Ecosystem health in Wellington City urban streams:

Stage one summary report

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Executive summary

There is an extensive network of streams in the Wellington City area. Many of these streams have been piped and historically there has been minimal information on their ecological health (in terms of habitat condition, macroinvertebrate community health and fish populations). To address this knowledge gap, Greater Wellington Regional Council (GWRC) has worked with Wellington City Council (WCC) over the last three years to better understand the ecological health of Wellington’s piped and open urban streams.

Monitoring commenced in 2016 and has continued over the summer months until 2019. During this time, a range of open urban streams in Wellington City have been surveyed on a single occasion to assess habitat condition, macroinvertebrate community health and fish populations. During this period habitat condition, macroinvertebrate and fish populations were also surveyed in piped streams by EOS Ecology.

The purpose of the monitoring is to provide a baseline of information from which a long-term monitoring programme for Wellington City stream ecosystem health can be developed. This monitoring programme is needed to report against National Policy Statement for Freshwater Management and GWRC Proposed Natural Resources Plan objectives for ecosystem health. Information is also needed to inform a range of Wellington City Council and Wellington Water strategies aimed at reducing the impact of urban land use on Wellington City stream ecosystems. This report presents the results of baseline monitoring for open streams. Interim results for the piped stream survey are attached as a separate report.

Ecosystem health data collected to date indicate Wellington City urban streams contain a range of values related to habitat, macroinvertebrates and fish. Key findings were:

- Macroinvertebrate communities were generally in better condition in streams with less urban landuse and impervious area in the upstream catchment.
- Fish communities within urban streams were generally in fair to poor condition. However, there is greater fish diversity in sections of stream with direct connection to the sea.
- Inanga spawning was occurring in bank vegetation in the lower Kaiwharawhara Stream.
- Banded kokopu and eel species were the most abundant fish species present across the majority of sites surveyed. Native fish species present included at risk and declining species such as koaro, inanga, redfin bully, longfin eel and giant kokopu.
- Barriers to fish movement are likely to be one of the major pressures influencing fish communities in Wellington urban streams. The only fish species found upstream of piped sections of stream are climbing species (banded kokopu, koaro and eel species). The presence of banded kokopu and eels in piped stream sections was confirmed in the piped stream survey.

- Macroinvertebrate and fish communities in Wellington City streams appear to be driven by different environmental stressors. The healthiest macroinvertebrate communities were generally found higher in catchments where habitat and water quality degradation from urban runoff is less. In contrast, fish communities were generally in better condition at sites lower in the catchment where there were likely to be less barriers to migration to and from the sea. This finding highlights the need for a whole of catchment approach for improving ecosystem health of Wellington City streams.

- The initial piped stream survey has shown that some sections of piped streams have habitat which supports fish and macroinvertebrate life, however species richness and abundance is greater in free flowing streams. The complete enclosing of open channels significantly reduces habitat quality for stream life and means only a subset of available taxa within catchments are able to persist there.

The next stage will involve design of a long term monitoring programme of Wellington City stream ecosystem health. This will involve working with WCC to identify objectives of the programme, monitoring sites, parameters to be measured, sampling frequency and reporting required. Targeted investigations needed to answer specific questions around management actions will also be identified. The programme will be designed in 2019/20 for implementation in 2020/21.

Contents

1. Introduction

1.1 Background and objectives

There is an extensive network of streams within the Wellington City area. Of the rivers and streams monitored in the Wellington region, those with significant urban landuse within their catchments are consistently identified as having the poorest water quality and ecological health (eg. Mitchell and Heath, 2019). Pressures on these urban streams include:

- Contamination and erosion from stormwater discharges
- Contamination from sewer overflows/cross connections and other unauthorised discharges
- Habitat degradation through straightening and lining of stream banks with concrete or rock armouring
- Loss of stream habitat and function through stream piping and reclamation
- Barriers to fish migrations such as weirs and perched culverts

Water and habitat quality in urban streams is frequently poor, reflecting the land use activities in surrounding urban catchments. This in turn affects biota, the ability of people to use waterways for recreation, and degrades downstream receiving environments. The poor ecological health of urban stream systems is commonly referred to as “urban stream syndrome” (Walsh et al., 2005), where several physical, chemical and biological characteristics of urban streams are altered. Urban stream health has been shown to be strongly correlated to the amount of impervious surfaces such as roofs, roads and carparks in the catchment (Walsh et al., 2005).

Previous analyses have shown that urban stream health in the Wellington region (indicated by macroinvertebrate communities) decreases to fair/poor condition with increasing impervious land cover greater than approximately 15% (Warr, 2009). However, to date, there is not a full understanding of the range of ecosystem health values related to habitat, fish and macroinvertebrates across the range of Wellington urban streams (James, 2015). Nor is there any ecological information on the habitat quality, macroinvertbrates and fish in the piped stream systems across Wellington City (James, 2015). This information is required to inform the decision making related to managing the effects of land development and stormwater management.

Greater Wellington Regional Council (GWRC) is implementing a programme to identify and monitor the ecosystem health values of Wellington City’s urban streams. The programme includes assessments in open and piped streams and is jointly funded by Wellington City Council (WCC) and GWRC.

Stage one monitoring commenced in 2016 and continued over the summer months until 2019. During this time, a range of open and piped streams in Wellington City have been surveyed to assess habitat condition, macroinvertebrate community health and fish populations. (see the interim piped streams project report attached in Appendix 2). The intention of this monitoring was to provide a baseline assessment of ecosystem health, which would then inform a long-term monitoring programme to measure the state and trends in the ecosystem health of urban streams in Wellington City (Stage two).

This monitoring will be used to report against the objectives in the National Polity Statement for Freshwater Management and Proposed Natural Resources Plan (PNRP) for the Greater Wellington Region. The monitoring results will be used to assess the effectiveness of Wellington City Council strategies which aim to decrease the impacts of urban land use and stormwater runoff on Wellington City streams.

This report presents the results of Stage one monitoring of WCC urban streams. The report also explores the likely effects of urbanisation on stream ecosystem health in Wellington City streams. Finally, next steps for long term monitoring of state and trends in the ecosystem health of streams in Wellington City (stage two) are presented.

1.2 Linkages to management of urban streams in Wellington City

There are several management strategies and policies which require information on the current state of ecosystem health of Wellington City urban streams and seek to reduce the effect of surrounding urban land use (Table 1.1).

Assessments of urban stream ecosystem health using habitat, macroinvertebrate and fish will support these policies and strategies by:

- Identifying the range of biodiversity values in Wellington City's urban streams related to fish and macroinvertebrate communities;
- Identifying habitat requirements for the management of healthy fish and macroinvertebrate communities in urban environments;
- Providing reliable data for community groups to target areas for restoration activities;
- Raising awareness of urban stream biodiversity among local communities
- Understanding the current distribution of fish species within the city and changes from historical distributions;
- Assessing the effectiveness of management actions; and
- Understanding how and where to prioritize actions such as improvements to fish passage in open and piped streams.

The monitoring programme will be designed to provide as much information as possible to inform these policies and strategies. However, it won't be possible to answer all questions about the effect of urban land use in WCC on stream ecosystem health. In some cases targeted studies may need to be set up to answer specific questions such as the effectiveness of stormwater action plans.

Table 1.1: Strategies and policies related to the management of urban stream ecosystem health in Wellington City

Agency	Strategy/Policy	Linkage
Greater Wellington Regional Council	Proposed Natural Resources Plan and National Policy Statement for Freshwater Management	Assessment of objectives related to ecosystem health
Wellington City Council	Our Natural Capital	Identification of biodiversity values and maintaining/improving these values into the future
Wellington City Council	Resilience Strategy	Understanding of current urban freshwater ecosystem health and effects of any actions to improve stormwater quality entering urban streams
Wellington City Council	Urban Growth Strategy	Understanding the effects of future urban development options or urban stream ecosystem health to minimise any impacts
Wellington City Council/New Zealand Transport Authority	Roading strategies	Effects of roading maintenance and construction on urban stream ecosystem health
Wellington Water/Wellington City Council	Stormwater management plans	Assessment of stormwater management actions related to the improvement of urban stream ecosystem health
Wellington Water	Stormwater system maintenance	Information to assist with the maintenance of stormwater assets and allowances for fish passage through piped streams

2. Methods

2.1 Site location and data collection

Fifty survey sites were spread across a range of urban streams throughout the WCC area, including sites upstream of urban areas and stream sections within the current urban footprint. Sites were also located in catchments with no current urban land use (Waipapa Stream catchment on the Wellington South Coast; South Makara stream catchment) (Figure 2.1). Data collected at each site is outlined in Table 2.1.

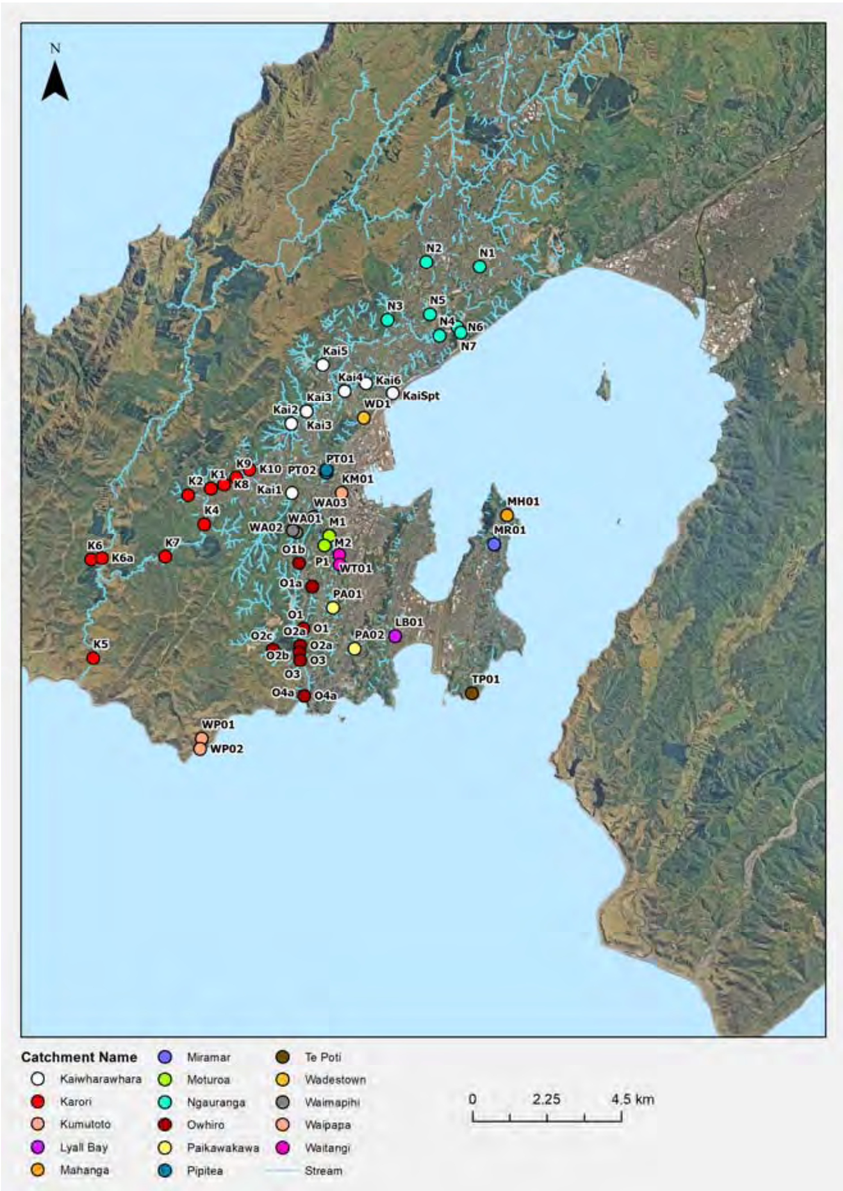

Figure 2.1: Locations of Wellington City stream sites surveyed for habitat quality, macroinvertebrate and fish community health between 2016 and 2019 (see Table 2 for site names and details)

Table 2.1: Location of survey sites and data collected at each site (✓ = collected 2018/19; ✓ = collected 2017/18; ✓ = collected 2016/17)

Catchment	Site code	Site name	Habitat	Macro-invertebrates	Fish	
					Electro Fishing	Spotlight
Karori	K1	Karori S at Karori Pk	✓	✓	✓	✓
	K2	Karori S at Castlemaine Cl	✓	✓	✓	✓
	K4	Karori S at Makara Peak Mt Bike Pk	✓	✓	✓	
	K5	Karori S at Makara coast	✓	✓	✓	✓
	K6	South Makara S tributary at South Makara Rd	✓	✓	✓	✓
	K6a	South Makara S at South Makara Rd				✓
	K7	Karori S at South Karori Rd	✓	✓	✓	
	K8	Karori S opposite Sunshine Ave	✓	✓	✓	
	K9	Karori S at Darwin St	✓	✓	✓	✓
	K10	Karori S at Futuna Cl			✓	✓
Ngauranga	N1	Ngauranga S at Newlands Rd	✓	✓	✓	
	N2	Ngauranga S near Alex Moore Pk	✓	✓	✓	
	N3	Ngauranga S at Mount Kaukau	✓	✓	✓	
	N4	Ngauranga S at Tyers Stream Reserve	✓	✓	✓	
	N5	Ngauranga S at Taylor Prestons	✓	✓	✓	
	N6	Ngauranga S at Ngauranga Gorge rail crossing				✓
	N7	Ngauranga S 400m above mouth	✓	✓	✓	✓
Moturoa	M1	Moturoa S at bottom of Central Pk	✓	✓	✓	
	M2	Moturoa S at top of Central Pk	✓	✓	✓	
Kaiwhara-whara	Kai1	Kaiwharawhara S below the dam	✓ ✓	✓	✓	✓
	Kai2	Kaiwharawhara S below piped section	✓ ✓	✓	✓	✓
	Kai3	Kaiwharawhara S at Otari Wilton's Bush	✓ ✓	✓	✓ ✓	✓
	Kai4	Kaiwharawhara S below Korimako confluence	✓	✓		✓
	Kai5	Korimako S at Girl Guides	✓ ✓	✓	✓	✓
	Kai6	Kaiwharawhara S at Ngaio Gorge	✓	✓		✓
	KaiSpt	Kaiwharawhara S at Spotlight				✓ ✓
Owhiro	O1	Owhiro S upstream of TNT Landfill	✓	✓	✓	✓
	O1a	Owhiro S on Ohiro Rd below Brooklyn town				✓
	O1b	Owhiro S headwaters at Elliot Pk				✓

Table 2.1 cont: Location of survey sites and data collected at each site (✓ [green] = collected 2018/19; ✓ [red] = collected 2017/18; ✓ [black] = collected 2016/17)

Catchment	Site code	Site name	Habitat	Macro-invertebrates	Fish	
					Electro Fishing	Spotlight
Owhiro	O2a	Owhiro S downstream of TNT Landfill	✓ [black]	✓ [black]	✓ [black]	✓ [red]
	O2b	Owhiro S below Landfill Rd Confluence				✓ [red]
	O2c	Owhiro S at S landfill gate on Landfill Rd				✓ [red]
	O3	Owhiro S upstream of Murchison St	✓ [black] ✓ [red]	✓ [red]	✓ [black]	✓ [red]
	O4a	Owhiro S downstream of Happy Valley Rd	✓ [black]	✓ [black]	✓ [black]	✓ [red]
Kumutoto	KM01	Kumutoto Stream at Vic Uni	✓ [green]	✓ [green]		✓ [green]
Lyall Bay	LB01	Ngaroma Stream	✓ [green]	✓ [green]		✓ [green]
Mahanga	MH01	Mahanga Bay Stream	✓ [green]	✓ [green]		✓ [green]
Miramar	MR01	Maupuia Stream	✓ [green]	✓ [green]		✓ [green]
Paikawakawa	PA01	Island Bay Stream trib at Farnham St	✓ [green]	✓ [green]		✓ [green]
	PA02	Island Bay Stream trib at Mana Karioi	✓ [green]	✓ [green]		✓ [green]
Pipitea	PT01	Puketea Stream at Botanical Gardens	✓ [green]	✓ [green]	✓ [green]	✓ [green]
	PT02	Pipitea Stream at Botanical Gardens below pond			✓ [green]	
Te Poti	TP01	Te Poti Stream	✓ [green]	✓ [green]		✓ [green]
Waimapihi	WA01	Waimapihi Stream	✓ [green]	✓ [green]	✓ [green]	
	WA02	Clinical Track Stream	✓ [green]	✓ [green]		✓ [green]
	WA03	Polhill Stream	✓ [green]	✓ [green]		✓ [green]
Waipapa	WP01	Waipapa Upstream	✓ [green]	✓ [green]	✓ [green]	✓ [green]
	WP02	Waipapa Stream at coast	✓ [green]	✓ [green]	✓ [green]	
Waitangi	WT01	Bells Rd Stream	✓ [green]	✓ [green]		✓ [green]
	P1	Papawai S at Prince of Wales Pk	✓ [red]	✓ [red]	✓ [red]	
Wadestown	WD1	Wadestown Stream				✓ [green]

2.2 Habitat Assessments

Habitat assessments were completed at 41 sites (once at 36 sites, twice at 5 sites – Table 2.1) following methods outlined in Clapcott (2015). Habitat assessments were only collected at sites where macroinvertebrates were collected which covered the range of stream types and urban impacts across Wellington City. The assessment provides an indication of the physical stream habitat condition and its ability to support stream biota. The assessment incorporates the following ten variables: deposited sediment cover, macroinvertebrate habitat abundance and diversity, fish habitat abundance and diversity, hydraulic heterogeneity, bank erosion and vegetation, and riparian width and shade. Each category is scored between 1 (‘poor’) and 10 (‘excellent’). Summation of individual scores provides an overall total habitat quality score for each site (lowest and highest possible scores are 10 and 100, respectively).

2.3 Macroinvertebrates

Macroinvertebrates were sampled at 41 sites with hard bottom substrate on a single occasion (Table 2.1). The sites sampled encompassed the range of streams and gradient of urban impacts across Wellington City. Where practicable, samples were not taken within two weeks of any flood event (flood events are defined as flows greater than three times the median river flow). Samples were collected with the use of a kick-net (0.5 mm mesh size) following Protocol C1 of the national macroinvertebrate sampling protocols (Stark et al., 2001). All samples are processed in accordance with Protocol P2 (Stark et al., 2001).

Macroinvertebrates were collected to calculate the Macroinvertebrate Community Index (MCI) and Quantitative MCI. The MCI is an index of sensitivity to a wide range of environmental variables (Stark and Maxted, 2007) used to measure macroinvertebrate community health. The MCI is used in the GWRC’s PNRP to measure ecosystem condition according to river classes defined by Clapcott and Goodwin (2014) (Table 2.2).

Table 2.2: MCI ecological condition classifications from Clapcott and Goodwin (2014) based on river class in the GWRC PNRP

River class		MCI ecological condition class			
		Poor	Fair	Good	Excellent
1	Steep, hard sedimentary	<110	110-120	120-130	≥130
2	Mid-gradient, coastal and hard sedimentary	<80	80-105	105-130	≥130
3	Mid-gradient, soft sedimentary	<80	80-105	105-130	≥130
4	Lowland, large, draining ranges	<90	90-110	110-130	≥130
5	Lowland, large, draining plains and eastern Wairarapa	<80	80-100	100-120	≥120
6	Lowland, small	<80	80-100	100-120	≥120

2.4 Fish

Fish surveys were conducted at 51 sites using backpack electrofishing and/or spotlighting, depending on stream habitat, at representative habitats in each sampling reach. Not all fishing methods were carried out at each site because of dangerous conditions or site access issues. Fishing methods used at each site are listed in Table 2.1. In 2016, inanga spawning assessments were conducted in Kaiwharawhara and Owhiro Streams (see Marshall and Taylor (2018) for more information).

The Index of Biotic Integrity (IBI) was calculated for each site to provide an indication of overall fish community condition and interpretation of scores was based on recommended classes in Joy (2004) (Table 2.3).

Table 2.3: Thresholds for interpretation of IBI scores for the Wellington Region from Joy (2004)

IBI score	Integrity class	Attributes
52–60	Excellent	Comparable to the best situations without human disturbance; all regionally expected species for the stream position are present. Site is above the 97th percentile of Wellington sites.
48–51	Very good	Site is above the 90th percentile of all Wellington sites; species richness is slightly less then best for the region.
38–47	Good	Site is above the 70th percentile of Wellington sites but species richness and habitat or migratory access reduced some signs of stress.
30–37	Fair	Score is just above average but species richness is significantly reduced habitat and or access impaired.
18–29	Poor	Site is less than average for Wellington region IBI scores, less than the 50th percentile, thus species richness and or habitat are severely impacted.
2–17	Very poor	Site is impacted or migratory access almost non-existent.
0	No native fish	Site is grossly impacted or access for fish is non-existent.

2.5 Data analysis

2.5.1 Impervious and vegetated area within each catchment

To get an indication of potential pressure from urban land use, the area and percentage of impervious and vegetated land cover in the catchment upstream of each site was calculated in ArcGIS Pro. Impervious and vegetated areas were defined using methods outlined by Kaspersen et al.(2015) using Sentinal 2b satellite imagery which covers Wellington City on the 15th June 2019. To estimate impervious and vegetated areas the Soil Adjusted Vegetation Index (SAVI) defined by Kaspersen et al.(2015) was used and reclassified so that values less than 0.9 were given the value of 1 (impervious surface) while all others were given 0 (vegetation). The resulting raster dataset was clipped to the Wellington City boundary and the values converted to vector polygons. All analysis was conducted in ArcGIS Pro.

Building outline data and road/rail parcel data were added to the analysis to be joined with the SAVI polygons. Some manual processing of the data also occurred for quality assurance purposes.

2.5.2 Macroinvertebrate and fish community structure

Similarities in macroinvertebrate and fish community structure between sites were analysed using the Bray-Curtis similarity measure, and visualised using non-metric multidimensional scaling ordination (NMDS) in Primer version 7. The Pearson correlation coefficient was calculated to determine the environmental factors correlated with each axis in the NMDS ordination. All analyses were conducted on relative abundance data, which was fourth root transformed.

3. Results

3.1 Habitat condition

Overall, habitat scores ranged from fair (33.5/100 at Ngauranga Stream at Taylor Prestons site N5) to excellent (94/100 at Waipapa Stream site WP01) with a median score of 73.25. Sites with the greatest habitat condition were generally located in stream segments upstream of urban areas (eg. Waimapihi Stream in Aro Valley) or in catchments with no urban cover and regenerating vegetation (eg. Waipapa stream on the Wellington South Coast) (Figure 3.1). A summary of the overall habitat scores and scores for each variable at each site is provided in the supplementary data spreadsheet.

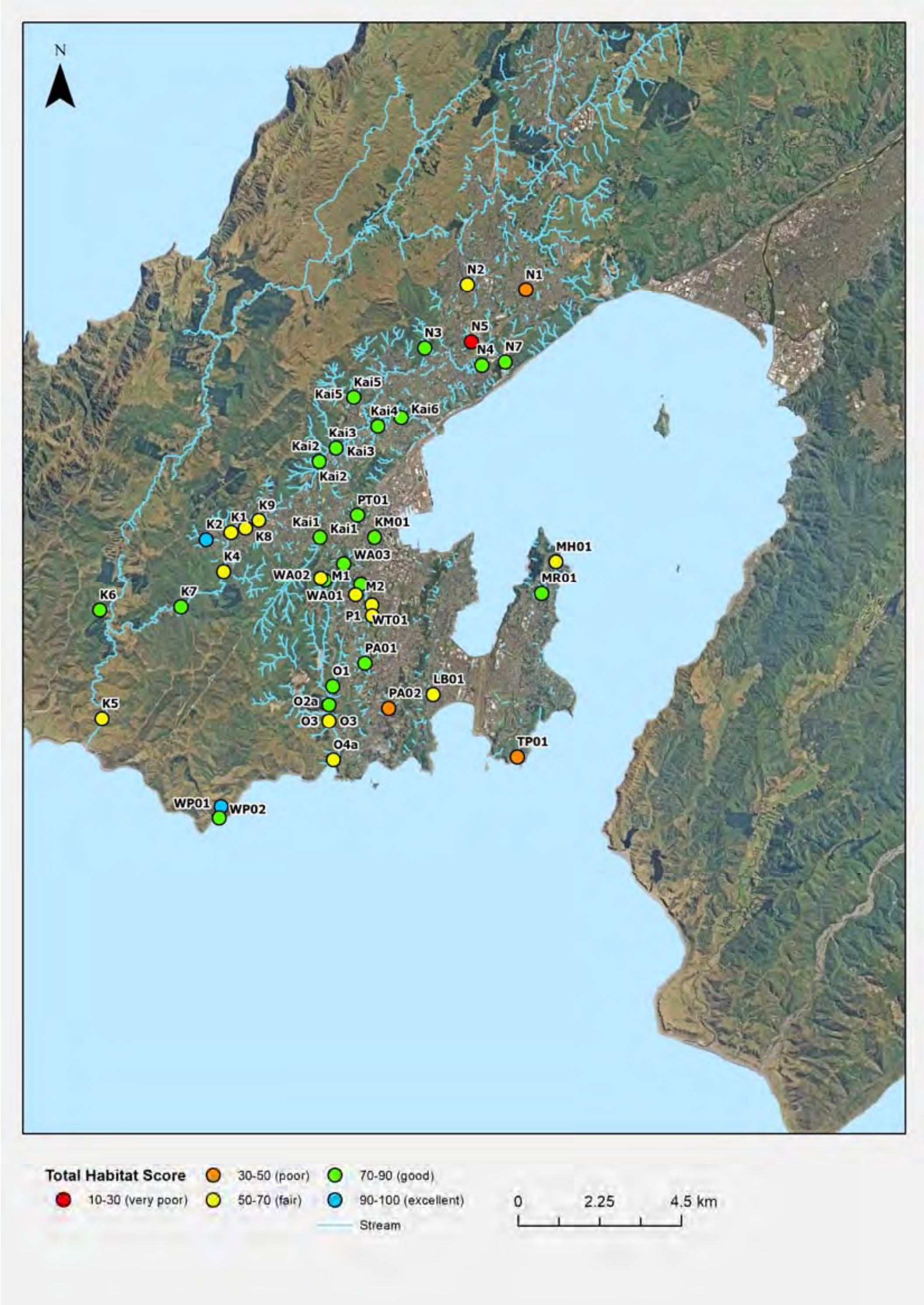

Figure 3.1: Results of habitat assessments at each survey site sampled between 2016 to 2019. The total habitat assessment score is shown for each site.

3.1.1 Macroinvertebrates

MCI scores ranged from 59 (poor ecological condition) at site N1 on Ngauranga Stream at Newlands Road, to 131 (excellent ecological condition) at site N3 on Ngauranga Stream at Mount Kaukau.

The five highest MCI scores were at sites:

- N3 (Ngauranga Stream at Mount Kaukau): 131
- K6 (South Makara Stream Tributary at South Makara Road: 129
- K2 (Karori Stream at Castlemaine Close): 122
- WP02 (Waipapa Stream at South Coast): 122
- WA01 (Waimapihi Stream): 119

The five lowest MC1 scores were at sites:

- N1 (Ngauranga Stream at Newlands Road): 58
- N2 (Ngauranga Stream near Alex Moore Park) : 62
- K9 (Karori Stream at Darwin Street): 72
- O4a (Owhiro Stream downstream of Happy Valley Road): 73
- K1 (Karori Stream at Karori Park): 73

The highest MCI scores were generally in areas with the greatest habitat quality (e.g. greater riparian cover) and the lowest levels of urban development in the surrounding catchment (Figure 3.2 and supplementary data spreadsheet). The lowest MCI scores were in catchments with higher levels of urban landuse. As impervious area in the upstream catchment of a site increased there was a decrease in the relative abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa which are sensitive to poor water and habitat quality. Sites with higher levels of imperviousness in the upstream catchment had higher relative abundances of taxa such as Diptera, Oligochaeta and Mollusca (primarily *Potamopyrgus* and *Physa* species) which are tolerant of poor habitat and water quality (Figure 3.3).

The percentage of impervious area upstream of a site had a possible influence on the type and abundance of macroinvertebrates present at a site, with a high negative correlation between percent impervious area upstream and position on axis 1 in the ordination plot. Furthermore, sites with less impervious area upstream (more vegetation cover upstream) and better habitat condition (e.g. less deposited sediment and greater habitat diversity were generally associated with greater MCI/QMCI scores (i.e. more taxa sensitive to poor water quality and habitat disturbance), taxa richness, percentage EPT abundance and EPT richness. The amount of riparian shading (assessed using the habitat assessment protocol) also had a high correlation with the composition of the macroinvertebrate community on axis 2 of the ordination (Figure 3.4, Table 3.1).

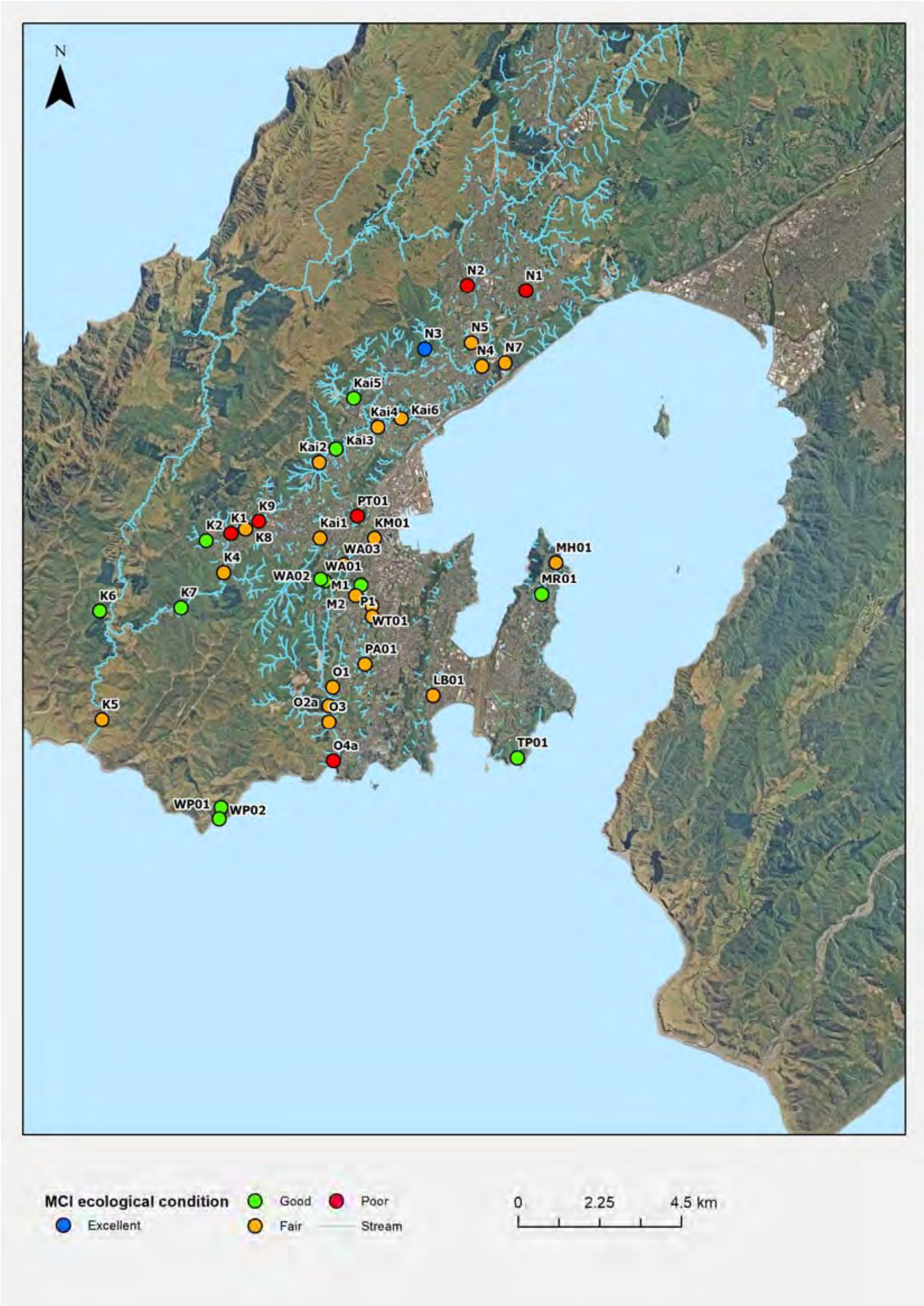

Figure 3.2: MCI ecological condition class (defined by Clapcott and Goodwin 2014) at each site where macroinvertebrates were collected between 2016 and 2019

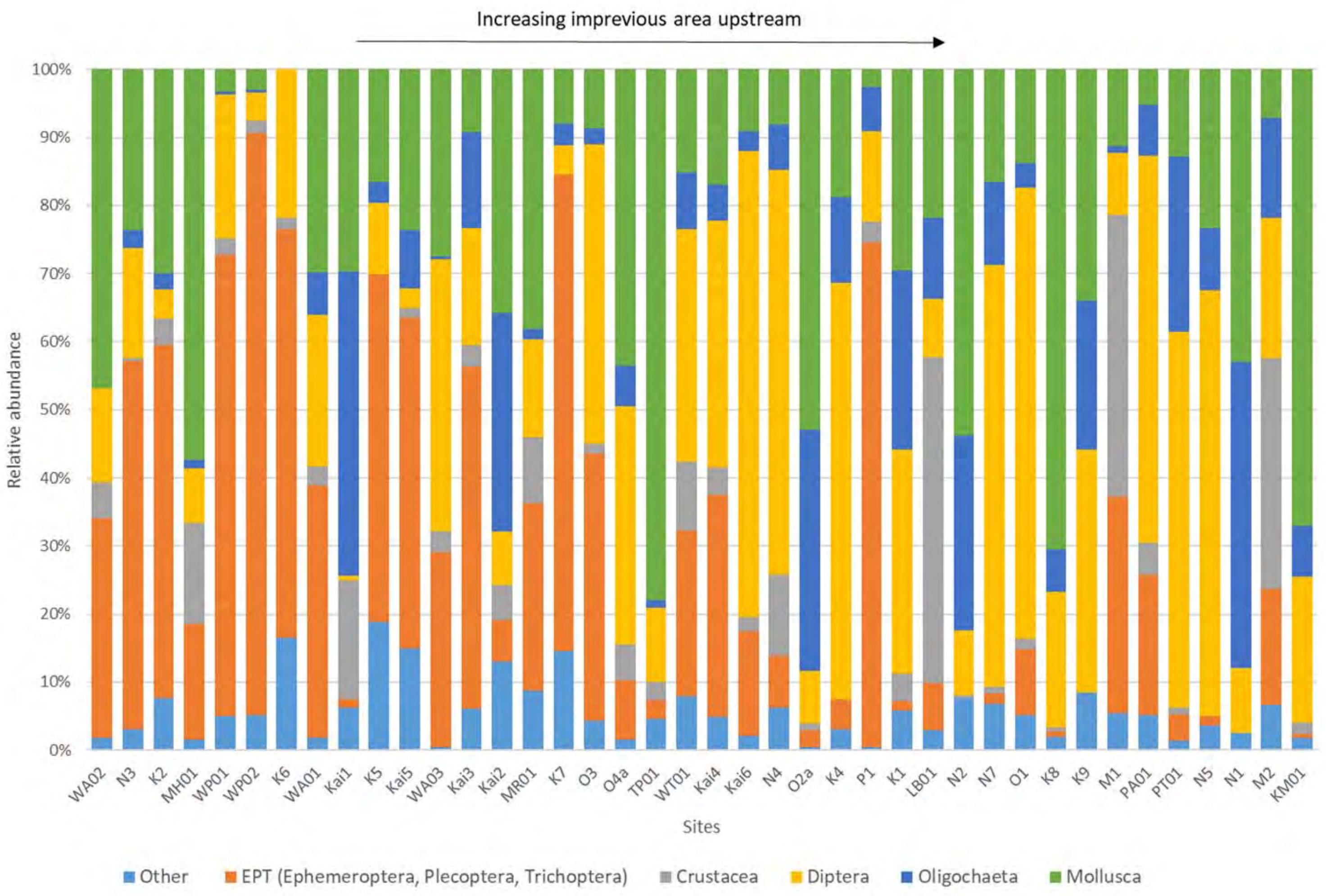

Figure 3.3: Relative abundance of macroinvertebrate taxa groups across all sites from 2016-2019. Sites on the x axis are listed in order of increasing impervious area upstream. Impervious area calculations for each site are listed in the supplementary data spreadsheet.

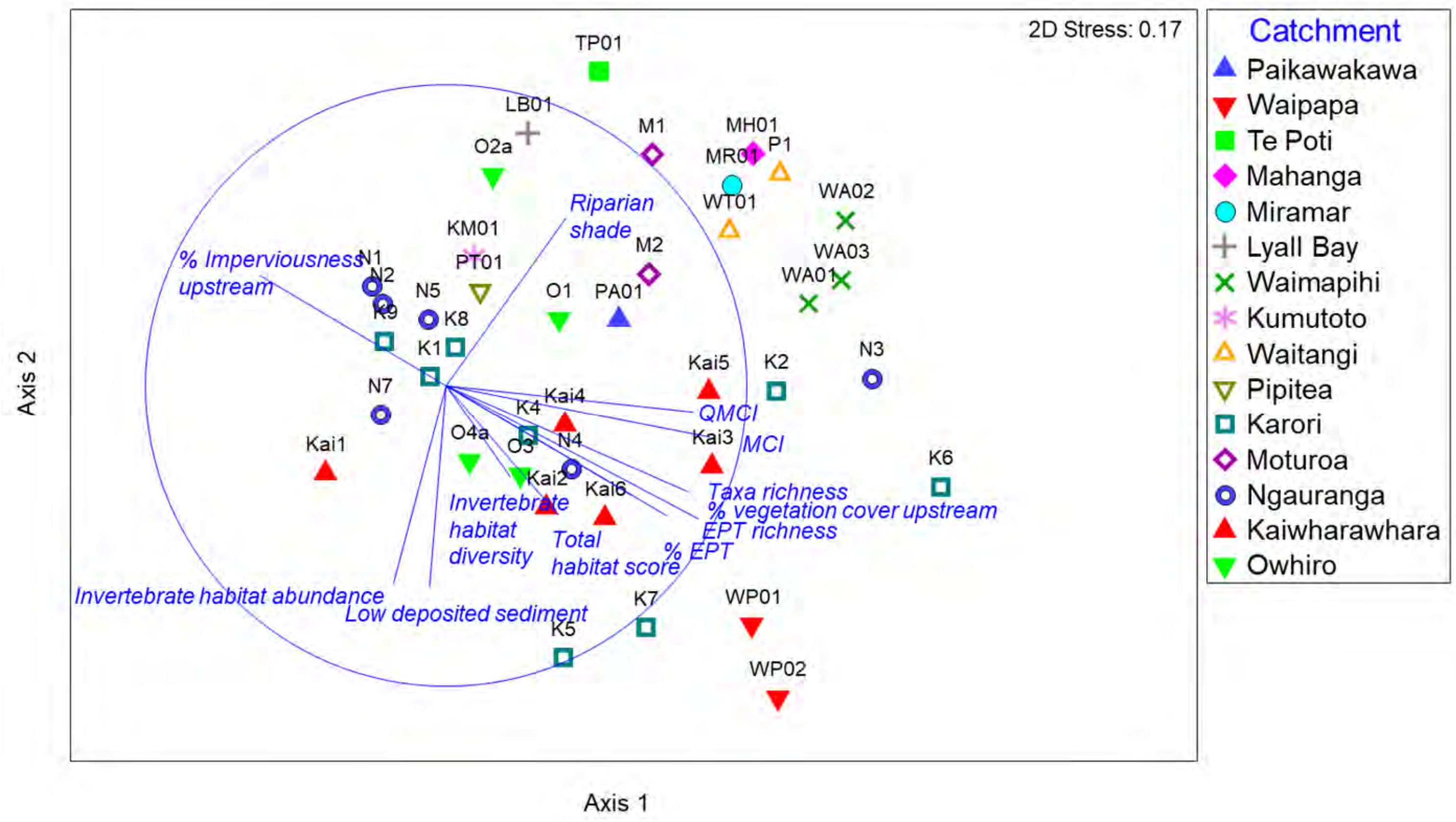

Figure 3.4: NMDS ordination of sites based on fourth root transformed macroinvertebrate relative abundance showing correlations with habitat assessment variables, % imperviousness upstream, % vegetation cover upstream and macroinvertebrate community measures. The closer the line to the circle the higher the correlation. Correlations with each axis are show in Table 3.1.

Table 3.1: Pearson correlations with axes 1 and 2 for variables overlaid in the ordination plot shown in Figure 3.4

Variable	Axis 1	Axis 2
Low deposited sediment	-0.05	-0.67
Invertebrate habitat diversity	0.22	-0.31
Invertebrate habitat abundance	-0.18	-0.66
Riparian shading	0.4	0.56
Total habitat score	0.37	-0.43
Taxa richness	0.81	-0.35
MCI	0.88	-0.17
QMCI	0.82	-0.09
EPT richness	0.84	-0.44
% EPT	0.74	-0.43
% imperviousness upstream	-0.62	0.37
% vegetation upstream	0.62	-0.37

3.1.2 Fish and koura

Fish communities within urban areas generally had fish IBI scores corresponding to fair or poor condition (Figure 3.5). At some sites no native fish were collected (IBI score of 0) and overall IBI scores ranged from 16 (very poor) to 56 (excellent):

The sites with the lowest IBI scores were:

- N5 (Ngauranga Stream at Taylor Prestons): 0
- O2a (Owhiro Stream downstream of TNT Landfill): 0
- O2c (Owhiro Stream at Southern landfill gate on Landfill Rd) : 0
- MH01 (Mahinga Bay Stream) : 0
- PA02 (Island Bay tributary at Mana Karioi) : 0
- TP01 (Te Poti Stream) : 0
- WA02 (Clinical track Stream) : 0
- WT01 (Bells Road Stream) : 0

- K5 (Karori Stream at Makara coast): 16
- Kai4 (Kaiwharawhara Stream below Korimoko confluence): 16
- O2b (Owhiro Stream below Landfill Rd confluence): 16

- K10 (Karori Stream at Futuna Close): 18
- N4 (Ngauranga Stream at Tyres Stream Reserve): 18
- MR01 (Maupuia Stream): 18

The sites with the highest IBI scores were:

- Kaiwharawhara Stream at Spotlight: 56
- WP02 (Waipapa Stream at coast): 50
- K2 (Karori Stream at Castlemaine Close): 42
- PT01 (Puketea Stream at Botanical Gardens): 40
- K6 (South Makara Stream tributary at South Makara Road): 40
- Kai1 (Kaiwharawhara Stream below the dam): 38

The sites with the highest IBI scores all had habitat with good to excellent fish cover diversity and cover abundance (habitat assessment ranging from 8 to 10/10 at sites WP02, K2, PT01, K6 and Kai 1 – see supplementary data). Kaiwharawhara Stream at Hutt Road/Spotlight and Waipapa Stream at the coast had direct access to the sea for migration with no barriers.

In total, fourteen fish species were identified along with koura (Table 3.2). Eel species and banded kokopu were the dominant species across the majority of sites (Figure 3.6). Climbing species such as eels, banded kokopu and koaro were the only species found in open stream sections upstream of pipes (e.g. Kumutoto Stream, Ngaroma Stream, Maupuia Stream and Moturoa Stream). Whereas species with poor climbing ability such as inanga and the bully species were only found in streams with direct access to the sea and no barriers (e.g. lower reaches of the Kaiwharawhara stream) Koura were found in all catchments except Kumutoto, Mahanga and Wadestown (Table 3.2, Figure 3.6). Potential inanga spawning habitat has also been identified and confirmed in the lower reaches of Kaiwharawhara Stream in bank vegetation (Marshall and Taylor, 2018).

The diversity and abundance of fish species was influenced by the diversity of fish habitat available (including riparian shading and hydraulic heterogeneity). The pattern of the fish community composition across sites was correlated with fish habitat cover diversity (Pearson correlation 0.35 axis 1) and riparian shading (Pearson correlation 0.61 axis 1) and hydraulic heterogeneity (Pearson correlation -0.38 axis 2) (Table 3.3, Figure 3.7). As fish habitat cover diversity and riparian shading increased there was a greater range of species present and higher abundance of banded kokopu (Figure 3.6, Figure 3.7). However, the correlations with fish community measures (IBI, taxa richness) and %imperviousness/vegetation cover upstream were not as high as those for the macroinvertebrate community, which indicates there are other key factors affecting fish not accounted for (e.g. fish passage barriers) (Table 3.1, Table 3.3).

The native fish collected included at risk and declining species such as koaro, inanga, redfin bully, longfin eel, giant kokopu (Dunn et al., 2018). The nationally vulnerable shortjaw kokopu was only found in the Waipapa Stream on Wellington's South Coast, which has no urban land use in the surrounding catchment (Table 3.2, Figure 3.6). See the supplementary data spreadsheet for a table of fish species identified at each site. Appendix 1 contains photos from fish sampling from various locations.

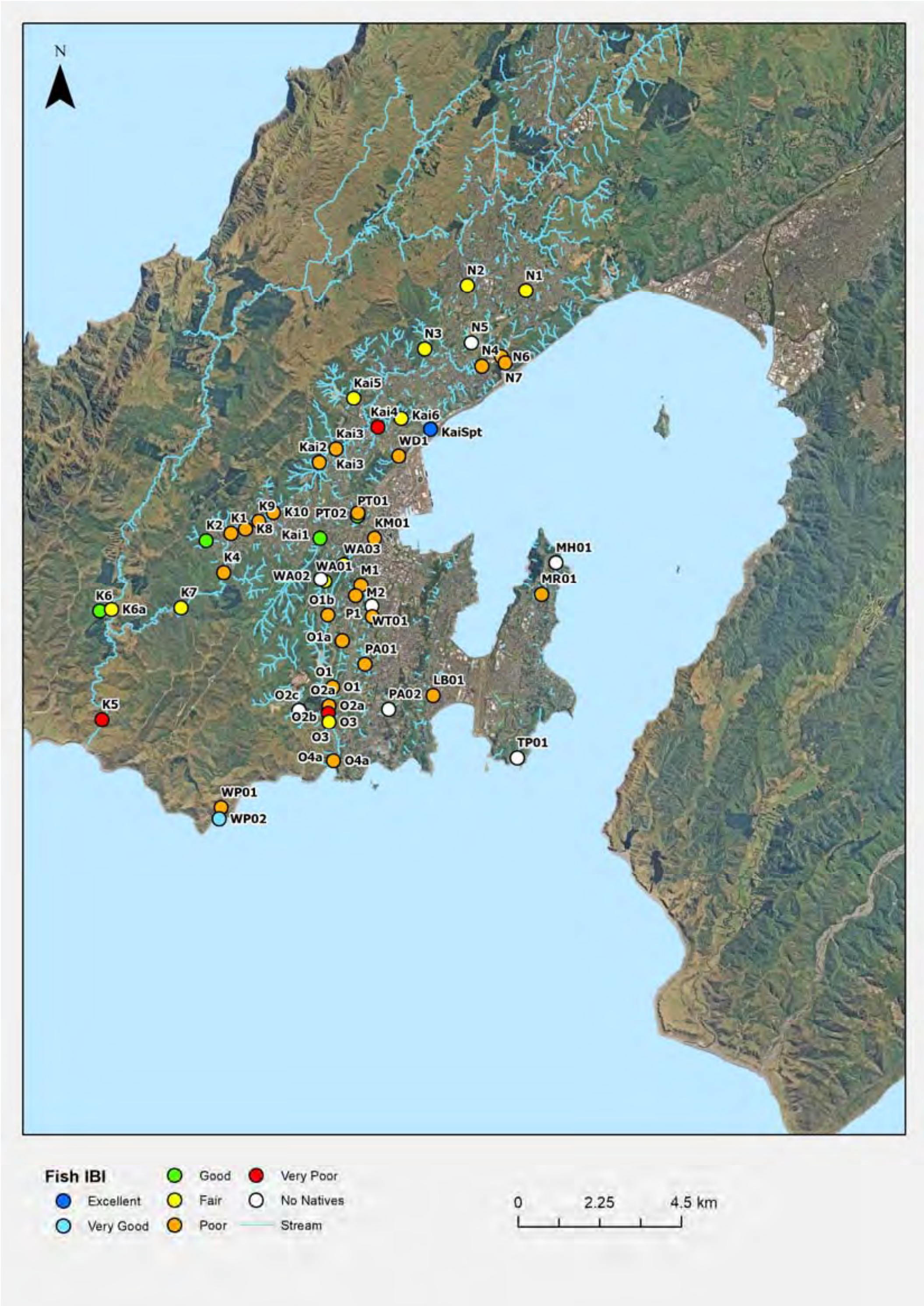

Figure 3.5: Fish IBI condition classes at each site where fish were surveyed between 2016 and 2019 (classes defined by Joy (2004) see Table 2.3)

Table 3.2: Summary of fish species (and koura) identified in Wellington urban stream catchments using both electric fishing and spotlighting methods from 2016 to 2019. * Note presence absence results have been added for the Kaiwharawhara Stream at Spotlight from fishing conducted in 2018 and 2019 for the Matariki event.

Catchment	Longfin eel	Shortfin eel	Banded kokopu	Giant kokopu	Shortjaw kokopu	Unidentified kokopu	Koaro	Inanga	Upland bully	Giant Bully	Redfin bully	Black flounder	Triplefin	Koura	Trout	Grey mullet	Unidentified eel	Unidentified galaxiid	Unidentified fish
Kaiwharawhara*	22	3	107	1		1				1	6	1	1	13			22		
Kumutoto			26				14												
Owhiro	54	15	15					7			14			3	2	1	1		
Karori	54	2	15	1			29		33					14	1		24		
Ngauranga	35	1	7				5	15						2			10		
Motoroa			5				6							2					
Lyall Bay	4	1	40											20					
Mahanga																	1		
Miramar		1	50											4					
Paikawakawa			12											22					
Pipitea	4		9				4							6			4		3
Te Poti														1			1		
Waimapihi			17				5							103				4	5
Waipapa	23	4	5	1	1		22							1				1	
Waitangi			6											28					
Wadestown	1		10																

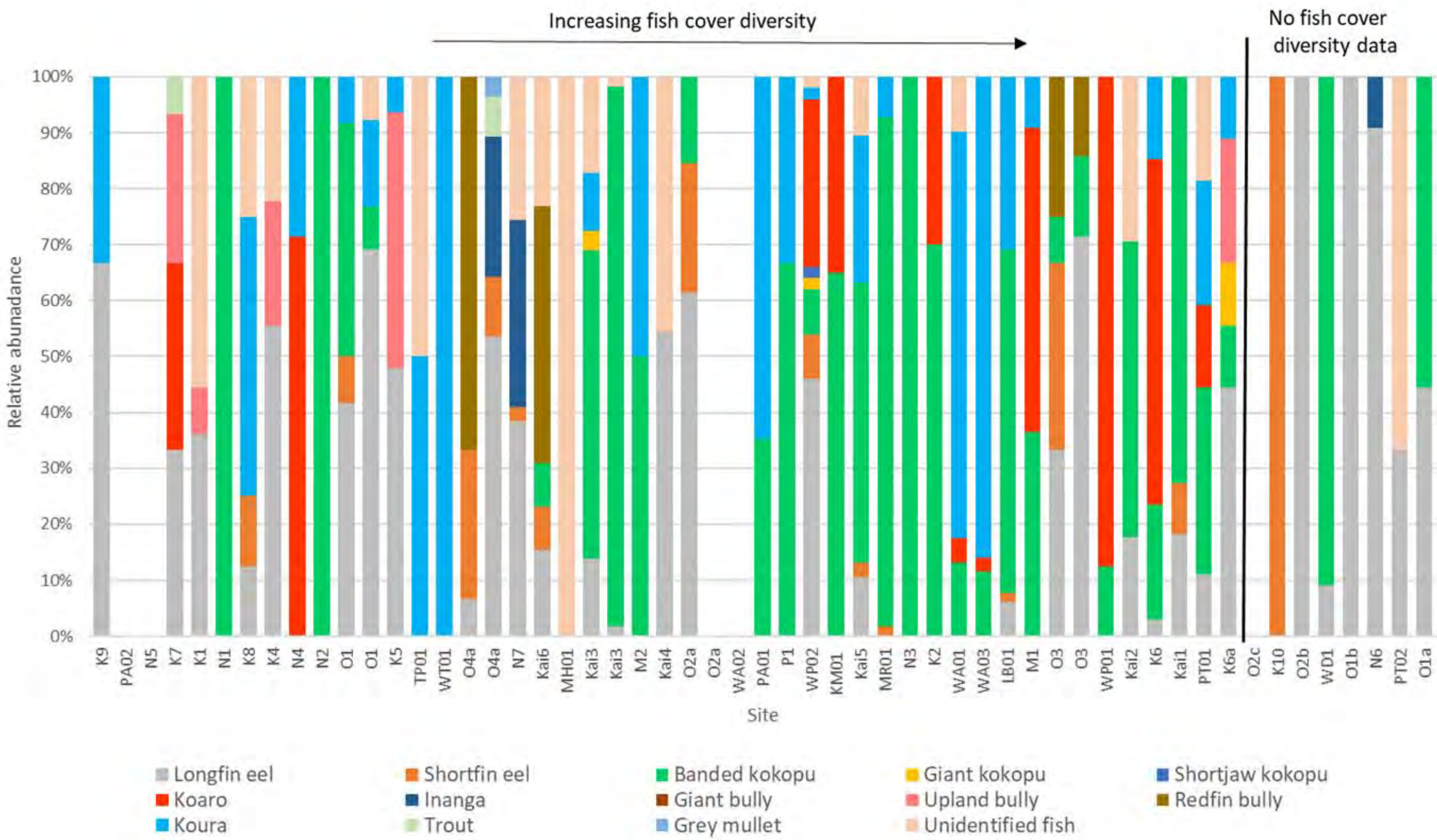

Figure 3.6: Relative abundance of fish species (and koura) identified in Wellington urban stream catchments using both electric fishing and spotlighting methods from 2016 to 2019. * Note results are not shown for the Kaiwharawhara Stream at Spotlight because this is presence absence data for fishing conducted in 2018 and 2019 for the Matariki event. Sites on the x axis are listed in order of increasing fish cover diversity measured by the habitat condition assessment. Fish cover diversity assessments were not undertaken at all sites.

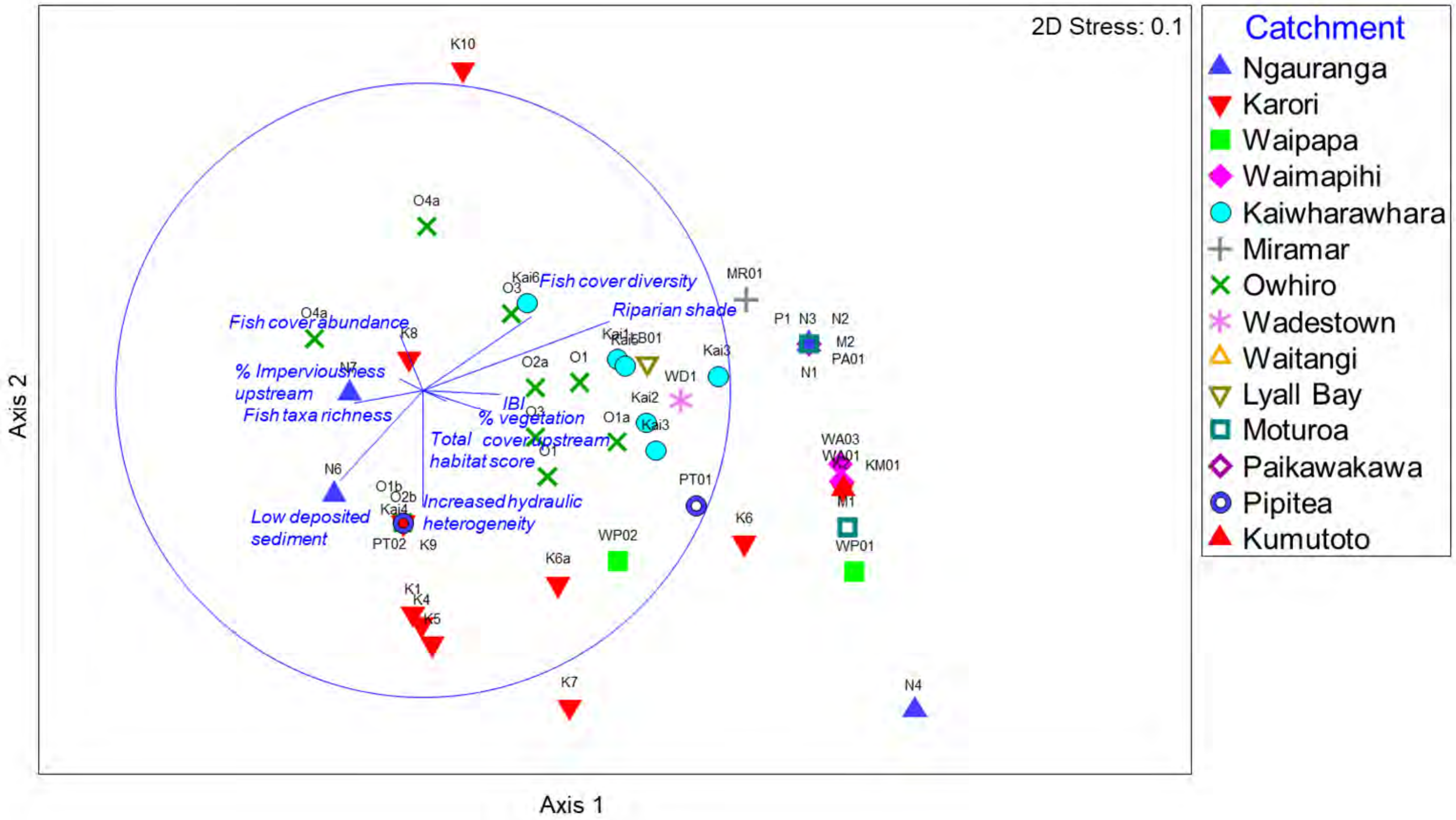

Figure 3.7: NMDS ordination sites based on fourth root transformed fish relative abundance showing correlations with habitat assessment variables, % imperviousness upstream, % vegetation cover upstream and fish community measures. The closer the line to the circle the higher the correlation.

* Note results are not shown for the Kaiwharawhara Stream at Spotlight because this is presence absence data for fishing conducted in 2018 and 2019 for the Matariki event.

Table 3.3: Pearson correlations with axes 1 and 2 for variables overlaid in the ordination plot shown in Figure 3.6

Variable	Axis 1	Axis 2
Low deposited sediment	-0.27	-0.29
Fish cover abundance	-0.07	0.18
Fish cover diversity	0.35	0.24
Riparian shading	0.61	0.22
Total habitat score	0.21	-0.07
Fish taxa richness	-0.22	-0.04
IBI	0.25	-0.01
Increased hydraulic heterogeneity	-0.0003	-0.38
% imperviousness upstream	-0.07	0.04
% vegetation upstream	0.07	-0.04

4. Discussion and conclusions

4.1 Urban stream ecosystem health and implications for urban stream management in Wellington City

The ecosystem health of urban streams within Wellington City (as represented by macroinvertebrate communities) is variable. Factors such as habitat diversity, riparian shading and impervious area in the upstream catchment influence the ecological health of Wellington City urban streams. The surveys conducted to date as a part of the Wellington City urban streams monitoring programme have provided information which can be used to set a baseline for the current state of ecosystem health values related to habitat, macroinvertebrates and fish.

Macroinvertebrate community health was best at Ngauranga Stream at Mt Kaukau, South Makara Stream tributary at South Makara Road and Karori Stream at Castlemaine Close, and worst at Ngauranga Stream at Newlands Road, Ngauranga Stream near Alex Moore Park and Karori Stream at Darwin Street. Macroinvertebrate communities were generally in better condition (as indicated by the greater presence of sensitive EPT taxa) in streams with less urban landuse and impervious area in the upstream catchment (Figure 3.3). Streams with urban areas upstream were likely to have more deposited fine sediment and lower quality habitat for macroinvertebrates. This result is in line with previous research on urban streams within the Wellington City area which showed there was declining ecosystem health indicated by macroinvertebrate communities when impervious area upstream increased (Warr, 2009). Increased impervious area in urban catchments can result in shorter and more severe high flow events, which can lead to stream bank erosion/sedimentation and effect macroinvertebrate communities in urban streams (Walsh et al., 2005).

Wellington City urban streams also support at risk and declining fish species such as koaro, inanga, redfin bully, longfin eel and giant kokopu (Dunn et al., 2018). The nationally vulnerable shortjaw kokopu (Dunn et al., 2018) was only found in the Waipapa Stream catchment, which has no urban landuse, emphasising that changes to stream habitat from urbanisation may have influenced the distribution of this species within Wellington City.

The condition of native fish communities within the streams assessed ranged from poor to excellent (Figure 3.5). The lowest IBI scores were at sites with no native fish collected in the Ngauranga, Owhiro, Mahinga Bay, Paikawakawa, Te Poti, Waimaphi and Waitangi Stream catchments. The highest fish community condition assessed using the IBI was at Kaiwharawhara Stream at Spotlight (excellent), Waipapa Stream at Coast (very good) and Karori Stream at Castlemaine Close (good). The diversity and abundance of fish species was influenced by factors such as habitat diversity, direct connection to the sea (Figure 3.6) and spawning habitat (e.g. inanga spawning in lower Kaiwharawhara Stream bank vegetation – Marshall and Taylor (2018)). However, not all of the habitat and environmental data collected explained the variation in fish community composition (Table 3.3). This means there are other factors which are influencing fish community composition. For example, barriers to fish movement are one of the major unmeasured pressures influencing native fish communities in Wellington urban streams. For example, the only fish species found upstream of piped sections of stream were climbing species such as banded kokopu, koaro and eel species. The presence of banded kokopu and eels in piped stream sections was confirmed in the piped stream survey (Figure 3.6, Appendix 2).

From the streams sampled as part of this programme there were generally different pictures of macroinvertebrate and fish community condition. For example, most sites with good macroinvertebrate community health were higher in the catchment and had poor fish community health. The stream sites with best fish community health tended to be in the lower reaches of streams where connectivity to the sea was best. Macroinvertebrate communities are strongly driven by urban activities in the catchment upstream that affect habitat and water quality (indicated by the percent cover for impervious area upstream). In contrast, fish communities appear to be more strongly affected by activities in the downstream catchment that affect fish migration (eg. fish barriers). Both macroinvertebrate and fish communities were related to riparian shading, which could be having an influence through reducing stream temperature or organic matter inputs. These differing relationships with environmental variables need to be taken into account when considering management actions to improve ecosystem health in Wellington City streams.

The initial piped stream survey has shown that some sections of piped streams in Wellington City have habitat which supports fish and macroinvertebrate life (see Appendix 2 report). For example:

- Some sites have natural cobble and gravel substrates (overlaying a concrete base, likely transported from upstream remnant open stream sections.

- Fish appear to be widespread in the piped stream network and were recorded at five of the six survey locations. However, diversity is low and is dominated by eels. In contrast, open stream sections tend to be dominated by banded kokopu. Inanga were also found in piped sections with direct access to the ocean. However, without spawning habitat in the tidal zone of the pipes it is highly unlikely they will ever be able to successfully spawn.

- Based on initial macroinvertebrate samples (there are 72 surber samples still to be analysed by late 2019), of the five most abundant macroinvertebrate taxa in both open and piped streams, three were the same – *Potamopyrgus* and *Physa* snails and Oligochaete worms. These taxa are more tolerant of poor habitat and water quality conditions.

- In open stream sites there was greater taxa richness and a higher percentage of sensitive EPT taxa than in piped stream sites. This is likely to be indicative of better habitat conditions at open stream sites. The complete enclosing of open channels significantly reduces the quality of habitat for aquatic life and results in only a subset of taxa within the catchment being able to persist there.

Further recommendations for the future management of piped streams and future monitoring options will be provided in a final report in early 2020.

4.2 Next steps for Wellington urban stream monitoring

The next stage of the Wellington City urban stream monitoring programme will focus on identifying any remaining streams which have not been sampled. These include streams within Wellington City peri-urban areas which may be subject to future development (Makara and Ohariu) and streams in the part of WCC located in the Porirua Harbour catchment. These streams will be the focus of monitoring in 2019/20.

In addition, a long term monitoring programme for Wellington City streams (stage two) will be designed in collaboration with WCC in 2019/20 for implementation in 2020/21. Aspects which should be considered as part of the monitoring programme design include:

- Agreement between GWRC and WCC urban ecology and policy staff on the objectives of the monitoring programme. Currently the main objective of the programme is to provide information to report on state and trends in ecosystem health within Wellington City urban streams. If the monitoring programme will inform policies and strategies this will mean establishing in the planning stage which questions the programme will and will not be able to answer, and questions which will need to be addressed by targeted investigations or other means.

- A coverage of sites which takes into account the range of locations and ecological/biodiversity values from the sites sampled to date. These sites should include sites with minimal urban impact, sites within the town belt in urban Wellington and sites within the urban areas with piped stream areas upstream/downstream. Having a range of sites with a varying degree of urban impacts such as impervious surfaces and stream piping will enable to effect of urbanisation on fish and invertebrates to be tracked through time.

- Opportunities for additional sites monitored by community citizen science groups to compliment the GWRC collected dataset.

- Additional, less frequent, inanga spawning habitat assessments.

- Ongoing piped stream sampling, subject to final recommendations in 2020.

- Type and frequency of reporting required.

Other knowledge gaps to address as part of the design of the monitoring programme or targeted studies include:

- Assessment of barriers to fish movement throughout the city.

- Assessments of fish population structure. It is currently not known how well fish populations in Wellington urban streams are recruiting.

- Assessments of food web and ecological processes as drivers of ecosystem health.
- Understanding macroinvertebrate community responses to stressors using stressor specific metrics (Clapcott et al., 2017).

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Appendix 1: Photos from fish sampling

Figure A1.1: Banded kokopu and a koaro (bottom left) from Moturoa Stream in Central Park. Photo S. Morar

Figure A1.2: Fishing in resident's yards on Ranelagh Street in Karori – longfin eels, shortfin eels and koura. Photo S. Morar

Figure A1.3: Karori Stream on the south coast - Lots of small upland bullies, koura and longfin eels. Photo S. Morar

Figure A1.4: Koaro from a tributary of the Karori Stream. Photo S. Morar

Figure A1.5: Ngauranga Stream 400m above mouth to Wellington Harbour - longfin eels and inanga. Photo S. Morar

Figure A1.6: Ngauranga Stream at end of Tyers Road off Centennial Highway - lots of koaro and koura. Photo S. Morar

Figure A1.7: A large giant kokopu from Kaiwharawhara Stream near the Old Hutt Road Bridge at Spotlight. Photo S. Morar

Figure A1.8: Koaro in Kumutoto Stream at Victoria University. Photo S. Morar

Figure A1.9: Whitebait sized banded kokopu from Ngaroma Stream in Lyall Bay. Photo S. Morar

Figure A1.10: Koura from Farnham Street Stream. Photo S. Morar

Appendix 2: Freshwater Ecology of Piped Streams in Wellington: Pilot Study Interim Report

Freshwater Ecology of Piped Streams in Wellington: Pilot Study Interim Report

EOS Ecology Report No. GRE01-17087-01 | July 2019

Prepared for Greater Wellington Regional Council

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SCIENCE + ENGAGEMENT

1 INTRODUCTION

In most cities urban streams have been extensively piped to provide land for development and alleviate flood and disease risk. In many catchments open stream habitat exists only as short remnant channels. To date ecological information on these highly modified catchments has primarily been derived from these remnant open sections for reasons of accessibility and safety, even though these sections make up a small percentage of total stream length. Further, the piped sections that join isolated open reaches are often managed as part of the stormwater network and have typically been ignored from an ecological perspective.

Wellington, with its steep topography and coastal location is a good example of a city where numerous small coastal stream catchments have been extensively piped, such that in several suburbs open stream channels are now only found as fragmented remnants. With the exception of some anecdotal reports of eels down stormwater grates, piped streams in Wellington have previously only been considered as migration pathways for some freshwater fishes that are known to be present in remnant open sections (e.g. banded kokopu, koaro, eels). The fish and macroinvertebrates living within the piped sections are unknown and there has never been any attempt to characterise freshwater habitat condition in these highly modified stream environments.

EOS Ecology undertook a series of urban stream catchments investigations for Wellington Water Limited (WWL) to support Integrated Catchment Management Plan (ICMP) development from 2015 to 2017, where the project brief was only to examine open sections of streams. It became apparent the ecological values of extensively piped catchments could not be fully determined without examining the piped sections (which were often the higher proportion of total stream length). Based on the catchment knowledge gained during the ICMP investigations EOS Ecology then developed a plan to undertake a pilot study to survey piped stream ecology in Wellington. The lack of information on piped stream ecology was suggested to Greater Wellington Regional Council (GWRC) as a major knowledge gap and they agreed to fund a pilot study of six sites focussing on fish, macroinvertebrates, and habitat quality.

EOS Ecology was contracted by GWRC to design, implement, and report on this pilot study. This interim report includes methodology, fish data, and manhole macroinvertebrate data; with a later final report to come once the detailed survey macroinvertebrate data is available. The final report will compare macroinvertebrate data among sites, catchments, method (manhole kick net vs in pipe Surber sampling), and between open and piped streams. It will also recommend future monitoring and identify knowledge gaps.

2 METHODS

2.1 Health and Safety

Underground pipes are classified as confined spaces meaning only appropriately trained persons are able to enter and special procedures are required (e.g., operating a permitting system, use of gas detectors, use of a winch and rescue-tether system). As WWL manages the piped stream network as part of the stormwater system, a WWL-approved contractor was required to assist with the project. WWL put us in touch with Silver Linings Contracting, who were then contracted to assist with all piped stream fieldwork. They were in charge of site health and safety and supplied all equipment required for confined space entry. From EOS Ecology, the author (Alex James) was confined spaces entry certified.

2.2 Site Selection

2.2.1 Desktop Exercise

WWL provided GIS layers of the stormwater network, manhole locations, and remnant open channels. These were overlain with Google Earth imagery and used to select manholes within Wellington's inner suburbs where entry for an ecological survey appeared logistically realistic. Criteria for potential sites including:

» Pipe diameters of no less than 1200 mm.

» Manholes to be located on footpaths and berms to avoid the requirement for traffic management or entering of private property (Figure 1).

» The catchment would preferably have permanently flowing open stream remnants from which fish were known.

Based on these criteria, 36 candidate manholes were identified with the expectation some would be inaccessible in the field.

Miramar Stream manhole on grassed berm

Pae Kawakawa Stream manhole on footpath

Figure 1 Examples of berm and footpath locations of candidate manholes.

2.2.2 Manhole Lifting Exercise

Over 1–2 May 2018 a manhole lifting site visit was undertaken with Silver Linings Contracting to aid selection of the final survey sites. Overall 20 manholes were opened with the remaining 16 either being inaccessible (e.g., buried, car parked over, building on top) or being in close proximity to an opened manhole. We also took the opportunity to trial macroinvertebrate sampling from the surface utilising a modified sampling net.

Once each manhole was opened a set procedure was undertaken:

» Lowering of a gas detector to check for unsafe concentrations of oxygen, hydrogen sulphide, carbon monoxide, and flammable gases (Figure 2).

» Measurement of surface to pipe bottom and pipe diameter using a Leica Disto laser measurement device.

» Visual estimation of water depth (dry/shallow/medium/deep), substrate type (brick, concrete, silt, cobbles, other), pipe shape/profile (circular/rectangular/arch/other), pipe material (concrete/brick/other).

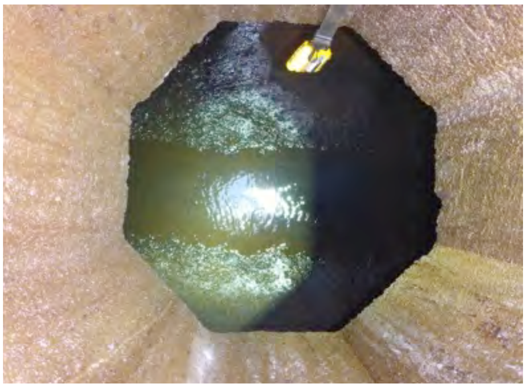
» Collection of macroinvertebrate samples using a brush and standard kick net with extendable handles (2.7–5 m). Such samples were collected from 16 sites (Figure 2). Samples were preserved with isopropyl alcohol (IPA) for later processing.

» The taking of photos of the manhole shaft and stream below.

» The taking of video footage from selected manholes using a GoPro video camera and torch attached to the extendable handle kick net (Figure 2).

Using the extendable-handle kick net to collect a macroinvertebrate sample

Using the extendable-handle kick net in conjunction with a brush to collect a macroinvertebrate sample



Measuring the atmosphere using a gas detector

The GoPro video camera setup

Figure 2 Examples of manhole lifting exercise methodology.

2.2.3 Final Site Selection

Six sites were selected for detailed ecological survey; three in Pae Kawakawa Stream catchment (Island Bay); two in Miramar Stream (Miramar); and one in Waipapa Stream (Hataitai) (Figure 3). The Pae Kawakawa Stream and Miramar Stream sites were all vertical entries down manholes, while Waipapa Stream involved entry via the ocean outlet at low tide. It was originally planned to have a site in the Waitangi Stream catchment, however the only suitable site was deemed too dangerous to enter without using breathing apparatus, for which extra specialist training would have been required. A third Pae Kawakawa Stream site was substituted.

Figure 3 Locations of the six detailed survey sites.

2.3 Detailed Ecological Survey

The six sampling sites were visited on two occasions for the detailed survey (stage 1: 6–7 March 2019 and stage 2: 20–21 March 2019). Stage 1 involved installation of trail/game cameras, sticky traps, and collection of macroinvertebrate samples, while stage 2 consisted of recovering of cameras and sticky traps and undertaking a fish survey. In practice fish were often sighted during stage 1, so an informal fish survey (consisting of noting if fish were seen) was also undertaken at that time. Additionally, an equipment mishap required macroinvertebrates at one site to be collected on the stage 2 visit. Details of the survey methodology are detailed below:

» **Trail/game cameras**: At each site a single trail camera was installed near the manhole with the lens facing towards the wetted channel in an attempt to obtain images of fish within the piped streams (Figure 4). Cameras were mounted on existing pipes or reinforcing steel rods where available, otherwise a steel extendable curtain rod was affixed across the width of the piped stream. Curtain rods were attached using cable ties to any available protrusions (e.g., ladder rungs, reinforcing steels) and/or appropriate concrete adhesives applied via caulking gun. Cameras were set to take time-lapse images every 10 minutes for the duration of deployment and also be triggered to take a photo by movement. The typical movement sensor of such cameras relies on a difference in temperature between the environment and the animal, hence, is unlikely to be triggered by fish. Where the camera model allowed (we used three different models) 10-second videos were also recorded every 10 minutes.

» **Sticky traps**: At each site a single 24.5 cm wide by 40 cm high plastic yellow sticky trap was installed as near the roof of the piped stream as possible (Figure 4). These were sticky on both the upstream and downstream sides and installed to existing pipes or reinforcing steels at some sites or to the curtain rod described above at others.

» **Macroinvertebrates**: Twelve Surber samples (0.09 x 0.09 m^2) were collected from each site over a 40 to 100 m length of stream depending on availability of habitat suitable for Surber sampling and access (Figure 4). Samples were preserved with isopropyl alcohol (IPA) for later processing.

» **Fish survey**: At each site a 200 m (100 m upstream and downstream of the manhole access point) reach was carefully searched for fish using a spotlight and hand netting technique (Figure 4). The exception was Waipapa Stream where we entered via the ocean outlet. At this site we searched for fish from the entrance all the way upstream to where the macroinvertebrate survey was undertaken. In practice in Waipapa Stream fish were only observed in the lower 90 m of pipe as above this point water became too shallow and cover lacking for the fish present. Any obvious fish cover elements (e.g., pieces of wood, brick, and assorted rubbish) were slowly lifted to determine if fish were underneath. Fish were identified to species, which the exception of those eels that were unable to be captured. Lengths were visually estimated.

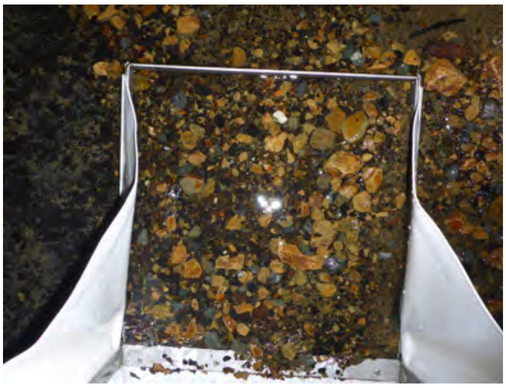
» **Habitat characterisation**: At each Surber sample location (12 at each site) water depth, wetted width, substrate composition, and organic matter cover (leaves, CPOM, biofilms) was recorded. We recorded the "head" where water depth was recorded to enable an estimate of water velocity using the ruler methodology (cf. Harding et al., 2009 – Appendix 3). Biofilm colour and thickness was also recorded. Site photos were taken including images of each Surber location prior to sampling (Figure 4). We also made site wide measurements of meso-habitat length (rapid, run, riffle, pool, fall) and made visual estimates of substrate composition and organic matter cover (leaves, roots, CPOM, biofilms). Any potential fish barriers were noted.

» **Water quality**: A YSI multiprobe supplied by GWRC was used to collect spot water quality records of temperature, dissolved oxygen, and conductivity.

Camera and sticky trap attached to reinforcing steel

Surber sampling

An eel captured via spotlighting and hand netting



Example of substrate sampled for macroinvertebrates

Figure 4 Images of detailed survey methodologies.

3 RESULTS

3.1 Habitat

Water depths were generally very shallow with only one site (the tidally influenced Waipapa Stream) having an average greater than 0.1 m (Table 1). Two sites had relatively swift water velocities (The Parade – Dover St and Waipapa), which were a result of pipe gradient. The other sites had very low water velocity with the 302 The Parade and Miramar – Shops sites having no detectable water velocity with the velocity head rod methodology used (Table 1). Two sites had virtually no mobile substrate with the streambed being entirely bare concrete (The Parade – Dover St) or bricks (Waipapa) (Table 1, Figure 5). These were also the two sites with the relatively high water velocities; hence it appears there are minimal depositional areas in these high gradient sections. The 302 The Parade site was also predominantly concrete but did have some areas of deposited substrate. The three other sites had a significant cover of a range of stony and sandy substrates (Table 1, Figure 5). Biofilms were prominent at all sites with the exception of 348 The Parade were there were none detected (Table 1). Other organic matter such as leaves and wood were relatively uncommon. Mesohabitat was predominantly runs, with the only riffle-type habitat present at 348 The Parade. Deeper pool habitat was only present at 302 The Parade and 348 The Parade (Table 1).

Spot water temperatures were in the 16.4–18.5 °C range across the sites, while specific conductivity was very high (28,440 µS/cm) at the Miramar – Shops site due to the influence of seawater (Table 1). The other five sites had relatively high specific conductivities (323–481 µS/cm) for freshwater systems. All sites had well oxygenated water with only the tidally influenced Miramar – Shops site being less than 80% saturation at the time of measurement (Table 1).

Table 1 Habitat characteristics measured at each Surber sampling location (n=12 per site), mesohabitat percentages measured over the length of the macroinvertebrate sampling reaches, and water quality spot measures recorded at the entrance manholes (or start of macroinvertebrate sampling reach in Waipapa Stream).

Parameter	Pae Kawakawa Stream			Waipapa Stream	Miramar Stream	
	The Parade – Dover St	302 The Parade	348 The Parade	Waipapa*	Miramar Park	Miramar – Shops**
Mean wetted width (m)	1.17	0.63	1.14	0.52	1.25	1.38
Mean water depth (m)	0.07	0.05	0.05	0.07	0.04	0.16
Mean water velocity (m/s)	0.51	0	0.05	0.61	0.02	0
Mean substrate composition (%)	Concrete: 100	Concrete: 77 Cobble: 2 Pebble: 3 Gravel: 5 Sand: 13	Concrete: 12 Cobble: 3 Pebble: 4 Gravel: 39 Sand: 41	Brick: 100	Cobble: 5 Gravel: 13 Pebble: 80 Sand: 2	Concrete: 25 Cobble: 5 Pebble: 37 Gravel: 31 Sand: 2
Mean organic matter cover (%)	Biofilms: 100 Leaves: 0.1	Biofilms: 76 Wood: 0.2 Leaves: 0.7	Wood: 2 Leaves: 1	Biofilms: 90	Biofilms: 92.5 Wood: 0.2 Leaves: 0.6	Biofilms: 60
Mesohabitat lengths (%)	Run: 100	Run: 97 Pool: 3	Run: 51 Riffle: 44 Pool: 5	Run: 100	Run: 100	Mesohabitat varies with tide
Spot temperature	16.4 °C	18.5 °C	18.2 °C	17.4 °C	17.7 °C	17.8 °C
Spot specific conductivity	481 µS/cm	323 µS/cm	580 µS/cm	371 µS/cm	440 µS/cm	28,440 µS/cm
Spot dissolved oxygen	83.6% 8.27 mg/L	93.4% 8.86 mg/L	83.6% 7.95 mg/L	95.2% 9.22 mg/L	84.6% 8.16 mg/L	74.8% 6.49 mg/L
Spot water quality measurement time	10:30 am	4:15 pm	3:00 pm	12:20 pm	9:00 am	2:15 pm

*The Waipapa site data presented was collected in the reach where macroinvertebrates were sampled, all fish were observed in the lower, tidally influenced 90 m of pipe, which had a mostly bare concrete base.

**The Miramar – Shops site was tidally influenced hence wetted width and depth will vary over tidal cycles.


The Parade – Dover St


302 The Parade


348 The Parade


Waipapa Stream


Miramar Park


Miramar - Shops

Figure 5 **Images of each site within the macroinvertebrate sampling reach.**

3.2 Fish

Fish were present at five of the six sites that underwent detailed ecological survey, with only The Parade – Dover St site not having any fish found over the 200 m survey reach (Figure 6). A total of 54 fish were found at the five piped sites. Fish abundance ranged from 6–14 individuals with the 348 The Parade site having the highest number of fish (15 fish) and the 302 The Parade site having the least (six fish) (Figure 6). Species diversity was low with four species being found across the sites, which were (in order of abundance) Longfin eel, shortfin eel banded kokopu, and inanga (Figure 6). Longfin and shortfin eels were found at all sites where fish were found, whilst two banded kokopu (a recently dead adult and a post-whitebait juvenile) and one inanga were only found at one site each (Figure 6, Figure 7). The two kokopu were found at the Miramar Park site. One was a recently dead adult banded kokopu (150 mm long), which based on the markings on the body had been killed by a large eel (Figure 6). One banded kokopu post-whitebait juvenile (50 mm long) was also found at this site. The single inanga was a young adult (70 mm) found at the tidally influenced Miramar – Shops site (Figure 6, Figure 7).

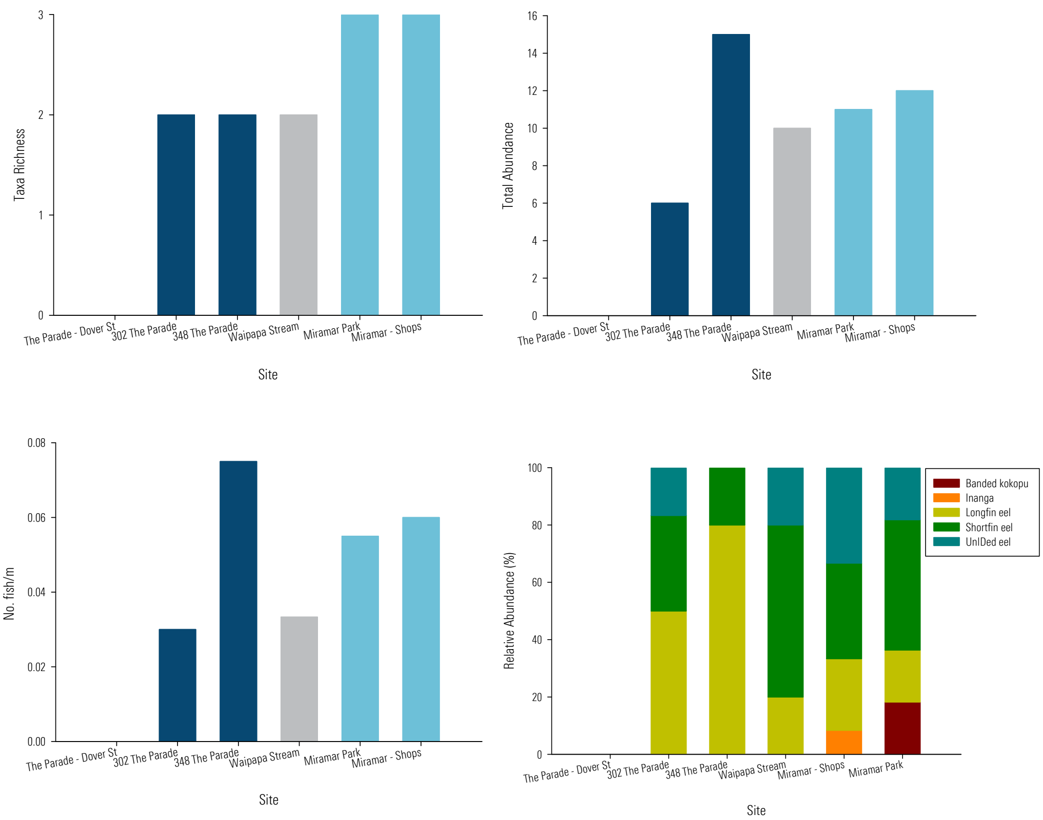
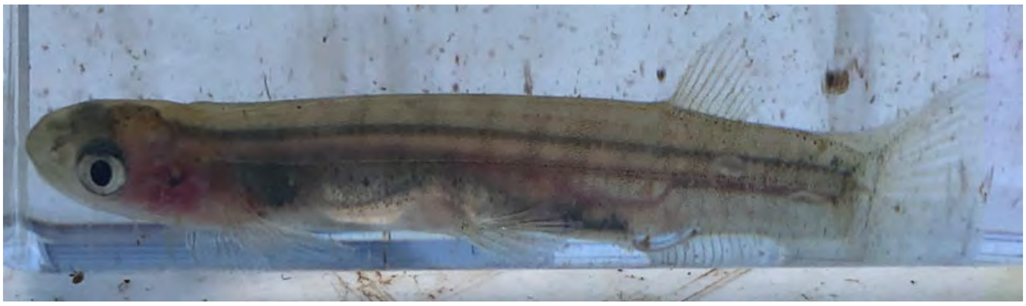


Figure 6 Fish community metrics and relative abundances from the six piped stream sites surveyed on 20–21 March 2019. 'UnIDed eel' = unidentified eels, and refers to those eels that were not able to be caught to allow for a definitive identification.

Longfin eel

Inanga young adult



Post-whitebait juvenile banded kokopu

Banded kokopu adult (dead)

Figure 7 **Fish species found during surveys of the six piped stream sites on 20–21 March 2019.**

For the Pae Kawakawa and Miramar Stream catchments there was recent GWRC fish survey data available from open stream sites allowing for comparison of fish assemblages between remnant open stream sections and piped stream sections (Figure 8). In Pae Kawakawa Stream no fish (or waikoura) where found at one open and one piped site. At sites where fish were found there was a distinct difference in composition between open and piped stream sections. Shortfin and longfin eel were found exclusively at the piped sites while the open site with fish had banded kokopu (Figure 8). In Miramar Stream eels (shortfin and longfin) also dominated in the piped sites and longfin eels were only found at piped sites, while the single open stream site surveyed had mostly banded kokopu (Figure 8). Waikoura (freshwater crayfish) were only found in open stream sites in both catchments. Overall, the addition of the piped stream surveys has increased the known diversity of fish in both catchments by two species (longfin and shortfin eel for Pae Kawakawa Stream, and inanga and longfin eel for Miramar Stream).

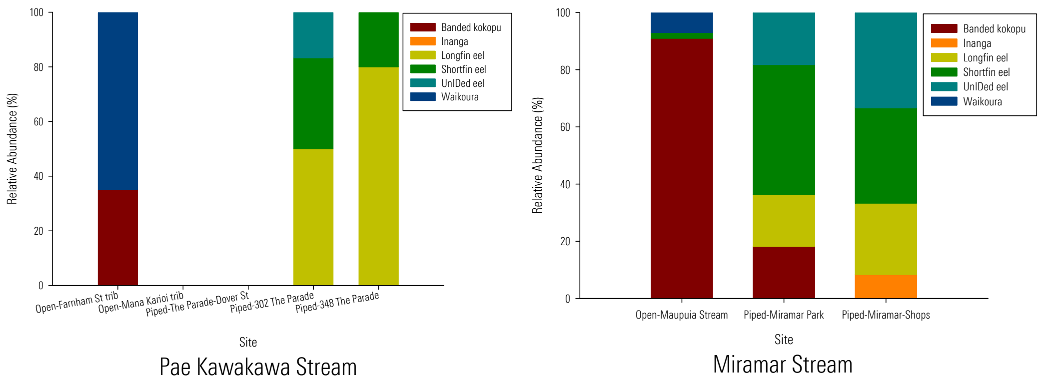


Figure 8 Relative abundance of fish species (including waikoura) at piped and open survey sites in the Pae Kawakawa Stream and Miramar Stream catchments. Open stream sites were surveyed by GWRC.

3.3 Benthic Macroinvertebrates – Manhole Lifting Kick Nets

A total of 21 invertebrate taxa were recorded from the 16 sampled manholes. The most diverse groups were the two-winged flies (Diptera: 6 taxa), molluscs (Mollusca: 5 taxa), and crustaceans (Crustacea: 3 taxa). Groups represented by one taxon included caddisflies (Trichoptera), springtails (Hexapoda: Collembola), mites (Arachnida: Acari), and four groups collectively called worms (Nematoda, Nemertea, Oligochaeta, Platyhelminthes).

The macroinvertebrate data collected during the manhole lifting exercise were compared to a GWRC dataset from the recent sampling of urban stream sites in Wellington city. This GWRC open stream sampling was undertaken in April 2018 and for comparison with our piped stream data we included sites within Karori Stream (three sites), Kaiwharawhara Stream (one site), Moturoa Stream (Central Park; two sites), Ngauranga Stream (two sites), and Papawai Stream (Prince of Wales Park; one site).

Potamopyrgus snails and Oligochaeta worms were the most abundant taxa overall in both open and piped urban stream sites, albeit in different order (Figure 9). Of the five most abundant taxa open stream and piped stream sites had three in common (*Potamopyrgus,* Oligochaete worms, and *Physa* snails) (Figure 9). The only insect taxon among the most common taxa in both open stream and piped stream sites were Chironomidae midge larvae – Orthocladiinae in open streams and Chironominae/*Polypedilum* in piped streams (Figure 9).

Open streams had greater taxa richness and percentage of pollution-intolerant EPT taxa (Figure 10). Open streams also had higher MCI scores with an overall mean just inside the "fair" interpretative category of Stark & Maxted (2007). The piped stream overall mean MCI was well within the "poor" category (Figure 10). Relative abundances of higher taxonomic groupings where similar with molluscs, oligochaetes, and Diptera being the most prominent groups in open and piped streams. Oligochaete worms were however particularly abundant at the piped stream sites, accounting for around 50% of all animals captured (Figure 10).

Open streams	Piped streams
 *Potamopyrgus* snails (29%; MCI=4)	 Oligochaeta worms (50%; MCI=1)
 Oligochaeta worms (22%; MCI=1)	 *Potamopyrgus* snails (20%; MCI=4)
 Orthocladiinae midge larvae (12%; MCI=2)	 *Physa* snails (9%; MCI=3)
 *Physa* snails (11%; MCI=3)	 *Polypedilum* midge larvae (8%; MCI=3)
 *Paracalliope* amphipods (6%; MCI=5)	 Collembola (5%; MCI=6)

Figure 9 The five most abundant taxa in Wellington open urban streams (9 sites combined) and pipes streams (16 sites combined). The relative abundance percentages and MCI-hb scores for each taxon are shown in parentheses. All images © EOS Ecology except *Polypedilum*, which is by Landcare Research.

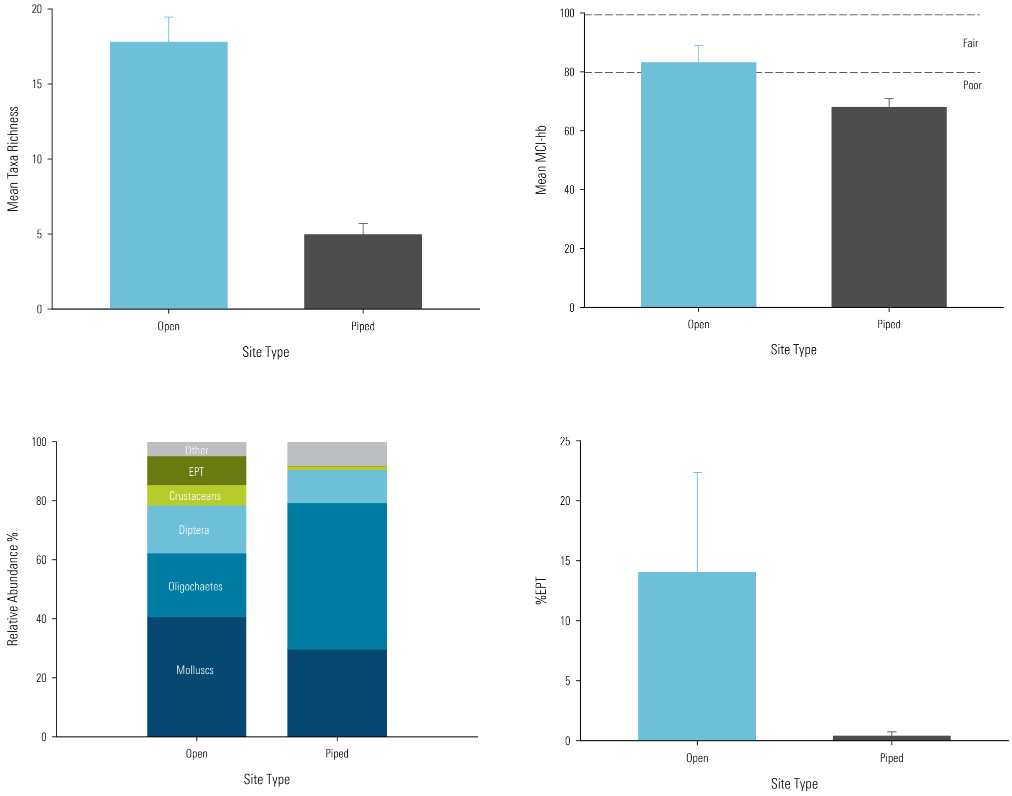


Figure 10 Macroinvertebrate community metrics and relative abundance comparisons between Wellington open urban streams (9 sites combined) and piped streams (16 sites combined). Piped stream sites only includes data from the kick net samples collected during the initial manhole lifting exercise. %EPT is based on abundance data (not taxa richness). Error bars are one standard error. For MCI-hb the generic nationwide water quality interpretative categories of Stark & Maxted (2007) are shown. Wellington-specific MCI classes were not used as GWRC's river classification does include a class for piped streams.

4 CONCLUSIONS

4.1 Habitat

- Some sites have natural cobble and gravels substrates (usually overlaying a concrete base), which have presumably been sourced from upstream remnant open stream sections and transported downstream by high flows. Other sites had minimal or no loose rocky substrates. It is likely that piped streams have depositional and erosional zones based on gradient and water velocity as in natural stream channels.
- Water depths are generally very shallow (<10 cm) and deeper pool habitat is generally very limited or absent.
- Brown-orange biofilms were prominent at five of the six sites and presumably are a food source for some macroinvertebrates.
- Spot measures of dissolved oxygen indicated relatively well oxygenated water.

4.2 Fish

- Fish appear to be widespread in the piped stream network, being present at five of the six detailed survey sites.
- Piped stream fish diversity is low and dominated by eels. Both longfin and shortfin eels are present.
- Inanga have the ability to live within piped streams. In catchments that are piped to the ocean it is highly unlikely they could ever successfully spawn due to a lack of spawning habitat.
- The eel population and lack of cover likely contributes to the general rarity of galaxiid species within piped streams.
- There appears to be clear habitat partitioning of the fish fauna (and waikoura) in catchments that have extensive piped sections and remnant open headwater sections. Eels dominate the pipes while banded kokopu (and also waikoura) dominate the open sections.
- The resident eels likely feed intensely on upstream migrating whitebait and elvers at certain times of the year.

4.3 Benthic Macroinvertebrates – Manhole Lifting Kick Nets

- It is possible to obtain macroinvertebrate samples from manholes without entering the piped system, thus avoiding a confined space entry. However, in practice collecting samples with a standard kick net on an extendable handle was awkward, especially down deeper shafts, and only allowed a very small area of streambed to be sampled. Comparison of manhole samples with detailed survey Surber samples will determine if manhole samples are sufficient to characterise the macroinvertebrate community of piped streams. This will be undertaken later in this Pilot Study.
- Based on manhole samples the macroinvertebrate assemblage of piped streams was quite similar to that off open urban streams with *Potamopyrgus* snails and oligochaeta worms being the two most abundant taxa at both site types. Of the five most abundant taxa, three were common between open and piped stream sites (*Potamopyrgus* snails, oligochaeta worms, and *Physa* snails).
- Open stream sites had much greater taxa richness and higher %EPT taxa than piped stream sites.
- Catchment urbanisation results in a series of environmental filters, which cause the decline and disappearance of a number of freshwater invertebrate taxa. Complete enclosing of most of the open channels in a catchment adds a further severe filter and creates conditions in which only a small subset of available taxa are able to persist.

5 MEDIA

» Ecological work in piped streams has the ability to capture the imagination of journalists as a press release by GWRC prior to the fieldwork resulted in stories by TVNZ's One News and Radio New Zealand:

- www.tvnz.co.nz/one-news/new-zealand/whitebait-eels-found-in-wellingtons-stormwater-system
- www.rnz.co.nz/national/programmes/ourchangingworld/audio/2018697287/the-streams-beneath-the-streets

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