Dunedin City Council

Stormwater Monitoring

July 2020 – June 2021

ryder

Dunedin City Council

Stormwater Monitoring

July 2020 to June 2021

Prepared for Dunedin City Council

by

Ben Ludgate, MSc.
Melanie Vermeulen, BSc (Hons).
Katerina Achilleos, PhD. candidate

Reviewed by

Greg Ryder, PhD.

Ryder Environmental Limited
195 Rattray Street
PO Box 1023
DUNEDIN, 9054
New Zealand
Phone: 03 477 2119
www.ryderenv.nz

Document version: 17 September 2021

Cover page: Otago Harbour adjacent to the Portobello Road stormwater outfall, 26 May 2021.

Table of Contents

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). Between July 2020 and June 2021, sampling included stormwater quality during dry weather conditions, harbour water quality during dry weather conditions, automated sampling of stormwater quality during one wet weather event, harbour sediments, and harbour biological communities. Further sampling was restricted by weather/tidal conditions not being met.

Dry weather sampling of stormwater found trigger levels of *Escherichia coli* were exceeded at most outfalls on at least one sampling occasion. Five stormwater outfalls (1, 5, 24, 25 and 27) had three consecutive sampling rounds with elevated *E. coli* concentrations and warrant further investigation for possible cross-connections between stormwater and wastewater systems.

Automated sampling was undertaken for one wet weather event but the rainfall event was not of high intensity. The contaminant profile during the rain event shows that concentrations of most heavy metals and PAHs were fairly consistent over the sampling period whereas *E. coli* and suspended solids were more variable. Three rain events have now been sampled in the Mason Street catchment, and it is recommended that the automatic sampler is moved to the next catchment (Halsey Street).

Harbour water quality sampling was undertaken during dry weather and found copper concentrations exceeded trigger levels at five of the six sites and zinc concentrations exceeded trigger levels at one site. The elevated copper concentrations at several sites indicates the source is unlikely to be a point source discharge but could be difficult to determine, while the elevated zinc concentrations at only one site (Substation H6) could be influenced by runoff from nearby roads (e.g., tyre wear) and/or buildings (e.g., zinc-coated roofing materials) within the Portsmouth Drive catchment.

Harbour sediment contaminant concentrations were below 2013 trigger levels in the consents, but concentrations of lead, zinc and PAHs were above ANZECC (2000) ISQG-Low values, indicating further investigation may be required.

Harbour biological communities were, in general, similar to those found in previous surveys, with relatively low diversity and high variability between sites. There were no significant overall effects of the stormwater outfalls on the biological communities, however the communities at Portobello Road and Macandrew Bay had high proportions of 'pollution-tolerant' species. Cockle flesh contaminant concentrations for enterococci and arsenic were higher than relevant standards for contaminant concentrations in shellfish for food.

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 to these receiving environments (Figure 1). Conditions of the consents 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 Ryder Environmental to undertake the required monitoring in 2020-21. This report summarises the monitoring undertaken between July 2020 and June 2021.

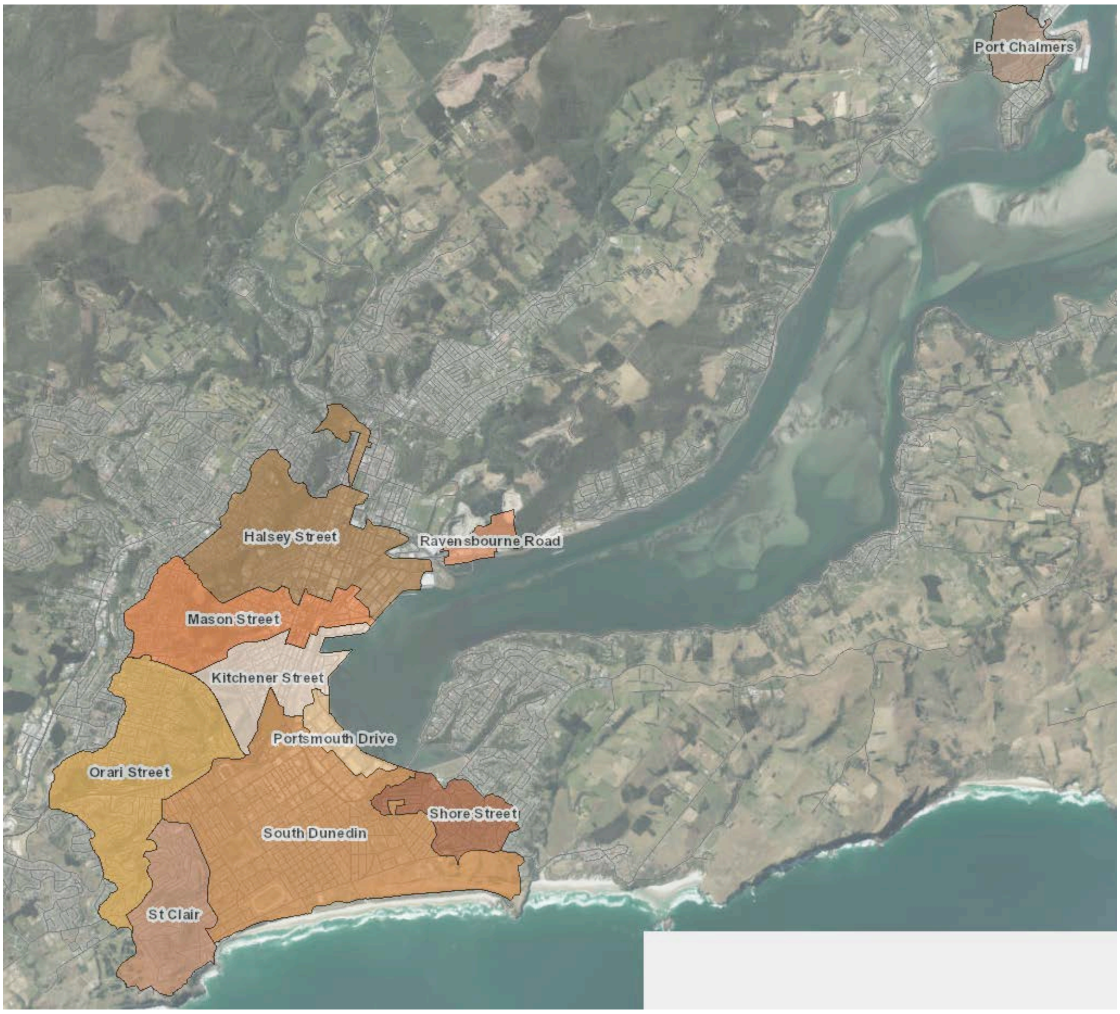

Figure 1. Dunedin stormwater catchments. From DCC webpage.

2. Methods

2.1. Stormwater outfalls

Monitoring of Dunedin's stormwater quality is required at 14 large outfalls and many smaller outfalls. The relevant stormwater outfalls are identified in Figure 2. 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. Monthly dry weather sampling sites (blue circles) and six-monthly dry weather sites (green circles). See Appendix One for outfall information. Aerial photo from Google Earth.

Figure 2 continued. Dunedin stormwater outfalls. Monthly dry weather sampling sites (blue circles) and six-monthly dry weather sites (green circles). See Appendix One for outfall information. Aerial photo from Google Earth.

2.2. Stormwater – Dry weather

Dry weather sampling is required at stormwater outfalls (Figure 2) under low tide conditions, to avoid seawater contamination. 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 sample is taken for that month.

Grab samples are collected 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 guts of humans and warm-blooded animals, and is used as an indicator of faecal contamination in freshwater. The indicator bacteria themselves do not pose a significant risk to human health, but rather indicate the likely presence of faecal material, which contains disease-causing pathogens. 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 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 human faecal pollution and a level of 0.2 ppb is strongly indicative of human faecal pollution (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).

Dry weather sampling allows the determination of background contaminant levels entering the receiving environments via stormwater outfalls, and 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) (Appendix One).

2.3. Stormwater – Wet weather

Wet weather sampling is required annually at ten major stormwater outfalls (Figure 3) 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. Sampling under these conditions is undertaken in an endeavour to sample the first flush, which typically contains the highest concentration of contaminants. Grab samples are collected for laboratory analysis (Eurofins) 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 3. Dunedin stormwater outfalls. Wet weather sampling sites (orange circles). See Appendix One for outfall information. Aerial photo from Google Earth.

Figure 3 continued. Dunedin stormwater outfalls. Wet weather sampling sites (orange circles). See Appendix One for outfall information. Aerial photo from Google Earth.

2.4. Automated sampler – Wet weather

An ISCO automated sampler is used to target specific stormwater outfalls to provide a contaminant profile across a rain event and is located within certain stormwater catchments as required by resource consents. Since February 2018, the automated sampler has been located near Toitū Museum, approximately 600 m up-pipe of the Mason Street stormwater outfall (Figure 4).

The automated sampler has been programmed to collect samples every 10 minutes over the first two-hour period of a rain event (more than 2.5 mm of rain). 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 successfully under the correct conditions, samples are collected for laboratory analysis (Eurofins) for total arsenic, cadmium, chromium, copper, nickel, lead, and zinc, and oil and grease, suspended solids, pH, polycyclic aromatic hydrocarbons (PAH), and *E. coli*. In addition, FWAs are measured using an *AquaFluor* handheld fluorometer.

Figure 4. The location of the ISCO automated sampler, near Toitū, sampling the Mason Street catchment. Mason Street stormwater outfall indicated by green circle. Aerial photo from Google Earth.

2.5. Harbour water

Monitoring of harbour water quality is required at six sites in the upper harbour (Figure 5) for one rainfall event and for one dry period.

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.

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. Grab samples are collected from approximately 20 cm below the water surface 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, would indicate a potential environmental problem, and so 'trigger' a management response.

Enterococci is a type of bacteria commonly found in the guts of humans and 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 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.

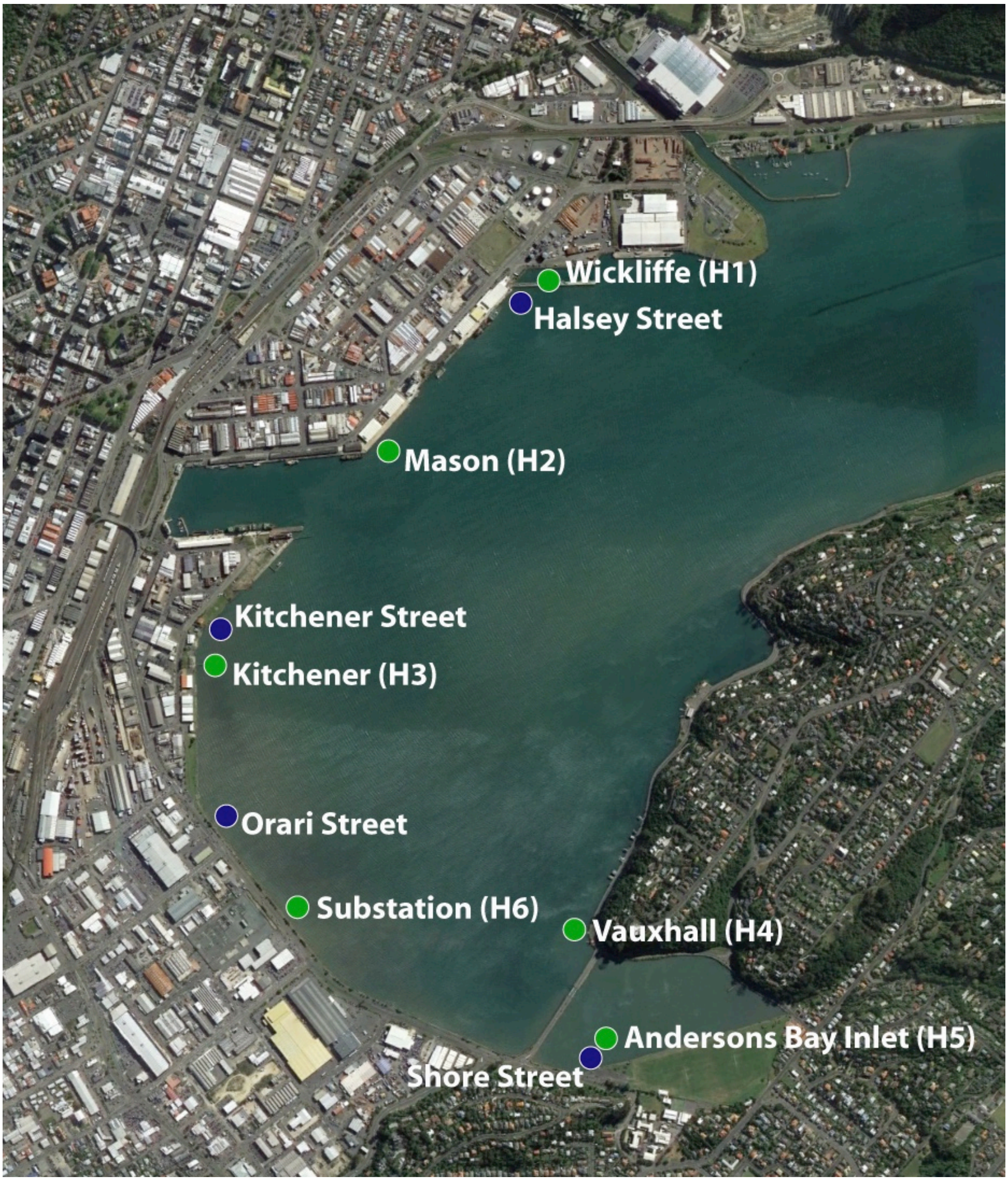

Figure 5. Otago Harbour water quality sampling sites (green circles) and sediment sampling sites (blue circles). Aerial photo from Google Earth.

2.6. Harbour sediment

Monitoring of harbour sediment quality is required at four sites in the upper harbour (Figure 5). Sediments are a potential source and sink for dissolved contaminants, and assessing sediment quality can identify where contaminant concentrations could result in adverse effects on ecological communities. Sampling of harbour sediment quality involves the collection of the uppermost 20 mm of sediment from an area approximately 20 m from the nearest stormwater outfall. At the Orari Street and Shore Street sites, samples are collected directly from the substrate by scraping the top 20 mm into a collection jar. 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. Samples are collected for laboratory analysis (Eurofins) for total arsenic, cadmium, chromium, copper, nickel, mercury, lead, and zinc, and weak acid extractable copper, total petroleum hydrocarbons (TPH), organochlorine pesticides, and polycyclic aromatic hydrocarbons (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 80^{th} 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 Total TPH and weak-acid extractable copper are yet to be determined. 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. Sediment grain size and total organic carbon content in sediment affects the bioavailability and toxicity of contaminants.

2.7. Harbour biological

Biological monitoring at selected Otago Harbour sites specified in the consents (Burkes, Kitchener Street, Orari Street, Portobello Road and Macandrew Bay; Figure 6) 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 6. Otago Harbour biological sampling sites. Aerial photo from Google Earth.

Table 1. Biological monitoring required at Otago Harbour sites.

Site	Status	Sampling 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

Sample collection and analysis

Epifauna

Benthic epifauna were 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 was completed to the lowest possible taxonomic level using photographs of the quadrats, with specimens collected when required. Epifauna species were recorded as individual counts, except for Serpulidae (sessile, tube-building annelids) at Kitchener Street which were recorded as percentage cover (estimated using photoQuad v. 1.4 (Trygonis and Sini 2012)); uniform spawn method, 400 points per quadrat.

Infauna

Benthic infauna samples were 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 were taken within three of the five epifauna quadrats. Core samples were returned to the Ryder Environmental laboratory for sieving (500 µm), identification and enumeration using a light microscope. Organisms were identified to the lowest possible taxonomic level.

Macroflora

Macroflora was 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 was completed to the lowest possible taxonomic level using photographs of the quadrats, with percentage cover recorded using photoQuad v. 1.4, as described above. Specimens were collected when required.

Cockles

Cockles were collected by hand within 20 m of the outfalls at the Kitchener Street, Orari Street and Portobello Road sites. Cockles were returned to Ryder Environmental laboratory where their size and weight were recorded before being delivered to Eurofins laboratory for analysis of the flesh 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 were conducted to assess community composition (infauna, epifauna and macroflora).

The five sites were 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 were 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 were transformed ($log_{10}(x+1)$ and square root, respectively) to meet assumptions of homogeneity. The two datasets (% cover and individual counts) were treated separately. Diversity indices were calculated and a multi-variate statistical analysis was used to investigate relationships between sites; details of these analyses can be found in Appendix Two.

3. Results and Discussion

3.1. Stormwater – Dry weather

Dry weather sampling of stormwater outfalls was undertaken under the required weather and tidal conditions in July, September, November and December 2020, and January, February and May 2021 (Appendix Three). Dry weather sampling could not be undertaken in other months between July 2020 and June 2021 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).

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. Five outfalls (outfalls 1 (St Clair catchment), 5 (Portsmouth Drive catchment), and 24, 25 and 27 (Halsey Street catchment)) had *E. coli* concentrations that exceeded the trigger level on three consecutive sampling rounds. These three Halsey Street outfalls (24, 25, and 27) also had *E. coli* concentrations that exceeded 100,000 cfu/100 mL on one occasion each. Only outfall 5 (Portsmouth Drive catchment) had both elevated FWA and *E. coli* concentrations, on two occasions. Sampling at outfalls not discussed above found variable levels for FWAs and/or *E. coli* in 2020-21, as has been found during previous years of monitoring.

3.2. Stormwater – Wet weather

Between July 2020 and June 2021, 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), and therefore no wet weather sampling was able to be completed in 2020-21.

3.3. Automated sampler – Wet weather

While sampling of wet weather events at several stormwater outfalls could not be undertaken under suitable conditions between July 2020 and June 2021, sampling of stormwater during a wet weather event was undertaken by the automated sampler (see below). The ISCO automated sampler, located at a Mason Street catchment site, has been programmed to collect samples over the first two-hour period of a rain event (more than 2.5 mm of rain). If the rain event coincides with low tide (to prevent mixing with seawater) and follows an antecedent dry period of at least 72 hours, the samples are collected and prepared for laboratory analysis.

However, the sampler can be triggered when not all the required conditions have been met, which results in 'false alarms'. False alarms can occur when the sampler is triggered 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 the sampler reset. Between July 2020 and June 2021, the sampler was incorrectly triggered on 22 occasions.

Between July 2020 and the end of May 2021, there were no rainfall events that met all of the required conditions for the automated sampler to collect samples during a rainfall event. Therefore, following discussions at the 2020 stormwater stakeholder meeting, and in an effort to collect some samples within the 2020-21 sampling year, it was decided to reduce the antecedent dry period to 48 hours. Subsequently, at 11.55am on 10 June 2021, the ISCO automated sampler was triggered during a rainfall event. The sampler was triggered at the time of a mid-flood tide and followed four days of dry weather (i.e., an antecedent dry period of more than the required 72 hours). However, while the MetService had recorded 2.6 mm of rain for the event (just above the required 2.5 mm), the DCC SCADA (which triggers the sampler) only recorded 0.7 mm of rain (with 0.5 mm in the first hour, which triggered the sampler). When the sample bottles were checked, only 8 samples could be collected from a possible 12 (due to declining rainfall during the event). However, as the bottles contained debris, indicating the 'first flush' of stormwater had been collected, and due to the time of year (and the very low chance of another rain event before the end of June 2021), it was decided to have the samples analysed at the laboratory to obtain some data for the 2020-21 period.

Of the contaminants tested for during the June 2021 rainfall event, concentrations of arsenic, cadmium, and PAH were all below laboratory detectable limits throughout the event (Appendix Four). Concentrations of suspended solids decreased during the June 2021 rain event, and were lower than during the March 2019 event (Figure 7). Concentrations of *E. coli*, however, were much higher than during previous events, with a peak 30 minutes into the event before declining and becoming stable. Oil and grease had a small peak in concentrations 20 minutes into the rain event, before becoming stable, but then increased 70-80 minutes into the event to a high peak. Unfortunately, due to the short nature of the rain event, no further samples were collected after 80 minutes. Concentrations of chromium, copper, lead and nickel all decreased during the event, and were generally at higher concentrations than during previous rain events. Zinc concentrations increased slightly during the event, and were higher than during previous rain events.

Variable results have also been found during previous years of monitoring, with the higher concentrations of contaminants during the 2021 event (relative to 2019 events) similar to those from previous automatic sampling in other catchments. Contaminant concentrations during a rainfall event are generally expected to follow a pattern of low initial concentrations at the start of the event, increasing contaminant concentrations with the first flush of runoff, and then gradually decreasing concentrations as the rainfall event progresses. Concentrations of suspended solids and faecal indicator bacteria are usually positively correlated with flow, total heavy metals can be moderately variable and petroleum hydrocarbons may be only intermittently present at measurable concentrations. The intensity of the rainfall event, rate of onset and location of source within the catchment have a bearing on values, as does the length of the antecedent dry period for contaminants that are source-limited and present in stormwater due to their build up on impervious surfaces. Thus, the resultant curves for each contaminant may differ markedly (Gadd and Milne 2019).

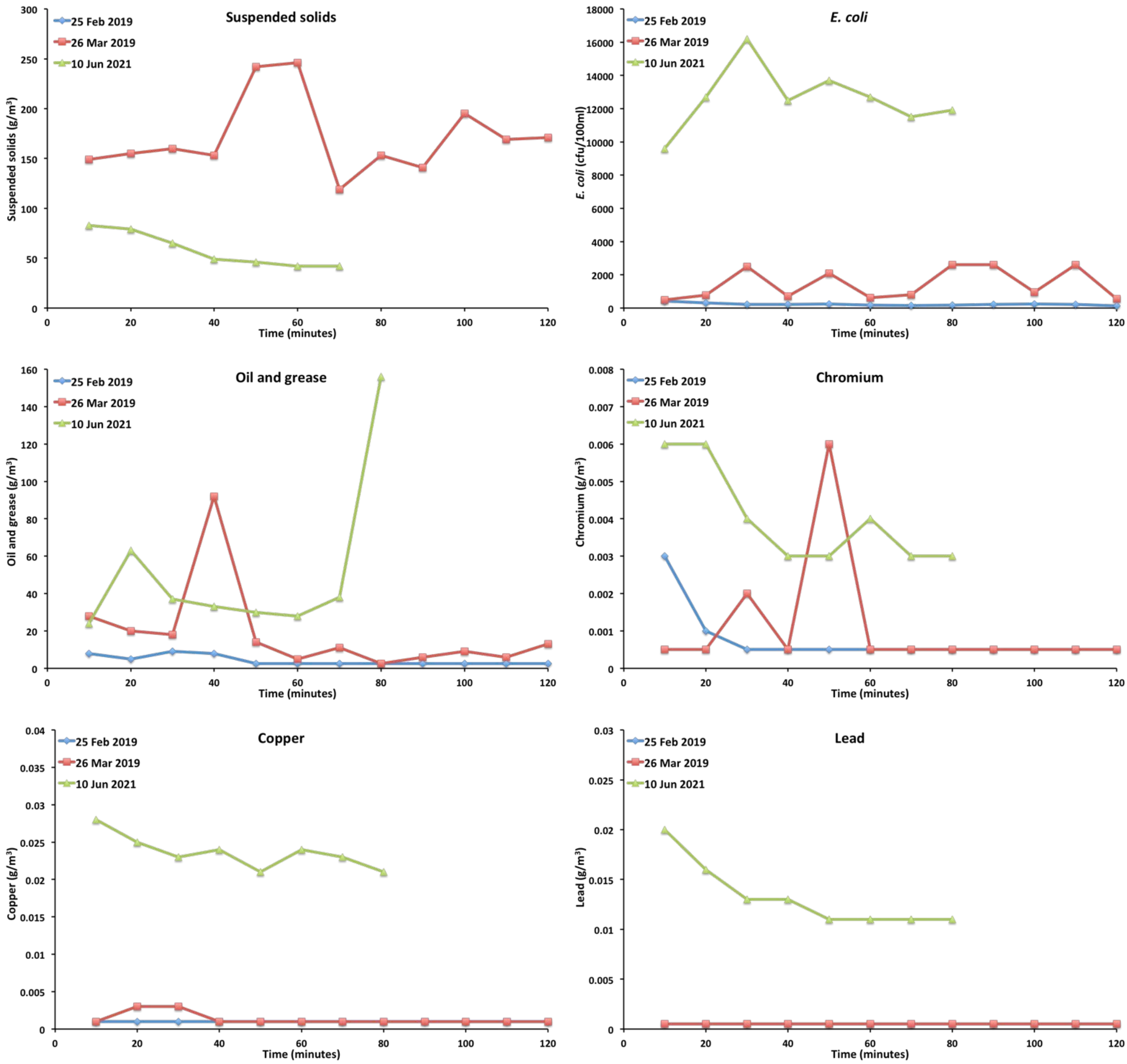

Figure 7. Concentrations of selected contaminants collected by the ISCO automated sampler in the Mason Street stormwater catchment. See Appendix Four for all data. Samples collected every ten minutes over a two-hour period during rainfall event in June 2021. Concentrations during rain events in February and March 2019 also shown.

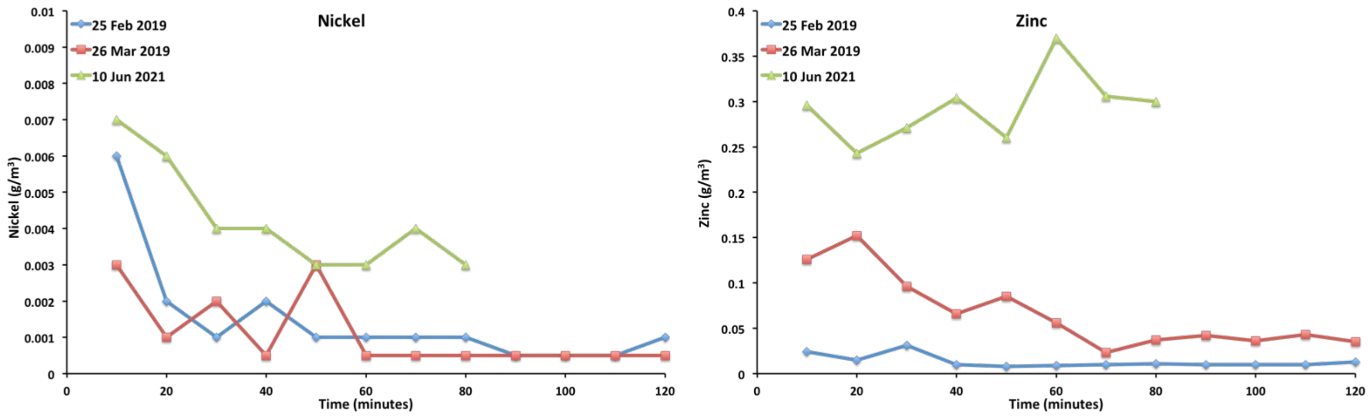

Figure 7 cont. Concentrations of selected contaminants collected by the ISCO automated sampler in the Mason Street stormwater catchment. See Appendix Four for all data. Samples collected every ten minutes over a two-hour period during rainfall event in June 2021. Concentrations during rain events in February and March 2019 also shown.

The ISCO automatic sampler has been located within the Mason Street catchment since February 2018. 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, until June 2021, only two sampling events have been captured (25 February 2019 and 26 March 2019, with no suitable events in 2019-20) and the sampler has therefore remained at the Mason Street site. With the capture of the June 2021 rainfall event, relocating the ISCO to the next catchment (Halsey Street catchment) is recommended.

3.4. Harbour water

Sampling of harbour water quality is required on four occasions, targeting one rainfall event and one dry period. Harbour water sampling can be used to determine the effects of stormwater discharges on water quality in Otago Harbour, and sampling during both a rain event and during a dry period each year allows comparison of results under the different conditions. However, in the 2020-21 sampling period only dry period sampling was undertaken as a rain event did not occur that met the required conditions of the consent.

Dry weather sampling was undertaken on 15 January 2021. On the mid-ebb tide, copper concentrations exceeded trigger values at Kitchener (H3), Substation (H6), Vauxhall (H4) and Anderson's Bay Inlet (H5) (Table 2). Concentrations of other metals were all lower than trigger levels, with concentrations of cadmium and lead generally lower than laboratory detection levels. Concentrations of enterococci were low, and lower than the 'amber/alert' limit. Concentrations on the mid-flood tide were similar, with copper concentrations exceeding the trigger level at the same sites but also at Mason (H2). In addition, the concentration of zinc exceeded the trigger level at Substation (H6). Concentrations of other metals and enterococci were all lower than trigger/alert levels.

As trigger levels were exceeded for copper and zinc, and as required by the resource consent, re-sampling and re-analysis for these contaminants was required. Subsequently, these two contaminants were re-sampled during the next suitable tide, on 2 February 2021, at the identified sites. On the mid-ebb tide, the copper concentration exceeded the trigger level at Mason (H2), Substation (H6) and Anderson's Bay Inlet (H5), but not at Kitchener (H3) and Vauxhall (H4), while the zinc concentration at Substation (H6) did not exceed the trigger level (Table 2). However, on the mid-flood tide, copper and zinc concentrations exceeded the trigger level at all resampled sites. As resampling exceeded trigger levels, the consent requires the protocol outlined in Condition 10 of the consent to be implemented, wherein an investigation is undertaken to determine the likely source of the contaminant(s) and whether it is attributed to the stormwater discharge authorised by the consent.

Dry weather sampling indicates background contaminant levels in harbour water without any influence from high volume stormwater inputs that occur during a rainfall event. The results demonstrate that background copper concentrations were elevated within all sampled catchments with the exception of Wickliffe (H1), and background zinc concentrations were elevated at Substation (H6). Previous sampling of harbour water has also found elevated copper concentrations at most sites during dry weather sampling, with elevated zinc 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.

Table 2. Harbour water sampling data from a dry weather sampling event on 15 January 2021 and re-sampling on 2 February 2021. Orange cells indicate values exceed trigger levels.

	Dry weather – sampling: 15 January 2021					Re-sampling: 2 February 2021	
	Cadmium (g/m^3)	Copper (g/m^3)	Lead (g/m^3)	Zinc (g/m^3)	Enterococci (cfu/100mL)	Copper (g/m^3)	Zinc (g/m^3)
Trigger levels	**0.0055[1]**	**0.0013[1]**	**0.0044[1]**	**0.015[1]**	**140[2]**	**0.0013[1]**	**0.015[1]**
Mid-ebb tide							
Wickliffe (H1)	<0.0002	0.0010	<0.0005	0.004	36	-	-
Mason (H2)	<0.0002	0.0011	<0.0005	0.005	46	0.0052	-
Kitchener (H3)	<0.0002	0.0018	<0.0005	0.005	20	0.0008	-
Substation (H6)	<0.0002	0.0031	0.0008	0.009	52	0.0013	0.008
Vauxhall (H4)	<0.0002	0.0037	<0.0005	0.004	8	0.0012	-
Andersons Bay Inlet (H5)	<0.0002	0.0037	<0.0005	0.003	92	0.0024	-
Mid-flood tide							
Wickliffe (H1)	<0.0002	0.0008	<0.0005	<0.002	8	-	-
Mason (H2)	<0.0002	0.0016	0.0006	0.010	28	0.0025	-
Kitchener (H3)	<0.0002	0.0020	<0.0005	0.004	<4	0.0021	-
Substation (H6)	<0.0002	0.0048	0.0023	0.016	46	0.0021	0.037
Vauxhall (H4)	<0.0002	0.0036	<0.0005	0.003	62	0.0021	-
Andersons Bay Inlet (H5)	<0.0002	0.0047	<0.0005	0.004	8	0.0025	-

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.

3.5. Harbour sediment

Sampling of harbour sediment quality was undertaken at the four upper harbour sites (Figure 5) on 25 and 26 May 2021.

Contaminant concentrations in harbour sediments at all sites were below the 2013 trigger levels listed in the resource consent (where applicable; Appendix Five). The ANZECC (2000) interim sediment quality (ISQG) Low guideline levels were exceeded for lead (Orari Street and Shore Street), zinc (Kitchener Street and Shore Street) and PAH (Kitchener Street and 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.

ANZECC (2000) does not provide guideline values for weak acid extractable (WAE) copper, organochlorine pesticides (OCP) and total petroleum hydrocarbons (TPH). However, 2018 sediment quality default guideline values (DGV) (ANZG 2018) are available for total TPHs (DGV 280 mg/kg, DGV-high 550 mg/kg) and individual OCPs (DGV range from 900-

4500 mg/kg). Total TPH (≤57 mg/kg) and total OCP (all less than laboratory detection limits, <0.25 mg/kg) concentrations were all low in 2021, and considerably lower than the relevant ANZG (2018) DGVs.

Overall, sediment sampling in 2021 found generally similar concentrations at all four sites as in recent years. Some variation is expected between years, due to movement and disturbance/redistribution of sediments, and elevated concentrations at some sites should not be cause for immediate alarm. For instance, a high PAH concentration of 142.82 mg/kg at Orari Street in 2018 was followed by much lower concentrations in 2019 (below laboratory detection limits).

Contaminant concentrations in sediments in recent years have been considerably lower than at some historic sites. The Kitchener Street site has historically been influenced by a scrap metal yard and a now defunct sandblasting operation, with high values of metal contaminants, while South Dunedin (Portobello Road) sites have had high PAH concentrations due to historic contamination from stormwater, especially from the old gas works. However, improvements in wastewater/stormwater connections and the cessation of many industrial activities have reduced contaminant inputs to the harbour.

3.6. Harbour biological

Biological sampling at the five sites (Burkes, Kitchener Street, Orari Street, Portobello Road and Macandrew Bay) was undertaken between 26 and 28 May 2021, at low tide.

Community overview

A total of nine phyla, 33 families and 40 species were recorded at the five sites. Fauna included 28 families and 33 species, and macroflora 5 families and 7 species (Appendices Six to Eight). The community at Kitchener Street was the most species rich (S’) regarding infauna and epifauna, with 16 species, whereas the Burkes (‘control’) community had the most diversity (H’) and evenness (J’) (Figure 8). Regarding macroflora, the Kitchener Street and Orari Street communities were the most species rich (S’), with five species, and Orari Street was also the most diverse (H’) and even (J’). The Macandrew Bay (‘control’) community had the lowest score for species richness, diversity and evenness for infauna and epifauna, and macroflora, while the Portobello Road site was the only site without macroflora present (Figure 8). Species richness and diversity indices can be found in Appendix Nine.

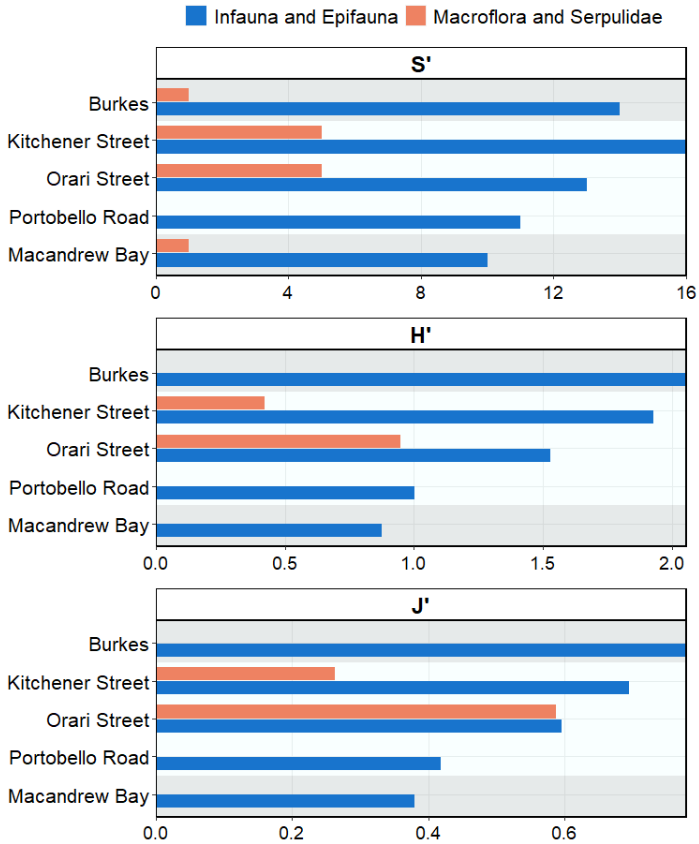

Figure 8. Community diversity indices for each site. S': species richness; H': Shannon Wiener index (a measure of community diversity; higher values indicate higher species diversity); J': Pielou's evenness index (a measure of species evenness; ranges from 0 to 1, from no evenness to complete evenness). 'Control' sites are highlighted in grey.

The most abundant phyla were Annelida and Mollusca and Rhodophyta, a pattern that was also reported in 2019 (Goodwin and Ludgate 2019) (Figure 9). 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).

Annelida was equally recorded at all sites (Figure 9), with the exception of the family Serpulidae (tube-building worms) which was only found at Kitchener Street. This family forms calcareous tubes which require hard substrate for settlement and growth. Kitchener Street is the only site supporting hard substrates (e.g., rocks, shell remains) and can therefore support the growth of Serpulids. The most abundant family was Capitellidae (polychaete worms), and specifically *Heteromastus* sp., with a total of 623 individuals across all sites. Similar to serpulids, Cnidaria (specifically the speckled anemone) were only recorded at Kitchener Street due to the presence of hard substrates, as sea anemones do not settle on soft sediments (Hadfield *et al.* 2021). Arthropoda, such as small amphipods and occasionally larger decapods (e.g., *Hemiplax hirtipes*), were mostly identified at the potential 'impact' sites (Figure 9).

Mollusca were also recorded at all sites (Figure 9). The cockle *A. stutchburyi* was the most abundant species with a total of 68 individuals (excluding the individuals collected for contaminant analysis). *Ostrea chilensis* oysters were only recorded at Kitchener Street, once more because of the hard substrate present as this species is less likely to settle on softer sediments (e.g., Menge 2000). A few nematodes were recorded at Macandrew Bay (Figure 9), but nematodes are easily missed during sample processing because of their size and it is therefore likely they are also present at the other sites. Sipuncula marine worms, and specifically 40 individuals of the small *Golfingia* sp., were only recorded at Burkes (Figure 9).

Similar to previous survey reports (e.g., Goodwin and Ludgate 2019), macroflora was mostly found at the Kitchener Street and Orari Street sites (Figure 9). While some of the algae were indeed settled and growing in the areas, most of the macroflora was found to be drifting algae. Portobello Road was the only site where macroflora was absent (settled or drifted). At Kitchener Street, the red algae *Crassiphycus secundatus* (Rhodophyta) was the most abundant species with a total average cover of about 40%, followed by the green algae *Codium fragile* subsp. *novae-zelandiae* (Chlorophyta) with an average cover of 14%. *Chaetomorpha aerea* (Chlorophyta) was only recorded at Orari Street, with only 0.6% cover, and was found growing in the area and not as drifting algae.

There were no statistically significant differences between the 'control' and potential 'impact' sites regarding overall fauna, including both infauna and epifauna, and no statistically significant differences were found between the zones of proximity to the outfall at the potential 'impact' sites ($p > 0.05$). Thus, there is no indication of significant adverse effects from the stormwater outfalls on the surrounding environment. Statistically significant differences were found regarding epifauna between the Burkes and Orari Street sites ($p = 0.005$), primarily due to differences recorded for Mollusca. Statistically significant differences were found regarding macroflora, between Orari Street and Kitchener Street and the rest of the sites ($p \leq 0.001$), likely due to the high algae cover recorded at these sites (which was primarily drift algae). Statistically significant differences observed between sites are likely a result of local variation, with local conditions leading to algae drifting and differences regarding the substrate. Details on the statistical results are in Appendix Ten.

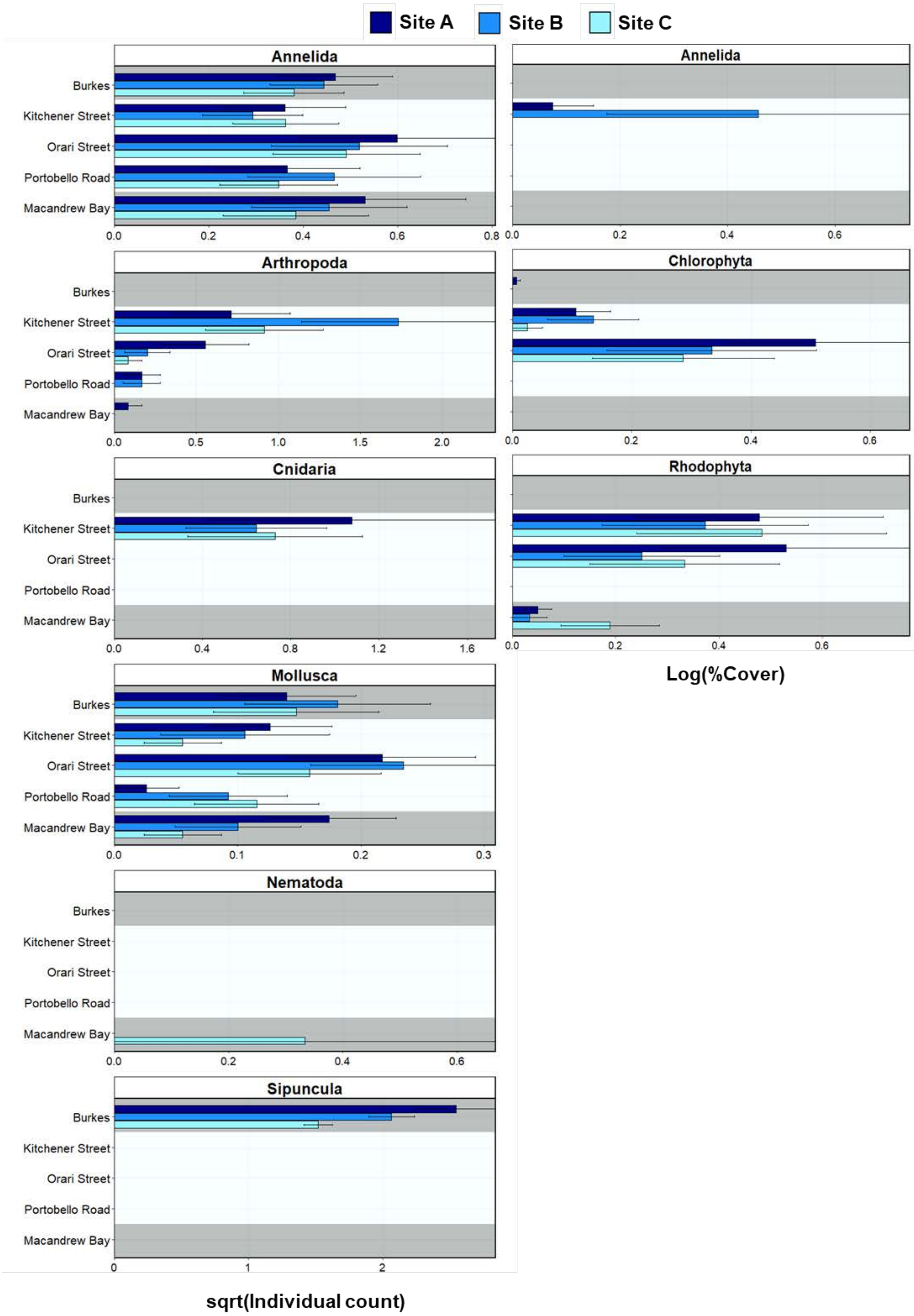

Figure 9. Community overview for each location per Phylum and sampling site. Note different scales on each graph. Annelida (right) represent the tube-building Serpulidae identified only at Kitchener Street. 'Control' sites are highlighted in grey. For potential 'impact' sites, 'Sites A, B and C' represent 0-5 m, 5-20 m and >50 m distance from the outfall, respectively.

The multidimensional scaling plot (Figure 10) shows some grouping within sites and in certain occasions between sites. The plot for the fauna (Figure 10, left) shows that Burkes is quite distinct from the rest of the sites, which could be attributed to the presence of Sipuncula marine worms, which were absent from the other sites, and also due to the absence of Arthropoda (see Figure 9). Portobello Road and Macandrew Bay are grouped closer together as the composition of their communities was very similar. Kitchener Street is loosely grouped but still distinct from the other sites, which is likely due to the presence of Cnidaria in the area, and also the higher abundance of Arthropoda (e.g., amphipods). Orari Street is also loosely grouped, but still close to Kitchener Street and Portobello Road, likely due to the similarities related to Arthropoda (see Figure 9). The plot for macroflora (and Serpulidae) (Figure 10, right) shows that Kitchener Street and Orari Street group very closely together as they had the highest percentage cover algae compared to the other sites. Kitchener Street is also represented by an isolated point at the top of the plot, due to the presence of serpulid tube-building worms on the hard substrates at this site. Burkes and Macandrew Bay are only represented by one species each, *Ulva compressa* and *Agarophyton chilense* respectively, and therefore they are both separated from Orari Street and Kitchener Street. No macroflora or Serpulidae were recorded at Portobello Road.

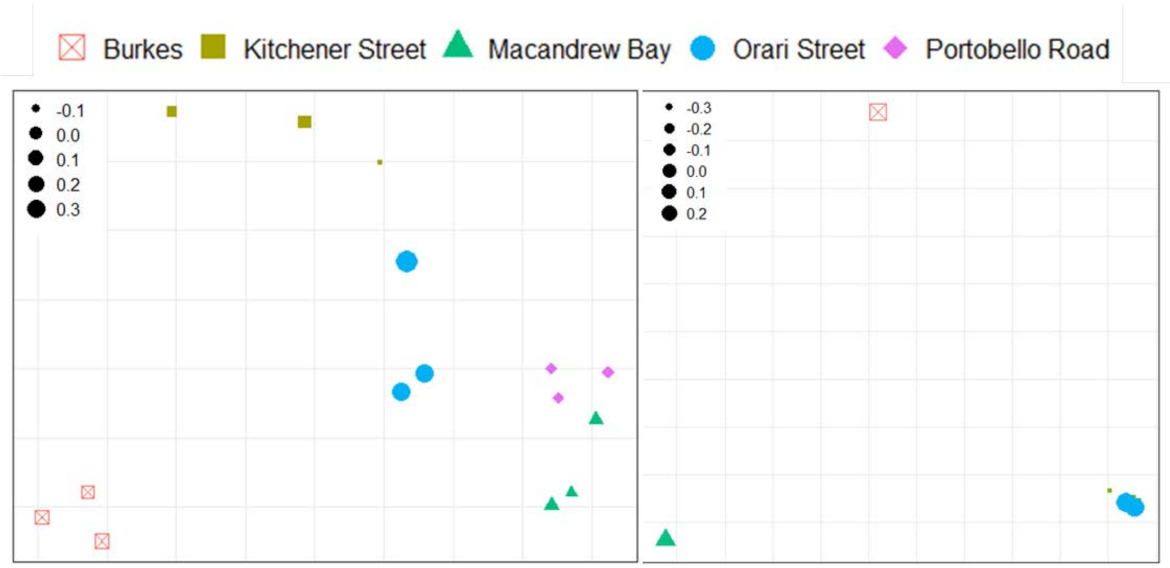

Figure 10. 3D Weighted Classical Multidimensional Scaling plots for infauna and epifauna (left) and macroflora and Serpulidae (right), based on species presence and abundance at the sampling areas (e.g., 0-5 m). Sites are shown in different shapes and colours. The size of the shape represents its position on the z-axis as indicated by the legend key.

Bioindicators

Results from AMBI and BENTIX biotic indices were in agreement for most sites (Table 3; see Appendix Two). Some differences between the two indices are due to their classification schemes with, for example, some species having a known classification with AMBI, but not the BENTIX index, which can affect the final result.

Results of the biotic indices indicate a gradient in ecological status from the west to the east of the harbor, with the least polluted site being the Burkes 'control' site and the most polluted site being the Macandrew Bay 'control' site. Macandrew Bay had highly abundant 'pollution-tolerant' species, such as annelids *Heteromastus* sp. and Nereididae spp., compared to more 'sensitive' species such as small arthropods. *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). Similarly, annelid worms in the family Nereididae respond positively to elevated nutrients/contaminants (Borja *et al.* 2000, Simboura and Zenetos 2002). The Macandrew Bay and Portobello Road sites contained 59.3% (369 individuals) and 83.9% (99 individuals) of the total abundance of *Heteromastus* sp. and Nereididae spp, across all sites respectively. These results differ from 2019 survey results, where only four and two individuals from the Capitellidae family were recorded at Macandrew Bay and Portobello Road, respectively.

The results for the Portobello Road site could have been influenced by a diesel spill (estimated 400-600 L) recorded at the Portobello Road outfall in November 2020[1]. For Macandrew Bay, previous surveys have found similarly low diversity and abundance of epifauna and higher abundance of infauna, however it is uncertain why the indices results for the Macandrew Bay site are poor. 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.

Considering the 'poor' results for Macandrew Bay, further statistical tests were undertaken excluding the Macandrew Bay site. These tests did not find any significant differences ($p > 0.05$) between potential 'impact' sites and the Burkes 'control' site, and we can therefore still conclude that overall there is no statistically significant effect on community composition as a result of discharges from the stormwater outfalls, other than local effects at the Portobello Road outfall.

[1] https://orc.govt.nz/news-and-events/news-and-media-releases/2020/november/orc-appealing-for-information-about-otago-harbour-diesel-spil

Table 3. AMBI and BENTIX values for all sites.

Location	Index	Value	Pollution Status	Ecological Status
Burkes	AMBI	2.27	Slightly polluted	Good
	BENTIX	3.83	Slightly polluted, transitional	Good
Kitchener Street	AMBI	2.62	Slightly polluted	Good
	BENTIX	2.67	Moderately polluted	Moderate
Orari Street	AMBI	4.07	Meanly Polluted	Moderate
	BENTIX	2.67	Moderately polluted	Moderate
Portobello Road	AMBI	4.14	Meanly Polluted	Moderate
	BENTIX	2.20	Heavily polluted	Poor
Macandrew Bay	AMBI	3.84	Meanly Polluted	Poor
	BENTIX	2.38	Heavily polluted	Poor

Contamination and marine litter

Evidence of the diesel spill at Portobello Road was notable during laboratory processing of the infauna samples from the Portobello Road site, especially samples from closest to the outfall (0-5 m). Also, macro- and micro-plastics were evident on the surface and in the sample cores, especially at the Portobello Road and Orari Street sites but also at Macandrew Bay, indicating the litter had been present long enough to be incorporated into the sediment (Figure 11). Overall, the density of marine litter was higher in the areas closest to the outfalls.

Figure 11. Marine litter detected in sample cores. From left to right: Macandrew Bay, Portobello Road, Orari Street, Kitchener Street and Burkes.

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 4).

Table 4. Contaminant concentrations in cockle flesh, 26-28 May 2021

	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	*Enteroccoci* (cfu/100g)	PAH (mg/kg)*
Portobello Road	11.9	0.035	0.65	1.50	0.20	<1000	0.189-0.195
Orari Street	9.63	0.028	0.57	1.11	0.12	1000	0.015-0.021
Kitchener Street	12.7	0.046	0.98	1.20	0.09	<1000	0.010-0.016

* 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 in 2021 at all locations were at or below the laboratory detection limit, and were similar to results from recent years. Metal concentrations were generally comparable to the previous sampling results, with some slight increases in concentrations since 2019. However, the concentrations of chromium and cadmium were higher at Kitchener Street than in 2019, and the chromium concentrations at all three sites were the highest since 2007. All other metal concentrations were within the ranges from previous surveys.

Cockles collected from the Portobello Road site have previously had much higher PAH concentrations than at the other sites, likely as a result of historic contamination of that site. PAH concentrations in cockle flesh have fluctuated over time but concentrations in 2021 were the lowest recorded (Figure 12).

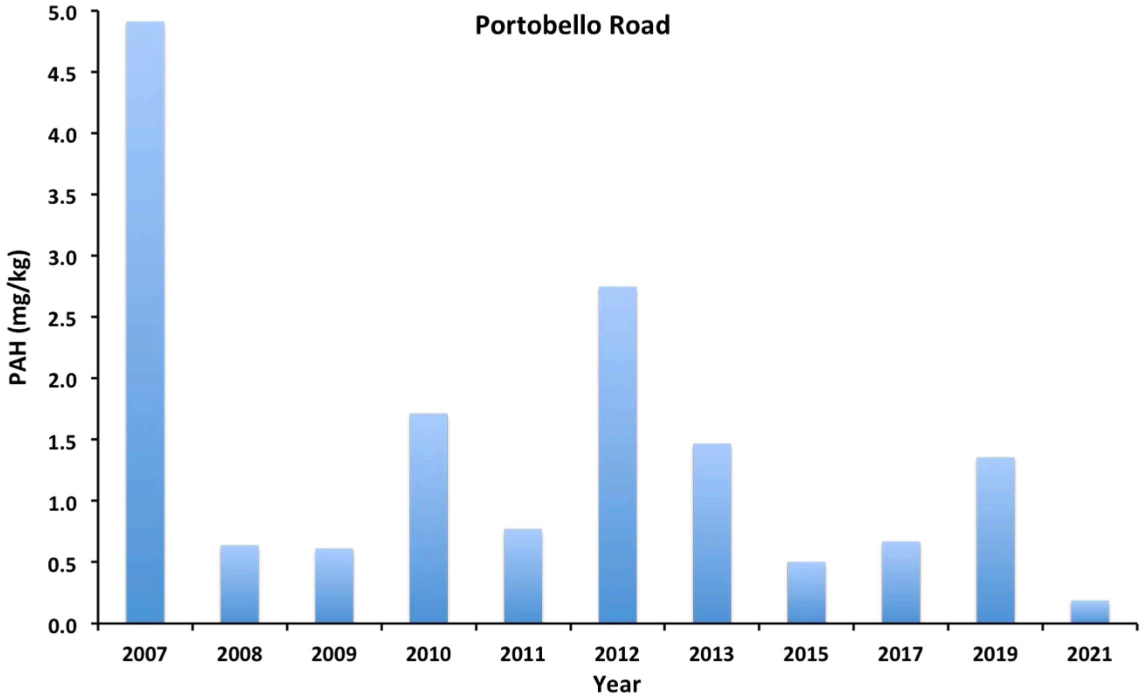

Figure 12. Concentrations of PAHs in cockle flesh at the Portobello Road site, 2007 to 2021.

Of the contaminants required for testing in cockle flesh by resource consent, Food Standards Australia New Zealand (FSANZ) (2017a) 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 (2017a) maximum concentrations (Table 5). For arsenic, the FSANZ (2017a) 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 0.96-1.27 mg/kg and therefore at or slightly higher than the FSANZ (2017a) maximum concentration (Table 5).

Table 5. Maximum concentrations of contaminants in shellfish as food from FSANZ (2017a). For the Otago Harbour sites, 'Lower' indicates concentrations in cockle flesh on 26-28 May 2021 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 (2017a)	Arsenic (inorganic): 1 mg/kg[1]	Higher	Lower	Higher
	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).

Ministry of Health (1995) microbiological reference criteria for food states that harvested and unprocessed shellfish with less than 230 faecal coliform bacteria per 100 g of flesh are 'acceptable' and shellfish with more than 330 faecal coliform bacteria per 100 g of flesh are 'unacceptable'. More recently, microbiological limits in food set by FSANZ (2017b) includes an unacceptable level for *E. coli* of 7/g (i.e., 700 MPN/100g) in bivalve molluses. The enteroccoci concentration at Orari Street was 1000 cfu/100 g and thus would be deemed 'unacceptable'. Enterococci concentrations at Portobello Road and Kitchener Street were below the laboratory detection limit (<1000 cfu/100 g) and therefore the actual concentrations are uncertain. However, given the previously high concentrations found at these sites, it is likely the concentrations would be above 'acceptable' limits.

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 13). The 2021 survey results are consistent with this pattern, and cockle lengths at all three sites were within the range of previous surveys. The only exception to this pattern since 2007 was in 2019, when cockles at Portobello Road were slightly larger than at Orari Street (Goodwin and Ludgate 2019).

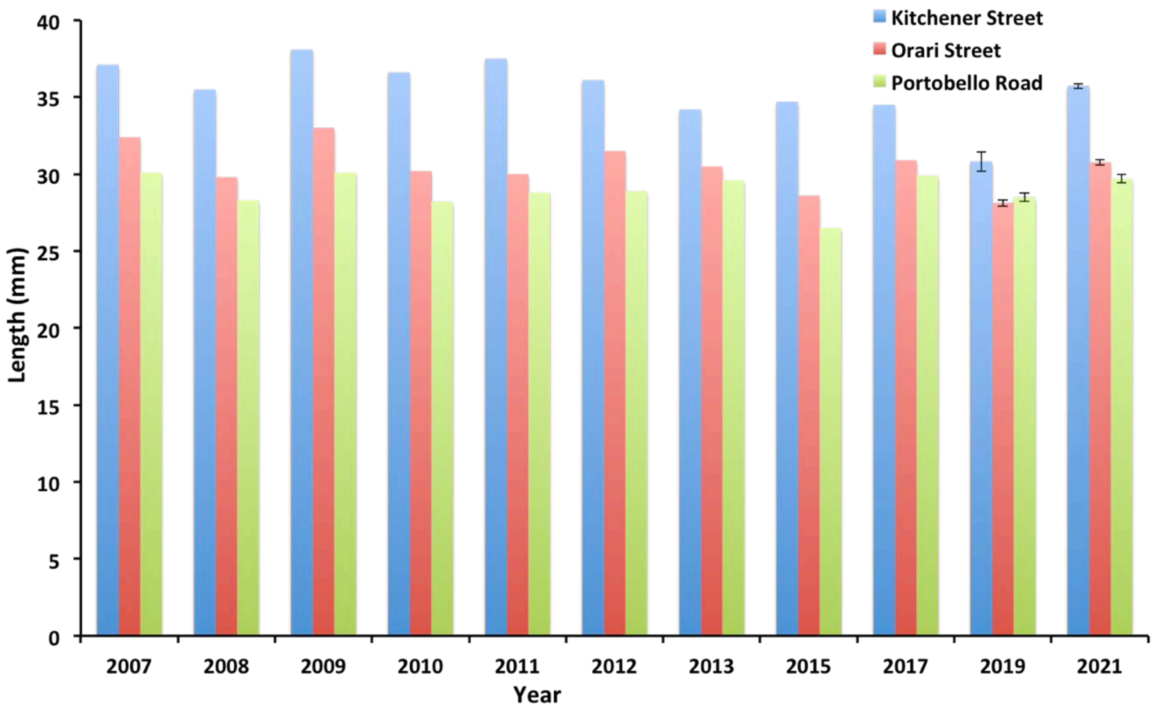

Figure 13. Mean cockle lengths (mm) at the three harbour biological sites, 2007 to 2021. Error bars for 2019 and 2021 means are +/- one standard error.

4. Summary and Conclusion

General

Monitoring of Dunedin's stormwater discharges and receiving environments (Otago Harbour) was undertaken between July 2020 and June 2021. Sampling included stormwater quality during dry weather conditions, harbour water quality during dry weather conditions, automated sampling of stormwater quality during one wet weather event, harbour sediments, and harbour biological communities. Sampling of stormwater and harbour water quality during wet weather conditions were not undertaken in 2020-2021 as the required conditions were not met.

The results of the 2020-21 monitoring continues to build on previous years of sampling in characterising the quality of the stormwater discharged to Otago Harbour, and identifying any effects of these discharges on harbour environments and biological communities. The sampling results can also assist with identifying areas where improvements and/or remediation may be required, such as outfalls, where results indicate possible cross-connections between stormwater and wastewater systems.

Stormwater – Dry weather

Dry weather sampling of stormwater outfalls in 2020-21 found contaminant concentrations were variable at many outfalls, with high concentrations of *E. coli* at most outfalls on at least one occasion. Outfalls 1, 5, 24, 25 and 27 had three consecutive sampling rounds with *E. coli* concentrations above the consented trigger level (550 cfu/100 mL), indicating further investigation for possible wastewater infiltration.

Automated sampler – Wet weather

The ISCO automated sampler captured a wet weather event in June 2021, however the rain event did not continue at a high enough intensity and subsequently not all sample bottles were filled. Analysis of the samples that were collected found concentrations of most heavy metals and PAHs were fairly consistent over the sampling period, while concentrations of *E. coli* peaked after 30 minutes then decreased and were then stable, and concentrations of suspended solids decreased during the event. Concentrations of zinc increased slightly during the event, and were higher than during previous rain events. Overall, variable results have been found during other sampling events, and the 2021 concentrations were similar to those from previous sampling in other catchments.

The ISCO automatic sampler has been located within the Mason Street catchment since February 2018 and has now captured three rainfall events, as required by the consent. Relocating the ISCO to the Halsey Street catchment should now be undertaken particularly given that dry weather sampling in the Halsey Street catchment has often found elevated *E. coli* concentrations at several outfalls, and sampling this catchment would be useful to determine inputs to the harbour from this catchment during wet weather.

Harbour water

Harbour water quality sampling could only be undertaken during a dry weather period in 2020-21. Concentrations of cadmium, lead, and enterococci were low at all sites, however copper concentrations exceeded trigger levels at five of the six sites, and zinc concentrations exceeded trigger levels at one site. Resampling for these two contaminants on the next suitable tide confirmed the elevated results. Previous sampling of harbour water under dry weather conditions has also found elevated copper concentrations at several sites. The high copper concentrations at more than one site indicates the source of the copper is unlikely to be a point source discharge, however copper is used in vehicle brakes, plumbing, and agricultural and industrial activities and determining the exact source is difficult. Zinc concentrations exceeded trigger levels at only one site (Substation H6), and could therefore have been influenced by tyre wear on roads in this area and/or by zinc-coated roofing materials on buildings within the Portsmouth Drive catchment .

Harbour sediment

Contaminant concentrations in harbour sediments at all sites were below the 2013 trigger levels specified in the resource consent, however concentrations of lead, zinc and PAHs were above ANZECC (2000) ISQG-Low values, which indicates further investigation may be required. Some sites have historically had high concentrations of some contaminants (e.g., PAHs at Portobello Road) but remediation works have greatly reduced contaminant inputs. Excluding new inputs, contaminant concentrations may be variable year to year as contaminated sediment is buried or disturbed.

Harbour biological

There were no significant overall differences between biological communities at sites influenced by stormwater outfalls and those sites with no outfalls. 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 at Kitchener Street, and drift algae found at two upper harbour sites. However, the 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 were generally similar to results from recent years, with much lower PAH concentrations at the Portobello Road site than previously found. However, the cockles sampled in May 2021 had elevated enterococci concentrations and arsenic concentrations were at or slightly higher than guideline levels. The cockles would therefore not be considered 'acceptable' to eat from a faecal contaminant or heavy metal (inorganic arsenic) perspective.

Summary

This report has summarised the July 2020 to June 2021 monitoring of Dunedin's stormwater and receiving environments, as required of DCC by ORC resource consents. Results from this monitoring period have identified several stormwater outfalls where investigation is warranted for possible cross-connections between stormwater and wastewater systems, and has identified continued elevated concentrations of some contaminants in receiving water. Monitoring has not identified any significant adverse effects of stormwater discharges on biological communities in the receiving environment.

5. References

ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ANZG. 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines

Borja, A., Franco, J. and Pérez, V. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Marine Pollution Bulletin*. **40(12)**: 1100-1114.

Ellis, J.I., Clark, D., Hewitt, J.E., Taiapa, C., Sinner, J., Patterson, M., Hardy, D., Park, S., Gardner, B., Morrison, A. and Culliford, D. 2017. Ecological survey of Tauranga harbour. Cawthron Institute.

Food Standards Australia New Zealand. 2017a. Australia New Zealand Food Standards Code – Schedule 19 – Maximum levels of contaminants and natural toxicants. Authorised Version F2017C00333 registered 18/04/2017.

Food Standards Australia New Zealand. 2017b. Australia New Zealand Food Standards Code – Schedule 27 – Microbiological limits in food. Authorised Version F2017C00323 registered 13/04/2017.

Gadd, J. and Milne, J. 2019. Monitoring water quality in urban streams and stormwater: Guidance for New Zealand practitioners. NIWA Client Report 2019168AK prepared for Envirolink. MBIE Contract No. CO1X1701.

Gilpin, B. and Devane, M. 2003. Advanced indicators for the identification of faecal pollution sources. Auckland Regional Council Technical Publication Number 338. 73p.

Goodwin, S. and Ludgate, B. 2019. Dunedin City Council. Stormwater Monitoring. July 2018 - June 2019. Report prepared for Dunedin City Council by Ryder Environmental Limited.

Hadfield, M.G., Freckelton, M.L. and Nedved, B.T. 2021. The natural sequence of events in larval settlement and metamorphosis of *Hydroides elegans* (Polychaeta; Serpulidae). *PLoS ONE*. **16(5)**: p.e0249692.

Inglis, G., Gust, N., Fitridge, I., Floerl, O., Woods, C., Hayden, B. and Fenwick, G. 2006. Dunedin Harbour (Port Otago and Port Chalmers). Baseline survey for nonindigenous marine species (Research project ZBS2000/4), Biosecurity New Zealand Technical Paper, (2005/10), p.99.

Menge, B.A. 2000. Top-down and bottom-up community regulation in marine rocky intertidal habitats. *Journal Of Experimental Marine Biology And Ecology*. **250(1-2)**: 257-289.

Ministry for the Environment. 2003. Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment, Wellington. Ref. ME474.

Ministry of Health. 1995. Ministry of Health microbiological reference criteria for food. Ministry of Health. October 1995.

Simboura, N. and Zenetos, A. 2002. Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index. *Mediterranean Marine Science*. **3(2)**: 77-111.

Single, M., Bell, R. and McComb, P. 2010. Physical coastal environment of Otago Harbour and offshore: assessment of effects of proposed dredging by Port Otago Ltd. Shore Processes and Management Ltd, Christchurch.

Smith, A.M. and Croot, P.L. 1993. A flushing time for Anderson's Bay Inlet, Dunedin, New Zealand. Department of Marine Science, University of Otago. Report prepared for the Otago Regional Council.

Smith, A.M. and Croot, P.L. 1994. The role of the shipping channel in flushing upper Otago harbour. Department of Marine Science, University of Otago. Report prepared for the Otago Regional Council.

Trygonis, V. and Sini, M. 2012. photoQuad: a dedicated seabed image processing software, and a comparative error analysis of four photoquadrat methods. *Journal of Experimental Marine Biology and Ecology*. **424-425**: 99-108.

United States Food and Drug Administration. 1993. Food and Drug Administration. Guidance document for arsenic in shellfish. Center for Food Safety and Applied Nutrition. January 1993.

Appendix One: Stormwater outfalls

Table A1.1. Dunedin stormwater outfall information.

Outfall	DCC reference	Resource consent	Location	Catchment	Frequency of dry weather sampling
1	SWX03979	RM11.313.10	Second Beach	St Clair	Monthly
2	SWX00011 & SWX00012	RM11.313.10	St Clair Beach	St Clair	Six monthly
3	SWX04625	RM11.313.04	Shore Street	Shore Street	Monthly
4	SWX03649	RM11.313.09	Portobello Road	South Dunedin	Monthly
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
9	SWX03579	RM11.313.07	Kitchener Street	Portsmouth Drive	Six monthly
10	SWX03568	RM11.313.06	Kitchener Street	Kitchener Street	Monthly
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
22	SWX03506	RM11.313.03	Bauchop Street	Halsey Street	Six monthly
23	SWX03466	RM11.313.03	Bauchop Street	Halsey Street	Monthly
24	SWX03455	RM11.313.03	Halsey Street	Halsey Street	Monthly
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
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
32	SWX12994	RM11.313.01	Sawyers Bay, Watson Park	Port Chalmers	Monthly
33	SWX12879	RM11.313.01	George Street (Port Otago)	Port Chalmers	Monthly

Appendix Two: 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. The indices were calculated using R statistical software (vegan package).

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. Residuals and quantile-quantile (Q-Q) plots were used to assess the distribution of the data. Levene's Test was conducted to check whether the data fulfilled the homogeneity of variance assumption. The data did not fulfil the requirements for a parametric test, therefore Barlett's Test and a Welch's ANOVA 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 and epifauna (excluding Serpulidae) were grouped together, and biotic indices AZTI Marine Biotic Index (AMBI) (Borja *et al.* 2000) and BENTIX (Simboura and Zenetos 2002) were used to assess ecosystem health. It is standard practise to calculate at least two biotic indices to improve accuracy, as each index might include different indicator species. Both indices are based on a classification system of benthic communities and include five levels of ecological quality (Bad, Poor, Moderate, Good, High) (Table A2.1). AMBI index was calculated in R statistical software using 'benthos' package based on methods outlined in Borja *et al.* (2000). BENTIX index was calculated based on the guidelines of Simboura and Zenetos (2002). The indices values were then assigned to the appropriate category.

Table A2.1. AMBI and BENTIX classification for benthic macrofauna. Species examples for the phylum Annelida are also provided.

AMBI			BENTIX		
Classification		**Species examples**	**Classification**		**Species examples**
I	Very sensitive species	Maldanidae spp.	**1**	Sensitive species	Maldanidae spp.
II	Species indifferent	*Glycera* spp.	**2**	Tolerant species	*Glycera* spp.
III	Tolerant species	Nereididae spp.	**3**	First order opportunistic species	*Heteromastus* spp.
IV	Second-order opportunistic species	*Chaetozone* spp.			
V	First order opportunistic species	*Heteromastus* spp.			

The corresponding levels of the biotic indices AMBI (Borja *et al.* 2000) and BENTIX (Simpoura and Zenetos 2000) are shown in Tables A2.2 and A2.3, respectively.

Table A2.2. 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

Table A2.3. BENTIX index for macroinvertebrates.

BENTIX	Pollution Classification	Ecological Quality Status (ECoQ)
4.5 <= BENTIX < 6.0	Normal/ Pristine	High
3.5 <= BENTIX < 4.5	Slightly polluted, transitional	Good
2.5 <= BENTIX < 3.5	Moderately polluted	Moderate
2.0 <= BENTIX < 2.5	Heavily polluted	Poor
0	Azoic	Bad

Appendix Three: Stormwater – dry weather

Table A3.1. **E. coli** ***concentrations and FWA levels from dry weather sampling between July 2020 and June 2021. Outfalls marked with grey cells are sampled six-monthly. Orange 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 (Outfalls 23, 24, 25 were sealed over during road repairs in February 2021).***

	21 July 2020		7 September 2020		4 November 2020		15 December 2020		14 January 2021		23 February 2021		27 May 2021	
Outfall	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)	FWA	*E. coli* (cfu/100mL)
1	0.071	220	0.062	220	0.091	7,100	0.068	696	0.072	3,400	0.050	3,300	0.043	7,600
2			NF	NF									NF	NF
3	0.107	480	0.091	310	0.073	1,400	0.080	423	0.057	412	0.054	918	0.044	6,000
4	0.084	600	0.115	100	0.124	100	0.014	4	0.029	84	NS	NS	0.039	<10
5	0.193	48	0.130	490	0.161	20	0.147	5,900	0.091	42,000	0.121	640	0.136	130
6	0.113	430	0.104	420	0.096	150	0.071	796	0.063	276	0.116	470	0.038	1,800
7	0.086	64	0.086	72	0.071	28,000	0.077	5,300	0.015	4	0.085	5,800	0.025	8,000
8	0.092	870	0.085	520	0.076	490	0.071	619	0.058	84	NF	NF	0.060	1,200
9			0.118	52									0.072	370
10	0.025	56	0.041	4,800	0.038	8,000	0.040	431	0.028	5,200	No access	No access	0.030	260
11			0.021	<4									0.034	<10
12	NF	NF	0.054	64	0.103	160	0.061	100	0.051	40	0.091	40	0.015	<10
13-22			No access	No access									No access	No access
23	0.035	84	0.038	4	-0.018	16,000	0.030	224	0.017	12	No access	No access	No access	No access
24	0.035	38,000	0.031	5,300	0.033	8,400	0.047	11,100	0.020	105,000	No access	No access	No access	No access
25	0.042	9,100	0.045	12,000	0.037	9,000	0.040	200,000	0.030	87,300	No access	No access	No access	No access
26	0.037	8	0.027	<4	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF
27	0.077	28,000	0.040	4,500	0.059	3,100	0.005	24	0.033	800,000	0.095	5,400	0.060	230
28			0.064	4									0.060	20
29			0.063	<4									0.007	<10
30	0.126	12	0.053	<4	0.118	36	0.057	58	0.097	104	No access	No access	0.101	<10
31			0.088	4,600									0.053	1,700
32	0.163	<4	0.154	<4	0.139	8	NF	NF	0.052	8	NF	NF	NF	NF
33	0.041	580	0.051	170	0.063	5,400	0.029	256	0.023	2,800	0.038	320	0.033	720

Appendix Four: Automated sampler – wet weather

Table A4.1. Contaminant concentrations from wet weather automatic sampling (ISCO) for rain event on 10 June 2021. Automated sampling ended after 80 minutes. PAH = polycyclic aromatic hydrocarbons. '< value' indicates all concentrations below laboratory detection limits.

Time (minutes)	pH	Total suspended solids	Oil and grease	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	*E. coli*	PAH
		g/m^3	g/m^3	g/m^3	g/m^3	g/m^3	g/m^3	g/m^3	g/m^3	g/m^3	cfu/100mL	mg/L
10	6.9	83	24	<0.002	<0.001	0.006	0.028	0.020	0.007	0.296	9600	<0.0051
20	7.1	79	63	<0.002	<0.001	0.006	0.025	0.016	0.006	0.243	12700	<0.0051
30	7.2	65	37	<0.002	<0.001	0.004	0.023	0.013	0.004	0.271	16200	<0.0051
40	7.1	49	33	<0.002	<0.001	0.003	0.024	0.013	0.004	0.304	12500	<0.0051
50	7.2	46	30	<0.002	<0.001	0.003	0.021	0.011	0.003	0.260	13700	<0.0051
60	7.3	42	28	<0.002	<0.001	0.004	0.024	0.011	0.003	0.370	12700	<0.0051
70	7.5	42	38	<0.002	<0.001	0.003	0.023	0.011	0.004	0.306	11500	<0.0051
80	7.3	-	156	<0.002	<0.001	0.003	0.021	0.011	0.003	0.300	11900	<0.0051
90	-	-	-	-	-	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-	-	-

Appendix Five: Harbour sediment

Table A5.1. Harbour sediment contaminant concentrations, 25-26 May 2021. 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	16	0.17	32	17.4	22	32	0.12	17	110	0.15-0.52	<35	<0.25
Kitchener Street	15	0.19	33	25	21	44	0.09	15	250	4.59-4.66	<35	<0.25
Orari Street	6.9	0.25	25	19.3	15	53	0.06	13	160	3.71-3.81	42	<0.25
Shore Street	14	0.34	31	26	24	61	0.11	18	300	12.90-12.94	57	<0.25

[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.

Appendix Six: Harbour biological – macroflora

Table A6.1. Percentage cover of macroflora per quadrat at the five harbour biological sites, 26-28 May 2021.

	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	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
Chlorophyta																																													
Chaetomorpha aerea																					0.6																								
Codium fragile subsp. *novae-zelandiae*										0.4	2.7	4.9	3.6	14.5	6.2		1.0		6.4	7.6	42.8	21.9	0.3	60.8	46.8	0.3	5.0																		
Ulva compressa		0.2																																											
Ulva sp.												0.7							4.6	5.1	7.2	2.9		0.5	5.1	0.1	0.2																		
Rhodophyta																																													
*Agarophyton chilense***																																					0.7	0.3	0.3	1.0			2.3	3.1	2.8
*Crassiphycus secundatus**										40.4	96.8	81.9	86.6	82.1	52.8	25.4	34.4	22.7	15.4	29.6	48.3	6.1		14.9	45.3	2.9	0.9																		
Pachymenia dichotoma												0.6								0.2	1.0	0.1		0.5	1.9																				
Total % cover	0	0.2	0	0	0	0	0	0	0	40.8	99.4	88.1	90.3	96.6	59.0	25.4	35.4	22.7	26.4	42.5	99.9	30.9	0.3	76.7	99.1	3.3	6.1	0	0	0	0	0	0	0	0	0	0.7	0.3	0.3	1.0	0	0	2.3	3.1	2.8
Number of taxa per quadrat	0	1.0	0	0	0	0	0	0	0	2.0	2.0	4.0	2.0	2.0	2.0	1.0	2.0	1.0	3.0	4.0	5.0	4.0	1.0	4.0	4.0	3.0	3.0	0	0	0	0	0	0	0	0	0	1.0	1.0	1.0	1.0	0	0	1.0	1.0	1.0
Mean % cover		0.1			0			0			76.1			81.9			27.8			56.3			36.0			36.1			0			0			0			0.4			0.3			2.7	
Mean number of taxa per quadrat		0.3			0			0			2.7			2.0			1.3			4.0			3.0			3.3			0			0			0			1.0			0.3			1.0	

* Synonymized *Gracilaria secundata*
** Synonymized *Gracilaria chilensis*

Appendix Seven: Harbour biological – epifauna

Table A7.1. Number of epifauna invertebrates per quadrat at the five harbour biological sites, 26-28 May 2021.

	Biotic Indices		Burkes															Kitchener Street															Orari Street														
	AMBI	BENTIX	0-5m					5-20m					>50m					0-5m					5-20m					>50m					0-5m					5-20m					>50m				
Taxon			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Mollusca																																															
Austrovenus stutchburyi	I	1							2	1	1							1																	1	6	3	2	2	2	1	4		2	1		1
Paphies subtriangulata	NA	NA																																		1											
Ostrea chilensis	I	NA																									11			1		1															
Diloma sp.	NA	NA																													1						3									2	
Diloma subrostrata	NA	NA																																													
Notoacmea sp.	NA	NA																																													
Cnidaria																																															
Oulactis muscosa	I	NA																	2	4	27					4	3	9	2		2																
Number of invertebrates per quadrat			0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	1	2	4	27	0	0	0	0	4	14	9	2	1	3	1	0	0	1	7	6	2	2	2	1	4	0	2	1	2	1
Number of taxa per quadrat			0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	2	1	1	1	2	1	0	0	1	2	2	1	1	1	1	1	0	1	1	1	1
Mean number of invertebrates per quadrat					0					0.8					0					6.8					3.6					3.2					2.8					2.2					1.2		
Mean number of taxa per quadrat					0					0.6					0					0.8					0.6					1.2					1					1					0.8		
Annelida																																															
Serpulidae (%)	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	17	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean % cover					0					0					0					0.2					5.3					0					0					0					0		

	Biotic Indices		Portobello Road															Macandrew Bay														
	AMBI	BENTIX	0-5m					5-20m					>50m					0-5m					5-20m					>50m				
Taxon			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Mollusca																																
Austrovenus stutchburyi	I	1					2										2		2	1	1					1			1			
Paphies subtriangulata	NA	NA																														
Ostrea chilensis	I	NA																														
Diloma sp.	NA	NA											1				2															
Diloma subrostrata	NA	NA								1																						
Notoacmea sp.	NA	NA								4																						
Cnidaria																																
Oulactis muscosa	I	NA																														
Number of invertebrates per quadrat			0	0	0	0	2	0	0	5	0	0	1	0	0	0	4	0	2	1	1	0	0	0	0	1	0	0	1	0	0	0
Number of taxa per quadrat			0	0	0	0	1	0	0	2	0	0	1	0	0	0	2	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0
Mean number of invertebrates per quadrat					0.4					1					1					0.8					0.2					0.2		
Mean number of taxa per quadrat					0.2					0.4					0.6					0.6					0.2					0.2		
Annelida																																
Serpulidae (%)	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean % cover					0					0					0					0					0					0		

Appendix Eight: Harbour biological – infauna

Table A8.1. Number of infauna invertebrates per core sample at the five harbour biological sites, 26-28 May 2021.

	Biotic indices		Burkes									Kitchener Street									Orari Street									Portobello Road									Macandrew Bay								
			1			2			3			1			2			3			1			2			3			1			2			3			1			2			3		
Taxon	AMBI	BENTIX	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
Annelida																																															
*Heteromastus*sp.	V	3	5	2	7	2	2	3	2	4		15		18	5	3	2	4	10	12	2	15	16	22	22	34	11	24	12	19	24	11	21	4	49	12	4	15	39	28	25	27	13	22	12	22	22
Capitella sp. 1	V	3																			24	55	10		5		7																				
Capitella sp. 2	V	3																										1																			
Chaetozone sp.	IV	3	2									4											3												3			1									
Dorvillaea sp.	NA	2										1						2																													
Glycera sp.	II	2								2																																					
Hemipodus sp.	II	2			1				1					2	1				1																												
Exogoninae	II	2			5	4	8		1	1	3																																				
Aglaophamus sp.	II	2																											1																		
Nerididae	III	2						1				3	1	3			1	1	1		1	1	1				3	2		2	6	5	6	8	2	2	1	9	12	6	21	1	6	4	1	4	3
Maldanidae	I	1	2		1	2		2	2																																	2	2	2			4
Asychis sp.	I	1		1																																											
Armandia sp.	I	1						1																																							
Eumenia sp.	NA	NA																				1		1	1	4		2																			
Prionospio sp.	IV	NA	8	6	6	7	4		5	10	4			2	11	2	8	3	3	1				9	4		1		10					3				1									
Spio sp.	IV	NA			3	4	3		1																																						
Exogone sp.	II	2																1																			1										
Nematoda	*	*																																												1	
Arthropoda																																															
Monocorophium acherusicum	III	3										3	2	16	15	11	42	9	3	1																											
Gammaridae	I	1													3		1																														
Hemiplax hirtipes	NA	NA																			2																										
Phoxocephalidae sp. 1	I	1										2			3	7		9	5		2	1	8	2		1		1		1	1		1		1						1						
Mollusca																																															
Austrovenus stutchburyi	I	1	3	1	2	4	3	7	4	3	5	2	1	1		2	1				2	1	2	1	4	2	1	3	1					1	1				1	1		1	4	2	1		
Lasaeidae	I	2																																						1							
Tellimya sp.	II	NA																																			2	1									
Paphies subtriangulata	NA	NA																							1																					1	
Linucula sp.	I	1												1																										1	1						
Cominella glandiformis	NA	NA																																							1						
Papawera cf. *zelandiae*	II	NA	2	1	1					1	1																																				
Zethalia zelandica	NA	NA												2																																	
Sipuncula																																															
Golfingia sp.	I	NA	7	4	9	5	5	3	3	2	2																																				
Cnidaria																																															
Oulactis muscosa	I	NA													2																																
Number of invertebrates per core			29	15	35	28	25	17	19	23	15	30	4	45	40	25	55	29	23	14	33	74	40	35	37	41	23	33	24	22	31	16	28	16	56	14	8	27	52	37	49	31	25	30	14	28	29
Number of taxa per core			7	6	9	7	6	6	8	7	5	7	3	8	7	5	6	7	6	3	6	6	6	5	6	4	5	6	4	3	3	2	3	4	5	2	4	5	3	5	5	4	4	4	3	4	3
Mean number of invertebrates per core			26.3			23.3			19.0			26.3			40.0			22.0			49.0			37.7			26.7			23.0			33.3			16.3			46.0			28.7			23.7		
Mean number of taxa per core			7.3			6.3			6.7			6.0			6.0			5.3			6.0			5.0			5.0			2.7			4.0			3.7			4.3			4.0			3.3		

Appendix Nine: Harbour biological diversity indices

Table A9.1. Species richness and diversity indices. H': Shannon-Wiener index; J': Pielou's evenness; S': Species richness.

Site	Status	Data	Index	Value
Burkes	'Control'	Infauna and Epifauna	S'	14
Burkes	'Control'	Infauna and Epifauna	H'	2.05
Burkes	'Control'	Infauna and Epifauna	J'	0.78
Kitchener Street	Potential 'impact'	Infauna and Epifauna	S'	16
Kitchener Street	Potential 'impact'	Infauna and Epifauna	H'	1.93
Kitchener Street	Potential 'impact'	Infauna and Epifauna	J'	0.69
Orari Street	Potential 'impact'	Infauna and Epifauna	S'	13
Orari Street	Potential 'impact'	Infauna and Epifauna	H'	1.53
Orari Street	Potential 'impact'	Infauna and Epifauna	J'	0.60
Portobello Road	Potential 'impact'	Infauna and Epifauna	S'	11
Portobello Road	Potential 'impact'	Infauna and Epifauna	H'	1.00
Portobello Road	Potential 'impact'	Infauna and Epifauna	J'	0.42
Macandrew Bay	'Control'	Infauna and Epifauna	S'	10
Macandrew Bay	'Control'	Infauna and Epifauna	H'	0.87
Macandrew Bay	'Control'	Infauna and Epifauna	J'	0.38
Burkes	'Control'	Macroflora and Serpulidae	S'	1
Burkes	'Control'	Macroflora and Serpulidae	H'	0
Burkes	'Control'	Macroflora and Serpulidae	J'	0
Kitchener Street	Potential 'impact'	Macroflora and Serpulidae	S'	5
Kitchener Street	Potential 'impact'	Macroflora and Serpulidae	H'	0.42
Kitchener Street	Potential 'impact'	Macroflora and Serpulidae	J'	0.26
Orari Street	Potential 'impact'	Macroflora and Serpulidae	S'	5
Orari Street	Potential 'impact'	Macroflora and Serpulidae	H'	0.95
Orari Street	Potential 'impact'	Macroflora and Serpulidae	J'	0.59
Portobello Road	Potential 'impact'	Macroflora and Serpulidae	S'	0
Portobello Road	Potential 'impact'	Macroflora and Serpulidae	H'	0
Portobello Road	Potential 'impact'	Macroflora and Serpulidae	J'	0
Macandrew Bay	'Control'	Macroflora and Serpulidae	S'	1
Macandrew Bay	'Control'	Macroflora and Serpulidae	H'	0
Macandrew Bay	'Control'	Macroflora and Serpulidae	J'	0

Appendix Ten: Harbour biological statistical results

Table A10.1. Welch 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 A10.2, A10.3). Status corresponds to 'Control' and potential 'impact' sites; Zones: zones of proximity to the outfall; Sites*: statistical test between sites excluding Macandrew Bay.

Dataset	Dependent variable	Independent variable	F-value	p-value
Infauna	Species abundance (sqrt)	Status	0.06	0.81
		Sites	1.26	0.28
		Sites*	1.57	0.19
		Zones	0.58	0.55
Epifauna	Species abundance (sqrt)	**Status**	**13.21**	**0.00031**
		Sites	**3.79**	**0.005**
		Zones	0.11	0.88
Macroflora	Percentage cover (log)	**Status**	**31.429**	**6.57e-08**
		Sites	**16.501**	**7.711e-09**
		Zones	0.79	0.45

Table A10.2. 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	0.7
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 A10.3. Games Howell posthoc test for Macroflora regarding Status and Sites.

Group 1	Group 2	*p*.adj value
Burkes	**Kitchener Street**	**0.001**
Burkes	Macandrew Bay	0.16
Burkes	**Orari Street**	**0.0000156**
Burkes	Portobello Road	0.85
Kitchener Street	**Macandrew Bay**	**0.006**
Kitchener Street	Orari Street	0.98
Kitchener Street	**Portobello Road**	**0.001**
Macandrew Bay	**Orari Street**	**0.00015**
Macandrew Bay	Portobello Road	0.13
Orari Street	**Portobello Road**	**0.0000145**