
Depth[14]	m	0.50	0.31	Year 1 lower	$13.42_{(1,10)}$	0.004
Velocity[14]	m/s	0.43	0.50	No change	$3.88_{(1,10)}$	0.08
Macrophyte Cover	%	40.13	21.71	No change	$0.55_{(1,10)}$	0.47
Periphyton Cover	%	29.52	56.26	Year 1 greater	$1.61_{(1,10)}$	0.23
Substrate Index		2.84	2.81	No change	$0.007_{(1,16)}$	0.94
Sediment cover	%	19.63	16.07	No change	$1.66_{(1,38)}$	0.21
Embeddedness		1.83	1.47	Year 1 lower	$4.3_{(1,118)}$	0.04
Compactness		3.67	2.33	Year 1 lower	$13.04_{(1,10)}$	<0.001

[14] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 14: Rehabilitation Site 4 looking downstream

Photo 15: Rehabilitation Site 4 looking upstream

5.2.8 Rehabilitation Site 5: Avon River near Kilmore Street

The final rehabilitation site, and also the most downstream, was located between Barbadoes and Kilmore Streets. The river was wide (12.1m) and shallow (22cm) and flowed at an average velocity of 0.55m/s. Wetted width had decreased by over 3m from the baseline, and depth had decreased slightly too. This change in width was due to the flood plain construction, and potentially depth too, although this could also be due to the drier sampling period compared to the baseline. Velocity had not altered. Table 17 presents summary statistics for comparisons between Baseline and Year 1 data.

Riparian habitat was essentially the same on both the TR and TL banks. Flood plains had been established using boulders and fill and had been planted with the same mixes of native wetland plants as seen at the other rehabilitation sites. The plants were very small with the weed matting almost entirely exposed. Several large exotic trees were on the TR providing good shading of the river, while there were only two individuals on the TL. The upper banks were grassed and above this, urban road run parallel to the river on both banks.

Macrophyte coverage at this site was essentially non-existent, due to the fact contractors had been through this part of the river the previous day and removed water plants from the river. During the baseline survey *P. crispus* and *E. canadensis* were present. As a result, coverage had significantly decreased. Periphyton coverage had increased and the composition had changed from predominantly long green filamentous during the baseline survey to a combination of short brown filamentous and thin brown film. The lack of long green filamentous periphyton is likely due to the clearing out of vegetation by contractors.

The SI increased from 1.36 indicating a substrate dominated by fine sediment, to a value of 3.78 indicating a much coarser substrate dominated by cobbles. This is supported by an overall increase in average substrate size ($F_{1,118}$=6.01, p=0.016). Both compactness and embeddedness decreased from the baseline survey, potentially due to the instream works or due to the macrophyte removal. Despite this, there was no change in average coverage of fine sediment or fine sediment depth ($F_{1,38}$=1.18, p=0.28).

Table 17: Results of comparisons between Baseline and Year 1 data for habitat variable at Rehabilitation Site 5

Variable		Baseline mean	Year 1 average	Change	F (DF)	P
Width[15]	m	15.43	12.07	Year 1 lower	13.76 $_{(1,10)}$	0.004
Depth[15]	m	0.31	0.22	Year 1 lower	44.05 $_{(1,10)}$	>0.01
Velocity[15]	m/s	0.43	0.55	Year 1 greater	80.6 $_{(1,10)}$	0.02
Macrophyte Cover	%	54.0	0	Year 1 lower	21.74 $_{(1,10)}$	<0.001
Periphyton Cover	%	6.97	93.5	Year 1 greater	36.12 $_{(1,10)}$	<0.001
Substrate Index		1.36	3.78	Year 1 greater	84.71 $_{(1,16)}$	<0.001
Sediment cover	%	8.07	2.2	No change	400 $_{(1,38)}$	0.98
Embeddedness		1.93	1.25	Year 1 lower	11.32 $_{(1,118)}$	<0.001
Compactness		3.5	2	Year 1 lower	64.03 $_{(1,10)}$	<0.001

[15] From data provided by ECan from their hydrology assessment using P3b protocol from Harding et al. (2009)

Photo 16: Rehabilitation Site 5 looking upstream

Photo 17: Rehabilitation Site 5 looking downstream

5.3 Macroinvertebrate Community

The Year 1 survey sampled a total of 36,374 individual macroinvertebrates, belonging to 40 taxonomic groups. The most diverse group was the true flies (Diptera) with a total of 13 different taxa present in the samples, followed by caddisflies (Trichoptera) with nine different taxa. Molluscs and Crustaceans were also reasonably well represented with six and four taxa respectively. The caddisfly *Pycnocentrodes* was the most abundant species across all the samples. No mayflies (Ephemeroptera) or stoneflies (Plecoptera) were found at any of the sites surveyed.

Caddisflies, crustaceans and molluscs dominated the data, collectively making up just under 80% of the macroinvertebrates collected across all eight sites.

Several taxa were present at all sites. These included seed shrimp ostracods, the freshwater amphipod *Paracolliope fluviatilis*, orthocladiinae and tanytarsini midges, the exotic *Physa* snail, the native mud snail *Potamopyrgus antipodarium*, oligochaete worms and the caddisflies *Hudsonema amabile*, *Oxyethira* albiceps and *Pycnocentrodes aureolus*.

The number of individuals collected per square metre at each of the sites ranged from 44 to 3873 however there was no statistical difference between the individual sites ($F_{1,32}$=1.62, p=0.16) (Table 14). There was a difference in the abundance between reference and rehabilitation sites ($F_{1,38}$=9.40, p=0.004). Reference sites yielded on average 445 individuals compared to 712 at the rehabilitation sites.

Between 12 and 21 taxa were found at each site and there was a difference between the number of taxa found at each site ($F_{7,32}$=3.00, p=0.02). Tukey HSD revealed the significant differences between Reference Site 2 and Rehabilitation Sites 3 and 5. All other sites could not be differentiated from each other. Rehabilitation sites had a more diverse community composition with an average of 17 different taxa compared to an average of 15 taxa at the reference sites ($F_{1,38}$=6.60, p=0.014).

Generally taxa collected in the kick net sample were essentially the same as the surber samples. Only a few extra taxa were collected in the kick nets.

Caddisflies were the only EPT present in the Avon River and were present at both reference and rehabilitation sites. Of the 12 caddisfly species present, two of these are non-sensitive hydroptilids. On average 4.3 EPT taxa were found at each site. EPT richness was statistically different between sites ($F_{7,32}$=6.76, p=<0.001). No difference could be found between the number of EPT taxa found at the reference and rehabilitation sites ($F_{1,38}$=0.02, p=0.9).

When Hydroptilids (pollution tolerant caddisflies) were excluded from the EPT data, there was again a statistical difference between sites ($F_{7,32}$=6.73, p=<0.001). However, there was no difference between reference and rehabilitation Sites ($F_{1,38}$=0.44, p=0.51).

Table 18: Average macroinvertebrate abundance, richness, EPT richness and EPT richness (without Hydroptilidae) for the Year 1 survey. Standard error are in parentheses.

Site	Abundance	Taxa Richness	EPT Richness	EPT (except Hydroptilidae) Richness	% EPT (except Hydroptilidae)
Reference Site 1	475.2 (129)	15.4 (1.2)	4.4 (0.2)	3.6 (0.2)	23.9 (2.4)
Reference Site 2	419.8 (110)	13.6 (0.8)	2.8 (0.4)	1.6 (0.4)	11.6 (2.5)
Reference Site 3	442.2 (150)	17.2 (1.0)	4.6 (0.24	3.8 (0.2)	22.2 (1.1)
Rehabilitation Site 1	739.2 (233)	16.4 (1.2)	5.2 (0.6)	3.6 (0.4)	22.0 (1.7)
Rehabilitation Site 2	503.2 (80)	16 (1.0)	4.8 (0.4)	3 (0.3)	18.6 (1.1)
Rehabilitation Site 3	605.6 (95)	17.8 (0.8)	4.2 (0.4)	3.2 (0.4)	17.8 (1.5)
Rehabilitation Site 4	845.8 (37)	17.4 (0.6)	3.8 (0.2)	2.4 (0.2)	13.8 (1.2)
Rehabilitation Site 5	864.8 (204)	18.6 (0.4)	4.6 (0.2)	3.2 (0.2)	17.2 (1.0)

MCI and QMCI use the taxa present to calculate an index giving an indication of stream health and water quality. Higher scores generally indicate streams in good ecological condition. MCI scores were similar across all sites (Figure 3) however there were some minor but significant differences between a small number of sites ($F_{7,40}$=5.18, p=<0.001). There was also a small but significant difference in MCI score between reference and rehabilitation sites ($F_{1,46}$=11.49, p=0.001). Reference sites had an average score of 74 compared to 70 at the rehabilitation sites. All MCI scores were below 80, indicating poor stream health. The MCI scores were likely constrained by urban impacts and catchment constraints.

QMCI scores were also different between sites ($F_{7,32}$=12.72, p=<0.001) (Figure 3) however there was no significant difference between the reference and rehabilitation scores ($F_{1,38}$=0.13, p=0.72). All rehabilitation sites with the exception of Site 5 had QMCI scores between 4 and 5 indicating 'fair' stream health. Reference Sites 1 and 3 were also considered to be 'fair', while Reference Site 2 and Rehabilitation Site 5 had scores less than 4, indicated 'poor' habitat quality.

Macrophyte coverage did significantly affect QMCI ($F_{1,8}$=5.95, p=0.04) with higher bed coverage generally equating to a higher QMCI. Macrophytes provide food and habitat for both fish and invertebrates as well has helping to stabilise substrate and modify flow. Velocity ($F_{1,8}$=0.78, p=0.40) and SI ($F_{1,8}$=0.30, p=0.60) did not affect QMCI and no interaction terms were significant.

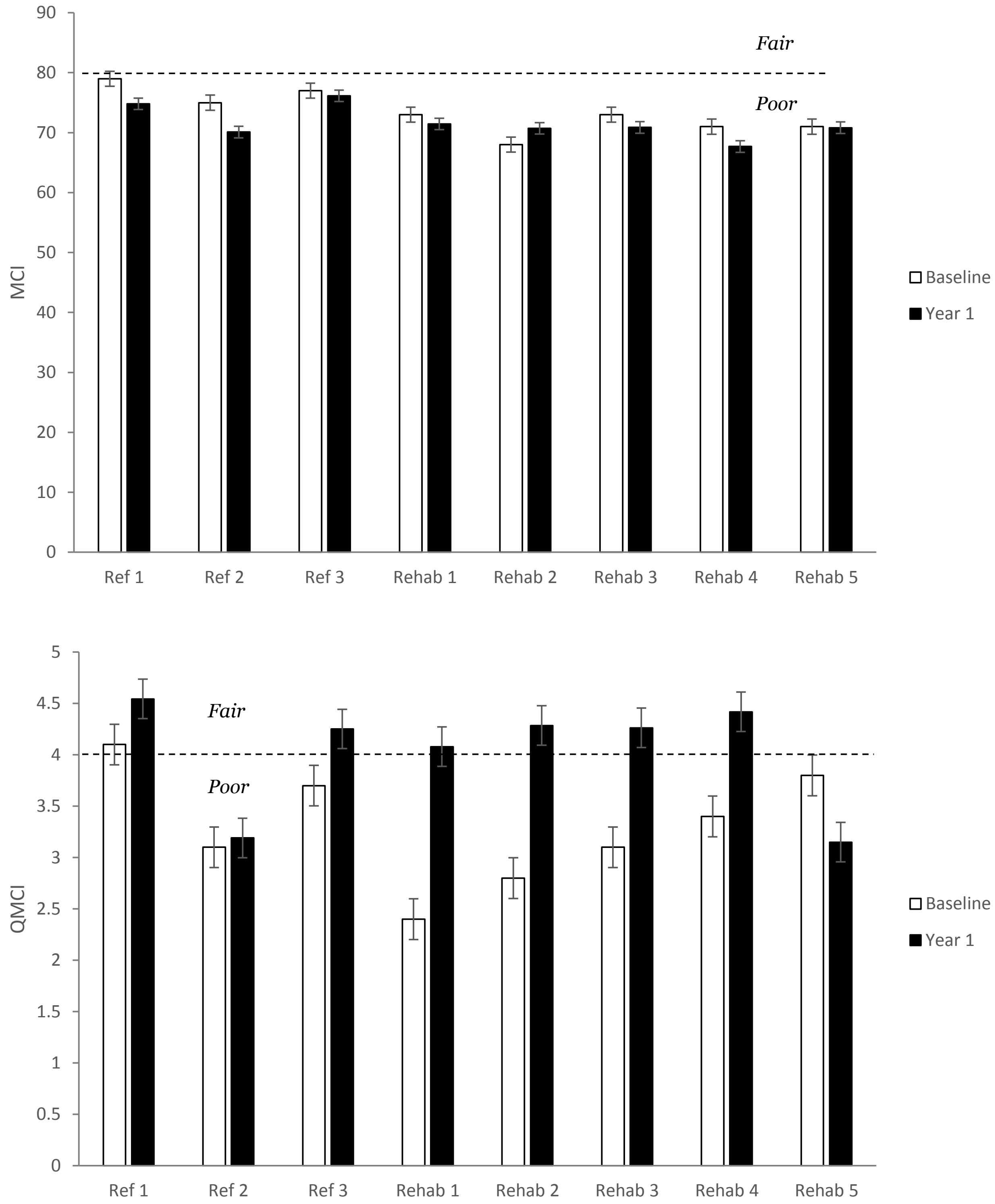

Figure 3: Average MCI and QMCI scores for each study reach during the Year 1 survey. Error bars are ±1 SE. Quality classes are given.

There was no significant change in MCI value detected between the Baseline and Year 1 data (Table 19), however, there was an increase in QMCI. The Year 1 data yielded an average QMCI of 4 indicating an increase in habitat quality from 'poor' to 'fair'. The number of taxa present also increased with an average of three more taxa present during the Year 1 survey. The number of taxa per m^2 increased significantly with an almost 65% increase in the number of macroinvertebrates counted.

The MCI at the rehabilitation sites (combining Baseline and Year 1 data) was significantly less than at the reference sites and the number of invertebrates per square metre was significantly greater. Other indices were no different (Table 20). Despite the significant differences in some indices between years and between sites, there were no significant interaction effects (Table 21). This suggests the in-river rehabilitation works have not had an effect on the macroinvertebrate community however this is discussed further below and in Section 6.6.

Table 19: Two-way ANOVA results showing differences between survey years. F value (degrees of freedom) and p values are given.

	Baseline mean	Year 1 mean	Change	$F_{(df)}$	P
MCI	73.38	71.63	No change	$2.666_{(1,12)}$	0.128
QMCI	3.3	4.03	Year 1 greater	$6.288_{(1,12)}$	0.028
Abundance	371	612	Year 1 greater	$10.855_{(1,12)}$	0.006
Taxa richness	20	23	Year 1 greater	$17.785_{(1,12)}$	0.001
%EPT (excluding Hydroptilidae)	23.2	18.4	No change	$3.525_{(1,12)}$	0.085

Table 20: Two-way ANOVA results showing differences between reference and rehabilitation sites. F value (degrees of freedom) and p values are given.

	Reference mean	Rehabilitation mean	Difference	$F_{(df)}$	P
MCI	75.33	70.80	Rehabilitation lower	$16.910_{(1,12)}$	0.001
QMCI	3.82	3.57	No difference	$0.789_{(1,12)}$	0.392
Abundance	378	560	Rehabilitation greater	$5.077_{(1,12)}$	0.044
Taxa richness	21	22	No difference	$1.317_{(1,12)}$	0.274
%EPT (excluding Hydroptilidae)	22.2	20.0	No difference	$0.442_{(1,12)}$	0.518

Table 21: Two-way ANOVA results showing the interaction between survey years and between reference and rehabilitation sites. F value (degrees of freedom) and p values are given.

	Baseline Reference mean	Baseline Rehabilitation mean	Year 1 Reference mean	Year 1 Rehabilitation mean	Significant interaction?	$F_{(df)}$	P
MCI	77.00	71.20	73.67	70.40	No	$1.254_{(1,12)}$	0.285
QMCI	3.63	3.10	4.00	4.04	No	$1.082_{(1,12)}$	0.319
Abundance	310	407	446	712	No	$0.189_{(1,12)}$	0.672
Taxa richness	20	21	23	24	No	$0.065_{(1,12)}$	0.804
%EPT (excluding Hydroptilidae)	25.1	22.1	19.2	17.9	No	$0.140_{(1,12)}$	0.714

Supporting the differences in invertebrate abundance and number of taxa present between years are the results from the NMDS ordination (Figure 4). There were clear differences between the two surveys and difference, though less pronounced, between reference and rehabilitation sites. The data points can be easily grouped into Baseline and Year 1 clusters however there is substantial overlap between the reference and rehabilitation sites within the years. The ANOSIM results confirmed this with significant difference between reference and rehabilitation sites (R=0.38, p=0.001) and a highly significant difference between surveys (R=0.8, p=0.001). The NMDS ordination gave a good representation of community dissimilarities with two-dimensional stress 2D=0.18. Where stress is less than 2 it is generally accepted there is no genuine risk of misleading interpretation (Quinn & Keough 2002).

SIMPER indicated the differences between reference and rehabilitation sites were predominantly due to differences in abundances of five macroinvertebrate species (the freshwater amphipod *Paracalliope*, the caddisfly *Pycnocentrodes*, the New Zealand mudsnail *P. antipodarium*, the midge larvae orthocladiinae and oligochaete worms). Differences between surveys were explained by differences in abundance between six species. The limited significant differences between sites and the lack of significant year by site interactions suggests that the different surveys are the main reason for differences in the invertebrate community structure. Therefore, differences are more likely to be a result of natural variation within the river and due to the different time of year the surveys were undertaken, than the rehabilitation works.

Abundances of four of these taxa also accounted for most of the differences in the community between the Baseline and Year 1 survey. *Paracalliope, Pycnocentrodes, P. antipodarium* and orthocladiinae midges along with the midge tanytarsini and the caddisfly *H. amabile* collectively accounted for almost 75% of the differences between surveys. As four of the taxa are responsible for a lot of the variation between both year and site, it suggests the changes are not a result of the rehabilitation works. If rehabilitation works had affected the invertebrate community, it would be expected that different species would account for the variation between years and sites. Full SIMPER results can be found in Appendix 3. However, these species are all relatively pollution tolerant and therefore the changes in community composition are not likely to indicate a change in habitat quality.

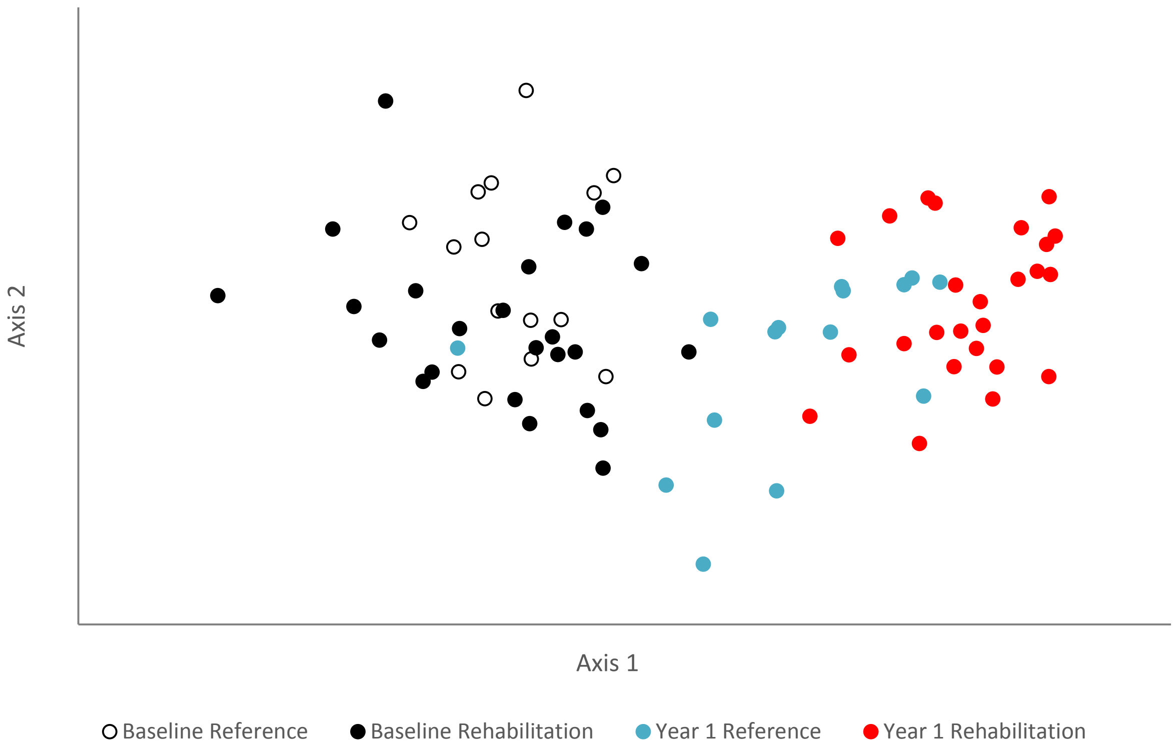

Figure 4: NMDS ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate data from the surber samples taken at each of the study sites.

5.4 Fish Community

A total of 358 individual fish were captured during the year one survey belonging to eight species. The eight species, listed from the most abundant to the least are given in Table 22. Their current threat status is also given.

Table 22: Fish species found during the Year 1 survey

Common name	Scientific name	Threat status (Goodman et al. 2013)
Common bully	*Gobiomorphus cotidianus*	Not threatened
Upland bully	*Gobiomorphus breviceps*	Not threatened
Longfin eel	*Anguilla dieffenbachii*	At risk – declining
Shortfin eel	*Anguilla australis*	Not threatened
Bluegill bully	*Gobiomorphus hubbsi*	At risk – declining
Brown trout	*Salmo trutta*	Introduced and naturalised
Giant bully	*Gobiomorphus gobioides*	Not threatened
Lamprey	*Geotria australis*	Nationally endangered

Species richness varied to some extent across the eight sites (Figure 5). The reference site at Carlton Corner recorded the lowest species diversity (four species) and 11 individuals in total. Rehabilitation site 5, near Kilmore Street, yielded the largest number of fish (71) and the highest CPUE (11.76 fish per 100m²), with five fish species recorded. All other sites had at least six species with Rehabilitation Site 1 containing all eight species found during the survey. This included the nationally endangered lamprey, a species that was not found during the baseline survey. However, this species was also found within the ARP during fish salvaging works prior to the instream works (EOS Ecology 2014). There are two other records of lamprey presence in the Avon River on the New Zealand Freshwater Fish Database, however the most recent of these is from 1991. On both occasions lamprey were found at the same location as Reference Site 1 in this study.

Common bully, longfin and shortfin eels were found at all sites. During the baseline survey, only shortfin eels were found at all sites with common bullies found at six and longfin eels found at five. Inanga were found at two sites during the baseline survey (four individuals at Rehabilitation Site 1 and one individual at Rehabilitation Site 3), however they were not encountered during the year one survey. Two inanga were found at Rehabilitation Site 1 during the first sampling occasion however as sampling at this site was repeated and none were found during the repeated survey, their presence has not been included in the final data. Bluegill bully, another 'At-Risk – Declining' species, was recorded at one of the reference sites (Reference Site 1) and four of the rehabilitation sites (Rehabilitation Sites 1, 2, 4 and 5). This is similar to that recorded during the baseline survey, with the exception that this species was not recorded at Rehabilitation Site 2.

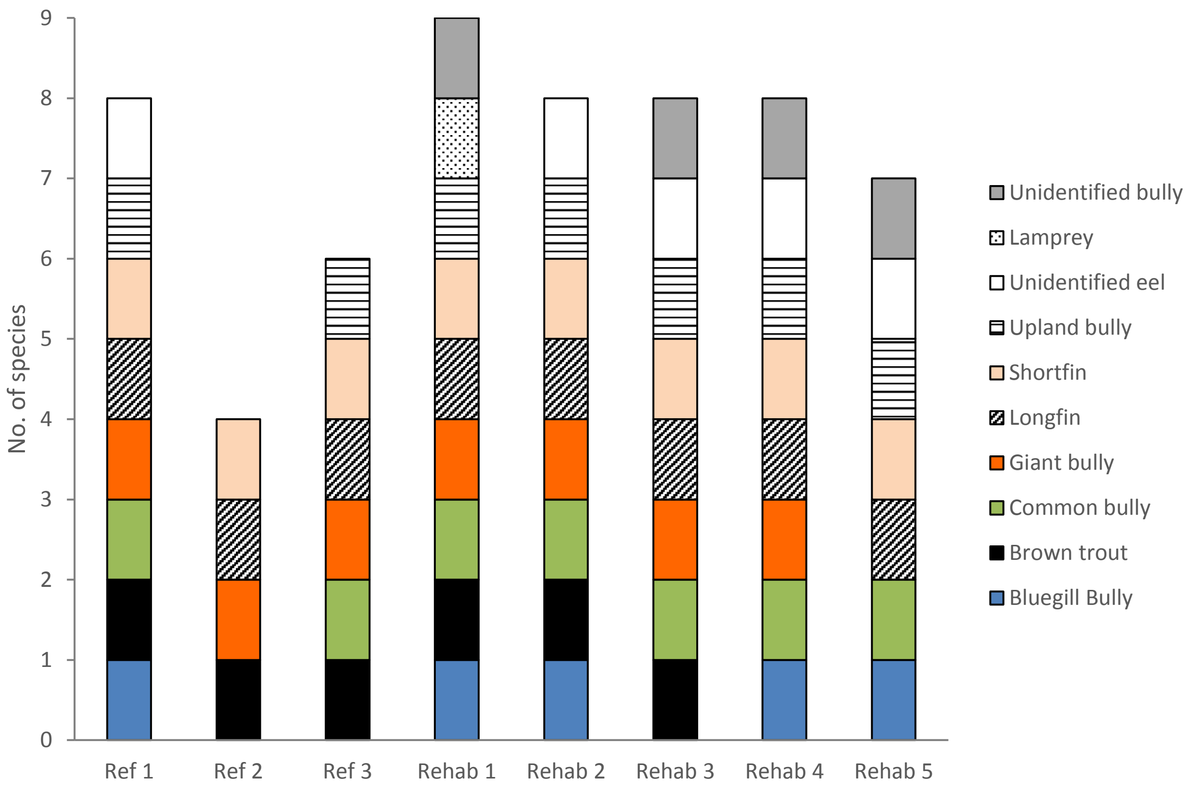

Figure 5: Species richness of fish captured during electric fishing of sites along the Avon River

Eels, upland bullies and common bullies dominated the community composition at all eight sites. Brown trout were present in smaller numbers, however at the three reference sites and at Rehabilitation Site 1 large adults were found, the largest of which measured 380mm in length. Rehabilitation Site 4 and to a lesser extent Reference Site 1 and Rehabilitation Sites 2 and 3 had a number of juvenile eel species that were too small to accurately determine their species.

Fish abundance (expressed as number caught per 100m^2; CPUE) ranged from 3.4 fish at Reference Site 2, to 11.8 fish at Rehabilitation Site 5. Rehabilitation Site 5 also recorded the most fish in the baseline survey and abundance has not substantially altered. There was no significant difference between survey year ($F_{1,12}$=0.562, p=0.468) or between reference and rehabilitation sites ($F_{1,12}$=4.596, p=0.053) and there was no significant interaction between year and site ($F_{1,12}$=0.798, p=0.389).

When the CPUE are split to give a CPUE per species, there were small increases between the surveys for two fish species CPUE, giant bully and upland bully (Table 23). Unidentified bullies also increased however this is of minimal ecological significance due to their unspecified nature. There were also small differences in the CUPE for brown trout and common bully between reference and rehabilitation sites (Table 24). No interactions were significant (Table 25) however suggesting it was variation between the years and sites that was responsible for the changes in community composition rather than as a result of the rehabilitation works.

Table 23: Comparisons of Baseline and Year 1 fish species CPUE data indicating if any change was detected, Two-way ANOVA F value (with degrees of freedom), and p significance value

	Baseline mean	Year 1 mean	Change	F (df)	P
Bluegill Bully	0.71	0.59	No change	0.009 (1,12)	0.924
Brown Trout	0.32	0.26	No change	0.181 (1,12)	0.678
Common Bully	1.28	2.26	No change	1.908 (1,12)	0.192
Giant Bully	0.04	0.16	Year 1 greater	6.611 (1,12)	0.024
Inanga	0.50	0.00	No change	1.400 (1,12)	0.260
Lamprey	0.00	0.23	No change	0.938 (1,12)	0.352
Longfin Eel	0.54	0.62	No change	0.310 (1,12)	0.588
Shortfin Eel	1.64	0.75	No change	4.643 (1,12)	0.052
Upland Bully	0.27	0.93	Year 1 greater	4.803 (1,12)	0.049
Unidentified Eel	0.57	0.51	No change	0.377 (1,12)	0.551
Unidentified Bully	0.00	0.11	Year 1 greater	5.133 (1,12)	0.043

Table 24: Reference and rehabilitation site comparisons indicating if any difference in fish species CPUE data was detected, Two-way ANOVA F value (degrees of freedom), and p value

	Reference mean	Rehabilitation mean	Difference	$F_{(df)}$	P
Bluegill Bully	0.12	0.97	No difference	$2.975_{(1,12)}$	0.110
Brown Trout	0.49	0.18	Rehabilitation lower	$4.762_{(1,12)}$	0.049
Common Bully	0.59	2.47	Rehabilitation greater	$7.606_{(1,12)}$	0.017
Giant Bully	0.11	0.09	No difference	$0.298_{(1,12)}$	0.595
Inanga	0.00	0.06	No difference	$0.840_{(1,12)}$	0.378
Lamprey	0.00	0.02	No difference	$0.563_{(1,12)}$	0.468
Longfin Eel	0.45	0.66	No difference	$1.647_{(1,12)}$	0.224
Shortfin Eel	1.42	1.06	No difference	$0.343_{(1,12)}$	0.569
Upland Bully	0.55	0.63	No difference	$0.006_{(1,12)}$	0.940
Unidentified Eel	0.30	0.69	No difference	$2.092_{(1,12)}$	0.174
Unidentified Bully	0.00	0.09	No difference	$3.080_{(1,12)}$	0.105

Table 25: Two-way ANOVA interaction significance for fish species CPUE data between survey year and site. F value (degrees of freedom) and p significance values are given

	Baseline Reference mean	Baseline Rehabilitation mean	Year 1 Reference mean	Year 1 Rehabilitation mean	Significant interaction?	$F_{(df)}$	P
Bluegill Bully	0.17	1.04	0.06	0.91	No	$0.040_{(1,12)}$	0.846
Brown Trout	0.47	0.24	0.52	0.11	No	$0.184_{(1,12)}$	0.676
Common Bully	0.64	1.66	0.55	3.29	No	$0.896_{(1,12)}$	0.362
Giant Bully	0.00	0.06	0.23	0.14	No	$3.373_{(1,12)}$	0.091
Inanga	0.00	0.12	0.00	0.00	No	$0.840_{(1,12)}$	0.378
Lamprey	0.00	0.00	0.00	0.05	No	$0.563_{(1,12)}$	0.468
Longfin Eel	0.44	0.61	0.46	0.72	No	$0.020_{(1,12)}$	0.890
Shortfin Eel	1.78	1.56	1.06	0.57	No	$0.293_{(1,12)}$	0.598
Upland Bully	0.47	0.15	0.62	1.12	No	$2.084_{(1,12)}$	0.174
Unidentified Eel	0.49	0.62	0.12	0.75	No	$0.844_{(1,12)}$	0.376
Unidentified Bully	0.00	0.00	0.00	0.17	No	$3.080_{(1,12)}$	0.105

The NMDS ordination of the fish species CPUE data demonstrated obvious differences in the Baseline and Year 1 data and the reference and rehabilitation data (Figure 6). ANOSIM indicated significant differences between the two surveys (R=0.42, p=0.009), and between the reference and rehabilitation sites (R=0.26, p=0.048). The ordination plot (Figure 6) supports the changes in species composition between the surveys for both reference and rehabilitation sites. Points on the ordination plot that are closer together indicate a community composition that is similar. Despite the significant differences, results of the two-way ANOVA's suggest the differences between sites and years is the result of natural variation, rather than as a direct result of the in river rehabilitation works.

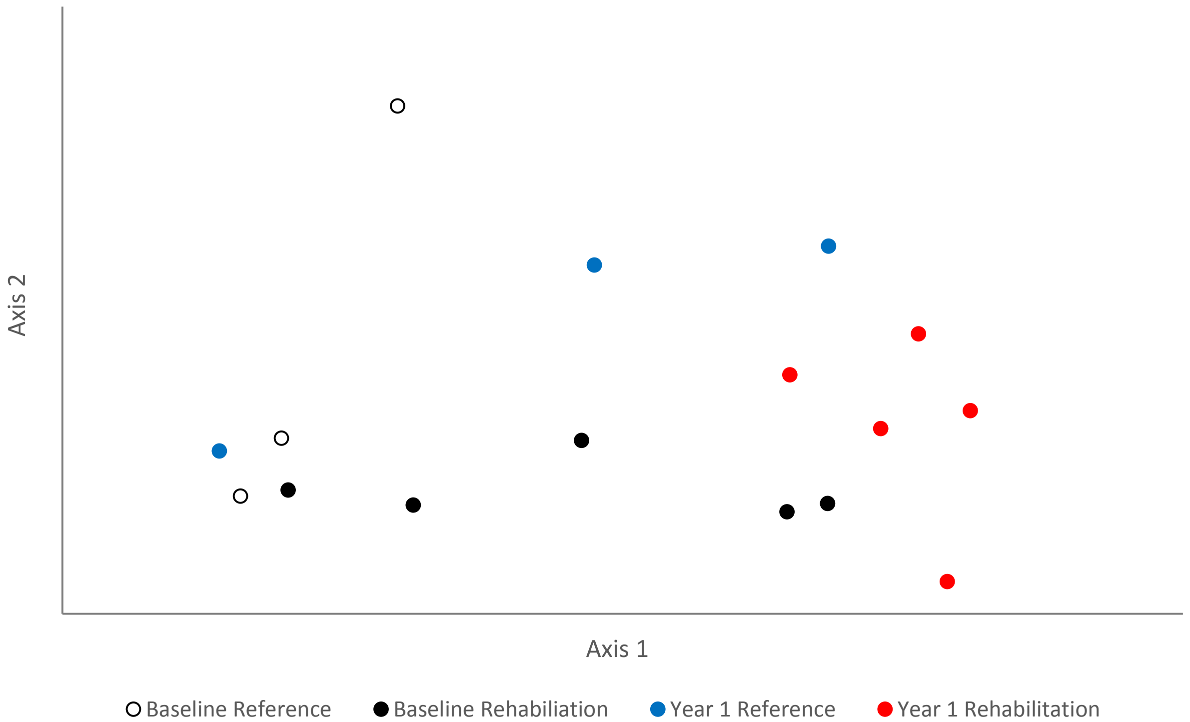

Figure 6: NMDS ordination calculated for fish species CPUE data for the eight study sites from the Baseline and Year 1 surveys.

6 Discussion

Parts of the Avon River underwent in-river and riparian rehabilitation as part of the larger ARP project. The ARP project is one of the 'Anchor Projects' being undertaken as part of the rebuilding of Christchurch following earthquakes in 2010 and 2011. The intention of the rehabilitation work was to return the Avon River to a more natural state both physically and biologically. Works to facilitate this included removing fine sediment, addition of larger substrates, narrowing of parts of the channel and extensive riparian planting.

Comparing data collected during a baseline survey to data collected in the year following the conclusion of rehabilitation works has identified a number of changes, both between individual sites, and between reference and rehabilitation sites, some likely due to the rehabilitation works and some not. However, as this survey was only undertaken within one year post-restoration, the sites may yet respond to the rehabilitation works in the future, which will become apparent in the longer term monitoring planned (at 3, 5 and 10 years post-restoration). However, possible reasons for the changes, or lack of changes, identified in the results are discussed below.

6.1 Dates of rehabilitation works

The nature of the rehabilitation works in the Avon River meant not all reaches of the river could be worked on simultaneously. Work was carried out on the Watermark Precinct (Rehabilitation Site 1) between March and July 2013. In-river work did not commence on the remainder of the sites until January 2014 with the most downstream site, Rehabilitation Site 5, having in-river works completed in November 2014. No in-river work was carried out between 1 May and 31 October 2014 as per conditions of the resource consent.

As already stated, works at Rehabilitation Site 1 occurred prior to the baseline survey being carried out and therefore the baseline results cannot be considered to be true baseline data. Works here were undertaken over a year before works were completed at the most downstream site and there were at least nine months between commencing work on the second rehabilitation site and completing them at the most downstream site.

Due to the large time difference, each site will be at a different stage of biotic community re-establishment, dictated by the length of time since disturbance ceased. Rehabilitation Sites 1 and 2 generally had higher EPT indices than the other rehabilitation sites. These two sites were the first to be rehabilitated suggesting a greater length of time since rehabilitation works results in an increase in EPT. The rehabilitation sites during the Year 1 survey had slightly lower %EPT (excluding Hydroptilidae) values compared to the Baseline rehabilitation sites, while the reference sites were similar for both surveys. As there were limited significant differences between reference and rehabilitation sites during the Year 1 survey it suggests the rehabilitation sites may still be in the recovery process following the in-river works or that it is other large scale factors, such as water quality or catchment land use, that are driving macroinvertebrate community composition.

In addition, there were only four months between work concluding at Rehabilitation Site 5 and the Year 1 survey being carried out. This is reflected in the much lower QMCI value for this site suggesting only the tolerant species have persisted during the disturbance to be able to recolonise quickly.

6.2 Inputs from upstream sediment

Upstream of Rehabilitation Site 1 no in-river rehabilitation works have been, or will be, carried out as part of the ARP project. As a result of this, there will continue to be inputs of accumulated fine sediments and other contaminants attached to sediment from the upper Avon River catchment (unless a sediment removal project is instigated in the future).

Figure 7 illustrates the average fine sediment cover for the five rehabilitation sites expressed as distance downstream from Rehabilitation Site 1. This relationship was tested using Spearman's rank correlation. Despite a low R^2 value of 0.051, there was a significant correlation between distance downstream and percent sediment cover (S=207610, p=0.014). This relationship shows the average fine sediment coverage decreasing as distance downstream increases. This is likely a reflection of the instream works starting at the top of the ARP and working downstream, and therefore the longer time for accumulation of sediment at the upstream sites.

In order to minimise the chance of fine sediment sourced from upstream being deposited in the ARP area, flow velocities need to be high enough that sediment does not get the chance to settle out and travels downstream instead. Rehabilitation site velocities during the Year 1 survey were significantly swifter than the reference sites, a result of the significant narrowing of portions of the river channel. Despite this, the rehabilitation sites still contain large amounts of sediment. This suggests either velocities are not swift enough to mobilise deposited sediment or fine sediment was not completely removed during in river works, or a combination of the two. A similar project of stream rehabilitation conducted by Suren et al. 2005 determined more active steps were required to reduce the quantities of sediment entering urban streams in Christchurch, particularly where gradients and velocities are not sufficient enough to flush sediment from the systems. In these systems, any benefit of adding coarse substrate or removing fine sediment will be reduced over time and sediment re-accumulates from upstream sources or from stormwater and other discharges.

Observations of the river following completion of works noted some areas still retained noticeable amounts of fine sediment (Belinda Margetts, Christchurch City Council, personal communication, June 2010). The river was particularly low during this Year 1 survey and therefore velocities may have been below average and not sufficient to mobilise sediment from the river bed. Sedimentation has been found to be a major limiting factor in the recovery of rehabilitated streams, specifically for macroinvertebrate communities (Blakely & Harding 2005). A study in Okeover Stream, Christchurch, suggested that the high inputs of sediment from sediment filled pools upstream of rehabilitated reaches periodically clog the downstream rehabilitated areas, limiting macroinvertebrate recovery (Blakely & Harding 2005). Further investigations are required to be able to determine if velocities are generally sufficient and should include regular velocity measurements incorporating base flow, high flow and flood flow, during the different seasons.

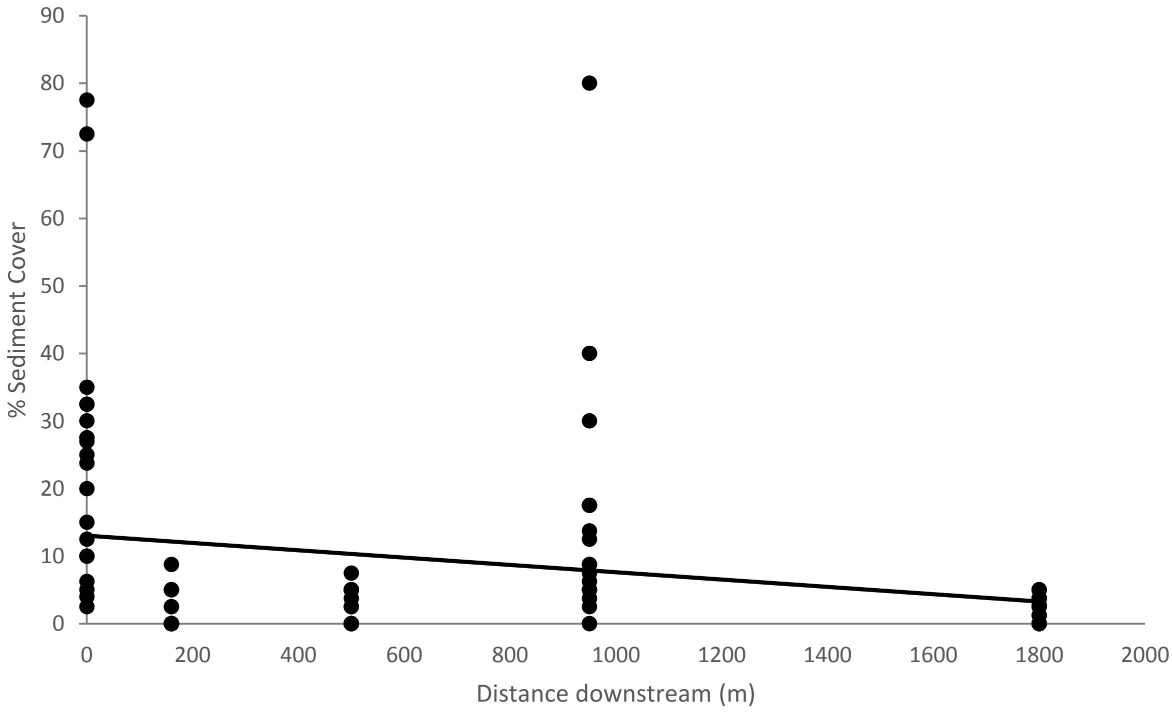

Figure 7: Average fine sediment coverage (Protocol 2 Clapcott et al.) for the five rehabilitation sites. Sites are labelled as distances downstream from Rehab1 (0m) i.e. Rehab2 (160m), Rehab3 (500m), Rehab4 (950m), and Rehab5 (1800m). Spearman's correlation (S=207610, p=0.014, R^2=0.051).

6.3 Low River Flows

Hydrology analysis for the Year 1 survey indicated the average discharge was 1.35m³/s. When compared to modelled low flows for the Avon (Opus 2014) the discharge was only slightly above the 1.2 m³/s that was modelled to be exceeded 99% of the time. Discharge was significantly lower during the Year 1 survey. The low levels of the river during the Year 1 survey make it difficult to assess if the in-river works have affected the discharge. It has already been determined that water velocities in the rehabilitation sites have increased following works, as a result of the narrowing of significant portions of the river.

Low flows have implications for a number of habitat variables including water temperature, pH, velocity, depth, depositional and scouring zones, fine sediment, periphyton and macrophyte growth, and prolonged periods of low flow can impact macroinvertebrate and fish communities (Bunn & Arthington 2002). Rivers with low flows can have less macrophytes and periphyton (Franklin et al. 2008). The differences in river flow at the time of the Baseline and Year 1 survey make it difficult to determine if there has actually been no change in macrophyte and periphyton coverage, or if this is just a product of the low river flows at the time of the Year 1 survey. No significant changes were found for either macrophyte or periphyton coverage. It is possible changes in these variables may have been demonstrated if river flow conditions had remained similar for both surveys. However, as water plants are actively removed from the river, it is difficult to determine if the rehabilitation works have resulted in changes in cover and composition, or if the maintenance is the limiting or influencing factor. With the addition of more monitoring, there will be more confidence in determining if there is a pattern of change, or lack of change.

While there were no changes in macrophyte cover, variable changes in periphyton cover and differences in physicochemical data, which were all likely a product of time of year rather than a result of river flows, it is likely the low discharge did have an impact on fine sediment coverage. As already mentioned, flow discharges and velocities influence the levels of fine sediment with higher velocities and flushing flows helping to mobilise sediment from the substrate before the water column carried it downstream. Higher velocities also minimise its deposition although other variables related to hydrology such as substrate size and turbulence also influence sediment deposition.

6.4 Subjective Measurements

Both compactness and embeddedness are components of the habitat assessment that require the measurer to make a subjective choice about the value assigned. The significant differences between the Baseline and Year 1 compactness and embeddedness data therefore must be interpreted with caution as two different people carried out these surveys and may have slightly different interpretations about which score should be assigned.

During the Year 1 survey, a number of the reference sites had high macrophyte coverage leaving only small amounts of the river substrate exposed. As a result of this, it was not possible to assess embeddedness, and fine sediment coverage and depth was possibly influenced by macrophtyes hindering visualising the bed. It is not known if this was a factor during the Baseline survey however at Reference Site 5 during the Baseline survey notes accompany the results stating macrophyte coverage was extensive. At this site sediment coverage was essentially absent suggesting issues visualising the substrate here as well.

In addition, the Baseline embeddedness data ranges from 1 to 5, however the methods accompanying this data state a scale of 1 to 4 should be used with 4 indicating substrates are heavily embedded.

6.5 Substrates

One of the main areas of focus during the rehabilitation work was the river bed. Throughout the ARP, almost 10,000 tonnes of fine sediment (silt and liquefaction sand) were removed (CCDU 2015). This was facilitated by excavating the substrate from the river, cleaning the substrate to remove fine sediment, and then returning the cleaned substrate to the river. Additional large substrate (cobbles, boulders) was added to the river in some locations.

During the Year 1 survey, the SI was significantly greater at the rehabilitation sites compared to the reference sites. In addition, coverage of fine sediment was significantly less at the rehabilitation sites compared to the reference sites. This is likely to have contributed to the significant decrease in embeddedness at the rehabilitation sites during the year 1 survey, as embeddedness is defined as the degree to which coarse stream substrates are surrounded by fine substrates (Harding et al. 2009). All these habitat variables indicate the substrate at the rehabilitation sites is more stable than the reference sites which will have implications for fish, macroinvertebrate and macrophyte communities. Fish and macroinvertebrates are discussed further below.

6.6 Macroinvertebrates

QMCI scores, taxa richness and abundance increased between the Baseline and Year 1 surveys.. However, when comparing Year 1 reference and rehabilitation sites there were no significant differences with the exception of MCI values where the reference sites had higher MCI scores than the rehabilitation sites. This trend was not supported by the QMCI scores. Large proportions of pollution tolerant taxa such as *P. antipodarium, Paracalliope*, orthocladiinae, and *Pycnocentrodes* dominate the communities, and therefore have a large influence on the QMCI score due to their abundance.

There were almost 60% more invertebrates and on average two more taxa found at the rehabilitation sites than the reference sites in this Year 1 survey. As already stated, the reference sites were characterised by a lower SI, dominated by less stable substrates such as sand and silt. Rivers and streams with less stable substrates generally contain less macroinvertebrate individuals and a lower species diversity (Cobb et al. 1992, Zimmermann & Death 2002). The macroinvertebrate community at less stable sites generally contain species with lifecycle and behaviour adaptations suited to these environments. However, as until recently, the rehabilitation sites too have been characterised by large amount of fine sediment, the community composition of these sites is expected to contain similar species to those of less stable sites.

There were differences in the community composition as demonstrated by the NMDS ordination (Figure 4). These changes were dominated by relatively pollution tolerant taxa with the exception of the caddisfly *Hudsonema*. However, *Hudsonema* has an MCI value of 6 indicating it is relatively tolerant. Its abundance increased from 21 individuals across all rehabilitation sites during the Baseline survey to 932 during the Year 1 survey. This could suggest an improvement in habitat, likely as a result of a change from a silt based substrate to a more stable coarser substrate. However the abundances also increased at the reference sites. The addition of another years monitoring will help to determine if this change is due to the rehabilitation works or if it's a product of the natural variation or different times of year the surveys were undertaken.

Rehabilitation Site 5 yielded a QMCI value of 3.1 which was one whole unit less than the next lowest QMCI score for the rehabilitation sites (Site 1). Contractors had moved through this site the day prior to sampling occurring and removed macrophytes and periphyton from the site. It is likely this also disturbed and/or removed significant numbers of macroinvertebrates from the site. Although the samples contained on average 865 individuals, the most abundant of all the sites, it was heavily dominated by Tanytarsini (49%), a small midge larvae that is considered to be generally robust in New Zealand (MCI value of 3). These midges are generally associated with aquatic vegetation and algae though may have been dislodged during macrophyte clearance, or were present on the remaining vegetation and algae and were more accessible to the surber sample due the removal of most of the vegetation.

Invertebrates have been found to colonise rehabilitated streams via drift from upstream (Gortz 1998, Larned et al. 2006). As the upstream reaches of the Avon River have not been included in the rehabilitation programme it is not expected this will present a significant source population. While many aquatic macroinvertebrates have an adult aerial stage capable of dispersing large distances (great than 5km in some cases) (Parkyn and Smith 2011), the absence of other source populations in close proximity to the Avon River will limit the chances of dispersal and colonisation by aerial adult stages. Other studies of stream rehabilitation in Christchurch have found only small changes to invertebrate communities, with small shifts in abundance, species evenness and diversity (Suren & McMurtrie 2005). Suren and McMurtrie's study concluded the lack of significant changes in the invertebrate community were either due to the rehabilitation works not providing substantial enough changes for invertebrates outside the catchment to recognise the enhanced areas as habitat suitable for dispersal, or due to alternative factors such as streambed contamination, reduced base flows and impacts of the urban environment.

Macroinvertebrate community structure changes with season and hydrology (Álvarez-Cabria et al. 2010). As such, there can be some differences expected between the Baseline and Year 1 data as a result of the differing time of year the samples were taken. This may be the reason for the significant differences between years on the NMDS ordination plot. Baseline and Year 1 macroinvertebrate communities had an average dissimilarity of 70.5%.

Several factors were investigated to determine if they had an effect on the macroinvertebrate community. Macrophyte coverage did significantly affect QMCI with QMCI scores increasing as macrophyte coverage increased. Macrophytes provide food and habitat for both fish and invertebrates as well has helping to stabilise substrate and modify flow. Velocity and SI did not affect QMCI and no interaction terms were significant. These variables did not affect any other invertebrate indices and coupled with the lack of significant difference between reference and rehabilitation sites suggests it is general habitat conditions including water quality and historic influences that are determining the invertebrate community. Trends may become more apparent once more time post rehabilitation works has elapsed. It is expected the next survey will be more revealing for macroinvertebrates.

6.7 Fish

There were minimal significant differences in the fish data between years and between reference and rehabilitation sites. At two of the rehabilitation sites, the CPUE more than doubled – from 3.98 to 8.02, and from 2.72 to 6.04 for Rehabilitations Sites 1 and 2 respectively. The CPUE for Rehabilitation Sites 3 and 4 also increased although not at the same scale, while Rehabilitation Site 5 stayed essentially the same (11.91 during Baseline, 11.76 during Year 1 survey). Despite this, there was no statistically significant difference between surveys, or between reference and rehabilitation sites for the total CPUE values.

As already discussed, Rehabilitation Sites 1 and 2 were among the first to be rehabilitated with works completed in 23 months prior to the Year 1 survey being carried out for Rehabilitation Site 1 and 11 months prior for Rehabilitation Site 2. While there are only two sampling occasions, it does suggest there may be a relationship between the time since disturbance in the form of in-river works, and the number of fish present within each site. The fish community may have been disturbed during and immediately following restoration, with fish moving away from the sites. As a result, it may take time for fish to return to the area. Fish were removed prior to rehabilitation works both from the river and from the sludge removed from the river. These fish were returned to the river, however they were released upstream from their removal sites and as such would need to return to the lower parts of the ARP. It may be that the fish that were relocated upstream are driving the higher fish densities at the two most upstream rehabilitation sties. However, this is highly speculative and further monitoring will be required to determine if this pattern continues over time. As the rehabilitated portions of the river contain different habitat compared to prior to restoration, it will take time for these new niches to be occupied by the species best suited to them as the fish relocated prior to in-river works recolonize areas downstream from where they were released. A study of river rehabilitation in Europe found that fish communities were both larger and more diverse following rehabilitation however in the immediate years following work results fluctuated (Thomas et al. 2015). They concluded that final assessment of rehabilitation success could not be accurately assessed in the first few years after works had concluded due to colonisation succession processes. Additional monitoring is scheduled to occur at 3, 5 and 10 years post-restoration, to determine the response of the fish community over the long-term.

The significant changes in substrate do not appear to have affected the fish community. In studies overseas, and in New Zealand, a correlation between increased fine sediment and a reduction in fish diversity has been detected. The increased fine sediment removes the variation between riffle, run and pool habitats, homogenising habitat and decreasing its suitability for species traditionally present (Cobb et al. 1992). As the Avon River has historically been highly influenced by fine sediment, fish diversity may increase as the riffle, run and pool habitats become more defined as a result of the removal of silt and liquefaction. With the exception of shortfin eel and common bully, the other native fish species present prefer average substrate sizes of around 50mm (Jowett & Richardson 1995). If sediment alone was the limiting factor influencing the fish community, it would be expected that the community structure would have changed significantly due to the significant increase in average substrate size. As more time elapses the influence of substrate will become more apparent. If no changes are detected in the future, other factors are responsible for the fish community such as wider land use and urban inputs.

While one new species was present during the Year 1 survey, it is not anticipated that species diversity will change dramatically, even as the time since rehabilitation progresses. Despite a large portion of the river undergoing rehabilitation, the river remains unchanged both up and downstream of these reaches and in a state highly influenced by the surrounding urban environment. This is likely to limit the probability of new species moving into the Avon River catchment, especially as adjacent urban river catchments also have limited fish diversity and abundance in parts.

The differences ANOSIM detected between both the survey years and between reference and rehabilitation sites supports the differences in composition illustrated in the NMDS ordination where obvious and significant differences between the fish communities of the reference and rehabilitation sites, and between surveys, were demonstrated. When this is coupled with significant differences between reference and rehabilitation CPUE, it suggests there has been changes brought about by the rehabilitation works. However only common bullies demonstrated a significant increase in abundance in the rehabilitation sites.

7 Conclusions

An ecological assessment was carried out on the Avon River with the aim of identifying if any changes had occurred as a result of in-river rehabilitation works within the ARP. The survey repeated protocols carried out in November 2013 which presented a set of baseline data. Results from this study were compared to the baseline data in addition to comparisons between reference and rehabilitation study sites.

The most obvious change can be found in the SI with a significant increase in SI value when rehabilitation sites are compared to reference sites. This indicates a reduction in sand, silt and gravel substrates in favour of coarser substrates including pebbles and cobbles. Channel width also decreased dramatically through the creation of the vegetated flood plains. This has increased buffer width where the flood plains are present.

There was generally no change in periphyton or macrophyte coverage, with the exception of Rehabilitation Site 5, where contractors had removed aquatic vegetation one day prior to the survey taking place.

It appears fine sediment may be beginning to re-deposit in the rehabilitated reaches where it has been removed, or it was not completely removed during in-river works. More sampling will add a more defined time variable and will enable the identification of temporal trends.

Macroinvertebrate abundance and number of taxa increased significantly between the Baseline and Year 1 survey however no significant differences were found between reference and rehabilitation sites during the Year 1 survey. There were significant differences in the community compositions of Baseline and Year 1 reference and rehabilitation communities, however these differences were predominantly driven by pollution tolerant taxa (*Pycnocentrodes*, *Paracalliope,* and *orthocladiinae*). Macrophytes significantly affected QMCI scores with scores increasing as macrophyte coverage increased. Generally, communities were dominated by the pollution tolerant taxa *Pycnocentrodes*, *Paracalliope* and *P. antipodarium*. The lack of significant changes in the macroinvertebrate community suggests it is not the physical habitat at the rehabilitation sites that is limiting the macroinvertebrate community. It implies other factors such as upstream conditions, catchment landuse, urban inputs and lack of source population are the limiting aspects.

There was a significant change in the relative abundance of fish species caught between surveys and between reference and rehabilitation sites. One new species was found (lamprey which is nationally endangered at Rehabilitation Site 1 - Watermark). There was no difference in fish abundance between surveys and there was no statistical interaction between survey year and reference and rehabilitation sites suggesting that there has been no change to fish abundance as a result of the rehabilitation works. However, the two sites that were rehabilitated first produced over twice the number of fish compared to the baseline survey. It will be interesting to see if this trend continues as the other sites settle over time.

Due to the relatively short period of time following rehabilitation works and the Year 1 survey, it is anticipated that any trends regarding changes in the physical and biotic condition of the river will become more apparent after the next assessment repetition. Alternatively, if no trends emerge or habitat variables show signs of decline over the next few years it is possible that elements such as surrounding land use, stormwater inputs and historical influences have more significant influence. Suren et al. (2005) concluded factors independent of rehabilitation works such as stormwater discharges, and sediment contamination associated with these discharges, coupled with catchment scale effects such as urban land use, are limiting factors for stream rehabilitation. Time will tell if the rehabilitation works in the Avon River have been sufficient to overcome these independent factors and have resulted in the original goals being achieved.

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APPENDIX 1:

SURVEY LOCATIONS

Site Name	Site Number	Location of downstream most transect
Avon River downstream of Mona Vale Weir	Reference Site 1	Directly adjacent to NE corner of school building
Avon River at Carlton Mill Corner	Reference Site 2	22m downstream from Carlton bridge on TL
Avon River in Hagley Park	Reference Site 3	Directly adjacent to *Prunus* tree on lower bank on TL
Avon River at Watermark	Rehabilitation Site 1	50m downstream from 6th boardwalk pillar on TL (also adjacent to last large tree on TL before reaching the Boat Sheds)
Avon River at Rhododendron Island	Rehabilitation Site 2	20m upstream from upstream extent of Rhododendron Island
Avon River at Hereford Street	Rehabilitation Site 3	3 sites on either side of Hereford Street Bridge. Downstream side – 36m downstream from bridge. Upstream side – 6m upstream from bridge
Avon River at Victoria Square	Rehabilitation Site 4	Adjacent to upstream most extent of exposed stone wall on the TR bank
Avon River near Kilmore Street	Rehabilitation Site 5	16 metres downstream from largest oak on TR bank at approx. GPS coordinates

APPENDIX 2:

RYDERS CONSULTING MACROINVERTEBRATE PROCESSING

Avon River

Summary of Freshwater Macroinvertebrate Sample Processing & Results

March 2015

ryderconsulting
environment + planning + project management

Avon River

Summary of Freshwater Macroinvertebrate Sample Processing & Results

March 2015

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1. Introduction

Preserved benthic macroinvertebrate samples were provided to Ryder Consulting Limited by Opus International Consultants Limited. Opus International Consultants Limited staff collected these samples in March 2015. Ryder Consulting Limited was engaged to process the samples, and report the results of taxonomic composition and abundance.

2. Laboratory Analysis

2.1 Processing

Macroinvertebrate samples were processed for macroinvertebrate species identification and abundance using the 'Full count with subsampling option' protocol (Protocol P3) outlined in the Ministry for the Environment's 'Protocols for sampling macroinvertebrates in wadeable streams' (Stark *et al.* 2001). This protocol is summarised briefly below.

Samples were passed through a 500 µm sieve to remove fine material. Contents of the sieve were then placed in a white tray and macroinvertebrates identified under a dissecting microscope (10-40X) using criteria from Winterbourn *et al.* (2006). When more than 500 individuals of one taxa were present, the number of individuals from a fixed fraction (between 10% and 50%) was counted and the number scaled up to the total number in each sample using a weighting factor based on the fraction of the sample that was counted.

2.2 Data summaries and metric calculations

For each site, benthic macroinvertebrate community health was assessed by determining the following characteristics:

Number of taxa: A measurement of the number of taxa present.

Number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa: These insect groups are generally dominated by invertebrates that are indicative of higher quality conditions. In stony bed rivers, these indexes usually increase with improved water quality and increased habitat diversity.

Macroinvertebrate Community Index (MCI) (Stark 1993): The MCI uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. Taxon scores are between 1 and 10, 1 representing species highly tolerant to organic pollution (e.g., worms and some dipteran species) and 10 representing species highly sensitive to organic pollution (e.g., most mayflies and stoneflies). A site score is obtained by summing the scores of individual taxa and dividing this total by the number of taxa present at the site. These scores can be interpreted in comparison with national standards (Table 1). For example, a low site score (e.g., 40) represents 'poor' conditions and a high score (e.g., 140) represents 'excellent' conditions.

$$\text{MCI} = \left(\frac{\text{Sum of taxa scores}}{\text{Number of scoring taxa}}\right) \text{x } 20$$

Quantitative Macroinvertebrate Community Index (QMCI) (Stark 1985): The QMCI uses the same approach as the MCI, but weights each taxa score based on how abundant the taxa is within the community. Site scores range between 0 and 10. As for MCI, QMCI scores can be interpreted in the context of national standards (Table 1).

$$\text{QMCI} = \sum_{i=1}^{i=S} \frac{(n_i \text{ x } a_i)}{N}$$

Where S = the total number of taxa in the sample, n_i is the number of invertebrates in the ith taxa, a_i is the score for the ith taxa, and N is the total number of invertebrates for the entire sample.

Table 1 *Interpretation of macroinvertebrate community index values from Boothroyd and Stark (2000) (Quality class A) and Stark and Maxted (2007) (Quality class B).*

Quality Class A	Quality Class B	MCI	QMCI
Clean water	Excellent	≥ 120	≥ 6.00
Doubtful quality	Good	100 – 119	5.00 – 5.99
Probable moderate pollution	Fair	80 – 99	4.00 – 4.99
Probable severe pollution	Poor	< 80	< 4.00

3. Results

3.1 Macroinvertebrate results

The macroinvertebrate results are included below and have also been forwarded to Opus International Consultants Limited in electronic form (Excel spreadsheet).

TAXON	**MCI score**	**Ref. 1**					
		Surber 1	**Surber 2**	**Surber 3**	**Surber 4**	**Surber 5**	**Kicknet**
ACARINA	5		3	7	1	12	2
CNIDARIA							
Hydra	3						
COLLEMBOLA	6					1	
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	3	36	27	21	26	71
Paracalliope	5	7	222	82	186	362	505
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2						
Empididae	3	1	5	5	3	4	5
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						
Muscidae	3						
Orthocladiinae	2	1	5	11	22	14	36
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5						3
Tanytarsini	3		3	42	40	20	14
HIRUDINEA	3						
MOLLUSCA							
Ferrissia	3		2	1		1	3
Gyraulus	3						1
Lymnaeidae	3						
Physa / Physella	3	1	10	4	4	3	92
Potamopyrgus	4	7	4	4	8	28	39
Sphaeriidae	3	6	1	3		1	6
NEMATODA	3						
NEMERTEA	3					1	
OLIGOCHAETA	1	9	17	5	17	13	29
PLATYHELMINTHES	3			9	6	1	10
TRICHOPTERA							
Hudsonema	6	6	92	166	97	211	344
Hydrobiosis	5	1		4	3	5	2
Oecetis	6						
Oxyethira	2		2	5	7	9	14
Paroxyethira	2						
Psilochorema	8			1		3	3
Pycnocentria	7		1				
Pycnocentrodes	5	1	61	103	119	140	66
Triplectides	5	1					2
Number of taxa		12	15	17	14	19	20
Number of EPT taxa		4	4	5	4	5	6
MCI score		75	73	75	71	77	77
QMCI score		3.6	4.8	4.8	4.6	5.0	-

TAXON	MCI score	Ref. 2					
		Surber 1	Surber 2	Surber 3	Surber 4	Surber 5	Kicknet
ACARINA	5				2	1	
CNIDARIA							
Hydra	3						
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	30	117	378	468	3	90
Paracalliope	5	14	4	2	8	9	129
DIPTERA							
Ceratopogonidae	3			2			
Chironomus	1						
Corynoneura	2						
Empididae	3					1	5
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						2
Muscidae	3						
Orthocladiinae	2	8	2		8	4	6
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5	1	3	3	10	1	2
Tanytarsini	3	6	6	8	3	7	96
HIRUDINEA	3						
MOLLUSCA							
Ferrissia	3						
Gyraulus	3						
Lymnaeidae	3						
Physa / Physella	3	13	4	4	12	3	15
Potamopyrgus	4	13	98	122	99	40	94
Sphaeriidae	3	6	28	47	29	6	14
NEMATODA	3				1		
NEMERTEA	3	1					
OLIGOCHAETA	1	54	79	47	56	48	43
PLATYHELMINTHES	3	6	1		2	4	3
TRICHOPTERA							
Hudsonema	6	11	9	5	17	85	120
Hydrobiosis	5					2	1
Oecetis	6			1			
Oxyethira	2	5	2	3	2	1	13
Paroxyethira	2						
Psilochorema	8						
Pycnocentria	7						
Pycnocentrodes	5					13	35
Triplectides	5				11		
Number of taxa		13	12	12	15	16	16
Number of EPT taxa		2	2	3	3	4	4
MCI score		66	67	73	71	73	71
QMCI score		2.7	2.9	3.1	3.1	4.1	-

TAXON	MCI score	Ref. 3					
		Surber 1	Surber 2	Surber 3	Surber 4	Surber 5	Kicknet
ACARINA	5	3	6	3	1	2	8
CNIDARIA							
Hydra	3		1				
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	8	50	10	7	3	35
Paracalliope	5	29	63	17	10	16	30
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2						
Empididae	3	1	5	8	7	1	5
Hexatomini	5		1				
Maoridiamesa	3		1				
Mischoderus	4						
Muscidae	3						
Orthocladiinae	2	12	141	6	6	8	23
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5		1	2			
Tanytarsini	3	48	314	20	8	43	36
HIRUDINEA	3						
MOLLUSCA							
Ferrissia	3	1	5	1			2
Gyraulus	3						
Lymnaeidae	3						
Physa / Physella	3	3	8	11	1	9	18
Potamopyrgus	4	1	13	4	4	6	32
Sphaeriidae	3	17	30	16	8	2	22
NEMATODA	3						1
NEMERTEA	3						
OLIGOCHAETA	1	21	47	48	40	46	71
PLATYHELMINTHES	3	3	9	4	1	1	6
TRICHOPTERA							
Hudsonema	6	231	299	212	72	74	91
Hydrobiosis	5	1	2	1			3
Oecetis	6				1		
Oxyethira	2	2	6		2	2	6
Paroxyethira	2						
Psilochorema	8	1	5	2	1	4	1
Pycnocentria	7						
Pycnocentrodes	5	29	8	14	16	4	13
Triplectides	5						
Number of taxa		17	21	17	16	15	18
Number of EPT taxa		5	5	4	5	4	5
MCI score		75	76	79	78	75	74
QMCI score		4.9	3.8	4.6	4.0	3.9	-

TAXON	MCI score	Rehab. 1 (Watermark)					
		Surber 1	Surber 2	Surber 3	Surber 4	Surber 5	Kicknet
ACARINA	5	1	2	2			2
CNIDARIA							
Hydra	3						
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	47	190	43	10	11	181
Paracalliope	5	166	224	523	47	320	430
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2						
Empididae	3	8	1	12		1	8
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						
Muscidae	3						1
Orthocladiinae	2	4	18	17	1	2	4
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5						1
Tanytarsini	3	17	2	85	2	6	11
HIRUDINEA	3	1	2			2	3
MOLLUSCA							
Ferrissia	3						
Gyraulus	3			1	1	1	8
Lymnaeidae	3						
Physa / Physella	3	50	10	224	63	70	266
Potamopyrgus	4	18	38	388	241	115	1022
Sphaeriidae	3	6	3	2	1	6	2
NEMATODA	3						
NEMERTEA	3						
OLIGOCHAETA	1	42	14	77		9	7
PLATYHELMINTHES	3	4	3	37		1	
TRICHOPTERA							
Hudsonema	6	49	10	117	19	49	62
Hydrobiosis	5	6	1	5		1	
Oecetis	6	2					1
Oxyethira	2	19	16	59	1	5	36
Paroxyethira	2	2	1	25			14
Psilochorema	8	2		2			
Pycnocentria	7						
Pycnocentrodes	5	44		42	4	19	26
Triplectides	5		1		3		
Number of taxa		19	17	18	12	16	19
Number of EPT taxa		7	5	6	4	4	5
MCI score		76	68	73	73	68	71
QMCI score		4.0	3.9	4.0	4.0	4.5	-

TAXON	MCI score	Rehab. 2 (Rhode Is.)					
		Surber 1	Surber 2	Surber 3	Surber 4	Surber 5	Kicknet
ACARINA	5	1	2	1	3	7	63
CNIDARIA							
Hydra	3						
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	97	104	44	2	1	4
Paracalliope	5	22	14	11	7	2	41
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2				1		
Empididae	3		4	1		2	10
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						
Muscidae	3						
Orthocladiinae	2	35	21	11	41	24	139
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5						
Tanytarsini	3		3	2	6	6	11
HIRUDINEA	3	2	5				
MOLLUSCA							
Ferrissia	3				1		
Gyraulus	3	1	2			4	30
Lymnaeidae	3		4				4
Physa / Physella	3	18	39	9	11	9	88
Potamopyrgus	4	24	105	11	80	161	241
Sphaeriidae	3	2	1				
NEMATODA	3						
NEMERTEA	3						
OLIGOCHAETA	1	26	17	7	2	2	3
PLATYHELMINTHES	3	8	7	4		2	34
TRICHOPTERA							
Hudsonema	6	103	41	63	14	52	40
Hydrobiosis	5		1			1	1
Oecetis	6						
Oxyethira	2	39	19	10	4	1	8
Paroxyethira	2	5	3	2	1		2
Psilochorema	8	1	2	2			
Pycnocentria	7						
Pycnocentrodes	5	292	266	283	66	206	290
Triplectides	5						1
Number of taxa		16	20	15	14	15	18
Number of EPT taxa		5	6	5	4	4	6
MCI score		73	72	73	66	71	70
QMCI score		4.2	4.1	4.7	3.9	4.5	-

		Rehab. 3 (Mill Is.)					
TAXON	**MCI score**	**Surber 1**	**Surber 2**	**Surber 3**	**Surber 4**	**Surber 5**	**Kicknet**
ACARINA	5	4	7	18	50	4	
CNIDARIA							
Hydra	3				3		
COLLEMBOLA	6			1			
CRUSTACEA							
Cladocera	5						
Isopoda	5						1
Ostracoda	3	10		1	5	1	26
Paracalliope	5	124	91	114	61	70	130
DIPTERA							
Ceratopogonidae	3						
Chironomus	1	6	1			1	
Corynoneura	2		1				
Empididae	3	10	40	12	3	4	1
Hexatomini	5						
Maoridiamesa	3	1			2		
Mischoderus	4						
Muscidae	3						1
Orthocladiinae	2	125	30	55	119	8	30
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5						
Tanytarsini	3	36	8	11	23	4	10
HIRUDINEA	3						
MOLLUSCA							
Ferrissia	3	13	10	2	6	1	1
Gyraulus	3	8	5	12	3	4	15
Lymnaeidae	3		2	12	11	18	4
Physa / Physella	3	26	2				28
Potamopyrgus	4	37	141	10	51	157	178
Sphaeriidae	3						
NEMATODA	3						
NEMERTEA	3	2		2			
OLIGOCHAETA	1	4	9	2	1	5	15
PLATYHELMINTHES	3	2	1		8		1
TRICHOPTERA							
Hudsonema	6	16	27	32	24	14	84
Hydrobiosis	5	1	2				3
Oecetis	6						
Oxyethira	2	27	1	7	5	7	21
Paroxyethira	2						1
Psilochorema	8	2		1	1		1
Pycnocentria	7						
Pycnocentrodes	5	437	75	417	248	52	435
Triplectides	5			1			1
Number of taxa		20	18	18	18	15	21
Number of EPT taxa		5	4	5	4	3	7
MCI score		71	66	78	72	65	73
QMCI score		4.2	4.1	4.6	4.2	4.2	-

		Rehab 4. (Vic. Sq.)					
TAXON	**MCI score**	**Surber 1**	**Surber 2**	**Surber 3**	**Surber 4**	**Surber 5**	**Kicknet**
ACARINA	5	7	11	14	27	10	9
CNIDARIA							
Hydra	3						
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5						
Isopoda	5						
Ostracoda	3	83	8	7	33	14	446
Paracalliope	5	188	170	193	259	190	804
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2						
Empididae	3	14	18	18	13	14	10
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						
Muscidae	3						
Orthocladiinae	2	13	5	5	3	3	15
Sciomyzidae	3						1
Stratiomyidae	5	1					
Tanypodinae	5						
Tanytarsini	3	3	6		4	3	8
HIRUDINEA	3						
MOLLUSCA							
Ferrissia	3		2	2	6	4	4
Gyraulus	3	3	24	8	6	6	38
Lymnaeidae	3	26	47	18	18	28	101
Physa / Physella	3	27	24	25	26	27	172
Potamopyrgus	4	191	115	177	155	193	1272
Sphaeriidae	3				1		3
NEMATODA	3	1	2				
NEMERTEA	3					1	
OLIGOCHAETA	1	30	16	12	13	15	29
PLATYHELMINTHES	3	4	2	1	3	14	48
TRICHOPTERA							
Hudsonema	6	26	32	33	27	25	53
Hydrobiosis	5	1				3	
Oecetis	6						
Oxyethira	2	13	11	6	9	9	81
Paroxyethira	2		1		1		5
Psilochorema	8						
Pycnocentria	7						
Pycnocentrodes	5	308	211	346	273	284	768
Triplectides	5						6
Number of taxa		18	18	15	18	18	20
Number of EPT taxa		4	4	3	4	4	5
MCI score		71	66	68	66	69	67
QMCI score		4.3	4.3	4.6	4.5	4.4	-

TAXON	MCI score	Rehab 5. (Kilmore)					
		Surber 1	Surber 2	Surber 3	Surber 4	Surber 5	Kicknet
ACARINA	5		3	4	3	4	
CNIDARIA							
Hydra	3		1				
COLLEMBOLA	6						
CRUSTACEA							
Cladocera	5		1				
Isopoda	5						
Ostracoda	3	140	93	40	22	218	356
Paracalliope	5	45	10	11	34	48	86
DIPTERA							
Ceratopogonidae	3						
Chironomus	1						
Corynoneura	2						3
Empididae	3		8	5	2	2	7
Hexatomini	5						
Maoridiamesa	3						
Mischoderus	4						
Muscidae	3				1		1
Orthocladiinae	2	398	47	67	64	204	403
Sciomyzidae	3						
Stratiomyidae	5						
Tanypodinae	5	11	8	4	5	21	7
Tanytarsini	3	726	471	265	158	480	110
HIRUDINEA	3						1
MOLLUSCA							
Ferrissia	3	1					
Gyraulus	3	11	1	1	1	3	12
Lymnaeidae	3	18	8	9	5	9	18
Physa / Physella	3	20	30	19	21	61	314
Potamopyrgus	4	12	7	5	9	9	107
Sphaeriidae	3						
NEMATODA	3	2	2	5	13	9	2
NEMERTEA	3						
OLIGOCHAETA	1	10	6	15	2	2	4
PLATYHELMINTHES	3	3	2			3	5
TRICHOPTERA							
Hudsonema	6	37	10	32	24	56	104
Hydrobiosis	5	10	17	8	4	8	17
Oecetis	6						
Oxyethira	2	3	10	8	2	16	11
Paroxyethira	2	1		1			
Psilochorema	8						1
Pycnocentria	7						
Pycnocentrodes	5	38	4	25	31	20	53
Triplectides	5					1	
Number of taxa		18	20	18	18	19	21
Number of EPT taxa		5	4	5	4	5	5
MCI score		68	72	70	71	73	71
QMCI score		2.9	3.1	3.2	3.4	3.1	-

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APPENDIX 3:

SIMPER RESULTS

Reference Sites
Average similarity: 42.26%

Macroinvertebrate Taxon	Average Abundance	Percent Contribution
Paracalliope	105.23	26.27
Oligochaeta	53.53	25.55
Hudsonema	56.73	14.92
Pycnocentrodes	27.83	7.38

Rehabilitation Sites
Average similarity: 44.96%

Macroinvertebrate Taxon	Average Abundance	Percent Contribution
Potamopyrus	87.00	20.41
Paracalliope	104.90	19.02
Orthocladiinae	86.00	17.12
Pycnocentrodes	92.62	13.76

Reference Sites vs Rehabilitation Sites
Average dissimilarity: 65.52

Macroinvertebrate Taxon	Reference Average Abundance	Rehabilitation Average Abundance	Percent Contribution
Paracalliope	105.23	104.90	21.5
Pycnocentrodes	27.83	91.62	14.94
Potamopyrus	23.07	87.00	13.21
Orthocladiinae	21.83	86.00	13.11
Oligochaeta	53.53	38.34	7.56

Baseline Survey
Average similarity: 48.02

Macroinvertebrate Taxon	Average Abundance	Percent Contribution
Oligochaeta	65.95	25.18
Paracalliope	110.68	24.88
Orthocladiinae	84.68	22.18

Year 1 Survey
Average similarity: 40.5

Macroinvertebrate Taxon	Average Abundance	Percent Contribution
Pycnocentrodes	112.48	22.04
Paracalliope	99.38	16
Potamopyrus	72.53	14.45
Hudsonema	62.98	13.86
Ostracoda	60.28	6.62

Baseline Survey vs Year 1 Survey
Average dissimilarity: 70.49

Macroinvertebrate Taxon	Baseline Average Abundance	Year 1 Average Abundance	Percent Contribution
Pycnocentrodes	22.93	112.48	17.38
Paracalliope	110.68	99.38	17.11
Orthocladiinae	84.68	39.20	11.06
Potamopyrus	53.53	72.53	10.33
Tanytarsini	3.78	72.38	8.99
Hudsonema	3.40	62.98	8.59

APPENDIX 4:

HABITAT ASSESSMENT METHODS

Sediment Assessment Method 2 – In-stream visual estimate of % sediment cover

Rationale	Semi-quantitative assessment of the surface area of the streambed covered by sediment. At least 20 readings are made within a single habitat
Equipment required	• Underwater viewer - *e.g.*, bathyscope (www.absolutemarine.co.nz) or bucket with a Perspex bottom marked with four quadrats • Field sheet
Application	Hard-bottomed streams
Type of assessment	Assessment of effects
Time to complete	30 minutes
Description of variables	
% sediment	A visual estimate of the proportion of the habitat covered by deposited sediment (<2 mm)
Useful hints	Work upstream to avoid disturbing the streambed being assessed. Mark a four-square grid on the viewer to help with estimates – determine the nearest 5% cover for each quadrat. Calculate the average of all quadrats as a continuous variable following data entry. More than five transects may be necessary for narrow streams, to ensure 20 locations are sampled.

Field procedure

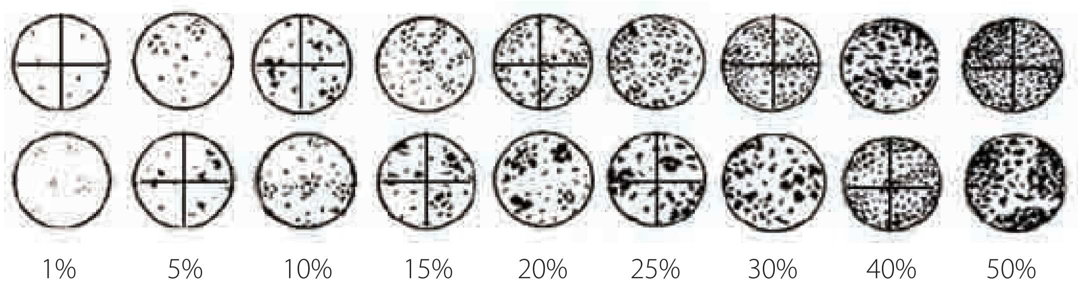
- Locate five random transects along the run.
- View the streambed at four randomly determined locations across each transect, starting at the downstream transect.
- Estimate the fine sediment cover in each quadrat of the underwater viewer in increments (1, 5, 10, 15, 20 …100%).
- Record results in the table below.
- Repeat for four more transects so that 20 locations are sampled in total.

Note: Estimation of cover in each quadrat is important during training but may not be necessary for experienced viewers – instead one measurement per location could be recorded.

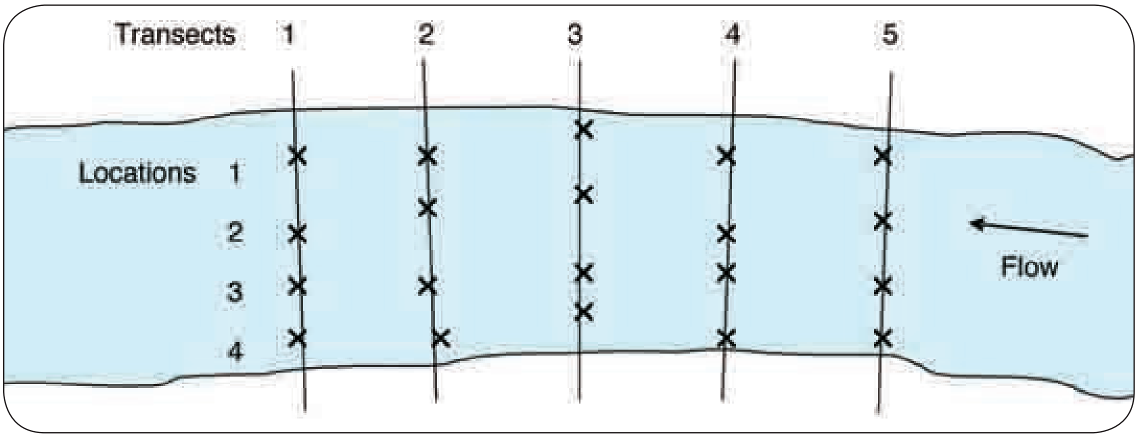
% sediment	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
Location 1	Q1	Q2								
	Q3	Q4								
Location 2										
Location 3										
Location 4										

Useful images

Digital examples of percent cover of sediment on the streambed as seen through an underwater viewer.



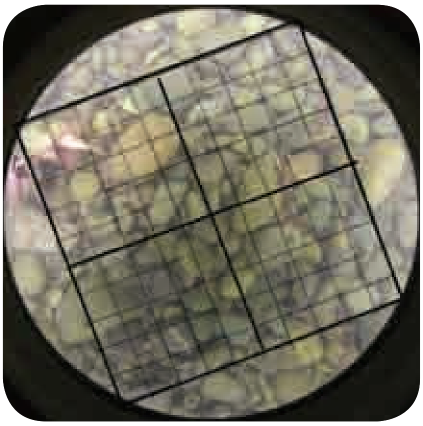
An example of viewer locations (x) for the in-stream visual assessment of sediment.



Real examples of percent cover of sediment on the streambed as seen through an underwater viewer.

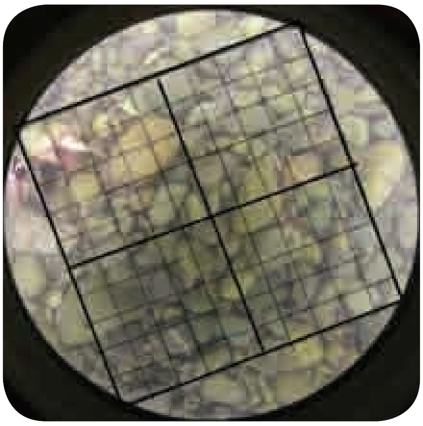
1%

1%



5%

5%



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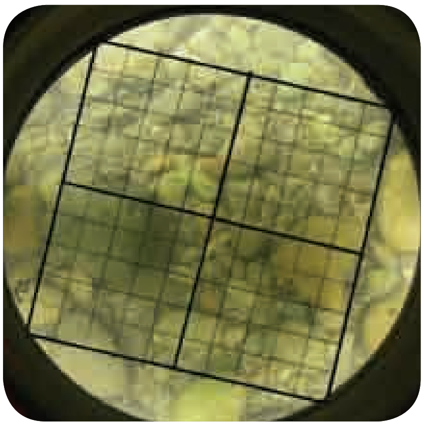

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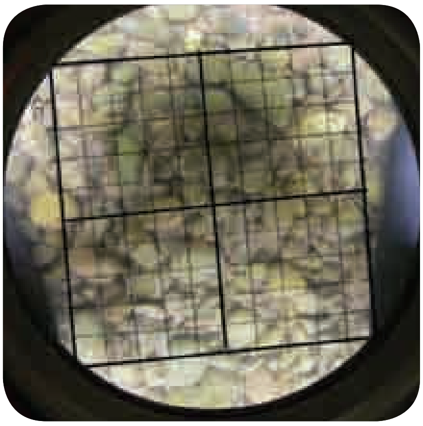

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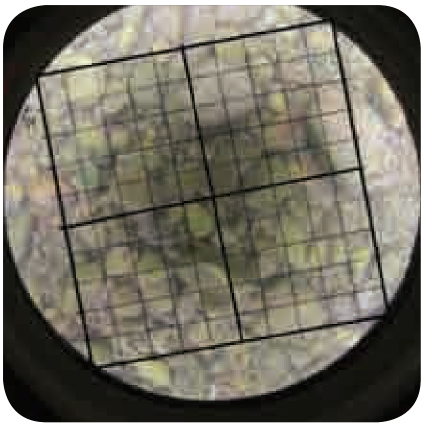

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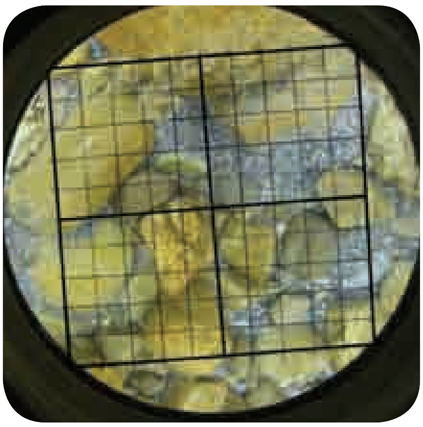

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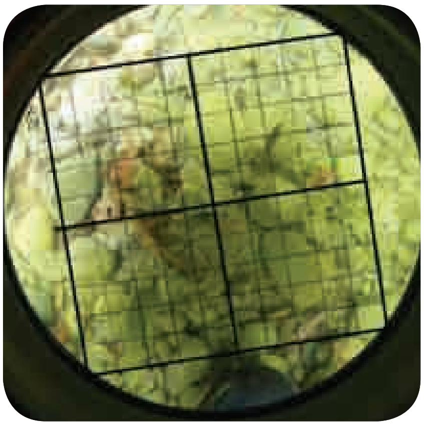

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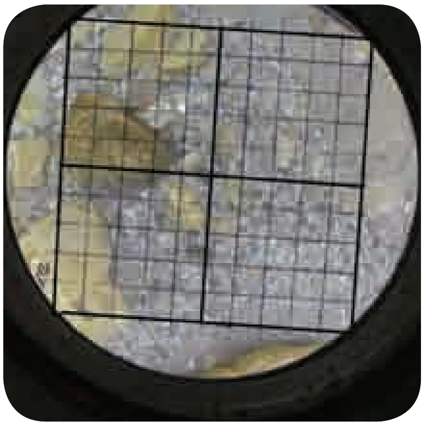

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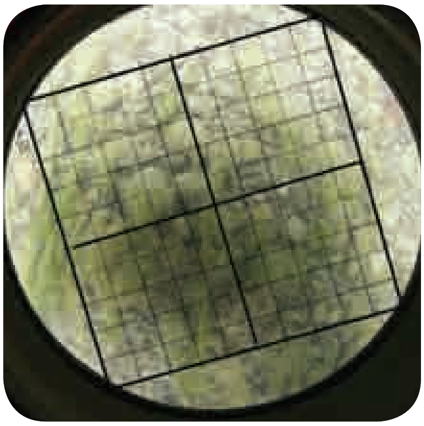

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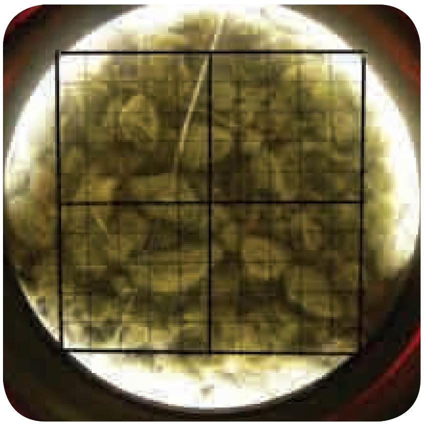

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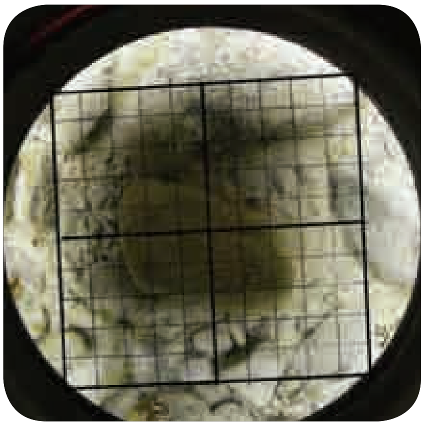


Sediment Assessment Method 6 –Sediment depth

Rationale	Quantitative assessment of the depth of sediment in a run habitat. At least 20 readings are made within a single habitat
Equipment required	• Ruler or ruled rod • Field sheet
Application	Hard-bottomed streams
Type of assessment	Assessment of effects
Time to complete	30 minutes
Description of variables	
Sediment depth (mm)	A measure of the depth of sediment (mm).
Useful hints	Determine the sampling grid first to ensure an even cover of edge and midstream locations. Move upstream to avoid disturbing the streambed being assessed. Calculate the average depth for each site. This method is usually only suitable when fine sediment is visible from the stream bank.

Field procedure

- Start downstream and randomly locate five transects along the run.
- Measure the sediment depth (mm) at four randomly determined locations across each transect and record depth in the table below.

Depth (mm)	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
Section 1					
Section 2					
Section 3					
Section 4					

Protocol 3 (P3) Quantitative protocol

Sample time	120-180 minutes
Site length	20x the mean wetted width at base flow (with a minimum of 50m and maximum of 500m)
Equipment	Camera, GPS or relevant topographic map. Flagging tape or similar, two or three 30m+ measuring tapes, water velocity meter, 1m ruler, range finder (optional), two 1.5m survey poles & inclinometer or builder's level, trowel or similar. A convex densiometer or a paired light sensor, and six temporary staff gauges (e.g., pieces of reinforcing bar or Warratahs) (optional, if follow up measurements of change in wetted width and depth are intended).
Overview	The aim of this protocol is to provide an intensive quantitative characterisation of a study site. It is suitable for baseline surveys and research projects where accurate data is required or long-term assessment of a site is expected. Sufficient data is obtained to calculate habitat metrics as well as conduct additional generalized habitat modelling.
Components	P3a – Desktop protocol P3b - An in-stream hydrological and morphological assessment P3c - An in-stream physical habitat assessment P3d - A riparian habitat assessment

P3b Hydrology and morphology procedure

1. Record site details such as **site code** (REC number), **site name**, as well as the name of the **assessor** and the **date**. Establish **reach start** by marking with a flagging tape or similar and GPS.
2. Measure the stream **wetted width** at a representative cross section (or measure 2-3 widths and calculate an average) and calculate the **reach length** as 20x wetted width.
3. Walk along the stream at the water's edge following the thalweg for the length of the sample reach measured by tape measure, tagline or pacing. Whilst walking record the **meso-habitat length** in meters for each meso-habitat encountered. (Identify areas to measure habitat parameters).
4. GPS the **reach end** point.
5. At each pool (maximum of six) measure residual pool depth by measuring the **maximum depth** of water at the deepest part of the pool and the **crest depth** of water at the riffle crest immediately downstream of the pool (an estimate of maximum pool depth is sufficient if it is too deep to measure, but note that it was estimated).
6. At the deepest part of each pool (maximum of six) measure the soft **sediment depth** by gently forcing your 1m ruler or wading rod into the substrate.
7. Locate a maximum of nine channel cross sections that represent the major meso-habitat types identified, e.g., three riffle, three run, and three pools. Within each meso-habitat

type, cross sections should be positioned in an attempt to encompass the range of variability represented, e.g., in the head, middle and tail of pools. However, locations that are not typical of the stream habitat should be avoided (e.g., extraordinarily wide riffles), as these 'habitat outliers' would bias the overall results.

8. At the channel cross section of a **run**, record location (e.g., head, middle, or tail) and extend a measuring tape across the channel perpendicular to stream flow. [Optional - mark the location of the cross section on both banks if follow up measurements of change in wetted width and depth are intended at a later date. Drive a temporary staff gauge into the stream bed and measure the water level relative to the top of the staff gauge. This gauge should be sufficient depth that it will not be dry by the time of the next measurement and protected from floods and debris. Do this for *run* cross sections only].
9. At left bankfull height (LBF) and at up to three points between bankfull and the water's edge (i.e., LB_1, LB_2, LB_3) record the **offset** (distance along the tape) and distance between the ground and horizontal measuring tape (record this height in the water depth cells). Aim to position the LB measurements at the points of greatest change in bank slope. Also record the offset and distance to the measuring tape at the water's edge (WE).
10. Record **water depth** and **water velocity** at up to 10 offsets across the transect. The aim is to define the cross-sectional area with as few offsets as possible (minimum = 5) whilst recording the variation in the stream bed. A rule of thumb is to choose the offsets at points where depth and/or water velocity change noticeably. Read water depth on the downstream side of a ruler or wading rod. Water velocity is measured at four-tenths of water depth up from the bed. Repeat bank measurements on the right bank.
11. Repeat cross sections at two more runs recording all variables.
12. Repeat the cross section at three **riffle** and three **pool** habitats, excluding water velocity readings.
13. Complete a **plan diagram** (bird's eye view) of the site including photo points, significant land marks, access points, N direction, direction of stream flow, location of roads and a rough scale.

Example of a completed P3b field form

P3b is similar to P2b with an additional 8 transects.

P3c In-stream habitat procedure

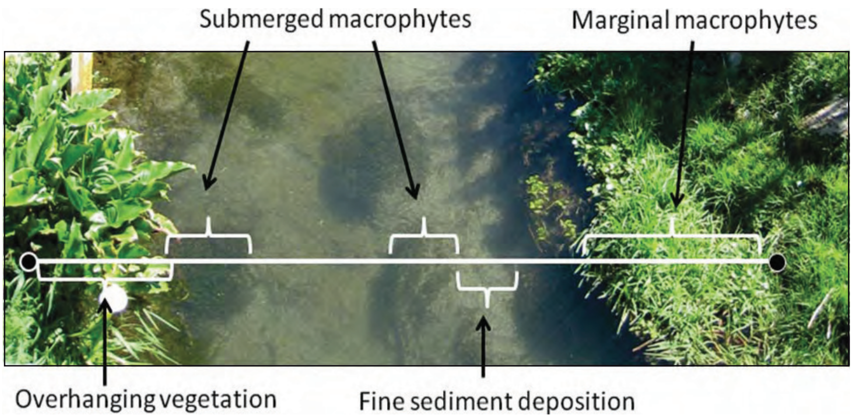
1. This assessment is made across the bankfull extent of the stream; it includes lower banks, any dry river bed and the wetted width of the stream.
2. Measure six cross-sections including two riffles, two runs and two pools. These cross-sections should be a subset of those used in the morphology and hydrology assessment (P3a). At each cross-section conduct the following:
3. Measure the **substrate size** of 10 randomly selected particles whilst wading across the stream cross-section. Measure the second narrowest axis of each particle.
4. For each of the 10 randomly selected particles, note the degree of **substrate embeddedness** using the 1-4 scale (Score 1 – Not embedded, the substrate on top of the bed. Score 2 – Slightly embedded, < 25% of the particle is buried or attached to the surrounding substrate. Score 3 – Firmly embedded, approximately 50% of the substrate is embedded

or attached to the surrounding substrate. Score 4 – Heavily embedded, >66% of the substrate is buried).

5. **Substrate compactness** - Walk across part of the riverbed and estimate the degree of compactness. Compactness is assessed on a 1- 4 scale. (1 = Loose, easily moved substrate, 2 = Mostly loose, little compaction, 3 = Moderately packed, 4 = Tightly packed substrate).
6. Measure the total amount of **depositional or scouring** zones across the measuring tape.
7. Measure the width of **macrophyte** beds that intersect the tape. Note if macrophytes are submerged, emergent or marginal (see glossary).
8. Measure the total width of **visible algal** growths that intersect the tape.
9. Measure the total width of visible **leaf packs** (> 10 cm^2) that intersect the tape.
10. Measure the longest axis of any large **wood** (> 20 cm longest axis) that intersect the tape.
11. Count the number of significant **obstructions to flow** such as large boulders and log jams (> 0.5m in size) that intersect the tape.
12. Measure the amount of wetted stream bed with **bank cover** referring to overhanging banks or vegetation (< 30 cm above water surface) across the cross section.
13. Repeat these measurements for another five cross-sections.

Diagram of in-stream features

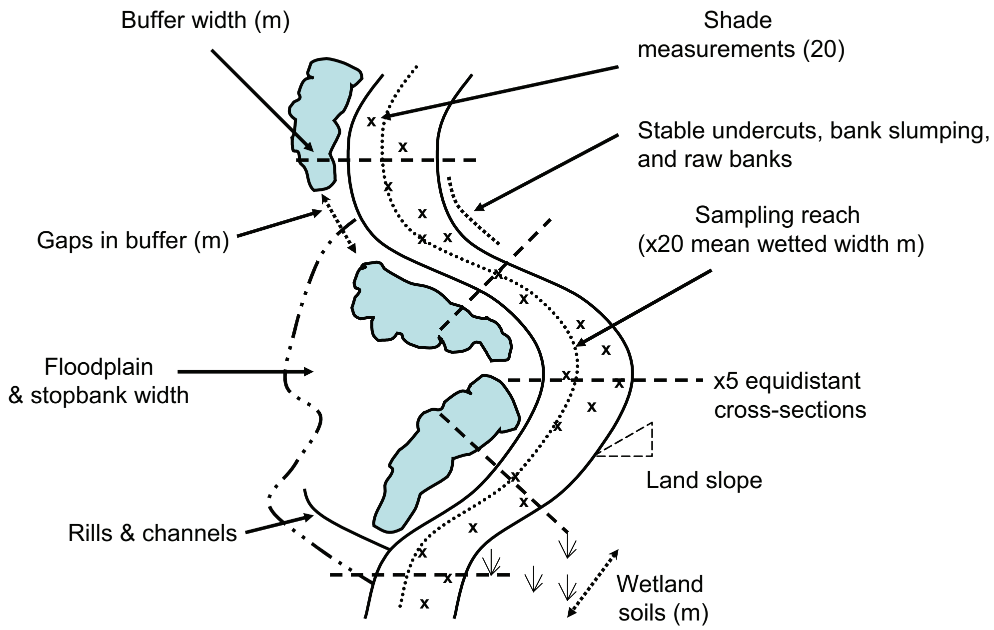
Black circles denote water's edge; the white line represents the measuring tape. Brackets indicate length of transect intersected by a given habitat feature.



P3d Riparian procedure

1. At five equidistant points along the reach record the **buffer width** and **floodplain width** (or **stopbank** width) by measuring the perpendicular distance from edge of the stream bank on each side of the stream to the in-land edges of the buffer (i.e. area managed differently to reduce the effects of the wider land use on stream; may be indicated by livestock exclusion fencing) and any stop banks or natural landward margins to the floodplain. Measurements can be by tape, hip chain or laser-based distance finder. Where the buffer comprises horizontal zones of management (e.g., native forest on stream banks, then production forest then grass filter strip to landward edge of buffer area), measure the width of these separately. Floodplain widths can often be discerned by changes in topography, vegetation and debris lines.
2. Measure riparian **land slope** (over the first 30 m from the stream bank edges) at each of five equidistant points along the reach. The simplest method involves using an inclinometer and two survey poles to measure the angle from the stream bank to 30 m from the bank.
3. Characterise, at five equidistant points along the reach, the **riparian vegetation** cover. Assess vegetation within 0.5, 3, 7.5 and 20m from the stream bank and note the presence of **native vegetation** and the percentage of vegetation at five different vegetation tier heights. The total of the vegetation at these five heights should total 100%.
4. Measure the stream bank length affected by **gaps in the buffer** (to the nearest 0.1 m).
5. Assess riparian **wetland soils** by measuring the length of stream bank with saturated or near saturated soils, i.e. soils that are soft/moist underfoot.
6. Measure the length of the stream bank with **stable undercuts**, often these are stabilised by vegetation roots.
7. Count the number of **livestock access** points.
8. Measure the length of the site subject to active **bank slumping**. This category includes only obvious slips and erosion.
9. Measure the length of **raw bank** on the left and right banks indicated by exposed unvegetated banks, including an absence of moss, lichen and small plants.
10. Measure the cross sectional area of eroded **rills and channels** along the length of the site.
11. At 20 random points measure the **shading of water** using a convex densiometer or paired (stream/open site) light sensor measurements (note reading and time).

Summary diagram of the variables assessed during P3d



P3b field form

Site code		Site name	
Assessor		Date	

Reach assessment

Wetted width (m)		
Reach length (m)		
	Easting	Northing
Reach start		
Reach end		

Pool	Maximum depth(m)	Sediment depth (m)	Crest depth (m)
1			
2			
3			
4			
5			
6			

Meso-habitat length (m)					
Rapid	Run	Riffle	Pool	Backwater	Other

Plan diagram of the site (include significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale)

Notes/comments

Cross sections

Run	Location⁺									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0

⁺ 'head', 'middle' or 'tail' of run
LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row), WE = water's edge

Run	Location⁺									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0

Run	Location⁺									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0

Riffle	Location+									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
+ 'head', 'middle' or 'tail' of run																				
Riffle	Location+									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Riffle	Location+									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				

Pool	Location[+]									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				

[+] 'head', 'middle' or 'tail' of run
LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row), WE = water's edge

Pool	Location[+]									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				

Pool	Location[+]									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				

P3c field form

Site name		Site code	
Assessor		Date	

Riffle 1	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Riffle 2	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Run 1	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Run 2	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Pool 1											
	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Pool 2											
	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

P3d field form

Site name		Site code	
Assessor		Date	

	Buffer width (m)		Land slope		Distance to stopbank (m)		Distance to floodplain (m)	
Cross-section	LB	RB	LB	RB	LB	RB	LB	RB
1								
2								
3								
4								
5								

Riparian vegetation	Distance from LB (m)				Distance from RB (m)			
Cross-section 1	0.5	3	7.5	20	0.5	3	7.5	20
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
>12 m Canopy								
Cross-section 2								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 3								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 4								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 5								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
>12 m Canopy								

	Left bank	Right bank
Gaps in buffer		
Wetland soils		
Stable undercuts		
Livestock access		
Bank slumping		
Raw bank		
Rills/Channels		
Drains (count)		

Shading of water				

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