Aquatic Ecology of sites within the Heathcote, Estuary & Coastal, and Avon SMP catchments

Informing the Comprehensive Discharge Consent

Prepared for Christchurch City Council

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Boffa Miskell

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Cover photograph: Heathcote River / Ōpāwaho downstream of Barrington Street © Boffa Miskell, 2015

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EXECUTIVE SUMMARY

The Christchurch City Council (CCC) is currently developing an application for a comprehensive stormwater discharge consent to be submitted to Environment Canterbury. This consent will authorise the discharge of stormwater from all catchments under CCC's jurisdiction. This ecological study was commissioned as part of this work, to provide an ecological survey of numerous sites within the Heathcote, Estuary & Coastal, and Avon Stormwater Management Plan (SMP) catchments.

The CCC commissioned Boffa Miskell to conduct an aquatic ecology survey of sites within the Heathcote, Estuary & Coastal, and Avon SMP catchments in 2015. This survey was designed to describe the current ecological condition of these waterways, compare how these conditions may have changed over time, and identify areas with high or low ecological health to inform the development of waterway management strategies and the SMP.

Riparian and in-stream habitat conditions, and the macroinvertebrate and fish communities were surveyed in fifteen sites located throughout the Heathcote, Estuary & Coastal, and Avon SMP catchments. Surveys were conducted in February and March 2015.

The basic water quality parameters of pH, dissolved oxygen, conductivity and temperature were within ranges expected in a spring-fed urban environment during base flow conditions. Dissolved oxygen levels were generally above the minimum guideline recommended by the proposed Land and Water Regional Plan (pLWRP). In-stream and riparian conditions, although variable among sites, were generally degraded often with low substrate indexes (indicating stream bed substrates dominated by finer particles and generally lacking in boulders and large cobbles). Very little shading was present at many sites, and channels were modified with limited in-stream habitat heterogeneity. Macrophyte and filamentous algal cover was generally low and the majority of sites were below the pLWRP guidelines for urban spring-fed systems. This may be due to frequent macrophyte clearance operations conducted within the waterways for flooding mitigation.

The macroinvertebrate communities were dominated by taxa typical of lowland urban waterways, with only a few representatives from the pollution-sensitive or "clean-water" EPT taxa present. However, kōura (freshwater crayfish) and kākahi (freshwater mussel) shells, both "at risk, declining" species, were also found at some sites. The fish communities were depauperate, with species richness generally around four to five fish species present at a site. However, some sites supported "at risk, declining" native freshwater fish species, longfin eel, inanga, and bluegill bully.

This ecological assessment indicated that the waterways within the Heathcote, Estuary & Coastal, and Avon SMP catchments were generally of poor ecological health. Nevertheless, it is important to remember that sites did provide habitat for ecologically important native macroinvertebrate and fish species.

The findings of this work reiterate the need for a multi-faceted approach to catchment management, whereby areas of greatest ecological health need to be maintained through appropriate management activities. Some of the more degraded areas, with lower ecological health, may also be improved over time through more intensive management of stormwater and contaminated sediments, and enhancements of in-stream and riparian habitat. The feasibility of

fully restoring these habitats may be somewhat limited due to the irreversible effects of historic urban development and activities (e.g. retrofitting ‘open’ stormwater systems to provide treatment prior to discharging to the waterways, removal of impervious surface areas in the surrounding landscape, and removing legacy contaminants in sediments).

BACKGROUND

The Christchurch City Council (CCC) is currently developing an application for a comprehensive stormwater discharge consent to be submitted to Environment Canterbury. If approved, this consent will authorise the discharge of stormwater from all catchments under CCC's jurisdiction. This ecological study was commissioned as part of this work, to provide an ecological survey of the Heathcote, Estuary & Coastal, and Avon Stormwater Management Plan (SMP) catchments.

The Heathcote SMP catchment is around 100 km^2, containing Ōpāwaho / the Heathcote River, one of Christchurch's main spring-fed waterways. Historically, Ōpāwaho / the Heathcote River meandered through wetlands and swamps but has been extensively controlled to better convey floodwaters and channelized as a result of the surrounding rural and urban development. Ōpāwaho / the Heathcote River flows from Templeton, collecting a number of tributaries including its largest, the Cashmere Stream, and meanders around the base of the Port Hills from west to south-east, before discharging into Ihutai / the Avon-Heathcote Estuary.

The Avon SMP catchment is around 84 km2 and drains much of the north, north-western and central areas of Christchurch before discharging into the north of Ihutai / the Avon-Heathcote Estuary. Estuary Drain within Bexley Park was the only waterway within the Avon SMP catchment surveyed in this study. The remainder of the Avon SMP catchment was surveyed by Boffa Miskell in 2013 (Boffa Miskell 2014).

The Estuary & Coastal SMP catchment is a smaller catchment, located to the north-west of Ihutai / the Avon-Heathcote Estuary. This area was also once swampland but has been extensively drained via numerous drainage channels. The City Outfall Drain / Linwood Canal was the only waterway within the Estuary & Coastal SMP catchment surveyed in this study.

SCOPE

The CCC commissioned Boffa Miskell to conduct an aquatic ecology survey of waterways within the Heathcote, Estuary & Coastal, and Avon SMP catchments in 2015. This survey was designed to:

- Describe the current ecological condition of these waterways and how these may vary, spatially;
- Compare trends over time by assessing the current ecological condition against the results of a previous survey (EOS Ecology 2010); and
- Identify areas with high or low ecological health, to inform the development of waterway management strategies and the SMPs.

METHODS

Site locations

The CCC provided Boffa Miskell with northing and easting co-ordinates for 17 sites (shown in Appendix 1[1]), located throughout the Heathcote SMP catchment (15 sites), the Estuary & Coastal SMP catchment (1 site), and the Avon SMP catchment (1 site) (Figure 1). These sites covered a range of habitat types (including tidal) and locations within wadeable and non-wadeable reaches, including one or more sites on the following waterways:

- Heathcote SMP catchment
  - Ōpāwaho / the Heathcote River (10 sites);
  - Cashmere Brook (1 site);
  - Cashmere Stream (2 sites);
  - Steamwharf Stream (1 site);
  - Jacksons Creek (1 site);
- Estuary & Coastal SMP catchment
  - City Outfall Drain / Linwood Canal (1 site).
- Avon SMP catchment
  - Estuary Drain (1 site)

[1]After discussions with Dr Belinda Margetts (Waterways Ecologist, CCC), site 16 (Heathcote River at Ferrymead Bridge) was removed from the original survey site list, as this was an estuarine site and was not representative of the Heathcote catchment's freshwater environment.

The co-ordinates (northing and easting) of each site (as provided by the CCC to Boffa Miskell) were loaded into Avenza pdf maps using ArcGIS, and using a geo-referenced pdf map on an iPad, sites were easily and accurately located and navigated to in the field.

At each of the 17 sites, assessments of riparian and in-stream habitat (including periphyton and macrophyte) conditions and the macroinvertebrate and fish communities were conducted during base-flow conditions and following seven consecutive days of fine weather. All methods were in line with that detailed in the CCC Waterway Ecology Standard Sampling Methodology.

Site surveys were conducted between 11 February and 5 March 2015. A 50 m reach was marked out at each site, the habitat and macroinvertebrate community was assessed within the first 20 m (downstream end), while the fish community was assessed within the upper 30 m of the reach.

Sites 13 (Heathcote River: Catherine Street) and 14 (Heathcote River: Tunnel Road) were tidal, and were surveyed during, or as close to, low tide as possible.

Site numbering as provided by the CCC was used with site numbers generally increasing with direction downstream. That is, sites 4-14 were all within the Heathcote River, with 4 located at the uppermost Heathcote River site and 14 at the downstream Heathcote River site; sites 1 and 2 were within Cashmere Stream, with site 1 upstream and 2 downstream; site 17 was within the Estuary & Coastal SMP catchment, and site 18 was within the Avon SMP catchment.

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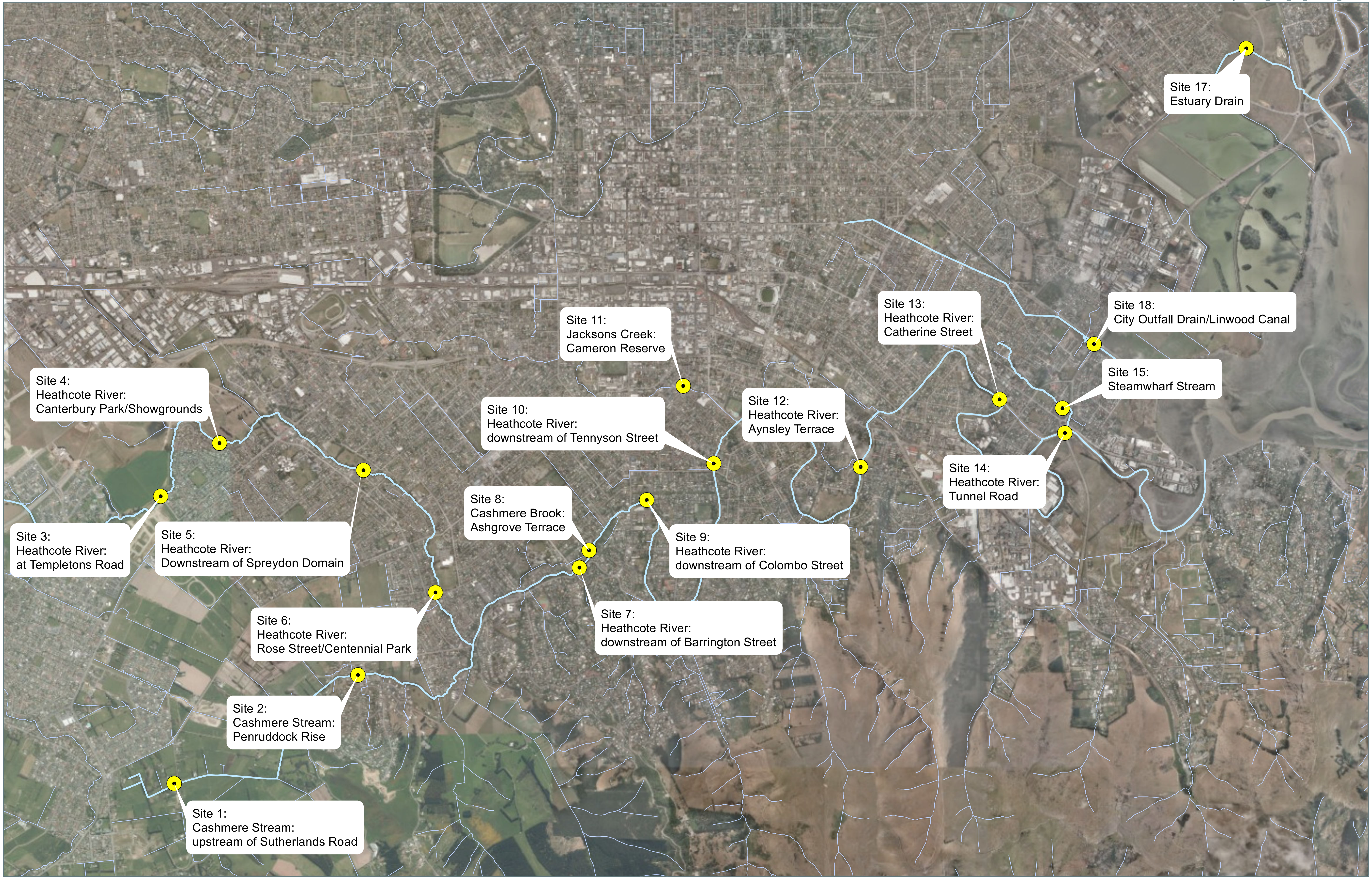

Boffa Miskell
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Data Sources:
Waterways data and aerial photograpgy sourced from CCC.
Projection: NZGD 2000 New Zealand Transverse Mercator

Legend
Sampling Sites

HEATHCOTE AND ESTUARY SMP CATCHMENTS

Figure 1 : Site Locations

Date: 29 June 2015 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

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Habitat conditions

A variety of riparian and in-stream habitat parameters were recorded at each site, either at the site scale (i.e. one measure for the entire study site), or across three transects located within each site (i.e. multiple measures across transects).

Water quality

At each site, spot measures of basic water chemistry (dissolved oxygen, pH, and specific conductivity) and water temperature were taken using handheld TPS WP-81 and TPS WP-82Y meters.

The percent composition of different flow habitats (i.e. riffle, run, or pool) was estimated for each site.

Three equally-spaced transects, spaced at 10 m intervals, were established across the waterway at each site, where the downstream most transect was approximately located at the co-ordinates provided in Appendix 1. Transects two and three were located 10 m and 20 m upstream of the first (transect one).

Water velocity was measured at each of the three transects, using a Seba Current Meter c/w counter and wading rods, where:

$$Velocity = (S * r.p.s) + C,$$

S = slope specific to the propeller used; *r.p.s* = revolutions per second as determined by the count meter; and *C* = constant.

Riparian and in-stream habitat

Total wetted width (m) was also recorded at each of the three transects, giving an average wetted width for each site. Canopy cover (%), bank erosion (%), extent of undercut bank (cm) and overhanging vegetation (cm) (if present), percent of bank with vegetation cover, bank slope (degrees), bank height (cm), type of bank material, types of riparian vegetation, and the surrounding land use were separately recorded on the true left (TL) and true right (TR) banks along each of these transects at each site.

Water depth (cm), soft sediment depth (cm), embeddedness (%), and substrate composition (%); depth (cm), percent cover, type (submerged or emergent), and dominant species of macrophytes present; percent cover and type of organic material (leaves, moss, coarse woody debris); and percent cover and type of periphyton were measured at five locations (TL bank, 25%, 50%, 75%, and TR bank) along each of the three transects at each site.

Embeddedness is a measure of the degree to which larger substrates are surrounded by fine particles, and therefore, an indication of the clogging of interstitial spaces.

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 five 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), boulders (256 – 4000 mm), and bedrock / concrete / artificial hard surfaces (> 4000 mm) (modified from Harding et al. 2009).

Photographs were also taken at each site.

Macroinvertebrate community

Macroinvertebrates (e.g., insects, snails and worms that live on the stream bed) can be extremely abundant in streams and are an important part of aquatic food webs and stream functioning. Macroinvertebrates vary widely in their tolerances to both physical and chemical conditions, and are therefore used regularly in biomonitoring, providing a long-term picture of the health of a waterway.

The macroinvertebrate community was assessed at each site within the same 20 m reach where riparian and in-stream habitat was surveyed. The macroinvertebrate community was sampled at each site on the same day that the habitat assessment was conducted (i.e. prior to habitat assessments, but after basic water chemistry and temperature parameters were measured).

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). That is, 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) so as to maximise the likelihood of collecting all macroinvertebrate taxa present at a site, including rare and habitat-specific taxa.

Macroinvertebrate samples were preserved, separately, in 70% ethanol prior to sending to Ryder Consulting, Dunedin, for identification and counting in accordance with protocol P3 (full count with subsampling option) of Stark et al (2001) (see Appendix 2 for further details on processing methods).

Fish community

The fish community was surveyed[2] within the upper 30 m of each site (i.e. immediately upstream of where the macroinvertebrate community and habitat assessments were made). This allowed habitat conditions, and macroinvertebrate and fish community to be conducted on the same day, but without disturbing fish present during the macroinvertebrate sampling. Each survey reach included the variety of habitats typically present in the reach being surveyed (e.g. stream margin, mid channel, undercut banks, macrophytes, silt, riffles, runs, pools). Survey reaches were divided into many subsections of approximately 2-3 m in length and electro-fished using a single pass with a Kainga EFM 300 backpack mounted electro-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 (fork length, mm) before being returned alive to the stream.

Five sites (sites 2, 13-15, and 18) were either too deep, or tidal, and non-wadeable and, therefore, electric fishing techniques were not safe, nor an appropriate method for sampling. A combination of baited fyke nets and Gee minnow traps were used at these sites. At each site, two fyke nets (baited with tinned cat food), and five Gee minnow traps (baited with Marmite) were set within the 30 m survey reach late in the afternoon and left overnight. The following

[2] Boffa Miskell holds: a Special Permit to *take* fish issued by the Ministry for Primary Industries pursuant to Section 97(1) of the Fisheries Act 1996; and approvals from the Department of Conservation and North Canterbury branch of Fish and Game to use an electric fishing machine under regulation 51 of the Freshwater Fisheries Regulations 1983 and Section 26ZR of the Conservation Act 1987.

morning, all fish captured were identified and measured (fork length, mm) before being returned alive to the stream.

Data analyses

Riparian and in-stream habitat assessments

Where parameters were measured at five locations across each of the transects (i.e. water depth, sediment depth, embeddedness, and macrophyte and periphyton cover), these were averaged to give a mean value for each transect.

A substrate index (SI) was calculated from the five replicate substrate composition measures taken along each transect. These values were then averaged, to give a mean SI for each transect.

The SI was calculated using the formula (modified from Harding et al. 2009):

SI = (0.03 x %silt / sand) + (0.04 x %gravel) + (0.05 x %pebble) + (0.06 x (%small cobble + %large cobble)) + (0.07 x %boulder)

The calculated SI can range between 3 and 7, where an SI of 3 indicated 100% silt / sand and an SI of 7 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, and smother food (algal) resources and macroinvertebrates inhabiting the waterway.

Wetted width was measured once at each of the three transects. These values were averaged to give a mean wetted width (m) for each site.

Changes in habitat over time

As part of the CCC's long term monitoring of Christchurch's waterways, EOS Ecology conducted a survey of 10 of the Heathcote SMP sites (Sites 1-2 and 4-11) in March 2010 (EOS Ecology 2010). This allowed a comparison to be made between some habitat conditions in 2010 (EOS Ecology 2010) and 2015 (this study). For those parameters where field methods were comparable across the two surveys, analyses of variance (ANOVA) were used to test for differences over time (parameters tested included, water depth, sediment depth, velocity, and substrate index). Analyses were conducted on average values for each transect, giving three measures of each response variable for each site, in 2010 and 2015.

Response variables were log transformed to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.0.2 (The R Foundation for Statistical Computing 2013).

Macroinvertebrate community

Biotic indices and stream health metrics

The following macroinvertebrate metrics were calculated from each kick-net sample, to provide an indication of stream health:

- **Total abundance** – the total number of individuals collected in the composite kick-net sample collected at each site. Macroinvertebrate abundance can be a good indicator of stream health, or ecological condition, because abundance tends to increase in the presence of organic enrichment, particularly for pollution-tolerant taxa (e.g. chironomid midge larvae and oligochaete worms).

- **Taxonomic richness** – the total number of macroinvertebrate taxa recorded from the composite kick-net sample 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 total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) from the composite kick-net sample collected at each site. These three insect orders (EPT) are generally sensitive to pollution and habitat degradation and therefore diversity of these insects provides 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 total number of EPT taxa excluding the family Hydroptilidae. The algal piercing caddisflies belonging to the family Hydroptilidae are generally considered more tolerant of degraded conditions than other EPT taxa. Excluding hydroptilid caddis from the EPT metric is a more conservative approach and more accurately represents the 'clean-water' EPT taxa.

- **%EPT richness** – the total abundance of macroinvertebrates that belong to the pollution-sensitive EPT orders, relative to the total abundance of all macroinvertebrates found in the composite kick-net collected at each site. High %EPT richness suggests high water quality.

- **%EPT richness (excl. hydroptilids)** – the percentage abundance of EPT taxa at each transect, excluding the more pollution-tolerant hydroptilid caddisflies.

- **Macroinvertebrate Community Index (MCI)** – this index is based on tolerance scores for individual macroinvertebrate taxa found in hard- or soft-bottomed streams (Stark 1985, Stark and Maxted 2007). These tolerance scores[3], which indicate a taxon's sensitivity to in-stream environmental conditions, are summed for the taxa present in a sample, and multiplied by 20 to give MCI values ranging from 0 – 200. Table 1 provides a summary of how MCI scores were used to evaluate stream health.

- **Quantitative Macroinvertebrate Community Index (QMCI)** – this is a variant of the MCI, which instead uses abundance data. The QMCI provides information about the dominance of pollution-sensitive species in hard- or soft-bottomed streams. Table 1 provides a summary of how QMCI scores were used to evaluate stream health.

[3] Hard- and soft-bottomed scores were used in this study. Hard-bottomed scores were used for sites 1, 4-7, and 9-10, while soft-bottomed scores were used for sites 2, 12-15, and 17-18.

Table 1. Interpretation of MCI and QMCI scores for hard- and 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 (hard- and soft-bottom scores) were developed primarily to assess the health of streams impacted by agricultural activities (e.g. organic enrichment) and should be interpreted with caution in relation to urban systems.

Sites were ranked from 1 (best) to 15 (worst) for the following biotic indices: taxonomic richness, EPT richness, %EPT richness, and QMCI scores. Other biotic indices were not included as many are derivatives of these key indices. These ranks (of the included biotic indices) were then summed to give an overall rank for each site, where 1 was the best site overall, and 15 was the worst site overall (based on the four biotic indices). This gave an indication of differing ecological conditions and values among sites and where each sat within the wider Heathcote, Estuary & Coastal, and Avon SMP catchments.

Once ranked, sites were grouped into one of three categories, where the top were classed as the "best" scoring sites, the next as "middle", and the bottom classed as the "worst" scoring sites. Sites that were ranked equally were classed in the same category.

Changes in community composition over time

Visual comparisons were made between taxonomic richness, EPT richness, and QMCI values calculated for 2010 (EOS Ecology 2010) and 2015 (this study); statistical analyses were not conducted as there was no replication within sites.

A non-metric multidimensional scaling (or NMDS) ordination[4], with 1000 random permutations, of abundance data was used to determine if the macroinvertebrate community found was similar between 2010 (EOS Ecology 2010) and 2015 (this study).

NMDS ordinations rank sites (i.e. Heathcote SMP catchment sites in 2010 and in 2015) 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 a 'site' can be presented on an x-y scatterplot to graphically show how similar (or dissimilar) the community was between 2010 and 2015. 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 2010 and 2015. 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

[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 years, 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 6.1.13 (Clarke and Warwick 2001).

Fish community

In order to account for the inevitable differences in areas sampled at each site, fish catches were converted into catch per unit effort (CPUE). Electric fishing data were converted to number of fish captured per 100 m^2 of stream surveyed; trapping data were presented as number of fish captured per trap, per night.

Qualitative comparisons were made between the fish community found at 5 sites in this study (2015) with the findings from previous surveys:

- Sites 6, 9, and 10 (Aquatic Ecology Limited 2012);
- Site 12 (Aquatic Ecology Limited 2005); and
- Site 17 (EOS Ecology 2013).

[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. sites 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.

RESULTS

Habitat conditions

Water quality

Specific conductivity

Conductivity, which is often used to indicate the level of pollutants in the water column, was variable within the Heathcote, Estuary & Coastal, and Avon SMP catchments (Figure 2). The highest conductivity recorded was in the Heathcote River at Tunnel Road (Site 14). This site was tidal, so the conductivity was likely a reflection of the saline influence at this site. All other sites ranged between 178 and 380 µS / cm. While these conductivities were not dissimilar to those recorded in some urban systems, they were generally higher than those recorded in the Avon River catchment during a similar aquatic ecology survey in 2013 (Boffa Miskell 2014).

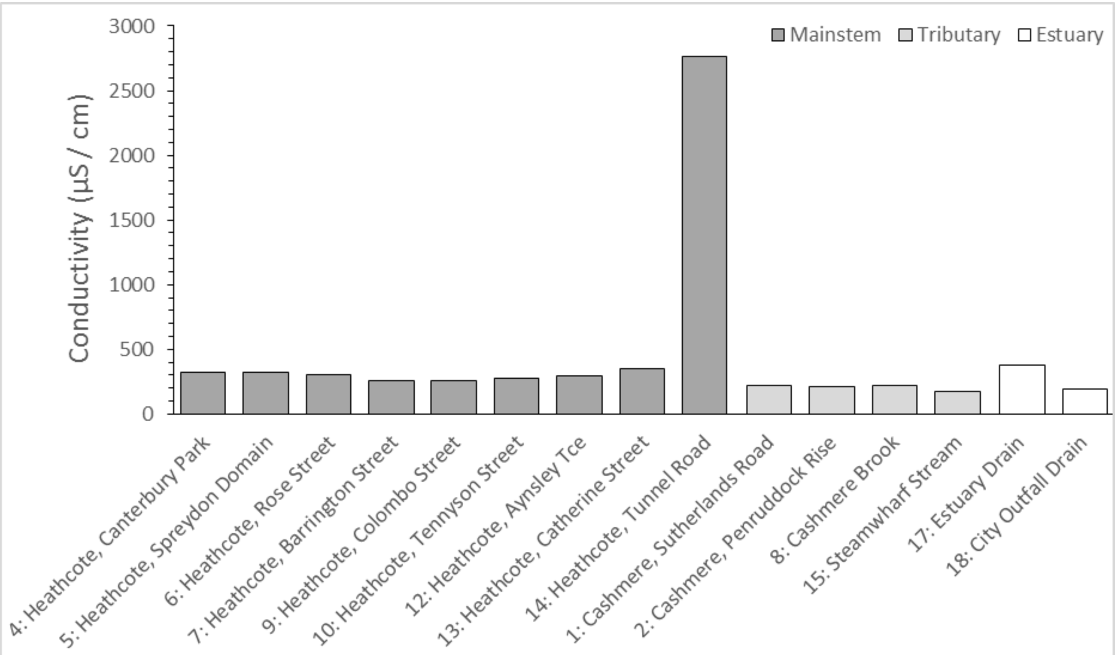

Figure 2. Specific conductivity measured, on one occasion, at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

pH

pH was also variable across sites, with the most variability observed among sites within the Heathcote River (mainstem), ranging from 6.5 at Site 4 to 8 at Site 12 (Figure 3).

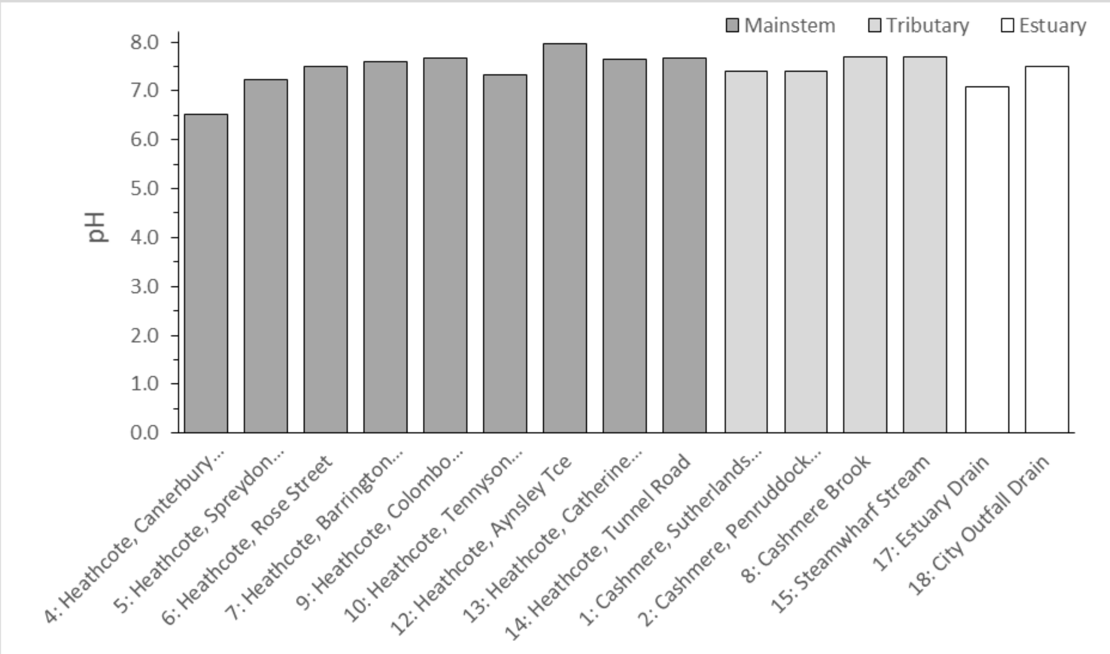

Figure 3. pH measured, on one occasion, at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Dissolved oxygen

Dissolved oxygen (DO) was variable across sites, particularly within the Heathcote mainstem and tributary sites (Figure 4). The lowest DO recordings were in Cashmere Stream upstream of Sutherlands Road (Site 1), Estuary Drain within Bexley Park (Site 17), and City Outfall Drain / Linwood Canal (Site 18). The DO concentrations recorded at these sites were also below Canterbury's proposed Land and Water Regional Plan (pLWRP) guidelines of 70% for spring-fed (plains) urban waterways. It is important to note, however, that DO was measured only once and during the daytime, and that DO can vary diurnally and seasonally.

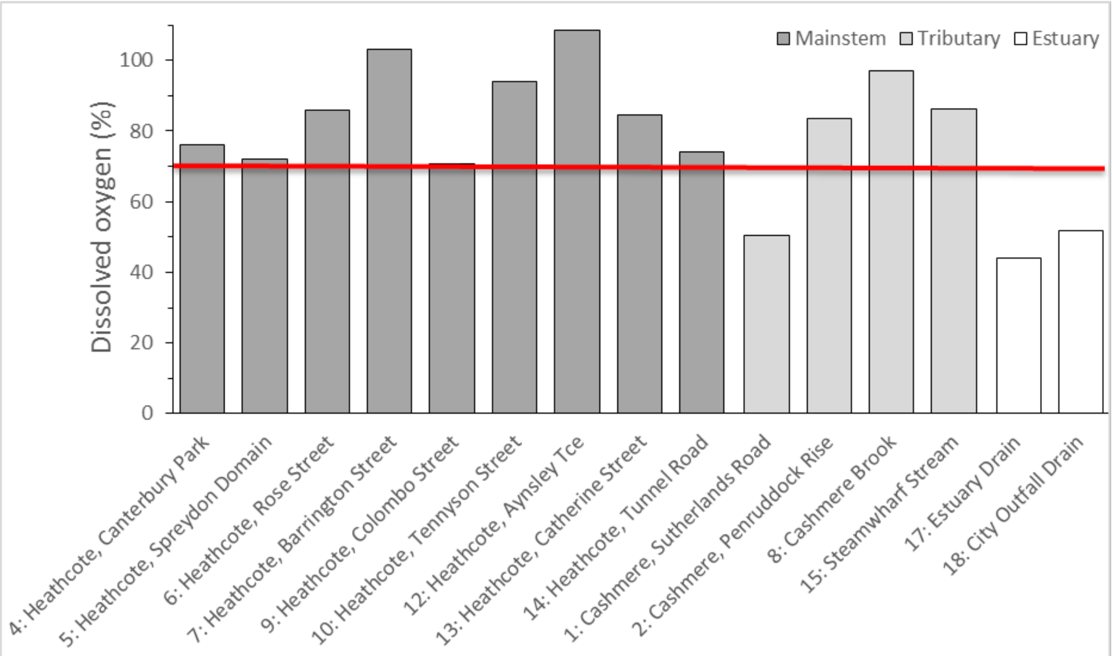

Figure 4. Dissolved oxygen (DO) measured, on one occasion, at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. The red line indicates the pLWRP guideline for DO in spring-fed – plains – urban systems.

Water temperature

Water temperature was variable across all sites, with the highest temperature recorded in Estuary Drain (Site 17) (Figure 5). However, all sites, except Estuary Drain, were below the pLWRP guideline for Canterbury Rivers of 20°C. The coolest water temperatures were recorded at Sites 1 (Cashmere Stream upstream of Sutherlands Road), 5 (Heathcote River downstream of Spreydon Domain), 6 (Heathcote River Rose Street / Centennial Park), and 9 (Heathcote River downstream of Colombo Street). Water temperatures in the Heathcote, Estuary & Coastal, and Avon SMP catchments were generally greater than those recorded in the Avon SMP aquatic ecology survey during 2013 (Boffa Miskell 2014), however, the latter were recorded in late spring-early summer, compared to late summer for this study. It is important to note, however, that temperature was measured only once and during the daytime, and that temperature can vary diurnally and seasonally.

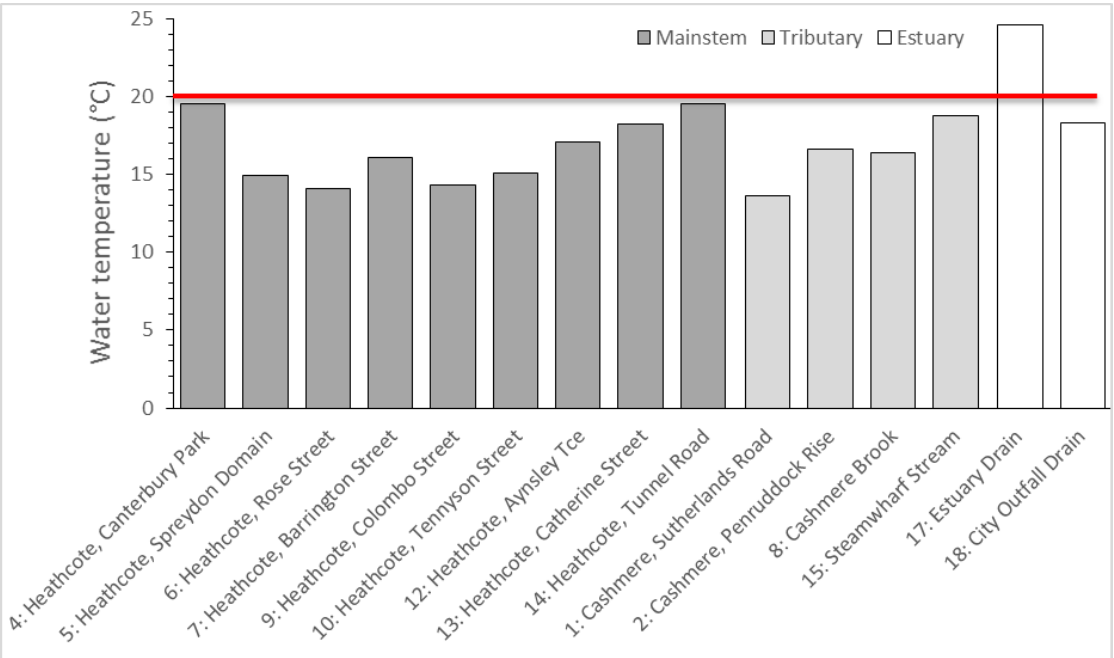

Figure 5. Water temperature measured, on one occasion, at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. The red line indicates the pLWRP guideline for temperature in Canterbury rivers.

Velocity

Water velocity was highly variable amongst sites, with the fastest being recorded at Site 9 (Heathcote River downstream of Colombo Street) and the slowest at Sites 4 (Heathcote River Canterbury Park / Showgrounds), 13 (Heathcote River at Catherine Street), and 18 (City Outfall Drain / Linwood Canal) (Figure 6).

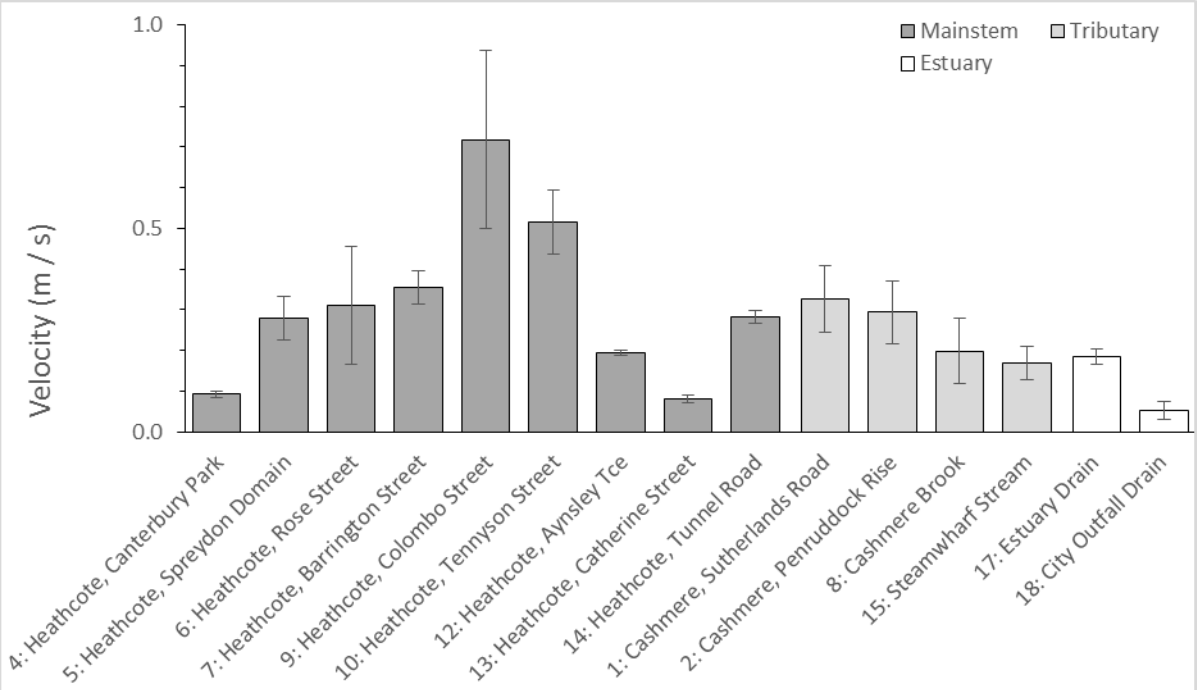

Figure 6. Mean (±1SE) velocity (m / s) measured once at each of three transects at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Velocity was significantly different among sites (ANOVA: $F_{8, 36} = 8.43$; $P < 0.001$), but there was no detectable difference in velocity recorded in 2010 and 2015.

Riparian and in-stream habitat

A brief summary of the general habitat conditions encountered at each site is given in Table 2; further site descriptions are provided in Appendix 3.

Table 2. Summary of the riparian and in-stream habitat conditions at each of the 15 sites surveyed between 11 February and 5 March 2015. TLB = true left bank; TRB = true right bank. Heathcote River sites are listed first, followed by 'tributary' sites, then the Avon and Estuary & Coastal SMP catchment sites.

	Surrounding land use	**Bank material**	**Canopy cover**	**Horizontal bank undercut**	**Overhanging vegetation**	**Flow habitat type (%still: backwater: pool:run:riffle)**
Site 4: Heathcote River, Canterbury Park / Showgrounds	TLB: Park / reserve, Canterbury Showgrounds TRB: Residential	TLB: Earth and wood TRB: Earth, wood, concrete / brick	TLB: 27% TRB: 27%	TLB: 33 cm TRB: 17 cm	TLB: 0 cm TRB: 117 cm	0:0:0:10:90
Site 5: Heathcote River, downstream of Spreydon Domain	TLB: Residential TRB: Residential	TLB: Earth TRB: Earth and rock	TLB: 50% TRB: 33%	TLB: 51 cm TRB: 12 cm	TLB: 53 cm TRB: 25 cm	0:0:0:95:5
Site 6: Heathcote River, Rose Street / Centennial Park	TLB: Park TRB: Residential	TLB: Earth TRB: Earth	TLB: 0% TRB: 12%	TLB: 22 cm TRB: 25 cm	TLB: 75 cm TRB: 223 cm	0:0:0:40:60
Site 7: Heathcote River, downstream of Barrington Street	TLB: Residential TRB: Reserve, Residential	TLB: Earth TRB: Earth	TLB: 37% TRB: 53%	TLB: 62 cm TRB: 67 cm	TLB: 103 cm TRB: 15 cm	0:0:0:100:0
Site 9: Heathcote River, downstream of Colombo Street	TLB: Residential TRB: Residential, reserve	TLB: Earth TRB: Earth	TLB: 50% TRB: 42%	TLB: 63 cm TRB: 58 cm	TLB: 17 cm TRB: 0 cm	0:0:0:85:15
Site 10: Heathcote River, downstream of Tennyson Street	TLB: Residential TRB: Residential	TLB: Earth, rock TRB: Earth, rock	TLB: 0% TRB: 0%	TLB: 13 cm TRB: 52 cm	TLB: 3 cm TRB: 3 cm	0:0:0:100:0
Site 12: Heathcote River, Aynsley Terrace	TLB: Reserve, residential TRB: Residential	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 40 cm TRB: 20 cm	TLB: 27 cm TRB: 23 cm	0:0:0:100:0
Site 13: Heathcote River, Catherine Street	TLB: Residential TRB: Park	TLB: Concrete, mud TRB: Concrete, mud	TLB: 0% TRB: 0%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	0:0:0:100:0
Site 14: Heathcote River, Tunnel Road	TLB: Residential TRB: Reserve	TLB: Rock, earth TRB: Rock, earth	TLB: 0% TRB: 0%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	0:0:0:100:0
Site 1: Cashmere Stream, upstream of Sutherlands Road	TLB: Rural TRB: Rural	TLB: Earth TRB: Earth	TLB: 48% TRB: 43%	TLB: 0 cm TRB: 33 cm	TLB: 3 cm TRB: 7 cm	0:5:0:60:35

	Surrounding land use	Bank material	Canopy cover	Horizontal bank undercut	Overhanging vegetation	Flow habitat type (%still: backwater: pool:run:riffle)
Site 2: Cashmere Stream, Penruddock Rise	TLB: Residential and park / reserve TRB: Residential and park / reserve	TLB: Earth TRB: Earth	TLB: 27% TRB: 23%	TLB: 72 cm TRB: 65 cm	TLB: 125 cm TRB: 114 cm	0:0:0:100:0
Site 8: Cashmere Brook, Ashgrove Terrace	TLB: Residential TRB: Residential, Reserve	TLB: Earth TRB: Earth	TLB: 65% TRB: 67%	TLB: 39 cm TRB: 18 cm	TLB: 23 cm TRB: 29 cm	20:0:0:60:20
Site 15: Steamwharf Stream	TLB: Reserve TRB: Residential	TLB: Earth TRB: Earth	TLB: 7% TRB: 0%	TLB: 3 cm TRB: 0 cm	TLB: 60cm TRB: 35 cm	0:0:0:100:0
Site 17: Estuary Drain	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	0:0:0:100:0
Site 18: City Outfall Drain / Linwood Canal	TLB: Residential TRB: Residential	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 10 cm TRB: 35 cm	TLB: 10 cm TRB: 60 cm	90:0:0:10:0

Wetted width and water depth

Wetted width varied among sites, but generally increased downstream (e.g. from sites 4-14 in the Heathcote River / Ōpāwaho; and sites 1-2 in Cashmere Stream) (Figure 7). The widest sites surveyed were all in the lower Heathcote River / Ōpāwaho, in the tidal and non-wadeable sites (Site 12, at Aynsley Terrace; Site 13, at Catherine Street; and Site 14, at Tunnel Road). Estuary Drain in Bexley Park (Site 17) and Cashmere Stream above Sutherlands Road (Site 1; a headwater site) were the narrowest sites surveyed.

Water depth also showed a trend of generally increasing downstream (Figure 7). Site 2, Cashmere Stream at Penruddock Rise was substantially deeper than Site 1, Cashmere Stream upstream of Sutherlands Road (approximately 2.5 km upstream). Site 1 was located in the headwaters of Cashmere Stream, while site 2 was nearing the confluence with the Heathcote River / Ōpāwaho. See Appendix 3 for further details.

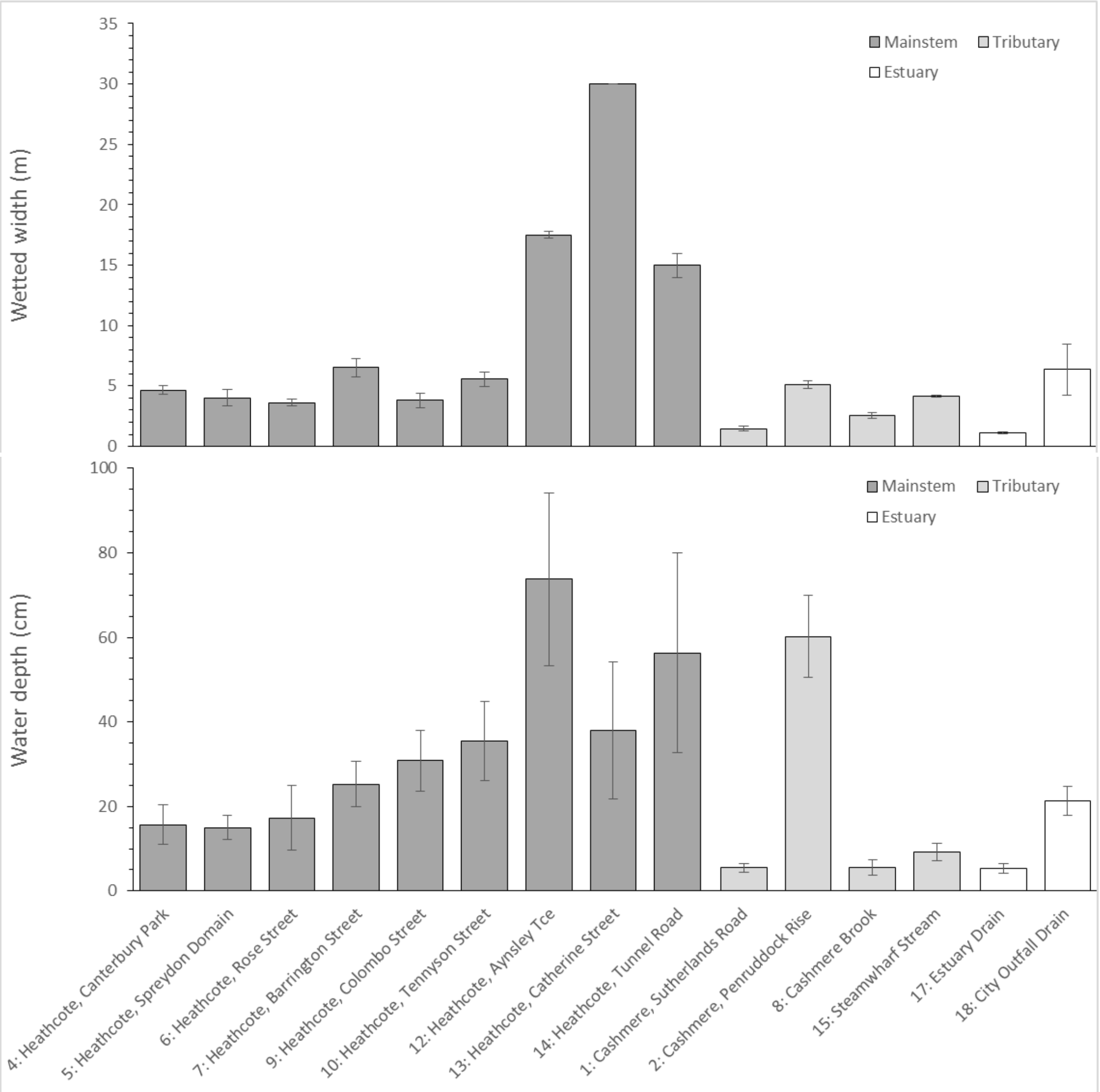

Figure 7. Mean (±1SE) wetted width (m) measured once (top) and mean (±1SE) water depth (cm) measured at five locations (bottom) at each of three transects at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Water depth was significantly different across the sites (ANOVA: $F_{8, 36} = 28.16$; $P < 0.001$) and between years (ANOVA: $F_{1, 36} = 30.25$; $P < 0.001$; depths: 2010<2015) (Figure 8).

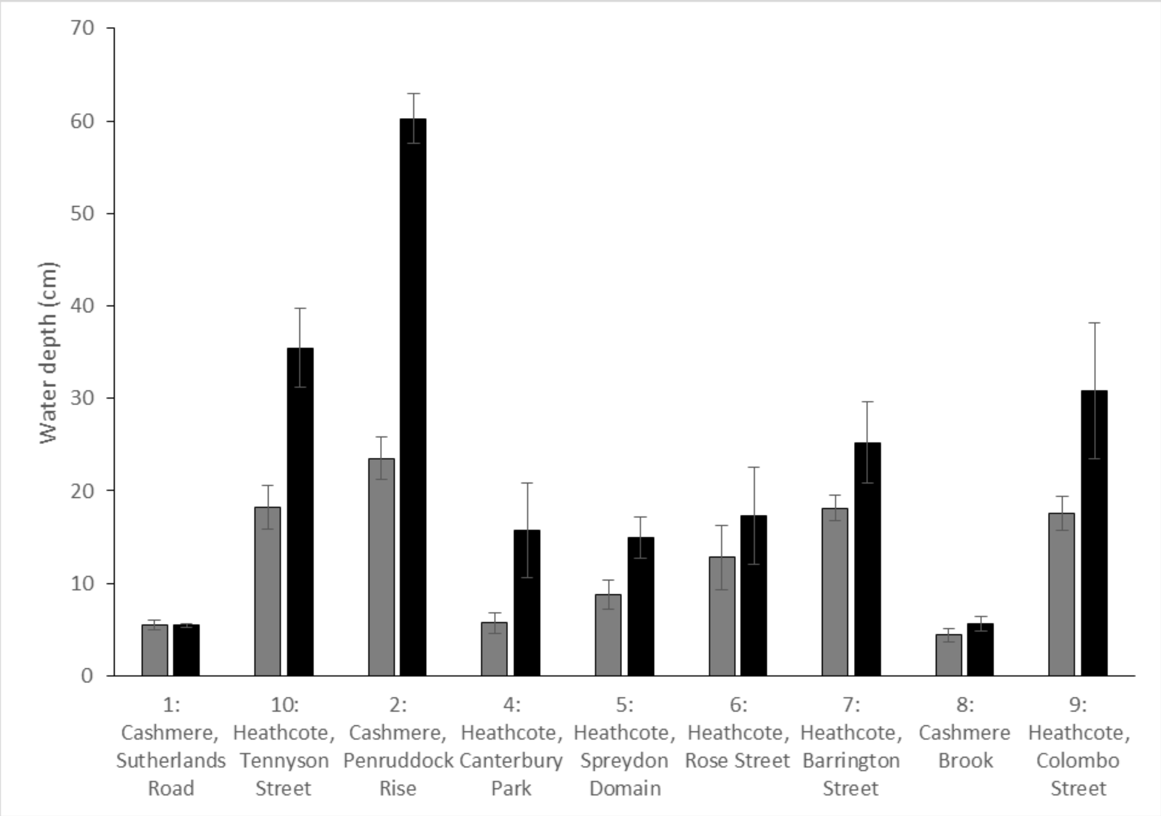

Figure 8. Mean (±1SE) water depth (cm) measured at each of three transects at nine sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in 2010 (EOS Ecology 2010; grey bars) and 2015 (this study, Boffa Miskell 2015; black bars).

Substrate index

The substrate index (SI), calculated from five replicate measures of substrate composition taken along each transect, generally ranged between 4 and 4.5 at the wadeable Heathcote River / Ōpāwaho sites (Sites 4-10). The non-wadeable sites within the Heathcote River / Ōpāwaho had lower SIs, with sites 12-14 all around 3 (Figure 9). The SIs also decreased with distance downstream in Cashmere Stream (site 4 had a higher SI than site 5). The Avon and Estuary & Coastal SMP catchment sites (sites 17 and 18) had lower SIs of 3. SIs of 3 indicated the stream bed was dominated by silt and sand, while SIs of 4-4.5 indicated the dominance of the coarser pebble and gravel substrates.

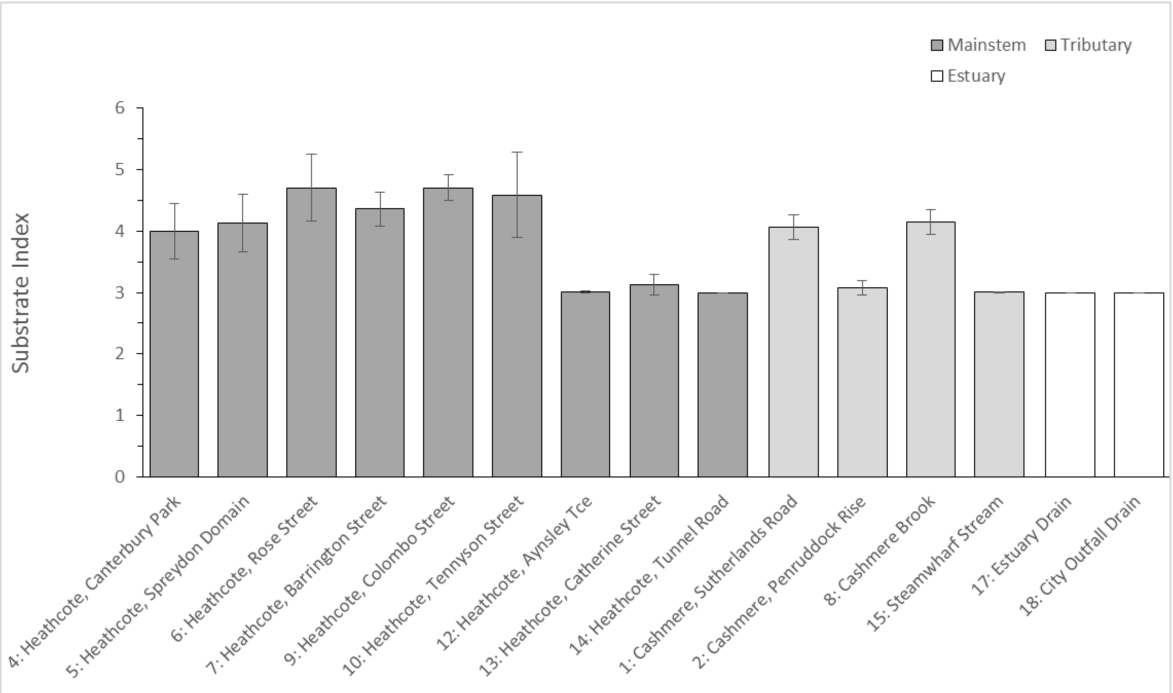

Figure 9. Mean (±1SE) substrate index calculated from substrate composition measures recorded at five locations along each of three transects at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

There were no detectable differences in substrate indices recorded in 2010 and 2015 (ANOVA: $F_{1, 36} = 2.45$; $P = 0.126$).

Embeddedness

Percent embeddedness varied among sites (Figure 10) with site 9 (Heathcote River downstream of Colombo Street) scoring as the least embedded (i.e. the most available interstitial spaces) of all 15 sites surveyed. Sites with the lowest SIs also had the highest embeddedness scores, which is unsurprising given that a low SI indicates bed substrates dominated by fine particles that also embed (surround) coarser substrates.

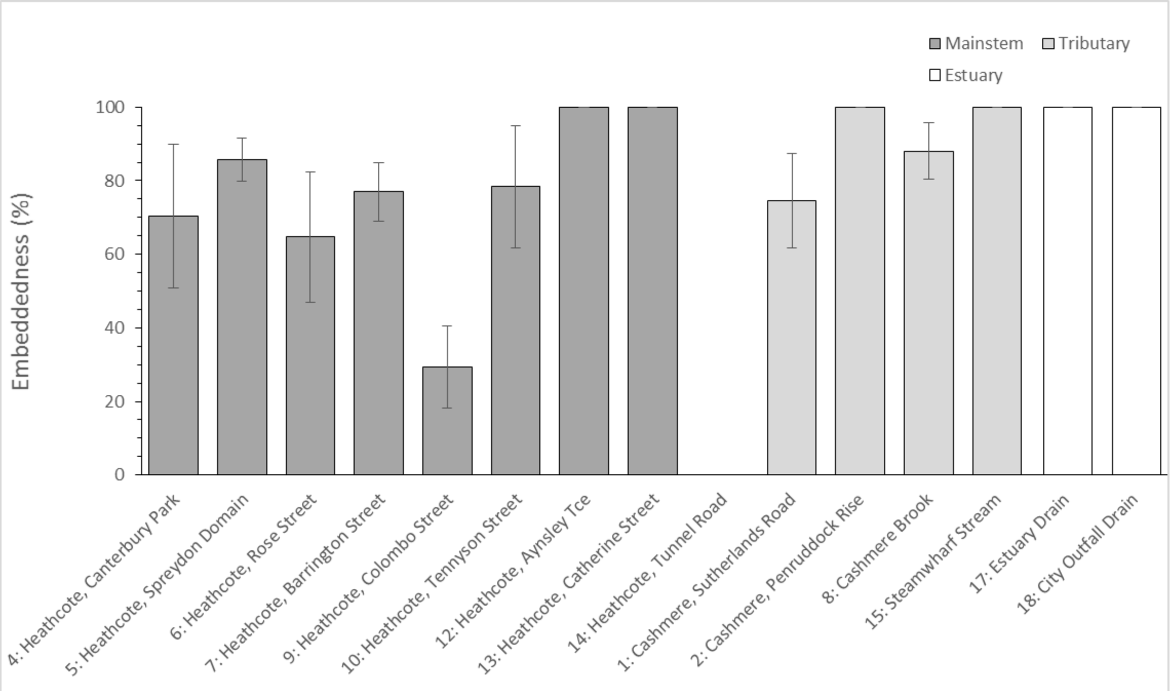

Figure 10. Mean (±1SE) percent embeddedness recorded at five locations along each of three transects at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Soft sediment depth

Soft sediment depth was greatest in Steamwharf Stream (site 15), Estuary Drain in Bexley Park (site 17), and the non-wadeable sites of the Heathcote River / Ōpāwaho (sites 12-14), with measures of 75 cm to more than 1 m in depth recorded in some places (Figure 11). Other sites generally had only shallow soft sediment deposits.

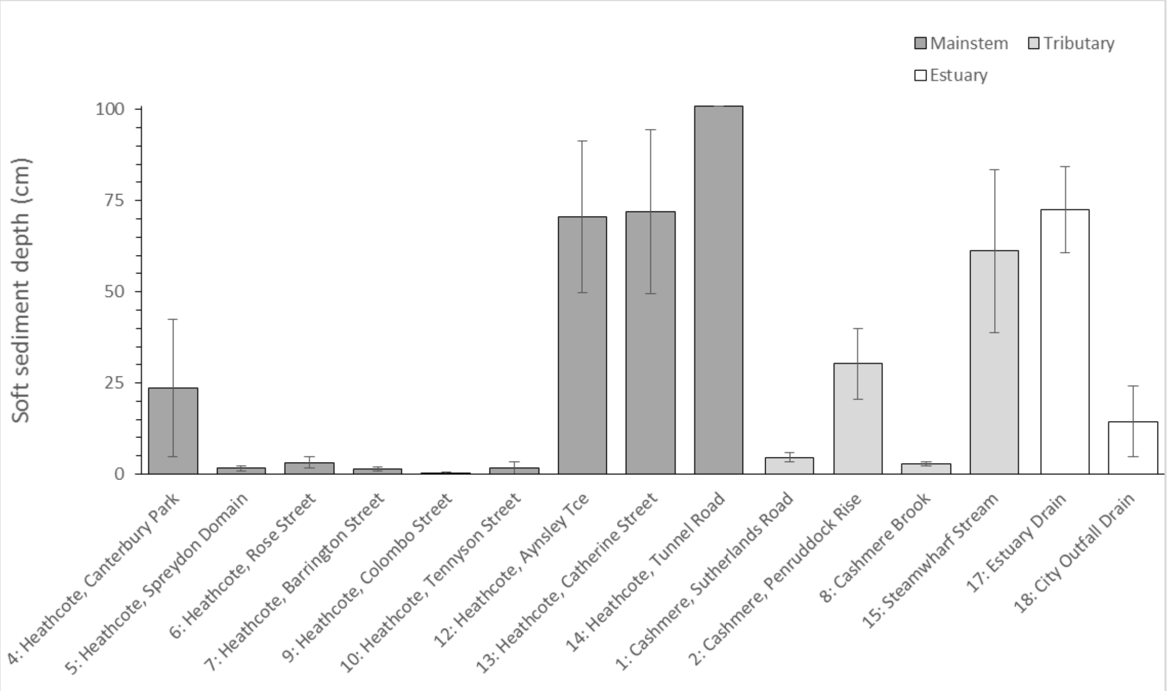

Figure 11. Mean (±1SE) soft sediment depth recorded at five locations along each of three transects at the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Soft sediment depth was significantly different across the sites (ANOVA: $F_{8, 36} = 4.42$; $P < 0.001$) and between years (ANOVA: $F_{1, 36} = 51.35$; $P < 0.001$; depths: 2010<2015), but a significant interaction effect (site: year $F_{8, 36} = 5.10$; $P < 0.001$) indicated this trend of greater soft sediment depths in 2015 than 2010 was not consistent across all sites (Figure 12).

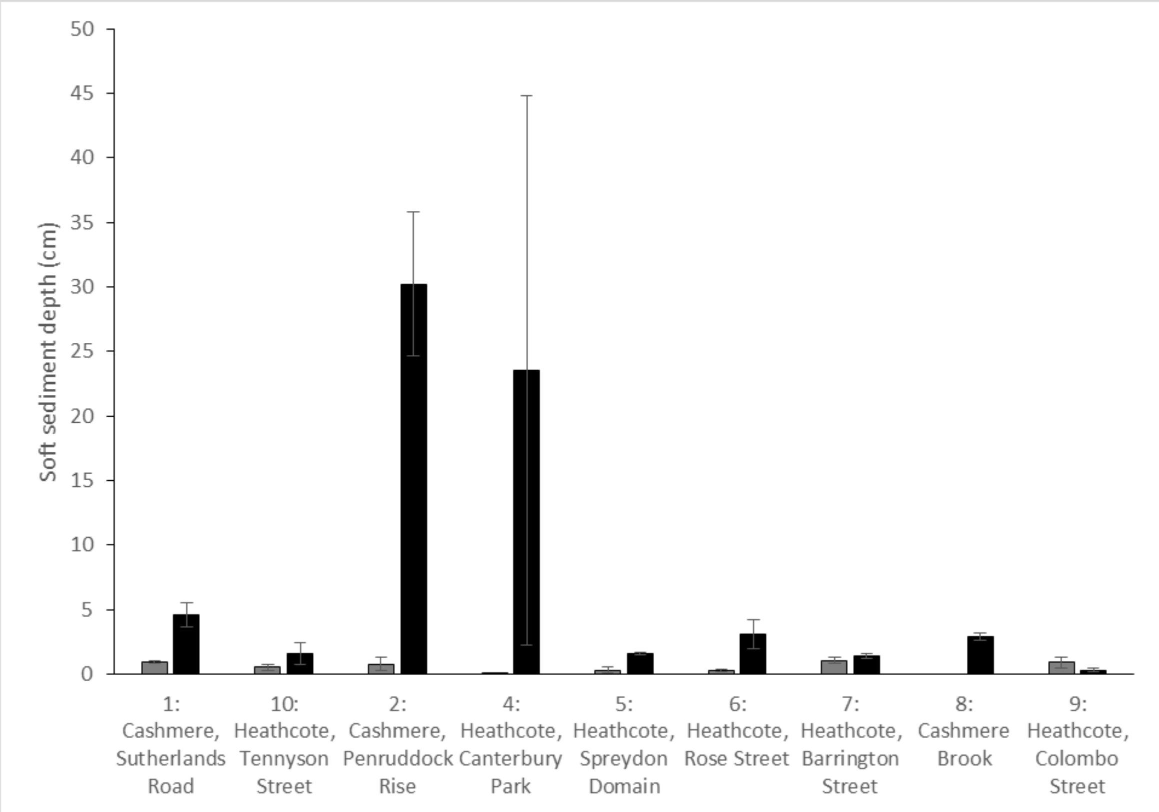

Figure 12. Mean (±1SE) soft sediment depth (cm) measured at each of three transects at nine sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in 2010 (EOS Ecology 2010; grey bars) and 2015 (this study, Boffa Miskell 2015; black bars).

Macrophytes

The percentage that macrophytes covered the stream bed was variable across sites, with very low macrophyte cover at sites 4 (Heathcote River Canterbury Park / Showgrounds), 5 (Heathcote River downstream of Spreydon Domain) and 15 (Steamwharf Stream). Macrophytes had been manually cleared from Site 4 prior to this survey, however, all other sites were surveyed before the macrophyte clearance / maintenance undertaken by City Care (Ben Lay, Waterways Supervisor, City Care, pers. comm). No macrophytes were found at Site 14 (Heathcote River Tunnel Road). Cashmere Stream at Penruddock Rise (Site 2) and Heathcote River at Aynsley Terrace (Site 12) were the only sites surveyed where macrophyte cover exceeded the pLWRP guidelines of 60% cover (maximum) for spring-fed (plains) urban waterways (Figure 13).

Macrophytes at all sites, including sites 2 and 12 (discussed above) were dominated by exotic species, and primarily the commonly occurring curly pondweed (*Potamogeton crispus*) and Canadian pondweed (*Elodea canadensis*), but native macrophytes were also present at many sites.

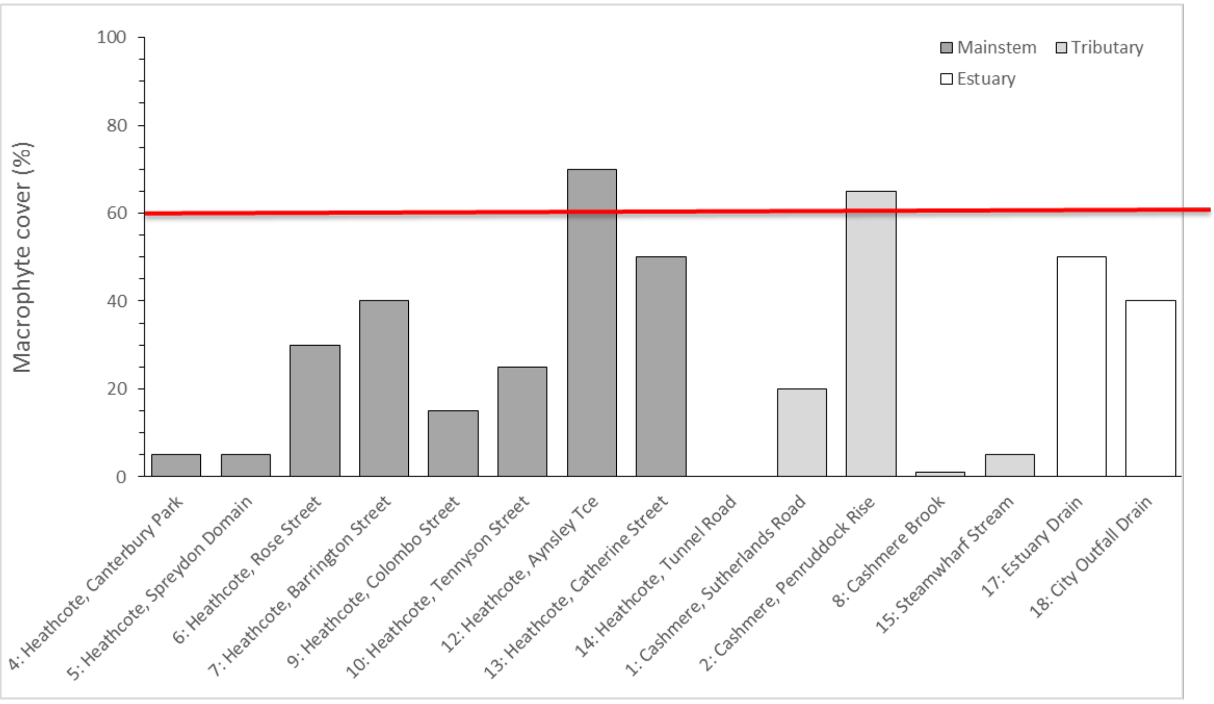

Figure 13. Total macrophyte cover (%) estimated for the entire site at each of the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. The red line indicates the pLWRP guideline for total macrophyte cover of 60% (maximum) in spring-fed – plains – urban systems.

Filamentous algae

Long (>20 mm) filamentous algae was generally rare or absent at most sites surveyed, however, Steamwharf Stream (site 15) and City Outfall Drain / Linwood Canal (site 18) both had moderately abundant algal cover either approaching or over the pLWRP guidelines for filamentous algae cover for spring-fed (plains) urban waterways (Figure 14).

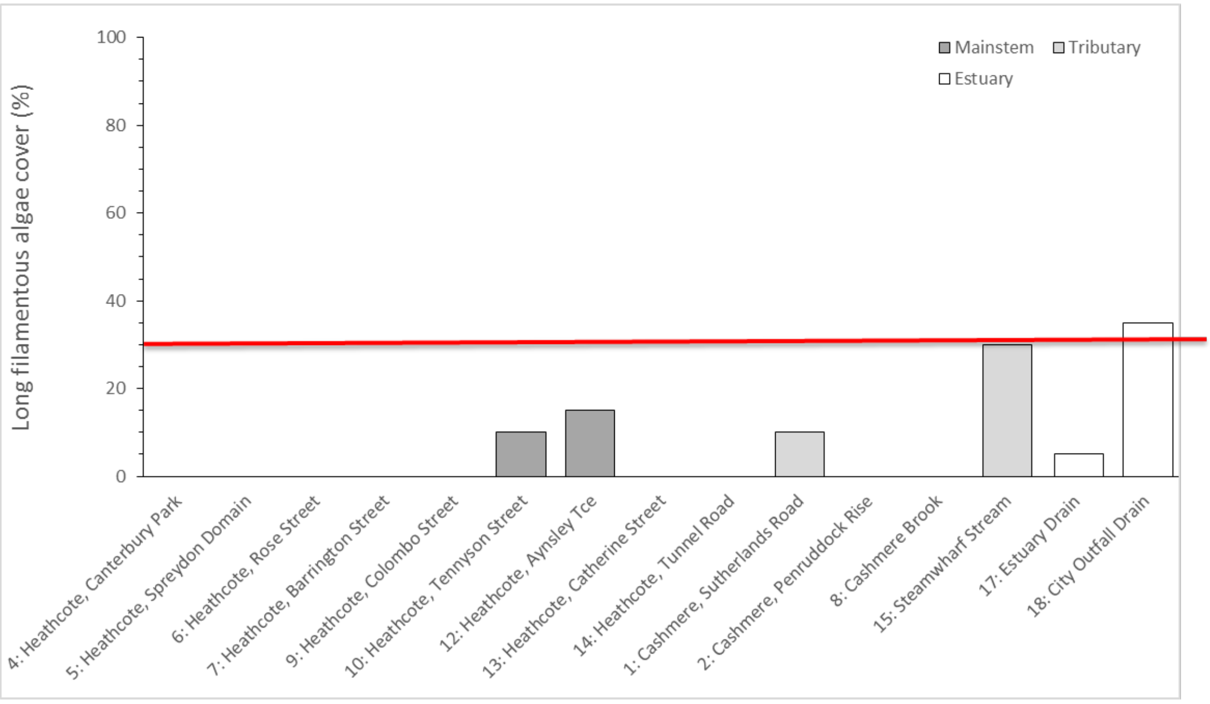

Figure 14. Total filamentous algae (long, > 20 mm) cover (%) estimated for the entire site at each of the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. The red line indicates the pLWRP guideline for total filamentous algae (long) cover of 30% (maximum) in spring-fed – plains – urban systems.

Macroinvertebrate community

Overview

A grand total of 91,532 macroinvertebrates, belonging to 47 taxonomic groups, was collected from the 15 sites surveyed with the Heathcote, Estuary & Coastal, and Avon SMP catchments. The most diverse group was the crustaceans, with 12 different taxa being recorded at the 15 sites. The true flies (or two-winged flies; Diptera) and caddisflies (Trichoptera) were the next most diverse groups, with 11 and 9 taxa respectively, followed by snails and bivalves (Mollusca: 4 taxa), true bugs (Hemiptera: 3 taxa), aquatic beetles (Coleoptera: 2 taxa), and one taxon each of dragonflies (Odonata), aquatic caterpillars (Lepidoptera), aquatic worms (Oligochaeta), leeches (Hirudinea), flatworms (Platyhelminthes), and nematodes (Nematoda).

Snails and bivalves (e.g. the ubiquitous New Zealand mud snail *Potamopyrgus antipodarium*, the introduced snail *Physella acuta*, and the tiny freshwater clam *Sphaerium*) and crustaceans (e.g seed shrimp ostracods and the freshwater amphipod *Paracalliope fluviatilis*) dominated the macroinvertebrate community, making up more than 86% of the macroinvertebrate community collected.

Potamopyrgus antipodarium and oligochaete worms were found at 14 of the 15 sites surveyed, while ostracods and orthoclad midge larvae were collected from 13 sites. Thirteen taxa were only found at one site, including some of the true bugs, many of the crustaceans, and both aquatic beetle taxa.

Two kōura (freshwater crayfish, *Paranephrops*, “at risk, declining” Grainger et al. 2013) were collected during the electric fishing at site 7 (Heathcote River downstream of Barrington Street). Kākahi (freshwater mussel, “at risk, declining” Grainger et al. 2013) shells were also found in Cashmere Stream upstream of Sutherlands Road (Site 1) and Heathcote River downstream of Barrington Street (Site 7).

Total abundance

The total number of macroinvertebrates varied markedly among sites, ranging from 1,400 to 16,345 individuals collected (Figure 15). Less than 2,000 individuals were collected in the kick-net sample from sites 7, 8, 9, 13, and 18. Sites 15, 4, 6, and 12 had the greatest total abundances, with 16,345, 13,036, 12,456, and 11,798 individuals collected, respectively. This was due to very high numbers of the ubiquitous and relatively pollution tolerant *Potamopyrgus antipodarium* (Site 15), ostracods (Sites 4 and 6), and *P. antipodarium*, *Physella acuta*, ostracods, and the amphipod *Paracalliope fluviatilis* (Site 12).

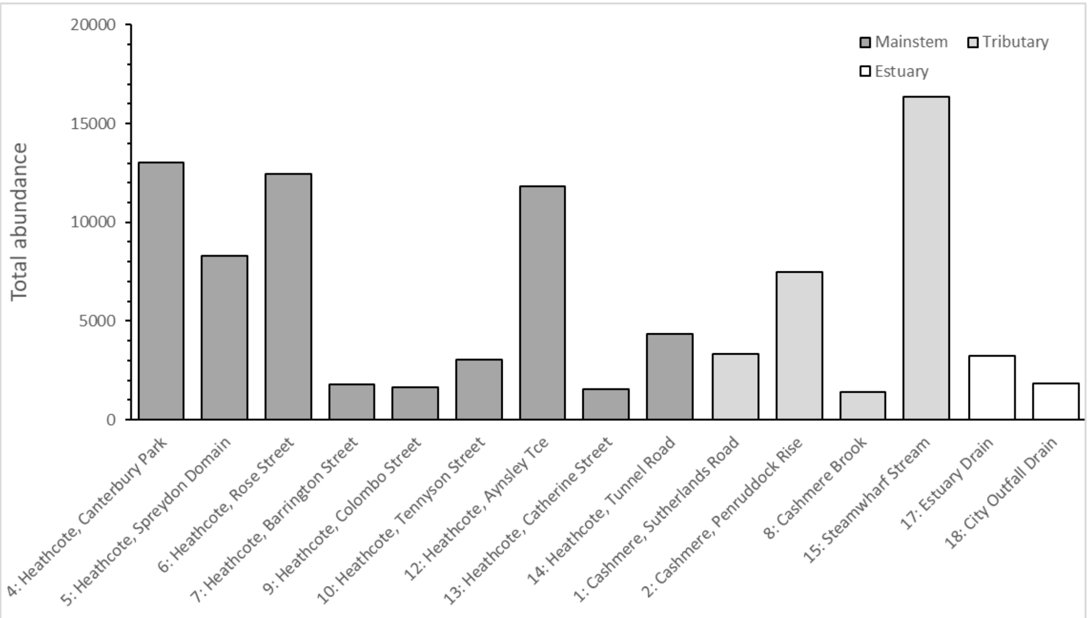

Figure 15. Total abundance of macroinvertebrates collected in a kick-net sample from each of the 15 sites surveyed in the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

Taxonomic richness

Taxonomic richness was less variable than total abundance among sites, but still ranged from 6 (Site 14, Heathcote River at Tunnel Road) to 21 (Site 12, Heathcote River at Aynsley Terrace) taxa. All sites, except site 14, had at least 10 macroinvertebrate taxa, while 40% of the sites had a taxon richness of 15 or more (Figure 16).

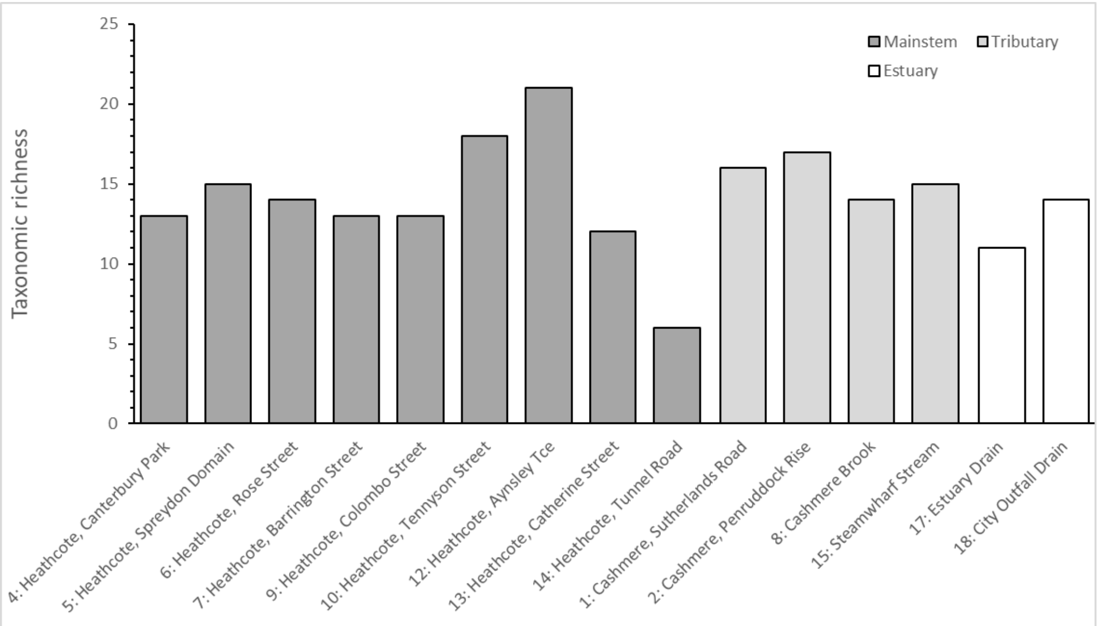

Figure 16. Taxonomic richness of macroinvertebrates collected in a kick-net sample from each of the 15 sites surveyed in the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015.

EPT richness

The EPT insect order (Ephemeroptera, mayflies; Plecoptera, stoneflies; and Trichoptera, caddisflies), which are generally sensitive to pollution and habitat degradation, are useful indicators of stream health. High EPT richness suggests high water and habitat quality, while low EPT richness suggests low water and habitat quality, and degraded stream health.

EPT richness was variable among sites, with the fewest EPT taxa being collected from the tidal sites (no EPT from site 14, Heathcote River at Tunnel Road; and 2 taxa from site 13, Heatcote River at Catherine Street). Three EPT taxa were found at the Heathcote River / Ōpāwaho sites 7 and 9, while 4 EPT taxa were collected from the upper Heathcote River / Ōpāwaho sites 4 and 5, site 12 (Aynsley Terrace) and in Cashmere Stream (site 1), Cashmere Brook (site 8) and Steamwharf Stream (site 15) (Figure 17). Heathcote River / Ōpāwaho sites 6 and 10, and Cashmere Stream site 2, had the greatest EPT richness with 5 taxa recorded from each site.

No EPT taxa were recorded from either of the Avon or Estuary & Coastal SMP catchment sites (sites 17 and 18) or in site 14 Heathcote River Tunnel Road.

Caddisflies were the only group of clean-water 'EPT taxa' present in the Heathcote SMP catchment; mayflies and stoneflies were absent from all sites.

Although a total of 9 caddisfly taxa were found in the Heathcote SMP catchment, many of these were encountered at a limited number of sites (6 taxa were found at 5 or fewer sites). For example, the stick caddis *Triplectides cephalotes* was recorded at just 2 sites and the algal piercing purse-cased caddis *Paroxyethira hendersoni*[7] was found at 3 of the 15 sites. The stick caddis *Hudsonema amabile* and the purse-cased caddis *Oxyethira albiceps*[7] were the most commonly encountered caddisfly taxa, each being found at 67% of the sites surveyed.

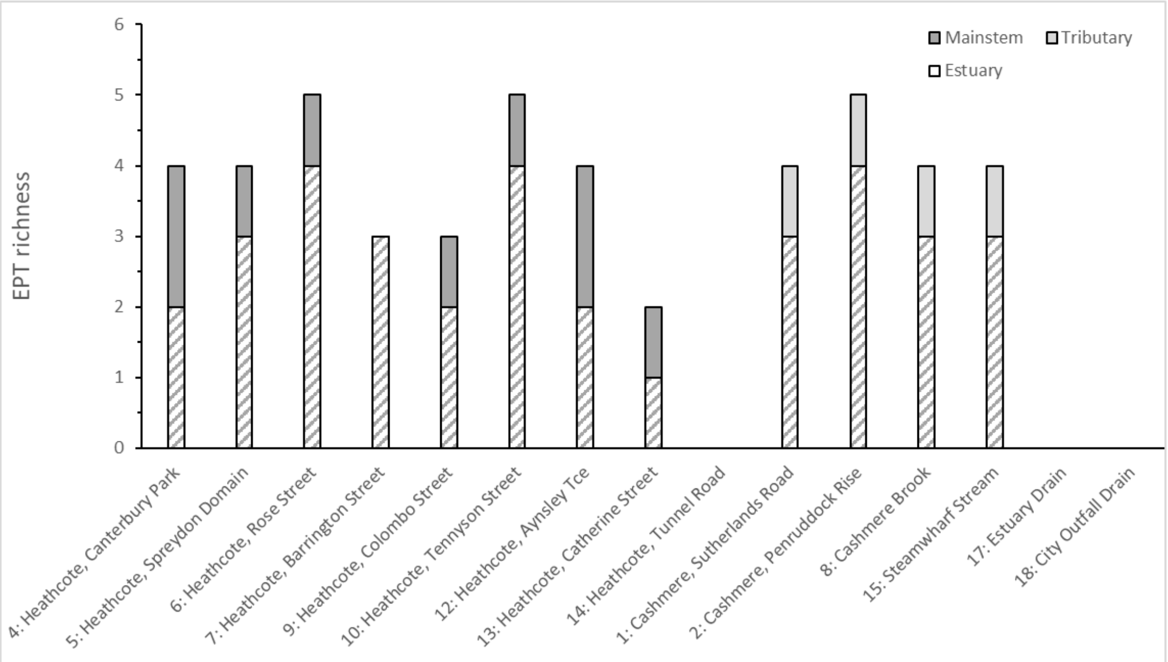

Figure 17. EPT taxonomic richness collected in a kick-net sample from each of the 15 sites surveyed in the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. Solid bars are EPT richness, while the hatched bars indicate EPT richness minus the pollution-tolerant Hydroptilidae caddis.

Macroinvertebrate Community Index

Although there was some variability in the MCI scores, all sites had “poor” stream health (based on the water quality categories of Stark and Maxted, 2007), with “probable severe enrichment” (Figure 18). Hard-bottom scores were used for the pebble / gravel dominated sites 1, 4-7, and 9-10, while soft-bottom scores were used for the non-wadeable or soft-bottom sites 2, 12-15 and 17-18.

QMCI showed a slightly different pattern, with sites 14 and 15 (Heathcote River at Tunnel Road and Steamwharf Stream, respectively) having the lowest QMCI scores (Figure 18). Thirteen of the 15 sites surveyed had a QMCI score of 4 or below, indicating “poor” stream health with “probable severe enrichment”. Of these, 9 sites fell below the pLWRP guideline for spring-fed (plains) urban waterways of a minimum QMCI of 3.5, while one site (Site 5) had a QMCI score of 3.5 (i.e. right on the guideline). Site 9 (Heathcote River downstream of Colombo Street) and site 13 (Heathcote River at Catherine Street) fell within the “fair” water quality or stream health category; site 13 was on the cusp of the “good” water quality category.

[7] *Paroxyethira hendersoni* and *Oxyethira albiceps* are both species of caddisflies belonging to the more pollution-tolerant family Hydroptilidae.

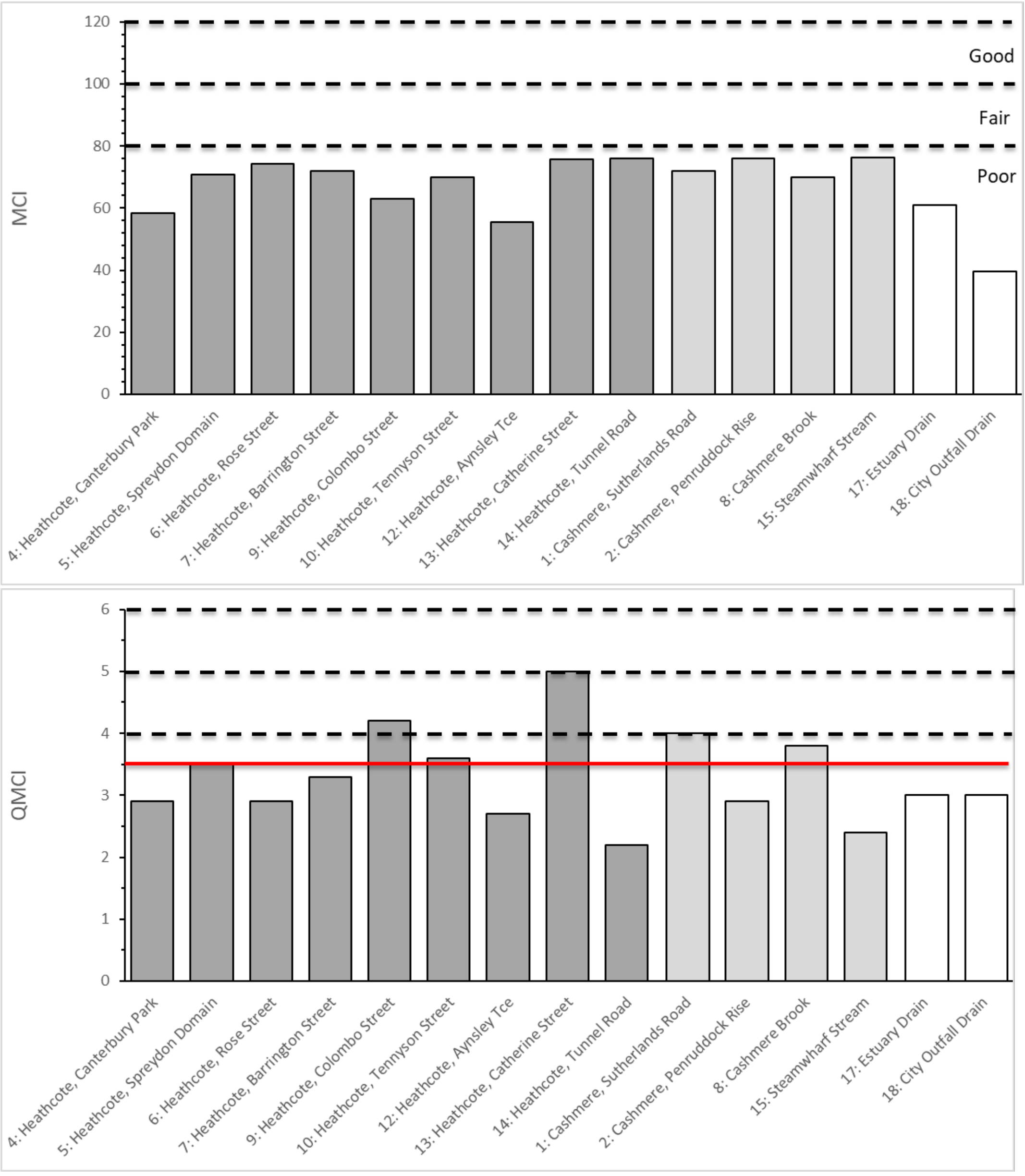

Figure 18. MCI (Macroinvertebrate Community Index) scores (top) and QMCI scores (bottom) for the 15 sites surveyed in the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. The dashed lines indicate the water quality categories of Stark and Maxted (2007), where "poor" = "probable severe enrichment", "fair" = "probable moderate enrichment", and "good" = "doubtful quality or possible mild enrichment". The "excellent" category of scores >120 has not been shown. The red line on the QMCI graph indicates the pLWRP guideline for spring-fed (plains) urban waterways. Hard-bottomed scores were used for sites 1, 4-7, and 9-10, while soft-bottomed scores were used for sites 2, 12-15 and 17-18.

Overall best and worst sites

When the biotic indices of taxonomic richness, EPT richness, %EPT richness, and QMCI scores were ranked, from 1 (best) to 15 (worst) for each of the 15 sites surveyed, Heathcote River, downstream of Tennyson Street (Site 10) was ranked as the best site overall (i.e. ranked first place across all four indices, across all sites) (Table 3). This site scored second highest for taxonomic richness, first equal for EPT richness, and fifth highest for both %EPT richness and QMCI, resulting in a ranking of first overall (Table 3). Cashmere Stream upstream of Sutherlands Road (Site 1) and Cashmere Brook at Ashgrove Terrace (Site 8) were ranked the second and third best sites overall, respectively. Steamwharf Stream (Site 15), Heathcote River at Catherine Street (Site 13), City Outfall Drain / Linwood Canal (Site 18), Estuary Drain in Bexley Park (Site 17), and Heathcote River Tunnel Road (Site 14) were the worst scoring sites (Table 3).

Table 3. Taxonomic richness, EPT richness, %EPT richness, and QMCI values have been ranked, from 1 (best) to 15 (worst) for each of the 15 sites surveyed in February and March 2015. These ranks were then summed to give a final rank, indicating the site that scored best out of these four biotic indices. Individual scores for the biotic indices are given in parentheses.

	Taxonomic richness	**EPT richness**	**%EPT richness**	**QMCI**	**Sum of ranks**	**Final rank**	**Final group**
Site 10: **Heathcote River, downstream of Tennyson Street**	2 (18)	1= (5)	5 (9.6)	5 (3.6)	13	**1**	Best
Site 1: **Cashmere Stream, upstream of Sutherlands Road**	4= (16)	4= (4)	3 (12.8)	3 (4.0)	14	2	Best
Site 8: **Cashmere Brook, Ashgrove Terrace**	7= (14)	4= (4)	2 (15.1)	4 (3.8)	17	3	Best
Site 9: **Heathcote River, downstream of Colombo Street**	10= (18)	10= (3)	1 (27.8)	2 (4.2)	23	4	Best
Site 12: **Heathcote River, Aynsley Terrace**	1 (21)	4= (5)	7 (1.3)	13 (2.7)	25	5=	Middle
Site 2: **Cashmere Stream, Penruddock Rise**	3 (15)	1= (4)	11 (0.9)	10= (2.9)	25	5=	Middle
Site 5: **Heathcote River, downstream of Spreydon Domain**	5= (15)	4= (4)	12 (0.9)	6 (3.5)	27	7=	Middle
Site 6: **Heathcote River, Rose Street / Centennial Park**	7= (13)	1= (5)	9 (1.0)	10= (2.9)	27	7=	Middle
Site 4: **Heathcote River, Canterbury Park / Showgrounds**	10= (13	4= (4)	6 (3.7)	10= (2.9)	30	9	Middle
Site 7: **Heathcote River, downstream of Barrington Street**	10= (13)	10= (3)	4 (12.2)	7 (3.3)	31	10	Middle
Site 15: **Steamwharf Stream**	5= (15)	4= (4)	10 (0.9)	14 (2.4)	33	11	Worst
Site 13: **Heathcote River, Catherine Street**	13 (12)	12 (2)	8 (1.3)	1 (5.0)	34	12	Worst
Site 18: **City Outfall Drain / Linwood Canal**	7= (14)	13= (0)	13= (0.0)	8= (3.0)	41	13	Worst
Site 17: **Estuary Drain**	14 (11)	13= (0)	13= (0.0)	8= (3.0)	48	14	Worst
Site 14: **Heathcote River, Tunnel Road**	15 (6)	13= (0)	13= (0.0)	15 (2.2)	56	15	Worst

Changes in community composition over time

Taxonomic richness and QMCI scores

Taxonomic richness and EPT richness was greater at all sites in 2010 (EOS Ecology 2010) than 2015 (this study) (Figure 19). However, this was possibly due to differences in sampling effort between the two sampling occasions. EOS Ecology (2010) collected three replicate kick-net samples from each site, while only one composite kick-net sample was collected from each site in 2015 (this study). It is, therefore, plausible that more individuals and more species were collected purely due to sampling a greater area of habitat in 2010, than in 2015.

QMCI scores were relatively similar between the two surveys (2010 and 2015) conducted at each site (Figure 19). More importantly, with the exception of site 9, all sites remained within the same water quality or stream health categories. The QMCI score at site 9 (Heathcote River downstream of Colombo Street) was within the “fair” category in 2015, versus “poor” category in 2010.

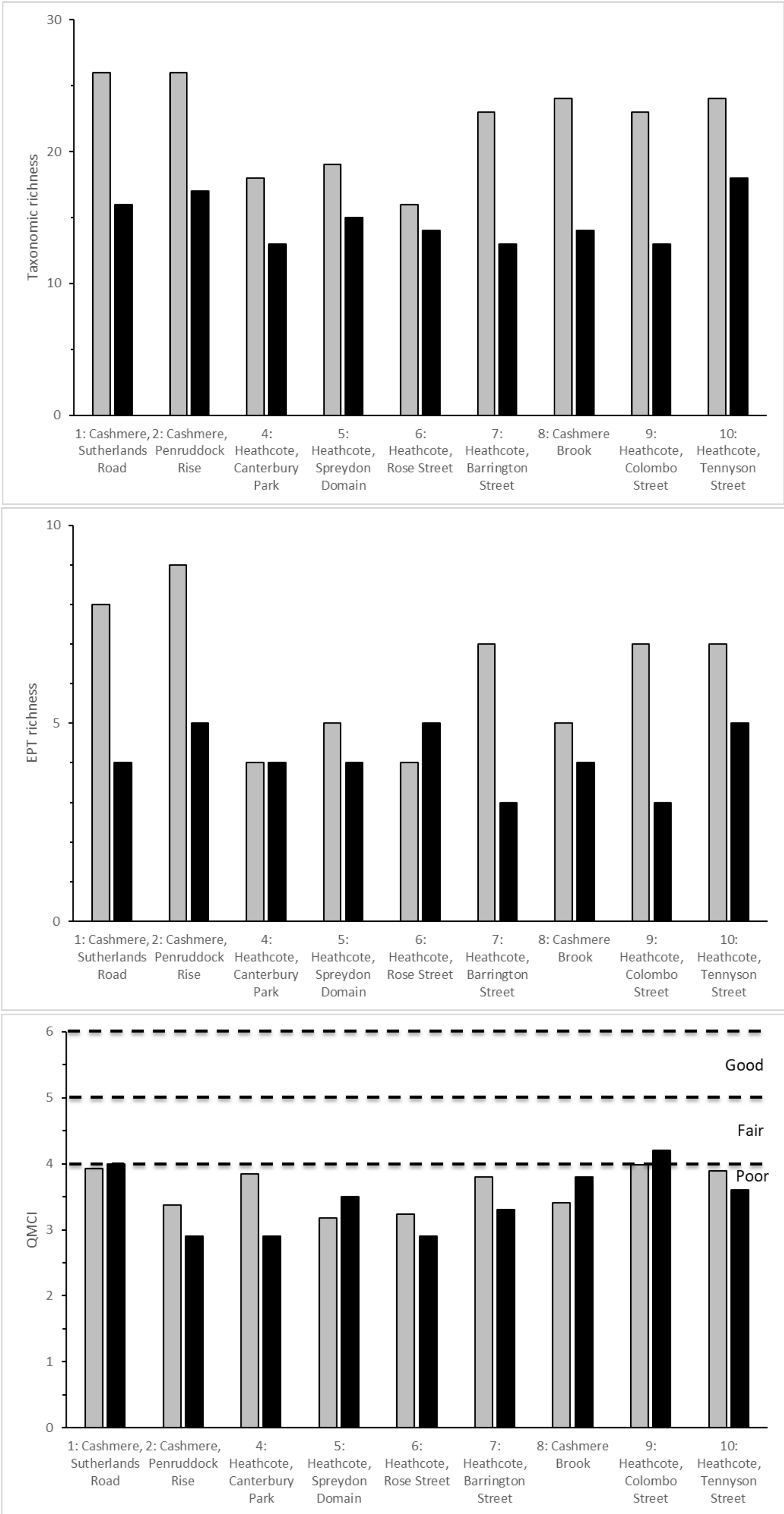

Figure 19. Taxonomic richness (top), EPT richness (middle), and QMCI scores (bottom) found at 9 sites surveyed in 2010 (EOS Ecology 2010) (grey bars) and 2015 (this study, Boffa Miskell 2015) (black bars).

Community composition

The NMDS ordination, confirmed by the ANOSIM results (ANOSIM R = 0.159; P = 0.069), indicated that there was no significant difference in the macroinvertebrate community found at the nine sites surveyed in 2010 (EOS Ecology 2010) and in 2015 (this study) (Figure 20). SIMPER were not calculated as ANOSIM did not reveal any significant differences in macroinvertebrate community composition within sites over time.

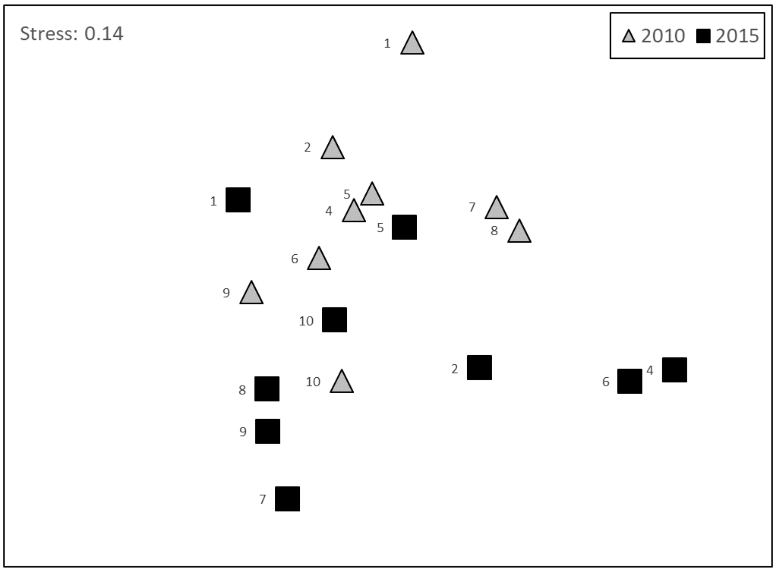

Figure 20. Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate abundance data collected from 9 sites in 2010 (grey triangles) (EOS Ecology 2010) and in 2015 (black squares) (this study) The NMDS ordination gave a good representation of the actual community dissimilarities between 2010 and 2015 (two-dimensional stress = 0.14). Axes are identically scaled so that the sites closest together are more similar in macroinvertebrate species composition than those further apart.

Fish community

Overview

A total of 844 fish, belonging to twelve species, were captured in the 15 sites of the Heathcote, Estuary & Coastal, and Avon SMP catchments. The twelve species were, in descending order of total abundance (i.e. across all sites): common bully (*Gobiomorphus cotidianus*), shortfin eel (*Anguilla australis*), giant bully (*G. gobioides*), inanga (*Galaxias maculatus*), upland bully (*G. breviceps*), bluegill bully (*G. hubbsi*), longfin eel (*A. dieffenbachii*), estuarine triplefin (*Grahamina* sp.), brown trout (*Salmo trutta*), yelloweye mullet (*Aldrichetta forsteri*), common smelt (*Retropinna retropinna*), and black flounder (*Rhombosolea retiaria*).

Longfin eel, inanga, and bluegill bully all have a conservation status of "at risk, declining", while the remaining nine species are currently listed as "not threatened" (Goodman et al. 2013).

Species richness

Species richness was variable across sites, with the most species found at site 13 (Heathcote River at Catherine Street); site 17 (Estuary Drain in Bexley Park) had the lowest species richness with only shortfin eels found (Figure 21).

Shortfin eel was the most commonly encountered species, being captured at all sites, while common bullies were found at all but one site (Site 17). Giant bullies were found at 67% of sites and upland bully, longfin eel, inanga, and brown trout were found at around 50% of the sites. Bluegill bully, common smelt, and black flounder were each only recorded at one site. Yelloweye mullet was found at all three non-wadeable Heathcote River sites (sites 12, 13, and 14); estuarine triplefin was only found at the tidal Heathcote River sites (sites 13 and 14); black flounder was only found in the Heathcote River at Tunnel Road (site 14).

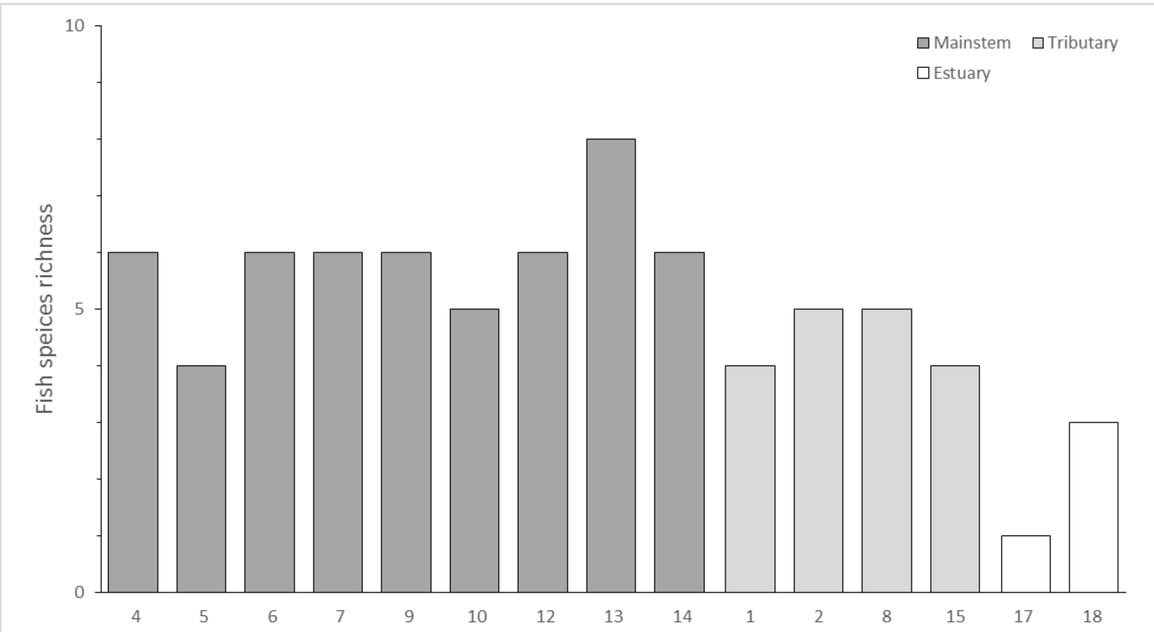

Figure 21. Species richness of freshwater fish captured at the 15 Heathcote, Estuary & Coastal, and Avon SMP catchment sites surveyed in February and March 2015. Eel elvers (i.e. *Anguilla* sp.) and bully species have been excluded from this calculation.

Size distribution of fish

Table 4 summarises the size information on fish captured at the 15 sites. The largest fish captured at any site was a 1200 mm longfin eel, found in the Heathcote River within Canterbury Park / Showgrounds (Site 4).

Giant bullies are often considered to be rare in Christchurch's waterways, however, they were regularly found in this study with a range of size classes found at most sites (Table 4). The largest giant bully captured was 154 mm in the Heathcote River at Tunnel Road (Site 14). Very large giant bullies were also captured at sites 4, 7 and 13.

Table 4. Size of fish caught at each of the 15 sites surveyed within the Heathcote, Estuary & Coastal, and Avon SMP catchments in February and March 2015. Size range (mm) with average length in parentheses are provided.

	Bluegill bully	Upland bully	Giant bully	Common bully	Bully species	Brown trout	Longfin eel	Shortfin eel	Elver (eel)	Inanga	Common smelt	Estuarine triplefin	Black flounder	Yelloweye mullet
Site 1: Cashmere Stream, upstream of Sutherlands Road	-	20-71 (43)	-	25-49 (40)	20-25 (23)	-	-	130-550 (258)	-	80	-	-	-	-
Site 2: Cashmere Stream, Penruddock Rise	-	-	88-100 (94)	38-112 (73)	-	-	470-920 (679)	740	-	145	-	-	-	-
Site 4: Heathcote River, Canterbury Park / Showgrounds	-	45-60 (53)	90-150 (120)	50-110 (80)	-	100	280-1200 (504)	100-450 (281)	-	-	-	-	-	-
Site 5: Heathcote River, downstream of Spreydon Domain	-	54-80 (67)	-	35-109 (58)	-	70-100 (88)	-	100-840 (276)	80	-	-	-	-	-
Site 6: Heathcote River, Rose Street / Centennial Park	-	30-60 (50)	90-138 (111)	40-120 (81)	-	110	160-720 (337)	100-580 (186)	70-90 (85)	-	-	-	-	-
Site 7: Heathcote River, downstream of Barrington Street	-	54	78-150 (98)	35-100 (76)	-	300	600	100-450 (191)	80-90 (83)	-	-	-	-	-
Site 8: Cashmere Brook, Ashgrove Terrace	-	-	50-90 (68)	30-90 (50)	-	80	-	110-320 (221)	70-90 (80)	60	-	-	-	-
Site 9: Heathcote River, downstream of Colombo Street	32-68 (50)	49-50 (50)	-	32-90 (58)	-	100-510 (305)	120-200 (167)	110-530 (248)	-	-	-	-	-	-
Site 10: Heathcote River,	-	40	38-100 (63)	15-90 (52)	-	-	750	100-520 (190)	80	-	-	-	-	-

	Bluegill bully	Upland bully	Giant bully	Common bully	Bully species	Brown trout	Longfin eel	Shortfin eel	Elver (eel)	Inanga	Common smelt	Estuarine triplefin	Black flounder	Yelloweye mullet
downstream of Tennyson Street														
Site 12: Heathcote River, Aynsley Terrace	-	-	60-120 (79)	32-120 (64)	22-30 (27)	-	460-1050 (708)	190-520 (337)	-	81-108 (97)	-	-	-	160-210 (192)
Site 13: Heathcote River, Catherine Street	-	-	55-150 (116)	40-110 (69)	20	-	-	250-600 (395)	80	70-185 (95)	80-150 (107)	40-95 (61)	170-210 (190)	115-160 (143)
Site 14: Heathcote River, Tunnel Road	-	-	80-154 (102)	69-130 (90)	50	-	500-630 (565)	110-600 (321)	90	-	-	30-100 (76)	-	170
Site 15: Steamwharf Stream	-	-	65	55-60 (58)	-	-	-	120-280 (171)	85-90 (88)	55-80 (69)	-	-	-	-
Site 17: Estuary Drain	-	-	-	-	-	-	-	120-240 (190)	-	-	-	-	-	-
Site 18: City Outfall Drain / Linwood Canal	-	-	-	34-54 (45)	-	-	-	270-430 (357)	-	70-80 (75)	-	-	-	-

Community composition

While shortfin eel and common bully were the most commonly encountered species, they did not always dominate the fish community (Figure 22). For example, the fish community at site 1 (Cashmere Stream upstream of Sutherlands Road) was dominated by upland bully and shortfin eel, while site 9 (Heathcote River downstream of Colombo Street) was dominated by the threatened bluegill bully and common bully (Figure 22). When present, inanga, giant bullies and brown trout were only ever a small proportion of the fish community. Estuarine triplefin, yelloweye mullet, common smelt, and black flounder were only at sites 12-14 (i.e. in the non-wadeable and tidal reaches of the Heathcote River / Ōpāwaho).

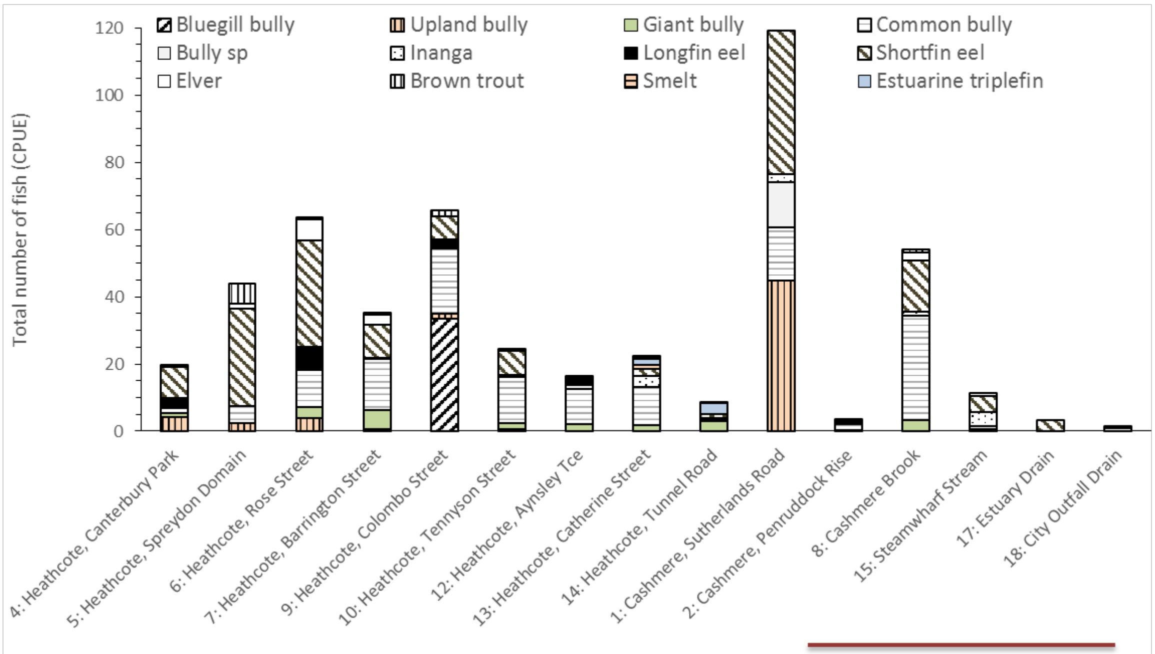

Figure 22. Total number of fish, separated by species, captured at each site surveyed in February and March 2015. Numbers are shown as catch per unit effort (CPUE): per 100 m^2 of area surveyed using electric fishing; or per net / night for trapping (Sites 2, 12-14, and 18). The dark red line indicates the sites where traps and nets were used to survey fish.

Comparisons with previous surveys

There were slight differences in the species composition found at five of the sites surveyed in this study (2015) and in previous studies (Table 5). In particular, giant bullies, bluegill bullies, common bullies, and inanga were not found consistently across the sampling occasions within a site (Table 5).

Of interest, a number of individuals of the "at risk, declining" bluegill bully were found in the Heathcote River, downstream of Colombo Street (site 9). This species was not found to be abundant at this site in 2011 (Aquatic Ecology Limited 2012) (Table 5).

It is important to note that sampling methodologies differed between sampling occasions at each site (Table 5), which may partly explain the slight differences in species found within a site (i.e. over the two sampling occasions).

Table 5. Fish species and dominant species (based on abundance data) found at five sites surveyed in this study (Boffa Miskell 2015) and previous work commissioned by the Christchurch City Council (Aquatic Ecology Limited 2005, 2012; EOS Ecology 2013). Species shown in bold were found in one survey, but not detected in the other. The fishing method used at each site is given in parentheses.

Site name / number	Species found in 2015	Species found previously	Previous study – reference
Heathcote River at Rose Street / Centennial Park (Site 6)	Dominant species: shortfin eel **Giant bully**, upland bully, common bully, brown trout, elvers, longfin eel, shortfin eel *(single-pass electric fishing)*	Dominant species: shortfin eel Upland bully, **bluegill bully**[8], common bully, brown trout, elvers, longfin eel, shortfin eel *(multiple-pass electric fishing)*	Aquatic Ecology Limited 2005
Heathcote River downstream of Colombo Street (Site 9)	Dominant species: bluegill bully and common bully Bluegill bully, upland bully, common bully, brown trout, longfin eel, shortfin eel *(single-pass electric fishing)*	Dominant species: shortfin eel and common bully **Giant bully**, bluegill bully, upland bully, common bully, elvers, longfin eel, shortfin eel *(multiple-pass electric fishing)*	Aquatic Ecology Limited 2012
Heathcote River downstream of Tennyson Street (Site 10)	Dominant species: common bully and shortfin eel Upland bully, giant bully, common bully, elvers, longfin eel, shortfin eel *(single-pass electric fishing)*	Dominant species: eel elvers, shortfin eel, common bully Upland bully, giant bully, **bluegill bully**, common bully, longfin eel, shortfin eel *(multiple-pass electric fishing)*	Aquatic Ecology Limited 2012
Heathcote River at Aynsley Terrace (Site 12)	Dominant species: common bully Giant bully, common bully, longfin eel, shortfin eel, **inanga**, yelloweye mullet *(fyke nets and Gee minnow traps)*	Dominant species: shortfin eel Giant bully, common bully, longfin eel, shortfin eel, yelloweye mullet *(fykes net only)*	Aquatic Ecology Limited 2005
Estuary Drain within Bexley Park (Site 17)	Dominant species: shortfin eel Shortfin eel *(single-pass electric fishing)*	Dominant species: inanga Shortfin eel, **common bully, inanga** *(electric fishing, trapping)*	EOS Ecology 2013

8 A single bluegill bully specimen was collected from this site by Aquatic Ecology Limited (2012). This is the only known record of bluegill bully occurring at this site.

DISCUSSION

Main findings

This ecological assessment indicated that the waterways within the Heathcote, Estuary & Coastal, and Avon SMP catchments were generally of poor ecological health. Of the 15 sites surveyed, only two (sites 9 and 13) fell within the “fair” water quality category. The remainder of the sites surveyed were classified as “poor”, with probable severe enrichment. The QMCI scores of 60% (9 of 15) sites surveyed also fell below the minimum score of the 3.5 QMCI guideline of the pLWRP for spring-fed urban waterways. This is somewhat in contrast to results from the 2013 survey of the Avon SMP catchment (Boffa Miskell 2014), which found that 6 (of 29) sites fell within the “fair” water quality category, while one site was classified as “good”. Nevertheless, nearly 50% of the Avon SMP catchment sites surveyed also fell below the 3.5 QMCI guideline of the pLWRP (Boffa Miskell 2014).

Water quality

The basic water quality parameters of pH, dissolved oxygen, conductivity and temperature were within ranges expected in a spring-fed urban environment during base flow conditions. The water temperatures recorded were all below the pLWRP guidelines, except for site 17 (Estuary Drain within Bexley Park) where the water temperature at the time of sampling was close to 25°C. There was very little stream shading along Estuary Drain within Bexley Park, with only the occasional tree in an otherwise grassed riparian environment. Conductivity levels recorded in this study were higher than those recorded in the Avon SMP catchment (Boffa Miskell 2014), but not outside of what might be expected in a moderately impacted urban environment. Dissolved oxygen levels were generally above the minimum guideline recommended by the pLWRP. It is important to note that all of these water quality parameters were measured on one occasion only at each site. Spot readings do not take into account the natural diurnal and seasonal variability in water chemistry and temperature, and the macroinvertebrate community is a much better indicator of long-term stream health (e.g. the MCI and QMCI scores as measures of water quality and stream health).

Riparian and in-stream habitat

In-stream and riparian conditions, although variable among sites, were generally degraded often with low substrate indexes (indicating stream bed substrates dominated by finer particles and generally lacking in boulders and large cobbles). All of these in-stream habitat characteristics are important determinants of the biotic communities able to inhabit them (e.g. macroinvertebrates and fish).

Very little shading was present at many sites, and channels were modified with limited in-stream habitat heterogeneity. High habitat heterogeneity is important for stream health, as a greater variety of habitat conditions will support more and a greater variety of macroinvertebrate and fish species, which all have variable and sometimes unique habitat condition requirements.

Macrophyte and filamentous algal cover was generally low across the Heathcote, Estuary & Coastal, and Avon SMP catchments and the majority of sites were below the pLWRP guidelines for urban spring-fed systems. Extensive macrophyte beds were, however, present in the

Heathcote River at Aynsley Terrace, but these are periodically maintained (removed) by City Care's Waterways Management group.

Water depth and sediment depth, although variable across sites, were both greater in 2015, than 2010. An increase in sediment depth may be a result of earthquake derived sediments entering the waterways, but could equally be due to slight differences in sampling, natural variation, or differences in transect locations at each site. It is similarly difficult to determine why there were greater water depths found in 2015 than 2010. The only site where there was a substantially greater depth of soft sediment recorded consistently across the three transects (i.e. tight error bars around the mean) was at site 2, Cashmere Stream at Penruddock Rise. It is difficult to determine if this may be due to earthquakes or because of some other unmeasured environmental condition.

Macroinvertebrate community

The macroinvertebrate community of the Heathcote, Estuary & Coastal, and Avon SMP catchment sites were dominated by taxa typical of lowland urban waterways, such as chironomid midges, snails, ostracods, oligochaete worms, and amphipods). The pollution-sensitive or "clean-water" EPT taxa were represented only by a few species of caddisflies, while mayflies and stoneflies were absent. The relatively pollution-tolerant hydroptilid caddisflies *Oxyethira albiceps* and *Paroxyethira hendersoni* were found at the majority of sites surveyed. Mayflies are present in only a few of greater Christchurch's waterways, including the Styx River and Otukaikino Stream (e.g. Boffa Miskell 2015, EOS Ecology 2008b).

Fish community

It is important to remember that although the vast majority of the sites surveyed in this study were classified as having "poor" water quality (as determined by the macroinvertebrate communities found), native fish species were present at these sites. Some of these sites supported inanga, longfin eel, and bluegill bully, all of which are classified as "at risk, declining" (Goodman et al. 2013). Moreover, kōura (freshwater crayfish, "at risk, declining" Grainger et al. 2013) and kākahi (freshwater mussel, "at risk, declining" Grainger et al. 2013) shells, which are not commonly found in many of Christchurch's heavily urbanised catchments, were also present in some areas of the Heathcote River / Ōpāwaho and Cashmere Stream.

There were slight differences in the species composition found at five of the sites surveyed in this study, compared to the results from previous studies commissioned by the CCC. However, these differences were likely to be due to differences in field methodologies employed (e.g. inanga were found in this study at site 12 (Heathcote River at Aynsley Tce), where a number of fyke nets and Gee minnow traps were used. Inanga were not detected at the same site in 2005 (Aquatic Ecology Limited 2005) when only fyke nets were used. Furthermore, giant bully were captured at in some years but not others, but are not only relatively habitat specific (so can easily be missed if the slow-moving areas along the margins of a waterway are not well surveyed) but also often difficult to identify in the field. Of note, however, was the reasonable number of bluegill bullies in the Heathcote River downstream of Colombo Street. Bluegill bullies were not found at this site in the previous survey (Aquatic Ecology 2012).

All-in-all the differences in species composition over time are considered to be of negligible biological relevance, expect for that of Estuary Drain within Bexley Park, where the most marked differences were found. Only shortfin eels were recorded as present in this study, while EOS Ecology also found inanga and common bully (EOS Ecology 2013). While EOS Ecology used trapping in addition to electric-fishing methods (only electric fishing was used in this study), the water depth was much lower in the summer of 2015, compared to 2005. Gee minnow traps and fyke nets could not be set anywhere within the study reach, or well upstream of this site, due to a lack of water depth.

Ecological health of the catchments

When sites were ranked according to four of the macroinvertebrate biotic indices (taxonomic richness, EPT richness, % EPT richness, and QMCI) there was a general trend of decreasing stream health from the upper to lower reaches. Two of the three non-wadeable, tidal reaches of the Heathcote, and the Avon and Estuary & Coastal SMP catchment sites were ranked as the worst sites overall. This is clearly depicted by Figure 23, where the ranked overall ecological health is shown as a graduated colour scale from green – yellow – orange – red, where green indicates the best sites and red indicates the worst sites. For example, the upper reaches of the Heathcote River / Ōpāwaho and the two Cashmere Stream sites scored best overall, with Cashmere Stream upstream of Sutherlands Road being ranked as the best site of the 15 surveyed. Sites within the lower reaches of the Heathcote River / Ōpāwaho and the two Avon and Estuary & Coastal SMP catchment sites scored the worst overall with respect to ecological health. However, it is important to remember that this ranking is based on indices including the QMCI, which was developed for wadeable streams, and may not be applicable for non-wadeable lowland streams. Caution must also be used when applying the MCI and QMCI to urban catchments.

Moreover, when the fish community is also considered, some of the worst scoring sites (e.g. Sites 13, 14, and 18) supported the threatened migratory freshwater fish species longfin eel and inanga. Generally speaking, however, the sites that scored the best in habitat conditions also supported the "healthiest" and most diverse macroinvertebrate communities, and threatened fish species (bluegill bully, inanga, longfin eel).

The importance of the presence of kōura in the Heathcote River downstream of Barrington Street is also noteworthy. Kōura are known from only a few of Christchurch's waterways today, and tend to be most abundant in the less urbanised areas, such as Cashmere Stream (EOS Ecology 2013a). Kōura are thought to have declined in Canterbury's waterways due to land use change, and particularly effects of urbanisation such as removal / alteration of habitat conditions essential for kōura survival (e.g. earth banks for burrowing into, debris clusters, and macrophytes for refugia). In this study, the two kōura found were both collected during the electric fishing and were collected from a willow branch that had accumulated a lot of organic debris and was snagged near an undercut bank. These are the kinds of habitat that are often absent in urban waterways and are worth conserving, especially for fauna such as kōura. EOS Ecology 2013a also points out the importance of debris clusters, earth banks, and macrophyte cover as habitat essential for the survival of kōura in Christchurch's waterways.

Of similar importance was the presence of kākahi shells at two sites: Cashmere Stream upstream of Sutherlands Road and the Heathcote River downstream of Barrington Street. Kākahi is an iconic species, and are of great importance to Maori. Kākahi have previously been found in Cashmere Stream (EOS Ecology 2008a), but generally only downstream of the sites surveyed in this study. The presence of kākahi shells could be an indicator of the presence of live individuals in the upper reaches of the Cashmere Stream, or may be more reflective of the species' historical distribution.

Although the overall ecological health of the Heathcote, Estuary & Coastal, and Avon SMP catchments was found to be poor, some sites were found to have higher ecological values than others. For example, the upper reaches of the Heathcote River / Ōpāwaho and the Cashmere Stream sites scored highest when ranking a range of macroinvertebrate biotic indices. These sites also more commonly supported threatened native freshwater fish species, such as longfin eel, inanga, and bluegill bully.

Sites in the lower reaches of the Heathcote, and the Avon and Estuary & Coastal SMP sites were found to be the worst with respect to ecological health. However, as discussed previously, the indices used to assess ecological health may not always be appropriate for non-wadeable tidal waterways. This is particularly important to consider when evaluating the lower Heathcote River / Ōpāwaho sites.

Effects of urbanisation

The effects of urbanisation on stream ecosystems are complex, and often there are multiple and interrelated stressors at play. It's not always straightforward to determine the main drivers responsible for loss of 'sensitive, clean water' taxa. However, one of the main drivers of changes in community composition in urban systems is the amount of impervious surfaces and untreated stormwaters discharged through an open stormwater network. Untreated stormwater brings with it fine sediments and contaminants, which can then smoother the stream bed or be directly consumed by freshwater fauna.

Moreover, the straightening and channelizing of urban waterways to improve the drainage capacity and efficiency has marked consequences on in-stream habitat and the macroinvertebrate and fish communities. The importance of woody debris, log jams, and leaf packs was particularly apparent during the electric fishing of the Heathcote River / Ōpāwaho, when two kōura (one of a very large size; Photo 1) were found inhabiting snagged willow branches and leaf pack. This kind of habitat is rare in urban waterways, and particularly in those that are regularly maintained for flood conveyance purposes.

Photo 1. Kōura captured during electric fishing of the Heathcote River downstream of Barrington Street.

Flow heterogeneity

Flow heterogeneity is also extremely important, and efforts to enhance the variety of flow habitat within these sites would assist these waterways in supporting a greater variety and number of species. In particular, a small bluegill population was found in a relatively fast riffle present at the Heathcote River downstream of Colombo Street. Efforts in enhancing and increasing the availability of these fast riffle habitats, which are the preferred habitat of bluegill bullies, could be considered, as has been done in areas of the Avon River catchment. However, future stormwater management activities must also focus on reducing the levels of contaminants (e.g. suspended sediments, heavy metals, hydrocarbons) that are likely to be entering the catchment via the stormwater and overland flow paths.

Aquatic insect dispersal

Aquatic insects, and macroinvertebrates in general, are an important component of freshwater ecosystems. They play a vital role in processing of organic material (e.g. leaves, algae) and form the basis of the foodweb in New Zealand's waterways (i.e. they are food for fish).

It is well understood that aerial dispersal is an important colonisation mechanism used by winged stages of aquatic insects (e.g. caddisfly adults). Insects may fly along a river corridor or navigate between waterways in the search of suitable oviposition (egg laying) habitats. Many freshwater insects have specific oviposition requirements; some caddisfly species deposit eggs masses on the undersides of boulders in stream channels, while others specifically select emergent boulders, with specific downstream water velocities for oviposition sites. The size of the emergent boulder is important to some species, while others, it's the downstream water velocity that is most critical (Reich and Downes 2003). The successful recruitment of aquatic insect species, which in turn provide food sources for many of New Zealand's native freshwater fishes, is dependent on the availability of suitable oviposition habitat. There is a real lack of oviposition habitats in Christchurch's urban streams available for some of New Zealand's EPT taxa (Blakely and Harding 2005). The addition of emergent boulders, strategically placed in the channels, for example, would greatly improve the amount of egg-laying habitat available for some of the caddisfly species found in the Avon River catchment.

Studies have also shown that adult aquatic insects often face a number of anthropogenic barriers to dispersal in urban environments, which can all have implications for recruitment. For example, road crossings (i.e. culverts), light pollution (many of our caddisfly species are nocturnal), and the probable confusion of the built environment (e.g. concrete, which when wet reflects polarised light that confuses insects; tall buildings with few riparian 'markers' for species to navigate along and between waterways) may all disrupt adult aquatic insect flight (see discussion in Blakely et al. 2006).

Ecological connectivity

Maintaining ecological connectivity along a waterway is a crucial element for fish and macroinvertebrate communities. Many roads intersect waterways in urban environments and culverts are used as an alternative to bridges to pipe waterways under roads. While these piped sections are generally short (e.g. approximately 20 m long), culverts can still have a marked influence on the ability of both fish and macroinvertebrates to navigate through a stream network. A poorly constructed and placed road culvert can act as a barrier to fish passage, thereby preventing its migration along a waterway (Boubée et al. 1999). Road culverts are also known to impede the movement of crustaceans along a waterway (Resh 2005) and can limit the dispersal of the winged adult stages of aquatic insects, such as caddisflies (Blakely et al. 2006). It may be that aquatic insects cannot navigate through culverts, or that predation pressure is increased by a great number of spiders that often sit-and-wait inside road culverts. Or it could be that adult aquatic insects instead disperse overland, between waterways, and become disconnected from the stream and lost in the urban environment. These factors are important considerations in catchment management, particularly when source populations (i.e. potential colonists) of 'clean-water taxa' are generally absent from the Christchurch area.

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Data Sources:
Waterways data and aerial photograpgy sourced from
Projection: NZGD 2000 New Zealand Transverse Mercator

HEATHCOTE AND ESTUARY SMP CATCHMENTS

Figure 23 : Overall Ecological Health

Date: 29 June 2015 | Revision: 0

Plan Prepared for CCC by Boffa Miskell Limited

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

Recommendations

- There needs to be a multi-faceted approach to the management of Christchurch's urban waterways. For example, a continued focus should be on both treatment of stormwater and habitat rehabilitation activities.
- Areas of greatest ecological health need to be maintained through appropriate management activities, while areas of lower health could be improved over time through intensive management of stormwater and contaminated sediments, and riparian and in-stream enhancements.
- Stormwater management needs to continue to focus on reducing the quantity of sediment and contaminant inputs into the catchment. This may include retrofitting of existing drainage and stormwater connections, where possible.
- Best practice stormwater management techniques need to be employed in areas of future residential and urban development, particularly in areas where ecological health is greatest and threatened species and species rare to Christchurch still occur.
- Enhancement of riparian and in-stream habitat conditions, particularly in areas:
    - Where retrofitting of stormwater connections is undertaken;
    - Of greatest ecological health; and
    - With limited ecological habitat.
- Consider assessing the effects of the current macrophyte and stream maintenance practices to reduce likely disturbance to in-stream fauna.
- Include the addition of a variety of larger substrates (e.g. emergent and submerged boulders, debris clusters, macrophyte beds) in habitat enhancement activities, particularly to increase the availability of oviposition habitats and refugia for freshwater fauna, including locally significant species such as caddisflies, bluegill bullies, longfin eels, kōura, and kākahi.
- Consider, and where possible, improving longitudinal connectivity along the stream corridors, by limiting impacts of in-stream structures such as culverts and low bridges on migrating freshwater fauna (fish and macroinvertebrates, including aerially dispersing adult aquatic insects).
- Consider the inclusion of lighting systems that limit the effects of light pollution on freshwater fauna.
- Use ecologically sensitive species when conducting riparian planting activities, including locally-sourced native species, and preferably evergreen or with low-leaf fall so as to avoid overwhelming streams with leaf litter inputs in the autumn.

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Appendix 1: Site Location Information Supplied by the CCC

[9] Sites shaded in grey were not surveyed in this study.

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
1	Heathcote River	Cashmere Stream: upstream of Sutherlands Road	2476053	5735601	Long-term & South-West SMP aquatic ecology site; long-term water quality site; nearby to 1988 sediment quality site	James, 2010: - Site 37 - Habitat, macrophytes & macroinvertebrates Christchurch Drainage Board, 1988: - Site 26 (nearby) - Sediment quality
2	Heathcote River	Cashmere Stream: Penruddock Rise	2477914	5736703	Long-term & South-West SMP aquatic ecology site; 1988 sediment quality site	James, 2010: - Site 33 - Habitat, macrophytes & macroinvertebrates Christchurch Drainage Board, 1988: - Site 42

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
						- Sediment quality
3	Heathcote River	Heathcote River: at Templetons Road	2475917	5738512	South-West SMP aquatic ecology site; 1988 sediment quality site;	Christchurch Drainage Board, 1988: - Site 83 - Sediment quality
4	Heathcote River	Heathcote River: Canterbury Park/Showgrounds	2476513	5739053	Long-term & South-West SMP aquatic ecology site; long-term sediment quality site	James, 2010: - Site 36 - Habitat, macrophytes & macroinvertebrates Christchurch Drainage Board, 1988 & Kingett Mitchell Ltd, 2005: - Site 90/HE22

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
						- Sediment quality
5	Heathcote River	Heathcote River: downstream of Spreydon Domain	2477972	5738777	Long-term & South-West SMP aquatic ecology site; nearby to 1988 sediment quality site	James, 2010: - Site 34 - Habitat, macrophytes & macroinvertebrates Christchurch Drainage Board, 1988: - Site 102 (nearby) - Sediment quality
6	Heathcote River	Heathcote River: Rose Street/Centennial Park	2478700	5737538	Long-term & South-West SMP aquatic ecology site; Long-term water quality site; nearby to long-term	James, 2010: - Site 35 - Habitat, macrophytes & macroinvertebrates Taylor & Blair, 2012 - Site 2

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
					sediment quality site	- Fish Christchurch Drainage Board, 1988 & Kingett Mitchell Ltd, 2005: - Site 115/HE27 (nearby) - Sediment quality
7	Heathcote River	Heathcote River: downstream of Barrington Street	2480159	5737791	Long-term aquatic ecology site; nearby to 1988 sediment quality site	James, 2010: - Site 31 - Habitat, macrophytes & macroinvertebrates Christchurch Drainage Board, 1988: - Site 124 (nearby) - Sediment quality

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
8	Heathcote River	Cashmere Brook: Ashgrove Terrace	2480258	5737964	Long-term aquatic ecology site	James, 2010: - Site 38 - Habitat, macrophytes & macroinvertebrates
9	Heathcote River	Heathcote River: downstream of Colombo Street	2480841	5738474	Long-term aquatic ecology site; nearby to 1988 sediment quality site	James, 2010: - Site 30 - Habitat, macrophytes & macroinvertebrates Taylor & Blair, 2012 - Site 8 - Fish Christchurch Drainage Board, 1988: - Site 127 (nearby) - Sediment quality

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
10	Heathcote River	Heathcote River: downstream of Tennyson Street	2481520	5738845	Long-term aquatic ecology site; nearby to 1988 sediment quality site	James, 2010: - Site 29 - Habitat, macrophytes & macroinvertebrates Taylor & Blair, 2012 - Site 1 - Fish Christchurch Drainage Board, 1988: - Site 138 (nearby) - Sediment quality
11	Heathcote River	Jacksons Creek: Cameron Reserve	2481211	5739629	Long-term aquatic ecology site	James, 2010: - Site 32 - Habitat, macrophytes & macroinvertebrates

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
12	Heathcote River	Heathcote River: Aynsley Terrace	2482928	5738430	Previous fish survey; nearby to 1988 sediment quality site	Taylor, 2005 - Site E & F - Fish Christchurch Drainage Board, 1988: - Site 147 (nearby) - Sediment quality
13	Heathcote River	Heathcote River: Catherine Street (tidal site)	2484415	5739494	Previous biological and botanical survey; long-term water quality site;1988 sediment quality site	Robb, 1994, and van den Ende & Partridge, 2008 - Site 164/H164 - Macrophytes & periphyton Christchurch Drainage Board, 1988: - Site 164 - Sediment quality

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
14	Heathcote River	Heathcote River: Tunnel Road (tidal site)	2485076	5739154	Previous biological and botanical survey; long-term water quality site;1988 sediment quality site	Robb, 1994, and van den Ende & Partridge, 2008 - Site 179/H179 - Macrophytes & periphyton Christchurch Drainage Board, 1988: - Site 179 - Sediment quality

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
15	Heathcote River	Steamwharf Stream	2485052	5739405	Previous inanga spawning reach severely impacted by sedimentation from earthquakes	Taylor & Blair 2011 - inanga spawning
16	Heathcote River	Heathcote River: Ferrymead Bridge (tidal site)	2486494	5738760	Previous biological and botanical survey; long-term water quality site; long-term sediment quality site	Robb, 1994, and van den Ende & Partridge, 2008 - Site 190/H190 - Macrophytes & periphyton Christchurch Drainage Board, 1988 & Kingett Mitchell, 2005: - Site 190/HE34 - Sediment quality

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
17	Estuary Drain (within Estuary SMP area)	Estuary Drain: Bexley Park	2486914 [10]	5743051	Previous fish survey	Sinton, 2013 - Site referred to as 'immediately below dewatering discharge'
18	City Outfall Drain/Linwood Canal (within Estuary SMP area)	City Outfall Drain/Linwood Canal: Dyers Road/Linwood Avenue	2485373	5740054	Previous botanical survey; 1988 sediment quality site	Robb et al., 1994 - Site Od 9 - Macrophytes & periphyton

[10] Coordinates to be confirmed on site

Site Number	Catchment	Site Name	Easting	Northing	Reasoning	Last Surveys
						Christchurch Drainage Board, 1988: - Site OD8 - Sediment quality

Appendix 2: Macroinvertebrate Sample Processing

Boffa Miskell

Heathcote River, March 2015

Summary of Freshwater Macroinvertebrate Sample Processing & Results

Prepared by Jarred Arthur, MSc.

Reviewed by Ben Ludgate, MSc.

June 2015

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Background

Preserved benthic macroinvertebrate samples were provided to Ryder Consulting by Boffa Miskell. Boffa Miskell staff collected these samples in March 2015. Ryder Consulting Ltd was engaged to process the Heathcote River samples, and report the results of taxonomic composition.

Laboratory Analysis

Samples were passed through a 500 µm sieve to remove fine material. Contents of the sieve were then placed in a white tray and macroinvertebrates were counted and identified by eye and under a dissecting microscope (10-40x) using criteria from Winterbourn *et al.* (2006).

Results

The macroinvertebrate results have been forwarded to Boffa Miskell in electronic form.

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Appendix 3: General Site Conditions

Site 1: Cashmere Stream upstream of Sutherlands Road

This site was located in the headwaters of Cashmere Stream, upstream of Sutherlands Road, in the rural outskirts of the city. Here the stream was approximately 1.5 m wide and shallow, with an average water depth of 5 cm. The velocity on the day of sampling was 0.33 m / s. Although the stream channel was natural (rather than lined), it was constrained by a shelter belt on the true right. This shelter belt provided a substantial amount of shade (50-75%) to the channel in the upper area of the site, but downstream towards Sutherlands Road was more open with much less stream shading (Photo 2). The stream bed was dominated by gravels and pebbles, with a Substrate index of 4. However, these coarser substrates were relatively embedded by fine substrates. Macrophyte cover was patchy within the site, with between 5% and 60% cover recorded across the three transects, including the macrophytes duckweed (*Lemna* sp.), floating sweetgrass (*Glyceria fluitans*) and the alga *Nitella hookeri*. Exotic species dominated the macrophyte community.


Photo 2. Cashmere Stream, upstream of Sutherlands Road (Site 1), looking downstream (left) and upstream (right).

Site 2: Cashmere Stream at Penruddock Rise

Site 2 was also located on Cashmere Stream at Penruddock Rise, approximately 2.5 km downstream of site 1 and around 1 km upstream of the confluence with the Heathcote River. Here Cashmere Stream was wider (approximately 5 m) and deeper (60 cm) than upstream at site 1. Velocity on the day of sampling was 0.29 m / s. Cashmere Stream at site 2 was within a residential area, but the immediate riparian margin was within Cashmere Stream Esplanade Reserve with substantial riparian vegetation cover (both native and exotic species) (Photo 3). However, the wider nature of the channel here meant that canopy cover (and shading) was patchy, ranging from 0% to 80% cover. The stream bed had a moderate substrate index (3.08), indicating the substrates were dominated by finer silt and sands with some cobbles and pebbles. Some large cobbles and artificial substrates (e.g. bricks and concrete pieces) were observed but were not recorded within the quadrats surveyed. Macrophyte cover, including species such as Canadian pondweed (*Elodea canadensis*), curly pondweed (*Potamogeton crispus*), and the alga *Nitella hookeri*, was high across much of the stream bed surveyed, with recordings of up to 80-100% in some quadrats. Exotic species dominated the macrophyte community. Organic material, such as leaves, sticks, and large woody debris, was relatively abundant at the site.

Photo 3. Cashmere Stream, at Penruddock Rise (Site 2), looking downstream (left) and upstream (right).

Site 3: Heathcote River at Templetons Road

Site 3, Heathcote River at Templetons Road, the uppermost site in the Heathcote River, was dry (with isolated pools) at the time of the survey (Photo 4). As such, an aquatic assessment was not conducted at this site during this 2015 study.

Photo 4. Heathcote River at Templetons Road (Site 3), looking downstream (left) and upstream (right). This site was dry with only a few isolated pools immediately up- and downstream of the proposed survey reach, so was not surveyed during this 2015 study.

Site 4: Heathcote River within Canterbury Park / Showgrounds

Site 4 was located in the Heathcote River, approximately 1.4 km downstream of site 3, where it flows through the Canterbury Park / Showgrounds (true left) (Photo 5). Here the river was approximately 4.5 m wide, with an average water depth of 15 cm. The velocity on the day of sampling was 0.09 m / s. The banks of the river were partially lined with timber (both banks) and concrete / brick (true right bank). The riparian vegetation consisted of grasses, flaxes, and scattered trees and shrubs, all of which provided some shading (at times) to the channel margins. However, much of the in-stream habitat was without shade at the time of surveying. Macrophytes were patchy throughout the survey reach, with some curly pondweed, sweetgrass, and duckweed present. Exotic species dominated the macrophyte community. City Care’s stream maintenance team had recently conducted the macrophyte maintenance / removal at this site (Ben Lay, Waterways Supervisor, City Care, pers. comm). The stream bed was dominated by gravels and pebbles, with a Substrate index of 4. However, these coarser substrates were relatively embedded by fine substrates.

Photo 5. Heathcote River within Canterbury Park / Showgrounds (Site 4), looking downstream (left) and upstream (right).

Site 5: Heathcote River downstream of Spreydon Domain

The Heathcote River downstream of Spreydon Domain (Site 5) was approximately 4 m wide, with an average water depth of 15 cm. On the day of sampling, velocity was 0.28 m / s. The river was within a residential area, but downstream of Spreydon Domain. This site was approximately 1.8 km downstream of site 4. The true left bank was earth, whereas the true right had some rock to stabilise it. There was quite a lot of *Carex* grasses overhanging the channel, some trees providing in-stream shading, and exotic species such as bear's breeches (*Acanthus* sp.) (Photo 6). The stream bed was dominated by gravels, pebbles, and cobbles, with a Substrate index of 4.1. These coarser substrates were embedded by fine sediments. There were few macrophytes present at the time of sampling.

Photo 6. Heathcote River downstream of Spreydon Domain (Site 5), looking downstream (left) and upstream (right).

Site 6: Heathcote River at Rose Street / Centennial Park

Site 6 was located on the Heathcote River where it flows through Centennial Park, approximately 1.7 km downstream of site 5. The site included a small riffle immediately upstream of Rose Street (Photo 7). The river was 3.5 m wide with an average depth of 17 cm. The velocity was 0.31 m / s. The river was within residential area (true right) and parkland (true left). On the right bank, the riparian vegetation was predominantly trees and shrubs, while the left bank was generally mown grasses of Centennial Park with some plantings of *Carex* grasses downstream towards Rose Street. The Substrate index at site 6 was moderate (4.7), indicating the substrate was dominated by gravels and pebbles. Macrophytes were present, with an average cover of 37%, including the common species curly pondweed and sweetgrass. Exotic species dominated the macrophyte community.

Photo 7. Heathcote River at Rose Street / Centennial Park (Site 6), looking downstream (left) and upstream (right).

Site 7: Heathcote River downstream of Barrington Street

Site 7 was located on the Heathcote River, downstream of Barrington Street (approximately 2 km downstream of site 6; and upstream of the confluence with Cashmere Brook). The river was wider and deeper, with an average width of 6.5 m and depth of 25 cm. The site included a moderately fast riffle section (Photo 8). On the day of sampling, the velocity was 0.36 m / s. Both banks were earth with scattered trees and grass. The trees provided some shading to the channel. The Substrate index was moderate, with a value of 4.4, indicating the substrates were dominated by gravels and pebbles. Macrophytes were present at the site, with approximately 70-90% cover dominated by curly pondweed. Exotic species dominated the macrophyte community, but the native species red pondweed (*Potamogeton cheesemanii*) was present.

There was a discharge (Photo 8, right hand image), presumed to be sediment from construction works upstream of the site, which began after the sampling was completed.

Photo 8. Heathcote River downstream of Barrington Street (Site 7), looking downstream (left) and upstream (right).

Site 8: Cashmere Brook at Ashgrove Terrace

Site 8 was within Cashmere Brook along Ashgrove Terrace. Cashmere Brook converges with the Heathcote River, just downstream of where site 7 was located. This tributary of the Heathcote River was approximately 2.5 m wide and 5 cm deep within the survey site. The survey site encompassed a small riffle section immediately upstream of the Ashgrove Terrace culvert. The velocity on the day of sampling was 0.20 m / s. The canopy cover and stream shading was variable within the site, with some areas with nearly 100% shade, while other areas were in full sun (Photo 9). The Substrate index of 4.15 indicated substrates dominated by gravels and pebbles, however, many of these coarser substrates were highly embedded by fine silts (especially at the upstream end of site 8). Macrophytes were generally absent, with only a small patch of the floating macrophyte, duckweed, observed when surveying.

Photo 9. Cashmere Brook at Ashgrove Terrace (Site 8), looking downstream (left) and upstream (right).

Site 9: Heathcote River downstream of Colombo Street

The Heathcote River downstream of Colombo Street (Site 9) ranged in width from 2.7-4.8 m (average 3.8 m), with an average water depth of 30 cm. This site was approximately 1 km downstream of site 7. A fast riffle was included in the survey site, and the average velocity on the day of sampling was 0.72 m / s. The riparian vegetation was dominated by grass, with some willow trees and shrubs providing some shade to the river (Photo 10). Curly pondweed (an exotic species) was abundant in places, but overall macrophyte cover was low. The substrate was dominated by gravels and pebbles, with a Substrate index of 4.7. Embeddedness was relatively low, compared to the other sites surveyed.

Photo 10. Heathcote River downstream of Colombo Street (Site 9), looking downstream (left) and upstream (right).

Site 10: Heathcote River downstream of Tennyson Street

Site 10 was located on the Heathcote River downstream of Tennyson Street, approximately 3 km downstream of site 9. The river was approximately 5.5 m wide and 35 cm deep here, with a velocity of 0.52 m / s on the day of sampling. Bank conditions were similar to that of Site 9 at Colombo Street, being dominated by grass with some willow trees and flaxes (Photo 11). Most of the survey site had limited canopy cover with little stream shading. Macrophytes were relatively common at site 10, with curly pondweed (an exotic species) covering about 25% of the channel. The substrate was dominated by silt / sand and small cobbles, with a Substrate index of 4.5.

Photo 11. Heathcote River downstream of Tennyson Street (Site 10), looking downstream (left) and upstream (right).

Site 11: Jacksons Creek within Cameron Reserve

Site 11, Jacksons Creek within Cameron Reserve, was dry at the time of the survey (Photo 12). As such, an aquatic assessment was not conducted at this site during this 2015 study.


Photo 12. Jacksons Creek within Cameron Reserve (Site 11), looking downstream (left) and upstream (right). This site was dry, so was not surveyed during the 2015 study.

Site 12: Heathcote River at Aynsley Terrace

Site 12 was located on the Heathcote River at Aynsley Terrace, approximately 3 km downstream of site Site 10. The river was tidally influenced at Site 12, with an average wetted width 17.5 m and 74 cm depth at low tide. There was a marked deep channel (> 1 m) of approximately 2 m in the middle of the river at this site. The remainder of the river was shallower, with macrophytes dominated by the exotic species curly pondweed and Canadian pondweed covering the majority of the bed. However, these macrophyte beds were largely cleared shortly after the survey was completed (Photo 13). The velocity on the day of sampling was 0.19 m / s (recorded in the middle of the channel). The substrate was dominated by fine silt and sand, with a Substrate index of 3.


Photo 13. Heathcote River at Aynsley Terrace (Site 12), looking downstream (left) and upstream (right). Note, the original photos taken of this site were corrupted; these photos were taken in May 2015 and show newly trimmed riparian vegetation. The aquatic macrophytes had also be removed from much of the channel at the time this photo was taken.

Site 13: Heathcote River at Catherine Street

The Heathcote River at Catherine Street (Site 13) was immediately upstream of the control gates of the Woolston Cut (Photo 14) and approximately 2.3 km downstream of site 12. This was a non-wadeable site, and when surveyed at low tide the mid-sections of the channel could not be fully surveyed. The site was approximately 30 m wide with an average depth of 38 cm (excluding the middle of the channel, which was much deeper). The velocity on the day of sampling was 0.08 m / s. The river bed was dominated by silt and sand, with a Substrate index of 3.1. Macrophytes was common in places, with curly pondweed, red pondweed and fennel-leaved pondweed (*P. pectinatus*), as well as *Nitella hookeri* (alga) and *Rivularia* (alga). Canadian pondweed was also present, but not common. Exotic species dominated the macrophyte community at this site.

Photo 14. Heathcote River at Catherine Street (Site 13), looking downstream (left) and upstream (right).

Site 14: Heathcote River at Tunnel Road

The downstream most site on the Heathcote River was located at Tunnel Road (Site 14). The river was very tidal here, with an average wetted width of approximately 15 m at low tide, but increasing to around 35 m at high tide (Photo 15). The river was, on average, 56 cm deep here (excluding the middle of the channel, which was much deeper) and velocity on the day of sampling was 0.28 m / s. The river banks were earth, with some rock reinforcing. The bed of the river was dominated by silt and sand as reflected by the Substrate index of 3 for this site. No macrophytes were observed at this site.

Photo 15. Heathcote River at Tunnel Road (Site 14), looking downstream (left) and upstream (right).

Site 15: Steamwharf Stream

Steamwharf Stream (Site 15) was upstream of Dyers Road and approximately 300 m upstream of its confluence with the Heathcote River. The stream flows through residential housing, with a small reserve (Steamwharf Stream Reserve) on the true left within the study site. The stream banks were earth, with high vegetation (dominated by native species) cover that provided some stream shading (Photo 16). The stream was approximately 4 m wide with an average depth of around 9 cm. On the day of sampling, the velocity was 0.17 m / s. The substrates consisted almost entirely of silt and sand with a Substrate index of 3. Macrophytes were sparse, with approximately 10% cover, dominated by bachelor's button (*Cotula coronopifolia*, native species). Long green filamentous algae was abundant at the site (total cover approximately 30%).

Photo 16. Steamwharf Stream (Site 15), looking downstream (left) and upstream (right).

Site 17: Estuary Drain within Bexley Park

Site 17 was located within Estuary Drain within Bexley Park. This waterway was approximately 1 m and very shallow (average 5 cm water depth) at the time of sampling. There was very little flow on the day of sampling, with a recorded velocity of 0.18 m / s. The stream bed was covered with a thick layer of silt and sand (more than 1 m in depth, in places), with a Substrate index of 3. The riparian vegetation was largely long pasture grasses with some trees, which provided very little shade to the channel. Watercress (*Nasturtium officinale*, exotic species) and bachelor's button (native species) formed extensive macrophyte beds along the channel margins (Photo 17). Few macrophytes were present in the channel. Short filamentous algae was abundant, with some patches of long green filamentous algae also present.

Photo 17. Estuary Drain within Bexley Park (Site 17), looking downstream (left) and upstream (right).

Site 18: City Outfall Drain / Linwood Canal

Site 18 was located in the City Outfall Drain, or Linwood Canal, which runs parallel to Linwood Road. This site was immediately upstream of Dyers Road and approximately 800 m upstream from its discharge point into the Avon-Heathcote Estuary. Wetted width and depth varied within the site, but on average was approximately 6 m wide and 21 cm deep. There was negligible flow (0.05 m / s) on the day of sampling (Photo 18). The City Outfall Drain, at the survey site, flowed through a residential area and a small area of roadside / streamside planting. This area was generally well planted with native species, with high riparian cover (dominated by native species) that provided some shade to the waterway, particularly along the margins. Macrophytes were relatively abundant, dominated by the exotic curly pondweed.

Photo 18. City Outfall Drain / Linwood Canal (Site 18), looking downstream (left) and upstream (right).