Boffa Miskell

Avon River Precinct Aquatic Ecology

Six-years' post-rehabilitation activities
Prepared for Christchurch City Council

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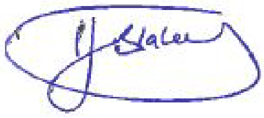
Reviewed by:	Tanya Blakely Senior Ecologist / Principal Boffa Miskell Limited	
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Cover photograph: Upstream view at Rehabilitation Site 2, © Boffa Miskell Limited, 2020

Executive Summary

The Christchurch City Council (CCC) commissioned Boffa Miskell Limited to conduct a repeat ecological survey of eight sites within the Avon River catchment as part of the long-term monitoring of the Avon River Precinct rehabilitation works. The monitoring programme aims to determine if the rehabilitation works has resulted in any measurable ecological changes and identify any limitations to the success of the rehabilitation works.

A variety of riparian and in-stream habitat variables, basic water quality measures and assessments of the macroinvertebrate and fish communities were made at three reference and five rehabilitation sites in March and April 2020. Methods used were the same as those used in the previous three surveys; baseline (2013, prior to rehabilitation works), one-year post-rehabilitation works (2014) and three-years post-rehabilitation works (2017).

Habitat conditions throughout the eight sites were generally similar, though some key differences between rehabilitation and reference sites were evident. Sediment cover and depth at rehabilitation sites was lower than that at reference sites and substrate size was larger, as was also observed in the previous two surveys in 2014 and 2017.

There have not been any significant changes in the macroinvertebrate community attributable to the rehabilitation works. The macroinvertebrate community found in 2014 showed an improvement in the ecological health when compared to the baseline survey condition (as indicated by MCI and QMCI scores). MCI and QMCI scores have, however, remained consistent through the 2014, 2017 and 2020 surveys as compared to the baseline condition.

Abundance of macroinvertebrates has increased, though taxa found remain typically “pollution tolerant”. Crustaceans were the dominant group found across all sites in this survey. A shift in the macroinvertebrate community has been observed since the baseline survey, however, cannot be attributed to the rehabilitation works.

The fish community continues to increase in abundance, with more fish caught in this and the previous survey (2017) than in the first two surveys (2013 and 2014). Furthermore, the number of fish caught at rehabilitation sites was significantly higher than at reference sites. While a similar number of species were caught in this survey as in previous surveys, and at rehabilitation and reference sites, it is worth noting that bluegill bullies were found in relatively high numbers at all but two sites in this survey. Bluegill bully was not found at Rehabilitation Site 4 in 2020 but was detected in 2017. While species such as lamprey and torrentfish were not encountered in this 2020 survey, they are only rarely encountered in the Avon River. Habitat for torrentfish is still limited in the Avon River, while lamprey are highly cryptic and rarely encountered in the catchment.

Overall, rehabilitation works have improved and diversified habitat at the rehabilitation sites. Lower sediment levels and larger substrate at rehabilitation sites indicates that there have been sustained positive effects

of sediment removal and habitat creation undertaken as part of the rehabilitation works. However, there are subtle trends of increased embeddedness and compactness, which is likely due to ongoing fine sediment inputs into the catchment.

Limitations to further ecological improvement exist, including ongoing disruption of the stream bed from macrophyte clearance and debris management, a lack of large boulders and logs providing greater habitat diversity, lack of useable habitat in installed fish hotels due to seasonally fluctuating water levels, continuing stormwater, sediment and contaminant inputs, and distance from source populations (particularly for aquatic insect species).

Ongoing management and continuation of rehabilitation work is likely necessary to sustain and further these gains throughout the Avon River Precinct.

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Appendices

1.0 Background

The Avon River / Ōtākaro is a spring-fed waterway, which is sourced from the western suburbs of Christchurch and flows through the central city before discharging into the Avon-Heathcote Estuary / Te Ihutai. As part of the Christchurch Rebuild, the Avon River Precinct (ARP) anchor project included selected rehabilitation works at five sites in the Avon River. This work was conducted in 2013, with the intention of returning the river to a more natural state and improving ecological conditions. The rehabilitation works included both in-stream and riparian works.

In-stream rehabilitation works included the construction of riffles and vegetated floodplains, removal of fine sediments and addition of larger boulder substrates. The riparian work included riparian planting and construction of wetland floodplains along the river.

The Avon River is situated in a predominantly urban catchment, receiving stormwater and runoff from heavily urbanised areas with minimal riparian buffer zones. The river received large amounts of liquefaction during the Canterbury earthquake events, which likely worsened conditions within a system already dominated by fine silt.

A baseline survey was conducted by Boffa Miskell Limited (Boffa Miskell) in 2013 prior to any rehabilitation works being undertaken[1]. The sites surveyed during the baseline study included three reference sites, where no rehabilitation works were to take place, and five rehabilitation sites where rehabilitation works were planned to be undertaken. In 2014, Opus resurveyed these sites (one year after the rehabilitation works) and in 2017 Boffa Miskell completed the second post-rehabilitation survey (three years' post-rehabilitation works). This 2020 report presents the findings of a survey conducted six years' after the rehabilitation works were completed.

2.0 Scope

The Christchurch City Council (CCC) contracted Boffa Miskell Limited (Boffa Miskell) to conduct an ecological survey of the ARP sites six-years' post-rehabilitation. This work was part of the long-term monitoring of the ARP river sites. The survey was conducted at the same 8 sites previously surveyed during the 'baseline', 'one-year post-rehabilitation' and 'three-years' post-rehabilitation' surveys.

The purpose of this report is to:

- Describe the current ecological conditions of the sites along the Avon River with respect to riparian and in-stream habitat conditions, and macroinvertebrate and fish communities;
- Compare conditions in reference and rehabilitation sites six-years' post-rehabilitation with those from the baseline, one- and three-year post-rehabilitation surveys; and
- Discuss:

[1] The baseline survey was conducted prior to rehabilitation works at four sites in the Avon River. However, rehabilitation work had already been completed at Rehabilitation Site 1, downstream of the Antigua Boatsheds, known as Watermark.

- Potential reasons for any significant patterns and trends recorded;
- The current success of the rehabilitation works; and
- Any limiting factors of the rehabilitation works.

3.0 Survey Methods

3.1 Site locations

The fish communities were assessed at the 8 monitoring sites along the Avon River between 18 and 23 March 2020; macroinvertebrate communities were assessed on 23 March 2020; riparian and in-stream conditions were measured between 29 April and 1 May 2020.

All surveying was completed during base-flow conditions.

The same field methods were used in this survey as during the baseline, one- and three-year post-rehabilitation surveys. Sites included three ‘reference’ sites upstream of the ARP where no rehabilitation works had been conducted; and the five ‘rehabilitation’ sites within the ARP (Table 1, Figure 1).

The CCC provided Boffa Miskell with GPS locations of these sites, which had been previously sampled in 2013 (baseline, Boffa Miskell 2014), 2014 (one-year post-rehabilitation, Opus 2015) and 2017 (three-years post rehabilitation, Boffa Miskell 2017).

All sites included a riffle or fast-flowing run; upstream reference sites were selected to be representative (i.e. a reasonable comparison) of the ‘rehabilitation’ sites downstream.

Table 1. Site name, number, and co-ordinates of each of the sites surveyed in this study.

Site name	Site Number	Northing	Easting
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 near Durham Street	Rehabilitation Site 1	5741381	2480081
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	5741998	2480483
Avon River near Kilmore Street	Rehabilitation Site 5	5742329	2481261

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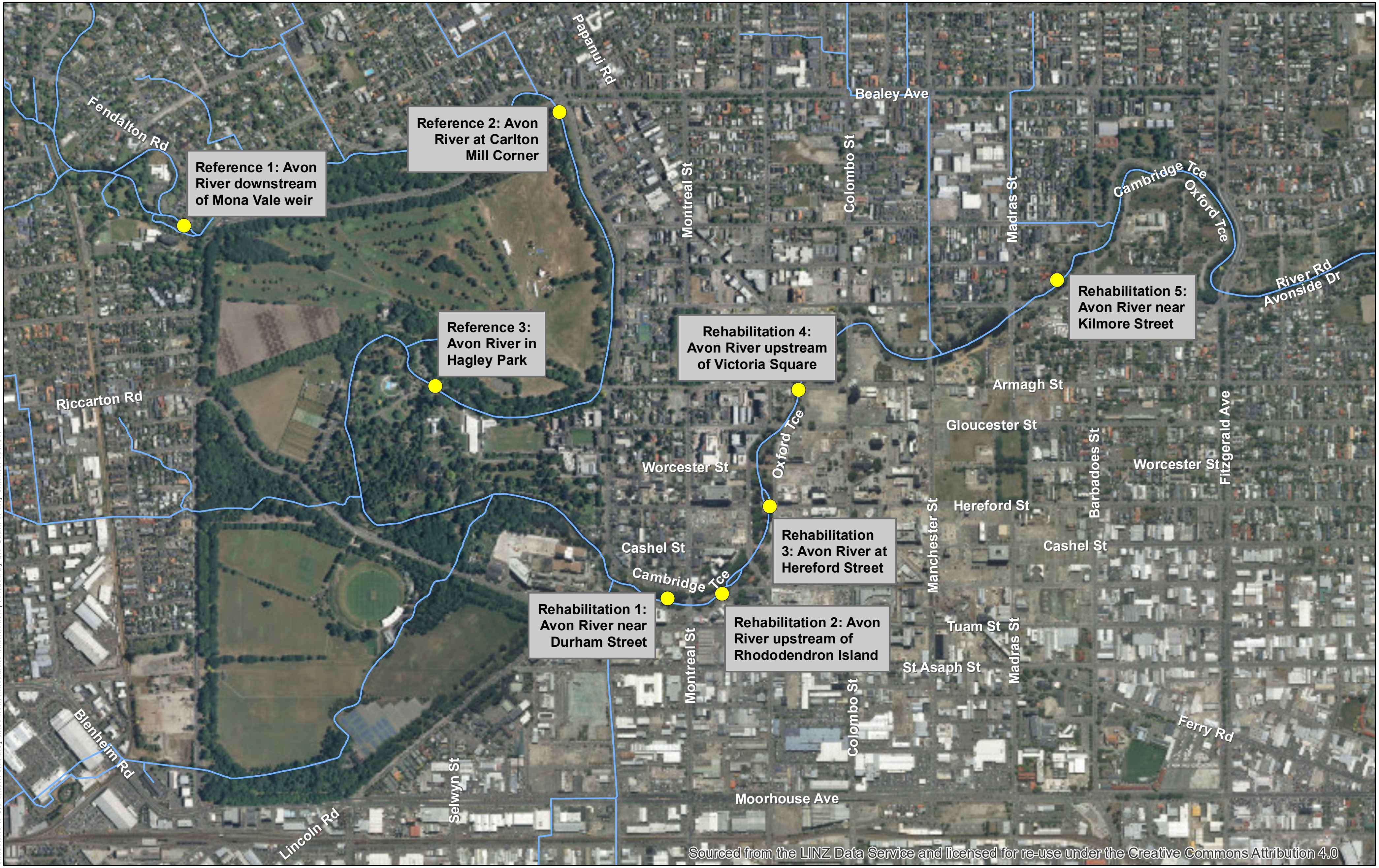

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Data Sources:
Cadastre sourced from LINZ data service
Waterways sourced from Christchurch City Council
Projection: NZGD 2000 New Zealand Transverse Mercator

LEGEND

- Survey Site
- Waterways

AVON RIVER PRECINCT AQUATIC ECOLOGY

2020 Monitoring Sites

Date: 22 June 2020 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: **tanya.blakely@boffamiskell.co.nz** | *Drawn:* BMc | *Checked:* TBI

Figure 1

3.2 Limitations

Due to the advent of COVID-19 work and travel restrictions, the survey period in which the ARP monitoring was being undertaken was disrupted. As such, investigations of the fish and macroinvertebrate communities took place between 18 - 23 March 2020. Riparian and in-stream habitat surveys took place between 29 April to 1 May. The hydrological monitoring was undertaken by the Canterbury Regional Council (ECan) in early June 2020.

As a result of these disruptions, there are some inconsistencies in timing of when the data was collected when compared to previous years. For example, in previous years, all field data has been collected in March and all parameters (chemistry, physical, biological) have been collected from each site within a few days of each other. However, all data was collected during base-flow conditions and generally comparable to previous years. Percent cover of in-stream organic matter may be one exception to this as habitat conditions were measured during late autumn when leaf fall was well advanced.

The habitat surveying was completed under COVID-19 Level 3 restrictions and access to field equipment was limited. For the 2020 survey, dissolved oxygen (DO) was measured in percent saturation, as opposed to mg / L as in previous surveys.

Velocity was measured by ECan in early June 2020, and was not measured at the same time as habitat surveys (conducted by Boffa Miskell) as in previous surveys.

3.3 Water quality

Spot measures of basic water chemistry (pH, dissolved oxygen (%), specific conductivity) and water temperature were collected at each site using a hand-held EXO2 Sonde s/n water-quality meter.

3.4 Riparian and in-stream habitat

A variety of in-stream and riparian habitat parameters were recorded at each site between 29 April and 1 May 2020, following the standard protocols of Harding et al. (2009) and Clapcott et al. (2011):

- Protocol 3 (P3) Quantitative protocol of Harding et al. (2009):
    - P3b: Hydrology and morphology procedure[2];
    - P3c: In-stream habitat procedure; and
    - P3d: Riparian procedure.
- Sediment Assessment Methods of Clapcott et al. (2011):
    - Sediment Assessment Method 2 (SAM2) – in-stream visual estimate of % sediment cover; and
    - Sediment Assessment Method 6 (SAM6) – sediment depth.

[2] P3b parameters were collected by Environment Canterbury's hydrologists. This was not done at the same time as the other in-stream habitat assessments due to COVID-19 related delays.

Full details of Protocol P3 (Harding et al. 2009), and SAM2 and SAM6 (Clapcott et al. 2011), including field-sheet templates, are provided in Appendices 1-3.

In summary, these habitat assessment methods involved measuring a range of riparian and in-stream physical habitat conditions at various distances across 6 equally spaced cross-sections established across the waterway every 10 m. The first (downstream most) cross section at each site was located at the co-ordinates provided in Table 1.

In addition, the following parameters were measured at each of the first three (downstream) transects:

- Total wetted width (m) was recorded to give an average wetted width (m) for each site.
- Canopy cover (%), undercut bank extent (cm) (if present), extent of any overhanging vegetation (cm), ground cover (%), and general riparian vegetation conditions were recorded on the true left (TL) and true right (TR) banks at each site.
- Water depth (cm), soft sediment depth (cm), substrate composition (%), macrophyte depth (cm), percent cover, type (submerged or emergent) and dominant species of macrophytes, percent cover of organic material (leaves, moss, coarse woody debris), and percent cover and type of periphyton were measured at three locations (TL bank, mid channel and TR bank) at each site.
    - Soft sediment depth was determined by gently pushing a metal rod (10 mm diameter) into the substrate until it hit the harder substrates underneath.
    - Substrate composition was measured within an approximately 20 x 20 cm quadrat randomly placed at each of the three locations along the three transects. Within each quadrat, the percent composition of the following sized substrates was estimated: silt / sand (< 2 mm); gravels (2 – 16 mm); pebbles (16 – 64 mm); small cobbles (64 – 128 mm); large cobbles (128 – 256 mm); and boulders (> 256 mm).

Photographs of the upstream and downstream views of each site were also taken.

3.5 Macroinvertebrate community

Macroinvertebrates vary widely in their tolerances to both physical and chemical conditions and are thus used regularly in biomonitoring as an indicator of stream health providing a long-term picture of the health of a waterway.

The macroinvertebrate community was assessed at each site (within the same 50 m reach where in-stream habitat was surveyed) using two complimentary methods, on 23 March 2020.

Five replicate Surber samples (0.05 m^2, 500 µm mesh) were collected at each of the 8 sites. Surber samples were randomly collected from shallow riffles or fast-flowing runs, and the substrate was disturbed to an approximate depth of 5 cm.

In addition, a single and extensive composite kick-net (500 µm mesh) sample was collected from each site in accordance with protocols C1 and C2 of Stark et al (2001). Approximately 0.6 m^2 of stream bed was sampled at each site (i.e. each kick net sampled approximately 0.3 m x 2.0 m of stream bed), including sampling the variety of microhabitats present (e.g. stream margin, mid channel, undercut banks, macrophytes) to maximise the likelihood of collecting all macroinvertebrate taxa present at a site, including rare and habitat-specific taxa.

All macroinvertebrate samples were preserved, separately, in 70% ethanol prior to sending to Biolive, Nelson, for identification and counting in accordance with Protocol P3 of Stark et al (2001). Macroinvertebrates were identified to species level, where possible, and thereafter to MCI level.

3.6 Fish community

The fish community of each site was surveyed between 18 and 23 March 2020. The fish community was surveyed from within a reach of at least 50 m (i.e. the same survey reach as habitat and macroinvertebrate community were to be assessed). Each survey reach included the variety of habitats typically present at that site (e.g. stream margin, mid channel, undercut banks, macrophytes, silt, riffles). Survey reaches were divided into many subsections of approximately 2-3 m in length and electro-fished using multiple passes with a Kainga EFM 300 backpack mounted electric-fishing machine (NIWA Instrument Systems, Christchurch). Fish were captured in a downstream push net or in a hand (dip) net and temporarily held in buckets. All fish were then identified, counted and measured (length, mm) before being returned alive to the stream.

The habitat where fish were found was noted (e.g. under overhanging *Carex* plants, in macrophyte beds, in mid-channel fast riffles).

3.7 Data Analysis

3.7.1 Water quality

A single measure of pH, dissolved oxygen, conductivity, and water temperature was measured at each site in 2013 (baseline), 2014 (one-year post-rehabilitation), 2017 (three-years post-rehabilitation) and 2020 (this study, six-years post-rehabilitation). Qualitative comparisons measures were made to detect any substantial changes in these parameters through time since rehabilitation activities.

3.7.2 Riparian and in-stream habitat

The multiple measures across transects, and at multiple transects within a site for water depth, soft sediment, substrate composition, macrophyte depth, percent cover of macrophytes, organic materials and periphyton were averaged to give one value for each parameter per site.

A substrate index (SI), modified from Jowett and Richardson (1990), was calculated for each measure taken across the three transects at each site using the formula:

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

The calculated SI can range between 1 and 6, where an SI of 1 indicated 100% silt / sand and 6 indicated 100% boulders. That is, the larger the SI, the coarser the substrate and the better the habitat for macroinvertebrate and fish communities. Finer substrates generally provide poor, and often unstable, in-stream habitat. The multiple SIs calculated for each site (i.e. multiple values across three transects at each site) were averaged to give one value per site.

Two-way analyses of variance (ANOVAs) were used to test for differences in select habitat conditions between reference and rehabilitation sites; and through time (i.e. baseline (Boffa

Miskell 2014), one-year post-rehabilitation (Opus 2015), three-year post-rehabilitation (Boffa Miskell 2017) and six-years post rehabilitation (this study)). The interaction between 'rehabilitation treatment' and 'year' was also tested to examine how rehabilitation works might have influenced parameters over time.

Response variables were *log* (*x*+1) transformed or ranked where necessary to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.5.1 (The R Foundation for Statistical Computing 2013).

3.7.3 Macroinvertebrate community

The following macroinvertebrate metrics and indices were calculated to provide an indication of stream health:

- **Macroinvertebrate abundance** – the average number of individuals collected in the five replicate Surber samples collected at each site. Comparisons of abundance of macroinvertebrates among sites can be useful as abundance tends to increase in the presence of organic enrichment, particularly for pollution-tolerant taxa.
- **Taxonomic richness** – the average number of macroinvertebrate taxa recorded from the five Surber samples collected at each site. Streams supporting high numbers of taxa generally indicate healthy communities, however, the pollution sensitivity / tolerance of each taxon needs to also be considered.
- **EPT taxonomic richness** – the average number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) recorded from the five Surber samples collected at each site. These three insect orders (EPT) are generally sensitive to pollution and habitat degradation and therefore the numbers of these insects provide a useful indicator of degradation. High EPT richness suggests high water quality, while low richness indicates low water or habitat quality.
- **EPT taxonomic richness (excl. hydroptilids)** – the average number of EPT taxa excluding caddisflies belonging to the family Hydroptilidae, which are generally more tolerant of degraded conditions than other EPT taxa.
- **%EPT richness** – the percentage of macroinvertebrates that belong to the pollution-sensitive EPT orders found in the five Surber samples collected at each site, i.e. relative to total richness of all macroinvertebrates at each site. High %EPT richness suggests high water quality.
- **%EPT (excl. hydroptilids)** – the percentage of EPT taxa at each site, excluding the more pollution-tolerant hydroptilid caddisflies.
- **Macroinvertebrate Community Index (MCI-hb)** – this index is based on the tolerance scores of Stark and Maxted (2007) for individual macroinvertebrate taxa found in the five Surber samples collected at each site. These tolerance scores, which indicate a taxon's sensitivity to in-stream environmental conditions, are summed for the taxa present at a site, and multiplied by 20 to give MCI-hb values ranging from 0 – 200.
- **Quantitative Macroinvertebrate Community Index (QMCI-hb)** – this is a variant of the MCI-hb, which instead uses abundance data of the five replicate Surber samples. The QMCI-hb provides information about the dominance of pollution-sensitive species at a site.

Table 2 provides a summary of how MCI-hb and QMCI-hb scores were used to evaluate stream health.

Table 2. *Interpretation of MCI-hb and QMCI-hb scores for soft- bottomed streams (Stark & Maxted 2007).*

Stream health	Water quality descriptions	MCI	QMCI
Excellent	Clean water	>119	>5.99
Good	Doubtful quality or possible mild enrichment	100-119	5.00-5.90
Fair	Probable moderate enrichment	80-99	4.00-4.99
Poor	Probable severe enrichment	<80	<4.00

Note, the MCI and QMCI were developed primarily to assess the health of streams impacted by agricultural activities and should be interpreted with caution in relation to urban systems.

ANOVAs were used to test for differences in averages[3]: (1) between treatments (reference and rehabilitation sites); (2) among years (2013, 2015, 2017 and 2020); and (3) the interaction between treatment and year:

- macroinvertebrate abundance;
- taxonomic richness;
- EPT richness;
- EPT-except Hydroptilidae richness;
- MCI; and
- QMCI values.

Response variables were *ln (x+1)* transformed to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.5.1 (The R Foundation for Statistical Computing 2013).

A non-metric multidimensional scaling (or NMDS) ordination[4], with 999 random permutations, using abundance data (averages from Surber samples) was used to determine if the macroinvertebrate community found was similar among the 8 sites surveyed, between reference and rehabilitation sites, and through time (i.e. baseline, one-year, and three-years post-rehabilitation).

NMDS ordinations rank sites such that distance in ordination space represents community dissimilarity (in this case using the Bray-Curtis metric). Therefore, an ordination score (an *x* and a *y* value) for the entire macroinvertebrate community found at any site can be presented on an *x-y* scatterplot to graphically show how similar (or dissimilar) the community at a site is from that found at another site. Ordination scores that are closest together are more similar in macroinvertebrate community composition, than those further apart (Quinn and Keough 2002).

An analysis of similarities (ANOSIM), with 100 permutations, was then used to test for significant differences in macroinvertebrate community composition: between reference and rehabilitation sites; and among baseline (Boffa Miskell 2014); one-year post-rehabilitation (Opus 2015); three years (Boffa Miskell 2017); and six-years post-rehabilitation (this survey).

It is helpful to view ANOSIM results when interpreting an NMDS ordination. An NMDS ordination may show that communities appear to be quite distinct (i.e. when shown graphically, sites could

[3] Averages were calculated using only Surber sample data.

[4] Goodness-of-fit of the NMDS ordination was assessed by the magnitude of the associated ‘stress’ value. A stress value of 0 indicates perfect fit (i.e. the configuration of points on the ordination diagram is a good representation of actual community dissimilarities). It is acceptable to have a stress value of up to 0.2, indicating an ordination with a stress value of <0.2 corresponds to a good ordination with no real prospect of misleading interpretation (Quinn & Keough 2002).

be quite distinct from one another in ordination space), but ANOSIM results show whether these differences are in fact statistically significantly different[5].

If ANOSIM revealed significant differences in macroinvertebrate community composition (i.e. $R \neq 0$ and $P \leq 0.05$) between treatments (reference and rehabilitation sites), or among years (baseline, one-year, three-years and six-years post-rehabilitation), similarity percentages (SIMPER) were calculated[6] to show which macroinvertebrate taxa were driving these differences.

NMDS, ANOSIM and SIMPER analyses were performed in PRIMER version 7.0.13 (Clarke and Warwick 2001; Clarke and Gorley 2006).

3.7.4 Fish community

The total distance fished (in metres) at each site and the amount of time spent actively fishing (i.e. time displayed on the electro-fishing machine) were recorded. The fish capture data was then expressed as 'catch per unit effort' (CPUE) to standardise for differences in sampling effort among sites (i.e. total distance). CPUE was calculated by dividing the number of fish captured by the total area fished (i.e. total distance fished multiplied by average wetted width of a site) and extrapolated up to 100 m^2 for each site. Thus, CPUE was expressed as number of fish captured per 100 m^2.

ANOVAs were used to test for differences in averages: (1) between treatments (reference and rehabilitation sites); (2) among years (2013, 2015, 2017 and 2020); and (3) the interaction between treatment and year, of abundance (CPUE) and total richness of fish captured.

Response variables were *ln (x+1)* transformed to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.5.1 (The R Foundation for Statistical Computing 2013).

An NMDS ordination, with 999 random permutations, using abundance data was also used to determine if the fish community found was similar among the 8 sites surveyed, between reference and rehabilitation sites, and through time (i.e. baseline, one-year, three-years and six-years post-rehabilitation).

An analysis of similarities (ANOSIM), with 100 permutations, was then used to test for significant differences in fish community composition: between reference and rehabilitation sites; and among baseline (Boffa Miskell 2014); one-year post-rehabilitation (Opus 2015); three-years post-rehabilitation (Boffa Miskell 2017); and six-years post-rehabilitation (this survey, 2020).

If ANOSIM revealed significant differences in fish community composition (i.e. $R \neq 0$ and $P \leq 0.05$) between treatments (reference and rehabilitation sites), or among years (baseline, one-year, and three-years post-rehabilitation), similarity percentages (SIMPER) were calculated to show which fish species were driving these differences.

NMDS, ANOSIM and SIMPER analyses were performed in PRIMER version 6.1.13 (Clarke and Warwick 2001; Clarke and Gorley 2006).

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[5] ANOSIM is a non-parametric permutation procedure applied to the rank similarity matrix underlying the NMDS ordination and compares the degree of separation among and within groups (i.e. treatment or years) using the test statistic, R. When R equals 0 there is no distinguishable difference in community composition, whereas an R-value of 1 indicates completely distinct communities (Quinn & Keough 2002).

[6] The SIMPER routine computes the percentage contribution of each macroinvertebrate taxon to the dissimilarities between all pairs of sites among groups.

4.0 Ecological Conditions

4.1 Site descriptions

4.1.1 Reference Site 1: Avon River downstream of Mona Vale Weir

Reference Site 1 was the most upstream site surveyed along the Avon River (Photo 1). The site was located downstream of Mona Vale Weir. The river was dominated by run habitat and was 7.8 m wide and 32 cm deep on average, with an average velocity of 0.50 m / s on the day of sampling[7].

The true left (TL) bank of the river is bordered by residential properties, with garden beds, lawn and a small courtyard extending to the edge of the river, as well as some sections of retaining wall and fencing. The upstream-most section of the surveyed reach on the TL (adjacent to the end of Wood Lane) has a large section of boulders along the bank, likely placed to prevent erosion. The true right (TR) bank of the river lies along the edge of the Christchurch Girls' High School grounds and was extensively vegetated with native trees and shrubs (including *Carex secta*, flaxes) and a significant covering of the exotic wandering willy (*Tradescantia fluminensis*).

Macrophyte cover was very high, with 90% of the stream bed covered by submerged macrophytes – much higher than what was found in the 2017 survey, though similar to cover in the 2014 survey. Curly pondweed (*Potamogeton crispus*) and common water milfoil (*Myriophyllum propinquum*) were the dominant macrophyte species found. Cover of both organic matter and algae was very low at 0.8% and 3% respectively.

The riverbed substrate was dominated by sand / silt material and pebbles, giving an average SI of 2.7. The substrate was firmly embedded, with an average embeddedness score of 3. Compactness was high, with an average score of 3.5 indicating the substrate was tightly packed.

Photo 1. Reference Site 1 – Avon River downstream of Mona Vale weir, looking upstream (left) and downstream (right).

[7] Velocity was measured by ECan on a different day to the habitat surveying.

4.1.2 Reference Site 2: Avon River at Carlton Mill Corner

Located at the north-eastern corner of Hagley Park by the Harper Ave Bridge, Reference Site 2 was the second-most upstream site surveyed along the Avon River (Photo 2). The river at this site had combination of riffle and run habitat. It was 10.2 m wide and 39 cm deep on average, with an average velocity of 0.43 m / s on the day of surveying.

Overall the site was relatively shallow, particularly under the Harper Ave Bridge. Along the TL, there were some faster-flowing deeper areas both up and downstream of the bridge. The upstream extent of the surveyed reach, on both TL and TR, was under the Harper Ave Bridge, where concrete extended down into the riverbed and formed the riparian edge of the river. The TL bank downstream of the bridge was relatively steep and was planted with a narrow strip of both exotic and native shrubs and trees. Additionally, there were some scattered *Carex* plants and rank grasses. Downstream of the road bridge on the TR, the riparian margin was dominated by exotic grasses in most places. A small area of planted *Carex* species is yet to establish properly.

Macrophytes cover was only 8% at the time of surveying, which is relatively low when compared to previous surveys. The dominant macrophyte species found were curly pondweed, common water milfoil and Canadian pondweed (*Elodia canadensis*). Organic matter cover was 7% and algae cover was 11%. Algae found was predominantly thin brown mat algae.

The riverbed substrate was dominated by sand / silt material and pebbles, giving an average SI of 2.4. The substrate was slightly embedded, with an average embeddedness score of 2. Compactness was also moderate, with an average score of 1.8 indicating relatively loose substrate.

Photo 2. Reference Site 2 – Avon River at Carlton Mill Corner, looking upstream (left) and downstream (right).

4.1.3 Reference Site 3: Avon River in Hagley Park

Reference Site 3 is located alongside the Botanic Gardens in Hagley Park, upstream of a footbridge from the carpark into the Gardens (Photo 3). The river at this site is wide (12.6 m on average), shallow (25 cm on average) and slow-flowing run habitat (0.44 m / s on average) on the day of sampling.

A wooden retaining wall, with large overhanging *Carex secta* plants, formed the majority of the riparian margin on the TL of the river at this site. Beyond the *Carex* plants, the riparian area was mainly lawn with scattered large exotic trees. The TR bank was predominantly mown lawn with unmown grasses at the water's edge, with some small exotic trees scattered along the bank downslope from a footpath. In the wider riparian area, there were some larger exotic trees, providing some shading (at times) to the river.

Overall, macrophytes covered 40% of the stream bed, comprised almost exclusively of submerged curly pondweed. Organic matter cover was 4% and appeared to be predominantly autumn leaf-fall matter. Algal cover was, on average, 14%, largely made up by thin brown mat algae.

Substrate at Reference Site 3 was predominantly comprised of pebble and small cobbles, with an average SI of 3.2, indicating moderately sized substrate particles. The substrate was slightly embedded, with an average embeddedness score of 2. The substrate was mostly loose with little compaction, with an average compactness score of 2.

Photo 3. Reference Site 3 – Avon River in Hagley Park, looking upstream (left) and downstream (right).

4.1.4 Rehabilitation Site 1: Avon River near Durham Street

The most upstream of the rehabilitation sites in the ARP, Rehabilitation Site 1, was downstream of the Antigua Boatsheds and upstream of the Durham St South Bridge (Photo 4). The site was dominated by run habitat and was, on average, 12 m wide, 43 cm deep and had an average velocity of 0.44 m / s on the day of hydrologic sampling.

The riparian vegetation on both banks immediately at the water's edge was dominated by rank grasses, but mown lawn above this. The TR bank was a relatively steep slope up to the road, with large chestnut trees set back from a constructed floodplain wetland at the upstream extent of the reach. The TL bank was dominated by lawn and occasional *Carex* and flaxes, with some chestnut trees set back from the immediate riparian zone.

Curly pondweed and common water milfoil were the dominant macrophyte species found at this site, covering, on average, 16% of the riverbed. Organic matter was negligible, with only 0.2% cover, while algae was also very low with only 1% cover – much lower than that found in any previous survey.

The substrate at this site was found to be comprised of small cobble and pebble particles, giving an average SI of 2.8. The substrates were only slightly embedded (average embeddedness score of 2.1), and mostly loose, with little compaction (average of 2.3 compactness).

Photo 4. Rehabilitation Site 1 – Avon River near Durham St, looking upstream (left) and downstream (right).

4.1.5 Rehabilitation Site 2: Avon River at Rhododendron Island

Rehabilitation Site 2 was located immediately upstream of Rhododendron Island and downstream of the Montreal Street Bridge, with the upstream extent of the surveyed reach being adjacent to the Christchurch Earthquake National Memorial Wall (Photo 5). On average, the river was 11.4 m wide and 37 cm deep on the day of surveying. The river was narrower alongside the wall, widening downstream towards Rhododendron Island. The river was deepest in the centre of the channel, where velocity was at its greatest, particularly at the downstream end of a constructed riffle. Velocity was, on average, 0.47 m / s on the day of surveying.

The upstream extent on the TR of the river was confined by the steps and footpaths along the base of the Memorial Wall. Several PVC pipes were present under the Memorial Wall platform and thought to be a combination of stormwater pipes draining tree pits along Oxford Terrace and “fish hotels” to provide habitat for in-stream fauna. However, at the time of surveying the PVC pipes were situated above the water level. Downstream of the wall, there was extensive native planting along constructed floodplain wetlands, including *Carex* species, flaxes, rushes and reeds and small shrubs that are becoming well established. Boulders have been placed along the toe of the constructed floodplain wetlands, especially on the TR side, creating effective erosion control and also providing habitat complexity for in-stream fauna. On the TL there was a constructed floodplain wetland with extensive large *Carex* plants, with boulders placed along the wetted margin.

Macrophytes covered 34% of the riverbed, on average, and were comprised of curly pondweed, common water milfoil and mosses. Organic matter cover was estimated as only 0.6% cover, and algal cover was also low with only 1% cover.

The riverbed substrate was dominated by small cobbles, giving an average SI of 3.3. The substrate was slightly embedded, with an average embeddedness score of 2.3, while compactness was also moderate, with an average score of 2.2, indicating the substrate is mostly loose with little compaction.

Photo 5. Rehabilitation Site 2 – Avon River at Rhododendron Island, looking upstream (left) and downstream (right).

4.1.6 Rehabilitation Site 3: Avon River at Hereford Street

Rehabilitation Site 3 was located at the Hereford Street Bridge, with the site running alongside Mill Island on the true left to the upstream extent of the Hereford Street Bridge (Photo 6). At this site, the river was on average 7.8 m wide and 30 cm deep on the day of surveying. The river was very wide and shallow under the bridge and split into two narrower channels alongside Mill Island. Riffle and run habitat was present, with the river being significantly deeper alongside Mill Island than under the road bridge, where it was very shallow. The average velocity on the day of surveying was 0.47 m / s.

The upstream extent of the surveyed reach on both TL and TR was under the Hereford Street Bridge, where the concrete bridge footings extended down into the riverbed and formed the edge / riparian margins of the river. Alongside Mill Island, the bank on the TR was a constructed brick / slate retaining wall. The island has dense native and exotic trees providing shading to the river. On the TL, the bank is steep with sparse *Carex* plantings immediately downstream of the bridge and mown grass along the remainder of the bank.

Macrophytes were extensive downstream of the bridge, though relatively absent under it. On average, macrophytes covered 44% of the riverbed and were primarily comprised of curly pondweed. Organic matter cover was negligible at 0.1% cover. Similarly, algal cover was low with only 4% cover, comprised of some filamentous green algae, and some thin brown mat algae.

Small cobbles dominated the substrate composition, but large cobbles and boulders were also present, giving an average SI of 3.7. The site received an average embeddedness score of 2.3, indicating that the substrate was slightly embedded, while the riverbed was somewhat loosely packed, with an average compactness score of 2.5.

Photo 6. Rehabilitation Site 3 – Avon River at Hereford St, looking upstream (left) and downstream (right).

4.1.7 Rehabilitation Site 4: Avon River at Victoria Square

Rehabilitation Site 4 was located immediately upstream of the Armagh Street Bridge near Victoria Square (Photo 7). The river at this site is relatively wide (11.1 m on average), has an average water depth of 44 cm (and was the deepest of all sites surveyed), was 100% run habitat and had an average velocity of 0.30 m / s (the slowest velocity of all sites) on the day surveyed.

On the TL of the river, the riparian vegetation (immediately adjacent to the stream) was dominated by large overhanging *Carex* plants and rank grasses with boulders placed along the toe of the bank in places. The grass was mown further up the bank. Upstream from the bridge, there was a planted area of small low-lying shrubs and grasses. Upstream of the planted area, the bank is predominantly mown lawn with some exotic trees scattered up higher on the bank. The TR bank had a relatively steep slope up to the road, with large chestnut trees set back from a constructed floodplain wetland at the upstream extent of the reach. The TL bank was dominated by dense exotic and native trees immediately upstream of the bridge. In the upstream extent of the reach, the riparian vegetation is more limited to mown grass higher on the bank, with rank grasses and large overhanging *Carex* plants at the water's edge.

Macrophyte cover at the site was very high at 69%, dominated by curly pondweed and common water milfoil. Red pondweed (*Potamogeton cheesemanii*) and Canadian pondweed were also present at this site. Organic matter cover was largely absent, with average cover only 0.1%. Algal cover was relatively high at this site at 39% cover, largely made up by filamentous green algae and thin brown mat algae.

Substrate at Rehabilitation Site 4 was predominantly comprised of large and small cobbles, with an average SI of 4.1, indicating moderate to large-sized substrate particles. The substrate was firmly to heavily embedded, with an average embeddedness score of 3.5. The substrate was moderately to tightly compacted, with an average compactness score of 3.5.

Photo 7. Rehabilitation Site 4 – Avon River at Victoria Square, looking upstream (left) and downstream (right).

4.1.8 Rehabilitation Site 5: Avon River at Kilmore St

Rehabilitation Site 5 was the most downstream site, located downstream of the Kilmore Street Bridge (Photo 8). At this site, the river was 10.3 m wide and was the shallowest of all sites with an average depth of 23 cm on the day of surveying. Velocity was the fastest recorded at any site, with an average of 0.64 m / s measured on the day of hydrological sampling. The habitat was a combination of riffle and run.

On both the TL and TR banks of the river, the large overhanging *Carex* plants and rank grasses made up the majority of the riparian vegetation immediately at the water's edge, with boulders placed along the toe of the bank and along areas of constructed floodplain wetland. In the wider riparian area, upslope on the TR, large chestnut trees were present providing some shading to the river. Beyond these, the TR bank extends to the road. On the TL, the riparian margins were grass (mown and unmown) and exotic trees, extending to the road.

Macrophyte cover was relatively high at 58%. The dominant species were curly pondweed, common water milfoil and moss. Organic matter cover was very low, with an average cover of just 1%. Algal cover was relatively high at this site, with 35% cover comprised of a combination of long filamentous green algae, short brown filamentous algae and thin brown mat algae.

The riverbed composition at Rehabilitation Site 4 was comprised predominantly of pebbles and small cobble, with some large cobbles. The SI at this site was an average of 3.5 indicating moderately sized substrate particles. Substrate was slightly to firmly embedded, with an average embeddedness score of 2.5 and moderately packed, with an average compactness score of 2.7.

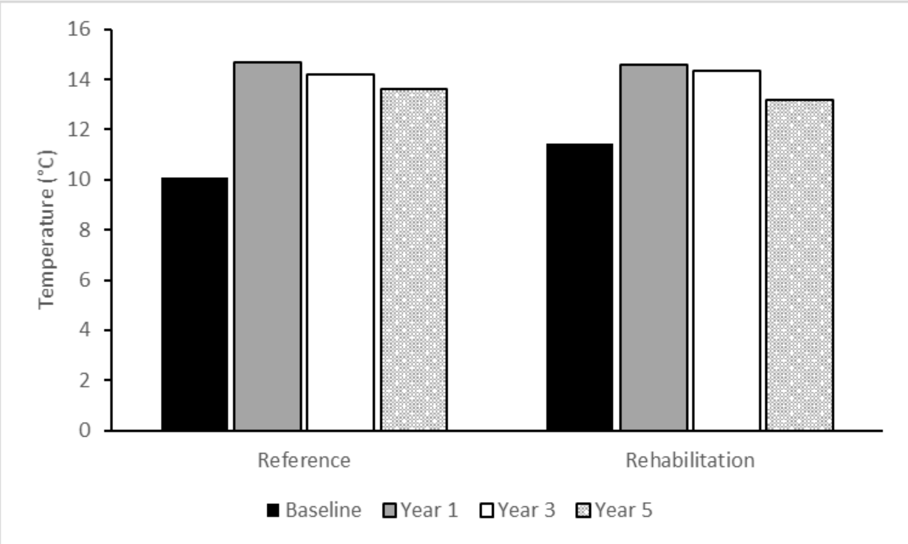
Photo 8. Rehabilitation Site 5 – Avon River at Kilmore St, looking upstream (left) and downstream (right).

4.2 General habitat conditions

4.2.1 Water quality

Water temperature

Water temperature varied across sites, with no discernible difference in temperature between reference and rehabilitation sites in this survey (Figure 2). Temperatures recorded in this survey (2020) were relatively similar to those in the previous two post-rehabilitation surveys and warmer than that recorded in the baseline survey. Temperature can fluctuate both daily and seasonally, so it is important to note that water temperature was only measured once at each site on each sampling occasion.



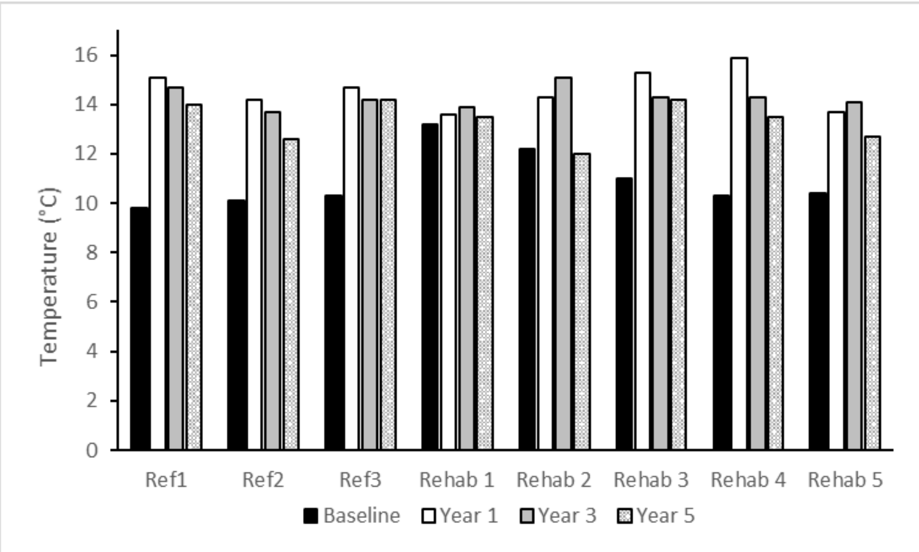


Figure 2. Water temperature (°C) measured at the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

pH

pH recorded in this survey (2020) was similar to that recorded in the prior post-rehabilitation surveys in 2014 and 2017, and lower (more neutral, i.e. closer to a pH of 7) than that recorded in the baseline survey (2013), as shown in Figure 3. There were no discernible differences in pH in any year between reference and rehabilitation sites. Nevertheless, the pH found at all sites in all years was circum-neutral and thus likely to be within a tolerable range for aquatic fauna.

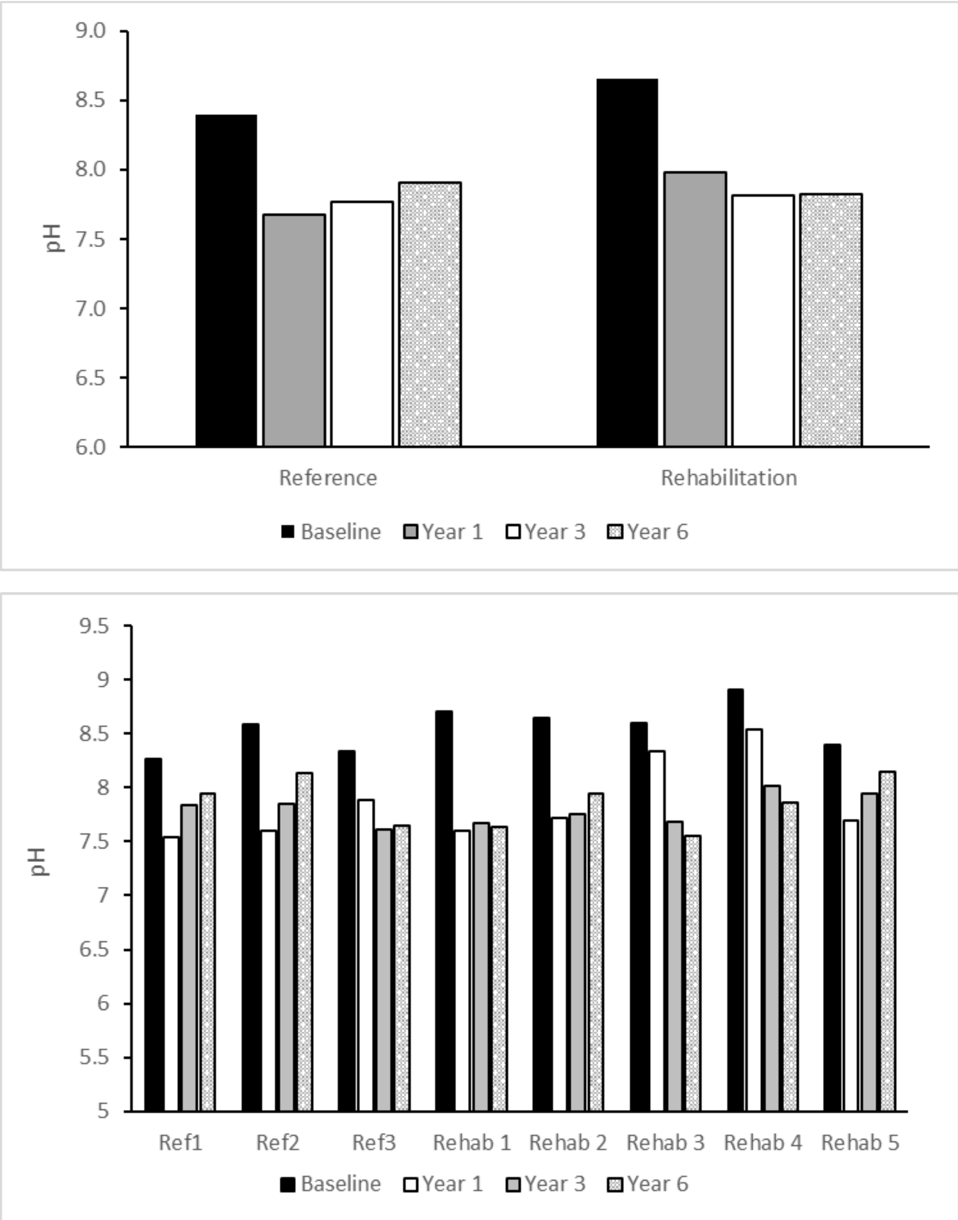


Figure 3. pH measured at the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Dissolved oxygen

The habitat surveying was completed under COVID-19 Level 3 restrictions and access to field equipment was limited. For the 2020 survey, dissolved oxygen (DO) was measured in percent saturation, as opposed to mg / L as in previous surveys. The Canterbury Land and Water Regional Plan (Environment Canterbury 2015) sets a guideline of 70% as the minimum acceptable value for "spring fed-plains-urban waterways". All sites had DO levels above this minimum, with DO concentrations ranging from 84 to 102%.

As noted for water temperature, it is important to note that DO was also only measured once at each site on each sampling occasion. DO can fluctuate both diurnally and seasonally and is also impacted by other factors such as cover of macrophytes. Together these factors may influence DO levels measured at a site.

Specific conductivity

Specific conductivity was similar at all sites in this survey (2020). Conductivity was variable through time, with levels recorded in this survey being higher than that measured in the previous survey (2017), though lower than that measured in the baseline (2013) and Year 1 surveys (2014).

Conductivity was only measured once at each site in each survey and can fluctuate both daily and seasonally, which is important to consider when analysing this data.

4.2.2 Riparian and in-stream habitat

Wetted width

Wetted width measured in this survey (2020) was relatively unchanged compared to previous years, with an average of width of 10.2 m at Reference sites and 10.5 m at Rehabilitation sites (Figure 4). There was no significant difference between years, nor between treatments (i.e. between reference and rehabilitation sites ($F_{3,24}$ = 10.35, P = 0.480; $F_{1,24}$ = 2.03, P = 0.486), however, rehabilitation sites are marginally narrower post-rehabilitation activities.

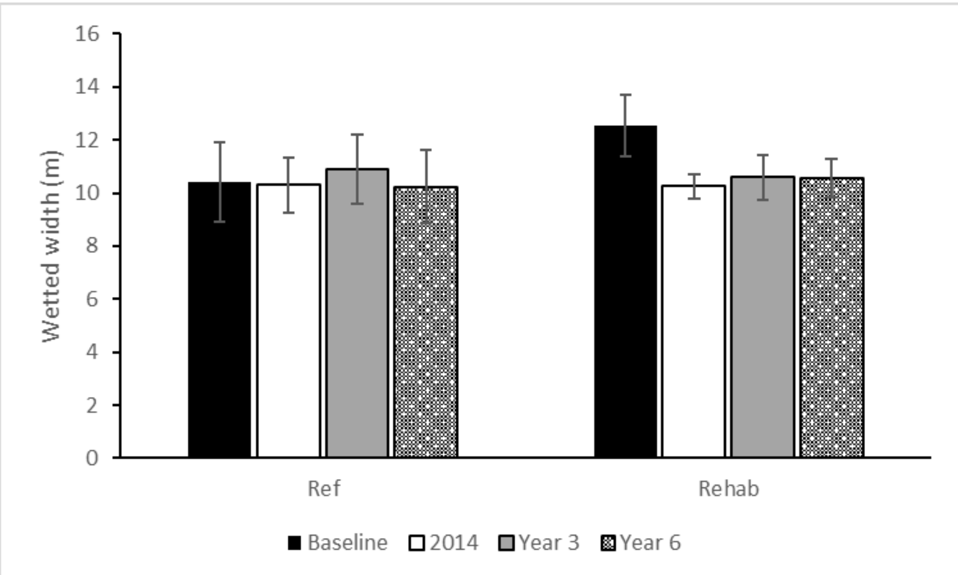


Figure 4. Average (±1SE) wetted width (m) measured at the reference and rehabilitation sites for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Water depth

Average water depth was remarkably variable across the sampling occasions, despite what should be relatively similar transect locations used each monitoring period. Average water depths of reference sites and rehabilitation sites were similar in this survey (average depths of 35.4 cm and 31.8 cm deep, respectively) (Figure 5). When all surveys were included in the analysis, there was no significant difference between surveys, nor between reference and rehabilitation sites ($F_{3,24} = 467.8$, $P = 0.078$; $F_{1,24} = 85.2$, $P = 0.248$).

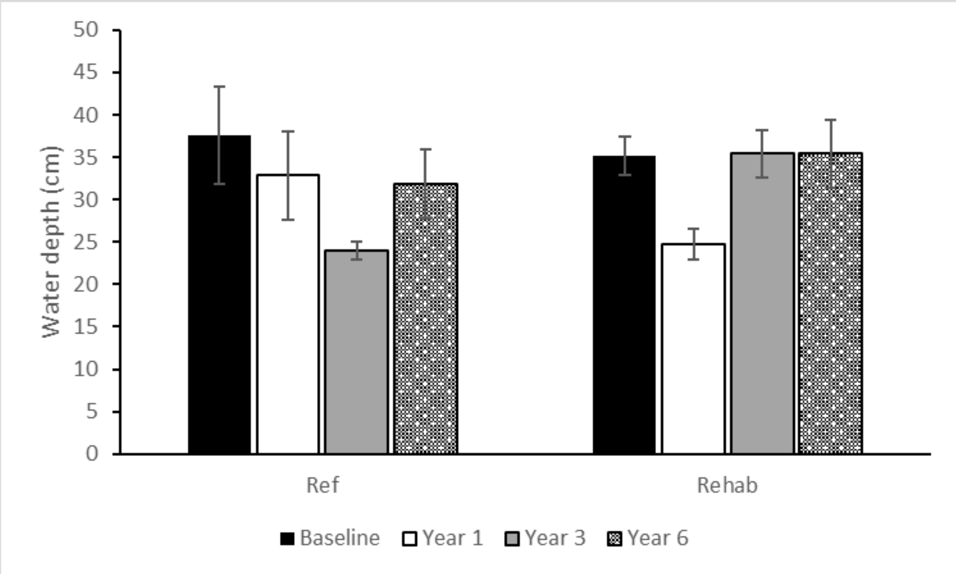


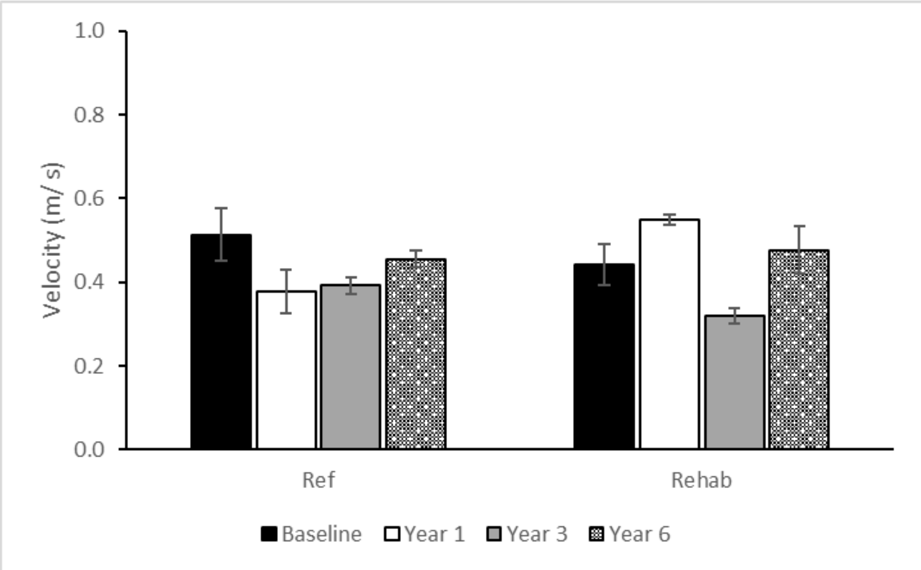
Figure 5. Average (±1SE) water depth (cm) measured at the reference and rehabilitation sites for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Velocity

Velocity in this survey was not measured on the same day as the remainder of habitat variables[8]. Statistical analysis of average velocities showed there was no significant difference between velocity at rehabilitation and reference sites ($F_{1,24} = 0.00024$, $P = 0.84$). There was, however, a difference detected between surveys ($F_{3,24} = 0.091$, $P < 0.01$) (Figure 6). A post-hoc Tukey test showed average velocity in 2017 (0.34 m / s) was lower than that recorded in both 2013 (0.46 m / s) and 2014 (0.48 m / s), but not different to the average velocity recorded in this survey (2020), at 0.47 m / s.

Furthermore, there was a significant interaction between treatment and year ($F_{3,24} = 0.075$, $P < 0.05$). The interaction suggests that rehabilitation sites in 2017 had slower velocity than reference sites in 2013 and rehabilitation sites in 2014. However, it is difficult to differentiate whether this reflects rehabilitation works impacting water velocities or is the result of slightly different sampling locations, preceding seasonal conditions or time of year sampling took place, as no other trends have arisen from the data.

[8] Due to COVID-19 work restrictions and delays, ECan was unable to coincide their velocity survey with the Boffa Miskell habitat survey.



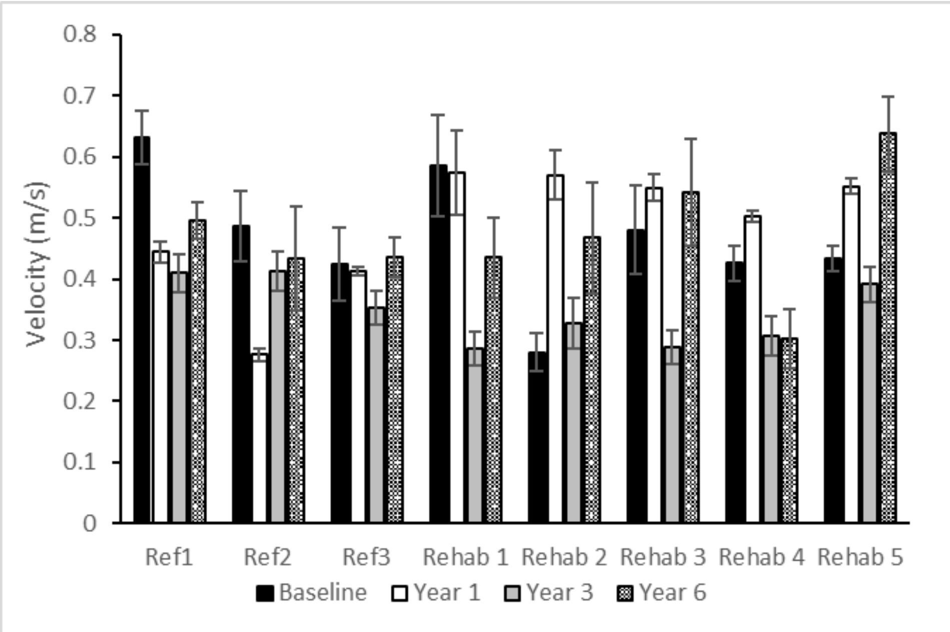


Figure 6. Average (±1SE) velocity (m / s) measured at the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Sediment depth

Sediment depth did not differ between reference and rehabilitation sites in this survey (2020), and generally, sediment depth was very low. This may have been a reflection of minor differences in the locations of transects within a site and sample locations along the transects.

However, when all surveys were analysed, a significant difference between reference and rehabilitation sites was detected ($F_{1,24} = 2.34$, $P < 0.05$). Sediment was deeper at reference sites than rehabilitation sites when all survey occasions were compared (Figure 7).

There was no significant difference in sediment depth detected among the survey occasions ($F_{3,24} = 2.79$, $P = 0.096$), but post-hoc Tukey tests showed that the significant site: time interaction was due to a significant difference in sediment depth measured between rehabilitation and reference sites in 2014. Sediment depth was greater at reference sites than at rehabilitation sites in 2014. It is probable that differences in measurement methodology have influenced this result[9].

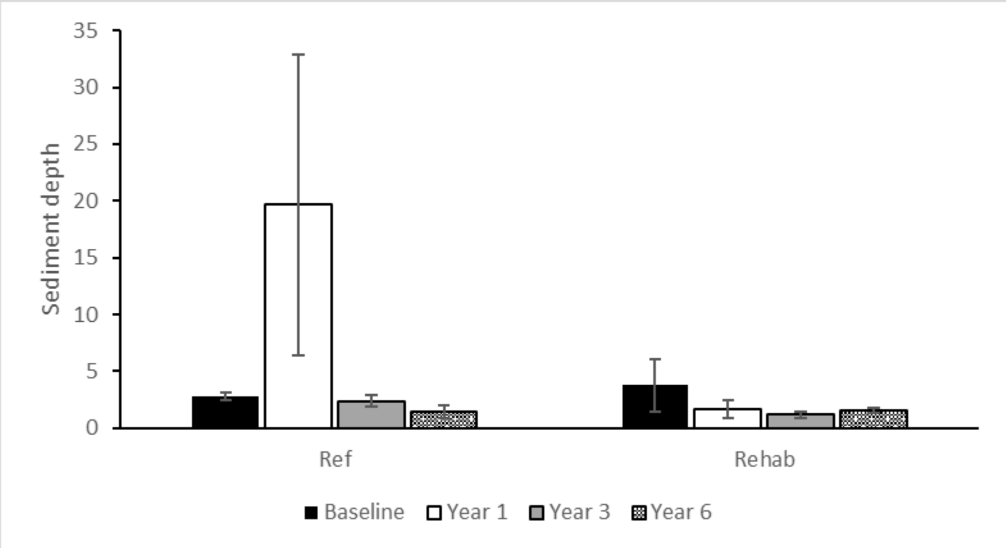


Figure 7. Average (±1SE) sediment depth (cm) measured at the reference and rehabilitation sites for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Sediment cover

In this survey, sediment cover (measured in % cover) was relatively similar between rehabilitation and reference sites. When all surveys were included in the analysis, there was a significant difference between rehabilitation and reference sites, where sediment cover was higher at reference sites than rehabilitation sites ($F_{1,24} = 433.2$, $P < 0.05$), with an average of 26% at reference sites and an average depth of 19% at rehabilitation sites. However, sediment cover was not significantly different between years ($F_{3,24} = 530.5$, $P = 0.083$).

[9] Sediment depth during the baseline (2013), three- and six-years' post-rehabilitation studies (2017 and 2020 respectively) was measured by gently pushing a 10 mm wading rod through the soft layer of sediment until hard substrate was reached below. Where macrophytes were present, sediment depth underneath the macrophytes was measured. A similar method was used in 2014 (Opus 2015), however, where macrophytes covered the area to be surveyed, sediment depth was not measured.

Substrate composition

The calculated Substrate Index was significantly greater at rehabilitation sites than at reference sites ($F_{1,24} = 4.72$, $P < 0.01$), indicating that rehabilitation sites had larger-sized substrate particles than that found at reference sites (Figure 8). The average SI at rehabilitation sites was 3.1 and SI at reference sites was 2.4. There was also a significant difference between surveys ($F_{3,24} = 3.31$, $P < 0.05$), and post-hoc Tukey tests showed this difference was due to SI being greater (i.e. substrate was larger) in this survey (2020) compared to the baseline survey (2013). It appears that rehabilitation works has resulted in increased substrate size (i.e. coarser substrates).

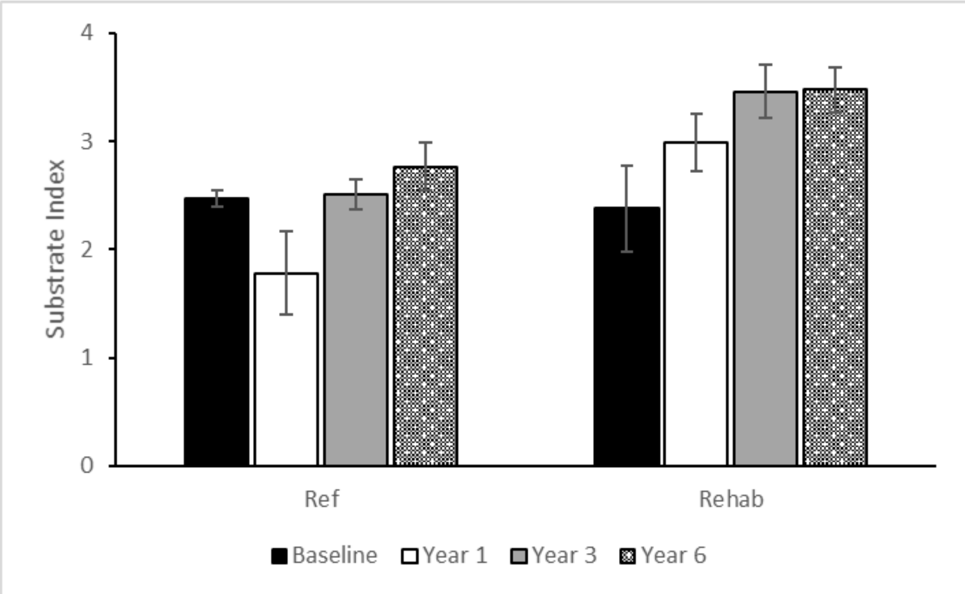
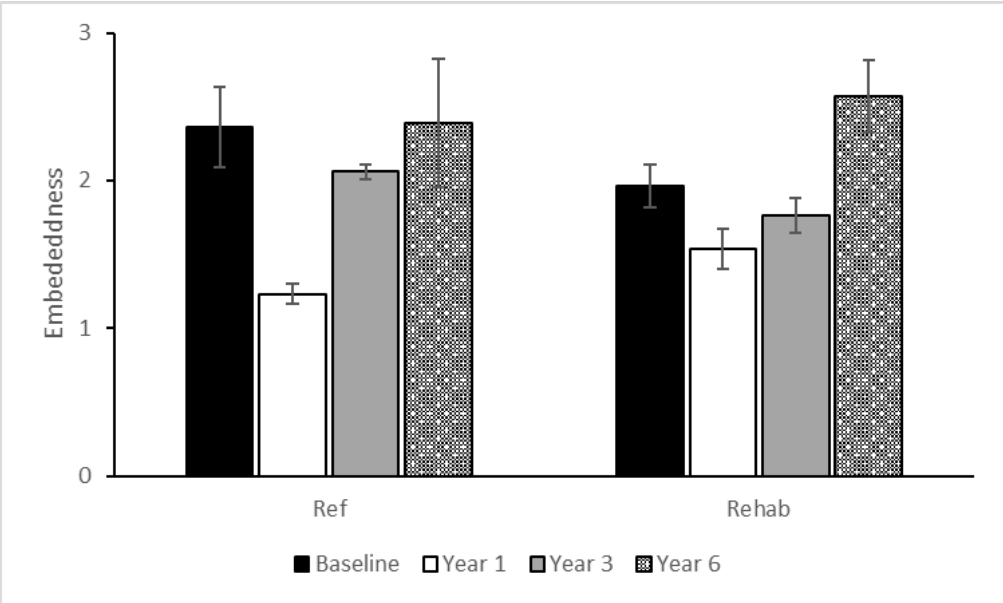


Figure 8. Average (±1SE) Substrate Index measured at the reference and rehabilitation sites for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Embeddedness

There was no noticeable difference in embeddedness between reference and rehabilitation sites in this survey. When all data were included in the analysis, again there was no significant difference in embeddedness between reference and rehabilitation sites ($F_{1,24} = 0.03$, $P = 0.685$) (Figure 9). There was, however, a significant difference detected in embeddedness between surveys ($F_{3,24} = 4.96$, $P < 0.01$). Pairwise comparisons showed a significant difference between the baseline and 2014 surveys, where embeddedness was lower in 2014. There was also a significant difference in average embeddedness between this survey (2020) and the previous survey (2017) with embeddedness being significantly higher in 2020. Substrates appear to be becoming more embedded at rehabilitation sites with time since the rehabilitation activities.



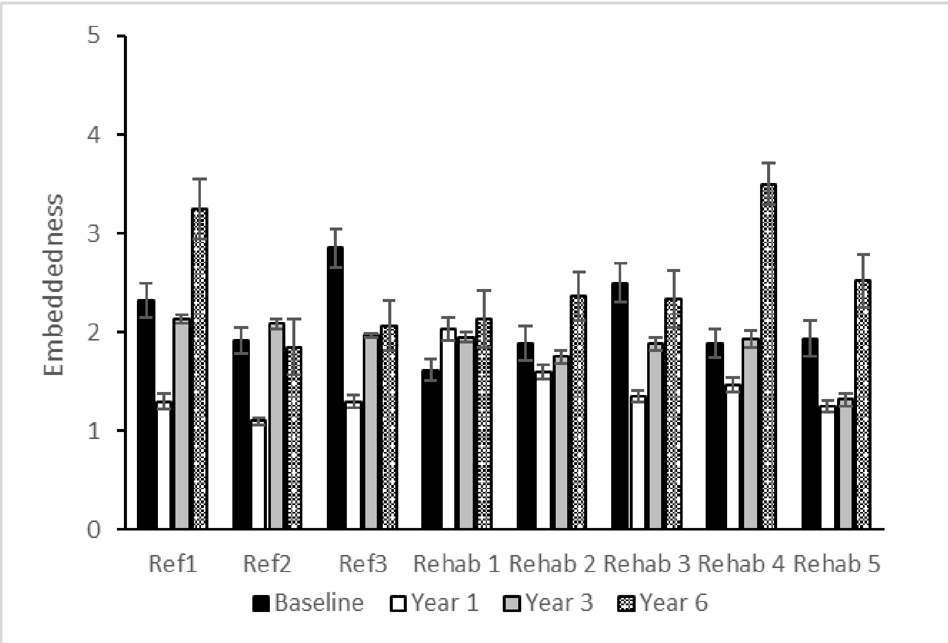
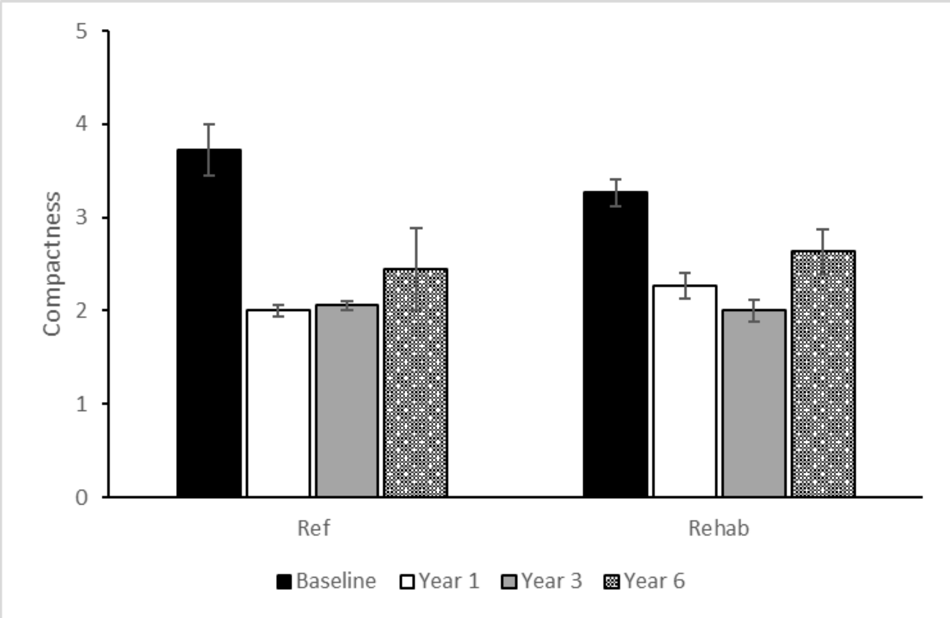


Figure 9. Average (±1SE) embeddedness measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Compactness

Compactness was, on average, similar between reference and rehabilitation sites in this survey. When all data were included in the analysis, again there was no significant difference in compactness between reference and rehabilitation sites ($F_{1,24} = 0.0001$, $P = 0.947$) (Figure 10). There was, however, a significant difference detected in compactness between surveys ($F_{3,24} = 0.651$, $P < 0.01$), and a post-hoc Tukey test showed the significant difference was due to differences between the baseline survey and both the 2014 and 2017 surveys, though not the 2020 survey. Compactness was significantly higher in the baseline survey (2013), than in the two subsequent surveys. Substrates appear to be becoming more compacted at rehabilitation sites with time since the rehabilitation activities.



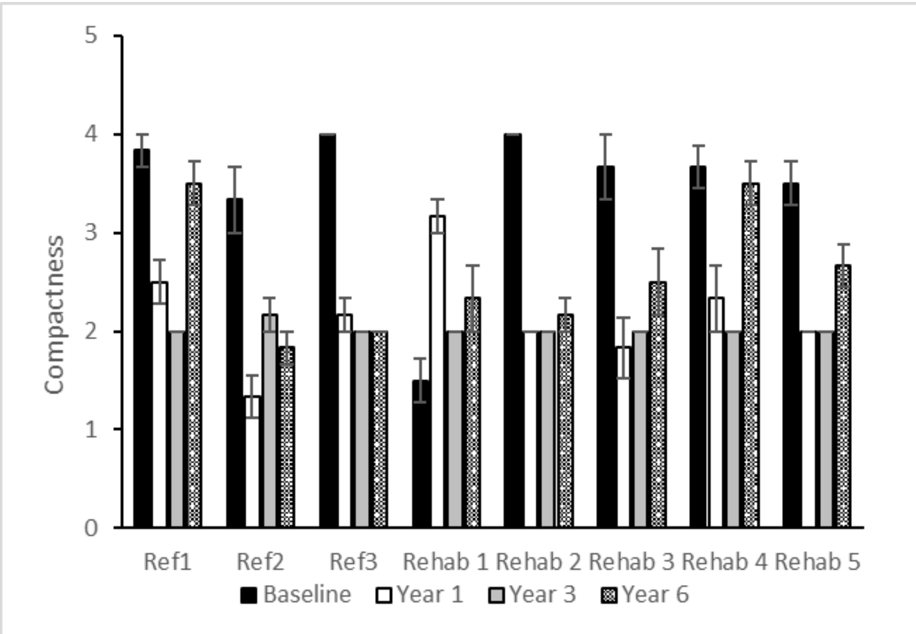


Figure 10. Average (±1SE) compactness measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Macrophyte cover

Macrophyte cover was highly variable in this survey, though on average, reference and rehabilitation sites had relatively similar overall cover (46% and 44% respectively) (Figure 11). Macrophyte cover was also variable in previous years, and when all data was considered, there was no significant difference in cover between rehabilitation and reference sites, nor across years, despite this variability ($F_{1,24}$ = 0.2, P = 0.967; $F_{3,24}$ = 294.1, P = 0.392).

Given that macrophytes are regularly cleared in the Avon River, these results are unsurprising – differences in macrophyte cover resulting from rehabilitation works are likely to be obscured by intermittent changes in macrophyte cover due to clearance.

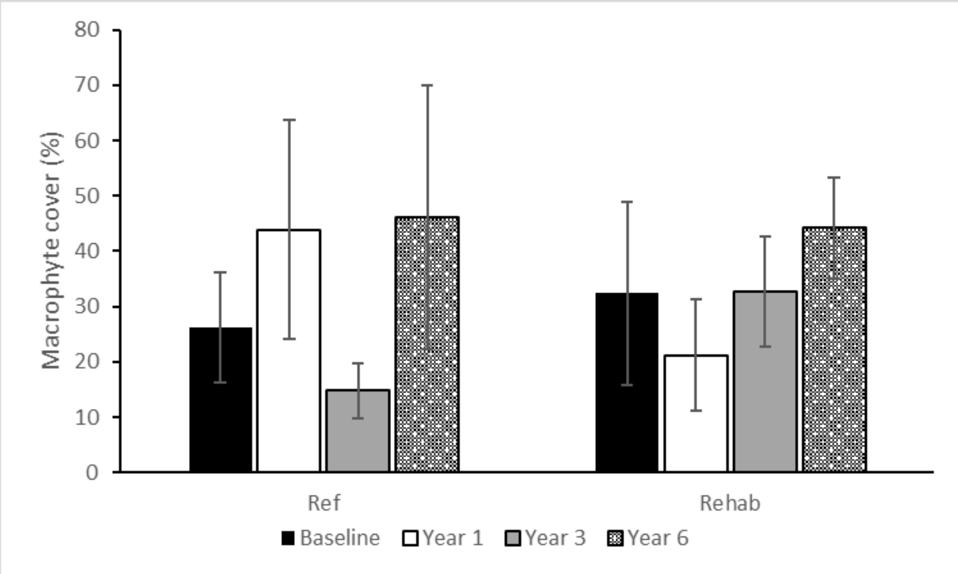


Figure 11. Average (±1SE) macrophyte cover (%) measured at the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

Algal cover

Variability was also observed in algal cover at reference and rehabilitation sites in this survey, where algae was virtually absent at some sites and at up to 40% cover on average at others. When all data were analysed, average algal cover was found to be significantly higher at rehabilitation sites than at reference sites ($F_{1,24}$ = 280.6, P < 0.05) (Figure 12). There was also a significant difference amongst years ($F_{3,24}$ = 1028.3, P < 0.01). Post-hoc Tukey tests showed algal cover was significantly lower in 2020 than in 2013 (baseline) and 2017 (three-year post-rehabilitation). Additionally, algal cover was higher in 2017 than in 2014.

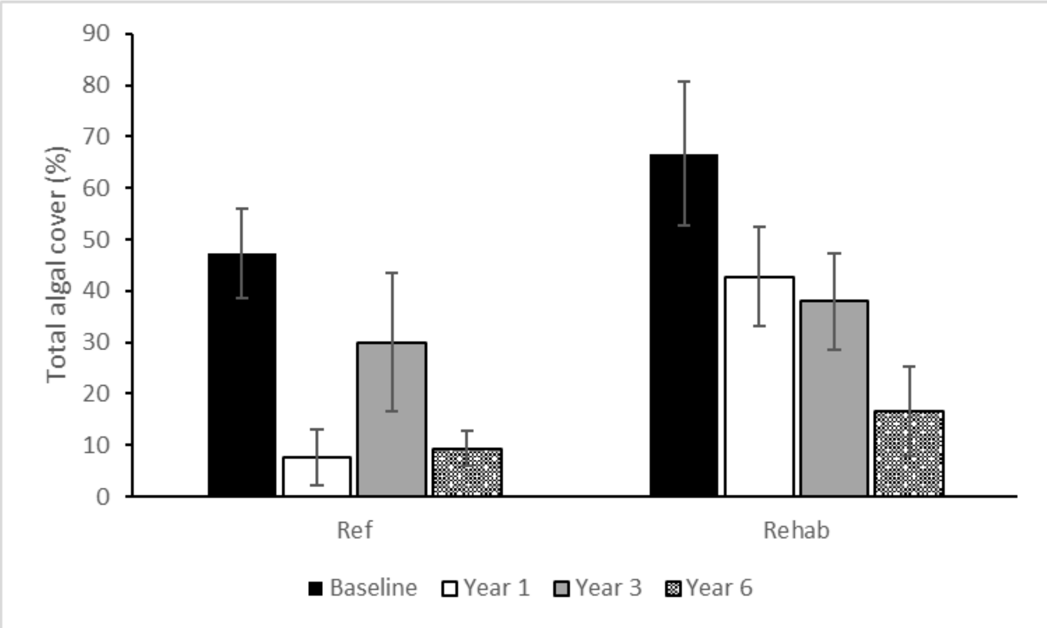


Figure 12. Average (±1SE) algal cover (%) measured at the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

4.3 Macroinvertebrate community

4.3.1 Overview

A total of 62,244 individuals belonging to 29 taxonomic groups were collected across the 8 sites in all Surber and kicknet samples.

The most diverse groups were caddisflies (Trichoptera), for which there were 9 different taxa across all samples, true flies (Diptera) with six taxa, and followed by molluscs (5 taxa), worms (Annelida) and crustaceans (two taxa). The remaining macroinvertebrate groups were represented by a single taxon (mites, Acarina; Hydra, Cnidaria; Nematomorpha; Nemertea and flatworms, Platyhelminthes).

While crustaceans (made up by ostracods (seed shrimp) and *Paracalliope* amphipods) were not particularly diverse, they were numerically dominant (i.e. the most abundant group). Snails (Mollusca) were the next most dominant group numerically, followed by true flies, then caddisflies. Some taxa were present in only very low numbers, with only one or two individuals found representing a single taxon in some cases.

Crustaceans were also the dominant macroinvertebrate group, making up 62% of all macroinvertebrates collected from the 8 sites. The most abundant taxon was the freshwater amphipod *Paracalliope*, which made up a significant proportion of communities found at each site. Molluscs (snails) made up the next largest proportion of the community at 16%. While caddisflies were the most diverse group of taxa collected, but only made up 8% of the macroinvertebrate community found.

There were several taxa found at all sites surveyed, including the highly abundant taxa *Paracalliope*, *Potamopyrgus*, worms (Oligochaetes) and the stony cased caddis *Pycnocentrodes*.

4.3.2 Total abundance

Macroinvertebrate abundance varied among sites, with between 2,949 and 6,904 individuals collected in Surber samples (Figure 13), with between 1,609 and 4,479 additional individuals collected from kick net samples.

Average macroinvertebrate abundance, as determined from Surber samples, did not differ between treatments (i.e. between reference and rehabilitation sites) ($F_{1,24}$ = 0.008, P = 0.829). However, significant differences in abundance were detected over time ($F_{3,24}$ = 4.01, P < 0.001). Post-hoc Tukey tests revealed a significant difference in the number of individuals collected between this sampling round (2020) and the baseline survey (2013), with more individuals collected in 2020 than in 2013.

There was some minor interaction between treatment and time sampled, with a trend of more individuals collected at reference and rehabilitation sites over the four sampling occasions (2013 to 2020) except at rehabilitation sites in 2017 where fewer macroinvertebrates were collected (Treatment:Year interaction: $F_{3,24}$ = 4.07, P < 0.1) (Figure 13).

4.3.3 Taxonomic richness

Taxonomic richness was relatively consistent across sites for Surber samples in this survey, ranging from 20 to 23 taxa per site (Figure 14). When kick net samples are included in this calculation, the range of number of taxa increased to 21 – 27 taxa per site, averaging an increase of 1.6 additional taxa.

The average number of macroinvertebrate taxa did not differ between reference and rehabilitation sites ($F_{1,24}$ = 1.14, P = 0.557). But there was a significant difference among the survey years ($F_{3,24}$ = 168.24, P < 0.001), with post-hoc Tukey testing indicating significant differences in average taxonomic richness between the baseline survey (2013) and all other sampling occasions (P < 0.01). There was also a significant difference between the three-yearly survey (2017) and this survey (P < 0.05), where more taxa were found previously (2017) than in this survey.

The taxonomic resolution used when processing samples may be a factor and these differences may not be of biological relevance.

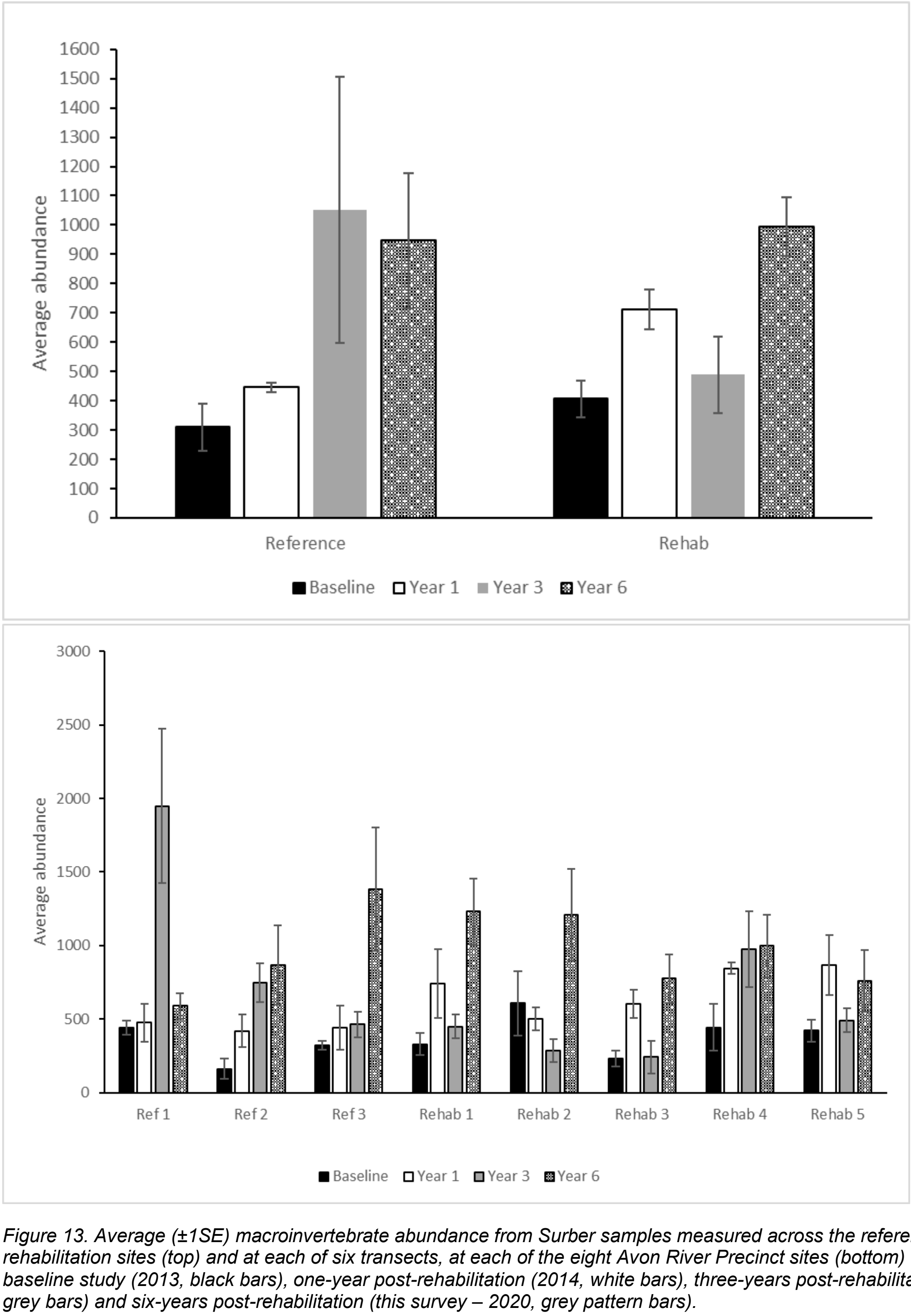


Figure 13. Average (±1SE) macroinvertebrate abundance from Surber samples measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

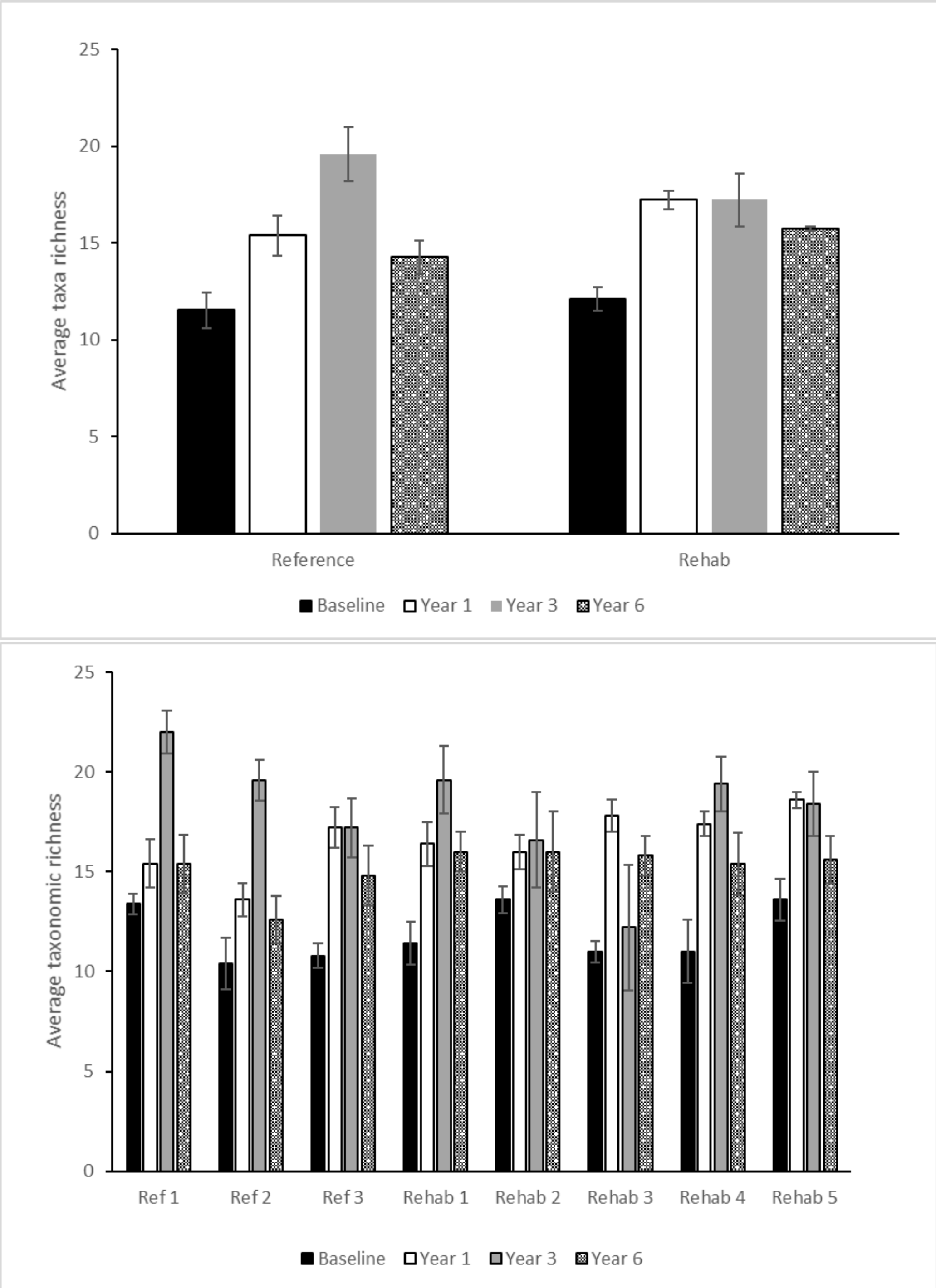


Figure 14. Average (±1SE) taxonomic richness from Surber samples measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars).

4.3.4 EPT richness

The EPT insect orders (Ephemeroptera, mayflies; Plecoptera, stoneflies; and Trichoptera, caddisflies) are generally sensitive to pollution and habitat degradation and are useful indicators of stream health. High EPT richness suggests good water and habitat quality, while low EPT richness suggests poorer water quality and degraded stream health. Caddisflies have been the only EPT taxa found in the Avon River in all surveys, including this one.

There was a total of 9 caddisfly taxa collected in the 2020 survey. This included *Pycnocentria*, for which only 2 individuals were collected at Reference Site 1. The average number of EPT taxa collected in Surber samples ranged between 3 and 5 taxa per site. Caddisfly diversity was lowest at Reference Site 2 and Rehabilitation Site 5, which both had an average of three caddisfly taxa. It was highest at Rehabilitation Sites 1 and 4, where an average of 5 taxa were found.

Of the taxa collected, *Pycnocentrodes* was the most abundant caddisfly found, and was found at every site. *Hudsonema amabile* was also abundant in relatively high numbers and was found at all sites except Reference Site 2. The pollution tolerant caddisfly *Oxyethira* (family Hydroptilidae) was present at all sites except Reference Site 2. Only one individual of the other pollution-tolerant caddisfly taxa, *Paroxythira*, was found at Rehabilitation Site 1, and one individual at Reference Site 2.

Average EPT richness did not differ between treatments (i.e. between reference and rehabilitation sites) ($F_{1,24} = 0.042$, $P = 0.262$) (Figure 15). There was, however, a significant difference in taxa richness between years ($F_{3,24} = 1.23$, $P < 0.001$) and a post-hoc Tukey test showed this difference was because average EPT richness in the baseline (2013) survey was lower than all other surveys ($P < 0.05$). There was also a significant difference between the 2014 and 2017 surveys, and between the 2017 and 2020 surveys, where EPT richness was highest in 2017 (three-year post-rehabilitation) than all other surveys.

When the pollution tolerant taxa *Oxyethira* and *Paroxythira* were excluded from the analysis, a significant difference in EPT taxa richness was found between rehabilitation and reference sites ($F_{1,24} = 0.209$, $P < 0.05$), where EPT taxa richness was higher at reference sites than at rehabilitation sites. There was also a significant difference in average EPT taxa found among years, though the only significant difference, shown through a post-hoc Tukey test, was between the 2013 and 2017 surveys ($P < 0.01$).

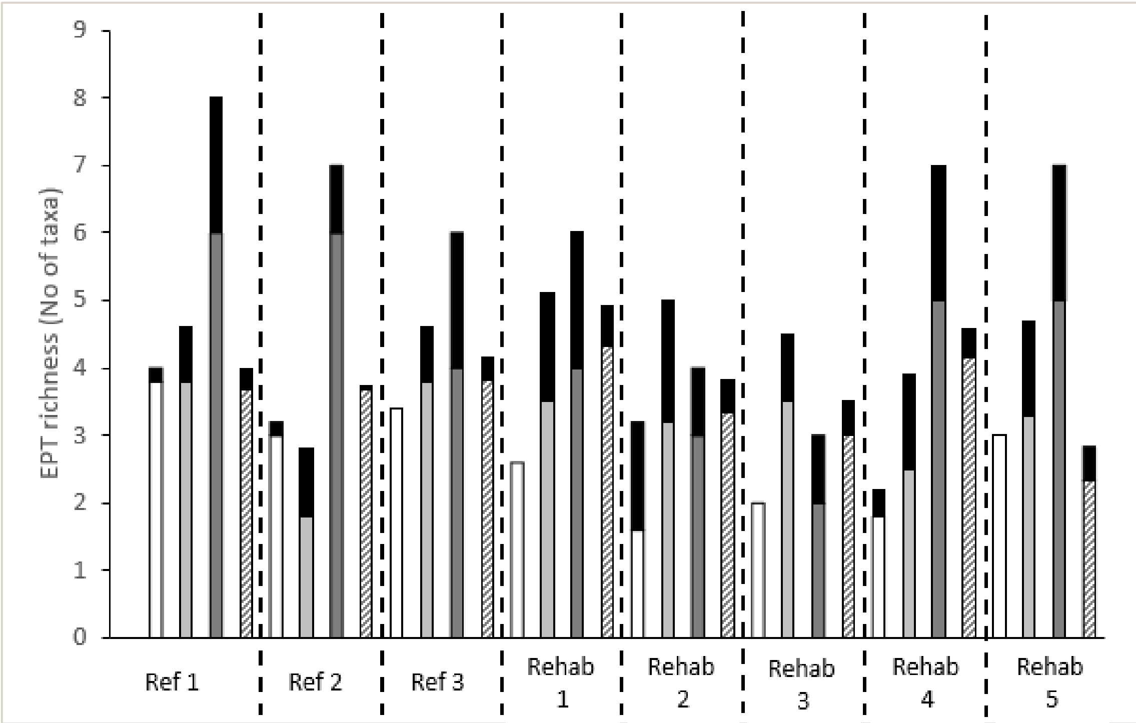


Figure 15. Average EPT richness (light bars) and hydroptilid richness (black bars) collected from Surber samples at all eight sites from for the baseline study (2013, white bars), one-year post-rehabilitation (2014, light grey bars), three-years post-rehabilitation (2017, dark grey bars) and six-years post-rehabilitation (this survey – 2020, grey striped bars). Note, the vertical dotted line is for visual aid to differentiate between sites. SE bars are not shown.

4.3.5 Macroinvertebrate Community Index

MCI

MCI and QMCI scores are a measure of stream, or ecological, health with higher scores indicating greater ecological condition.

MCI scores were relatively similar across surveys and between reference and rehabilitation sites (Figure 16). However, when data across all surveys was compared, there was a significant difference between reference and rehabilitation average MCI scores, with reference sites having a slightly higher average MCI score than rehabilitation sites (74.9 and 70.9, respectively) ($F_{1,24}$ = 118.01, P < 0.001) (Figure 16).

All sites in all years had MCI scores below 80, indicating “poor” stream health with “probable or severe enrichment” (based on the water quality categories of Stark and Maxted 2007). There was no significant difference in MCI score averages over time ($F_{3,24}$ = 12.44, P = 0.565).

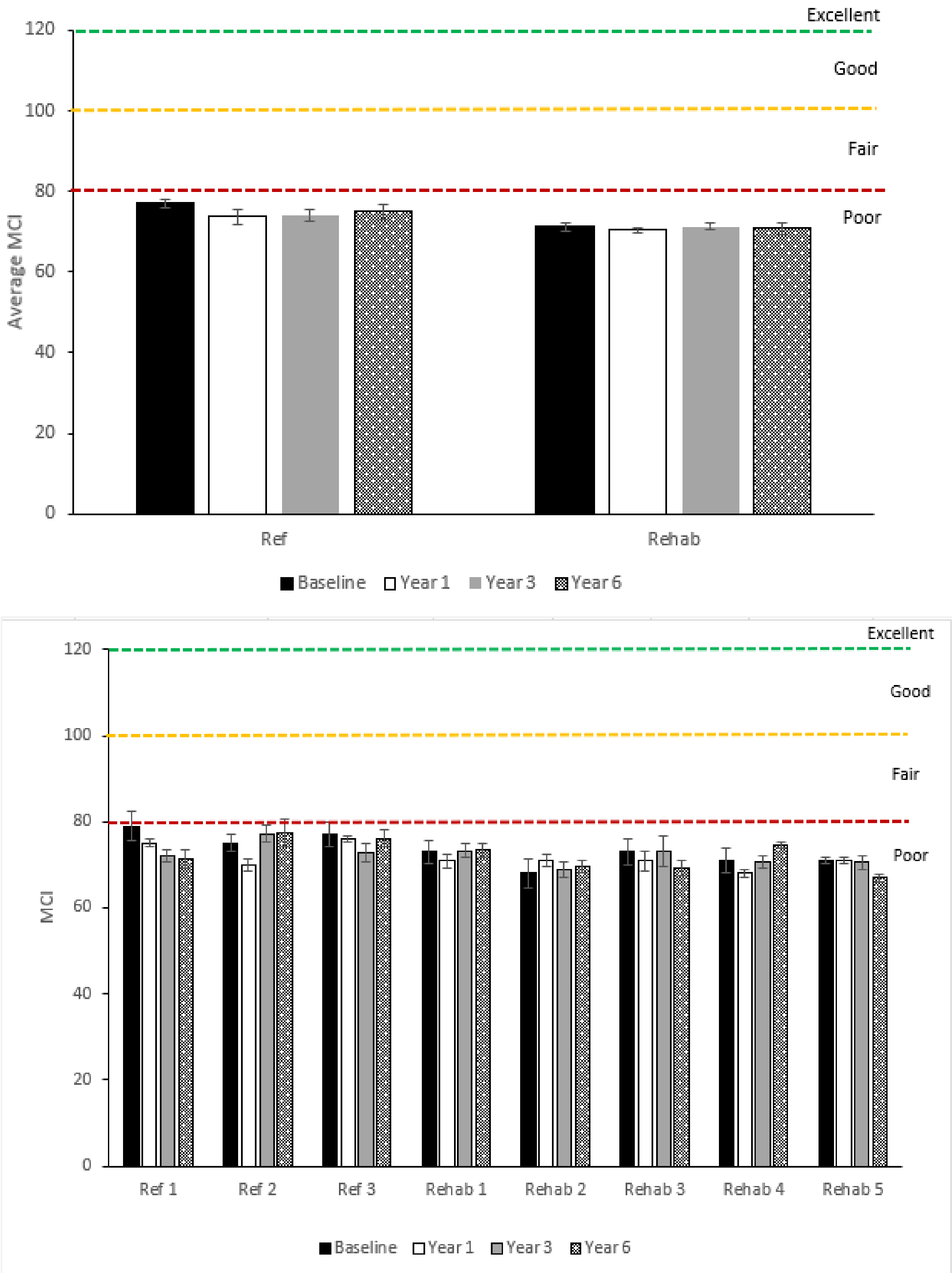


Figure 16. Average (±1SE) Macroinvertebrate Community Index (MCI) measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars). The dashed lines indicate the water quality categories of Stark and Maxted (2007). See Table 2 for further information.

QMCI

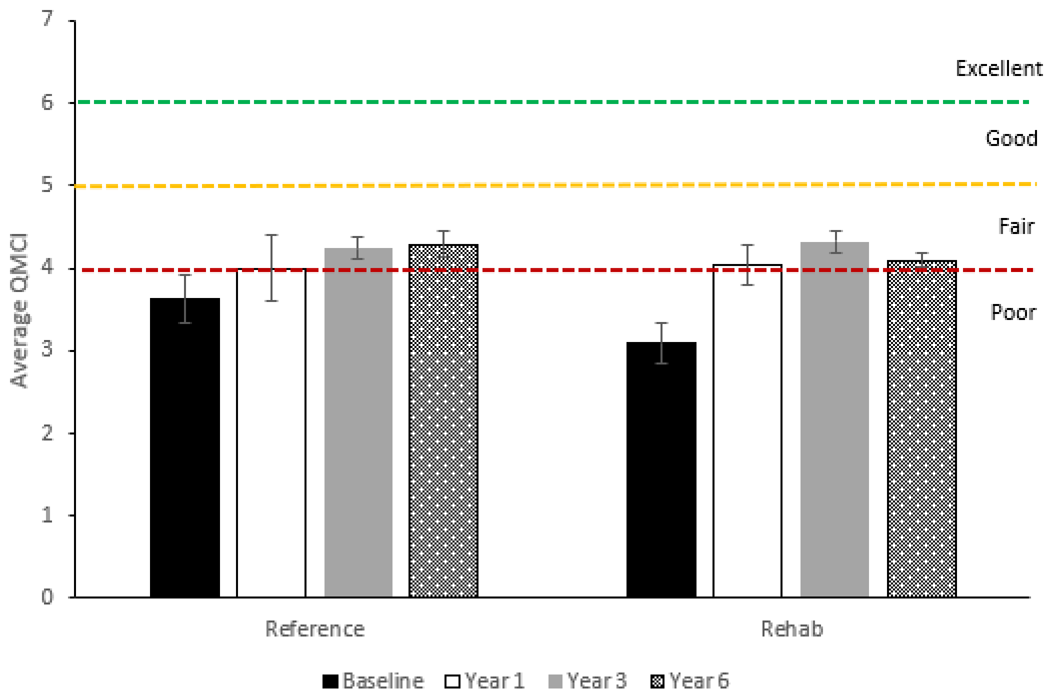
QMCI, the quantitative variant of the MCI, is often considered a better indicator of "health" than MCI as it also accounts for abundances of macroinvertebrate taxa, while MCI only accounts for presence and can be biased (or inflated) by rare but sensitive taxa or vice versa.

QMCI scores from this (2020) survey, showed stream health at reference and rehabilitation sites was, on average, "fair". However, Reference Site 1 and Rehabilitation Sites 1 and 2 had "poor" health (Figure 17).

There was no significant difference in mean QMCI at reference and rehabilitation sites (4.0 and 3.9 respectively) in 2020.

There was a significant difference in QMCI through time ($F_{3,24} = 4.733$, $P < 0.001$), where the baseline (2013) survey had a significantly lower QMCI score than all subsequent surveys (Figure 17).

QMCI scores improved in rehabilitation sites from 2013 to 2014 (the one-year post-rehabilitation survey), but have remained relatively consistent since then (Figure 17).



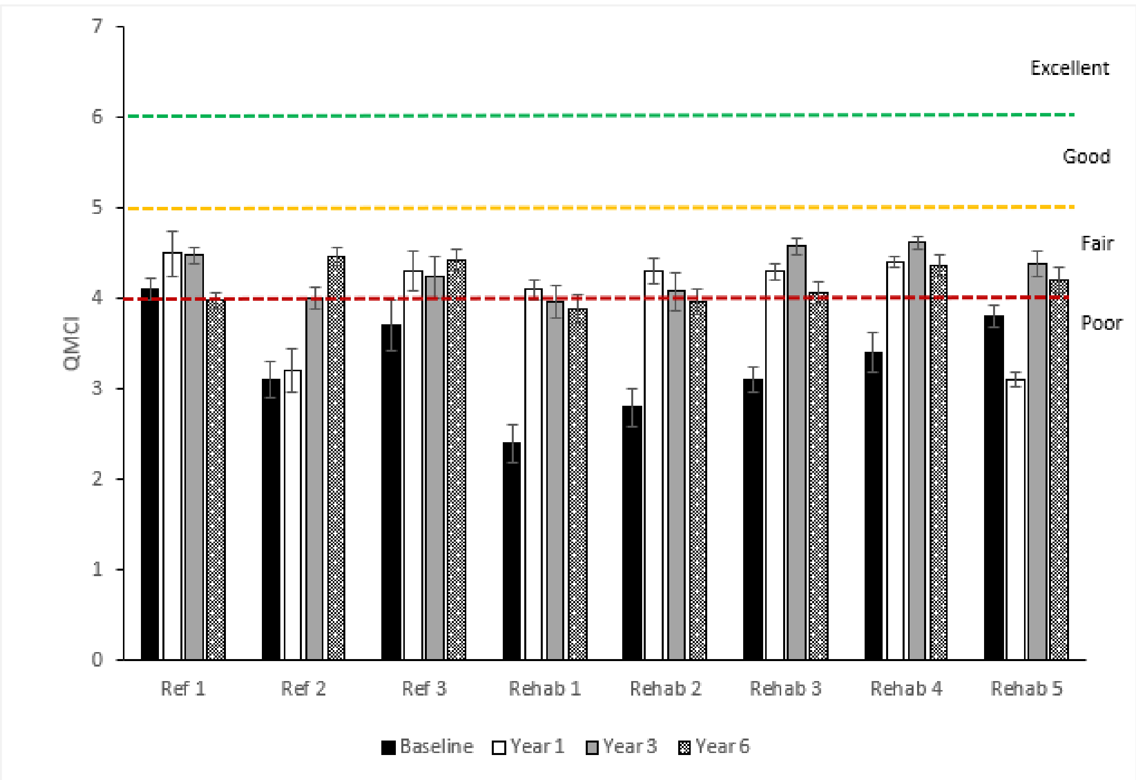


Figure 17. Average (±1SE) QMCI measured across the reference and rehabilitation sites (top) and at each of six transects, at each of the eight Avon River Precinct sites (bottom) for the baseline study (2013, black bars), one-year post-rehabilitation (2014, white bars), and three-years post-rehabilitation (2017, grey bars) and six-years post-rehabilitation (this survey – 2020, grey pattern bars). The dashed lines indicate the threshold between water quality categories of Stark and Maxted (2007). See Table 2 for further information.

4.3.6 Community composition

Community composition has changed somewhat over time and has been largely driven by changes in the relative dominance, rather than the absence, of taxa.

The macroinvertebrate community in this survey (2020) was dominated by crustaceans in both rehabilitation and reference sites, with this group making up around 60% of the community (Figure 18). In the baseline study, the proportion of crustaceans was 37% and 23% for reference and rehabilitation sites, respectively; and quite similar in 2014, the one-year post-rehabilitation survey. The 2020 results are similar to that seen in the previous survey (2017).

Furthermore, the community composition in general also appears to be relatively similar to that found in 2017 (Figure 18). These latest two surveys (2017 & 2020) contrast with the baseline survey, where true flies and aquatic worms made up a greater proportion of the community. The 2014 survey had the greatest proportion of caddisflies.

In general, community composition has remained similar between rehabilitation and reference sites. However, several taxa that were only ever found in low numbers in previous surveys were not found in this survey. For example, ceratopogonid larvae (biting midges), the non-biting midges *Chironomus* and Tanypodinae, Cladocera (water fleas) and Collembola (springtails) were not found in the 2020 survey. These taxa were typically only found in very low (i.e. no more than 9 individuals at each site) numbers in previous surveys. Furthermore, these taxa generally have low tolerance scores (with MCIs of < 5). The absence of these taxa is unlikely to be due to rehabilitation activities and instead more likely a reflection of the relative low abundances of these taxa and, therefore, reduced likelihood of collecting these. Because these taxa are rare, they will have had little impact on the analysis of community composition or QMCI results. More importantly no new taxa were collected in 2020.

Despite an apparent initial increase in the relative abundance of caddisflies in 2014 from the baseline survey, caddisfly relative abundance in this survey was lower (10% and 5% for reference and rehabilitation sites, respectively) than in the 2017 survey (17% for both reference and rehabilitation sites). The relative abundance of caddisflies seen at rehabilitation sites in this survey was the lowest seen in any survey undertaken thus far at 5%.

While the relative abundance of molluscs and worms appeared to be decreasing since the baseline survey (Boffa Miskell 2017), molluscs were found at a similar proportion of the community in this survey as compared to other surveys, making up an average of 15% across all sites.

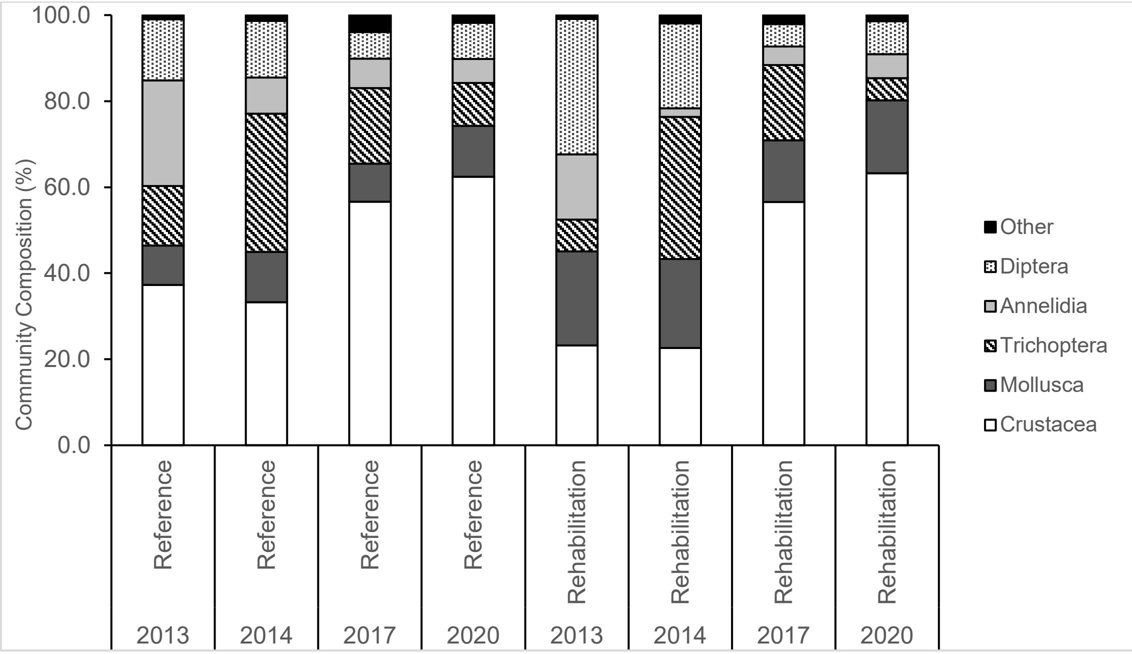


Figure 18. Average macroinvertebrate community composition (%) found at reference and rehabilitation sites across the baseline survey (2013), one-year post-rehabilitation (2014), three-years post-rehabilitation (2017) and six-years post-rehabilitation (2020) surveys.

The NMDS ordination, confirmed by the ANOSIM results, also indicated significant differences in the macroinvertebrate community through time (ANOSIM $R = 0.737$, $P < 0.01$). The greatest difference was seen between the 2013 and 2020 macroinvertebrate communities ($R = 0.953$, $P = 0.001$). The 2014 and 2017 communities were the most similar, though were still significantly different ($R = 0.381$, $P < 0.01$).

The NMDS and ANOSIM indicate a shift in community composition since the surveying first commenced, and this is not due to rehabilitation activities (Figure 19).

SIMPER indicated that these significant differences in community composition were largely due to differences in the average number of occurrences of some taxa (i.e. greater or lesser numbers of individuals), rather than the presence or absence of a particular taxon changing among sampling occasions. For example, the amphipod *Paracalliope* was most abundant in 2020, where it was 5.5 times more abundant than in the 2017 samples. *Paracalliope* was substantially more abundant in both the 2017 and 2020 surveys, compared to the 2013 and 2014 surveys.

In the 2020 survey, stratiomyid larvae (true fly) were more abundant in 2020, compared to previous years. Ostracods (freshwater seed shrimp), Sphaeriidae (freshwater bivalves) and Tanytarsini fly larvae were also in higher abundances in the 2020 survey compared to other surveys. The stony-cased caddisfly *Pycnocentrodes*, aquatic worms (Oligochaetes) and the chironomid midge Orthocladiinae were less abundant in the 2020 survey compared to other surveys and were strong drivers of differences in community composition.

There was a significant difference in the macroinvertebrate community found in reference sites and rehabilitation sites, however, the relationship was relatively weak ($R = 0.267$, $P = 0.011$). These differences were again predominantly driven by differences in abundances of some taxa, including *Paracalliope*, which was around four times more prevalent at reference sites than rehabilitation sites. The cased caddis *Hudsonema*, ostracods and the chironomid midge Tanytarsini were also more prevalent at reference sites than rehabilitation sites. The stony-cased caddisfly *Pycnocentrodes* and the snail *Potamopyrgus* were about three times as abundant at rehabilitation sites than at reference sites, with Orthocladiinae about twice as abundant at rehabilitation sites (see Appendix 4 for further details on SIMPER results).

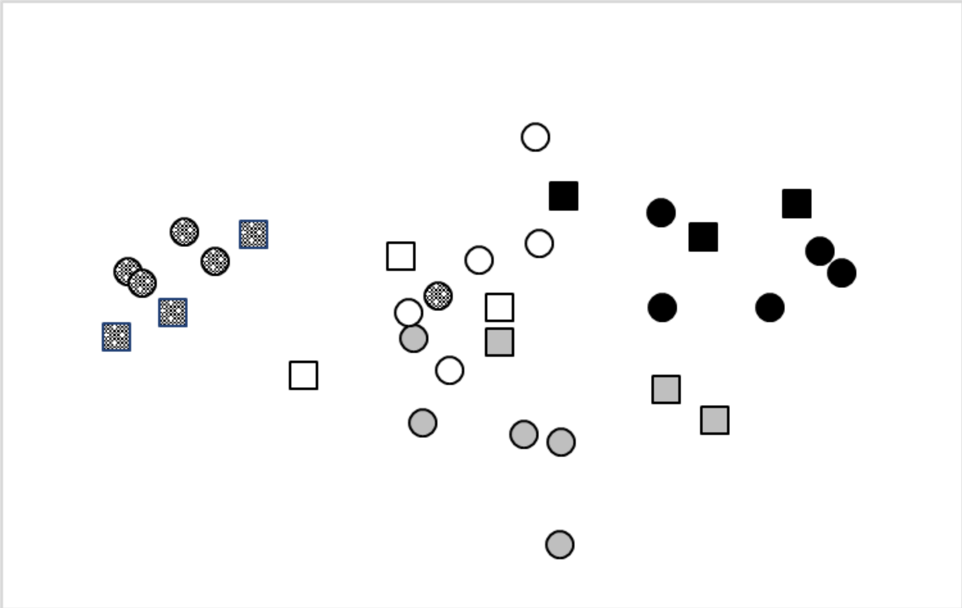


Figure 19. Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate abundance data collected from the eight sites surveyed in 2013 (baseline survey – black symbols; Boffa Miskell 2014), 2014 (one-year post-rehabilitation – white symbols; Opus 2015), 2017 (three-years post-rehabilitation – grey symbols) and 2020 (six-years post-rehabilitation, grey-pattern symbols; this study). Reference sites are shown as squares; rehabilitation sites are shown as circles. Axes are identically scaled so that sites closest together are more similar in macroinvertebrate composition, than those further apart. The 2-dimensional stress value was 0.18. The significance of differences in community dissimilarity was confirmed using Analysis of Similarities (ANOSIM).

4.4 Fish community

4.4.1 Overview

A total of 104 individuals, belonging to 9 different species, were captured at the 8 sites in the Avon River in March 2020.

The species caught, in descending order from most to least abundant, were: bluegill bully (*Gobiomorphus hubbsi*), upland bully (*G. breviceps*), common bully (*G. cotidanus*), shortfin eel (*Anguilla australis*), longfin eel (*A. dieffenbachii*), giant bully (*G. gobioides*), inanga (*Galaxias maculatus*), and the introduced brown trout (*Salmo trutta*). Longfin eel and bluegill bully are classified as At Risk, Declining, while the other species captured are Not Threatened or Introduced and Naturalised (brown trout) (Dunn et al. 2018).

Fish of all species were of varying sizes, with both adults and juveniles of all species found. Giant bullies and eels (of both species) were typically found along the margins of the waterway, often where banks were undercut, or the wetted margin extending into wetland zones (for eels).

Meanwhile, bluegill bullies, whose preferred habitat is fast riffle habitat, were found in the central part of the river, in areas of clear substrate or where macrophytes were present but where water velocities were fastest.

4.4.2 Total abundance and species richness

Species richness was relatively consistent across sites, with an average of six species being found at each site. Reference Site 3 had the highest species richness, with 7 species captured, while Rehabilitation Site 1 had the lowest species richness, with 4 species captured.

Longfin eel, juvenile eels (<180 mm; elvers) and common bullies were found at all 8 sites in the March 2020 survey. Giant bullies were uncommon, with six individuals caught across four sites – three in reference sites and three at rehabilitation sites. Inanga were also uncommon, with only two individuals caught at Reference Site 3. Only one brown trout was caught – at Reference Site 3.

Bluegill bullies were the most numerically abundant species, with 293 individuals caught across the 8 sites, caught at all sites except Reference 3 and Rehabilitation 1. A large proportion of these were caught at Rehabilitation Site 5, where 180 individuals were caught. Bluegill bullies have never previously been found at Reference Site 2 (Carlton Mill Corner), where two individuals were found in this survey. No bluegill bullies were found at Rehabilitation Site 2 (Rhododendron Island) in this survey, despite having been caught at this site in all previous surveys. The species has not yet been found at Reference Site 3 (Hagley Park) – possibly a reflection of the lack of fast-flowing riffle habitat at this site.

There was a significant difference in number of fish caught between surveys ($F_{3,24} = 7.857$, $P < 0.001$) (Figure 20). When pairwise comparisons were made, we found significantly more fish were caught in the 2020 and 2017 surveys than in the 2013 and 2014 surveys. There was, however, no significant difference in the number of fish caught between the 2017 and 2020 surveys. This was largely driven by high numbers of fish caught in rehabilitation sites – in particular, Rehabilitation Site 5, where very high numbers of bluegill bullies were caught. The high number of fish caught at rehabilitation sites was also significantly greater than the number caught at reference sites ($F_{1,24} = 1.280$, $P < 0.05$).

A similar number of species were caught in each treatment (i.e. taxa richness in reference versus rehabilitation sites), and when including data from all surveys, species richness between reference and rehabilitation sites was not significantly different ($F_{1,24} = 0.675$, $P = 0.469$) (Figure 20).

Several fish species found in previous surveys were not found in this survey, including lamprey, common smelt and torrentfish. Thus, there was a significant difference in taxa richness between surveys ($F_{3,24} = 14.13$, $P < 0.05$), though pairwise comparisons showed the only significant difference in taxa richness found to be between the 2013 and 2017 surveys, where more species were found in 2017.

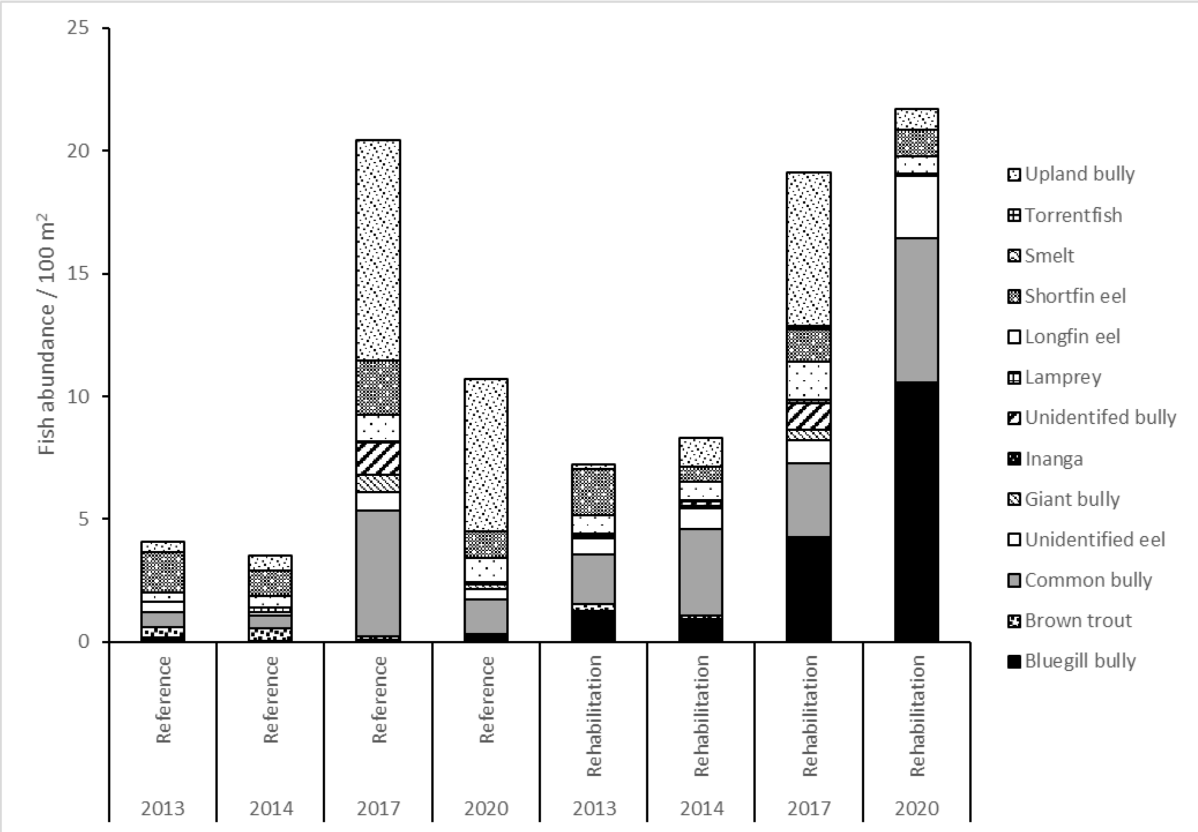


Figure 20. Total abundance of fish, separated by species, found at reference and rehabilitation sites across the baseline survey (2013), one-year post-rehabilitation (2014), three-years post-rehabilitation (2017) and six-years post-rehabilitation (2020) surveys. Numbers are show as catch per unit effort (CPUE): per 100 m^2 of waterway surveyed using electric fishing.

4.4.3 Community composition

The NMDS ordination, confirmed by the ANOSIM, showed there to be a significant difference in fish community composition through time, though the differences were weak (ANOSIM R = 0.417, P < 0.01) (Figure 21). The greatest difference was seen between the 2013 and 2017 fish communities (R = 0.734, P = 0.002). Statistically significant differences in community composition were found between the 2017 survey and all other surveys, and between the 2013 and 2014 surveys (ANOSIM results in Appendix 5). There was no significant difference between communities in any other pairwise comparison of sampling occasion.

SIMPER analysis showed the abundance of fish species, rather than presence or absence of species, to be the primary cause of differences detected between sampling occasions. In 2014, common bullies, upland bullies, shortfin eels and bluegill bullies were 5-7 times more abundant than in 2013. In 2017, upland bullies were 13 times more abundant than in 2013, with other species being 4-7 times more abundant.

Between treatments (i.e. reference vs rehabilitation sites), there was also a significant, albeit weak difference detected (ANOSIM R = 0.462, P < 0.01).

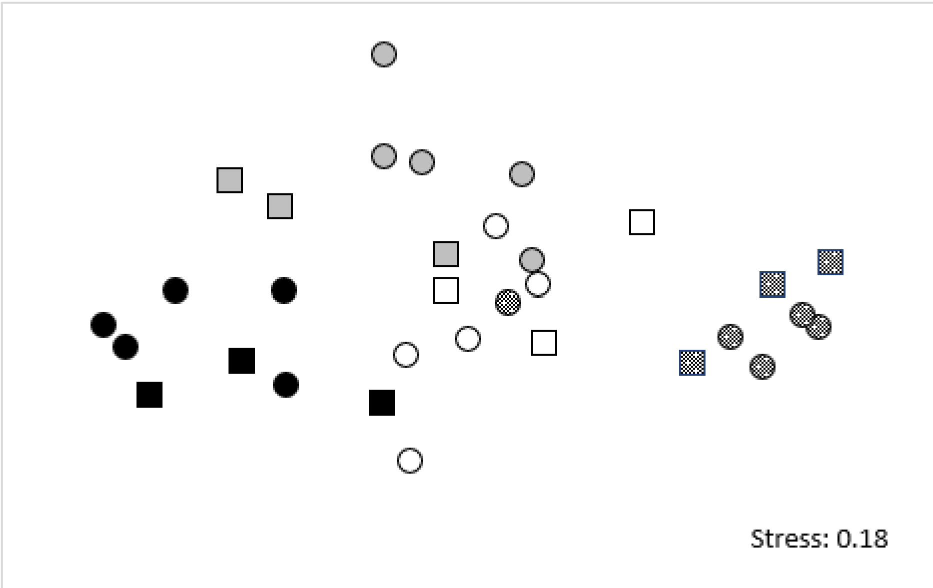


Figure 21. Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from fish abundance (CPUE) data collected from the eight sites surveyed in in 2013 (baseline survey – black squares; Boffa Miskell 2014), 2014 (one-year post-rehabilitation – white squares; Opus 2015), 2017 (three-years post-rehabilitation – grey squares) and 2020 (six-years post-rehabilitation, grey-pattern squares; this study). Reference sites are shown as squares; rehabilitation sites are shown as diamonds. Axes are identically scaled so that sites closest together are more similar in macroinvertebrate composition, than those further apart. The significance of differences in community dissimilarity was confirmed using Analysis of Similarities (ANOSIM).

5.0 Discussion

The Avon River Precinct rehabilitation project was undertaken as an "anchor project" under the Christchurch Central Recovery Plan in 2013 and 2014. Rehabilitation was undertaken at five sites with the aim to return the river to more natural flow regimes as well as improve water quality and ecological health. A monitoring programme was established to evaluate the success of the works, beginning with a baseline survey to evaluate the "original" state of the river undertaken in 2013. Three "post-rehabilitation" surveys (2014, 2017 and this survey, 2020) have been undertaken since rehabilitation works to measure any significant changes in water quality and ecological factors in the river.

Ecological parameters measured in this (2020) and previous (2013, 2014, 2017) surveys showed the general ecological condition at all sites as remaining largely unchanged, though with some slight improvements. When investigating the riparian and in-stream habitat, we found velocity has increased at rehabilitation sites due to constructed riffles, as well as larger substrate and lower sediment cover (compared to the baseline condition). While there is certainly likely to be seasonal variation associated with some parameters (e.g. macrophyte and algal cover), some of the changes seen are likely a result of rehabilitation works (substrate size, velocity, presence of constructed floodplain wetlands).

Differences in the macroinvertebrate community indices and fish community are more subtle and it is difficult to detect strong "treatment" effects six-years' post-rehabilitation activities. The macroinvertebrate community at all sites indicate the conditions are of "poor" to "fair" health, with macroinvertebrate communities dominated by pollution-tolerant taxa such crustaceans (freshwater amphipods and ostracods). Caddisflies make up a small proportion of the community at all sites. The abundance of fish found has increased at rehabilitation sites, though the number of species found remains relatively similar between rehabilitation and reference sites.

5.1 Water quality

There were no discernible differences in water quality measures between reference and rehabilitation sites in this survey, nor were there any marked differences between surveys. As noted previously, the water quality parameters measured can vary diurnally and seasonally and only single measures of each parameter were taken at each site in each survey.

Rehabilitation works undertaken, such as planting, bank reshaping and grading that would be expected to improve water quality conditions by improving shading and reducing urban runoff may not yet be established enough to have a measurable impact. External influences such as incoming stormwater from throughout the catchment, and other inputs from the urban environment will still have a significant influence on water quality.

Nevertheless, the measured temperature, pH, conductivity and pH in the 2020 survey were all within or above guideline levels set out in the Land and Water Regional Plan and the Discharge Consent guidelines and are within ranges aquatic life can tolerate.

5.2 Habitat characteristics

Rehabilitation works were focussed around improving the habitat quality of the Avon River by creating riffles, additional riparian cover and stability, constructing wetland margins and “floodplains” to mitigate the impact of rainfall events, and removal of sediment and ‘cleaning’ of stream substrates.

As was intended, riparian plantings have become well established in most places, providing increased bank stability, and some shading and cover over the waterway, thereby increasing habitat diversity. Stream shade is still somewhat limited to the river margins as few trees (or taller height tier vegetation) have been planted at the water’s edge to create shading across the full width of the river.

While water depth, velocity and wetted width have remained relatively unchanged across the course of the four surveys, it was noted in the previous report (Boffa Miskell 2017) that dry summer conditions may have contributed to low water levels. The summer preceding this survey (2020) was also considered dry, though water levels were not markedly lower than that seen in any previous surveys.

Sediment depth has markedly decreased; sediment depth was significantly shallower at rehabilitation sites than reference sites. Furthermore, the amount of sediment found in 2020 was markedly less than that found in any other year. In 2020, large accumulations of sediment along the transects were relatively uncommon. While sediment was still present, it was often a thin covering over cobbly substrate as opposed to deep sediment. Measured proportion of sediment cover has appeared to decrease through time, particularly at rehabilitation sites, and though there was some increase of sediment cover seen in 2014, it is probable the disparity can be attributed to differing survey methods used in 2014 (Opus 2015). A clearer trend may become apparent with further monitoring rounds.

Nevertheless, reduced sediment levels observed is a tentatively positive result of the rehabilitation works. Fine sediment smother substrates and algae, which can be an important food source for macroinvertebrates. Sediment can also smother macroinvertebrates and block fish gills.

The reduced sediment levels are further reflected in the increase seen in Substrate Index through time. A higher SI indicates coarser substrates, e.g. dominated by cobbles and boulders. Embeddedness appears to be steadily increasing, which may be due to several factors. Compactness was found to be relatively similar to baseline levels in this survey, despite an initial apparent decrease after the baseline survey. Larger substrates provide greater habitat variation by creating interstitial spaces along the riverbed, and larger substrates are more stable and less likely to be disturbed / moved during higher flow events. Interstitial spaces are important refuges for fish, as well as creating habitat for macroinvertebrates.

Macrophyte and algal cover have been variable across surveys, and in this survey, there were no clear disparities between levels seen at reference and rehabilitation sites. As macrophytes, and thus any algae associated with those macrophytes, are regularly cleared from the waterway, it is difficult to determine whether macrophyte and algal cover have been impacted by rehabilitation works. It is likely that differences in macrophyte and algal cover are more a result of seasonal variation than rehabilitation activities, per se. However, the slightly increased shading by riparian vegetation may positively influence (reduce) nuisance macrophyte and algal cover.

5.3 Macroinvertebrate communities

The macroinvertebrate community found in the 2020 survey was significantly different in composition to the community found in the baseline survey, though more subtly different from the previous surveys in 2014 and 2017. There has been a small, but statistically significant, increase in the total number of macroinvertebrates collected since the baseline survey. The number of taxa collected has also been consistently higher in post-rehabilitation surveys than the number of taxa found in baseline, though no new notable taxa (including of higher ecological value or sensitivity) have been found.

Through time, the average MCI scores found at each site have remained relatively similar, with no measurable increase or decrease in ecological health indicated by the score. When taking relative abundance into account, the average QMCI has increased since the baseline survey, though no notable increases have occurred since the 2014 (Year 1) survey, with scores indicating all sites have been of "poor" or "fair" health.

While there has been a shift in community composition over time, ultimately the taxa found have remained the typically "pollution-tolerant" taxa, going from communities dominated by true-flies in the baseline survey and caddisflies in the 2014 survey, to communities dominated by crustaceans in the 2017 and 2020 surveys.

Analysis of the composition of species at reference versus rehabilitation sites showed a small number of taxa differ in abundance between the treatments. However, the relationship was weak and suggested that, overall, the communities found in each survey remained relatively similar between reference and rehabilitation sites.

While a number of taxa, such as ceratopogonid larvae (biting midges), the non-biting midges *Chironomus* and Tanypodinae, Cladocera (water fleas) and Collembola (springtails), found in previous surveys were not found in this survey, those absent taxa are not considered particularly "sensitive" taxa (i.e. intolerant of polluted waterways). Furthermore, these taxa were only rarely encountered in previous surveys, and therefore may be present but were not collected in this survey.

It is important to note that macroinvertebrate communities can be variable through time and are sensitive to disturbances. As there have been no discernible differences in community between rehabilitation and reference sites, it is unlikely that the community differences detected are entirely as a direct result of rehabilitation works.

In this survey (2020), there were no substantial differences in community between reference and rehabilitation sites, suggesting that the shift in macroinvertebrate community was consistent with changes throughout the mid-reaches of the river, rather than being directly attributable to improvements made to habitat from rehabilitation works.

Further analysis of the data may reveal an insight into the factors influencing the macroinvertebrate community. The shift in community could be as a result of several factors, including changes to the habitat available, water chemistry attributes, and general conditions caused by the time of year and the weather preceding the survey. In addition, more localised point-source events via the stormwater network may be a greater determinant of community composition.

5.4 Fish communities

The fish community found in each survey and between rehabilitation and reference sites has been variable, both in total abundance and species richness.

A comparable number of fish was caught in this survey and the previous (2017) survey – both of which were significantly higher numbers than had been caught in the prior two surveys (2013 and 2014).

Of note are the higher number of bluegill bullies caught in this and the 2017 survey, with bluegill bullies being found at all but two sites in each of the latest surveys, and in very high numbers at some sites. While found in relatively low numbers at some sites, bluegill bullies appear to be establishing well across both rehabilitation and reference sites and are particularly prevalent where their preferred riffle habitat is more readily available.

While several species caught in previous surveys were not caught in this survey (lamprey, torrentfish and common smelt), the former two species are relatively rare and often only occur in very low densities within a waterway. Furthermore, they are known to not be typically easy to catch using electric fishing methods.

While a clear trend in the number of fish and number of species present at each site has not yet arisen, there is some evidence that the total population of fish in the river has increased, particularly at rehabilitation sites. Fish caught were also of varying sizes (seen particularly with bully and eel species), suggesting that in addition to recolonisation by species to sites, recruitment may also be occurring.

5.5 Current successes and limitations of rehabilitation works

Riparian and in-stream habitat conditions have been improved at the rehabilitation sites within the Avon River Precinct. These improvements have increased habitat diversity and availability for aquatic fauna. However, the ecological condition of the river appears to have remained of “poor” to “fair” health when considering the macroinvertebrate communities found (as indicated by MCI and QMCI scores). There are likely a number of limiting factors contributing to this, as discussed below.

Habitat

The works undertaken to construct riffles and wetland floodplains, in addition to riparian planting, have become further established and thus increased available habitat to both fish and macroinvertebrate fauna. Heterogeneity of substrate and in-stream habitat is incredibly important for aquatic fauna, with variety providing diverse options for refuge, feeding and breeding habitat. Many macroinvertebrate species require cobbles clear of algae and macrophytes as habitat and for laying eggs, while fish species such as bullies use stable boulders as breeding habitat. In general, in-stream conditions between rehabilitation and reference sites have remained relatively similar, although there were some noticeable differences between 2013 and 2014 measurements.

Several key differences between reference and rehabilitation sites have arisen from data collected in this survey, including trends of shallower sediment, lower overall proportion of sediment cover at rehabilitation sites, and larger substrate size at rehabilitation sites. Reduced sediment levels and larger substrate size suggest that the effects of rehabilitation works, such as the removal of sediment from the stream bed, have had sustained positive effects on in-stream conditions, reflected in some changes observed in the faunal communities found. However, the differences are subtle.

The substrate observed in this and previous surveys is, in general, still relatively homogenous and of smaller size, dominated by gravels and small cobbles, with a lack of larger cobbles and boulders. This lack of larger substrates limits the availability of suitable habitat for a wider range of species.

Furthermore, additional habitat placed during the rehabilitation works (i.e. fish “hotels”) were unlikely to be useable at the time of this survey, due to low water levels (where the PVC pipes were not submerged by surface water. This was also observed in the three-years post-rehabilitation monitoring (Boffa Miskell 2017). These fish habitats may be inhabitable during higher water levels, however, were not during “dry” summer and autumn baseflows.

It is probable that the riparian wetlands and vegetation provide an improved buffer to urban runoff into the river. Incorporating analysis of water chemistry measures, such as dissolved metals, nutrient levels and other common urban inputs into waterways, could provide a more complete understanding as to the influence of the rehabilitation works on stream health, and in turn, the faunal communities within it.

Fauna

There have been incremental changes to the faunal communities found at ARP sites since the first survey in 2013, which may be in response to the rehabilitation works. Larger populations of fish, particularly at rehabilitation sites, have been observed in the 2017 and 2020 surveys. Of note is the significant increase in the number of bluegill bullies present.

While not all species found in the previous surveys were caught in the 2020 survey, those species (common smelt, torrentfish and lamprey) have only ever been caught in low numbers. It is likely that their populations remain relatively small and the likelihood of capture is also low.

Other species were found in high numbers and fish were of varying sizes, suggesting recolonisation and recruitment continues to occur. Should the reduced sediment levels be sustained, and habitat such as undercut banks and riffles remain, or indeed become more, available, increased population sizes, and recruitment by ‘new’ species is likely to continue.

A shift in the macroinvertebrate community has been observed since the baseline survey in 2013, where crustaceans such as *Paracalliope* have become more prevalent, while the proportion of EPT taxa (here only made up by caddisflies) in the community has decreased. No trends of either decline or improvement in water quality, as indicated by MCI and QMCI scores, has become apparent, despite the shift in community composition.

Colonisation of the river by new macroinvertebrate taxa has not been apparent from any prior surveys, and nor does it seem noticeable from this survey (2020). The limitations that have contributed to this are likely to be complex. For example, the in-stream changes may not have been substantial enough, or focused on species-specific requirements, to improve habitat for macroinvertebrate taxa. Aquatic insect colonisation via aerial colonisation from other waterways may also be limited for a variety of reasons. Colonisation by way of aerial dispersal of adult insects with winged adult life stages, such as EPT taxa, is likely more difficult in the urban environment where cross-catchment dispersal paths may be disrupted by the general urban environment (i.e. road crossings, buildings etc.). A further barrier to recolonisation is a general lack of source populations by taxa, such as mayflies and stoneflies, which are present in only a few streams or catchments in the wider Christchurch area (Boffa Miskell 2017; Blakely et al. 2006), though are not well connected to the Avon River catchment.

The life-histories of aquatic fauna – both fish and macroinvertebrate species – may be slowing the rate of colonisation and recruitment. Most fish found in the Avon River (all except upland bullies) are migratory and spend at least some portion of their life cycle at sea, returning to freshwater to feed and breed (except eels). Preferable habitat for species like torrentfish, which as the name suggests like very fast-flowing habitat, is not as prevalent as is likely needed to provide sufficient habitat to support a sizeable population.

It is also probable that the periodic clearing of macrophytes and debris from the river disrupts the fish and macroinvertebrate communities and may impact the ability of populations to establish and sustain sufficient numbers to maintain viable populations. Some fish species, such as bluegill bullies, were commonly caught in areas of dense macrophyte, and clearing the plant matter can disrupt the rivers' substrate, redistribute fine sediments bound up in the macrophyte beds, and disrupt interstitial spaces by turning cobbles which fish and macroinvertebrates would use as habitat.

As was discussed in the three-years' post-rehabilitation survey report (Boffa Miskell 2017), there is a high likelihood that fauna get caught in the macrophyte when it is cleared, leading to some mortality of fish. Reviewing the frequency, timing and general methods of macrophyte clearance would be of benefit. Targeting problematic areas and leaving macrophytes and debris where they are not likely to cause flooding problems would help to diversify habitat available for both macroinvertebrates and fish.

6.0 Conclusions

The Avon River Precinct rehabilitation works aimed to return the Avon River to a more "natural" state, as well as improve ecological health and water quality in the river. The riparian and in-stream condition of the river, in particular, has been subtly improved from these works, creating a variety of both terrestrial and aquatic habitats. Riparian plantings are now of a size that provide bank stabilisation, as well as overhanging the waterway providing shading for the stream and cover for aquatic fauna.

These habitat improvements are being reflected in the faunal communities found in the Avon River. Bluegill bully populations have been found at all but one site in the four surveys to date, including at all rehabilitation sites (note that bluegill bullies were not detected at Rehabilitation Site 1 in 2020), and in high abundances. The macroinvertebrate community response is less evident, with caddisfly abundance in this (2020) survey being similar to that of the baseline survey in 2013. Routine macrophyte clearance may have a large enough influence on the macroinvertebrate community that overall improvement in the community composition may take longer to show. As monitoring continues, a more evident trend in macroinvertebrate community changes may arise.

Additional rehabilitation works, which could further enhance ecological improvements within the ARP could include:

- Refinement and changes to the macrophyte and debris management regime;
- Addition of materials such as boulders and logs to increase and diversify available habitat; and
- Multi-faceted approach to stormwater management, to reduce the inputs of sediments and contaminants to the river.

While riparian and in-stream habitat changes are more immediately obvious, ecological gains are likely to take longer to become evident. Recovery and establishment of fauna in the Avon River is ongoing, though is limited by the proximity of source populations of taxa not already in the catchment. As habitat conditions continue to improve in the catchment, species such as bluegill bullies will continue to establish and recolonise the precinct. A single torrentfish was found at Rehabilitation Site 4: Victoria Square in 2017. This species has not been found in other surveys and is not regularly recorded in the Avon River. Torrentfish habitat (fast-flowing water with emergent boulders) is uncommon or absent from much of the river. Macroinvertebrate taxa may be slower to show changes in community composition, given limitations in dispersal ability from the wider Christchurch area and limited source populations of insect taxa that are not already present in the Avon River catchment (e.g. mayflies).

Ongoing management and continuation of rehabilitation work is likely necessary to continue to sustain and further these gains. Nevertheless, at this stage, the ecological improvements observed at the ARP sites indicate the rehabilitation works have had an overall positive impact. It will be important to continue to monitor and limit fine sediment inputs as these are contributors of changes / trends seen in declining embeddedness and compactness at rehabilitation sites.

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Appendix 1: Protocol 2 (P3), Harding et al., 2009

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

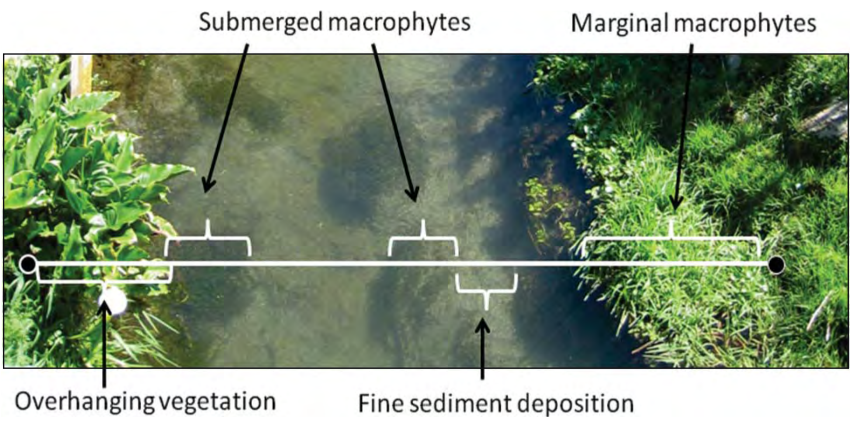
1. This assessment is made across the bankfull extent of the stream; it includes lower banks, any dry river bed and the wetted width of the stream.
2. Measure six cross-sections including two riffles, two runs and two pools. These cross-sections should be a subset of those used in the morphology and 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.



Example of a partially completed P3c field form

Site name	Okeover Stm	Site code	Ok 4
Assessor	JSH	Date	10 March 2008

Riffle 1

Cross-section	1	2	3	4	5	6	7	8	9	10
Substrate size	25	10	62	1	12	15	·8	0.5	silt	silt
Embeddedness	2	3	2	1	2	3	2	1	1	1
Compactness	3									
Depositional & scouring (cm)	5 cm									
Macrophytes (cm)	0									
Algae (cm)	100									
Leaf packs (cm)	5									
Woody debris (cm)	10									
Large boulders & log jams (count)	3									
Bank cover (m)	Left bank	0	Right bank	2m						

Riffle 2

Cross-section	1	2	3	4	5	6	7	8	9	10
Substrate size	35	silt	20	17	1	57	silt	2	5	12
Embeddedness	3	1	3	2	1	3	1	1	1	2
Compactness	4									
Depositional & scouring (cm)	0 cm									
Macrophytes (cm)	0									
Algae (cm)	95									
Leaf packs (cm)	12									
Woody debris (cm)	15									
Large boulders & log jams (count)	2									
Bank cover (m)	Left bank	1	Right bank	2.7m						

Run 1

Cross-section	1	2	3	4	5	6	7	8	9	10
Substrate size	silt	17	0.5	3	36	4	6	11	2	16
Embeddedness	1	3	1	1	4	1	1	2	1	2
Compactness	3									
Depositional & scouring (cm)	12 + 5									
Macrophytes (cm)	23									
Algae (cm)	80									
Leaf packs (cm)	0									
Woody debris (cm)	0									
Large boulders & log jams (count)	1									
Bank cover (m)	Left bank	1.3 m	Right bank	3.7m						

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).

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				

Appendix 2: Sediment Assessment Method 2 (SAM2), Clapcott et al., 2011

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

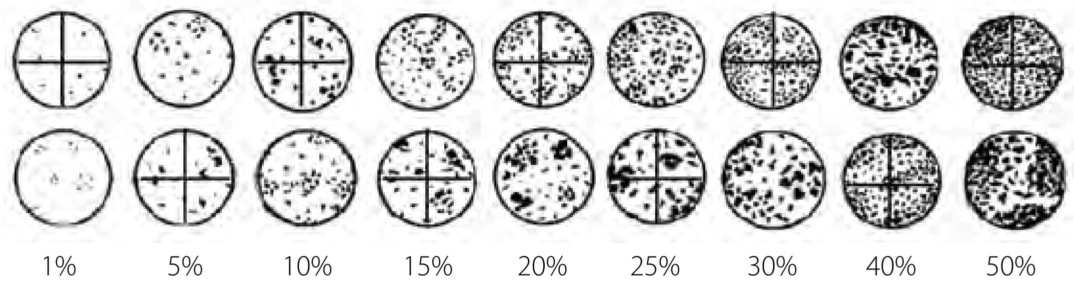
- Locate five random transects along the run.
- View the streambed at four randomly determined locations across each transect, starting at the downstream transect.
- Estimate the fine sediment cover in each quadrat of the underwater viewer in increments (1, 5, 10, 15, 20 …100%).
- Record results in the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

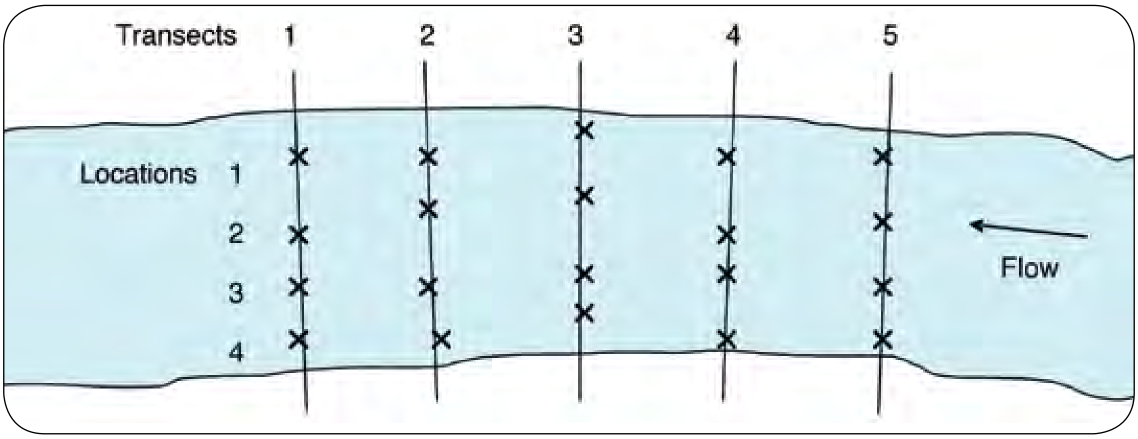
% sediment	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
Location 1	Q1	Q2								
	Q3	Q4								
Location 2										
Location 3										
Location 4										

Useful images

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



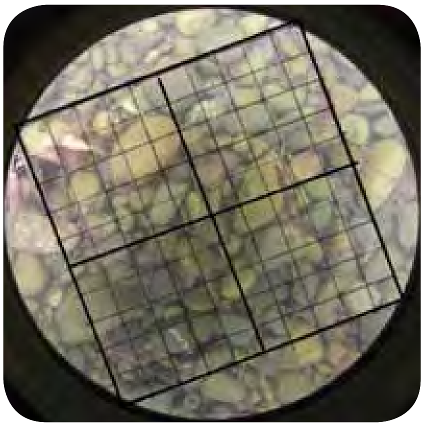
An example of viewer locations (x) for the in-stream visual assessment of sediment.



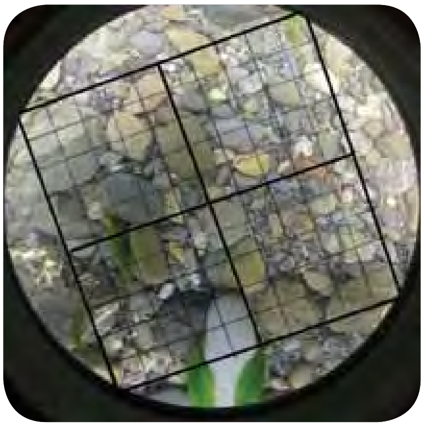
Real examples of percent cover of sediment on the streambed as seen through an underwater viewer.

1%

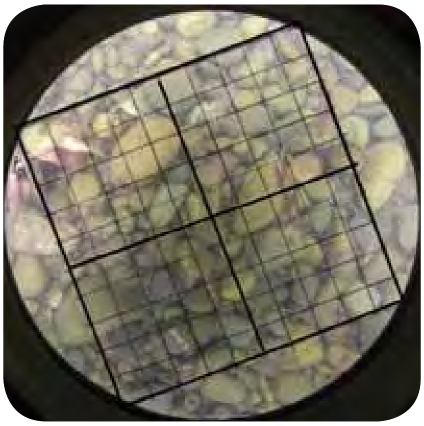
1%



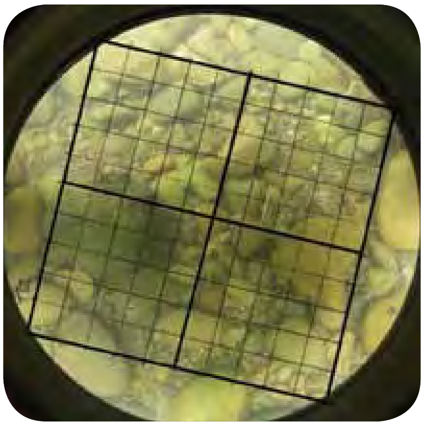
5%



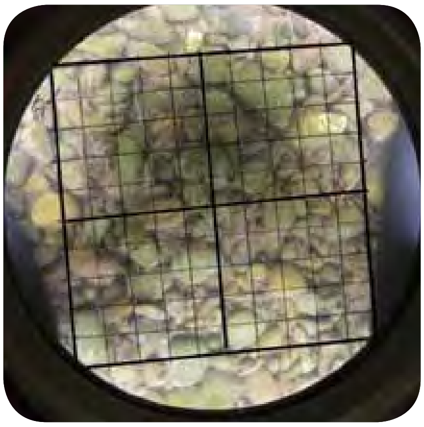
5%



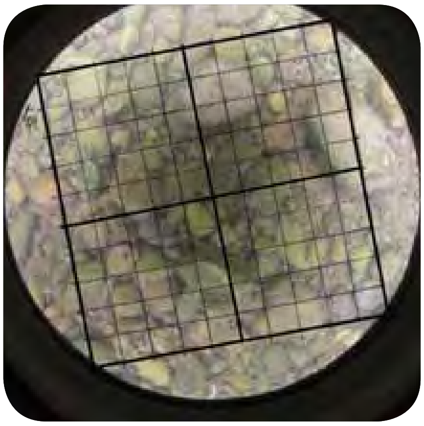
10%



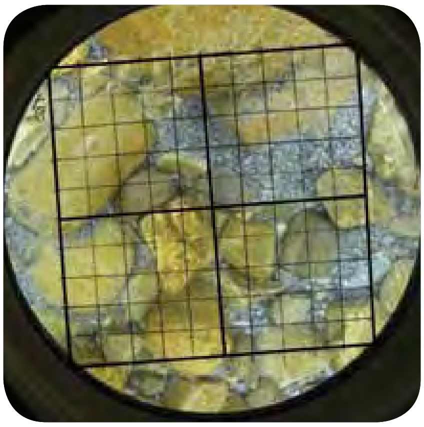
10%



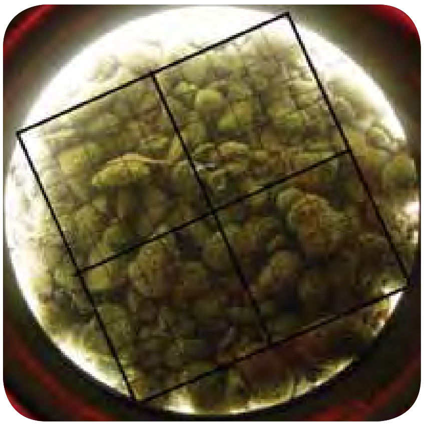
15%



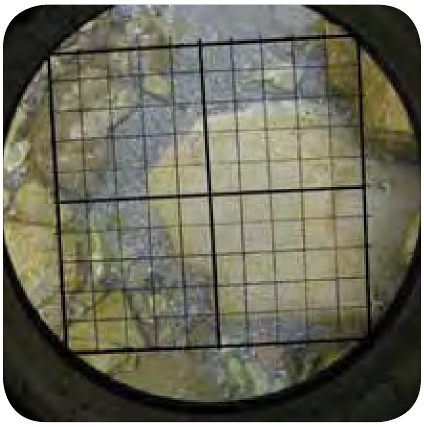
15%



20%

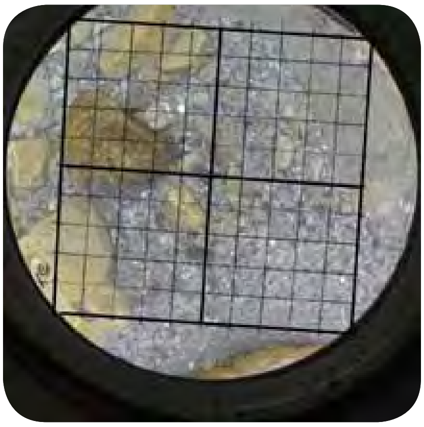


20%

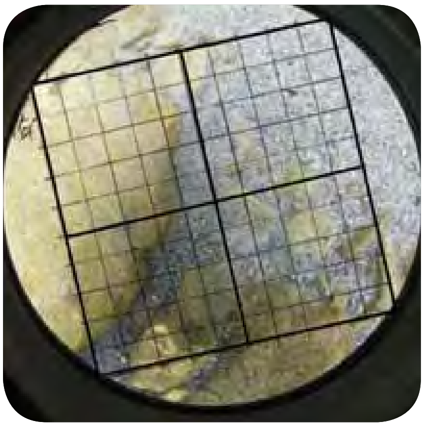


25%

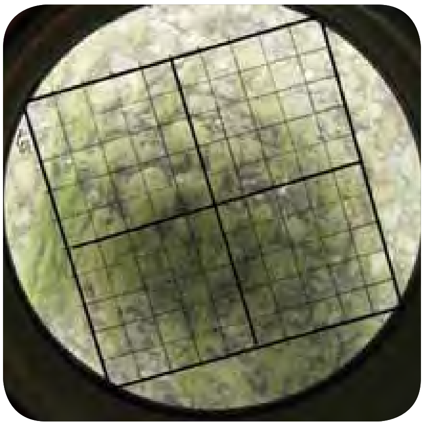
30%



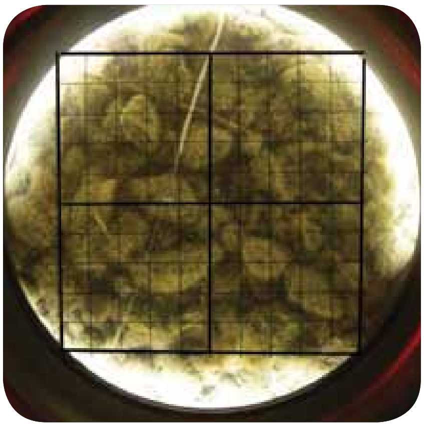
40%



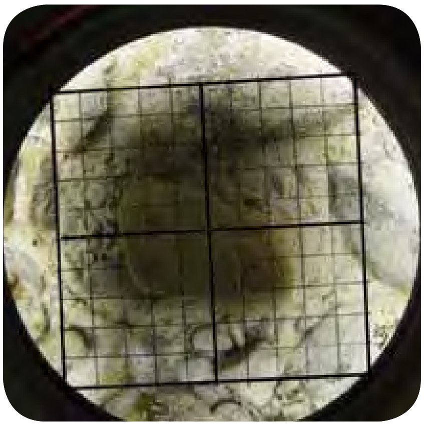
50%



90%



100%



Appendix 3: Sediment Assessment Method 6 (SAM6), Clapcott et al., 2011

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					

Appendix 4: SIMPER & ANOSIM results - macroinvertebrates

SIMPER
Similarity Percentages - species contributions

Two-Way Analysis

Data worksheet
Name: Macroinvertebrates_sqrt
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray-Curtis similarity
Cut off for low contributions: 70.00%

Factor Groups

Sample	Year x Treatment
2013 Ref 1	2013 x Ref
2013 Ref 2	2013 x Ref
2013 Ref 3	2013 x Ref
2013 Rehab 1	2013 x Rehab
2013 Rehab 2	2013 x Rehab
2013 Rehab 3	2013 x Rehab
2013 Rehab 4	2013 x Rehab
2013 Rehab 5	2013 x Rehab
2014 Ref 1	2014 x Ref
2014 Ref 2	2014 x Ref
2014 Ref 3	2014 x Ref
2014 Rehab 1	2014 x Rehab
2014 Rehab 2	2014 x Rehab
2014 Rehab 3	2014 x Rehab
2014 Rehab 4	2014 x Rehab
2014 Rehab 5	2014 x Rehab
2017 Ref 1	2017 x Ref
2017 Ref 2	2017 x Ref
2017 Ref 3	2017 x Ref
2017 Rehab 1	2017 x Rehab
2017 Rehab 2	2017 x Rehab
2017 Rehab 3	2017 x Rehab
2017 Rehab 4	2017 x Rehab
2017 Rehab 5	2017 x Rehab
2020 Ref1	2020 x Ref
2020 Ref2	2020 x Ref
2020 Ref3	2020 x Ref
2020 Rehab1	2020 x Rehab
2020 Rehab2	2020 x Rehab
2020 Rehab3	2020 x Rehab
2020 Rehab4	2020 x Rehab
2020 Rehab5	2020 x Rehab

Examines Year groups
(across all Treatment groups)
Group 2013
Average similarity: 70.42

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Orthocladiinae	8.39	12.17	3.03	17.28	17.28
Oligochaeta	8.01	11.87	6.7	16.86	34.13
Potamopyrgus	6.9	11.09	3.96	15.75	49.88
Paracalliope	9.6	10.93	3.33	15.52	65.41
Tanytarsini	2.22	3.14	3.14	4.46	69.87
Ostracoda	2.7	3.1	5.79	4.4	74.27

Group 2014
Average similarity: 64.26

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pycnocentrodes	8.95	7.86	1.32	12.24	12.24
Hudsonema	7.4	7.09	2.62	11.03	23.27
Potamopyrgus	7.53	6.98	1.75	10.87	34.13
Paracalliope	8.69	6.68	1.89	10.39	44.52
Ostracoda	6.87	5.46	2.16	8.49	53.02
Orthocladiinae	5.3	4.13	2.06	6.43	59.44
Physella (Physa)	4.19	4.07	3.25	6.33	65.77
Oligochaeta	4.36	3.91	1.93	6.08	71.86

Group 2017
Average similarity: 71.32

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Paracalliope	18.41	18.47	6.85	25.9	25.9
Potamopyrgus	5.78	6.93	4.14	9.72	35.61
Oligochaeta	5.52	5.11	4.34	7.17	42.78
Oxyethira	3.93	4.68	4.25	6.56	49.34
Pycnocentrodes	6.28	4.23	1.41	5.93	55.27
Physella (Physa)	4.09	3.96	5.25	5.55	60.82
Hudsonema	4.77	3.41	2.02	4.79	65.61
Orthocladiinae	3.4	3.39	3.07	4.76	70.37

Group 2020
Average similarity: 73.67

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Paracalliope	23.31	24.11	11.06	32.72	32.72
Potamopyrgus	7.78	6.56	2.44	8.9	41.63
Tanytarsini	6.88	6.39	3.12	8.67	50.3
Ostracoda	7.32	6.38	2.19	8.66	58.96
Sphaeriidae	6.48	5.95	8.52	8.08	67.05
Stratiomyidae	6.02	4.3	1.24	5.84	72.88

Groups 2013 & 2014
Average dissimilarity = 44.57

	Group 2013	Group 201				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Pycnocentrodes	3.65	8.95	5.26	1.42	11.8	11.8
Hudsonema	1.48	7.4	4.17	2.07	9.36	21.16
Paracalliope	9.6	8.69	3.86	1.35	8.67	29.83
Ostracoda	2.7	6.87	3.23	1.17	7.25	37.09
Orthocladiinae	8.39	5.3	3.12	1.33	7	44.09
Tanytarsini	2.22	6.16	2.97	0.73	6.67	50.75
Oligochaeta	8.01	4.36	2.69	1.93	6.03	56.79
Potamopyrgus	6.9	7.53	2.22	1.56	4.98	61.77
Physella (Physa)	1.46	4.19	2.04	1.49	4.57	66.34
Oxyethira	0.63	2.82	1.69	1.93	3.79	70.13

Groups 2013 & 2017
Average dissimilarity = 40.80

	Group 2013	Group 201				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	9.6	18.41	6.14	1.42	15.04	15.04
Orthocladiinae	8.39	3.4	4.48	1.27	10.99	26.02
Pycnocentrodes	3.65	6.28	3.37	1.08	8.27	34.29
Oxyethira	0.63	3.93	2.59	2.46	6.36	40.65
Oligochaeta	8.01	5.52	2.54	1.4	6.22	46.87
Hudsonema	1.48	4.77	2.08	1.35	5.09	51.96
Potamopyrgus	6.9	5.78	1.98	1.29	4.85	56.81
Ostracoda	2.7	3.57	1.55	1.22	3.8	60.61
Physella (Physa)	1.46	4.09	1.54	1.16	3.77	64.39
Tanypodinae	1.65	0.08	1.27	1.36	3.12	67.5
Playthelminthes	1.36	3	1.19	1.36	2.91	70.41

Groups 2014 & 2017
Average dissimilarity = 38.58

	Group 2014	Group 201				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	8.69	18.41	5.75	1.31	14.9	14.9
Pycnocentrodes	8.95	6.28	4.39	1.25	11.39	26.29
Ostracoda	6.87	3.57	2.9	1.36	7.51	33.8
Tanytarsini	6.16	3.35	2.71	0.71	7.01	40.81
Potamopyrgus	7.53	5.78	2.68	1.76	6.95	47.76
Hudsonema	7.4	4.77	2.25	1.41	5.83	53.6
Orthocladiinae	5.3	3.4	2.07	1.02	5.36	58.96
Physella (Physa)	4.19	4.09	1.56	1.19	4.06	63.01
Oligochaeta	4.36	5.52	1.23	1.42	3.19	66.2
Lymnaeidae	1.52	0.27	1.2	1.06	3.12	69.32
Sphaeriidae	1.66	2.94	1.04	1.57	2.7	72.03

Groups 2013 & 2020
Average dissimilarity = 54.66

	Group 2013	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	9.6	23.31	9.59	2.43	17.54	17.54
Orthocladiinae	8.39	0.61	5.59	2.18	10.23	27.76
Oligochaeta	8.01	0.87	4.81	2.57	8.79	36.56
Stratiomyidae	0	6.02	4.06	1.89	7.42	43.98
Ostracoda	2.7	7.32	3.43	1.61	6.27	50.25
Tanytarsini	2.22	6.88	3.29	2.48	6.02	56.27
Sphaeriidae	1.89	6.48	3.23	2.19	5.9	62.17
Potamopyrgus	6.9	7.78	2.23	1.6	4.08	66.25
Oxyethira	0.63	3.15	2.06	1.27	3.77	70.02

Groups 2014 & 2020
Average dissimilarity = 46.95

	Group 2014	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	8.69	23.31	8.58	2.24	18.27	18.27
Pycnocentrodes	8.95	4.41	4.26	1.36	9.07	27.34
Stratiomyidae	0.06	6.02	3.5	1.88	7.46	34.79
Tanytarsini	6.16	6.88	3.02	1.33	6.43	41.22
Sphaeriidae	1.66	6.48	2.99	2.1	6.38	47.6
Orthocladiinae	5.3	0.61	2.99	1.58	6.37	53.96
Oligochaeta	4.36	0.87	2.49	2.03	5.31	59.27
Potamopyrgus	7.53	7.78	2.39	1.55	5.09	64.36
Ostracoda	6.87	7.32	2.3	1.22	4.91	69.27
Hudsonema	7.4	3.69	2.23	1.13	4.75	74.02

Groups 2017 & 2020
Average dissimilarity = 40.31

	Group 2017	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	18.41	23.31	5.45	1.86	13.51	13.51
Stratiomyidae	0	6.02	3.68	1.84	9.12	22.63
Ostracoda	3.57	7.32	3.24	1.54	8.03	30.66
Oligochaeta	5.52	0.87	2.95	2.43	7.33	37.99
Tanytarsini	3.35	6.88	2.69	2.11	6.68	44.67
Sphaeriidae	2.94	6.48	2.67	1.69	6.62	51.29
Pycnocentrodes	6.28	4.41	2.45	1.06	6.07	57.36
Potamopyrgus	5.78	7.78	2.2	1.15	5.45	62.81
Orthocladiinae	3.4	0.61	1.92	2.37	4.76	67.57
Hudsonema	4.77	3.69	1.55	1.38	3.84	71.41

Examines Treatment groups
(across all Year groups)
Group Ref

Average similarity: 68.06

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Paracalliope	16.08	13.9	1.83	20.42	20.42
Oligochaeta	5.42	6.66	1.23	9.79	30.21
Hudsonema	6	5.34	1.3	7.84	38.05
Potamopyrgus	5.11	4.84	2.34	7.11	45.15
Tanytarsini	4.94	4.67	2.26	6.87	52.02
Pycnocentrodes	5.55	4.49	1.61	6.6	58.62
Orthocladiinae	3.23	4.13	1.23	6.06	64.68
Ostracoda	5.14	4.09	2.26	6.01	70.69

Group Rehab
Average similarity: 70.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Paracalliope	14.36	15.39	2.09	21.84	21.84
Potamopyrgus	8.13	8.81	2.78	12.5	34.34
Orthocladiinae	5.14	5.16	0.95	7.32	41.66
Oligochaeta	4.25	4.79	1.13	6.8	48.46
Pycnocentrodes	5.98	4.56	1.01	6.47	54.93
Ostracoda	5.1	4.46	1.63	6.33	61.26
Physella (Physa)	3.69	3.68	3.22	5.22	66.48
Tanytarsini	4.48	3.67	1.79	5.21	71.69

Groups Ref & Rehab
Average dissimilarity = 33.64

	Group Ref	Group Reha				
Species	Av.Abund	Av.Abunc	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope	16.08	14.36	4.24	1.3	12.6	12.6
Pycnocentrodes	5.55	5.98	3.43	1.35	10.18	22.79
Potamopyrgus	5.11	8.13	2.72	1.41	8.09	30.87
Hudsonema	6	3.34	2.22	1.56	6.6	37.47
Ostracoda	5.14	5.1	2.07	1.19	6.16	43.62
Orthocladiinae	3.23	5.14	2.05	0.83	6.11	49.73
Tanytarsini	4.94	4.48	1.9	0.88	5.65	55.38
Oligochaeta	5.42	4.25	1.53	1.07	4.54	59.92
Physella (Physa)	3.08	3.69	1.41	1.31	4.19	64.11
Sphaeriidae	4.07	2.74	1.39	1.35	4.14	68.25
Oxyethira	1.81	3.13	1.1	1.14	3.28	71.52

ANOSIM
Analysis of Similarities

Two-Way Crossed - AxB

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All

Factors

Place	Name	Type	Levels
A	Year	Unordered	4
B	Treatment	Unordered	2

Year levels
2013
2014
2017
2020

Treatment levels
Ref
Rehab

Tests for differences between unordered Year groups
(across all Treatment groups)
Global Test
Sample statistic (Average R): 0.737
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutatic	Actual Permutatic	Number >= Observed
2013, 2014	0.776	0.2	1260	999	1
2013, 2017	0.787	0.1	1260	999	0
2013, 2020	0.953	0.1	1260	999	0
2014, 2017	0.381	0.5	1260	999	4
2014, 2020	0.756	0.2	1260	999	1
2017, 2020	0.78	0.2	1260	999	1

Tests for differences between unordered Treatment groups
(across all Year groups)
Global Test
Sample statistic (Average R): 0.267
Significance level of sample statistic: 1.1%
Number of permutations: 999 (Random sample from 9834496)
Number of permuted statistics greater than or equal to Average R: 10

Outputs
Plot: Graph5
Plot: Graph6
Worksheet: Resem2
Worksheet: Resem3

Appendix 5: SIMPER & ANOSIM results – fish

SIMPER
Similarity Percentages - species contributions

Two-Way Analysis

Data worksheet
Name: Fish_sqrt
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray-Curtis similarity
Cut off for low contributions: 70.00%

Factor Groups

Sample	Treatment x Year
2013 Ref 1	Ref x 2013
2013 Ref 2	Ref x 2013
2013 Ref 3	Ref x 2013
2014 Ref 1	Ref x 2014
2014 Ref 2	Ref x 2014
2014 Ref 3	Ref x 2014
2017 Ref 1	Ref x 2017
2017 Ref 2	Ref x 2017
2017 Ref 3	Ref x 2017
2020 Ref 1	Ref x 2020
2020 Ref 2	Ref x 2020
2020 Ref 3	Ref x 2020
2013 Rehab 1	Rehab x 2013
2013 Rehab 2	Rehab x 2013
2013 Rehab 3	Rehab x 2013
2013 Rehab 4	Rehab x 2013
2013 Rehab 5	Rehab x 2013
2014 Rehab 1	Rehab x 2014
2014 Rehab 2	Rehab x 2014
2014 Rehab 3	Rehab x 2014
2014 Rehab 4	Rehab x 2014
2014 Rehab 5	Rehab x 2014
2017 Rehab 1	Rehab x 2017
2017 Rehab 2	Rehab x 2017
2017 Rehab 3	Rehab x 2017
2017 Rehab 4	Rehab x 2017
2017 Rehab 5	Rehab x 2017
2020 Rehab 1	Rehab x 2020
2020 Rehab 2	Rehab x 2020
2020 Rehab 3	Rehab x 2020
2020 Rehab 4	Rehab x 2020
2020 Rehab 5	Rehab x 2020

Examines Treatment groups
(across all Year groups)
Group Ref
Average similarity: 65.22

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Upland bully	3.87	17.38	1.73	26.65	26.65
Shortfin eel	2.45	12.6	1.52	19.32	45.97
Longfin eel	1.81	9.79	1.64	15.01	60.98
Common bully	2.5	8.58	1.06	13.16	74.14

Group Rehab
Average similarity: 67.18

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Common bully	4.17	16.64	2.31	24.76	24.76
Shortfin eel	2.53	9.9	1.4	14.74	39.5
Eel sp	2.45	9.43	1.61	14.03	53.54
Longfin eel	2.28	8.96	2.38	13.34	66.88
Bluegill bully	3.71	8.27	0.93	12.32	79.2

Groups Ref & Rehab
Average dissimilarity = 43.01

	Group Ref	Group Reh				
Species	Av.Abund	Av.Abunc	Av.Diss	Diss/SD	Contrib%	Cum.%
Bluegill bully	0.55	3.71	8.99	1.23	20.9	20.9
Common bully	2.5	4.17	8.21	1.29	19.1	40
Upland bully	3.87	2.78	6.43	1.09	14.94	54.94
Eel sp	1.24	2.45	4.74	1.17	11.03	65.97
Shortfin eel	2.45	2.53	3.89	1.15	9.05	75.02

Examines Year groups
(across all Treatment groups)
Group 2013
Average similarity: 62.76

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Shortfin eel	3.3	19.68	3.76	31.36	31.36
Eel sp	2	11.52	3.12	18.36	49.72
Common bully	2.49	10.81	1.49	17.22	66.94
Longfin eel	1.87	9.36	1.67	14.91	81.85

Group 2014
Average similarity: 68.85

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Common bully	3.62	18.26	1.9	26.52	26.52
Longfin eel	2	11.65	3.53	16.92	43.45
Shortfin eel	1.96	9.69	1.9	14.08	57.53

Upland bully	2.28	8.92	1.43	12.95	70.48

Group 2017
Average similarity: 71.68

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Upland bully	6.34	19.85	5.19	27.69	27.69
Common bully	4.16	10.14	1.88	14.14	41.83
Bluegill bully	3.21	9.8	1.36	13.67	55.5
Shortfin eel	2.91	8.19	1.99	11.43	66.93
Bully sp	2.34	7.09	2.06	9.9	76.83

Group 2020
Average similarity: 63.61

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Common bully	3.9	19.91	4.25	31.29	31.29
Eel sp	2.55	12.15	1.94	19.11	50.4
Longfin eel	2.03	9.21	2.75	14.49	64.89
Bluegill bully	4.03	9.05	0.74	14.23	79.12

Groups 2013 & 2014
Average dissimilarity = 39.70

	Group 2013	Group 2014				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Common bully	2.49	3.62	6.58	1.33	16.57	16.57
Upland bully	1.06	2.28	5.91	1.47	14.9	31.47
Shortfin eel	3.3	1.96	5.42	1.86	13.66	45.13
Bluegill bully	1.42	1.44	5.02	1.32	12.65	57.78
Eel sp	2	1.45	4.17	1.28	10.49	68.27
Giant bully	0.25	0.93	3.43	1.74	8.64	76.91

Groups 2013 & 2017
Average dissimilarity = 49.72

	Group 2013	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Upland bully	1.06	6.34	13.14	3.04	26.43	26.43
Bluegill bully	1.42	3.21	6.55	1.21	13.17	39.6
Common bully	2.49	4.16	6.42	1.2	12.91	52.51
Bully sp	0	2.34	5.76	2.24	11.58	64.09
Giant bully	0.25	1.64	3.83	1.69	7.69	71.79

Groups 2014 & 2017
Average dissimilarity = 38.89

	Group 2014	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Upland bully	2.28	6.34	9.51	1.58	24.44	24.44

Common bully	3.62	4.16	5.73	1.17	14.74	39.18
Bluegill bully	1.44	3.21	5.22	1.14	13.41	52.6
Bully sp	0.63	2.34	3.93	1.35	10.11	62.71
Eel sp	1.45	1.99	3.35	1.41	8.62	71.33

Groups 2013 & 2020
Average dissimilarity = 44.55

	Group 2013	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Bluegill bully	1.42	4.03	10.94	1.13	24.57	24.57
Upland bully	1.06	3.09	6.88	1.01	15.45	40.02
Shortfin eel	3.3	1.84	6.4	1.26	14.37	54.39
Common bully	2.49	3.9	6.24	1.27	14	68.39
Eel sp	2	2.55	3.53	1.89	7.92	76.31

Groups 2014 & 2020
Average dissimilarity = 39.70

	Group 2014	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Bluegill bully	1.44	4.03	9.79	1.2	24.66	24.66
Upland bully	2.28	3.09	7.97	1.08	20.08	44.75
Common bully	3.62	3.9	4.16	1.09	10.47	55.22
Eel sp	1.45	2.55	4.11	1.49	10.36	65.57
Shortfin eel	1.96	1.84	3.92	1.32	9.87	75.44

Groups 2017 & 2020
Average dissimilarity = 41.11

	Group 2017	Group 202(				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Upland bully	6.34	3.09	9.2	1.91	22.38	22.38
Bluegill bully	3.21	4.03	7.54	1.2	18.35	40.73
Bully sp	2.34	0	5.31	2.29	12.92	53.65
Common bully	4.16	3.9	4.43	1.49	10.78	64.43
Shortfin eel	2.91	1.84	3.73	1.25	9.08	73.51

ANOSIM
Analysis of Similarities

Two-Way Crossed - AxB

Resemblance worksheet
Name: Resem4
Data type: Similarity
Selection: All

Factors

Place	Name	Type	Levels
A	Treatment	Unordered	2
B	Year	Unordered	4

Treatment levels
Ref
Rehab

Year levels
2013
2014
2017
2020

Tests for differences between unordered Treatment groups
(across all Year groups)
Global Test
Sample statistic (Average R): 0.462
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 9834496)
Number of permuted statistics greater than or equal to Average R: 0

Tests for differences between unordered Year groups
(across all Treatment groups)
Global Test
Sample statistic (Average R): 0.417
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2013, 2014	0.323	0.8	1260	999	7
2013, 2017	0.734	0.2	1260	999	1
2013, 2020	0.331	3.2	1260	999	31
2014, 2017	0.513	0.3	1260	999	2
2014, 2020	0.241	3.1	1260	999	30
2017, 2020	0.427	0.4	1260	999	3

Outputs
Plot: Graph11
Plot: Graph12

About Boffa Miskell

Boffa Miskell is a leading New Zealand professional services consultancy with offices in Auckland, Hamilton, Tauranga, Wellington, Christchurch, Dunedin and Queenstown. We work with a wide range of local and international private and public sector clients in the areas of planning, urban design, landscape architecture, landscape planning, ecology, biosecurity, cultural heritage, graphics and mapping. Over the past four decades we have built a reputation for professionalism, innovation and excellence. During this time we have been associated with a significant number of projects that have shaped New Zealand's environment.

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