STORMWATER DISCHARGES TO THE COASTAL MARINE AREA: RM11.313.01 – RM11.313.10

JULY 2022 TO JUNE 2023 MONITORING

For Dunedin City Council

August 2023

REPORT INFORMATION AND QUALITY CONTROL

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CONTENTS Page

List of Tables

List of Figures

List of Appendices

EXECUTIVE SUMMARY

Dunedin City Council operates the Dunedin stormwater system. Monitoring of stormwater and the receiving environments is required by Otago Regional Council resource consents (RM11.313.01 – RM11.313.10). Such monitoring was conducted between July 2022 and June 2023, including stormwater quality during dry weather conditions, harbour water quality during dry weather conditions, sampling of harbour sediments, and sampling of harbour biological communities. Further sampling/re-sampling was restricted by weather/tidal conditions not being met.

Dry weather sampling of stormwater found that trigger levels of *Escherichia coli* were exceeded at most outfalls on at least one sampling occasion. As there were several months without suitable conditions for sampling there were not three consecutive months of sampling over the twelve month period. However, Outfalls 3 (Shore Street catchment), 5 and 7 (Portsmouth Drive catchment), and 27 (Halsey Street catchment) all had *E. coli* concentrations that exceeded the trigger level over three consecutive sampling rounds.

Wet weather sampling of stormwater at outfalls during a rainfall event at low tide following a period of dry weather was not undertaken between July 2022 and June 2023 as the required conditions were not met.

Automated sampling was not undertaken during any wet weather events between July 2022 and June 2023 as the conditions required for the automated sampler to trigger and collect samples of the first flush of a rain event were not met. Between July 2022 and June 2023 there were 23 occasions when the sampler was incorrectly triggered ('false alarms').

Harbour water quality sampling was undertaken during dry weather in 2023. Sampling revealed copper, zinc, and enterococci concentrations exceeded consented trigger levels at several sites during dry weather, indicating elevated background concentrations of these contaminants not a non-compliance.

Harbour sediment contaminant concentrations were similar to those from recent years however copper and zinc concentrations appear to be increasing over time at the Shore Street site. Concentrations in 2023 were all below 2013 trigger levels listed in the consents. Concentrations of lead, zinc, mercury and PAHs at some sites were above ANZECC (2000) ISQG-Low levels, which represent the threshold for potential effects to occur and is a trigger for further investigation, but remained well below ISQG-High levels, which represent a point where a high probability of effects is possible.

Harbour biological communities were, in general, similar to those found in previous surveys, with relatively low diversity and high variability between sites. There were statistically significant differences in the species abundance among sites, however the communities at Portobello Road and Macandrew Bay had high proportions of 'pollution-tolerant' species, despite being potential 'Impact' and 'Control' sites, respectively. Metal concentrations in cockle flesh were within food safety guideline values. Enterococci concentration in cockle flesh were elevated, however, there are no suitable food safety guidelines for this parameter.

1 INTRODUCTION

Dunedin City Council (DCC) operates the Dunedin stormwater system, which comprises a network of gutters, open channels, pipes, mud tanks, and outfalls. The principal coastal receiving water environments for Dunedin's reticulated stormwater are the upper basin of Otago Harbour, Port Chalmers, and, on the open coast, Second Beach and St Clair Beach. Otago Regional Council (ORC) resource consents (RM11.313.01 – RM11.313.10) authorise the discharge of stormwater from ten stormwater catchments (St Clair, Shore Street, South Dunedin, Portsmouth Drive, Orari Street, Kitchener Street, Mason Street, Halsey Street, Ravensbourne, and Port Chalmers catchments) to these receiving environments (Figure 1). The consent conditions require monitoring of stormwater quality during dry and wet weather conditions, harbour water quality during dry and wet weather conditions, harbour sediments, and on a biennial basis, harbour biological communities.

DCC engaged 4Sight Consulting – Part of SLR (4Sight) to undertake the required monitoring between July 2022 and June 2023. This report summarises the results of that monitoring.

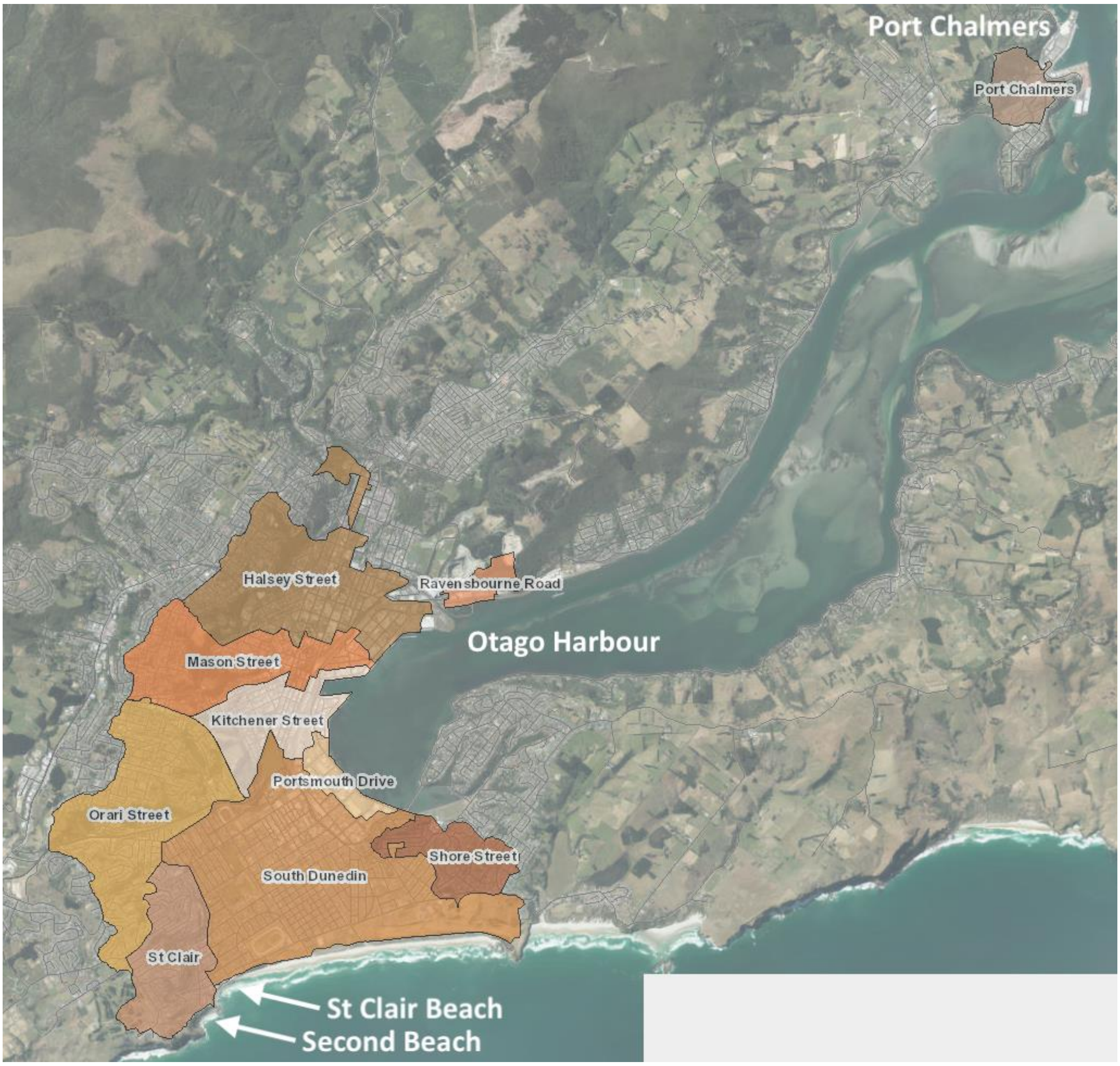

Figure 1: Dunedin 3 Waters catchment boundaries. Modified from DCC webpage.

2 STORMWATER OUTFALL LOCATIONS

Monitoring of Dunedin's stormwater quality is required at 14 large outfalls and many smaller outfalls (Figure 2; Appendix A). Many of Dunedin's outfalls have long histories dating back to the early settlement of the city. A number of the outfalls do not have outfall structures or are inaccessible for sampling, and it is therefore neither practical nor possible to sample all 33 outfalls at the discharge point (outfall) to the receiving environment. However, access at many sites is available via manholes a short distance upstream from the outfall.

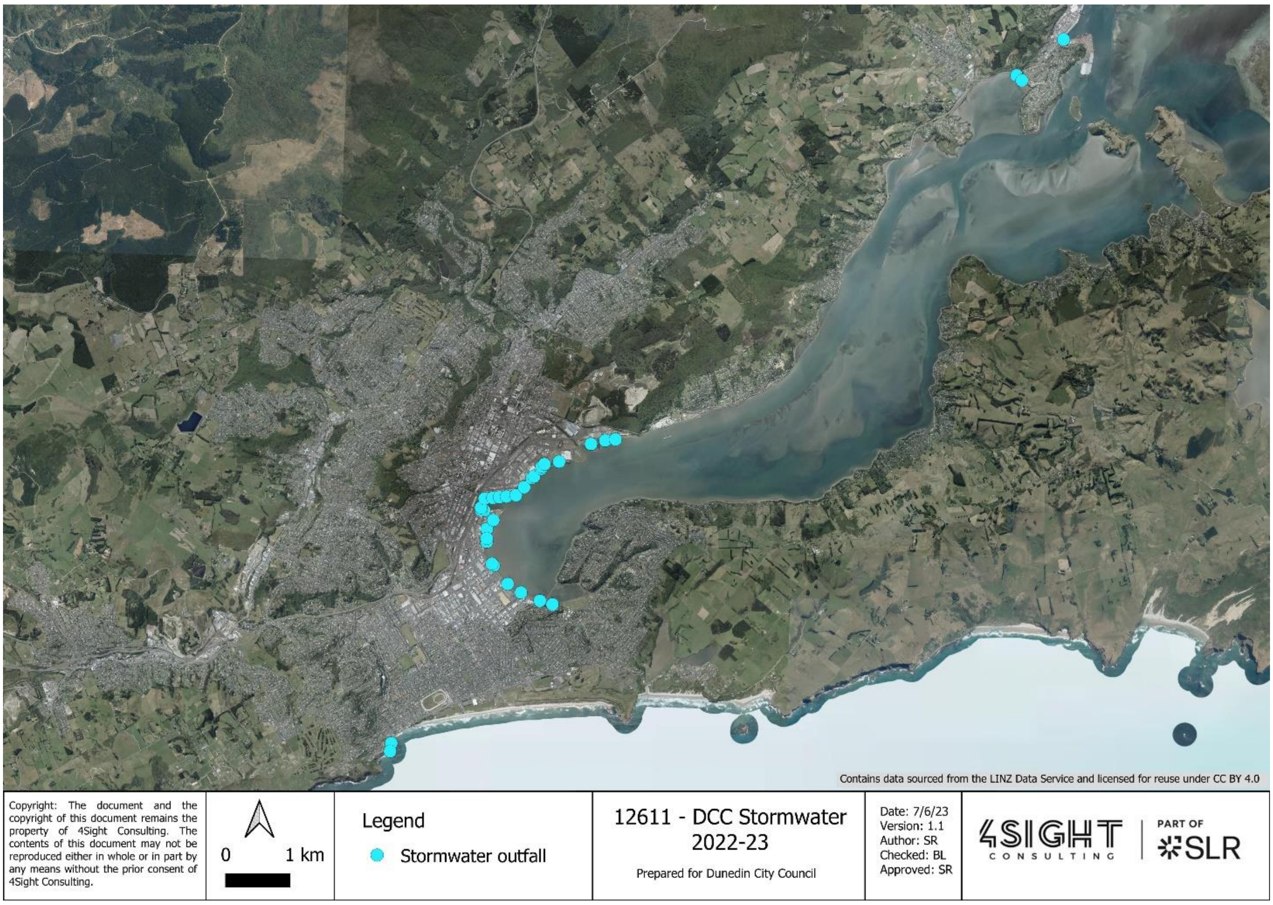

Figure 2: Dunedin stormwater outfalls.

3 SAMPLING REQUIREMENTS AND METHODS

3.1 Dry weather stormwater sampling

Dry weather water sampling is undertaken to determine background contaminant levels entering the receiving environments via stormwater outfalls and it can indicate possible cross-connections between stormwater and wastewater systems. At some outfalls where indicators of human wastewater have not been detected or there is generally no flow, sampling is only required six-monthly, while sampling at other outfalls is required monthly (when all conditions for sampling are met) (Figure 3 and Figure 4; Appendix A). At many six-monthly sampling sites, there is no access to the outfall. However, due to the small size of the receiving catchments for these outfalls, there is not expected to be any flow under dry conditions.

Dry weather water sampling is required at stormwater outfalls under low tide conditions, to avoid dilution by seawater. Dry weather is defined as a period of at least 72 hours with no more than 1 mm of measurable rainfall. If no dry weather conditions occur within a calendar month, no sampling is undertaken for that month.

When conditions are suitable, grab samples of water are collected in laboratory-provided containers from the end of the outfall pipe, or as near as practicable prior to the discharge mixing with seawater, for laboratory analysis (Eurofins) for *Escherichia coli* (*E. coli*). *E. coli* is a type of bacteria commonly found in the gut of humans and other warm-blooded animals and is used as an indicator of faecal contamination in freshwater. The indicator bacteria themselves do not necessarily pose a significant risk to human health, but rather indicate the likely presence of faecal material, which contains disease-causing pathogens, including a range of bacteria and viruses. Potential sources of *E. coli* in stormwater include sewage and faecal deposition by animals (e.g., birds, rodents, domestic pets). If the *E. coli* concentration in samples from three consecutive months is greater than 550 units per 100 millilitres, the consent requires investigation and remedial action, if required. The *E. coli* trigger level is based on Ministry for the Environment (MfE) (2003) action (red) level guidelines where water poses an unacceptable health risk from bathing.

Grab samples of water are also collected and analysed on site for fluorescent whitening agents (FWAs) using an AquaFluor handheld fluorometer. Measurement of FWAs is not required by resource consents, however they provide a useful indicator of potential contamination. FWAs are used in laundry detergents and, as household plumbing mixes effluent from toilets with washing machine 'grey water', FWAs can be associated with human faecal contamination and indicate possible wastewater infiltration to the stormwater system. Detection of 0.1 ppb of FWA is suggestive of contamination from grey/wastewater and a level of 0.2 ppb is strongly indicative of contamination from grey/wastewater (Gilpin and Devane 2003). While samples with higher levels of FWAs generally also contain high levels of *E. coli*, a direct linear relationship between the two is not always evident as FWAs are chemicals that may have different movement and survival characteristics to microbial pathogens (Gilpin and Devane 2003).

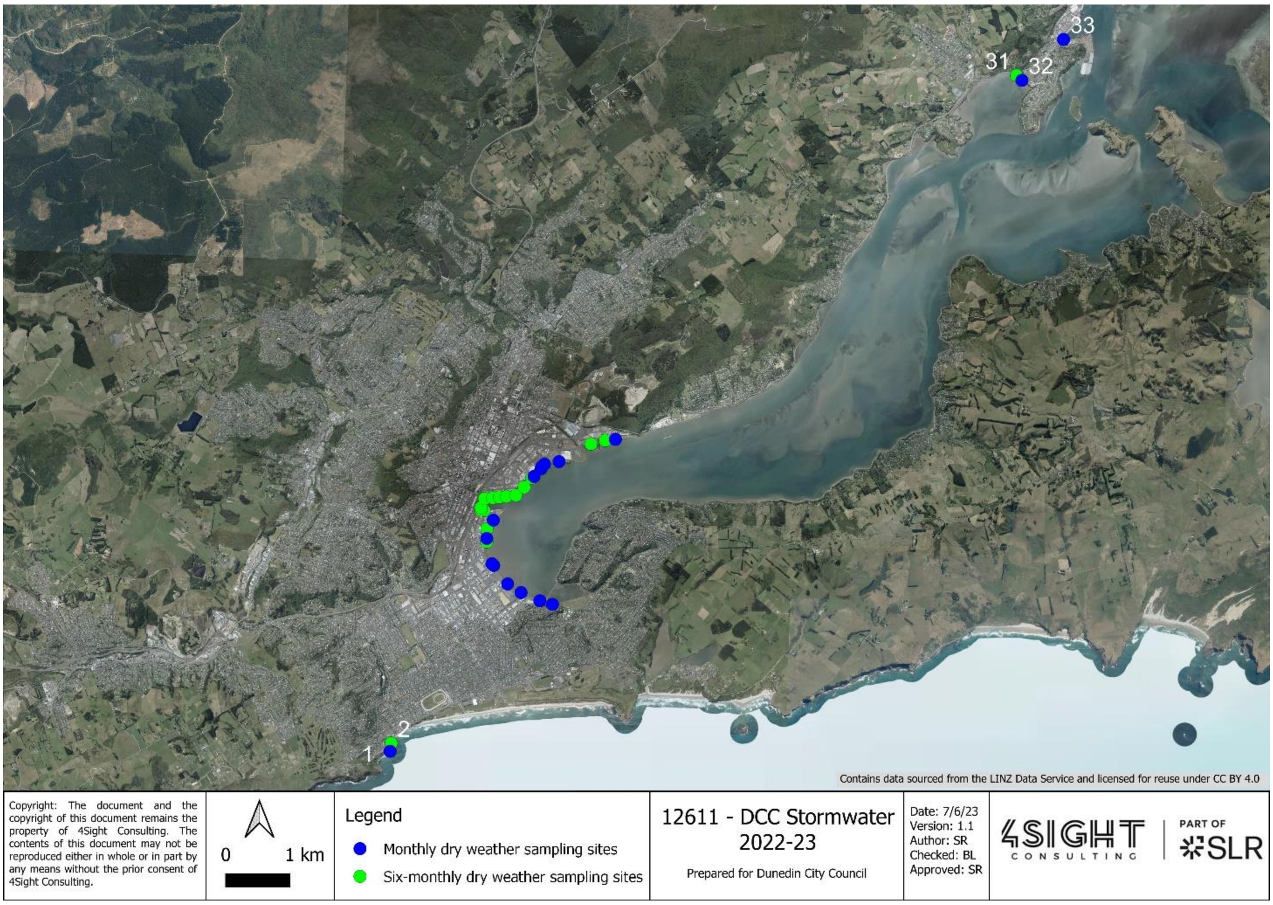

Figure 3: Dunedin stormwater outfalls – monthly and six-monthly dry weather sites (all sites).

Figure 4: Dunedin stormwater outfalls – monthly and six-monthly dry weather sites (upper harbour sites).

3.2 Wet weather stormwater sampling

Wet weather water sampling is undertaken in an endeavour to sample the first flush of stormwater, which typically contains the highest concentration of contaminants, into the receiving environment.

Wet weather water sampling is required annually at ten major stormwater outfalls (Figure 5 and Figure 6, Appendix A) at low tide within two hours of the commencement of a rain event (more than 2.5 mm of rain), following an antecedent dry period of at least 72 hours of no rainfall in the catchment.

When conditions are suitable, grab samples of water are collected in laboratory-provided containers from the end of the outfall pipe, or as near as practicable prior to the discharge mixing with seawater, for laboratory analysis (Hill Labs) for total arsenic, cadmium, chromium, copper, nickel, lead, and zinc, and oil and grease, suspended solids, pH, polycyclic aromatic hydrocarbons (PAH), and *E. coli*.

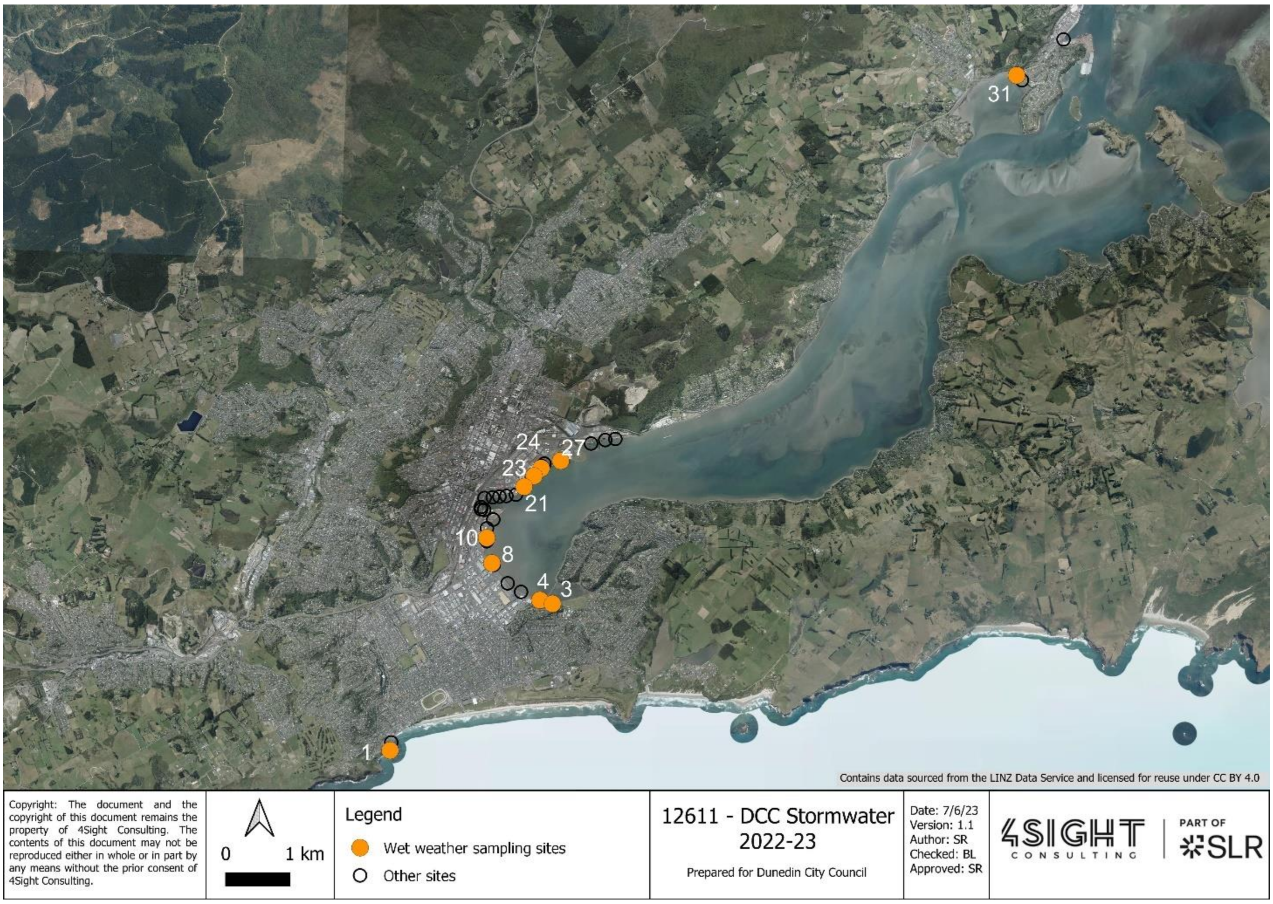

Figure 5: Dunedin stormwater outfalls – wet weather sampling sites (all sites).

Figure 6: Dunedin stormwater outfalls – wet weather sampling sites (upper harbour sites).

3.3 Wet weather stormwater sampling – automated sampler

An ISCO automated sampler is a sampling device used to remotely collect water samples. The sampler is installed next to an opening into the stormwater network (e.g., manhole), and a tube installed from the sampler into the stormwater pipe. When the required conditions are met, the sampler is triggered to collect water samples with a pump used to extract water from the stormwater pipe and fill bottles within the sampling device. Samples from these bottles can then be analysed to provide a contaminant profile through time.

The sampler can only be installed within one stormwater catchment at a time, so it is used to target specific outfalls within certain stormwater catchments (South Dunedin, Halsey Street, Shore Street, Kitchener Street and Mason Street catchments), as required by resource consents. Consent conditions require sampling of three storm events per year, with the sampler to be moved yearly such that each catchment is sampled once every five years. However, the sampler has remained at a site longer than one year due to the difficulty in capturing three suitable events (that meet all required conditions) within this period.

Installation at the Halsey Street catchment, approximately 75 m up-pipe of a Halsey Steet stormwater outfall (Figure 7), was completed in early December 2021.

The sampler is programmed to collect 1 L water samples every five minutes over the first two-hour period of a rain event (more than 2.5 mm of rain), to provide a contaminant profile across the rain event including the first flush of stormwater. Consent conditions for sample analysis require an antecedent dry period of at least 72 hours of no rainfall in the catchment and no mixing with seawater (i.e., low tide).

When the automated sampler is triggered under suitable conditions, water samples are collected within the sampler's 24 internal 1 L bottles. These bottles need to be emptied within four hours of collection, to ensure the integrity of the samples. Due to the volume of water required for laboratory analysis, samples from two bottles are combined to make one 10-minute sample (12 samples in total over the two-hour rain event), and these samples are transferred into laboratory-provided containers. Following removal of the samples, the internal 1 L bottles are thoroughly rinsed with distilled water and replaced within the sampler, which is reset to prepare for further sampling. Samples are transferred to the laboratory (Hill Labs) and analysed for total arsenic, cadmium, chromium, copper, nickel, lead, and zinc, and oil and grease, suspended solids, pH, PAH, and *E. coli*. In addition, FWAs are measured using an AquaFluor handheld fluorometer.

The sampler sometimes triggers when not all the required conditions have been met, which results in 'false alarms'. False alarms can occur when the sampler triggers at the time of a higher tide that could result in potential saltwater intrusion into the collected samples, or when the rain event does not continue with sufficient rainfall and the sample bottles do not get filled sufficiently. Other causes for false alarms include malfunctions or maintenance issues with the sampler (e.g., perforated tubing within the sampler, flat battery, errors with communication between sampler and rain gauge). Following false alarms, the sampler is checked, bottles emptied (if required) and rinsed with distilled water, and the sampler reset.

Figure 7: The location of the ISCO automated sampler since December 2021, sampling the Halsey Street catchment.

3.4 Harbour water sampling – dry and wet weather

Monitoring of harbour water quality is undertaken during dry weather and during wet weather (i.e., a rain event). Dry weather sampling allows the determination of background contaminant levels in harbour water, while wet weather sampling assesses the contribution of contaminants from high volume stormwater inputs. Ebb tides (outgoing tides) are likely to move stormwater contaminants down harbour while flood tides (incoming tides) may lead to higher concentrations of stormwater contaminants in the upper harbour. However, inputs from the Water of Leith can complicate contaminant levels, especially during flood tides. The upper harbour basin requires 4–6 tidal cycles to flush completely (Smith and Croot 1993, 1994) and therefore contaminants within the upper harbour basin may gradually increase in concentration throughout prolonged wet spells.

Harbour water sampling is required at six sites in the upper harbour (Figure 8) for one dry weather period and for one rainfall event each year. Dry sampling follows high tide and occurs three hours apart on the mid ebb tide and then mid flood tide during a period when there has been no measurable rainfall for at least 72 hours prior to sampling. Wet sampling occurs at the same state of tides as the dry round, no less than three hours after the commencement of a rain event that is likely to produce at least 2 mm of rainfall and that has had an antecedent dry period of at least 72 hours.

When conditions are suitable, grab samples of water are collected from approximately 20 cm below the water surface, in laboratory-provided containers for laboratory analysis (Eurofins) for total cadmium, copper, lead, and zinc and enterococci.

Results for heavy metals are assessed against 2013 trigger levels specified in the consents, which originate from ANZECC (2000) 95% protection trigger values for 'slightly to moderately disturbed' ecosystems, with 95% signifying the percentage of species expected to be protected. For marine systems, this ecosystem condition would typically have largely intact habitats and associated biological communities. Examples are marine ecosystems lying immediately adjacent to metropolitan areas, such as Otago Harbour. Trigger values are concentrations that, if exceeded, could indicate a potential environmental problem, and so 'trigger' a management response.

Enterococci is a type of bacteria commonly found in the gut of humans and other warm-blooded animals and is used as an indicator of faecal contamination in marine water. Enterococci have been identified as having the best relationship with health effects in marine waters (MfE 2003). The indicator bacteria themselves do not necessarily pose a significant risk to human health; instead they indicate the presence of faecal material, which contains disease-causing pathogens. Potential sources of enterococci bacteria in Otago Harbour include sewage and faecal deposition by animals (e.g., birds, rodents, domestic pets, livestock). Results for enterococci are compared against MfE (2003) bacteriological 'trigger' values for bathing. In the consent, the trigger value has been set at the 'amber/alert' mode, where if a single sample has greater than 140 cfu/100 mL, a management response is triggered, which includes increased monitoring, investigation of source and risk assessment. Although the upper harbour basin is popular with wind surfers, paddle boarders, and other boat users when conditions permit, it is not a recognised swimming area. Consequently, the alert (amber) limit could be considered conservative and potentially not appropriate for much of the time.

Re-sampling of harbour water is required if trigger levels are exceeded, with re-sampling to be undertaken when the conditions are next suitable.

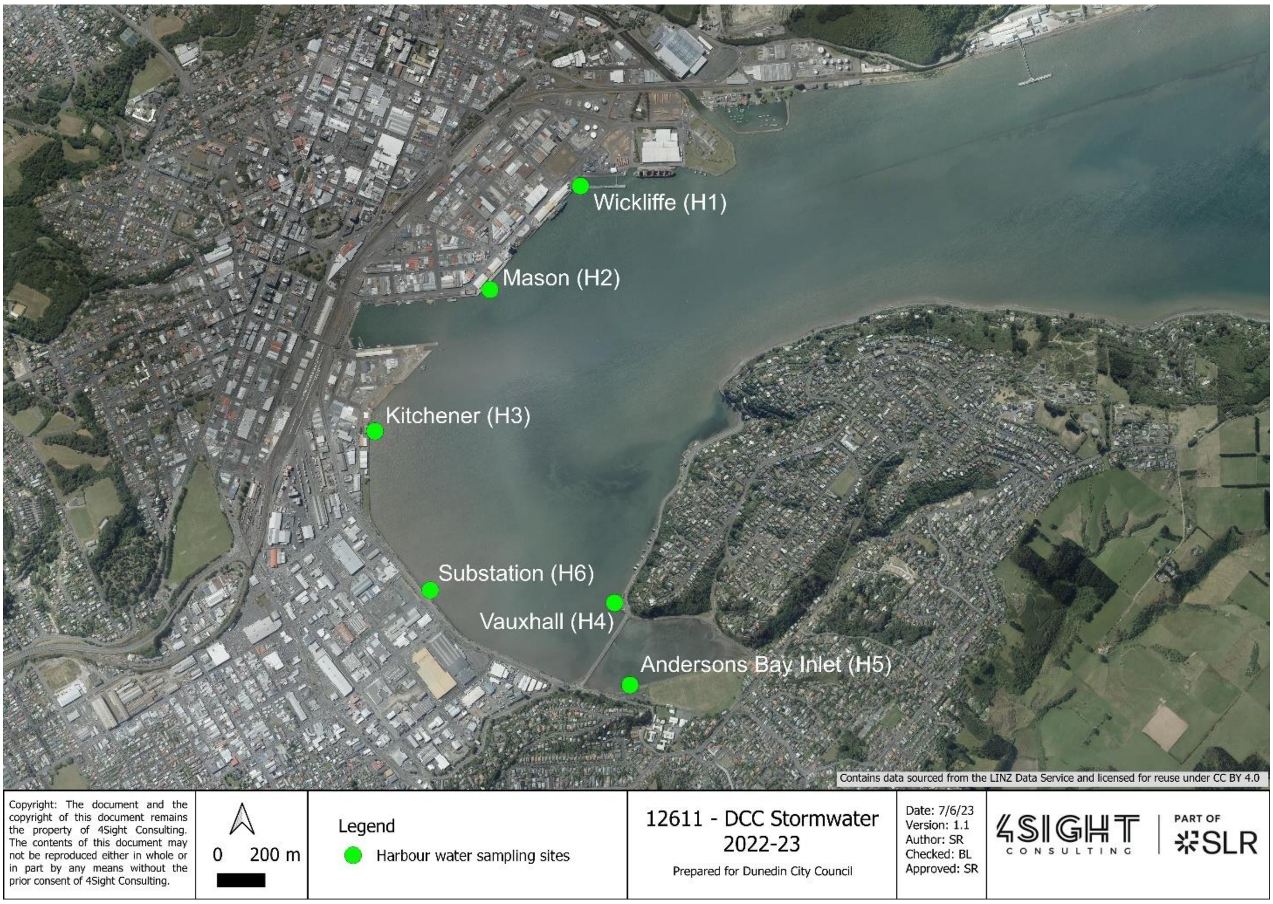

Figure 8: Otago Harbour water quality sampling sites.

3.5 Harbour sediment sampling

Monitoring of harbour sediment quality is undertaken as sediments are a potential source and sink for dissolved contaminants. Assessing sediment quality can identify where contaminant concentrations could result in adverse effects on ecological communities.

Harbour sediment sampling is required once annually at four sites in the upper harbour (Figure 9).

Samples are collected from the uppermost 20 mm of sediment from the area within approximately 20 m from the nearest stormwater outfall. At the Orari Street and Shore Street sites, samples are collected by scooping the top 20 mm of the harbour bed sediment and transferring the sediments into laboratory-provided containers. At the Halsey Street and Kitchener Street sites, sampling is required in deep water (approximately 3-7 m deep). Sediment at these sites is therefore collected using a petit ponar grab, with a subsample obtained from the uppermost 20 mm of the contents of the grab and transferred into laboratory-provided containers. Samples are collected for laboratory analysis (Eurofins) for total arsenic, cadmium, chromium, copper, nickel, mercury, lead, and zinc, and weak-acid extractable (WAE) copper, total petroleum hydrocarbons (TPH), organochlorine pesticides (OCP), and PAH.

Concentrations of contaminants in each sediment sample are assessed against 2013 trigger levels specified in the consents. Total arsenic, cadmium, copper, lead and zinc and PAH trigger levels were determined from the 80th percentile of samples collected to that date. Total chromium and nickel trigger levels originate from ANZECC (2000) interim sediment quality guidelines (ISQG). Trigger values for TPH and WAE copper are yet to be determined, but TPH can be compared with 2018 sediment quality default guideline values (ANZG 2018). ANZECC (2000) ISQG-low values indicate concentrations at which there could be a possible biological effect and is intended as a trigger value for further investigation, whereas ISQG-high values indicate concentrations at which toxic-related adverse effects are expected.

Figure 9: Otago Harbour sediment sampling sites.

3.6 Harbour biological sampling

Biological monitoring at selected Otago Harbour sites specified in the consents (Burkes, Kitchener Street, Orari Street, Portobello Road and Macandrew Bay; Figure 10) is required every two years. Kitchener Street, Orari Street and Portobello Road sites are located near stormwater outfalls and could potentially be affected by stormwater inputs, and are therefore potential 'Impact' sites. Burkes and Macandrew Bay sites are considered 'Control' sites as they are not expected to be affected by stormwater inputs due to their distance from the outfalls.

Biological monitoring at each site includes the assessment of infauna, epifauna and macroflora at the waters edge, at low tide, in three areas (0-5 m from the stormwater outfall, 5-20 m from the outfall, and >50 m from the outfall) (Table 1). Due to the absence of stormwater outfalls at the Burkes and Macandrew Bay control sites, sampling is undertaken at three random areas along the waters edge at low tide.

Further, little-neck clams (*Austrovenus stutchburyi*, commonly referred to as cockles) are collected from the three potential 'Impact' sites (Table 1) for contaminant analysis.

Figure 10: Otago Harbour biological sampling sites.

Table 1: Biological monitoring required at Otago Harbour sites.

Site	Status	Sample areas	Assessments required
Kitchener Street	Potential 'Impact'	0-5 m, 5-20 m, >50 m from outfall	Infauna, Epifauna, Macroflora, Cockles
Orari Street	Potential 'Impact'	0-5 m, 5-20 m, >50 m from outfall	Infauna, Epifauna, Macroflora, Cockles
Portobello Road	Potential 'Impact'	0-5 m, 5-20 m, >50 m from outfall	Infauna, Epifauna, Macroflora, Cockles
Burkes	'Control'	3 random areas (as no outfall)	Infauna, Epifauna, Macroflora
Macandrew Bay	'Control'	3 random areas (as no outfall)	Infauna, Epifauna, Macroflora

Epifauna

Benthic epifauna are recorded in five quadrats (0.25 m^2) randomly placed within each of the three sampling areas (e.g., 0-5 m from outfall). Species identification is completed to the lowest possible taxonomic level, with specimens collected when required. Epifauna species are recorded as individual counts, except for Serpulidae (sessile, tube-building annelids) at Kitchener Street which are recorded as percentage cover.

Infauna

Benthic infauna samples are collected using a core sampler (75 mm diameter, 200 mm deep), with three core samples collected within each of the three sampling areas (e.g., 0-5 m from outfall); core samples are taken within three of the five epifauna quadrats. Core samples are preserved in ethanol and sent to SLR Consulting's Nelson laboratory for sieving (500 µm), identification and enumeration using a light microscope. Organisms are identified to the lowest possible taxonomic level.

Macroflora

Macroflora is recorded in three quadrats (1 m^2) randomly placed within each of the three sampling areas (e.g., 0-5 m from outfall). Species identification is completed to the lowest possible taxonomic level, with percentage cover recorded. Specimens are collected when required.

Cockles

Cockles are collected by hand within 20 m of the outfalls at the Kitchener Street, Orari Street and Portobello Road sites. Cockles are returned to 4Sight Consulting's laboratory where their size and weight are recorded before being sent for laboratory analysis of the flesh (Hill Labs) for total arsenic, cadmium, chromium, copper and lead, polycyclic aromatic hydrocarbons (PAHs) and enterococci (the marine faecal indicator bacteria).

Data analysis

Data and statistical analyses are conducted to assess community composition (infauna, epifauna and macroflora).

The five sites are grouped based on their status (potential 'Impact' and 'Control'), to assess the overall effect of stormwater discharges on community composition. Further, the sampling areas at potential 'Impact' sites are grouped based on distance from the outfall (i.e., Zone A: 0-5 m from outfall, Zone B: 5-20 m, Zone C: >50 m) to assess any influence of distance to the outfall on community composition.

If stormwater discharges were impacting the health of the surrounding ecosystem, we would expect:

- Changes in community composition between 'Control' and potential 'Impact' sites: higher abundance of 'pollution-tolerant' species and lower abundance or absence of 'sensitive' species at the potential 'Impact' sites, and lower abundance of 'pollution-tolerant' species and presence of 'sensitive' species at the 'Control' sites.
- Changes in community composition related to proximity to the outfall (e.g., Zone A: 0-5 m from outfall): higher abundance of 'pollution-tolerant' species and lower abundance or absence of 'sensitive' species closer to the outfall, and lower abundance of 'pollution-tolerant' species and presence of 'sensitive' species in zones farther from the outfall.

Raw percentage and individual count data are transformed (log10(x+1) and square root, respectively) to meet assumptions of homogeneity. The two datasets (% cover and individual counts) are treated separately. Diversity indices are calculated and a multi-variate statistical analysis used to investigate relationships between sites; details of these analyses can be found in Appendix B.

3.7 Sampling overview

Table 2 provides an overview of the sampling requirements, parameters, and relevant guidelines, as specified by the consents.

Table 2: Dunedin stormwater sampling requirements.

Sampling type	Requirements	Locations	Parameters	Guidelines (from consents)
Dry weather sampling: outfalls	**Monthly/six-monthly:** Low tide 72 hours dry weather	33 outfalls	*E. coli*, FWA	**MfE (2003):** *E. coli*: 550 cfu/100mL
Wet weather sampling: outfalls	**One rain event per year:** Low tide 72 hours dry weather >2.5 mm rain in first 2 hours	10 outfalls	Total arsenic, cadmium, chromium, copper, nickel, lead, zinc, oil and grease, suspended solids, pH, PAH, *E. coli*	–
Wet weather sampling: automated sampler	**Three rain events per year:** Low tide 72 hours dry weather >2.5 mm rain in first 2 hours	Currently at Halsey Street site	Total arsenic, cadmium, chromium, copper, nickel, lead, zinc, oil and grease, suspended solids, pH, PAH, *E. coli*	–
Harbour water	**One rain event and one dry weather period per year:** 72 hours dry weather Incoming and outgoing tide Rain event: >2mm rain	6 sites	Total cadmium, copper, lead, zinc, enterococci	**2013 trigger levels (from ANZECC 2000):** Cadmium: 0.0055 g/m^3 Copper: 0.0013 g/m^3 Lead: 0.0044 g/m^3 Zinc: 0.015 g/m^3 **MfE (2003):** Enterococci: 140 cfu/100mL
Harbour sediments	**Once per year (between January and June):** Low tide (required for access)	4 sites	Total arsenic, cadmium, chromium, copper, nickel, mercury, lead, zinc, WAE copper, TPH, OCP, PAH	**2013 trigger levels (from 80th percentile of previous samples):** Arsenic: 19 mg/kg Cadmium: 1.7 mg/kg Copper: 122 mg/kg Lead: 209 mg/kg Zinc: 902 mg/kg PAH: 183 mg/kg **ANZECC (2000) ISQG-Low:** Chromium: 80 mg/kg Mercury: 0.15 mg/kg Nickel: 21 mg/kg
Harbour biological	**Once every two years (between January and June):** Low tide (required for access)	5 sites	Infauna, epifauna, macroflora, cockles	–

4 RESULTS AND DISCUSSION

4.1 Stormwater – Dry weather

4.1.1 Sampling results

Dry weather sampling of stormwater outfalls was undertaken under the required weather and tidal conditions during four of the twelve months: November 2022, and January, February, and June 2023 (see Appendix C). Dry weather sampling could not be undertaken in other months between July 2022 and June 2023 due to weather conditions not being suitable (e.g., no antecedent dry period of at least 72 hours) and/or tidal conditions not being suitable for sampling (e.g., low tide in the middle of the night, or low tides not suitable for accessing outfalls).

Most of the stormwater outfalls sampled had concentrations of *E. coli* that exceeded the consented trigger level (550 cfu/100 mL) on at least one occasion during the monitoring period (Table 3). Outfalls 4 (South Dunedin catchment), 9 (Portsmouth Drive catchment), 11 and 12 (Kitchener Street catchment), 28 (Ravensbourne catchment), and 32 (Port Chalmers catchment) were the only outfalls sampled that did not exceed the trigger level. Of these outfalls, 9, 11, and 28 are only sampled on a six-monthly basis. Outfall 2 is also sampled six-monthly, but there was no flow at this site when this was last undertaken. Similarly, Outfalls 13-22 are to be sampled on a six-monthly basis, but there is no access to these outfalls. However, due to the small size of the receiving catchments for these outfalls, there is not expected to be any flow under dry conditions. Outfall 26 is sampled on a monthly basis, but had no flowing water when sampling was undertaken.

Due to the timing of the monthly sampling, with several months without suitable conditions for sampling, there were no three consecutive months of sampling over the twelve month period. However, Outfalls 3 (Shore Street catchment), 5 and 7 (Portsmouth Drive catchment), and 27 (Halsey Street catchment) all had *E. coli* concentrations that exceeded the trigger level over three consecutive sampling rounds (Table 3).

FWA concentrations were variable at the stormwater outfalls, with only Outfalls 5 (Portsmouth Drive catchment), 30 (Ravensbourne catchment) and 32 (Port Chalmers catchment) having elevated FWA concentrations on multiple occasions during the 2022-23 monitoring period. This indicates that possible cross-connections between stormwater and wastewater systems are unlikely.

Overall, over the 2022-23 monitoring period, dry weather sampling at stormwater outfalls revealed several outfalls with elevated *E. coli* concentrations on multiple occasions. According to the consent conditions, if the *E. coli* concentration in samples from three consecutive months is greater than the trigger level, the consent requires investigation and remedial action, if required.

4.1.2 Future

It is important to note that the *E. coli* trigger level for this dry weather sampling is based on MfE guidelines for recreation, with results above the trigger level indicating water is considered unsafe for swimming. The dry weather sampling is useful to assist with determining whether there are any cross-connections between stormwater and wastewater systems, however as recreation/bathing would not be undertaken within the stormwater pipes, it is arguable whether this sampling is useful for determining whether the water poses a health risk for bathing; harbour water quality sampling would be more useful for determining any health risks for bathing associated with any dry-weather discharges from the stormwater outfalls.

It could be worthwhile to review the sampling regime for dry weather monitoring, to remove the requirement for sampling of some outfalls. These could be outfalls where there has consistently been no indicators of wastewater in previous sampling or those which frequently contain no flowing water (e.g., Outfalls 12, 26, 32), or are sampled six-monthly (due to previously been found to have no indicators of wastewater or be frequently dry) and are consistently dry during dry weather (e.g., Outfall 2, 9, 11, Outfalls 13-22 which are also inaccessible).

Table 3: *E. coli* dry weather sampling results between July 2022 and June 2023, compared with the *E. coli* trigger level of 550 cfu/100mL (MfE (2003) action (red) limit). Grey cells: no sampling or no access or no flow. Green cells: results below trigger levels. Red cells: results above trigger levels.

Outfall	Location	Frequency	Nov 2022	Jan 2023	Feb 2023	Jun 2023
1	Second Beach	Monthly	[green]	[green]	[red]	[red]
2	St Clair Beach	Six-monthly	[grey]	[grey]	[grey]	[grey]
3	Shore Street	Monthly	[red]	[red]	[red]	[green]
4	Portobello Road	Monthly	[green]	[green]	[green]	[green]
5	Teviot Street	Monthly	[green]	[red]	[red]	[red]
6	Midland Street	Monthly	[red]	[red]	[green]	[red]
7	Orari Street	Monthly	[red]	[red]	[red]	[red]
8	Orari Street	Monthly	[green]	[green]	[red]	[red]
9	Kitchener Street	Six-monthly	[grey]	[green]	[grey]	[grey]
10	Kitchener Street	Monthly	[grey]	[green]	[green]	[red]
11	French Street	Six-monthly	[grey]	[green]	[grey]	[grey]
12	Kitchener Street	Monthly	[grey]	[green]	[green]	[green]
13-22	Birch, Wharf, Fryatt, Mason, Bauchop Streets	Six-monthly	[grey]	[grey]	[grey]	[grey]
23	Bauchop Street	Monthly	[green]	[grey]	[red]	[red]
24	Halsey Street	Monthly	[red]	[grey]	[red]	[red]
25	Halsey Street	Monthly	[red]	[grey]	[red]	[red]
26	Halsey Street	Monthly	[grey]	[grey]	[grey]	[grey]
27	Wickliffe Street	Monthly	[red]	[red]	[red]	[red]
28	Magnet Street	Six-monthly	[grey]	[green]	[grey]	[grey]
29	Magnet Street	Six-monthly	[grey]	[red]	[grey]	[grey]
30	Ravensbourne Road	Monthly	[green]	[green]	[red]	[green]
31	George Street / SH88	Six-monthly	[grey]	[red]	[grey]	[grey]
32	Sawyers Bay, Watson Park	Monthly	[green]	[green]	[green]	[green]
33	George Street (Port Otago)	Monthly	[green]	[grey]	[red]	[red]

4.2 Stormwater – Wet weather

Between July 2022 and June 2023 the conditions required to undertake wet weather sampling at stormwater outfalls (i.e., at low tide, within two hours of the commencement of a rain event (more than 2.5 mm of rain), and following an antecedent dry period of at least 72 hours of no rainfall in the catchment), were not met within daylight hours (required for safety reasons). There were therefore no suitable occasions for wet weather sampling to be completed in 2022-23. There have not been suitable conditions for sampling for several years, given the difficulty in having all conditions coinciding with daylight hours to allow safe sampling of the outfalls. Given the difficulty in meeting the required conditions, consideration should be given to reducing the length of the antecedent dry period in an effort to capture a rain event.

To increase the changes of completing some sampling, these potential reductions to the antecedent dry period are generally considered towards the end of the monitoring period each year (e.g., in April/May) when there have not been any suitable sampling occasions prior. However, this did not result in suitable conditions being met in 2023.

4.3 Automated sampler – Wet weather

4.3.1 Sampling results

The automated sampler has been located at the Halsey Street site since December 2021. Between July 2022 and June 2023 the conditions required for the automated sampler to trigger and collect samples of the first flush of a rain event were not met. The previous rain event captured by the sampler was in April 2022.

4.3.2 False alarms

Monitoring of the automated sampler includes monitoring for 'false alarms', which occur when the sampler is triggered when a rainfall event starts, but the event ends up not being suitable for sampling as the required conditions have not all been met. This often occurs when rainfall intensity is high at the start of an event, but then rain stops after only a short period of time, and also when rainfall starts at high tide, and thus the sampler would collect harbour water that had entered the stormwater pipes.

Between July 2022 and June 2023 there were 23 occasions when the sampler was incorrectly triggered.

4.3.3 Future

The ISCO automated sampler has been located within the Halsey Street catchment since early December 2021. Consent conditions require sampling of three rain events per year, with the sampler to be moved yearly such that each of the specified catchments is sampled once every five years. However, only the two April 2022 rain events have been captured at the Halsey Street catchment site, and the sampler should therefore remain at the current site until a third rain event is captured.

The stormwater catchments where the automated sampler is required to capture rain events are the South Dunedin, Halsey Street, Shore Street, Kitchener Street and Mason Street catchments. The automated sampler has been in the South Dunedin catchment (2014 to 2015), the Shore Street catchment (2015 to 2016), the Kitchener Street catchment (2016 to 2018), the Mason Street catchment (2018 to 2021), and the Halsey Street catchment (since December 2021). Following the conclusion of the deployment at the Halsey Street catchment site, the automated sampler can be re-deployed in the other catchments, potentially starting with the South Dunedin catchment (to retain the same order as previous deployments).

4.4 Harbour water

4.4.1 Sampling results – wet weather

Between July 2022 and June 2023 the conditions required to undertake wet weather sampling of harbour water were not met within daylight hours (required for safety reasons).

4.4.2 Sampling results – dry weather

Dry weather sampling was undertaken on 7 June 2023. On the mid-ebb tide, cadmium concentrations at all six sites were lower than laboratory detection limits (Table 4). Copper concentrations exceeded trigger values at the Wickliffe, Mason, and Kitchener sites, while lead and enterococci concentrations exceeded trigger values at the Substation site and zinc concentrations exceeded trigger values at the Vauxhall site. At the Andersons Bay Inlet site, all concentrations were lower than trigger values.

On the mid-flood tide, cadmium concentrations were lower than laboratory detection limits at all six sites (Table 4). At the Kitchener site, concentrations of copper, lead, and zinc exceeded trigger values, while at the Substation site, copper, lead, zinc, and enterococci concentrations exceeded trigger values. At the Andersons Bay Inlet site, copper, zinc, and enterococci concentrations exceeded trigger values. At the Wickliffe and Mason sites, all concentrations were lower than trigger values.

As trigger levels were exceeded for copper, lead, zinc, and enterococci at different sites, re-sampling for these contaminants during similar weather conditions was required. However, there were no suitable occasions with the required conditions to complete re-sampling.

Table 4: Harbour water sampling data from a dry weather sampling event on 7 June 2023. Teal cells indicate values exceed trigger levels.

	Dry weather – sampling: 7 June 2023				
	Cadmium (g/m³)	Copper (g/m³)	Lead (g/m³)	Zinc (g/m³)	Enterococci (cfu/100mL)
Trigger levels	0.0055[1]	0.0013[1]	0.0044[1]	0.015[1]	140[2]
Mid-ebb tide					
Wickliffe (H1)	<0.001	0.003	<0.001	0.005	< 10
Mason (H2)	<0.001	0.003	<0.001	0.009	40
Kitchener (H3)	<0.001	0.003	<0.001	0.005	< 10
Substation (H6)	<0.001	<0.002	<0.001	0.01	260
Vauxhall (H4)	<0.001	<0.002	<0.001	0.017	< 10
Andersons Bay Inlet (H5)	<0.001	<0.002	<0.001	0.008	40
Mid-flood tide					
Wickliffe (H1)	<0.001	<0.002	<0.001	<0.005	20
Mason (H2)	<0.001	<0.002	<0.001	0.006	< 10
Kitchener (H3)	<0.001	0.006	0.007	0.039	60
Substation (H6)	<0.001	0.014	0.013	0.078	10000
Vauxhall (H4)	<0.001	<0.002	<0.001	0.005	< 10
Andersons Bay Inlet (H5)	<0.001	0.012	<0.001	0.056	4000

1. ANZECC (2000) trigger values for protection of 95% of species (from resource consent).
2. MfE (2003) alert (amber) limit (from resource consent). The alert (or amber) mode is triggered when a single sample is greater than 140 enterococci per 100 mL for marine waters.

4.4.3 Dry weather and rain event comparison

Dry weather sampling results indicate background contaminant levels in harbour water without any influence from high volume stormwater inputs that occur during a rainfall event. Sampling in 2023 found copper, lead, and zinc concentrations exceeded the consented trigger levels at several sites during the mid-flood tide, which is when contaminants in harbour water would be moved into the upper harbour rather than out towards the harbour mouth. Previous sampling of harbour water has also found elevated copper concentrations at most sites during dry weather sampling, with elevated zinc and lead concentrations more variable by site and year. Common sources of copper include dust from wear of vehicle brake linings that have accumulated on impervious surfaces, copper building materials such as roofs, spouting and cladding, and a range of agricultural and industrial activities. Common sources of zinc include tyre wear and zinc-coated roofing materials. Common sources of lead include lead-based paints, roofing materials, and vehicles.

Comparing contaminant concentrations during rain events and dry weather reveals the relative inputs of contaminants during the different weather types. Figure 11 and Figure 12 display contaminant concentrations from sampling undertaken between 2017 and 2023, with results only shown where concentrations were above laboratory detection limits. The comparison indicates that copper concentrations are frequently higher during dry weather conditions than during rain events, while there are no obvious patterns with zinc concentrations, with similarly high concentrations irrespective of weather conditions (Figure 11). Lead concentrations are higher in harbour water during dry weather conditions, with only a few results from rain event sampling being above laboratory detection limits (Figure 12). Conversely, enterococci concentrations are higher during rain events, although there have been some high sampling results during dry conditions.

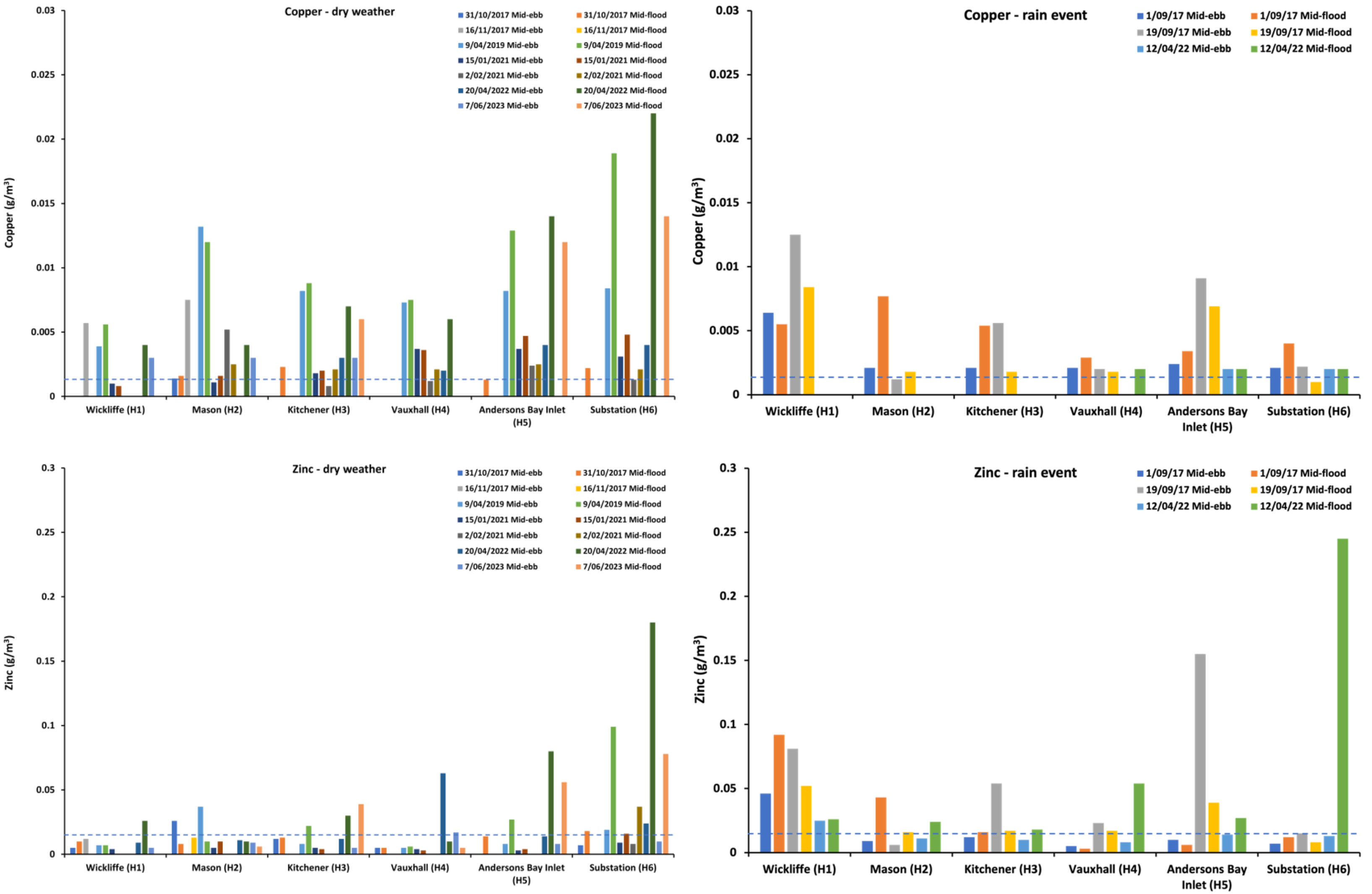

Figure 11: Contaminant concentrations in harbour water during dry weather and rain events, 2017-2023. Dashed lines indicate consent trigger levels.

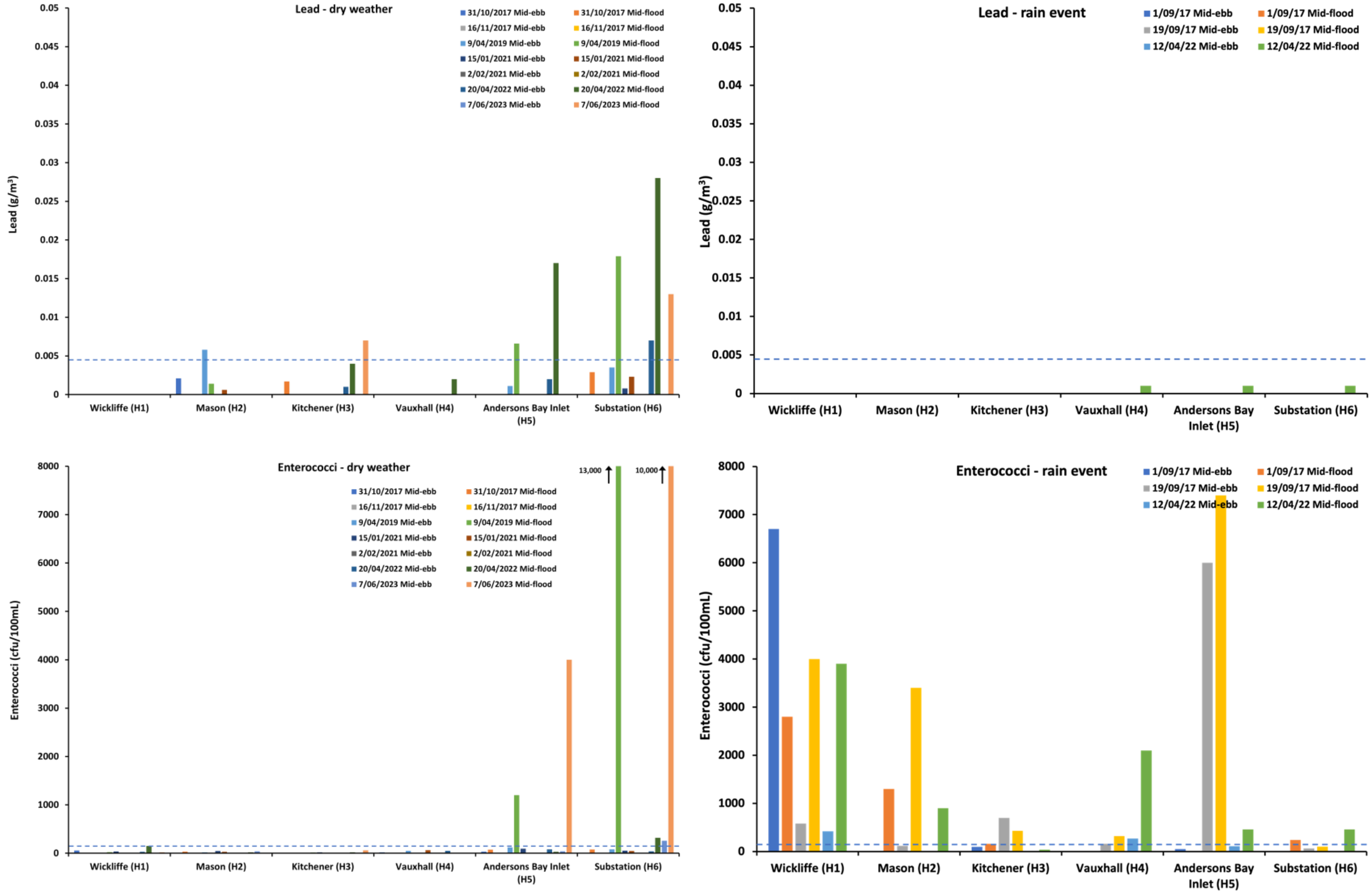

Figure 12: Contaminant concentrations in harbour water during dry weather and rain events, 2017-2023. Dashed lines indicate consent trigger levels.

4.5 Harbour sediment

4.5.1 Sampling results

Sampling of harbour sediment quality was undertaken at the four upper harbour sites on 7 June 2023. See Appendix D for tabulated results from this sampling.

Contaminant concentrations in harbour sediments at all sites were below the 2013 trigger levels listed in the resource consent (where applicable; Appendix D). The ANZECC (2000) ISQG-Low guideline levels were exceeded for lead and zinc (Orari Street and Shore Street), mercury (Halsey Street), and PAH (Shore Street), but contaminant concentrations were well below the ISQG-High levels at all sites. The ISQG-Low represents the threshold for potential effects to occur and is a trigger for further investigation, while the ISQG-High represents a point where a high probability of effects is possible. These results are generally similar to those from recent years, however zinc concentrations at the Shore Street site and mercury concentrations at the Halsey Street site were the highest found at those sites since 2017.

ANZECC (2000) guidelines, specified in the consents, do not provide guideline values for WAE copper, OCP and TPH. However, 2018 sediment quality default guideline values (DGV) (ANZG 2018) are available for TPHs (DGV 280 mg/kg, DGV-high 550 mg/kg) and individual OCPs (DGV range from 900-4500 mg/kg). TPH concentrations were less than laboratory detection limits (<5 mg/kg) at the Halsey Street and Kitchener Street sites, with the highest concentrations at (159 mg/kg) at the Shore Street site. All TPH concentrations were considerably lower than the ANZG (2018) DGV. Total OCP concentrations were less than laboratory detection limits (<1.7 mg/kg) at all sites, and considerably lower than the ANZG (2018) DGV.

Overall, sediment sampling in 2023 found generally similar concentrations at all four sites as in recent years. For many contaminants there are no obvious patterns in concentrations through time, however concentrations of copper and zinc appear to be increasing through time at the Shore Street site (Figure 13, Figure 14, and Figure 15). The increase of copper and zinc concentrations over time at Shore St may warrant further investigation to determine their source. The strict sampling criteria have resulted in no wet-weather sampling, making it difficult to determine whether such increases are due to stormwater or some other source.

Contaminant concentrations in sediments in recent years have been considerably lower than at some historic sites. For instance, Kitchener Street's catchment has historically included a scrap metal yard and a sandblasting operation, with high metal contaminants, while other sites have historically been influenced by the old gas works, which contributed high PAH concentrations to stormwater. Improvements in wastewater/stormwater connections and the cessation of many industrial activities have reduced many sources of contaminant inputs to the harbour.

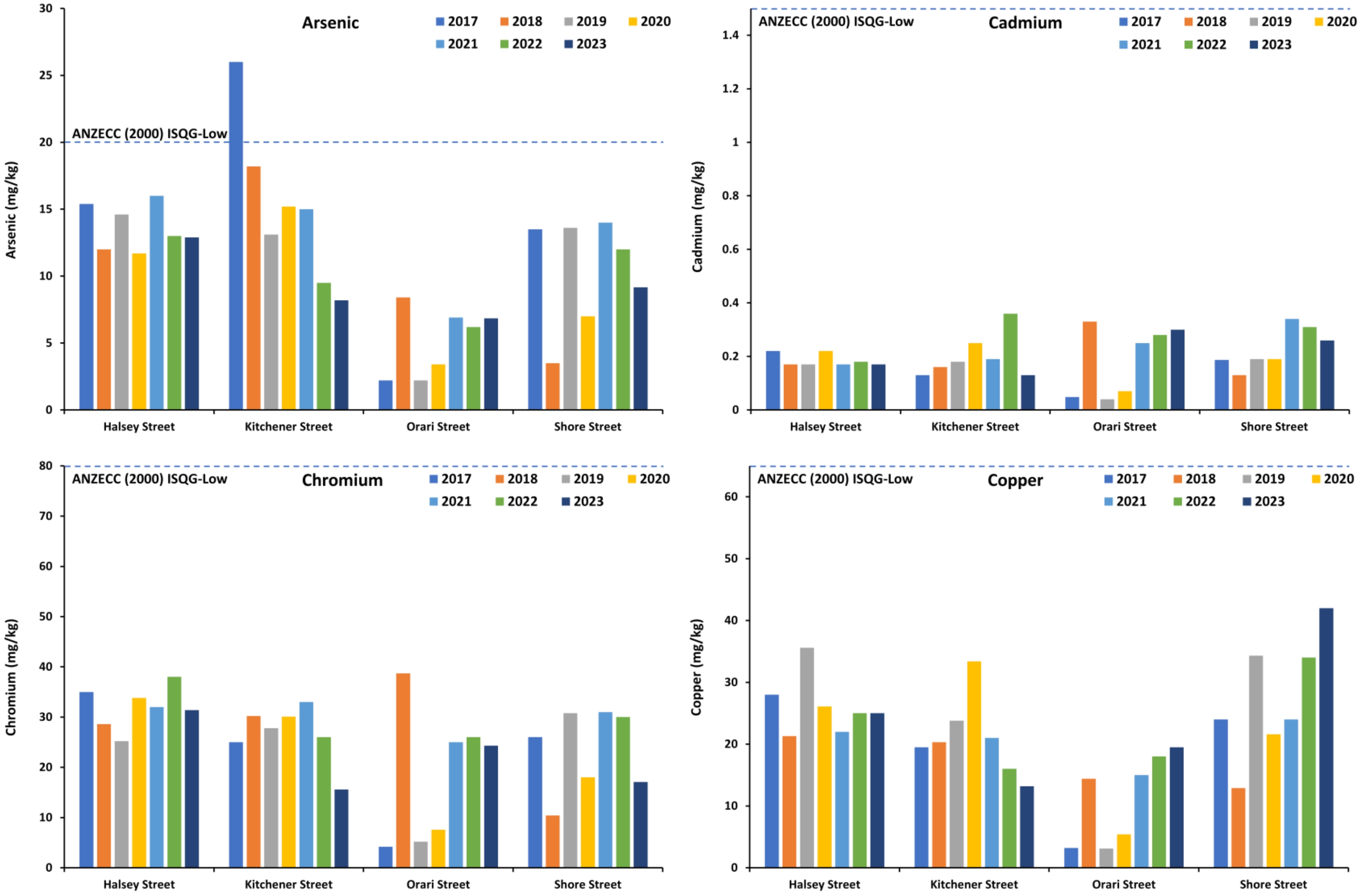

Figure 13: Contaminant concentrations collected from harbour sediments between 2017 and 2023. Dashed lines indicate ANZECC (2000) ISQG guideline levels.

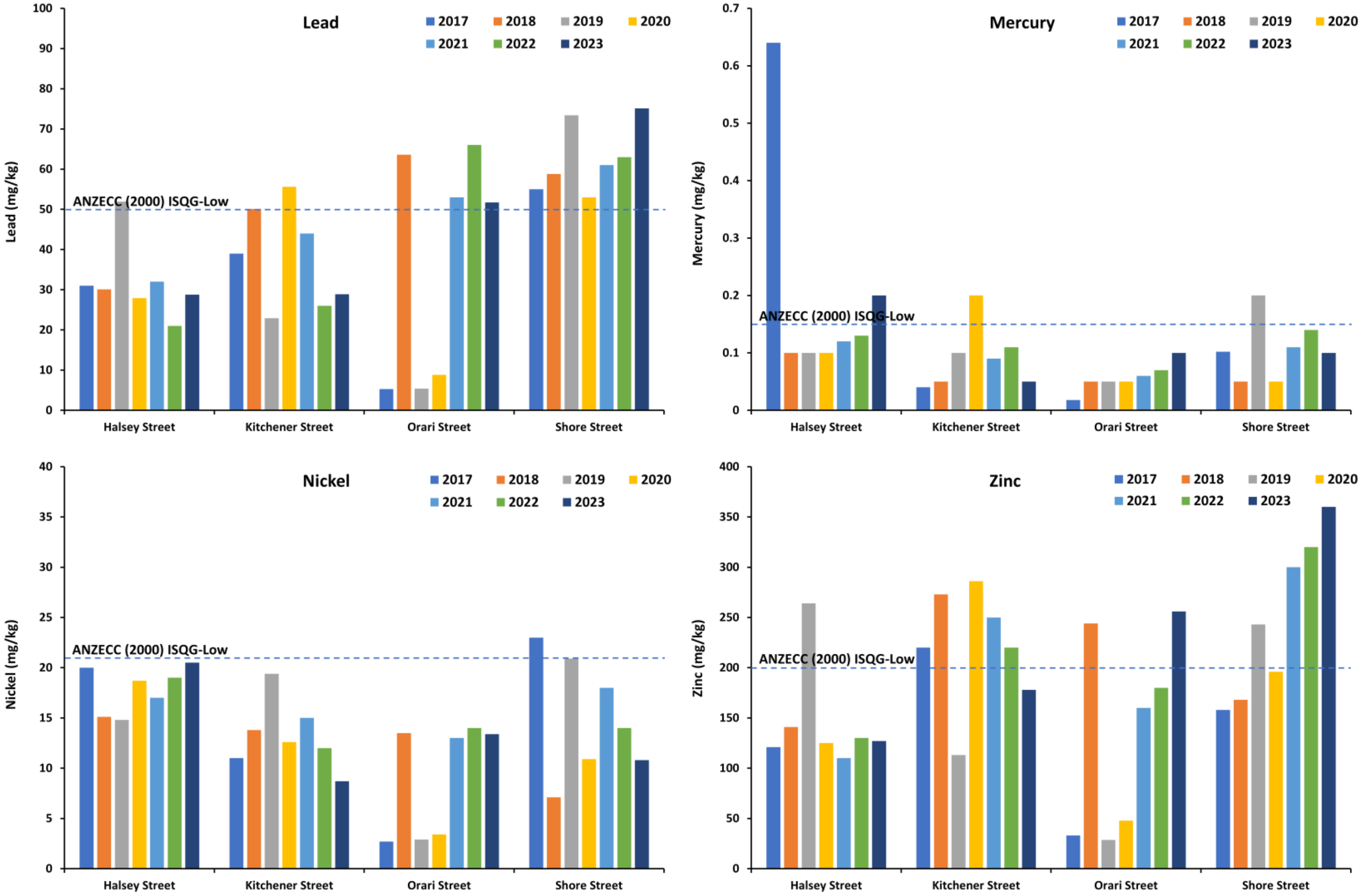

Figure 14: Contaminant concentrations collected from harbour sediments between 2017 and 2023. Dashed lines indicate ANZECC (2000) ISQG guideline levels.

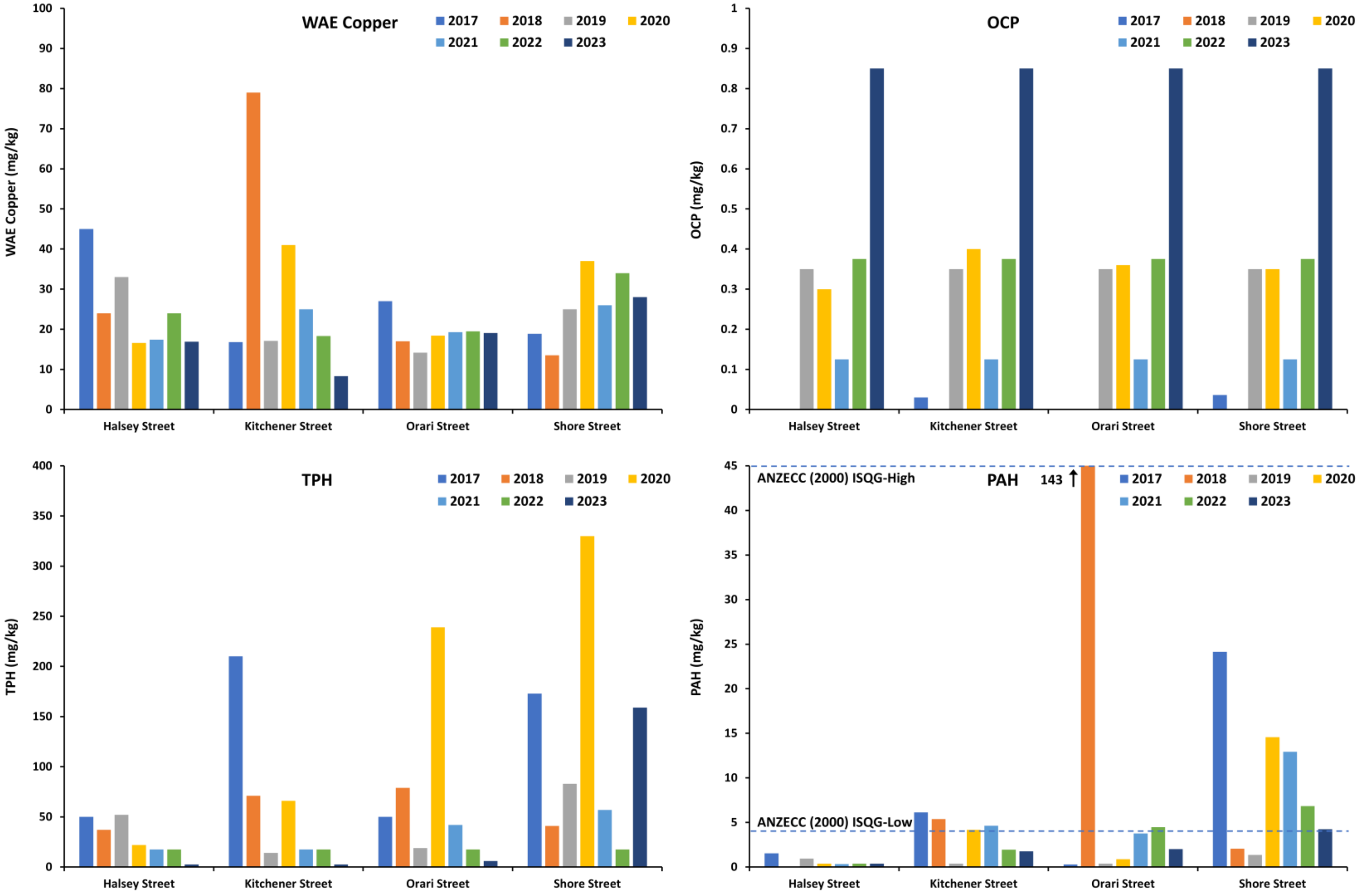

Figure 15: Contaminant concentrations collected from harbour sediments between 2017 and 2023. Dashed lines indicate ANZECC (2000) ISQG guideline levels Note OCP were all lower than laboratory detection limits, however these limits were higher in 2023 than in previous years.

4.6 Harbour biological

Biological sampling at the five sites (Burkes, Kitchener Street, Orari Street, Portobello Road and Macandrew Bay) was undertaken on 8 and 9 May 2023, at low tide.

4.6.1 Community overview

A total of 11 phyla, 69 families and 94 species were recorded at the five sites. Macroflora included six families and seven species, epifauna included 12 families and 15 species and infauna included 51 families and 75 species (Appendices E).

Macroflora was recorded as percentage of cover in 0.25 m^2 quadrats, unattached seaweed was also recorded within each quadrat. The highest average percent coverage was recorded at Orari Street while the lowest was seen at Burkes. The seaweed *Ulva compressa* accounted for the majority of percent coverage at Orari Street and was absent at the other sites (Appendix E).

Figure 16 below outlines the species richness (S'), diversity (H') and evenness (J') of the epifauna and infauna recorded at each site. Portobello Road showed the highest epifauna species richness with 11 species found throughout the site, ranging down to three species recorded at Macandrew Bay. Species diversity was low overall for epifauna, with the highest Shannon-Wiener Diversity Index score recorded at Burkes at 1.24, ranging down to 0.15 at Orari Street. This is due to the barnacle (*Austrominius modestus*) accounting for the majority of individuals present in each sample. At Orari Street, the total number of individuals recorded was 1063, with 1038 of those being from the same species of barnacle (Appendix E). This also accounts for the species evenness being the lowest at Orari Street, with a score of 0.07, ranging up to a score of 0.89 at Burkes.

Orari Street showed the highest infauna species richness with 46 species recorded, ranging down to 17 species found at Portobello Road. Species diversity was highest at Kitchener Street, with a Shannon-Wiener Diversity Index score of 2.24, this ranged down to a score of 1.76 at Macandrew Bay. Echoing the epifauna results, the lowest score for species evenness was recorded at Orari Street with a score of 0.46, ranging up to a score of 0.68 at Burkes.

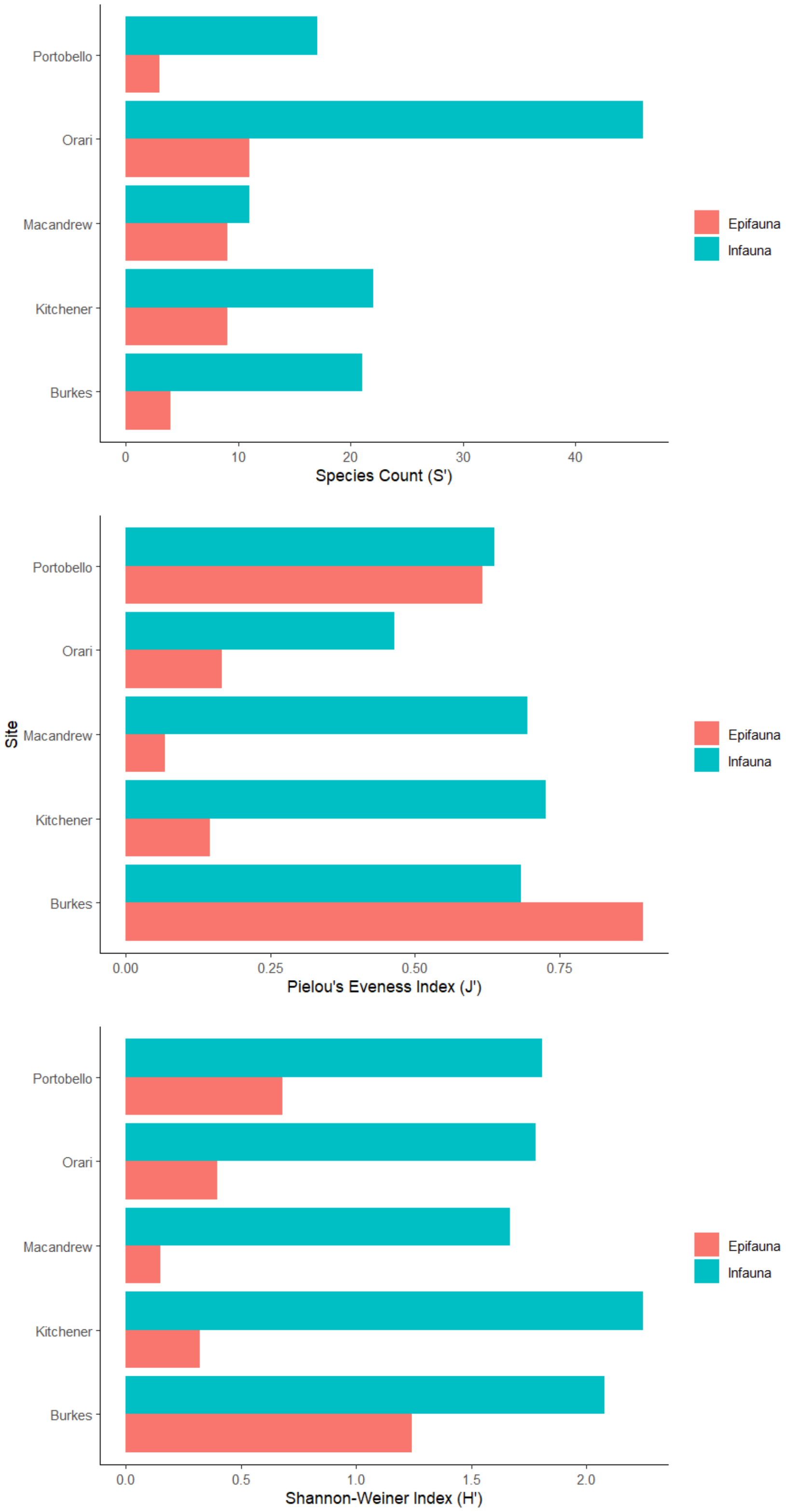

Figure 16: Community diversity indices for each site. S': species richness; J': Pielou's evenness index (a measure of species evenness; ranges from 0 to 1, from no evenness to complete evenness); H': Shannon Wiener index (a measure of community diversity; higher values indicate higher species diversity). 'Control' sites are Macandrew Bay and Burkes.

Average percentage composition was calculated for infauna and epifauna combined and is presented in Figure 17 below. Taxa that were recorded in percent coverage were excluded as they could not be compared to taxa recorded by counts. The barnacle species *Austrominius modestus* was also excluded. This species was present in much greater abundances than other taxa and skewed results towards the dominance of arthropoda, obscuring the rest of the species assemblage. The barnacle *A. modestus* was the most abundant taxa with a total of 3468 individuals present across the sites.

The most abundant phyla were Annelida and Mollusca, a pattern that was also reported in 2019 and 2021 (Goodwin and Ludgate 2019, Ludgate *et al.* 2021) (Figure 17). These results also agree with previous reports for the phyla found in Otago Harbour, where Annelida and Mollusca were two of the most abundant groups (Inglis *et al.* 2006). Rhodophyta were present at the most sites but in low abundances while chlorophyta species were abundant where they were present, at Orari Street and Portobello Road sites (Figure 18). However, it is acknowledged that a lot of the algae reported was not fixed to substrate.

Annelida were present at all sample sites. Capitellid worms made up the majority of the Annelida present, with the Capitellid worm *Heteromastus filiformis* recording 937 individuals identified across the sites. *H. filiformis* can be used as an indicator species in estuaries as this species can tolerate higher levels of copper and mud contents, typically becoming more abundant in areas not tolerated by more sensitive species. There does not appear to be a pattern of increasing abundance near any of the three outfall sites (Appendix E). Serpulidae (tube-building worms) were present at all 'Impact' sites and absent from Burkes and Macandrew Bay. These worms are dependent on hard substrate to build their tubes and are not a useful indicator of the potential impacts from stormwater discharges.

Mollusca were also present at all sites (Figure 17). The most abundant taxa were *Notoacmea*, the limpet genus with 95 individuals counted across all sites, and the cockle, *Austrovenus stutchburyi,* with 77 individuals present across all sites. *Notoacmea*, like Serpulidae, require hard substrates to live on and are also most abundant at the 'Impact' sites. *A. stutchburyi* is present throughout all sites and locations.

Arthropods were present at many 'Impact' and 'Control' sites, but were particularly abundant at Orari 0-5 m sites. This is a result of very few Annelida present at this site, increasing the relative abundance of Arthropods. Nematodes were present in the highest relative abundances at the 'Impact' sites. However, nematodes are easily missed during sample processing because of their size and it is therefore likely they are also present at the other sites.

As a general overview, healthy and established macroflora is a relatively uncommon occurrence across the majority of the survey sites, both 'Control' and potential 'Impact'. The highest abundance of fixed and growing algae was at Orari Street where *Ulva* sp*.* was well established on boulders of the breakwater and found in increasing abundance with distance from the outfall. Portobello Road had large amounts of rubbish and woody debris mixed with floating fragments of *Codium fragile novae-zelandiae* and *Adamsiella* sp*.* The only fixed and growing algae was the rhodophyte *Nemalion helminthoides* found in clusters >50 m from the stormwater discharge. All other sites had negligible recordings of macroflora.

One-way ANOVAs were performed on abundance data for infauna, epifauna, and macroflora at three levels to assess whether there are any statistically significant differences among abundances at each site: 'Control vs potential 'Impact', Sites, and Zones. There were statistically significant differences between 'Control' and potential 'Impact' sites for all three fauna groups ($p < 0.05$). There were also statistically significant differences between Sites for all three fauna groups. This is not surprising as there are some large differences in species abundance among the sites (e.g., Portobello vs. Orari). There were no significant differences detected between the different Zones for all three fauna groups ($p > 0.05$; Table E5, Appendix E).

Games-Howell Post-hoc tests were performed on all three fauna groups to identify which sites were significantly different from one another. When assessed by Site, infauna communities were not significantly different from one another, with the exception of Burkes and Portobello Road ($p = 0.037$). Epifauna were also not significantly different from one another, with the exception of Burkes and Orari Street ($p = 0.03$). A number of macroflora sites were significantly different from one another (Table E8, Appendix E), however given the sampling method included macroflora that was not fixed, the variable nature of algae sourced from other locations and transported to the study sites would in our opinion account for the majority of the significant differences observed between sites in this study.

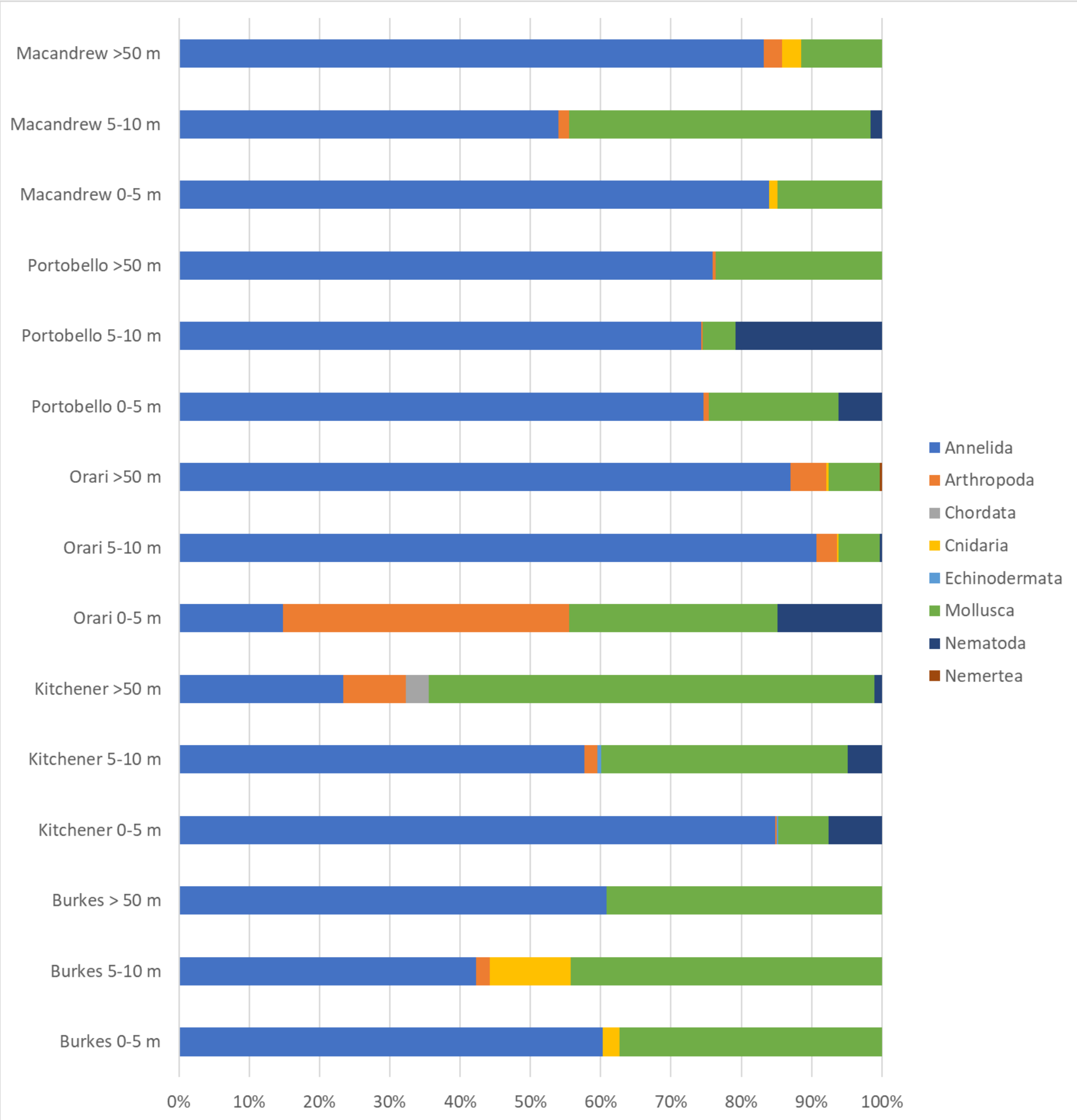

Figure 17: Average percentage composition of infauna and epifauna Phyla at each location and sampling site. Percentage cover taxa were excluded. Burkes and Macandrew Bay are 'Control' sites.

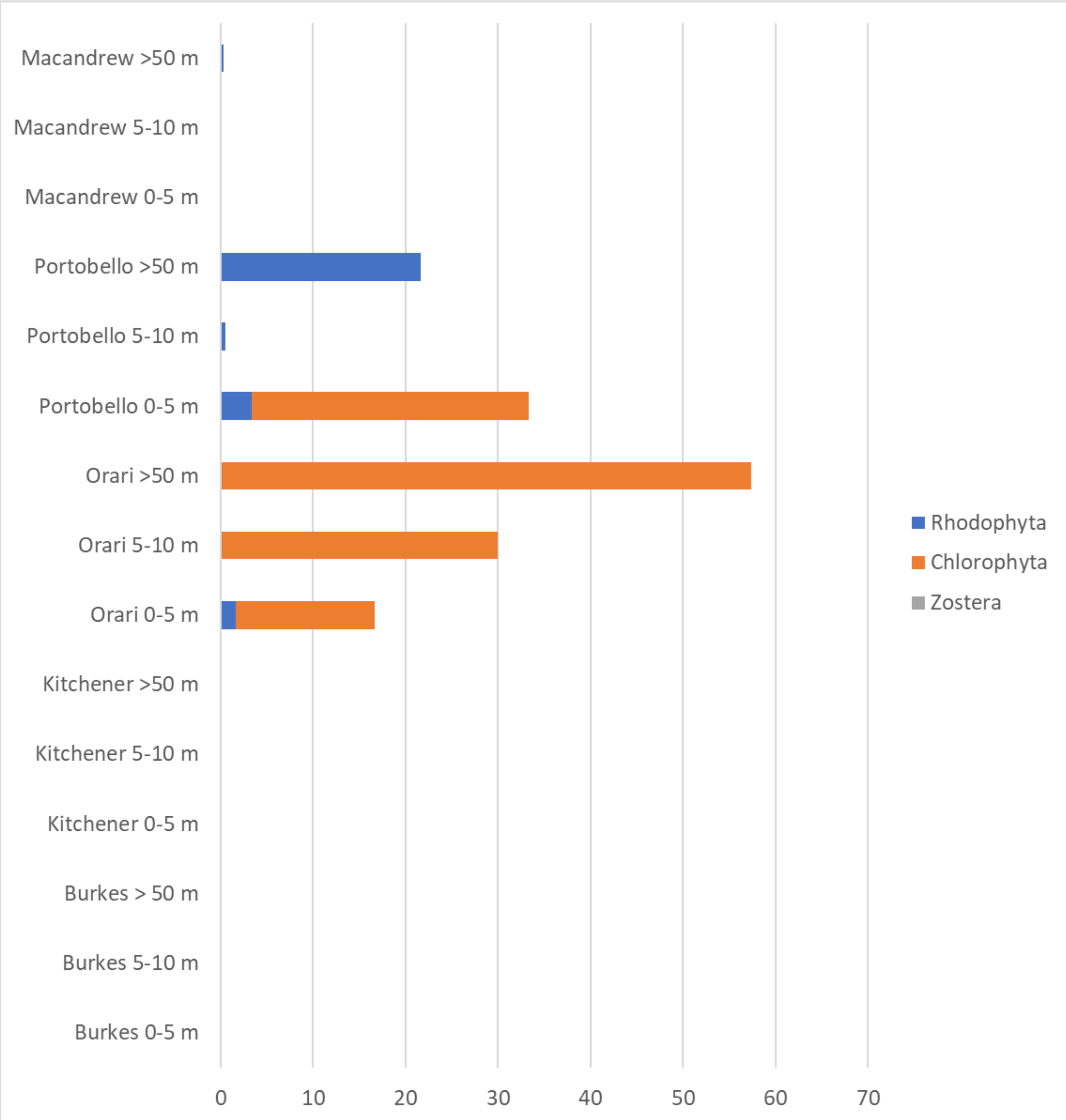

Figure 18: Average percent coverage of macroflora Phylum at each location and sampling site. Average percent coverage Burkes and Macandrew Bay are 'Control' sites.

The multidimensional scaling plots (Figure 19-21) show grouping within sites and in certain occasions between sites. The plot for epifauna (Figure 19) shows that that all five sites have relatively similar community assemblages. Portobello has the most variable community illustrated by the larger ellipse, with almost all other data points from the remaining site nested inside. The close similarity in epifauna communities is likely due to a number of sampling sites being located at the base of breakwaters, i.e., on rocky substrate, for the 2022-23 survey. This is reflected by a number of taxa identified being molluscs adapted to rocky reef substrate (e.g., *Notoacmea* sp., *Chiton glaucus*). The comparison between 'Control' and potential 'Impact' sites shows a large amount of overlap between ellipses but with a greater spread of points for 'Impact' sites. So while there is a statistically significant difference between the two groups, the differences shown in the nMDS plot are not substantial deviations from normal epifauna communities, with such deviations expected if stormwater discharges were having adverse effects.

The plot for infauna (Figure 20) shows a similar relationship between sites as the epifauna data with a large amount of overlap between the ellipticals of each site. Orari is the most diverse site with the majority of other data points nested inside. The comparison between 'Control' and potential 'Impact' sites shows a large amount of overlap between ellipticals, suggesting again that the differences are not substantial deviations from normal infauna communities, with such deviations expected if stormwater discharges were having adverse effects.

The nMDS plot for macroflora (Figure 21) is missing ellipticals as a number of sites did not contain enough data points, i.e., Burkes and Macandrew Bay. However, the groupings of the data points that were plotted were relatively similar, with the exception of two core samples collected at Orari. Similarly, there were not enough data points collected at the 'Control' sites to produce a meaningful comparison to the potential 'Impact' sites.

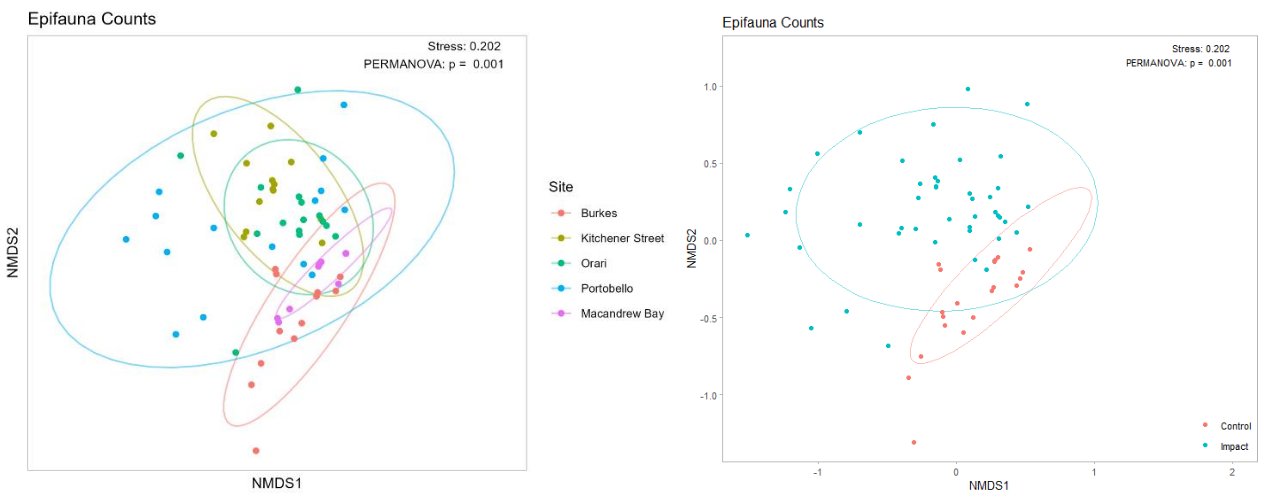

Figure 19: Multidimensional Scaling plots comparing epifauna communities between sites (left) and between 'Control' and potential 'Impact' sites (right).

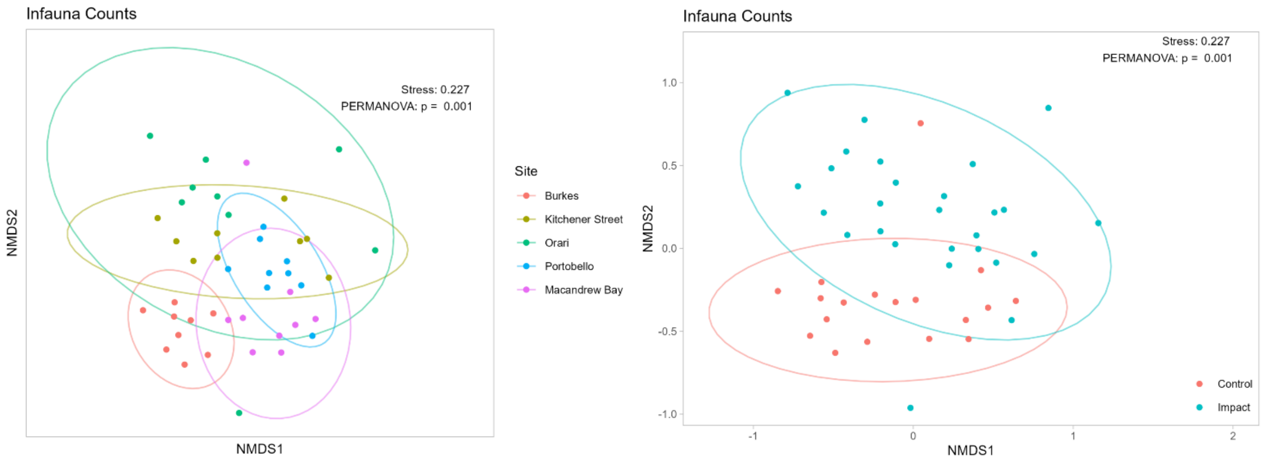

Figure 20: Multidimensional Scaling plots comparing infauna communities between sites (left) and between 'Control' and potential 'Impact' sites (right).

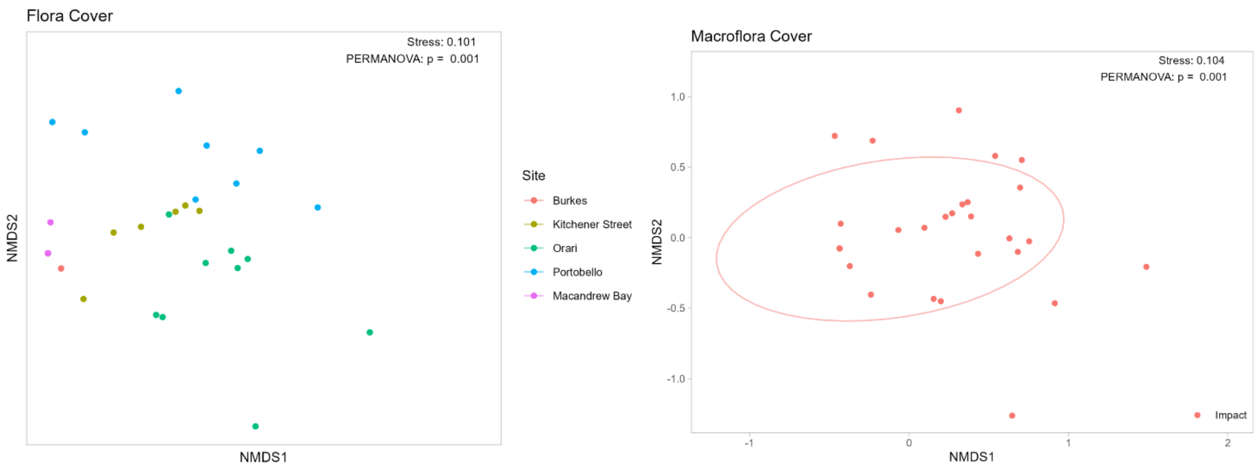

Figure 21: Multidimensional Scaling plots comparing macroflora communities and *Serpulidae* between sites (left) and between 'Control' and potential 'Impact' sites (right). Note there are no orbital groupings for comparisons between sites due to limited macroflora cover at some sites. Note no 'Control' site data for comparisons between 'Control' and potential 'Impact' sites due to extremely low macroflora cover at Burkes and Macandrew Bay.

4.6.2 Bioindicators

Results of the AMBI assessment indicate a gradient in ecological status from the west to the east of the harbour (Table 5), with the least 'impacted' site being the Burkes 'Control' site and the most 'impacted' site being the Macandrew Bay 'Control' site. This is a trend that was more so apparent in the last round of harbour biological reporting (2020–2021). Macandrew Bay had relatively high abundance of 'pollution-tolerant' species, such as annelids *Heteromastus* sp., compared to more 'sensitive' species such as small arthropods. Although Orari Street and Portobella had higher counts of *Heteromastus* sp., Macandrew Bay had notably low total number of species, and the few that were present were in low abundances. *Heteromastus* sp. polychaetes belongs to family Capitellidae and is a first order opportunistic species, responding positively to elevated nutrients/contaminants (Borja *et al.* 2000, Simboura and Zenetos 2002, Ellis *et al.* 2017). The Macandrew Bay, Portobello Road, and Orari Street sites contained 83.4% (781 individuals) of the total abundance of *Heteromastus* sp., across all sites. These and the 2021 results differ from 2019 results, where only four and two individuals from the Capitellidae family were recorded at Macandrew Bay and Portobello Road, respectively. Annnelid worms in the family Nereididae respond positively to elevated nutrients/contaminants (Borja *et al.* 2000, Simboura and Zenetos 2002). There were 99 individuals previously reported at the Macandrew Bay and Portobello Road sites in 2021, however, only 10 individuals were identified across all five sampling sites in this study.

For Macandrew Bay, previous surveys have found similarly low diversity and abundance of infauna, however it is uncertain why the index results for the Macandrew Bay site are poor. It was previously theorised that the predominant winds in Otago Harbour are northerlies and westerlies (Single *et al.* 2010), and therefore any contaminants could be transported towards the eastern sides of the harbour where Macandrew Bay is located. The sample site is also located at a 'dogleg' bend where the majority of the water flows during the low tidal cycle. It is possible that the site is in a slightly higher energy environment and sediment transport is an inhibiting factor when it comes to infauna colonisation.

Kitchener Street had an AMBI score of 2.62 in 2021 and 3.99 in this study. The site has the median species richness and the highest species diversity (AMBI output data), which is reflected in the Peilou's evenness and Shannon-Weiner indices. However, 13.1% of the taxa present were not able to be assigned an AMBI ecological category (due to lack of reference data), whereas the next highest percentage of not assigned taxa is 0.6% at Orari. While this would suggest there has been a change in community composition, it may also be an example of the limitations of the AMBI approach and an explanation for the large change between years.

The AMBI score at Portobello Road slightly increased from 4.14 in 2021 to 4.32 in this study, which changes its ecological status to from 'Moderate' to 'Poor'. However, such minor changes can be the result of natural variation and more detailed trend analyses on these data may be beneficial in the future.

Table 5: AMBI values for all sites.

Location	Value	Dominant Ecological Group	Ecological Status
Burkes	3.12	III	Good
Kitchener Street	3.99	IV – V	Moderate
Orari Street	3.39	IV – V	Moderate
Portobello Road	4.32	IV – V	Poor
Macandrew Bay	4.50	IV – V	Poor

4.6.3 Cockles - contaminants

Shellfish are filter feeders and can therefore accumulate contaminants from their environment. Sampling of cockle flesh from potential 'Impact' sites in Otago Harbour revealed contaminant concentrations were similar across the sites (Table 6).

Table 6: Contaminant concentrations in cockle flesh, 9 May 2023.

	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Enteroccoci (cfu/100g)	PAH (mg/kg)[1]
Portobello Road	5.5	0.022	0.25	1.32	0.22	< 1000	0.720-0.750
Orari Street	6.5	0.02	0.28	1.1	0.123	2600	0.015-0.031
Kitchener Street	9.1	0.024	0.78	1.06	0.099	2000	0.017-0.028

1. PAH = polycyclic aromatic hydrocarbons. PAH concentration ranges are between known concentrations and the maximum possible concentrations (as some samples were below laboratory detection limits).

Enterococci concentrations at the Portobello Road site in 2023 were below the laboratory detection limit and within the detectable range at Orari Street and Kitchener Street. All concentrations were within the range from recent years. Metal concentrations were generally comparable to previous sampling results, however the concentration of chromium at Kitchener Street was lower than in 2021 but remained higher than in previous years.

Cockles collected from the Portobello Road site have previously had much higher PAH concentrations than at the other sites, likely a result of historic contamination of that site. PAH concentrations in cockle flesh have fluctuated over time, with concentrations in 2023 higher than in 2021 but within the range of results of previous years (Figure 22).

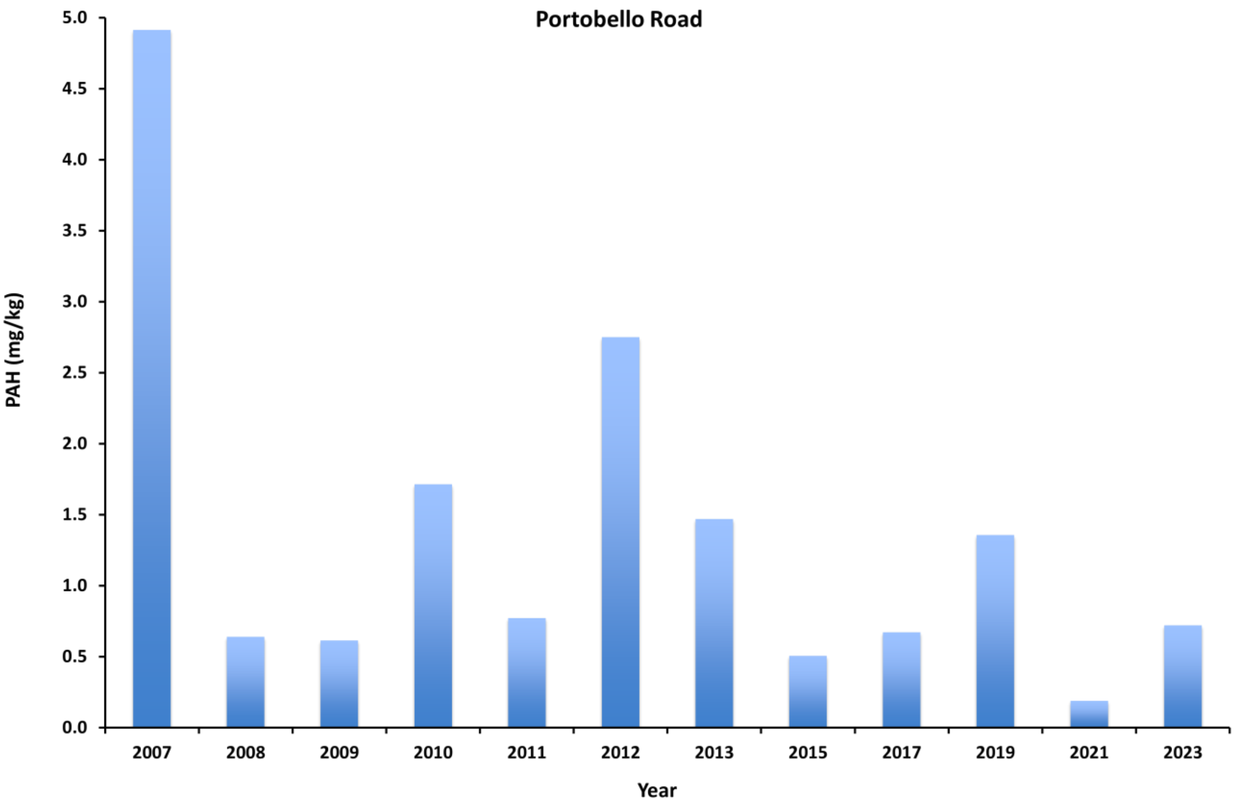

Figure 22: Concentrations of PAHs in cockle flesh at the Portobello Road site, 2007 to 2023.

Of the contaminants required for testing in cockle flesh, Food Standards Australia New Zealand (FSANZ) (2017) has set maximum concentrations for the heavy metals arsenic, cadmium (limit 2 mg/kg), and lead (limit 2 mg/kg) in shellfish as food. Cockles at all sites had cadmium and lead concentrations well below the FSANZ (2017) maximum concentrations (Table 7). For arsenic, the FSANZ (2017) provides guidelines for levels of inorganic arsenic in shellfish (limit 1 mg/kg), however total arsenic is typically assessed due to the difficulty and expense of measuring inorganic arsenic. United States Food and Drug Administration (USFDA) (1993) proposed estimating inorganic arsenic as only 10% of the arsenic in shellfish, allowing conversion of total arsenic to estimates of inorganic arsenic (rather than having results specific for inorganic arsenic). Using this approach, inorganic arsenic concentrations in Otago Harbour cockles were approximately 0.55-0.91 mg/kg and therefore lower than the FSANZ (2017) maximum concentration (Table 7).

Table 7: Maximum concentrations of contaminants in shellfish as food from FSANZ (2017). For the Otago Harbour sites, 'Lower' indicates concentrations in cockle flesh on 9 May 2023 that were lower than maximum concentrations, whereas 'Higher' indicates concentrations that were higher than maximum concentrations.

	Maximum concentration in shellfish for food	**Portobello Road**	**Orari Street**	**Kitchener Street**
Food Standards Australia New Zealand (2017)	Arsenic (inorganic): 1 mg/kg[1]	Lower	Lower	Lower
	Cadmium: 2 mg/kg	Lower	Lower	Lower
	Lead: 2 mg/kg	Lower	Lower	Lower

1. Arsenic concentrations lower than maximum concentrations when converted from total arsenic to the required inorganic arsenic, using the 10% conversion from USFDA (1993).

The enteroccoci concentrations at Orari Street and Kitchener Street were 2,600 cfu/100g and 2,000 cfu/100g respectively, however, there are no suitable food safety guidelines for enterococci. Concentrations in these ranges may suggest, however, that there are elevated levels of faecal bacteria in the shellfish.

4.6.4 Cockles - size

Measuring cockle length is useful to determine if there is any relationship between contaminant concentrations and the size of cockles. Of the three sites where cockles are sampled, cockles have historically been largest at the Kitchener Street site, with decreasing size across the foreshore at Orari Street, and with the smallest at the Portobello Road site (Figure 23). Since 2007, the only exceptions to this pattern have been in 2019 and the current 2023 survey where cockles at Portobello Road were slightly larger than at Orari Street (Figure 23). The length of cockles in the current survey is the smallest recorded across all three sites.

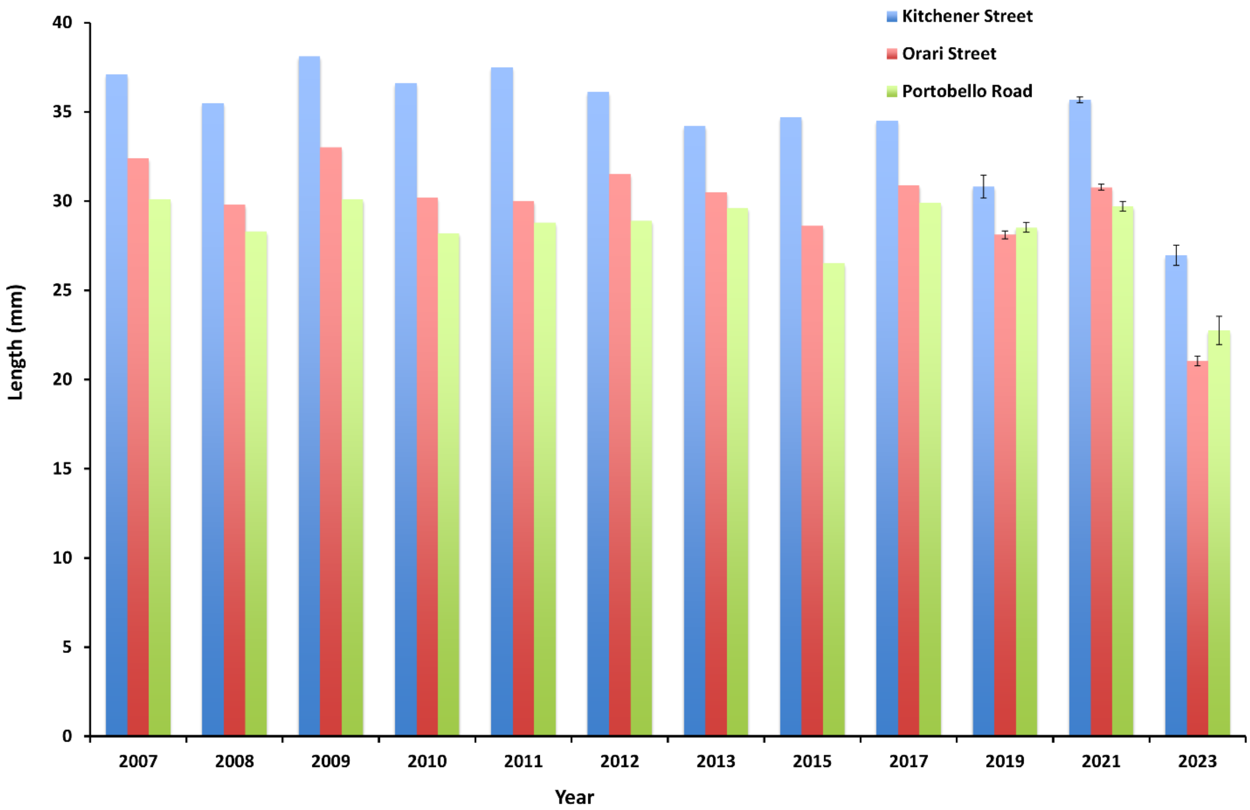

Figure 23: Mean cockle lengths (mm) at the three harbour biological sites, 2007 to 2023. Error bars for 2019 to 2023 means are +/- one standard error.

5 SUMMARY AND CONCLUSION

Monitoring of Dunedin's stormwater discharges and receiving environments (Otago Harbour) was undertaken between July 2022 and June 2023, as required of DCC by ORC resource consents (RM11.313.01 - RM11.313.10). Sampling included stormwater quality during dry weather conditions, harbour water quality during dry weather conditions, sampling of harbour sediments, and sampling of harbour biological communities. Further sampling/re-sampling was restricted by weather/tidal conditions not being met.

Results from dry weather sampling of stormwater identified several stormwater outfalls with elevated faecal contaminant indicators, a result which has been found in previous years. Previous investigations for some catchments, following elevated results, identified cross-connections between stormwater and wastewater systems. As potential sources of *E. coli* in stormwater include sewage but also faecal deposition by animals (e.g., birds, rodents, domestic pets), such contamination is common with stormwater.

Sampling of stormwater at outfalls during a rainfall event, and sampling of a rain event by the automated sampler located in the Halsey Street catchment, were not undertaken between July 2022 and June 2023 as the required conditions were not met. The automated sampler captured two events in the Halsey Street catchment and, following one further event being captured, can be moved to the next catchment required by consent. Based on the order of previous deployments, this is the South Dunedin catchment.

Harbour water quality sampling was only undertaken during dry weather in 2023. Sampling revealed copper, lead, zinc, and enterococci concentrations exceeded consented trigger levels at several sites during dry weather. Elevated concentrations of several contaminants have previously been found during dry weather conditions at multiple sites, indicating inputs are unlikely to be from single point sources. Contaminants can be sourced from vehicles/roading and also from building materials and industrial activities. Harbour water quality is influenced by stormwater inputs, but also other sources such as the Water of Leith. Comparison of sampling results from previous years indicates elevated copper and lead concentrations during dry weather rather than during rain events, and elevated faecal indicator bacteria concentrations during rain events than during dry weather conditions. These results support the discussion above regarding potential sources of contaminants in the stormwater and into the harbour. It must also be recognised that sampling during rainfall events is undertaken during relatively high intensity rainfall, to capture the peak concentrations during the 'first flush'. However, there are many rain events where rainfall levels remain low (e.g., drizzle) that would also contribute contaminants to the harbour and therefore contribute to harbour water contaminant levels.

Sampling of contaminants in harbour sediments revealed similar concentrations to those from recent years, however concentrations of copper and zinc appearing to be increasing over time at the Shore Street site. Concentrations in 2023 were all below 2013 trigger levels listed in the consents. Concentrations of lead, zinc, mercury and PAHs at some sites were above ANZECC (2000) ISQG-Low levels, which represent the threshold for potential effects to occur and is a trigger for further investigation, but remained well below ISQG-High levels, which represent a point where a high probability of effects is possible. Some sites have historically had high concentrations of some contaminants (e.g., PAHs at Portobello Road) however the cessation of some industrial activities (e.g., gas works) have reduced many sources of contaminant inputs to the harbour. Contaminant concentrations are expected to be variable year to year as contaminated sediment is buried or disturbed, and further monitoring will help determine if Shore Street contaminant concentrations continue to increase.

Sampling of harbour biological communities was undertaken in 2023, with a total of 94 species identified in this survey, an increase from 40 species in 2021. While a positive change, this is primarily due to a change in methods for taxonomic analysis. There were significant overall differences between biological communities at sites influenced by stormwater outfalls and those sites with no outfalls. However, the trend of decreasing AMBI scores moving east–west, with the two 'Control' sites scoring the highest and lowest scores, suggest there are substantial environmental factors affecting benthic community composition. Some sites supported different taxa compared to other sites due to differences in habitat, such as tube-building worms, anemones and oysters on the hard rock surfaces such as at Kitchener Street, Portobello, and Orari. The latter two sites had previously been surveyed on more soft substrate which may be due to changing sediment regimes locally this year and due to access restrictions depending on tide heights and wave conditions, and also accounts for some of the stronger differences in communities (e.g., Burkes and Portobello). Drift algae accounted for the majority of macroflora surveyed which can be more reflective of weather conditions and storm events than localised water and sediment quality. Portobello Road and Macandrew Bay sites supported biological communities with more 'pollution-tolerant' species than at other sites, and while the Macandrew Bay site is a 'Control' site, away from other stormwater outfalls, biotic indices were poor for this site.

Contaminant concentrations in cockles sampled in May 2023 were generally similar to results from recent years, with higher PAH concentrations at the Portobello Road site than found in 2021 but within the range from previous years. The cockles collected from the three sites had elevated enterococci concentrations however heavy metal (arsenic, cadmium, lead) concentrations were with food safety guideline levels. The cockles would therefore not be considered 'acceptable' to eat from a faecal contaminant perspective.

Overall, stormwater monitoring between July 2022 and June 2023 has not resulted in clear patterns or trends of measured variables, with the exception of sediment copper and zinc at Shore Street.

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Appendix A:

Stormwater outfalls

Table A1: Dunedin stormwater outfall information.

Outfall	DCC reference	Resource consent	Location	Catchment	Frequency of dry weather sampling	Wet weather sampling?
1	SWX03979	RM11.313.10	Second Beach	St Clair	Monthly	Yes
2	SWX00011 & SWX00012	RM11.313.10	St Clair Beach	St Clair	Six-monthly	-
3	SWX04625	RM11.313.04	Shore Street	Shore Street	Monthly	Yes
4	SWX03649	RM11.313.09	Portobello Road	South Dunedin	Monthly	Yes
5	SWX03644	RM11.313.07	Teviot Street	Portsmouth Drive	Monthly	-
6	SWX03640	RM11.313.07	Midland Street	Portsmouth Drive	Monthly	-
7	SWX03631	RM11.313.07	Orari Street	Portsmouth Drive	Monthly	-
8	SWX03635 & SWX70740	RM11.313.08	Orari Street	Orari Street	Monthly	Yes
9	SWX03579	RM11.313.07	Kitchener Street	Portsmouth Drive	Six-monthly	-
10	SWX03568	RM11.313.06	Kitchener Street	Kitchener Street	Monthly	Yes
11	SWX70102	RM11.313.06	French Street	Kitchener Street	Six-monthly	-
12	SWX03547	RM11.313.06	Kitchener Street	Kitchener Street	Monthly	-
13	SWX03562	RM11.313.06	Birch Street	Kitchener Street	Six-monthly	-
14	SWX03556	RM11.313.06	Birch Street	Kitchener Street	Six-monthly	-
15	SWX03559	RM11.313.06	Wharf Street	Kitchener Street	Six-monthly	-
16	SWZ70569	RM11.313.06	Fryatt Street	Kitchener Street	Six-monthly	-
17	SWX03540	RM11.313.06	Fryatt Street	Kitchener Street	Six-monthly	-
18	SWX03536	RM11.313.06	Fryatt Street	Kitchener Street	Six-monthly	-
19	SWX03532	RM11.313.06	Fryatt Street	Kitchener Street	Six-monthly	-
20	SWX70370	RM11.313.06	Fryatt Street	Kitchener Street	Six-monthly	-
21	SWX03489	RM11.313.05	Mason Street	Mason Street	Six-monthly	Yes
22	SWX03506	RM11.313.03	Bauchop Street	Halsey Street	Six-monthly	-
23	SWX03466	RM11.313.03	Bauchop Street	Halsey Street	Monthly	Yes
24	SWX03455	RM11.313.03	Halsey Street	Halsey Street	Monthly	Yes
25	SWX03450	RM11.313.03	Halsey Street	Halsey Street	Monthly	-
26	SWX03472	RM11.313.03	Halsey Street	Halsey Street	Monthly	-
27	SWX03718	RM11.313.03	Wickliffe Street	Halsey Street	Monthly	Yes
28	SWX02628	RM11.313.02	Magnet Street	Ravensbourne	Six-monthly	-
29	SWX02623	RM11.313.02	Magnet Street	Ravensbourne	Six-monthly	-
30	SPN02502	RM11.313.02	Ravensbourne Road	Ravensbourne	Monthly	-
31	SWX12941	RM11.313.01	George Street / SH88	Port Chalmers	Six-monthly	Yes
32	SWX12994	RM11.313.01	Sawyers Bay, Watson Park	Port Chalmers	Monthly	-
33	SWX12879	RM11.313.01	George Street (Port Otago)	Port Chalmers	Monthly	-

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Appendix B:

Harbour biological data and analysis

Community diversity

Species richness (S') was calculated for each site. Shannon-Wiener (H') index was calculated to measure community diversity between sites; the higher the value of the H' index, the higher the species diversity in the community. Pielou's evenness (J') was also calculated to assess the species evenness; Pielou's evenness ranges from 0 to 1, from no evenness to complete evenness, respectively.

Community composition

A multi-variate statistical analysis was used to investigate relationships between sites. A Weighted Classical Multidimensional Scaling (wcmdscale), based on Bray-Curtis similarity index, was constructed to map the similarity between species presence and abundance at the different sites using R statistical software (vegan package).

The five sites were compared based on their status (potential 'Impact' and 'Control'), compared individually, and at potential 'Impact' sites compared based on proximity to outfall. Levene's Test was conducted to check whether the data fulfilled the homogeneity of variance assumption. Standard One-Way ANOVAs were conducted to investigate any differences between sites. If any of these tests were significant, Games Howell post-hoc test was conducted to explore the differences. Statistical tests were performed using R statistical software (stats and rstatix packages).

Bioindicators

Infauna was assessed following the AZTI Marine Biotic Index (AMBI) (Borja *et al.* 2000) which was used to assess ecosystem health. It is noted that while this approach provides useful insight into the health and condition of the benthic environment, it is limited by available sensitivity data for a number of taxa. The AMBI index is based on a classification system of benthic communities and includes five levels of ecological quality (Bad, Poor, Moderate, Good, High) (Tables B1 and B2). AMBI index was calculated using the AMBI software version 6.0 provided by AZTI. The index values were then assigned to the appropriate category.

Table B1: AMBI classification for benthic macrofauna. Species examples for the phylum Annelida are also provided.

AMBI		
Classification		**Species examples**
I	Very sensitive species	Maldanidae spp.
II	Species indifferent	*Glycera* spp.
III	Tolerant species	Nereididae spp.
IV	Second-order opportunistic species	*Chaetozone* spp.
V	First order opportunistic species	*Heteromastus* spp.

Table B2: AMBI – AZTI Marine Biotic Index for macroinvertebrates.

AMBI value	Dominating Ecological Group	Benthic community health	Site pollution classification	Ecological Status
0.0 < BC <= 0.2	I	Normal	Unpolluted	High Status
0.2 < BC <= 1.2		Impoverished		
1.2 < BC <= 3.3	III	Unbalanced	Slightly polluted	Good Status
3.3 < BC <= 4.3	IV - V	Transitional to pollution	Meanly Polluted	Moderate Status
4.3 < BC <= 5.0		Polluted		Poor Status
5.0 < BC <= 5.5	V	Transitional to heavy pollution	Heavily Polluted	Poor Status
5.5 < BC <= 6.0		Heavily polluted		Bad Status
Azoic (7.0)	Azoic	Azoic	Extremely Polluted	Bad Status

Appendix C:

Stormwater – dry weather sampling results, 2022-2023

Table C1: Contaminant concentrations (FWA, *E. coli*) in water from dry weather sampling between July 2022 and June 2023. Outfalls marked with grey cells are sampled six-monthly. Blue cells indicate values exceed trigger levels: FWA level of 0.1 ppb is suggestive of human faecal pollution (Gilpin and Devane 2003). *E. coli* trigger level of 550 cfu/100mL (MfE (2003) action (red) limit). NF = no flow; No Access = no available access to stormwater. No TTM = No temporary traffic management available (due to large event in Dunedin).

Outfall	11 November 2022		26 January 2023		20 February 2023		9 June 2023	
	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)
1	0.048	290	0.056	<10	0.051	20,000	0.050	7,500
2			NF	NF				
3	0.042	800	0.057	910	0.068	1,600	0.055	150
4	0.007	<10	0.004	<10	0.012	<10	0.117	10
5	0.150	90	0.127	6,300	0.088	780	0.112	1,500
6	0.096	2,000	0.068	910	0.063	250	0.067	1,300
7	0.037	560	0.053	2,300	0.055	60,000	0.127	60,000
8	0.065	440	0.078	180	0.074	640	0.068	2,600
9			0.037	10				
10	No Access (tide conditions)	No Access (tide conditions)	0.040	490	0.026	210	0.050	2,700
11			0.021	80				
12	NF	NF	0.007	<10	0.015	10	0.052	<10
13-22			No Access	No Access				
23	0.033	30	No TTM	No TTM	0.027	730	0.061	730
24	0.090	660,000	No TTM	No TTM	0.020	90,000	0.027	10,000
25	0.045	120,000	No TTM	No TTM	0.032	>800,000	0.038	20,000
26	NF	NF	NF	NF	NF	NF	NF	NF
27	0.050	30,000	0.040	3,600	0.033	390,000	0.062	6,500
28			0.052	100				
29			0.136	680				
30	0.132	20	0.040	30	0.299	50,000	0.058	40
31			0.039	640				
32	0.130	10	0.051	10	0.029	40	0.124	<10
33	0.055	60	No TTM	No TTM	0.073	390,000	0.090	7,500

Appendix D:

Harbour sediment sampling results, 2022-2023

Table D1: Harbour sediment contaminant concentrations, 7 June 2023. Trigger and guideline values are specified in resource consents.

	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	WAE Copper[1] (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)	PAH[2] (mg/kg)	TPH[3] (mg/kg)	OCP[4] (mg/kg)
2013 trigger levels	19	1.7	80	-	122	209	-	21	902	183	-	-
ANZECC (2000) ISQG-Low[5]	20	1.5	80	-	65	50	0.15	21	200	4	-	-
ANZECC (2000) ISQG-High[5]	70	10	370	-	270	220	1	52	410	45	-	-
Halsey Street	12.9	0.17	31.4	16.9	25	28.8	0.2	20.5	127	0.05-0.70	<5	<1.7
Kitchener Street	8.2	0.13	15.6	8.3	13.2	28.9	<0.1	8.7	178	1.67-1.87	<5	<1.7
Orari Street	6.85	0.3	24.3	19.1	19.5	51.7	0.1	13.4	256	1.95-2.10	6	<1.7
Shore Street	9.17	0.26	17.1	28	42	75.1	0.1	10.8	360	4.19-4.29	159	<1.7

1. WAE copper = Weak-acid extractable copper.
2. PAH = polycyclic aromatic hydrocarbons. Concentration ranges are between known concentrations and the maximum possible concentrations (as some samples below laboratory detection limits). '< value' indicates all concentrations below laboratory detection limits.
3. TPH = total petroleum hydrocarbons – maximum content.
4. OCP = organochlorine pesticides. Concentration ranges are between known concentrations and the maximum possible concentrations (as some samples below laboratory detection limits). '< value' indicates all concentrations below laboratory detection limits.
5. ANZECC (2000) interim sediment quality (ISQG) guideline values, as listed in the resource consent.

<u>**Appendix E:**</u>

Harbour biological results, 2022-2023

Table E1: Percentage cover of macroflora per quadrat at the five harbour biological sites, 8-9 May 2023.

	Burkes									**Kitchener Street**									**Orari Street**									**Portobello Road**									**Macandrew Bay**								
	0-5m			**5-20m**			**>50m**			**0-5m**			**5-20m**			**>50m**			**0-5m**			**5-20m**			**>50m**			**0-5m**			**5-20m**			**>50m**			**0-5m**			**5-20m**			**>50m**		
Taxon (% cover)	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Rhodophyta																																													
Agarophyton chilense																																	1	40	25									1	
Adamsiella sp.					0.1								0.25			0.5			5									10																	
Pachymenia dichotoma																																	0.5												
Chlorophyta																																													
Codium fragile novae-zelandiae																													50	40															
Ulva compressa																			10		35	15	40	30	90	50	30																		
Ulva sp.																									2																				
Zostera muelleri subsp. *novazelandica* * (Seagrass)																			2																										
Total % cover	0	0	0	0	0.1	0	0	0	0	0	0	0	0.25	0	0	0.5	0	0	17.0	0	35.0	15.0	40.0	30.0	92.0	50.0	30.0	10.0	50.0	40.0	0	0	1.5	40.0	25.0	0	0	0	0	0	0	0	0	1.0	0
Number of taxa per quadrat	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	3	0	1	1	1	1	2	1	1	1	1	1	0	0	2	1	1	0	0	0	0	0	0	0	0	1	0
Mean % cover		0			0.0			0			0			0.1			0.2			17.3			28.3			57.3			33.3			0.5			21.7			0			0			0.3	
Mean number of taxa per quadrat		0			0.3			0			0			0.3			0.3			1.3			1.0			1.3			1.0			0.7			0.7			0			0			0.3	

Table E2: Number of epifauna invertebrates per quadrat at the five harbour biological sites, 8-9 May 2023.

	Burkes														
	0-5m					5-20m					>50m				
Taxon	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Arthropoda															
Austrominius modestus															
Mollusca															
Acanthochiona zelandica															
Austrovenus stutchburyi	3		3	3		1						1		1	
Chiton glaucus															
Cominella glandiformis	11				1			2							
Diloma sp.															
Diloma aethiops															
Diloma subrostrata						2	1			1		2	1	1	3
Lunella smaragda															
Micrelenchus huttonii															
Mytilus galloprovincialis															
Notoacmea sp.							1								1
Ostrea chilensis															
Sypharochiton pelliserpentis															
Zeacumantus subcarinatus															
Number of invertebrates per quadrat	14	0	3	3	1	3	2	2	0	1	0	3	1	2	4
Number of taxa per quadrat	2	0	1	1	1	2	2	1	0	1	0	2	1	2	2
Mean number of invertebrates per quadrat			4.2					1.6					2		
Mean number of taxa per quadrat			1					1.2					1.4		
Annelida															
Serpulidae (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean % cover			0					0					0		

	Kitchener Street														
	0-5m					5-20m					>50m				
Taxon	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Arthropoda															
Austrominius modestus	150		100	100		50		150		30	200	300	50	100	50
Mollusca															
Acanthochiona zelandica															
Austrovenus stutchburyi															
Chiton glaucus	1									1					
Cominella glandiformis															
Diloma sp.															1
Diloma aethiops				1											
Diloma subrostrata															
Lunella smaragda															
Micrelenchus huttonii															
Mytilus galloprovincialis	1				1			1							
Notoacmea sp.	5					5		5	7	1	3	7		20	25
Ostrea chilensis													1		
Sypharochiton pelliserpentis									3	4					
Zeacumantus subcarinatus	1	1		3				1							
Number of invertebrates per quadrat	158	1	100	104	1	55	0	157	10	36	203	307	51	120	76
Number of taxa per quadrat	5	1	1	3	1	2	0	4	2	4	2	2	2	2	3
Mean number of invertebrates per quadrat			72.8					51.6					151.4		
Mean number of taxa per quadrat			2.2					2.4					2.2		
Annelida															
Serpulidae (%)	5	5	10	2	15	5	2	0	2	10	0	0	1	0	0
Mean % cover			7.4					3.8					0.2		

	Orari														
	0-5m					5-20m					>50m				
Taxon	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Arthropoda															
Austrominius modestus	60	40	2	50	220	25	150	4	60	7	70	100	50	100	100
Mollusca															
Acanthochiona zelandica						1			1						
Austrovenus stutchburyi	1														
Chiton glaucus															
Cominella glandiformis															
Diloma sp.						3									
Diloma aethiops															
Diloma subrostrata							1								
Lunella smaragda												1			
Micrelenchus huttonii												1			
Mytilus galloprovincialis	1												2	1	1
Notoacmea sp.			3		1	3	1	2					1		
Ostrea chilensis															
Sypharochiton pelliserpentis															
Zeacumantus subcarinatus															
Number of invertebrates per quadrat	62	40	5	50	221	32	152	6	61	7	70	102	53	101	101
Number of taxa per quadrat	3	1	2	1	2	4	3	2	2	1	1	3	3	2	2
Mean number of invertebrates per quadrat			75.6					51.6					85.4		
Mean number of taxa per quadrat			1.8					2.4					2.2		
Annelida															
Serpulidae (%)	0	5	0	5	5	0	5	10	10	0	1	10	5	2	2
Mean % cover			3					5					4		

	Portobello														
	0-5m					5-20m					>50m				
Taxon	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Arthropoda															
Austrominius modestus					1000					150					
Mollusca															
Acanthochiona zelandica		2	2	1							2		3		
Austrovenus stutchburyi														1	
Chiton glaucus	1		3	2							8	3	16	3	2
Cominella glandiformis															
Diloma sp.													1	5	
Diloma aethiops															
Diloma subrostrata	3														
Lunella smaragda															
Micrelenchus huttonii						3		1	1	1					
Mytilus galloprovincialis															
Notoacmea sp.				2							1		1		1
Ostrea chilensis		1	1												
Sypharochiton pelliserpentis	1	5	1	1									1	1	
Zeacumantus subcarinatus		1					2		5						2
Number of invertebrates per quadrat	5	9	7	6	1000	3	2	1	6	151	11	3	22	10	5
Number of taxa per quadrat	3	4	4	4	1	1	1	1	2	2	3	1	5	4	3
Mean number of invertebrates per quadrat			205.4					32.6					10.2		
Mean number of taxa per quadrat			3.2					1.4					3.2		
Annelida															
Serpulidae (%)	2	10	5	20	10	1	1	5	20	15	0	2	0	0	10
Mean % cover			9.4					8.4					2.4		

	Macandrew Bay														
	0-5m					5-20m					>50m				
Taxon	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Arthropoda															
Austrominius modestus															
Mollusca															
Acanthochiona zelandica															
Austrovenus stutchburyi							1		1				1		
Chiton glaucus															
Cominella glandiformis														1	
Diloma sp.															
Diloma aethiops															
Diloma subrostrata															
Lunella smaragda															
Micrelenchus huttonii															
Mytilus galloprovincialis															
Notoacmea sp.															
Ostrea chilensis															
Sypharochiton pelliserpentis															
Zeacumantus subcarinatus			1		1		1		6	3			1		
Number of invertebrates per quadrat	0	0	1	0	1	0	2	0	7	3	0	0	2	1	0
Number of taxa per quadrat	0	0	1	0	1	0	2	0	2	1	0	0	2	1	0
Mean number of invertebrates per quadrat			0.4					2.4					0.6		
Mean number of taxa per quadrat			0.4					1					0.6		
Annelida															
Serpulidae (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean % cover			0					0					0		

Table E3: Number of infauna invertebrates per core sample at the Burkes, Kitchener Street and Orari Street sites, 8-9 May 2023.

	Burkes									Kitchener Street									Orari Street								
	0-5			*5-20			>50			0-5			*5-20			>50			0-5			*5-20			>50		
Taxon	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Annelida																											
Oligochaete		1								37	6	83	5	1	2	1	4	2			1	4	1		1	7	
Abarenicola affinis																			1			1			3		1
Barantolla lepte																									3		
Capitella sp. 1																											
Capitella sp. *2*																											
Capitella spp.			2								1	6										1	10	3	8	1	
Heteromastus sp.	6	13	13	7	4		11	3	7	6		24	9	23	26	1	2	1				77	##	55	83	60	52
Chaetozone sp.																											
Cirratulidae											1	1	3	1			1						1				
Dorvillea sp.										58		7	1	2	1												
Glycera sp.																				1							
Hemipodus sp.																											
Asychis sp.																											
Maldanidae								1							1							1					
Microphthalmus cf																									2		
Aglaophamus sp.																											
Nerididae						1			2	1		1									1						
Nicon aestuariensis		1																								1	1
Perinereis vallata		1	2	1	1			1																			
Platynereis australis																											1
Armandia sp.																											
Scoloplos cylindrifer		1	1	1	1	1	1	1	1																		
Myriochelle	1	1																				1					
Paraonidae		1						1	1			10										1					
Eumenia sp.																											
Sphaerodopsis												1										1	3				
Aonides trifida																											
Polydorid		3		1		3	1			9		31	1	4	1	2	3	4				20	14	19	12	14	10
Prionospio aucklandica																									1		
Prionospio sp.																											2
Rhynchospio sp.																							1	9			
Scolecolepides benhami	1																										
Spio sp.																											1
Exogoninae	0	0	2	0	0	1	0	0	0	31	0	9	3	3	7	0	0	0	0	0	0	12	13	13	8	3	9
Exogone sp.																									2	1	
Arthropoda																											
Copepoda																											
Monocorophium acherusicum																											
Gammaridae																					1						1
Lysianassidae																										1	
Oedicerotidae																				1							
Phoxocephalidae															2	1	4	2		1		4		2	2	1	1
Hemiplax hirtipes																											
Halicarcinus varius																											1
Euphausiacea																			2								
Exosphaeroma obtusum																					1						
Mysida					1																						
Diasterope grisea																								1			1
Parasterope quadrata												1	1				1		2	2			2		1		7
Pleoschisma agilis																				1		1	1				
Ostracoda																							1				
Cirrepedia																									1		
Chordata																											
Asterocarpa coerulea																	3										
Cnidaria																											
Oulactis muscosa																											
Edwardsia neozelanica		1	1		3	3																1					1
Echinodermata																											
Taeniogyrus dunedinensis										1			1														
Mollusca																											
Nucula nitidula										3													2	4			
Macomona liliana						1			1	1			1	7	4												
Arthritica	3	1		1		1							1									1					
Lasaea cf parengaensis																											
Tellimya sp.																											
Linucula recens			1																								1
Linucula sp.																											
Paphies subtriangulata																											
Austrovenus stutchburyi	2	2	1	4	3	5	3	2	2	4		3	4	5	6						1	2	2	1	3	2	2
Zeacumantus subcarinatus																											
Papawera cf. *zelandiae*																											1
Potamopyrgus estuarinus																					1						
Amphibola crenata							1																				
Turbonilla sp.												1													1	3	1
Cominella glandiformis								1		1				1												1	1
Neoguraleus																											1
Zethalia zelandica																											
Nematoda																											
Nematoda										20	1	8	1	3	4		1		4	1		1					
Nemertea																											
Nemertea																										1	
Sipuncula																											
Golfingia sp.																											

Table E4: Number of infauna invertebrates per core sample at the Portobello Road and Macandrew Bay sites, 8-9 May 2023.

	Portobello Road									Macandrew Bay								
	0-5			*5-20			>50			0-5			*5-20			>50		
Taxon	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Annelida																		
Oligochaete	3		35	47	19	22	3	4	2	1		4				4	1	
Abarenicola affinis																		
Barantolla lepte																		
Capitella sp. 1																		
Capitella sp. *2*																		
Capitella spp.	2	1	9	17	10	28		2	1	8	4	8	3	1	11	11	26	1
Heteromastus sp.	19	1	32	11	22	21	30	75	41	6	11	14	5	5	7	23	16	7
Chaetozone sp.																		
Cirratulidae	1					1			2									
Dorvillea sp.						1												
Glycera sp.																		
Hemipodus sp.																		
Asychis sp.																		
Maldanidae																		
Microphthalmus cf				11		36					3	2				1		
Aglaophamus sp.																		
Nerididae										1	1	2						
Nicon aestuariensis	1						2		3			1						
Perinereis vallata			2	3	2						1		1		1		2	
Platynereis australis										1								
Armandia sp.																		
Scoloplos cylindrifer																		
Myriochelle																		1
Paraonidae																		
Eumenia sp.																		
Sphaerodopsis																		
Aonides trifida			1		1													
Polydorid									3							1		
Prionospio aucklandica																		
Prionospio sp.																		
Rhynchospio sp.																		
Scolecolepides benhami																		
Spio sp.																		
Exogoninae	0	1	1	11	19	4	0	1	1	0	0	0	0	0	0	0	0	0
Exogone sp.																		
Arthropoda																		
Copepoda																1		
Monocorophium acherusicum																		
Gammaridae																		
Lysianassidae																		
Oedicerotidae																		
Phoxocephalidae			1					1							1	2		
Hemiplax hirtipes																		
Halicarcinus varius																		
Euphausiacea																		
Exosphaeroma obtusum																		
Mysida																		
Diasterope grisea						1												
Parasterope quadrata																		
Pleoschisma agilis																		
Ostracoda																		
Cirrepedia																		
Chordata																		
Asterocarpa coerulea																		
Cnidaria																		
Oulactis muscosa																		
Edwardsia neozelanica												1				1	1	1
Echinodermata																		
Taeniogyrus dunedinensis																		
Mollusca																		
Nucula nitidula																1		1
Macomona liliana																		1
Arthritica				4		1										4		
Lasaea cf parengaensis												2		2		2	2	
Tellimya sp.																		
Linucula recens																1		
Linucula sp.																		
Paphies subtriangulata																		
Austrovenus stutchburyi									1			4					1	
Zeacumantus subcarinatus									1									
Papawera cf. *zelandiae*																		
Potamopyrgus estuarinus																		
Amphibola crenata																		
Turbonilla sp.																		
Cominella glandiformis																		
Neoguraleus																		
Zethalia zelandica																		
Nematoda																		
Nematoda	3	1	5	51	3	26									1			
Nemertea																		
Nemertea																		
Sipuncula																		
Golfingia sp.																		

Table E5: One-way ANOVA results for the biological communities at the Otago Harbour. Significance was determined at the 0.05 alpha (p-value) level. A post-hoc test was conducted if the overall result was considered significant (see Tables E6, E7, and E8). Status corresponds to 'Control' and potential 'Impact' sites; Zones: zones of proximity to the outfall; Sites: statistical test between sites.

Dataset	Dependent variable	Independent variable	F-value	p-value
Infauna	Species abundance (sqrt)	Status	**16.178**	**<0.001**
		Sites	**5.544**	**0.004**
		Zones	0.884	0.42
Epifauna	Species abundance (sqrt)	**Status**	**45.228**	**<0.001**
		Sites	**20.033**	**<0.001**
		Zones	0.846	0.44
Macroflora	Percentage cover (log)	**Status**	**31.429**	**<0.001**
		Sites	**16.501**	**<0.001**
		Zones	0.207	0.8141

Table E6: Games Howell posthoc test for Infauna regarding Status and Sites.

Group 1	Group 2	p.adj value
Burkes	Kitchener Street	0.425
Burkes	Macandrew Bay	0.703
Burkes	Orari Street	0.097
Burkes	**Portobello Road**	**0.037**
Kitchener Street	Macandrew Bay	0.748
Kitchener Street	Orari Street	0.930
Kitchener Street	Portobello Road	0.927
Macandrew Bay	Orari Street	0.231
Macandrew Bay	Portobello Road	0.121
Orari Street	Portobello Road	1

Table E7: Games Howell posthoc test for Epifauna regarding Status and Sites.

Group 1	Group 2	p.adj value
Burkes	Kitchener Street	0.058
Burkes	Macandrew Bay	0.96
Burkes	**Orari Street**	**0.03**
Burkes	Portobello Road	0.70
Kitchener Street	Macandrew Bay	0.11
Kitchener Street	Orari Street	0.97
Kitchener Street	Portobello Road	0.26
Macandrew Bay	Orari Street	0.09
Macandrew Bay	Portobello Road	0.96
Orari Street	Portobello Road	0.33

Table 8 Games Howell posthoc test for Macroflora regarding Status and Sites.

Group 1	Group 2	p.adj value
Burkes	**Kitchener Street**	**0.03**
Burkes	Macandrew Bay	0.962
Burkes	**Orari Street**	**<0.001**
Burkes	Portobello Road	**0.006**
Kitchener Street	**Macandrew Bay**	**0.041**
Kitchener Street	Orari Street	**0.001**
Kitchener Street	**Portobello Road**	0.052
Macandrew Bay	**Orari Street**	**<0.001**
Macandrew Bay	Portobello Road	0.006
Orari Street	**Portobello Road**	0.776

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