Te Whanganui-a-Tara (Wellington Harbour) subtidal monitoring

Results from the 2020 survey

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Executive summary

In 2020, the Greater Wellington Regional Council (GWRC) contracted NIWA to collect, prepare and process marine sediment samples from fifteen selected sites in Te Whanganui-a-Tara (Wellington Harbour) as part of a long-term assessment of seafloor community health and sediment quality.

Samples were collected from 15 subtidal sites in November 2020. Sediments were analysed for benthic infaunal community composition, selected heavy metals, total organic carbon (TOC), polycyclic aromatic hydrocarbons (PAHs), and particle size distributions.

The sediment particle size was predominantly mud, ranging between 69-96% at all sites except the southernmost site in Evans Bay, EB2, where sediments were well mixed and contained <20% mud. Organic matter content ranged from 3.6-8.1%, and was lowest at EB2 and two mid-harbour sites, WH5 and WH9.

Arsenic, cadmium, chromium, nickel and total PAHs were below concentration guidelines in sediments at all sites. Two sites, WH15 located near the entrance of the Hutt River, and WH17 between of Makaro/Ward Island and Matiu/Somes Island, did not exceed guidelines for any of the chemical contaminants measured. Lead and mercury, two of the most toxic heavy metals commonly found in the marine environment, exceeded guidelines at all other sites. Zinc and copper were above guideline concentrations at four sites (WH1 in eastern Evans Bay; WH3 at Lambton Basin entrance; and LB1 and LB2 in Lambton Basin), and two sites near Aotea Quay (AQ1 and AQ2) are approaching exceedance concentrations for copper. These high numbers of exceedances demonstrate that there is reason for concern about contamination in Wellington Harbour sediments

Representative seafloor invertebrate specimens from the 15 sites were photographed and set aside for long term preservation and research with the NIWA National Invertebrate Collection. A total of 630 invertebrate voucher specimens were collected. These taxonomic vouchers and photographs will allow for consistent taxonomic identification in future years.

Evans Bay site EB2 was clearly distinct in terms of its benthic (seafloor) invertebrate community composition, with an average of 38 taxa and 315 individuals per core. This site had substantially higher species diversity and numbers of individuals than any other sites. The remaining 14 sites had between 14 and 22 taxa and 40 to 124 individuals per core, with similar and overlapping community compositions.

The Traits-based index, based on biological traits of the benthic taxa, was used to assess the relative health status of the different sites in 2020. All sites were classified as having 'high' functional redundancy health scores.

Two benthic health models (BHM) used to track the health of New Zealand's intertidal estuarine benthic communities in response to increased surface sediment mud content ('BHMmud'), and lead, copper and zinc contamination ('BHMmetal'), were trialled on this subtidal sampling programme. The intertidal mud model was checked against the percentage mud concentrations measured at each of the subtidal sites and, as they did not fit the model well, it was deemed inappropriate to run the mud model for Wellington Harbour. The BHMmetal model, checked against the actual concentrations of copper, lead and zinc at the Wellington Harbour sites, revealed a reasonable fit with the intertidal model. The majority of the Wellington Harbour sites were categorised as 'good', with only EB2 in the 'moderate' category.

Five sediment-associated variables explained 64% of the variation in benthic community composition between sites. These included concentrations of the contaminants PAH, cadmium and mercury, along with total organic carbon and coarse sand.

While the number of individuals and taxa, and benthic community composition at each site has changed over time, on any particular sampling date (2006, 2011, 2016 or 2020) the majority of the sites have communities that are similar to each other. EB2 was introduced into the monitoring programme in 2016 and has been distinct from the other sites on the two dates it has been sampled.

The 2016 sampling date showed the lowest numbers of individuals and taxa of the four sampling dates, at all sites, potentially due to the considerable disturbance from storms and a major earthquake that occurred during the sampling month. The Traits Based Index was high at all sites on all sampling dates, with the exception of 2016 when only three of the 15 sites had high functional redundancy. The unusual environmental conditions around the time of sampling in 2016 may have contributed to the unusual patterns in 2016. More sampling times (a longer time series) are required to confirm this supposition.

Recommendations:

- The monitoring programme should continue in its present form, with one exception. The size of the benthic faunal cores collected from the 'benthic circle' should be reduced to enable cores to be collected remotely, and to become more in line with the sizes of subtidal samples collected in other harbours. This will require adjusting of sample sizes to ensure comparability between years in future reports.
- Analysis of benthic community characteristics must be preceded by checking and amalgamating to ensure that species lists from different sampling occasions are validly comparable. This will enable time-series analyses, which is central to all monitoring programmes. Full data sets with reconciled species lists are also required for benthic health score calculations and comparisons.
- A formal comparison should be undertaken to determine the relationship between the results of sediment particle sizes determined using two methods in 2020: laser particle size analyser and wet sieving. In 2006, 2011 and 2016 sediment particle size was determined using the laser particle size analyser. On future sampling dates wet sieving will be the preferred method. This comparison will enable any limitations of the laser-derived data from early years to be understood, and used in evaluations of sediment size changes over time.
- EB2 has very a different sediment type and benthic faunal community relative to the remaining Wellington Harbour sites. Nevertheless, it remains an important component of the monitoring programme as a representative of the state and health of inner Evans Bay, and should be retained. Consideration should be given to establishing a site further towards the main harbour, or conducting a one-off survey to delineate the location of the muddy/sandy transition in the bay. The latter would be useful for detecting change in the state of Evans Bay in future years.

1 Introduction

Greater Wellington Regional Council (GWRC) commissioned NIWA to conduct a subtidal survey of Wellington Harbour sediments and benthos from Te Whanganui-a-Tara (Wellington Harbour). This survey is required for (i) Wellington Water Ltd consent conditions to monitor the accumulation and impact of stormwater contaminants on sediment quality and harbour invertebrate community health, and for (ii) State of the Environment monitoring undertaken by GWRC.

This survey includes sampling at 15 specified sites in Wellington Harbour in 2020, using collection and processing methods previously employed by Stephenson et al. (2008) for the same monitoring programme in 2006, 2011, and 2016. Details of the sediment contaminant and particle size methodologies and results have been presented in a separate report (Olsen et al. 2021) and are only briefly discussed here.

This report describes the sampling methods used to quantify benthic communities, along with a brief description of methods used for determining particle size and chemical contaminant concentrations of associated sediments. It then provides an evaluation of the status of the Wellington Harbour subtidal benthos and sediment health in 2020, a comparison of results over the four survey periods, and recommendations for future monitoring.

2 Methods

2.1 2020 Sample Collection

Subtidal sediment samples were collected from 15 Wellington Harbour sites (Figure 2-1) by NIWA divers, between 2nd and 26th November 2020 (Table 2-1).

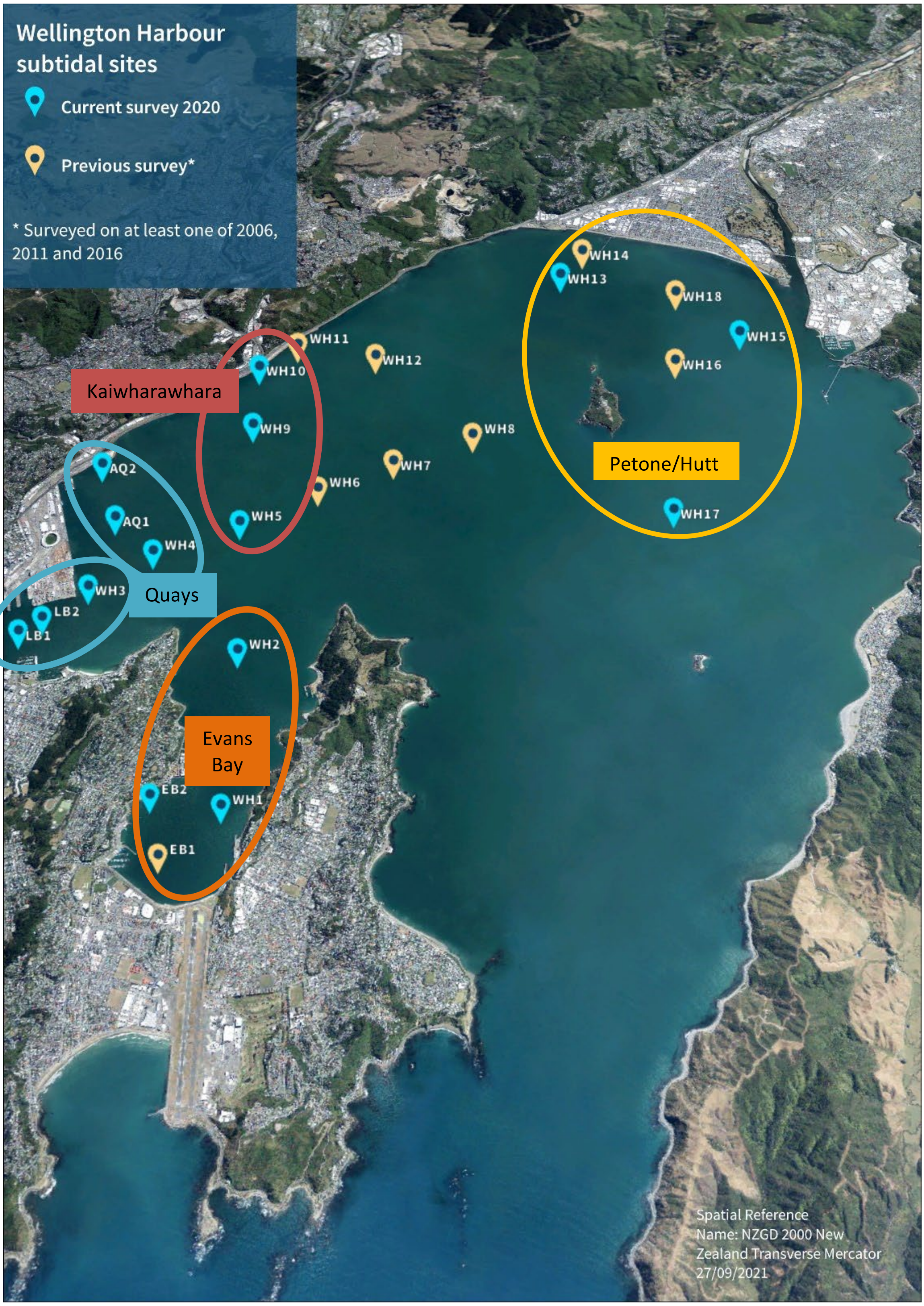

Figure 2-1: Map of Wellington Harbour subtidal sites sampled in 2020 (blue markers). Sites depicted by blue markers were surveyed in 2020 and sites depicted by yellow shading were surveyed in previous years (but were not resurveyed in 2020). The current sites have been grouped by location into Evans Bay (EB2, WH1, WH2), the Quays (southern grouping of LB1, LB2, WH3; northern grouping of WH4, AQ1, AQ2), Kaiwharawhara (WH5, WH9, WH10), and Petone/Hutt (WH13, WH15, WH17).

Table 2-1: Site position and collection details for subtidal benthos and sediments collected from Wellington Harbour in 2020. Co-ordinates are for the centre of the benthic and sediment circles. Benthic circles are indicated with a 'B' in the site name. Modified from Olsen et al. (2021).

Site	Position (NZTM coordinates)		Group	Location	Collection date	Depth[1]
	Easting	Northing				(m)
WH1	1751530	5425348	Evans Bay	South-eastern Evans Bay	6/11/2020	19
WH1B	1751492	5425333				
WH2	1751710	5427288	Evans Bay	Northern Evans Bay	6/11/2020	19
WH2B	1751744	5427271				
WH3	1750056	5428340	Quays, south	Lambton Basin entrance	26/11/2020	18
WH3B	1750055	5428303				
WH4	1750763	5428789	Quays, north	~ 0.7 km NW of Pt Jerningham	24/11/2020	20
WH4B	1750775	5428760				
WH5	1751748	5429138	Kaiwhara-whara	~ 1.2 km NNE of Pt Jerningham	24/11/2020	21
WH5B	1751743	5429104				
WH9	1751921	5430708	Kaiwhara-whara	~ 1.5 km SSE of Ngauranga Stream mouth	25/11/2020	20
WH9B	1751975	5430747				
WH10	1752012	5431724	Kaiwhara-whara	~ 0.5 km SSE of Ngauranga Stream mouth	4/11/2020	20
WH10B	1752008	5431740				
WH13	1756023	5433121	Petone / Hutt	~ 1.25 km S of Petone Wharf	3/11/2020	16
WH13B	1756061	5433126				
WH15	1758160	5431778	Petone / Hutt	~ 1.1 km SW of Seaview (Hutt River mouth)	3/11/2020	16
WH15B	1758176	5431750				
WH17	1756770	5428847	Petone / Hutt	~ 1.6 km NNW of Makaro/Ward Island	23/11/2020	21
WH17B	1756793	5428858				
LB1	1749263	5427887	Quays, south	Lambton Harbour ~ 250 m from shore (Frank Kitts Park)	2/11/2020	10
LB1B	1749262	5427872				
LB2	1749576	5427939	Quays, south	Lambton Harbour ~ 500 m from shore (Frank Kitts Park)	25/11/2020	14
LB2B	1749541	5427940				
AQ1	1750317	5429346	Quays, north	~ 0.5 km ENE of Aotea Quay east	23/11/2020	20
AQ1B	1750331	5429374				
AQ2	1750125	5430214	Quays, north	~ 0.5 km ENE of Aotea Quay west	26/11/2020	16
AQ2B	1750133	5430254				
EB2	1750817.6	5425538.7	Evans Bay	South-western Evans Bay	4/11/2020	7
EB2B	1750817.6	5425538.7				

[1] Approximate water depth at mean low water neap tide

Sampling procedures followed prescribed methodologies previously used for sampling in Wellington Harbour in 2006, 2011 and 2016 (outlined in Williamson et al. 2004 and Stephenson et al. 2008), with the inclusion of an additional method for particle size analysis. The methods used in 2020 have been detailed in Olsen et al. (2021) and are briefly described below.

Each site was located using GPS, and a buoy deployed to mark its position. Sampling was conducted in two distinct areas at each site – a 'benthic' and a 'sediment' circle, each 20 m in diameter. The benthic and sediment circles were located approximately 20 m apart (Figure 2-2). On the seabed, each circular collection area was 'divided' into quadrants on the cardinal points of the compass.

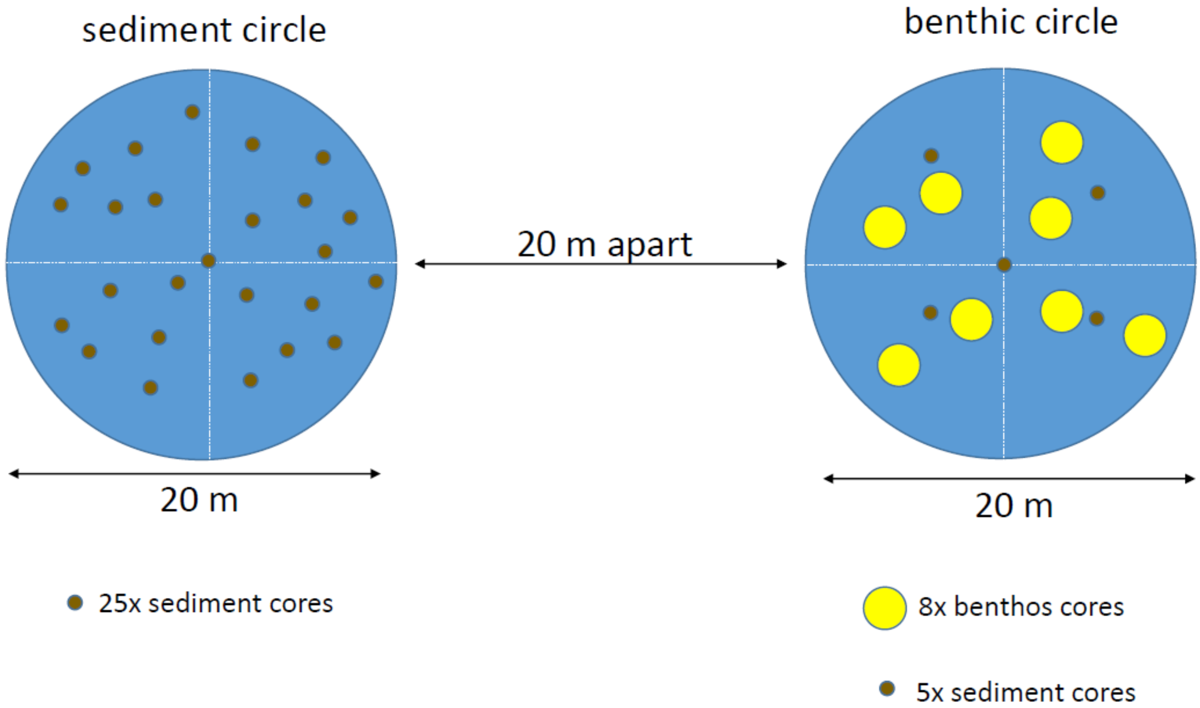

Figure 2-2: Schematic of subtidal sampling methodology followed for collection of benthic faunal and chemistry samples from Wellington Harbour in 2020. Not to scale.

From each quadrant of the **benthic circle**, two 200 mm diameter x 250 mm deep cores were taken for benthic fauna with a total of eight cores per site (Figure 2-2). One sediment core (50 mm diameter x 120 mm deep) was obtained from each quadrant and one from the central part of the benthic circle, for particle size analysis (total of five cores per site). The sediment corers consisted of a screw-top polyethylene bottle, with the bottom cut off and replaced with a plastic insert.

Within each quadrant of the **sediment circle**, five sediment cores were collected at random. An additional core was taken near the centre of the collection area to give a total of 25 samples per site. All sediment cores were kept upright in a custom designed crate and brought to the surface (Figure 2-4 A), where they were then placed in an insulated bin containing ice-packs for transport to the laboratory.

2.2 Sample analysis

2.2.1 Benthic fauna

The benthic fauna cores were transferred into labelled plastic bags for transport to the laboratory, where they were sieved through 500 µm mesh and preserved with 80% ethanol. Samples were later stained with rose bengal, re-sieved and sorted to remove all fauna. To confirm the accuracy of the fauna sorting, one sample from every site was checked by a different staff member to confirm that at least 90% of the fauna had been removed from the sediment. These fauna were then identified using a stereo microscope and enumerated. The accuracy of the counts and identifications were checked in one sample from every site by another staff member.

Voucher specimens of each taxa were retained from all sites to confirm identifications and to ensure consistency in taxonomy between sites. For 13 of the 15 sites, representative individuals of all taxa identified at each site were kept as voucher specimens. For the two remaining sites (WH15 and WH17) only rare taxa that had not been found at the other sites were kept as vouchers. All voucher specimens were given to specialist taxonomists to confirm their identification. Voucher specimens were then set aside for long term preservation in the NIWA National Invertebrate Collection, and a set of photographs taken of each taxon to allow for consistent taxonomic identification in future years.

The sizes of all bivalves were determined either by measuring the bivalve under a microscope against a calibrated mm background, or using vernier callipers (for larger specimens). The size frequency of each taxa was recorded according to the following size classes: 0-2 mm, 2-5 mm, 5-10 mm, 10-20 mm, 20- 40 mm, and >40 mm (longest axis; Figure 2-3). The width of each common heart urchin, *Echinocardium cordatum*, was measured to the nearest 0.5 mm using calipers (Figure 2-3). These data are provided in Appendix A.

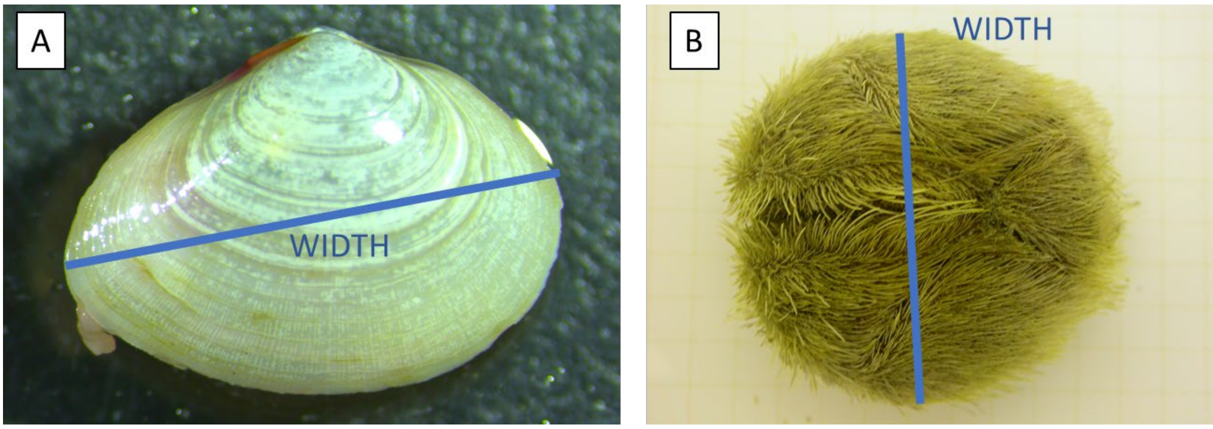

Figure 2-3: The width of bivalves and heart urchins (*Echinocardium cordatum*) were measured as shown by the blue lines in A and B. A. Bivalve *Leptomya retiaria* (photo: Barry Greenfield); B. heart urchin *Echinocardium cordatum* (photo: Drew Lohrer).

2.2.2 Sediment characteristics

Sediment cores were stored upright in a refrigerator at 4°C for a minimum of 12 hours to allow the water content of the surface sediment to reduce. Each sample bottle was then placed on a tray, the top cap removed, and any overlying water carefully siphoned off (Figure 2-4 B). The bottom plug was loosened, and the core extruded until the top 30 mm remained. The core was cut at this level and the top 30 mm of the sediment was collected. The sediment circle samples from each site were randomly divided into five sets of five cores. These groups became the five replicate composite samples for that site and the composite samples were frozen. The benthic circle samples were similarly frozen in a polyethylene bag.

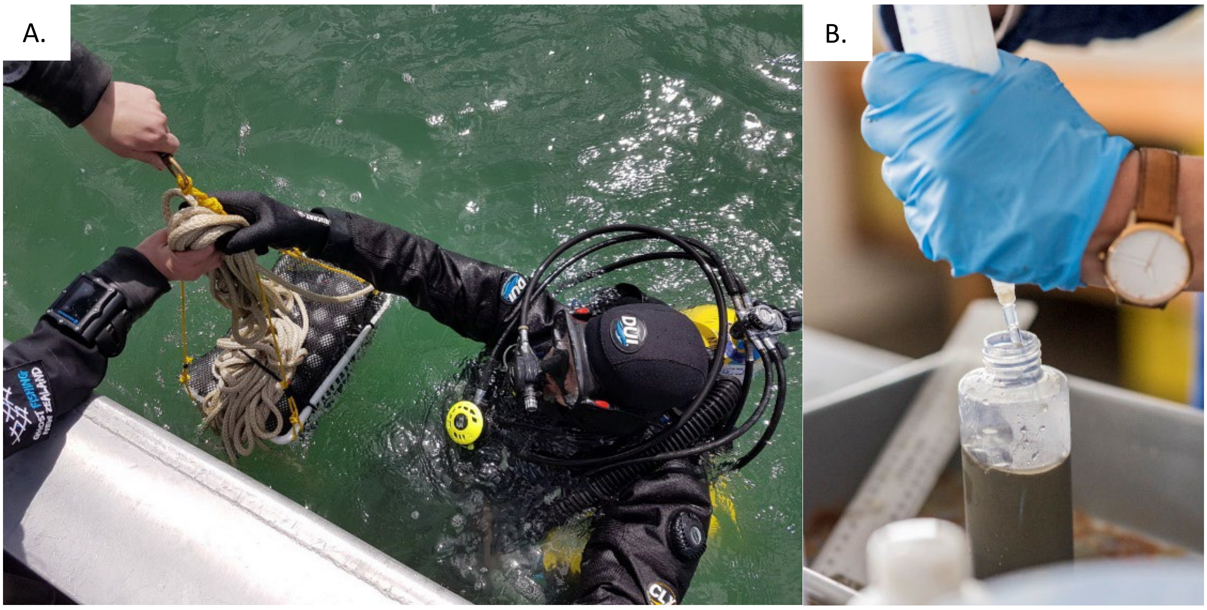

Figure 2-4: Examples of sediment cores collected from Wellington Harbour. A. Crate of sediment cores being transported to the boat by diver after collection (photo: Peter Marriott, NIWA); B. Seawater being carefully syringed off the core surface prior to extrusion and sectioning (photo: Dave Allen, NIWA). Only the top 30 mm of sediment was collected for sediment chemistry and particle size analyses.

Frozen sediments from all 15 sites (Table 2-1) were sent via frozen courier from NIWA Wellington on 16th December 2020 and arrived at NIWA Hamilton's laboratories the next day. Prior to their analysis, frozen sediments were thawed at room temperature, thoroughly homogenised, and subsampled. A sub-sample of the homogenised sediment (ca. 10-20 g) was removed and frozen in a clean plastic Elkay container for analyses of particle size distribution by wet sieving and for determination of organic matter content. The remainder of the whole wet sample was frozen, freeze-dried (-10°C) and sieved through a 500 µm sieve to remove any large particles (e.g. shell) before analysis. This sieving step reduces variability associated with the presence of large debris, which can be significant in samples from some sites, while retaining sufficient original sample to allow analysis of contaminants.

The sediment circle samples were analysed for particle size, total recoverable metals, total organic carbon (TOC), polyaromatic hydrocarbon (PAH) content, sediment particle size and organic matter content. The benthic circle samples were analysed for particle size and organic matter content only. Details of these analyses are provided in Olsen et al. (2021) and are only briefly described below. All chemical analyses were conducted by Hills Laboratories.

Particle size analysis

In 2020 particle size analysis was conducted using two methods: wet sieving and a laser particle size analyser. In 2006, 2011 and 2016 sediment particle size was determined using an Ambivalue Eyetech Combi Particle Size Analyser with a B-lens. A move to wet sieving was recommended by Hewitt et al. (2019) to avoid inconsistencies between brands and models of laser particle size analysers. Use of both techniques in 2020 was to enable a comparison of results to be made and a conversion factor to be developed for each site. Understanding the limitations of the laser-derived data, which encompasses a more limited particle size fraction (i.e. 10-500 µm, compared to 0-2000 µm for wet sieving) will be important to evaluate sediment size changes over time.

Laser particle analyser

The freeze-dried <500 µm sieved sediments were analysed using an Ambivalue Eyetech Combi Particle Size Analyser. Samples were analysed in the 10-500 µm (B-lens) particle size range only. Sediment samples were dispersed by ultrasound for four minutes before particle size analysis. Typically, 10^5–10^6 particles are counted per sample. Particle volumes were calculated using the measured particle diameters, from which a particle-size volume distribution for each sample was obtained.

Wet sieving

Sediments (ca. 10-20 g) were treated with ca. 9% hydrogen peroxide solution to digest any organic matter, with small volumes of hydrogen peroxide added to the samples successively until all bubbling ceased. The sediments were wet sieved through 2000 µm, 500 µm, 250 µm, 125 µm and 63 µm mesh sieves. Pipette analysis was used to further separate the <63 µm fraction into >3.9 µm and <3.9 µm fractions. All fractions were then dried at 60°C to constant weight. The results are presented as percentage weight (mass) of gravel/shell hash (>2000 µm), coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (125 – 250 µm), very fine sand (63 – 125 µm), silt (3.9 – 63 µm) and clay (<3.9 µm). Mud content is calculated as the sum of the silt and clay (total mass <63 µm fraction).

Organic matter content

Organic matter content was measured concurrently with particle size. A 5 g subsample of homogenised frozen sediment was placed in a dry, pre-weighed tray and the sample dried to constant weight in a drying oven (60°C). The mass loss represents the moisture content of the sample. The dried sample was then combusted for 5.5 h at 400°C and reweighed. The difference in mass before and after combustion represents the portion of organic matter in the sample and is reported as % organic content.

Total Metals

The three replicates of the homogenised, freeze-dried <500 µm sieved sediment from each chemistry site were digested in acid and analysed for total recoverable metals by inductively coupled plasma mass spectrometry (ICP-MS). Individual metal results were obtained for lead (Pb), copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), arsenic (As), nickel (Ni) and mercury (Hg).

Heavy metals were analysed principally for comparing with sediment quality guidelines reported in Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018a) or for trend assessments (ARC 2003). The ANZG guidelines are described using the Default Guideline Value (DGV) and Guideline Value-High (GV-high) thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively.

Total organic carbon (TOC)

Total organic carbon (TOC) content is a direct measure of the carbon content in the sediments. TOC was determined after acid pre-treatment of the freeze-dried sediments to remove carbonates by Catalytic Combustion (900°C, O_2), separation and detection via Thermal Conductivity Detector using an Elementar Analyser.

Frozen sediments from all fifteen sites (Table 2-1) were sent via frozen courier from NIWA Wellington on 16th December 2020 and arrived at NIWA Hamilton's laboratories the next day. Each sediment sample was frozen, freeze-dried (-10°C) and sieved through a 500 µm sieve to remove any large particles (e.g. shell) before analysis.

Polycyclic aromatic hydrocarbons (PAHs)

Sub-samples of each replicate (freeze-dried <500 µm) from each site were analysed for 16 United States Environmental Protection Agency (USEPA) Priority PAHs and 1-methylnaphthalene, 2-methylnaphthalene and perylene. All samples were extracted with organic solvents and prepared prior to analyses by capillary gas chromatography with mass selective detector operated in selected ion mode (GC/MS-SIM).

PAH data has been summarised as 'Total PAH' (sum of all sixteen USEPA priority PAH compounds), and as 'Total High Molecular Weight' (HMW) PAH, which is the sum of the concentrations of the six PAHs containing four or more rings (namely chrysene, fluoranthene, pyrene, benzo[a]anthracene, benzo[a]pyrene and dibenzo[a,h]anthracene). This is the total used for the ANZG (2018a) sediment quality guidelines.

In addition, PAH totals were normalised to 1% TOC by dividing the Total PAH or Total HMW PAH by the % TOC (for values between 0.2 and 10.0%). This enabled comparison of sediments with different TOC content as per recommendations of the ANZG (2018a) sediment quality guidelines and ARC (2003) ERC.

Evaluating sediment quality

Sediment quality status was assessed using both the ANZG 2018 (formerly known as ANZECC 2000 and incorporating updates from Simpson et al. 2013) and the Auckland Regional Council (ARC) Environmental Response Criteria (ERC) (ARC 2004) sediment quality guidelines.

The metal concentration guidelines used in this report are generally considered to be reasonably robust, and conservative (i.e., they err on the side of environmental protection). They are not 'pass or fail' numbers, and the developers of the guidelines emphasise that they are best used as one part of a 'weight of evidence' approach to evaluating potential effects of contaminants on benthic biota.

The ANZG (2018) sediment quality guidelines values are listed as 'default' and 'high' guideline values (DGV and GV-high, respectively) on the published ANZG webpage[2]:

- The default guideline values (DGV) (formerly ANZECC ISQG-Low, TEL[3] and ERL[2]) are nominally indicative of the contaminant concentrations where the onset of biological effects could possibly occur. These values provide an 'early warning', enabling management intervention to prevent or minimise adverse environmental effects.
- The guideline value-high (GV-high) (formerly ANZECC ISQG-High, PEL[4] and ERM[3]) are nominally indicative of the contaminant concentrations where significant biological effects are expected. Exceedance of these values – in particular the GV-high values –

[2] http://www.waterquality.gov.au/anz-guidelines
[3] TEL is the Threshold Effects Level (MacDonald et al. 1996) and ERL is the Effects Range Low (Long & Morgan 1990 and Long et al. 1995).
[4] PEL is the Probable Effects Level (MacDonald et al. 1996) and ERM is the Effects Range Medium (Long & Morgan 1990 and Long et al. 1995).

suggests adverse environmental effects are probably already occurring, and management intervention may be required to remediate the problem.

- The former Auckland Regional Council (now Auckland Council) introduced 'Environmental Response Criteria' (ERC) in 2004. These are derived from the Threshold Effect Levels (TEL) and Effects Range Low (ERL) values (with rounding) of MacDonald et al. (1994), Long and Morgan (1990), and (Kelly 2007). These guidelines provide a conservative, yet practical early warning of environmental degradation which allows time for investigations into the causes of contamination to be carried out and the options for limiting the extent of degradation to be developed (Kelly 2007, ARC 2004).

The use of sediment quality guidelines is a 'first-step' approach to assessing the potential impacts of contaminated sediments on benthic ecology. Whilst ANZG (2018) promotes site specific guideline derivation, in the absence of this (as is often the case) default guideline values are applied. Thus, default guidelines provide for indicative, rather than absolute, evidence for adverse effects; exceedances should ideally be assessed via a 'weight of evidence' framework (ANZG 2018) that takes into account multiple lines of evidence (i.e., pressure-stressor-ecosystem receptor causal pathway assessment). This approach is required to determine with greater certainty whether adverse ecological effects are actually occurring at the affected site(s). Investigations could include ecological evaluations, toxicity testing, source identification, prediction of future sediment quality, and an evaluation of management options.

2.3 Statistical analyses

2.3.1 Benthic ecology

Spatial and temporal variation in benthic communities was examined using biodiversity indices, a benthic health assessment, and multivariate analyses of benthic invertebrate community composition. Analyses were carried out in PRIMER-E v7.0.12, and are described below.

The 2020 benthic invertebrate data set was merged with data from the three previous sampling years (i.e. 2006, 2011 and 2016). Modifications were made to the taxa list to ensure that the same level of taxonomic resolution was being compared over time. This was necessary due to the different approaches/expertise from the three different teams that had conducted the identifications since the monitoring programme was initiated in 2006, and involved merging several species to higher taxonomic levels (e.g. amphipods), as detailed in Appendix B. All of the univariate and multivariate analyses were conducted on the combined data set.

The Traits Based Index (TBI) benthic health assessment for 2020 was conducted using both the combined and the original (unmodified) data sets, to investigate whether this made a significant difference to the indices generated. The Benthic Health Model (BHM) assessment was conducted using the original (unmodified) data set only.

2.3.2 Benthic community analyses

2020 status

Univariate measures of macroinvertebrate communities calculated for each site were: number of taxa, total abundance, species richness (Margalef's), taxonomic evenness (Pielou's) and taxa diversity (Shannon Weiner Index).

Non-metric multi-dimensional scaling [nMDS procedure (Clarke et al. 2014)] and average linkage cluster analysis were used to identify spatial patterns, based on the Bray-Curtis similarities of untransformed and square root transformed[5] count data. Spatial differences between sites were analysed using analysis of similarities (ANOSIM). The individual taxa contributing to the differences in invertebrate communities between sites were identified using the similarity percentages procedure, SIMPER (Clarke et al. 2014).

Environmental drivers of these patterns were determined by using the sediment particle size and chemical characteristics as explanatory variables in a DISTLM procedure (Anderson et al. 2008). This procedure extracts variation in community composition that relates linearly to normalised explanatory variables; for consistency with the most recent previous report on 2016 data (Hewitt 2019) we used forward selection with Akaike's Information stopping Criterion (AIC), and untransformed community composition data. Variables included in this procedure were sediment characteristics (% gravel, coarse, medium, fine and very fine sand, silt and clay, % mud and % organic content; see also Table 2-1 below) and chemical contaminants (metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc; PAH and high molecular weight PAH) along with total organic content; see also Table 3-2). Similar to previous reports, the highly correlated variables copper, lead and zinc, were replaced by the first axis of a PCA ordination which represented 91% of the variability.

[5] These two data treatments provide complementary information by emphasizing the importance of dominant and rare species, respectively.

Communities over time

Changes in numbers of taxa and individuals, and selected taxa at each site, were examined graphically across the four years of the sampling programme. Community compositional variation across sampling years was examined using nMDS, which was based on the Bray-Curtis similarity of square root transformed abundance data. Spatial and temporal patterns were assessed over time using PERMANOVA (Anderson et al. 2008).

2.3.3 Benthic Health

The health status of the benthic communities in 2020 was assessed using the NIWA Traits-Based Index (Hewitt et al. 2012; Rodil et al. 2013) and the national Benthic Health Model (Clark et al. 2020).

Traits Based Index (TBI). Organisms can be categorised according to biological characteristics (traits) that are likely to reflect ecosystem function. An index based on the sensitivities of different trait groups to stressors (mud and heavy metals) was developed from the richness of taxa in seven broad trait categories (living position, influence on sediment topography and direction of sediment particle movement, degree of mobility, feeding behaviour, body size, body shape and body hardness) (Hewitt et al. 2012; Rodil et al. 2013).

Values of this index range from 0-1. In the Auckland region where the index was developed, TBI scores <0.3 indicate low levels of functional redundancy and highly degraded sites, scores of 0.3-0.4 indicate intermediate conditions, and scores >0.4 indicate high levels of functional redundancy where the communities likely have some inherent resilience to environmental change (Rodil et al. 2013). A means of standardising TBI scores from sites sampled in different ways (e.g. different core sizes, differing numbers of replicates) has been developed (Rodil et al. 2013; D. Lohrer, pers. comm.). Here, we adjusted the calculations to account for the use of eight replicate 20 cm internal diameter cores (which is roughly equivalent to nineteen replicate 13 cm internal diameter cores; ~18.8 replicate equivalents).

Although the TBI was developed from intertidal estuarine data in the Auckland Region, it has subsequently been shown to be a sensitive index in estuaries across New Zealand (Berthelsen et al. 2018). As the TBI is based on biological traits, it is slightly more flexible than indices based on specific taxa lists. This is because while species may differ across sites or regions, functional traits usually do not, allowing for equitable comparisons of index values across sites or regions. Whilst the TBI has not been explicitly validated in the subtidal realm yet, TBI scores can be calculated from subtidal macroinvertebrate community data sets. Here we use it as an indication of the relative health status of the different sites sampled in Wellington Harbour.

Benthic Health Model (BHM). Benthic health models have been developed to track the health of New Zealand estuarine benthic communities in response to two key coastal stressors: sedimentation and heavy metal contamination (Clark et al. 2020). BHMs provide a score between 1 (least impacted) and 6 (most impacted) that indicates the health of a site relative to other estuarine sites across New Zealand. These scores can be simplified into five-category health score system with equally spaced boundaries between groups, from Group 1 (least impacted) to Group 5 (most impacted). This enables the relative health of sites to be evaluated both in space and through time. One model is based on benthic community response to sediment mud content (Mud BHM) and the other is based on response to sediment-associated copper, lead and zinc concentrations (Metals BHM). The health scores assigned for each model type were derived from the modelled relationship between macrofaunal community structure and the environmental gradient (i.e. mud and metals), which are based on Canonical analysis of principal coordinates (CAP; see Clark et al. 2020). The model CAP scores were simplified into a five-category health score system by splitting the CAP score gradient into five evenly spaced groups. For the Mud BHM health scores, the taxa characterising Group 1 prefer sandy sediments, and many of the taxa characterising Group 5 prefer mud. For the Metals BHM health scores, many of the taxa characterising Group 1 have been found to be sensitive to metals, while taxa more tolerant of metals only begin to characterise benthic community structure in Group 3 and higher (Clark et al. 2020).

Intertidal vs subtidal. As noted above, both the TBI and BHM were developed for intertidal species and have not yet been validated for subtidal communities (although this is in progress for both the TBI and BHM, with preliminary results anticipated in June 2020; Drew Lohrer pers. comm.).

For TBI calculations, any species found in the Porirua Harbour 2020 subtidal samples that was not already listed in the NIWA Functional Traits database was assigned characteristics of the most similar intertidal species. This allowed us to use all identified taxa in the TBI calculations. Separate calculations were made using the full 2020 data set and the condensed data set.

For the BHM analyses, only the full 2020 benthic community data set was analysed. However, two sets of scores were calculated: firstly with all subtidal species included and allocated to the same group as the most similar intertidal species on the list (‘subtidal species included’), and secondly after omitting subtidal species from the data set (‘subtidal species excluded’).

2.4 Sediment characteristics

Sediment characteristics at each site are described for 2020, and over time for the four sampling dates. Changes in sediment characteristics (total metals, PAH, TOC, and 10-63 µm sediment particles determined via laser analyser) over time were examined using Spearman rho correlation analysis, conducted in SAS (PROC CORR; SAS 9.4). EB2 was not included in these analyses as this site was only introduced into the monitoring programme in 2016.

The potential for overall changes in sediment characteristics was also assessed by comparing the pattern of dissimilarity (Euclidian dissimilarity matrices) between the sites in 2006 and 2020, and 2011 and 2020 (as some sites were only introduced into the monitoring programme in 2011) using the RELATE procedure (Clarke et al. 2014) in Primer-E (Clarke and Gorley, 2015).

3 Results and discussion

3.1 Sediment characteristics in 2020

3.1.1 Sediment particle size and organic matter content

At all biology sites except EB2, sediments were dominated by mud (particles <63 µm), with sediment mud content ranging between 69-96%. The mud at these 14 sites was comprised of 53-79% silt and 14-28 % clay (Table 3-1A). EB2 sediments were well mixed, containing <20% mud, and very similar fractions of the other particle size classes. Organic matter content ranged from 3.6-8.1%, and was lowest at EB2, WH5 and WH9 (Table 3-1A).

Table 3-1: Summary of particle size distributions from all the A. benthic (identified with 'B' suffix, N=1) and B. sediment chemistry (no suffix, N = 5) sampling circles at each Wellington Harbour site in 2020. Particle sizes were determined using wet sieving.

GWRC Site	Grain size distribution (µm)							Organic Matter	Mud content
	clay	silt	v. fine sand	fine sand	med sand	coarse sand	gravel	%	%
	<3.9	3.9-63	63-125	125-250	250-500	500-2000	>2000	%	%
A. Benthic circle									
WH1B	25.18	59.60	12.75	2.15	0.21	0.11	0.00	7.64	84.8
WH2B	15.15	79.20	4.71	0.76	0.14	0.03	0.00	7.05	94.4
WH3B	24.16	64.43	8.85	1.34	0.22	0.14	0.85	7.86	88.6
WH4B	19.09	68.18	9.64	2.45	0.25	0.37	0.02	7.46	87.3
WH5B	24.95	69.59	4.40	0.65	0.26	0.14	0.01	3.56	94.5
WH9B	23.85	72.20	2.52	1.13	0.15	0.15	0.00	3.94	96.0
WH10B	23.14	72.30	3.26	1.08	0.11	0.11	0.00	8.06	95.4
WH13B	25.92	66.91	5.55	1.33	0.10	0.19	0.00	7.95	92.8
WH15B	28.16	64.57	6.02	0.90	0.17	0.17	0.02	7.75	92.7
WH17B	17.23	68.42	13.44	0.76	0.08	0.07	0.00	6.73	85.7
EB2B	6.34	10.67	19.84	22.94	10.38	11.06	18.77	3.74	17.0
AQ1B	17.79	67.59	10.66	3.04	0.64	0.29	0.00	6.84	85.4
AQ2B	18.40	56.10	12.58	8.96	2.11	0.99	0.86	3.78	74.5
LB1B	16.28	52.80	14.05	11.40	3.30	1.82	0.36	6.30	69.1
LB2B	14.43	56.35	13.71	11.64	2.63	1.22	0.02	6.69	70.8
B. Sediment chemistry circle									
WH1	16.54	70.95	10.47	1.88	0.10	0.05	0.00	5.23	87.49
WH2	16.04	74.61	7.10	1.27	0.24	0.46	0.28	7.13	90.65
WH3	17.95	72.43	7.41	2.01	0.12	0.08	0.00	4.57	90.38
WH4	15.26	74.74	7.89	1.50	0.19	0.23	0.19	7.41	90.00
WH5	19.34	74.51	4.66	1.13	0.16	0.11	0.09	3.82	93.85
WH9	20.91	73.62	4.37	0.84	0.09	0.07	0.09	4.28	94.53
WH10	21.22	73.43	4.30	0.88	0.09	0.07	0.00	4.60	94.65
WH13	24.26	68.27	5.19	2.08	0.11	0.08	0.01	7.95	92.53
WH15	24.90	66.02	7.85	1.05	0.11	0.09	0.00	7.94	90.91
WH17	19.42	61.56	16.51	2.14	0.20	0.14	0.03	5.03	80.98
EB2	6.92	11.32	20.74	23.47	10.44	9.79	17.30	2.89	18.25
AQ1	17.36	68.35	10.42	3.04	0.34	0.32	0.18	7.11	85.71
AQ2	19.75	46.32	13.40	12.02	4.38	3.02	1.10	3.68	66.07
LB1	18.06	54.67	14.02	9.41	2.08	1.19	0.57	5.52	72.73
LB2	19.28	51.25	13.20	12.11	2.89	0.96	0.30	3.75	70.53

3.1.2 Sediment contaminants

No sites exceeded any of the guidelines for arsenic, cadmium, chromium, nickel or total PAH (Table 3-2). WH15 and WH17 did not exceed guidelines for any of the chemicals measured.

Lead is still pervasive within the sediments, exceeding ARC amber or red guidelines at all sites except WH13 and WH15 (Table 3-2), despite it being removed from the gasoline used in cars ~25 years ago. Roadside soils still retain traces of lead (derived from fuels) and are likely still contributing to on-going lead contamination. Other sources of lead may include lead-based paints, wheel balance weights, plumbing materials, solders and old batteries.

Mercury concentrations exceed DGV guidelines at the same 13 sites as lead (Table 3-2). It is not clear if mercury originates solely from anthropogenic inputs (e.g., historical uses of herbicides, fungicides and antifouling agents) or from natural contributions.

Zinc, typically derived from galvanised roof run-off and to a lesser extent, tyre wear on vehicles, is only found at elevated levels at those sites where all metals levels are typically elevated; ARC amber guidelines for zinc are exceeded at WH1 and WH3, and ARC red guidelines at the two Lambton Basin sites (Table 3-2). Similarly, copper exceeds ARC guideline concentrations at the same four sites, although those at the two Aotea Quay sites are only just below the ARC amber threshold (Table 3-2). WH3, LB1 and LB2, and AQ1 and AQ2 are all sites closest to the central city port and marina. Copper is derived mainly from vehicle brake linings and also from treated timber, and could potentially enter the harbour through run off.

HMW PAH guidelines were exceeded at sites in the southern end of the harbour only. At EB2, WH1 and WH2 (Evans Bay) and at WH4, EB2, AQ1 and AQ2 (northern Quays), ARC amber guidelines were exceeded. The southern Quays sites also exceeded ARC guidelines for HMW PAH - ARC amber at WH3 and ARC red at the two Lambton Basin sites (LB1 and LB2) (Table 3-2). PAHs are generated by incomplete carbon combustion and during industrial processes. PAHs in sediments are mainly derived from vehicle exhausts and from smoke from fires/cigarettes. Road run-off is recognised as the most significant contribution to PAH levels in surficial sediments, resulting in highest concentrations closer to shore. In areas around ports, PAHs may also be derived from petroleum products, which typically show higher concentrations of low molecular weight PAHs such as naphthalene and fluorene, etc. Evans Bay's Burnham Wharf has previously been identified as a historical source of high molecular weight PAHs, which are considered to be derived from coal tar, a by-product of gas works (Ahrens & Olsen 2008).

In terms of harbour location, LB1, LB2, WH3 (the southern Quay sites) and WH1 (eastern Evans Bay) exceeded guidelines for four metals and HMW PAH. The northern Quay sites (AQ1, AQ2 and WH4) along with EB2 and WH2 in Evans Bay, each exceeded guidelines for two metals and HMW PAH.

Table 3-2: Chemical contaminant guidelines and their exceedances in subtidal sediments at Wellington Harbour sites in 2020. The first four lines of the Table give guideline types and the highlight colour used to show when they are exceeded. Values are site averages. Metal concentrations are given as mg/kg dry weight. PAHs are normalised to 1%TOC and reported as µg/kg dry weight. The DGV (Default Guideline Value) reflects the potential for possible ecological effects to occur; the GV-high (Guideline Value-High) reflects the potential for probable ecological effects to occur. Please see Methods for a full explanation of the guidelines.

Guidelines	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Total PAH	HMW PAH	No. of Exceedances
ARC amber				19	30			124		660	
ARC red				34	50			150		1700	
DGV	20	1.5	80	65	50	0.15	21	200	10000		
DGV-High	70	10	370	270	220	1	52	410	50000		
Site											
WH1B	5.7	0.1	25.8	22.8	69.8	0.70	16.2	129.0	2481.4	1461.0	5
WH2B	5.5	0.0	24.2	15.9	49.2	0.51	15.9	105.4	1392.8	822.8	3
WH3B	6.7	0.1	26.2	27.4	64.6	0.60	16.8	129.2	2101.1	1247.7	5
WH4B	6.1	0.0	24.8	17.1	46.4	0.40	16.6	107.4	1325.0	774.1	3
WH5B	6.1	0.0	23.8	13.0	35.6	0.26	16.6	93.6	682.7	387.9	2
WH9B	6.4	0.0	24.6	13.8	37.6	0.23	17.3	100.4	536.2	294.2	2
WH10B	6.9	0.0	26.0	17.2	48.0	0.32	17.9	115.0	847.1	473.2	2
WH13B	7.4	0.1	23.2	15.7	39.2	0.18	17.0	104.4	359.6	195.5	2
WH15B	7.4	0.1	19.4	14.4	29.4	0.14	15.7	90.8	196.6	102.5	0
WH17B	5.7	0.0	20.8	10.7	28.2	0.13	16.1	83.0	344.8	183.2	0
EB2B	3.4	0.0	14.1	9.1	38.2	0.45	7.1	68.8	2673.1	1574.0	3
AQ1B	6.2	0.0	23.6	18.8	48.4	0.43	16.2	109.2	1811.9	1059.8	3
AQ2B	6.0	0.1	21.8	18.3	52.2	0.39	14.7	105.6	2061.5	1182.9	3
LB1B	6.3	0.0	23.6	45.8	70.0	0.65	14.7	132.8	3123.1	1821.0	5
LB2B	6.9	0.1	23.4	34.2	67.0	0.64	14.7	126.4	3041.0	1798.2	5

3.2 Benthic ecology in 2020

3.2.1 Biodiversity

Average number of taxa and number of individuals recorded at each site in 2020 are shown in Figure 3-5 and Table 3-4**.** One site in Evans Bay, EB2, recorded substantially higher species diversity and numbers of individuals than any of the other sites, with an average of 38 taxa and 315 individuals per core. The remaining sites had from 14 to 22 taxa, and from 40 to 124 individuals per core, with these minimum numbers of taxa and individuals were recorded at WH15, and the maximum numbers at AQ2.

Taxa richness (the number of species at the site) and species evenness (relative abundance of the different species) were highest (6.42) and lowest (0.67), respectively, at EB2 (Table 3-4). At the other sites, taxa richness ranged from 3.61-4.91 and evenness from 0.77-0.89 (Table 3-4). Shannon-Weiner diversity (an index reflective of richness and evenness) was very similar across all sites, ranging from 2.33 to 2.71 (Table 3-4). There are no clear patterns in these diversity indices dependent on location of sites in the harbour (Table 3-4).

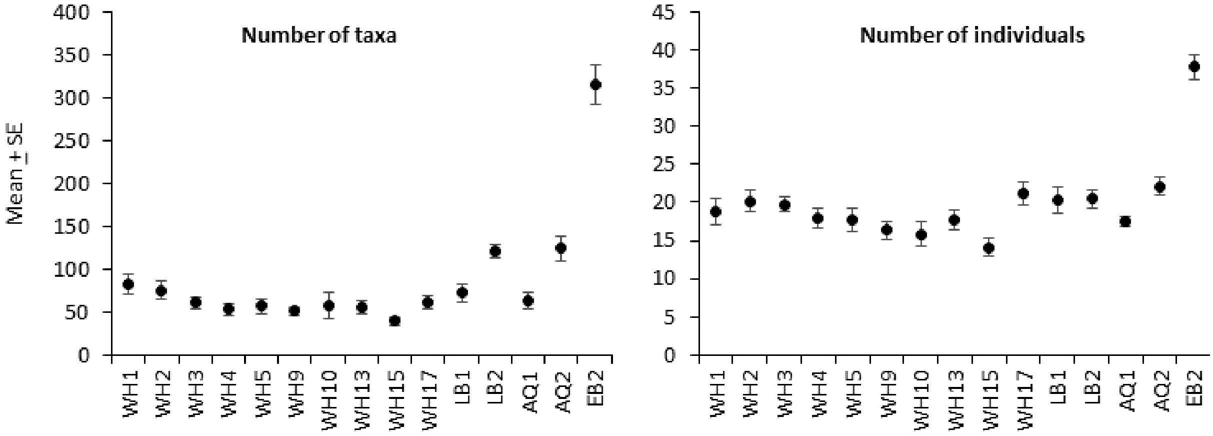

Figure 3-1: Total number of taxa and individuals found at each site in 2020. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

Table 3-3: Average diversity indices for each site in 2020.

Site	Number of individuals	Number of species	Taxa richness (Margalef)	Evenness	Shannon diversity
WH1B	83.13	18.75	4.05	0.83	2.41
WH2B	75.50	20.13	4.47	0.82	2.44
WH3B	61.38	19.75	4.59	0.88	2.61
WH4B	53.25	17.88	4.26	0.87	2.50
WH5B	57.38	17.63	4.13	0.88	2.51
WH9B	51.13	16.38	3.95	0.89	2.48
WH10B	58.25	15.88	3.79	0.87	2.37
WH13B	55.75	17.63	4.15	0.88	2.52
WH15B	39.50	14.13	3.61	0.89	2.33
WH17B	61.38	21.13	4.91	0.89	2.71
EB2B	315.38	37.75	6.42	0.67	2.42
AQ1B	63.88	17.50	4.04	0.84	2.40
AQ2B	124.13	22.13	4.43	0.80	2.48
LB1B	72.63	20.25	4.52	0.88	2.62
LB2B	121.38	20.50	4.08	0.77	2.33

3.2.2 Community composition and sediment characteristics

Here we discuss invertebrate community composition and sediment characteristics site-by-site, in order of their location grouping in the harbour (Figure 2-1). We then present the results of the formal community analysis (nMDS).

Evans Bay

Evans Bay site 2, located in south-west Evans Bay, offshore of Hataitai Beach (Figure 2-1), was unusual amongst the Wellington Harbour sites in both community diversity and habitat type. It is also the shallowest site at 7 m deep (Table 2-1). Sediments here were comparatively coarse, comprising of ~20% gravel sized particles and <20% mud (Table 3-1). Reasons for the strong difference between this area of Evans Bay (EB2, and EB1 from previous years' monitoring; Figure 2-1) and the remaining Wellington Harbour monitoring sites may include their distance from the Hutt River limiting transport of silt to this area (O'Callaghan et al. 2018), the shallowness of the sites making the area more prone to wind driven resuspension of fine sediments (currents in Evans Bay are predominantly wind rather than tidally driven; Abraham 1997), or historical sedimentation patterns in Evans Bay prior to the uplift of the Rongotai isthmus. Many taxa found at EB2 were not present at any of the other sites (i.e. 30 taxa, including nine mollusca and 13 polychaeta; Appendix C), likely reflecting the coarse and heterogeneous nature of the EB2 substrate. The dominant taxa were polychaetes, the spionid *Carazziella phillipensis* and the capitellid *Barantolla lepte* (average of 101 and 72 ind core^{-1}, respectively). The amphipod *Torridoharpinia hurleyi* was also very common (29 ind. core^{-1}).

WH1 is located on the opposite (eastern) side of Evans Bay to EB2 (Figure 2-1) and has very muddy sediments (~85%) with high organic matter content (~8%) (Table 3-1). The benthic community is dominated by the small bivalve *Theora lubrica* (average of 20 ind. core^{-1}), a non-indigenous surface deposit feeding bivalve known to be common in muddy and organically enriched environments (Lohrer et al. 2013, and references therein). The amphipod *Torridoharpinia hurleyi* was also common (11 ind. core^{-1}). *Torridoharpinia* are Phoxocephalidae amphipods, which are considered indifferent to mud and are sensitive to disturbance (Norkko et al. 2001, Ellis et al. 2017). The phyllodocid polychaete *Labiosthenolepis laevis* (5 ind. core^{-1}), the cirratulid polychaete *Aphelochaeta* spp. (4 ind. core^{-1}) and the cossurid polychaete *Cossura consimilis* (2 ind. core^{-1}) were also found at this site. While *Cossura* is known to be mud/enrichment tolerant, we have no information on the resilience of the other polychaetes to these conditions.

WH2 is at the entrance to Evans Bay (Figure 2-1) and has organically rich sediments that are comprised almost totally of mud (7% organic matter content; ~95% mud; Table 3-1). *Torridoharpinia hurleyi* was the most common taxa found here (21 ind. core^{-1}) and *Theora lubrica* was also found in reasonable numbers (9 ind. core^{-1}). Small mobile crustaceans Cumacea spp. (7 ind. core^{-1}) and Ostracoda (4 ind. core^{-1}) and, as at WH1, *Labiosthenolepis laevis,* were all common *(*4 ind. core^{-1}). The nut shell *Linucula* sp., a small bivalve apparently sensitive to mud, was also common (3 ind. core^{-1}).

Quays, south

LB1 is located in Lambton Harbour, in the vicinity of Frank Kitts Park (Figure 2-1). The sediments here are ~70% mud and 24% fine sand and contain 6.3% organic material (Table 3-1). This site is the second least muddy of all of the harbour sites in this monitoring programme (after EB2), though 70% mud content is considered to be a highly muddy sediment. LB1 was also the shallowest site after EB2, at 10 m deep (Table 2-1). This site and EB2 may be less muddy due to the increasing penetration of wave energy to the seabed as depth decreases. The benthic community at LB1 was dominated by the small bivalve *Arthritica* spp. (8 ind. core^{-1}) and several polychaete species (*Cossura consimilis, Labiosthenolepis laevis,* Nephtyidae polychaete *Aglaophamus verrilli*, *Aphelochaeta* spp.; 7-4 inds. core^{-1}). Of these polychaetes, *Cossura* is considered mud/enrichment tolerant, but the sensitivities of the others are unknown. *Arthritica* spp. is common in intertidal areas, where it is considered to be mud/enrichment tolerant (Robertson et al. 2016). The small crustaceans Ostracoda spp. (7 ind. core^{-1}) and Cumacea spp. (4 ind. core^{-1}) were also common, as were two small bivalves, *Ennucula strangei* (a nutshell in the same family as *Linucula* sp. 1) and *Theora lubrica* (both 3 ind. core^{-1}).

LB2, the second Lambton Harbour site, is further north and offshore from LB1 and slightly deeper (14 m) (Figure 2-1) but has very similar mud and organic content (71% mud, 6.7% organic matter; Table 3-1). The benthic community composition indicates a more disturbed environment, however as *Theora lubrica* and ostracods are the most common taxon (each 29 ind. core^{-1}). Cumacea spp. were very abundant (12 ind. core^{-1}), as were *Torridoharpinia hurleyi* (8.5 ind. core^{-1}), and polychaetes (*Labiosthenolepis laevis* 6 ind. core^{-1}; *Aglaophamus verrilli* 4 ind. core^{-1}; Lumbrineridae spp. 3 ind. core^{-1}).

WH3 is located at the entrance to Lambton Basin (Figure 2-1) and is a very muddy and organically enriched site (89% mud, 7.9% organic matter content; 18 m deep). Similar to LB2, crustaceans were common here (Cumacea spp., 10 ind. core^{-1}, Ostracoda spp. 5 ind. core^{-1}) as were *Theora lubrica* and *Torridoharpinia hurleyi* (each 7 ind. core^{-1}). Polychaetes that were common at LB1 and LB2 also feature at WH2 (*Cossura consimilis*, Lumbrineridae spp., *Aglaophamus verrilli*, *Labiosthenolepis laevis;* 2-4 ind. core^{-1}) as were the cirratulid *Aphelochaeta* spp. (4 ind. core^{-1}) and *Linucula* sp. 1 (3 ind. core^{-1}). The brittle star *Amphiura rosea* was also found at this site (2 ind. core^{-1}). *Amphiura* is a widely distributed deposit feeding brittle star, common in muddy to sandy subtrates, and often occurring in association with *Dosinia* or *Gari* bivalves, depending on the mud prevalence (McKnight 1969, Powell 1936). *Dosinia greyi* were found at this site, albeit in low numbers (Figure 3-4, Appendix A).

Quays, north

The three northern Quay sites share many similarities in mud and organic content, and community composition, with the southern Quay sites described above. WH4 is located north of WH3 and east of AQ1, at the entrance to both Quays (Figure 2-1). Sediments are very muddy and organically enriched (87% mud, 7% organic matter content; Table 3-1). *Torridoharpinia hurleyi* and *Theora lubrica* were the most abundant taxa (7 and 6 ind. core^{-1}, respectively), polychaetes (*Cossura consimilis*, *Aglaophamus verrilli*, *Labiosthenolepis laevis;* 3-4 ind. core^{-1}) and bivalves (*Linucula* sp. 1 and *Arthritica* spp., both 4 ind. core^{-1}) were common.

AQ1 is located ~ 0.5 km north of Aotea Quay, Wellington's main domestic ferry and ship wharf. The seafloor at AQ1 has very muddy, enriched sediments (85% mud, 7% organic matter content; Table 3-1)). The amphipod *Torridoharpinia hurleyi* was the most abundant taxa (15 ind. core^{-1}) and the small bivalves *Theora lubrica* (8 ind. core^{-1}) and *Arthritica* spp. (6 ind. core^{-1}) were also common. Four polychaete species [*Aglaophamus verrilli*, *Labiosthenolepis laevis*, the cirratulid *Aphelochaeta* spp. and the capitellid *Carazziella phillipensis* (2-4 ind. core^{-1} on average)], and two crustacean taxa (Cumacea spp. and Ostracods; 4 and 3 ind. core^{-1}, respectively) were also consistently found in the AQ1 cores.

AQ2 is situated north of Aotea Quay and closer to shore than AQ1, near to the outflow of Kaiwharawhara Stream and the beginning of the Wellington Urban motorway (Figure 2-1). AQ2 is comparatively less muddy (75%) and organically enriched (4%) than AQ1 (Table 3-1). Similar taxa were found at both sites although the dominant taxa differed - at AQ2 the crustaceans Ostracoda and Cumacea (24 and 12 ind. core^{-1}, respectively) dominated the benthos along with *Torridoharpinia hurleyi* (10 ind. core^{-1}). Four polychaete species (*Cossura consimilis, Aglaophamus verrilli*, *Labiosthenolepis laevis* and Lumbrineridae spp.; 4 -7 ind. core^{-1}), and the small bivalve *Arthritica* spp. (5 ind. core^{-1}) were also common.

Kaiwharawhara

Sites in the Kaiwharawhara area are located at increasing distances from where the Ngauranga Stream enters the harbour (Figure 2-1). All are extremely muddy (95-96% mud; Table 3-1). WH10 is closest of the three sites to the stream mouth (~ 0.5 km SSE) and its sediments have the highest organic content (8%; Table 3-1). The benthic community was dominated by *Theora lubrica* (12 ind. core^{-1}) and *Torridoharpinia hurleyi* (7 ind. core^{-1}). Polychaetes (*Aglaophamus verrilli*, *Labiosthenolepis laevis*, *Cossura consimilis* 2-6 ind. core^{-1}), Cumacea spp. (4 ind. core^{-1}), bivalves (*Arthritica* spp. and *Linucula* sp.; both 3 ind. core^{-1}), and the brittle star *Amphiura rosea* (2 ind. core^{-1}) were all important components of the benthos.

WH9 is located ~1.5 km SSE of Ngauranga Stream mouth (Figure 2-1) and sediments here have lower organic matter content than WH10 (i.e. 4%; Table 3-1). *Theora lubrica* were amongst the dominant taxa (9 ind. core^{-1}). *Torridoharpinia hurleyi* were also common (4 ind. core^{-1}), as was the nepthyd polychaete *Agalophamus* (6 ind. core^{-1}). *Amphiura rosea* was more abundant here than at WH10 (4 ind. core^{-1}). The bivalves *Arthritica* spp. and *Borniola reniformis* also featured (both 2 ind. core^{-1}).

WH5 is located ~1.2 km NNE of Point Jerningham and sediments here have lower organic matter content than WH10 (i.e. 4%; Table 3-1). Similar to WH10, *Torridoharpinia hurleyi* (9 ind. core^{-1}) and *Theora lubrica* (4 ind. core^{-1}) were amongst the dominant taxa and Cumacea spp. (6 ind. core^{-1}), *Cossura consimilis* (5 ind. core^{-1}), *Aglaophamus verrilli* (4 ind. core^{-1}), *Labiosthenolepis laevis* (3.5 ind core^{-1}) and *Linucula* sp. (3 ind. core^{-1}) all featured. *Amphiura rosea* was found in the same numbers as at WH9 (4 ind. core^{-1}). In addition, *Aphelochaeta* spp. were common (4 ind. core^{-1}). WH5 is, at 21 m, one of the deepest monitoring sites.

Petone/Hutt

The northernmost group of sites in the monitoring programme includes two located off the Petone/Seaview foreshore (WH13, WH15) and the site most distant from any shorelines (WH17) located in the centre of the harbour between Matiu/Somes and Makaro/Ward Islands (Figure 2-1). Sediments at these three sites are amongst the muddiest and most organically enriched of all monitored sites (Table 3-1).

WH13 is south of Petone Wharf (Figure 2-1). As observed at a number of the monitored sites, *Theora lubrica* and *Torridoharpinia hurleyi* are the dominant taxa (each 8 ind. core^{-1}) at this muddy, organically rich site (93% mud, 8% organic matter content; Table 3-1). While polychaetes common at other sites featured here (*Labiosthenolepis laevis* and *Aglaophamus verrilli,* both 5 ind. core^{-1}; *Cossura consimilis* 2 ind. core^{-1}) this site differed in having tanaid crustaceans Tanaidacea spp. (3 ind. core^{-1}) and the small bivalve *Montacuta* sp. (2 ind. core^{-1}) amongst its' most abundant taxa. *Montacuta* is in the same family (Lasaeidae) as many of the other small bivalves found in Wellington Harbour, including *Linucula* sp. 1 which was also common at WH13 (3 ind. core^{-1}). *Montacuta* belong to a genus that is commensal with echinoderms. *Echinocardium* was also found at this site (see Section 3.2.3).

WH15 is located south of the Hutt River mouth and, like WH13, is very muddy with high organic content (93% and 8%, respectively (Table 3-1). Most abundant in the benthic community here were polychaetes (*Aglaophamus verrilli, Cossura consimilis and Labiosthenolepis laevis; 4-5 ind.* core^{-1}) *Theora lubrica* (5 ind. core^{-1}) and *Torridoharpinia hurleyi* (4 ind. core^{-1}). Tanaidacea spp. and *Lumbrineridae* spp. polychaetes were also common (each 2 ind. core^{-1}).

WH17 is situated in the centre of Wellington Harbour, relatively remote from any direct harbour inputs, and one of the two deepest monitored sites at 21 m. The sediments are very muddy (86% mud) and their organic matter content is high (7%) (Table 3-1). *Linucula* sp. 1 (7 ind. core^{-1}), *Labiosthenolepis laevis* (6 ind. core^{-1}) and *Amphiura rosea* (5 ind. core^{-1}) dominated this site, with bivalves and crustaceans also common (i.e. *Theora lubrica*, *Ennucula strangei*, *Torridoharpinia hurleyi* and Tanaidacea spp.; 2-4 ind. core^{-1}).

Harbour community composition

The relative differences and similarities in benthic community composition at the different sites is illustrated in the ordination diagram in Figure 3-2. The community at EB2 in Evans Bay was clearly very different to those of the remaining sites, reflecting its considerably greater diversity and abundance (Figure 3-2). The remaining 14 sites had similar and overlapping community composition. One or two of the cores at LB1, WH4 and WH10 were also separated from the main grouping. The spatial arrangement of all 15 sites was similar whether the untransformed or square root transformed data were used, indicating that those community patterns were not strongly driven by differences in dominant or rare species, respectively. There were strong significant differences in community composition between Wellington Harbour sites in 2020 [detected by ANOSIM: p = 0.001 (0.1%); R-statistics = 0.545 untransformed data, 0.508 square root transformed data], a result likely driven by the diverse community in the shallower and sandier se5diments at EB2.

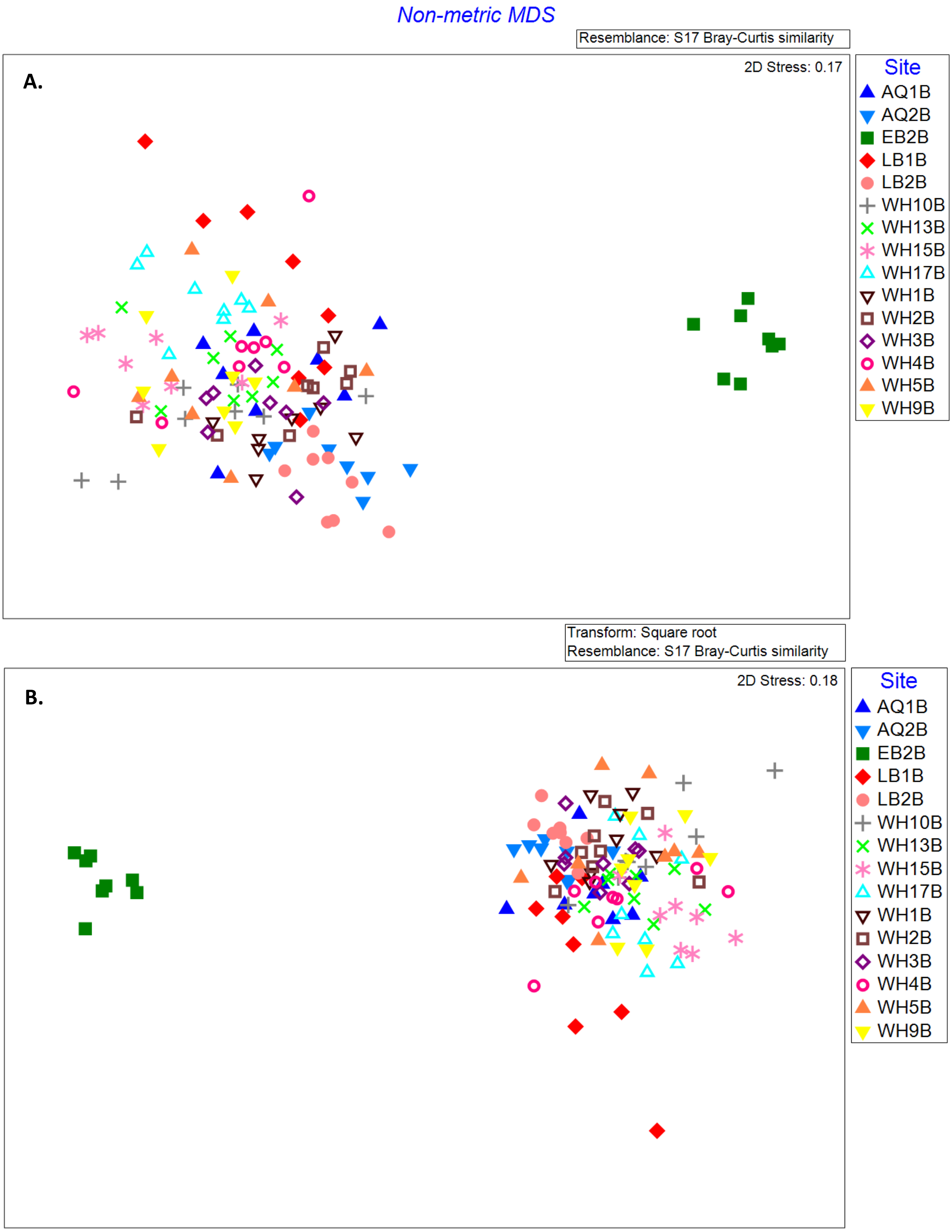

Figure 3-2: Non-metric multidimensional scaling ordination diagram of benthic community similarity amongst Wellington Harbour sampling sites in 2020. Data are untransformed (A) and square root transformed (B) abundance values from benthic macro-infauna core samples. Distances represent Bray–Curtis similarities among sites. All eight cores (each 20 cm diam.) are represented from each site.

3.2.3 Bivalve and *Echinocardium* population structure in 2020

The size class distributions of the common bivalves in 2020 are shown in Figure 3-4. Information on the size classes of bivalves is helpful for understanding the population make up and for determining whether there are reproductive-sized individuals present at a site. The data are provided in Appendix A. Reconciling benthic invertebrate data sets collected over the monitoring programme..

Theora lubrica is a small non-indigenous species known to Japan and other parts of Asia. It is considered a pollution indicator species because it is frequently dominant in highly polluted (muddy, organically enriched, metal contaminated) and disturbed sediments (e.g. Johnson et al. 2005). It has a very thin shell which is easily broken during the collection process and for this reason it is not generally measured in monitoring programmes (as it requires estimating the size of damaged individuals). This was the most abundant bivalve in Wellington Harbour, especially at AQ2, LB2, WH1 and to a lesser extent WH10. These sites are all close to shore, including near ports (AQ2, LB2, WH1) or stream entrances (WH10) indicating disturbed and contaminated sediments, although they are not unusual with respect to the rest of the sites in their contaminant, mud or organic matter concentrations (Table 3-1).

Arthritica bifurca is a small bivalve (max width ~6 mm, Family Lasaeidae; Powell 1979) that in the intertidal is considered to be tolerant to muddy sediments and organic enrichment. *Arthritica* was found at all 15 sites and was particularly abundant AQ1 and LB1 (Figure 3-3). While the majority of the *Arthritica* found in 2020 were <2 mm in size (Figure 3-3, Appendix A), individuals in the 2-5 mm size class were found too most notably at the Lambton basin sites (LB1, LB2) and WH1. For a naturally very small species like *Arthritica* size class measurements are less useful for understanding population structure as it is difficult to distinguish the reproductively active size classes or to track cohorts; for this reason, this bivalve is not usually recommended for measuring in monitoring programmes. However, as Booth (1979) considers specimens >2.5 mm to be adults we can assume that individuals in the 2-5 mm size class are mature.

Linucula sp. 1 (nut shell) were the next most abundant taxa in 2020 and were found at 15 sites and were particularly abundant at WH17 (~55 individuals; Figure 3-4). *Linucula* are small Nuculiidae bivalves which attain a maximum width of ~8 mm (Powell 1979). Individuals from the 5-10 mm size class were found only at EB2, likely indicating the presence of reproductive adults at this site (Figure 3-3). A similar species present in intertidal habitats, *Linucula hartvigiana*, is considered to be mud-sensitive, whereas most of the subtidal sites in Wellington Harbour are considered very muddy. The majority of *Linucula* sp. 1 individuals found were very small (<2 mm), with only this smallest size class found at WH15 and LB2 (Figure 3-4; Appendix A).

Another Nuculiidae bivalve, *Ennucula strangei*, was found at all sites except EB2. This species grows to ~13 mm wide (Powell 1979), larger than *Linucula* sp. 1. Individuals in the 5-10 mm size class (potentially adults) were found at 11 sites (Figure 3-4; Appendix A).

Borniola reniformis is a Lasaeidae bivalve found in 'clean, coastal situations' (Ponder 1967; cited in Booth 1979) and has a maximum size of ~10 mm wide. Booth (1979) successfully spawned specimens >4 mm, but the lower size range for reproductively viable individuals is not known. There were no individuals in the 5-10 mm size range at any site (Figure 3-4; Appendix A).

Thracia vitrea grows to ~25 mm wide, and was most common at LB2. Larger individuals (10-20 mm) were found at five sites (WH3, WH13, EB2, AQ2 and LB1), although total numbers in this size class were low (Figure 3-4; Appendix A).

Neilo australis was found at all sites except EB2, in low numbers (<12 individuals total at a site; Figure 3-4, Appendix A). A range of size classes were found across the harbour. Although none were as large as the maximum size recorded for this bivalve (~42 mm wide).

The venerid bivalve *Dosinia greyi* is found in soft mud in the shallow subtidal. It was found at seven of the 15 sites in 2020 in low numbers (maximum total abundance of 5 individuals, at WH2) and several individuals in the 20-40 mm size class were collected across the harbour (Figure 3-4, Appendix A). This bivalve attains a maximum width of ~50 mm.

Heart urchins, *Echinocardium cordatum*, were found at 11 of the 15 sites. They ranged in size from 15.0 mm to 36.5 mm wide and were 28.7 mm on average (Figure 3-5). The smallest individuals were found at WH3, WH10 and LB1, and the largest at WH2, WH9, WH15 and AQ1. *Echinocardium cordatum* is a large burrowing deposit feeder common in both sandy and muddy subtidal habitats. It has been found to be sensitive to increased sediment concentrations, with burial times and death rates increasing at higher concentrations (Nichols et al. 2003). Echinocardium is considered to be a key species with its burrowing activities (bioturbation) mixing a large volume of surficial sediment, increasing oxygen penetration into the sediment column, and increasing productivity by releasing nutrients such as ammonium and phosphate from the sediment (Lohrer et al. 2003).

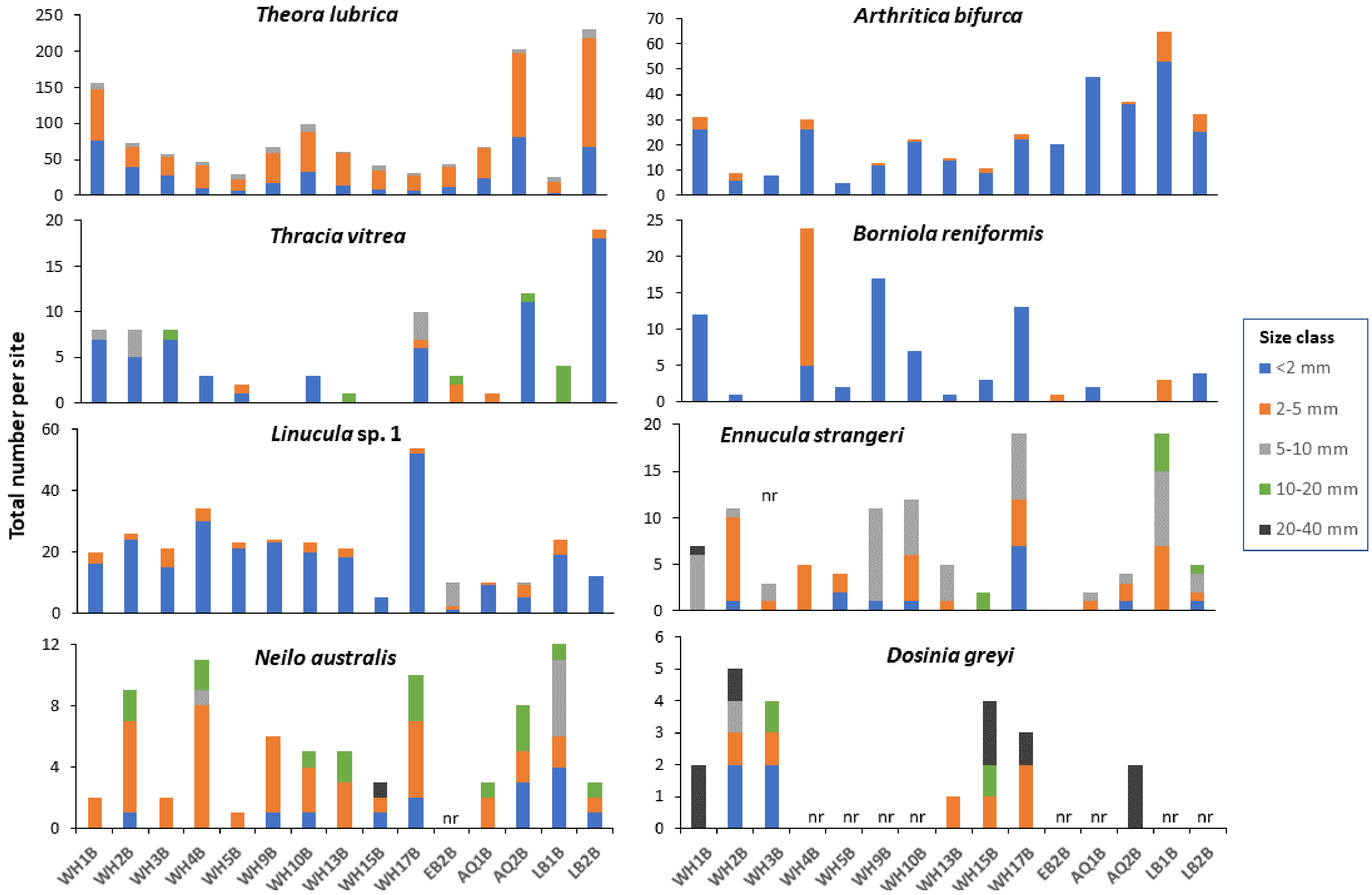

Figure 3-3: Total number of bivalves found in each size class at each site in 2020. Values presented are totals from all benthic cores (eight 20 cm diam. cores). nr = none recorded at that site.

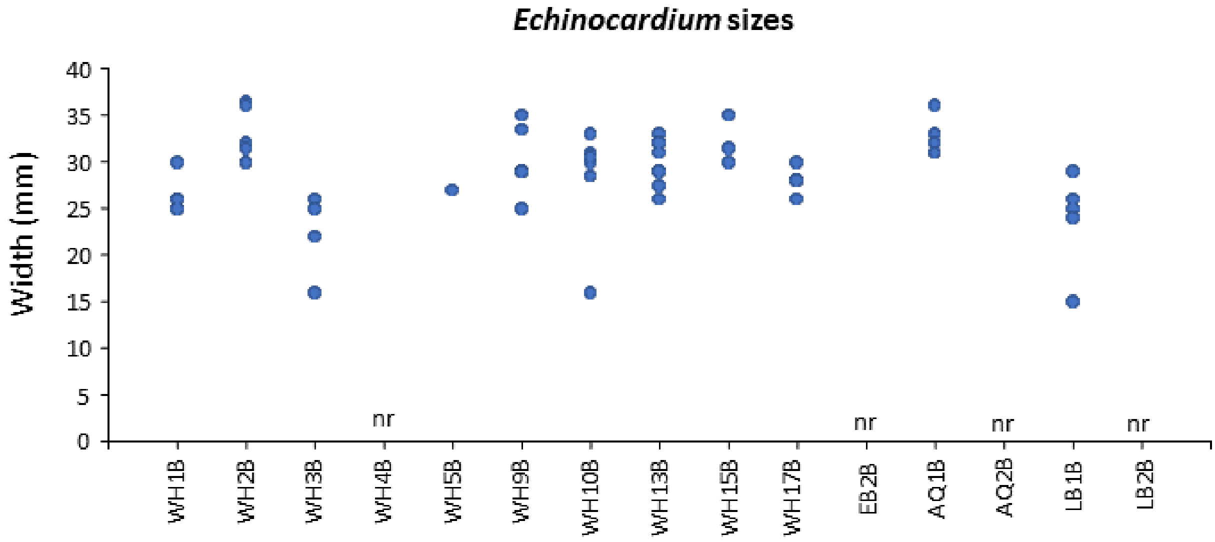

Figure 3-5: Sizes of the individual *Echinocardium cordatum* found at each site in 2020. nr = none recorded at that site.

3.2.4 Benthic Health

Traits Based Index

All of the Wellington Harbour sites were classified as having 'high' functional redundancy health scores when the full 2020 data set was used in the calculations (Table 3-4). WH15, located near the mouth of the Hutt River near Seaview (Figure 3-1), had an 'intermediate' functional redundancy health score when the condensed data set with lower taxonomic resolution was used. The TBI scores for the condensed data set were generally slightly higher than those generated using the full data set, which was unexpected because reduced taxa numbers tend to dampen TBI scores.

Not all species contribute to TBI equally with some having more influence than others. For example, nereid (e.g., *Nicon*), maldanid (e.g., *Asychis*), polydorid (e.g., *Boccardia*), glycerid/goniadid, and polynoid polychaetes have a relatively high weight in TBI calculations. Groups that do not score very highly for TBI (but which doesn't mean they should be totally ignored) include capitellid polychaetes, crabs, isopods, surfac e grazing gastropods, cumaceans, and many of the amphipods. However, every species identified counts toward TBI scores, so if species richness is high this tends to increase TBI scores. Subtidal sites are generally more stable and are exposed to fewer physical stressors than intertidal habitats (which experience desiccation, thermal swings due to emersion/immersion, freshwater precipitation, etc.) and tend to have higher species richness than comparable intertidal sites. The subtidal sites in Wellington Harbour were numerically dominated by mud- and pollution-tolerant species (e.g., *Theora*, *Arthritica*), however, they may have had low abundances of a large number of rarer species (represented by one or two individuals each). This would tend to elevate the TBI scores, as the TBI is based on the richness of trait groups only (abundance does not factor into it). All of the TBI scores calculated for Wellington Harbour were above 0.4, and most were above 0.5 (Table 3-3). Variation in TBI scores above 0.4 or 0.5 is generally not indicative of better/worse; above this level, functional redundancy and its contribution to benthic health is considered to be high.

Table 3-4: Health status of benthic ecology in 2020. Health scores based on the Traits-based index (TBI) were calculated using two versions of the 2020 data, the condensed data set which has lower taxonomic resolution as described in Section 2.3.3, and the complete data set. Scores indicate the levels of community functional redundancy and the degree of site degradation. TBI scores <0.3 = 'low'; 0.3-0.4 = 'intermediate'; >0.4 = 'high'.

	Condensed 2020 data set		Complete 2020 data set	
Site	TBI score	Health score	TBI score	Health score
WH1B	0.55	High	0.53	High
WH2B	0.51	High	0.51	High
WH3B	0.52	High	0.51	High
WH4B	0.48	High	0.48	High
WH5B	0.53	High	0.52	High
WH9B	0.43	High	0.42	High
WH10B	0.45	High	0.53	High
WH13B	0.47	High	0.51	High
WH15B	0.40	Intermediate	0.51	High
WH17B	0.57	High	0.48	High
EB2B	0.99	High	1.00	High
AQ1B	0.57	High	0.57	High
AQ2B	0.65	High	0.62	High
LB1B	0.66	High	0.64	High
LB2B	0.55	High	0.53	High

Benthic Health Model

BHM scores at a site are based on the presence and abundance of species (using all replicate cores) in list of species used previously to create the benthic health models. Note that 34 of the taxa found in Wellington Harbour in 2020 were not listed in the existing BHM model species list. These taxa were from multiple phyla/classes, and included seven polychaete, 11 bivalve and five gastropod taxa. Of those not in the model, 13 taxa were uniquely subtidal species. The models were run in two ways: Firstly, on a complete Wellington Harbour dataset with all subtidal species included and allocated to the same group as the most similar intertidal species in the BHM model taxa list. Secondly, the 13 taxa occurring only subtidally were omitted from the data set altogether to create a condensed Wellington Harbour 2020 dataset.

The BHM mud and metal scores were checked against the actual percentage mud and metal concentrations, respectively, measured at each of the benthic sites (Table 3-1). For the BHM mud, there was a poor fit with the intertidal model regardless of whether the subtidal species were included in the model (Figure 3-3A). Substrates at all but one of the sites comprised 70-96% mud. Only Site EB2, with 17% mud, fit the model well (Figure 3-3A). Because of the very poor fit, it is not advisable to run the BHM mud model to determine scores and health category ratings for this Wellington Harbour programme.

There was a slightly better fit between the intertidal model's BHMmet scores and the actual concentrations of copper, lead and zinc (converted to a PCA score) measured at each of the benthic sites (Figure 3-3B). This fit was reduced if the subtidal species were excluded from the data set

(Figure 3-3B). A good correlation was found between BHMmet scores calculated with and without subtidal species (R = 0.59). The PCA axis score was calculated from the model equation and supplementary information contained in Clark et al. (2020):

PC1Met = 0.653 x (log[Cu] in sample - 1.80) + 0.536 x (log[Pb] in sample - 2.28) + 0.535 x (log[Zn] in sample - 3.83)

Because of the reasonable fit, the BHM metals model was run to determine scores and health category ratings, using the model with the subtidal species included.

Very recently, consultants Salt Ecology (Nelson) queried the utility of the five health categories defined by the national BHM. A small group of the original authors (Clark et al. 2020) and Drew Lohrer (NIWA) considered these concerns and have suggested some changes (Prof. Judi Hewitt, pers comm.). The national BHM was derived from a set of intertidal sites that included many sites with very low metal concentrations. Although the sampling sites used for BHM development spanned a significant gradient in sediment heavy metal contaminant concentration, metal concentrations certainly did not range as high as have been documented in highly industrialised ports in Asia, Europe or the US (e.g., Hong Kong, Barcelona, Los Angeles). Nevertheless, sediment heavy metal concentrations at contaminated sites in New Zealand are high enough to have measurable effects on benthic macrofaunal communities and communities at these sites can be separated from those at sites with lower concentrations (Hewitt et al. 2005, 2009; Thrush et al. 2008). This fact is the basis of the BHM models (Hewitt et al. 2005). The authors' work group will be looking into quantifying the actual changes from one category to another and the repercussions for benthic "health" (Prof. Judi Hewitt, pers comm.). At present they recommend that the five categories be used to express the position of the site relative to other intertidal estuarine New Zealand sites, and that for more absolute comparisons a re-scaled three category BHMmud system be used to represent the level of impact relative to other estuarine sites in New Zealand. For this re-scaled category, values < 3.6 are considered 'good', values 3.6 < 4.8 are considered fair, and values < 4.8 are considered poor (Prof. Judi Hewitt, pers comm.). As most of the Wellington Harbour sites are < 3.6 on the re-scaled category, they are scored 'good', with only EB2B being in the 'moderate' category (Table 3-5). There are no sites in the 'poor' category.

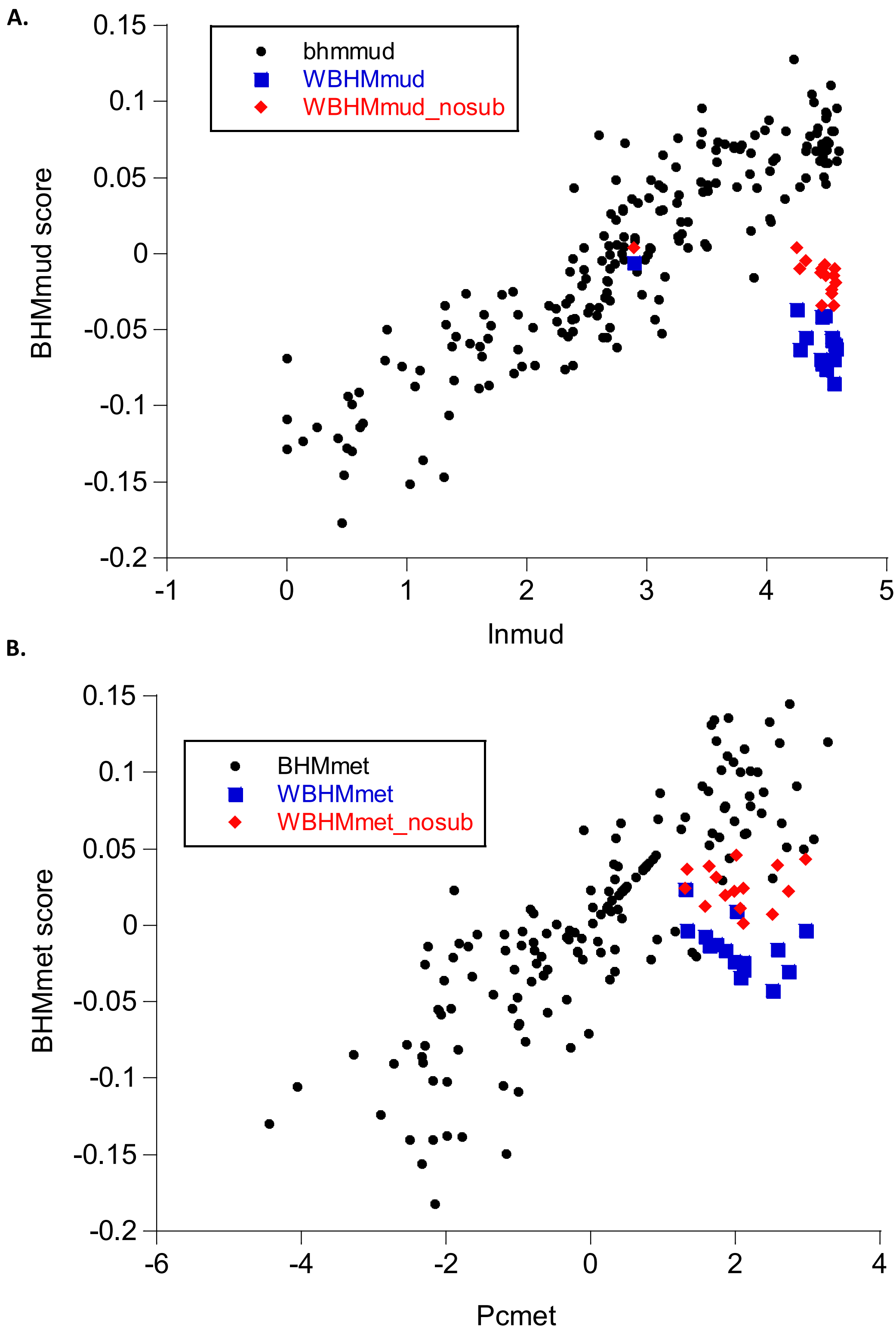

Figure 3-4: Relationship between the Benthic Health Model (BHM) scores and measured mud and metal concentrations. A. Mud BHM scores and the percentage mud content of the sediments measured (via wet sieving analysis), and B. the Metals Benthic Health Model (BHM) scores and PCmet (i.e. the PCA axis 1 scores from the PCA on the copper, lead and zinc concentrations), at each site. Blue squares are the Wellington Harbour scores for the model run with subtidal species included and allocated to the same group as the most similar intertidal species on the list. Red diamonds are the scores for the model run with subtidal species omitted from the data set. Black symbols are the relationship for a range of intertidal sites around New Zealand.

Table 3-5: Scores and health category ratings for the BHMmetal model at the Wellington Harbour sites in 2020. Absolute health category ratings range from good (scores < 3.6), to moderate (scores 3.6 < 4.8), to poor (scores > 4.8). Subtidal species that did not already appear in the model were included and assigned attributes of the nearest/most similar intertidal species.

Site	PCA score	BHM metals	BHM metals rescaled	Category
WH1B	2.510037	-0.04275	2.561279	good
WH2B	1.993444	-0.02342	2.916251	good
WH3B	2.585359	-0.01571	3.057815	good
WH4B	2.020429	0.009384	3.518477	good
WH5B	1.640746	-0.01291	3.109068	good
WH9B	1.740873	-0.01235	3.119411	good
WH10	2.077349	-0.03442	2.714157	good
WH13	1.864657	-0.0164	3.045058	good
WH15	1.58734	-0.00752	3.208128	good
WH17	1.339085	-0.00309	3.289378	good
EB2B	1.303309	0.023758	3.782385	moderate
AQ1B	2.109887	-0.02911	2.811642	good
AQ2B	2.115173	-0.02408	2.90408	good
LB1B	2.96852	-0.00304	3.290377	good
LB2B	2.733159	-0.02992	2.796814	good

3.2.5 Sediment characteristics correlated with benthic community composition

Five sediment variables explained 64% of the variation in benthic community composition among sites. These included concentrations of the contaminants PAH, cadmium and mercury, along with TOC and coarse sand (Figure 3-5).

Cadmium and total PAH (normalised to TOC) were the strongest drivers of community similarities between sites. The results of the DistLM analysis demonstrated the problem with using forward selection of major drivers when two strong drivers are correlated. The marginal test explained 22.8% of the correlation for cadmium (p = 0.002) and 15.9% for PAH (p = 0.12). Because of this correlation, PAH did not initially appear in the forward selection results. A way to understand the interaction between these variables is to constrain the analysis to choose PAH and then produce the effect of the other variables on the residuals. When this was done, the analysis could explain 64% of the variation between sites with five variables (PAH, cadmium, TOC, coarse sand and mercury) all explaining >5% with non-significant p-values (see Table 3-6).

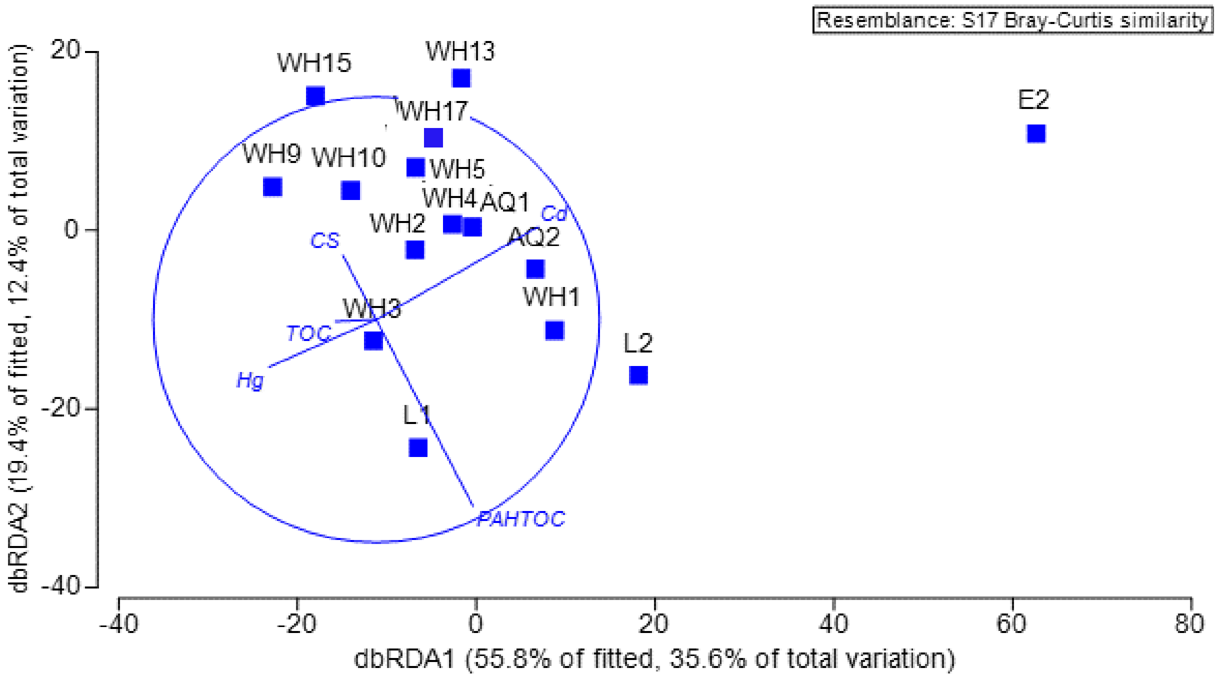

Figure 3-5: A constrained ordination of benthic faunal data and sediment characteristics. The blue lines indicate the strength and direction of the forward selected sediment characteristics as drivers of benthic community similarities between sites. PAHTOC = PAH normalised to % TOC, Cd = cadmium, TOC = total organic carbon, CS = coarse sand, Hg = mercury. L1 and L2 indicate sites LB1 and LB2, respectively.

Table 3-6: Variables important in explaining differences in community composition. Results of forward selection conducted in DISTLM, with variables shown in order of selection after constraining the analysis to choose PAH.

Variable	p-value	Proportion explained
PAH (normalised to % TOC)	0.012	15.9
Cadmium (Cd)	0.029	17.6
Total Organic Carbon (TOC)	0.080	9.4
Coarse sand (CS)	0.038	10.7
Mercury (Hg)	0.016	10.3

3.3 Reconciling benthic invertebrate data sets collected over the monitoring programme

A total of 630 invertebrate voucher specimens were collected. Specialist taxonomists identified 138 unique taxa from these vouchers.

As noted in Section 2.3.1, when merging the data sets from each of the six years of monitoring, modifications were made to the taxa list to ensure that the same level of taxonomic resolution was compared over time (Appendix B). We examined the final combined data set to identify any potential issues with taxonomic identifications that required further investigation. These findings are summarised in Appendix D. Other taxa that were combined were either rare or their merging was well justified/obvious.

In the combined data set, many taxa that occurred in the 2006-2016 sampling were not identified in 2020, and taxa identified in 2020 had not been identified in previous sampling years (Appendix B). In several instances the differences between taxa lists pre- and post-2020 could be resolved by taxonomic expert checks on voucher specimens.

For taxa that were present in high numbers of individuals, we recommend that voucher specimens should be examined in order to aid reconciling the entire data set. These include crustaceans (Amphipods, Phoxocephalidae), sipunculids, and polynoid polychaetes (Appendix C).

3.4 Sediment characteristics over time

In this section we examine we discuss temporal patterns in sediment particle size, TOC, metals and/or metalloid contaminants and PAH concentrations. There was no change in the overall spatial pattern of sediment characteristics (metals, TOC, 10-63 µm sediment particles, PAH's) over time with RELATE revealing a good correlation (Spearman rank) of these characteristics between 2006 and 2020 (Rho = 0.89, p = 0.001) and between 2011 and 2020 (Rho = 0.95, p = 0.001). Both year comparisons were conducted because some sites were only introduced into the monitoring programme in 2011 (i.e. LB1, LB2, AQ1, AQ2).

The concentrations of fine sediment particles (10-63 µm) over time at each site, measured using the laser particle size analyser, is shown in Figure 3-6. This plot shows this sediment fraction increasing at some sites and decreasing at others (Figure 3-6), with largest apparent increases at WH1 (Evans Bay) and WH15 (near the Hutt River estuary entrance), and the greatest decreases at WH4 (southern Quay).

Correlation analysis indicates a strong, positive and significant relationship of 10-63 µm sediment concentration with sampling year at WH15 (Figure 3-7; Figure 2-1). This analysis detected a strong, negative and significant relationship at WH4 and AQ1. The fact that the statistical results support some (but not all) of the visual patterns of increases and decreases over time around the harbour shown in Figure 3-6 shows the danger of analysis with few data points, and that it is not yet possible to confidently discuss temporal change.

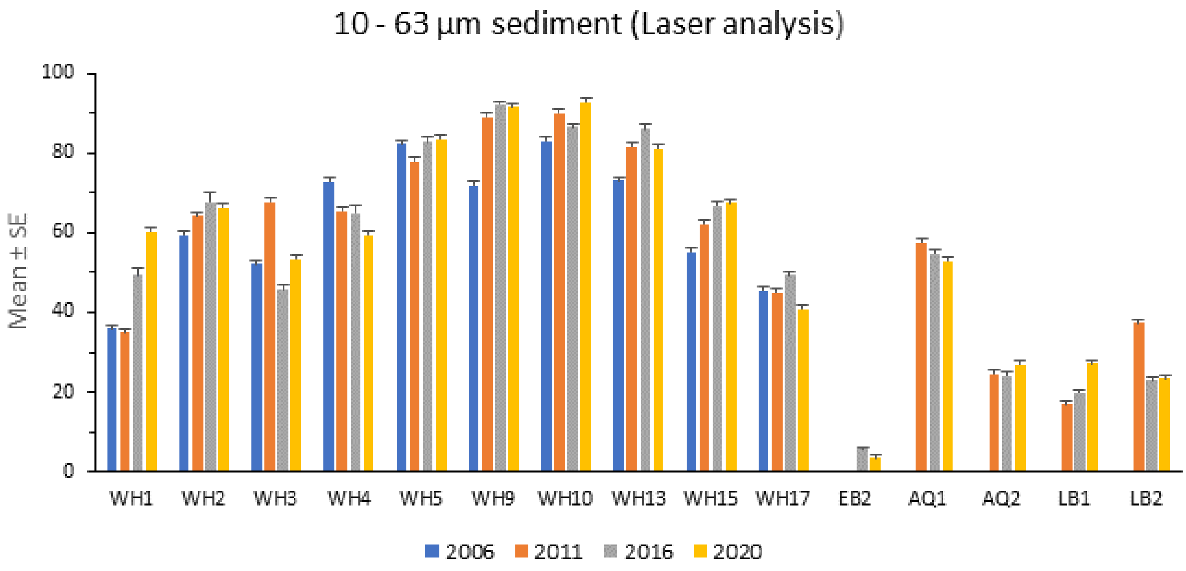

Figure 3-7: Concentration of fine sized sediments at each site on each monitoring occasion. Percentage of sediment particles in the 10-63 µm particle size range determined using laser analyser (N=3; sediment chemistry circle).

For comparison with the laser analysed data, we have included percent mud content determined by wet sieving of the benthic circle in Figure 3-8. These values were used in the analyses of the 2020 benthic indices because they are a true percent mud value, incorporating clay (<3.9 mm) and silt (3.9-63 mm) sediment fractions. At all sites, the percent mud was considerably higher than the laser-derived 10-63 mm measurements for 2020 (Figure 3-7), and unlike the laser data, was very similar in concentration across all of the 'WH' pre-fix sites (Figure 3-7). As previously noted in Section 3-1-1 there is strong similarity between the mud content of sediments (determined via wet sieving) from the benthic and the sediment chemistry sampling circles.

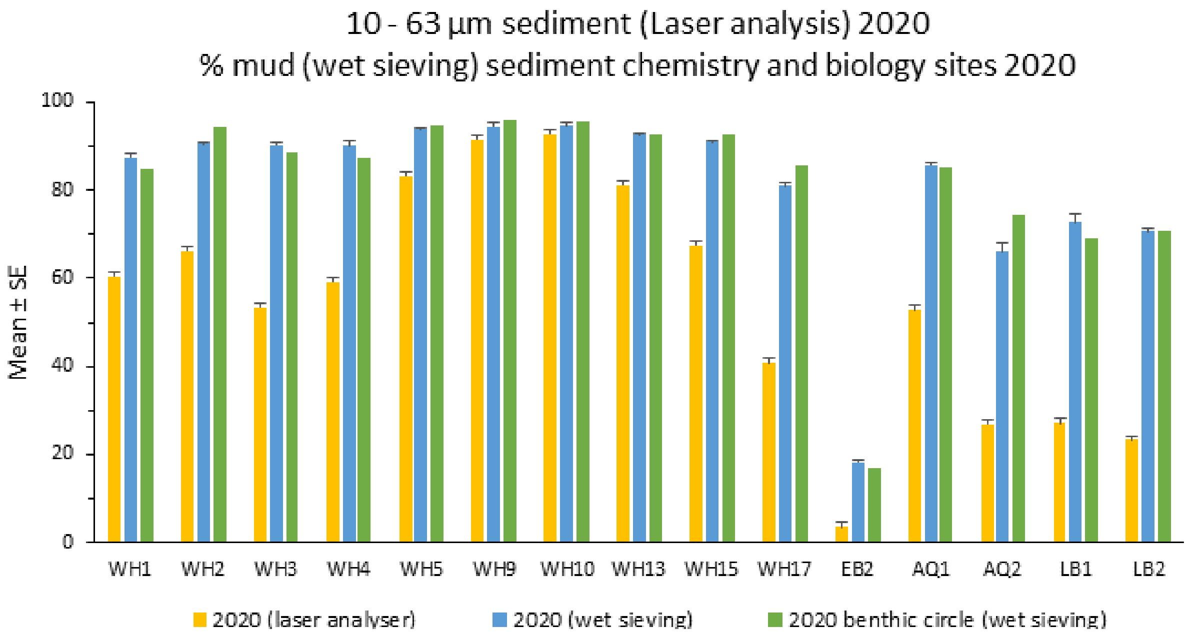

Figure 3-8: Concentration of finer sediments in 2020 determined using laser analysis and wet sieving. Plot shows the percentage of 10-63 µm sediments determined from the sediment circle using the laser analyser (N=5; green bars), and of mud sized particles (0-63 µm) using wet sieving analysis (N=5; black bars). Also shown is the percentage of mud from the benthic circle (N=1; brown bars).

Table 3-7: Summary of results of analyses of relationships between sediment characteristics and time, at each site in Wellington Harbour. Full results, on which this summary is based, are presented in Appendix E. We present changes for which there were strong correlations (i.e. Rho >0.90). -ve = negative correlations; +ve = positive correlations.

Site	10-63 µm sediments	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	PAH	HMW PAH	TOC	Total strong correlations
WH1		-ve	-ve									-ve	3
WH2						-ve						-ve	2
WH3		+ve											1
WH4	-ve				-ve	-ve							3
WH5													0
WH9			-ve										1
WH10													0
WH13						-ve							1
WH15	+ve												1
WH17		-ve										-ve	2
AQ1	-ve		-ve									-ve	3
AQ2		-ve			+ve	-ve	+ve	-ve				-ve	6
LB1	+ve		-ve		+ve		+ve		+ve			+ve	6
LB2		+ve	-ve		-ve								3
+ve	2	2	0	0	2	0	2	0	1	0	0	1	10
-ve	2	3	5	0	2	4	0	1	0	0	0	5	20

Reflecting the difficulty of robust detection of change with time with only four data points (maximum) spread over 16 years, we only discuss the changes for which there were strong correlations (i.e. Rho >0.9) and which were also statistically significant (Pr > |r| > 0.05) (Table 3-7). There were strong, significant negative correlations in average concentration over time for (i) Cd at five sites (WH1, WH9, AQ1, LB1, LB2), (ii) Hg at three sites (WH2, WH4, AQ2), and (iii) Pb at one site (AQ2). Strong, significant positive correlations were detected for Ni at two sites (AQ2, LB1) and for Zn at LB1. A mix of increases and decreases were detected for As, Cu and TOC (Table 3-7). Negative correlations for As with time were noted at WH17 and AQ2, and positive correlations at two northern Quay sites WH3 and LB2. Negative correlations for Cu were found at WH4 and LB2, and positive corelations at AQ2 and LB1. Six correlations were found for TOC, five of them negative (at WH1, WH2, WH17, AQ1 and AQ2) and one positive (at LB1). No correlations were found for Cr or PAH.

Across all sites and contaminants, 10 correlations were positive (implying increased concentrations over time) and 20 were negative (implying decreased concentrations over time) (Table 3-7). Most of the significant correlations were found at the Quay sites (i.e. 20 cf. 8 elsewhere in the harbour) and, especially, at AQ2 and LB1. We recommend caution in use of these results as there is difficulty with statistically comparing changes over time with only a few data points. At least 10 are recommended to be able to be confident in the significance of the finding (i.e. that it results from a true (un)correlation and not just from chance). Increasing the sampling frequency would provide more robust trend analysis.

3.5 Benthic ecology over time

3.5.1 Biodiversity

The total number of taxa and individuals track very closely over time for all sites except for EB2 (Figure 3-6). Clearly, the 2016 sampling date showed the lowest numbers at all sites, potentially due to the considerable disturbance from storms and a major earthquake that occurred during the sampling.

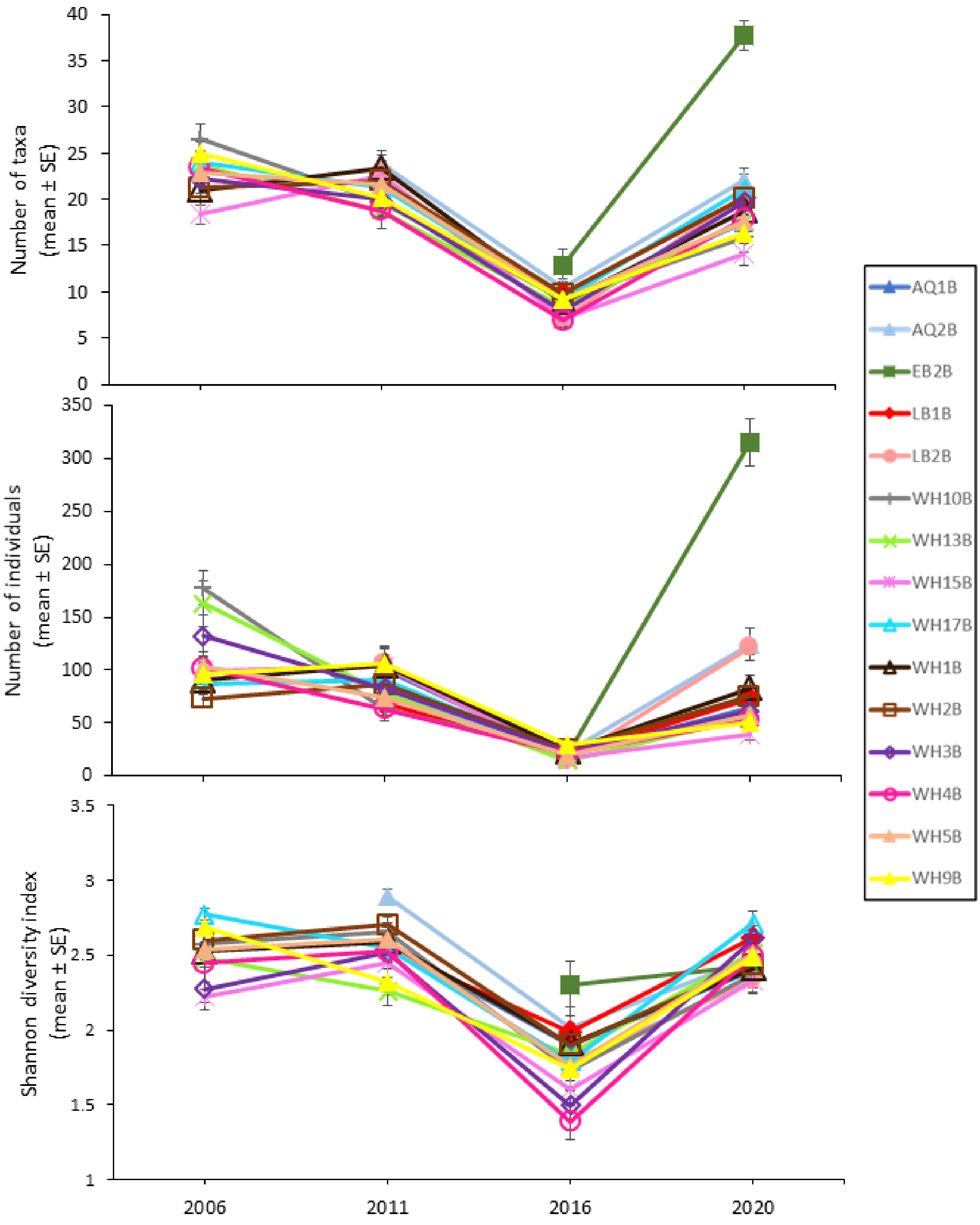

Figure 3-6: Total number of taxa and individuals, and the Shannon diversity index at each Wellington Harbour site on the four sampling occasions. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

3.5.2 Community composition

As for the number of individuals and taxa, benthic community composition has changed over time, with all sites remaining similar to each other on any particular sampling date (Figure 3-7). EB2 was introduced into the monitoring programme in 2016, and is distinct from the other sites.

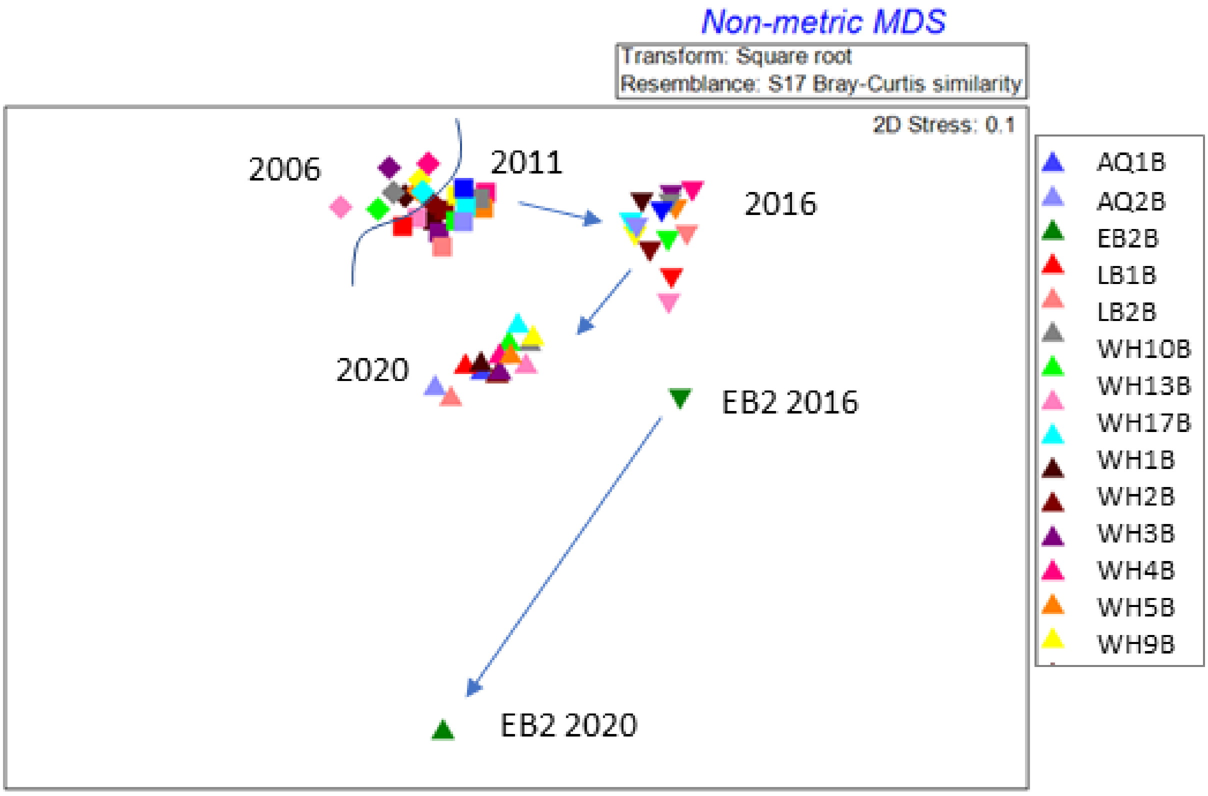

Figure 3-7: Non-metric multidimensional scaling ordination diagram of benthic community similarity amongst Wellington Harbour sampling sites for all years of the sampling programme (2006, 2011, 2016 and 2020). Data are square root transformed abundance values from benthic macro-infauna core samples. Only the centroids of the site replicates are plotted. EB2 was sampled in 2016 and 2020 only.

We chose the taxa that were dominant in 2020 as examples to plot over time, including bivalves (*Theora lubrica*, *Arthritica bifurca*, *Linucula* sp. 1), amphipods (Phoxocephalidae sp., #1, *Torridoharpinia hurleyi*,) and polychaetes *(Sipunculida* spp. *Cossura consimilis, Aglaophamus verrilli*) (Figure 3-8). All of these taxa exhibited low abundances in 2016.

In the combined data set analysis, we note that Phoxocephalidae #1 has declined in abundance while numbers of *Torridoharpinia hurleyi* (also a phoxocephalid amphipod) have increased over time. We caution that some mismatch in identifications may have occurred in these early data sets.

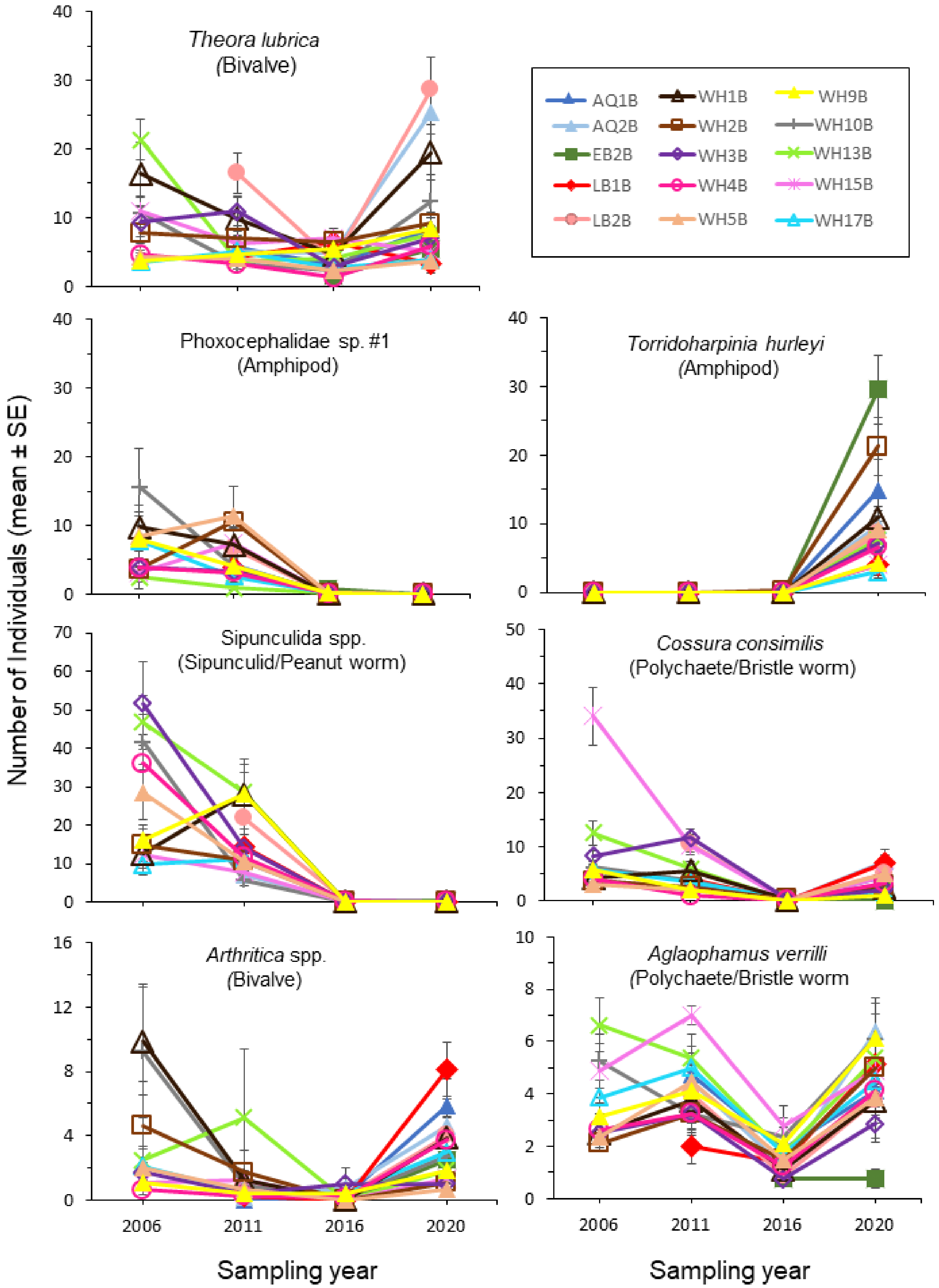

Figure 3-8: Total number of individuals of the common taxa found at each site in 2006, 2011, 2016 and 2020. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

3.5.3 Benthic Health

Traits Based Index over time

In 2006, 2011 and 2020, the TBI was high at all sites (Table 3-8). In 2016, only three of the 15 sites had high TBI (WH17, EB2, AQ2), four sites were classed as having 'low' health (WH4, WH13, WH15 and LB2) and the remainder were 'intermediate' or 'intermediate/high'. As noted previously for other sediment and faunal characteristics, the unusual environmental conditions around the time of sampling in 2016 may have contributed to the patterns in 2016. A longer time series is required to confirm this suggestion.

Table 3-8: Health status of benthic ecology over time. Health scores, based on the Traits-based index, using the full data sets on each sampling date. The index uses a SUMmax parameter that can be adjusted to suit differing numbers of replicates. Scores indicate the levels of community functional redundancy and the degree of site degradation. TBI scores <0.3 = 'low'; 0.3-0.4 = 'intermediate'; >0.4 = 'high'.

	2006		2011		2016		2020	
	score	index	score	index	score	index	score	index
WH1B	0.59	high	0.58	high	0.40	inter/high	0.53	high
WH2B	0.56	high	0.47	high	0.38	inter	0.51	high
WH3B	0.68	high	0.56	high	0.33	inter	0.51	high
WH4B	0.58	high	0.49	high	0.29	low	0.48	high
WH5B	0.52	high	0.52	high	0.40	inter/high	0.52	high
WH9B	0.65	high	0.44	high	0.39	inter	0.42	high
WH10B	0.60	high	0.69	high	0.40	inter/high	0.53	high
WH13B	0.53	high	0.54	high	0.27	low	0.51	high
WH15B	0.51	high	0.57	high	0.27	low	0.51	high
WH17B	0.61	high	0.52	high	0.43	high	0.48	high
AQ1B			0.52	high	0.33	inter	0.57	high
AQ2B			0.65	high	0.41	high	0.62	high
EB2B					0.53	high	1.00	high
LB1B			0.59	high	0.37	inter	0.64	high
LB2B			0.57	high	0.28	low	0.53	high

4 Summary

Subtidal sediments collected in 2020 were very muddy ranging from 69-96% mud at all but one of the 15 sites, EB2, located in inner Evans Bay (<20%). Organic matter content was ~4-8%.

Analysis of a variety of sediment contaminants, including heavy metals and PAHs, revealed guideline exceedances for lead and mercury (two of the most toxic heavy metals commonly found in the marine environment) at all but two sites. These sites, WH15 located SW of Seaview and WH17 NNW of Makaro/Ward Island, did not exceed guidelines for any of the contaminants measured. This is similar to findings from previous sampling dates (Hewitt 2019). Zinc and copper exceed guideline concentrations at four sites (WH1 SE of Evans Bay; WH3 at Lambton Basin entrance; and LB1 and LB2 in Lambton Basin), and two other sites (AQ1 and AQ2 ENE of Aotea Quay) are approaching exceedance of the ARC amber copper guidelines (Table 3-2). Together, these high numbers of exceedances demonstrate that there is reason for concern about contamination in Wellington Harbour sediments. Arsenic, cadmium, chromium, nickel and total PAH were, however, below concentration guidelines at all sites.

The benthic communities at each site were generally diverse with reasonable abundances of bivalves, polychaetes and crustaceans and mixtures of functional types (large and small animals, suspension and deposit feeders, etc.). WH15 had the lowest number of taxa and individuals of all sites (average of 14 and 40 per core, respectively), while the southernmost Evans Bay site, EB2, recorded substantially higher species diversity and numbers of individuals than any of the other sites (38 taxa and 315 individuals per core). The community at EB2 was clearly very different to those of the remaining sites, with a unique species assemblage (30 of the 38 taxa were exclusive to Evan's Bay). This is likely a reflection of the very different sediment type at EB2 as already noted above (<20% mud, >20% gravel/shell hash). The remaining 14 sites were very muddy (>69%) and had community compositions similar to each other but distinct from the EB2 community.

Benthic health assessments were used to assess the relative health status of the different sites. The Traits Based Index, based on biological traits of the benthic taxa, classified all sites sampled in Wellington Harbour as having 'high' functional redundancy in 2020. Although a mud content of ~70-95% in intertidal habitats is generally associated with low taxa richness and concomitantly low TBI scores, it appears that very muddy subtidal seafloor habitats in Wellington Harbour support a relatively high abundance and diversity of macrofauna. The unexpectedly high TBI scores (given the muddiness and metal contamination) may have resulted from low numbers of individuals present across a large number of taxa.

The Benthic Health Model for metals classified 14 of the 15 sites as having 'good' health when all species were included. Site EB2 was categorised as 'moderate'. As the macrofauna community at EB2 was by far the richest and most abundant, the lower BHM metal score at site EB2 was paradoxical and indicates a potential problem in applying the model to the subtidal datasets collected from Wellington Harbour. The national BHMs have been developed for estuarine intertidal sites, and have not yet been validated for subtidal and more open coastal sites and species. The existing BHMmetals model was checked against the actual concentrations of copper, lead and zinc at the Wellington Harbour sites, and revealed a reasonable fit with the intertidal model. As noted for the TBI analyses, an evaluation of the validity of these models to the subtidal zone is underway at NIWA at present. Our analyses here suggest that separate models will be required for intertidal and subtidal sites.

Five sediment-associated variables explained 64% of the variation in benthic community composition between sites. These included concentrations of the contaminants PAH, cadmium and mercury, along with total organic carbon and coarse sand.

In a previous report, Prof. Judi Hewitt (University of Auckland) recommended that one Wellington Harbour site, either WH5 or WH9, be sampled annually in November to enable determination of natural annual variability (Hewitt 2019). Both sites are located in a similar area of the harbour (NNE of Point Jerningham and SSE of the Ngauranga Stream mouth, respectively), and were chosen because they had the least number of trends observed in a preliminary analysis of temporal change (Hewitt 2019). In 2020, the two sites were again found to have similar characteristics, although WH5 had higher concentrations of Total PAH and HMW PAH (Table 3-2). On this basis, WH9 was selected and was sampled in November 2020 (Jane Halliday (NIWA) pers. comm.).

A visual assessment of the patterns in benthic community composition, numbers of individuals and taxa over the four sampling dates showed that, on any one sampling occasion, the sites were similar to each other. The sites did exhibit change over time, however. The 2016 sampling date showed the lowest numbers of individuals and taxa of the four sampling dates, at all sites. Similarly, the Traits Based Index was high at all sites on all sampling dates, with the exception of 2016 when only three of the 15 sites had high functional redundancy. The environmental conditions around the time of sampling in 2016 were unusual, with extreme weather events that caused severe flooding, slips and input of freshwater and sediments into the harbour. A major earthquake also occurred (Kaikoura Earthquake, magnitude 7.8, 14 November), and divers noted that the seafloor sediments were more fluid than usual. It is possible that these events may have contributed to the unusual patterns in 2016, although a longer time series, possibly with more frequent monitoring, is required to resolve this question.

4.1 Recommendations

- The monitoring programme should continue in its present form, with one exception. The size of the benthic faunal cores collected from the 'benthic circle' should be reduced to enable cores to be collected remotely, and to become more in line with the sizes of subtidal samples collected in other harbours. We recommend that a 13.6 cm diam. x 20 cm deep KC Denmark HAPS corer, available at NIWA and trialled during the single site sampling in November 2021, should be used. This will require adjusting of sample sizes to ensure comparability between years in future reports. We consider the core quality to be equal to or better than that collected by divers, and that the procedure will cause less benthic disturbance as the cores can be extracted from the sediments more easily.

- Analysis of benthic community characteristics must be preceded by checking and amalgamating to ensure that species lists from different sampling occasions are validly comparable. This will enable time-series analyses, which is central to all monitoring programmes. Full data sets with reconciled species lists are also required for benthic health score calculations and comparisons.

- A formal comparison should be undertaken to determine the relationship between the results of sediment particle sizes determined using two methods in 2020: laser particle size analyser and wet sieving. Samples were analysed using both methods to allow future standardisation on to wet sieving and a conversion factor to be developed for each site. This follows the recommendation for wet sieving as the preferred method for particle size analysis in future (Hewitt et al. 2019). In 2006, 2011 and 2016 sediment particle size was determined using an Ambivalue Eyetech Combi Particle Size Analyser with a B-lens. The move to wet sieving in future has been recommended as different machine analysers may not produce identical results, are influenced by the lens used in the analysis, and the need to replace aging instruments with other models. A comparison of results from the two methods will enable any limitations of the laser-derived data, which encompasses a more limited particle size fraction (10-500 µm, compared to 0-2000 µm for wet sieving) to be understood, which will be important in evaluations of sediment size changes over time.

- EB2 has very different sediment type and benthic faunal community to the remaining Wellington Harbour sites. Nevertheless, it remains an important component of the monitoring programme as a representative of the state and health of inner Evans Bay, and should be retained. Consideration should be given to establishing a site further towards the main harbour, or conducting a one-off video survey to delineate the location of the muddy/sandy transition in the bay. The latter in particular could be useful for detecting change in the state of Evans Bay in future years.

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6 Glossary of abbreviations and terms

TN	Total nitrogen
TP	Total Phosphorous
TS	Total Sulphur
AIC	Akaike's Information Criterion
ANOSIM	Analysis Of Similarities
ANZG	Australia and New Zealand Guidelines
ARC	Auckland Regional Council (now Auckland Council)
As	Arsenic
BHM	Benthic Health Model
BHMmet	Benthic Health Model based on benthic community response to sediment mud content
BHMmud	Benthic Health Model based on response to sediment-associated copper, lead and zinc concentrations
CAP	canonical analysis of principal coordinates
Cd	Cadmium
Cr	Chromium
Cu	Copper
DISTLM	Distance-based Linear Model
DVG	Default Guideline Value
ECRI	Estuary Condition Risk Indicator
ERC	Environmental Response Criteria
ETI	Estuary Trophic Index
GPS	Global Positioning System
GPS	Global Positioning System
GV-high	Guideline Value-High
GWRC	Greater Wellington Regional Council
GWRC	Greater Wellington Regional Council
Hg	Mercury
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
Ni	Nickel
nMDS	Non-metric Multi-Dimensional Scaling
PAHs	Polycyclic aromatic hydrocarbons

Pb	Lead
PCA	Principal Component Analysis
PERMANOVA	Permutational Multivariate Analysis Of Variance
SIMPER	Similarity Percentages
TBI	Traits Based Index
TOC	Total organic carbon (g/100g dry weight)
Total PAH	Sum of concentrations of 16 USEPA PAH priority pollutants (mg/kg dry weight)
USEPA	United States Environmental Protection Agency
Zn	Zinc

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Appendix A Bivalve and *Echinocardium cordatum* sizes at each site in Wellington Harbour in 2020.

A. Bivalves. For each size class, the total number of individuals collected in all eight cores is given.

	Size class (mm)					
Site and taxa	**<2 mm**	**2-5 mm**	**5-10 mm**	**10-20 mm**	**20-40 mm**	**>40 mm**
WH1B						
Arthritica bifurca	26	5				
Borniola reniformis	12					
Dosinia greyi					2	
Dosinia sp	4					
Ennucula strangeri			6		1	
Linucula sp. 1 (Spencer, 2009)	16	4				
Neilo australis		2				
Thacia vitrea	7		1			
Theora lubrica	76	71	9			
WH2B						
Arthritica bifurca	6	3				
Borniola reniformis	1					
Dosinia greyi	2	1	1		1	
Ennucula strangeri	1	9	1			
Leptomya retiaria	1					
Linucula sp. 1 (Spencer, 2009)	24	2				
Montacuta sp.	1					
Neilo australis	1	6		2		
Thacia vitrea	5		3			
Theora lubrica	39	29	5			
WH3B						
Arthritica bifurca	8					
Dosinia greyi	2	1		1		
Ennucula strangeri		1	2			
Linucula sp. 1 (Spencer, 2009)	15	6				
Neilo australis		2				
Neolepton sp.	2					
Tawera spissa	1					
Thacia vitrea	7			1		
Theora lubrica	27	27	3			
WH4B						
Arthritica bifurca	26	4				
Borniola reniformis	5	19				

	Size class (mm)					
Site and taxa	**<2 mm**	**2-5 mm**	**5-10 mm**	**10-20 mm**	**20-40 mm**	**>40 mm**
Ennucula strangeri		5				
Linucula sp. 1 (Spencer, 2009)	30	4				
Mysella hounselli	1					
Neilo australis		8	1	2		
Thacia vitrea	3					
Theora lubrica	10	32	5			
WH5B						
Arthritica bifurca	5					
Borniola reniformis	2					
Ennucula strangeri	2	2				
Linucula sp. 1 (Spencer, 2009)	21	2				
Neilo australis		1				
Thacia vitrea	1	1				
Theora lubrica	7	16	7			
Zemysina globus					1	
WH9B						
Arthritica bifurca	12	1				
Borniola reniformis	17					
Ennucula strangeri	1		10			
Linucula sp. 1 (Spencer, 2009)	23	1				
Montacuta sp.	1					
Neilo australis	1	5				
Theora lubrica	17	41	10			
WH10B						
Arthritica bifurca	21	1				
Borniola reniformis	7					
Ennucula strangeri	1	5	6			
Linucula sp. 1 (Spencer, 2009)	20	3				
Neilo australis	1	3		1		
Thacia vitrea	3					
Theora lubrica	33	56	10			
WH13B						
Arthritica bifurca	14	1				
Borniola reniformis	1					
Dosinia greyi		1				
Ennucula strangeri		1	4			
Linucula sp. 1 (Spencer, 2009)	18	3				
Montacuta sp	17					

	Size class (mm)					
Site and taxa	**<2 mm**	**2-5 mm**	**5-10 mm**	**10-20 mm**	**20-40 mm**	**>40 mm**
Neilo australis		3		2		
Pratulum pulchellum					1	
Thacia vitrea				1		
Theora lubrica	14	44	3			
WH15B						
Arthritica bifurca	9	2				
Borniola reniformis	3					
Dosinia greyi		1		1	2	
Ennucula strangeri				2		
Linucula sp. 1 (Spencer, 2009)	5					
Neilo australis	1	1			1	
Theora lubrica	9	25	7			
WH17B						
Arthritica bifurca	22	2				
Borniola reniformis	13					
Dosinia greyi		2			1	
Ennucula strangeri	7	5	7			
Linucula sp. 1 (Spencer, 2009)	52	2				
Mysella hounselli	12		1			
Neilo australis	2	5		3		
Scintillona sp.	1		2			
Thacia vitrea	6	1	3			
Theora lubrica	6	22	3			
Zenatia acinaces						1
EB2B						
Arthritica bifurca	20					
Borniola reniformis		1				
Corbula zelandica			1	6		
Dosinia lambata				1		
Hiatula siliquens		2		1		
Leptomya retiaria	14	12	18	25		
Linucula sp. 1 (Spencer, 2009)	1	1	8			
Scintillona sp.	2	2	1			
Tawera spissa		5	2	7		
Thacia vitrea		2		1		
Theora lubrica	12	27	5			
Venerupis largillierti	1	6	10		3	1
Zemysina globus	10	15	1	3	1	

Site and taxa	Size class (mm)					
	<2 mm	2-5 mm	5-10 mm	10-20 mm	20-40 mm	>40 mm
AQ1B						
Arthritica bifurca	47					
Borniola reniformis	2					
Ennucula strangeri		1	1			
Linucula sp. 1 (Spencer, 2009)	9	1				
Neilo australis		2		1		
Pratulum pulchellum		1				
Thacia vitrea		1				
Theora lubrica	24	41	2			
Zemysina globus					1	
AQ2B						
Arthritica bifurca	36	1				
Dosinia greyi					2	
Dosinia sp		1				
Ennucula strangeri	1	2	1			
Linucula sp. 1 (Spencer, 2009)	5	4	1			
Neilo australis	3	2		3		
Tawera spissa	1					
Thacia vitrea	11			1		
Theora lubrica	81	117	4			
LB1B						
Arthritica bifurca	53	12				
Borniola reniformis		3				
Dosinia sp	6					
Ennucula strangeri		7	8	4		
Linucula sp. 1 (Spencer, 2009)	19	5				
Mysella hounselli	2					
Neilo australis	4	2	5	1		
Tawera spissa	6					
Thacia vitrea				4		
Theora lubrica	3	16	7			
LB2B						
Arthritica bifurca	25	7				
Borniola reniformis	4					
Corbula zelandica				1		
Ennucula strangeri	1	1	2			
Ennucula strangei				1		
Linucula sp. 1 (Spencer, 2009)	12					

Site and taxa	Size class (mm) <2 mm	2-5 mm	5-10 mm	10-20 mm	20-40 mm	>40 mm
Neilo australis	1	1		1		
Pratulum pulchellum				2		
Tawera spissa	8	1				
Tawera spissa	1					
Thacia vitrea	18	1				
Theora lubrica	67	151	12			

B. Echinoderms. Sizes of the common heart urchin *Echinocardium cordatum* (to the nearest 0.5 mm). Measurements to the nearest 0.5 mm.

SITE	REP	Width (mm)	Length (mm)
WH1B	3	25.0	26.0
	3	26.0	27.0
	5	25.0	26.0
	5	26.0	27.0
	7	30.0	31.0
WH2B	1	36.5	37.0
	1	32.0	32.0
	4	36.0	36.5
	6	30.0	32.5
	8	30.0	31.5
	8	31.5	32.5
WH3B	3	22.0	23.0
	6	26.0	28.0
	7	25.0	26.0
	8	16.0	17.0
WH5B	5	27.0	29.0
WH9B	2	35.0	36.0
	3	29.0	31.0
	4	25.0	27.0
	6	29.0	31.5
	6	33.5	35.0
	8	29.0	29.0
WH10B	4	30.0	31.0
	5	16.0	17.5
	5	31.0	32.0
	6	28.5	29.0
	7	33.0	33.5

SITE	REP	Width (mm)	Length (mm)
	7	30.5	34.0
	7	28.5	31.5
WH13B	2	33.0	34.0
	3	26.0	27.5
	5	32.0	34.5
	5	31.0	32.0
	5	32.0	32.0
	6	29.0	29.0
	7	27.5	30.5
	8	29.0	31.0
WH15B	1	35.0	38.0
	5	30.0	30.5
	8	31.5	34.5
WH17B	1	30.0	30.0
	7	28.0	30.5
	8	26.0	27.0
	9	28.0	29.0
	10	28.0	30.0
LB1B	1	25.0	27.0
	2	29.0	31.0
	3	26.0	27.0
	3	24.0	25.0
	7	15.0	17.0
AQ1B	2	36.0	36.0
	2	33.0	34.0
	4	31.0	33.0
	7	32.0	35.0
	8	31.0	33.0

Appendix B Reconciling benthic invertebrate data sets collected over the monitoring programme.

Table highlighting differences between the pre-2020 and 2020 taxa lists, and recommendations on how to reconcile for future analysis. Pre-2020 includes monitoring years 2006, 2011 and 2016.

		Abundance (total number)			
	taxa	2006, 2011, 2016	2020	notes	Recommendations
Amphipod	Phoxocephalidae sp. #1	1141	0	Kept separate in analysis	Voucher specimens of Phoxocephalidae sp. #1 could be examined by Rachael Peart to determine their ID (likely to be *Torridoharpinia*). Because there is only one ind. of Phoxocephalidae sp. 2 there is no need to check voucher - unless it is easily found.
	Phoxocephalidae sp. #2	1	0	Kept separate in analysis	
	Amphipod sp. #1 Amphipod sp. #2 Amphipod sp. #6 Amphipod sp. #4 (unid) Amphipod sp. #7 Amphipod sp. #8	14	0	Combined as Amphipod spp.	Voucher specimens from pre-2020 could be examined by Rachael Peart to determine their ID, potentially allowing separation of this group in the analysis and increasing overall diversity. However, total numbers are low.
	Liljeborgia sp. 1 *Amphilochus* sp. 1 *Bemlos*? sp. 1	0	14	IDs confirmed by Rachael Peart	
	Amphipod sp. # 9 (*Torridoharpina hurleyi*)	2	0	'Amphipod sp. # 9 (*Torridoharpina hurleyi*)' from pre 2020 were combined with *Torridoharpinia hurleyi* in the pre-2020 dataset. ID of *Torridoharpinia hurleyi* in 2020 confirmed by Rachel Peart	No action necessary due to only 2 individuals pre-2020
	Torridoharpinia hurleyi	0	1183		
Mollusca	*Erycina parva*	19	0		*Erycina, Lasaea, Borniola* and *Montacuta* are from the same family (Lasaeidae). Voucher specimens of *Erycina parva* and *Lasaea* sp. #1 could be examined by Bruce Marshall to confirm their IDs. *OR* Taxa from this family could be combined in future analyses.
	Lasaea sp. #1	5	0		
	Borniola reniformis	0	90	IDs were confirmed by Vonda Cummings.	
	Montacuta sp.	0	19	IDs were confirmed by Bruce Marshall.	

		Abundance (total number)			
	taxa	2006, 2011, 2016	2020	notes	Recommendations
	Mysella hounselli	0	17	Not found pre-2020. IDs were confirmed by Bruce Marshall.	No action required.
	Tawera spissa	0	32	IDs were confirmed by Vonda Cummings.	No action required.
Cnidaria	*Edwardsia* sp.	0	51	No *Edwardsia* sp. were found prior to the 2020 sampling.	
Ophiuroidea	*Amphipholis squamata*	0	15	Two species of Ophiuroidea were confirmed in the Wellington Harbour samples (*Amphipholis squamata* and *Amphiura rosea*) by Sadie Mills. *Amphipholis squamata* was found at site EB2 only.	Ophiuroidea could be combined in future long-term analyses.
	Amphiura rosea	1444	234		
Oligochaeta	Naididae	0	17	No Oligochaetes were found prior to 2020. ID in 2020 confirmed by Geoff Read.	No action required.
Polychaetes (misc.)	*Hemipodia simplex*	0	35	ID of this Glyceridae polychaete was confirmed by Geoff Read.	
	Prionospio multicristata	0	52	ID of this Spionidae polychaete was confirmed by Geoff Read. This is a new occurrence of this taxa in this monitoring programme; more Spionidae taxa and individuals were found in 2020 than previous years.	No action required.
	Barantolla lepte	0	574	This capitellid polychaete was only found at EB2.	No action required.
	Asychis sp. #1	277	0	*Asychis* sp. #1 and *Asychis asychis*-B were combined as *Asychis asychis*-B in the analysis	Voucher specimens of *Asychis* sp. #1 could be checked by Geoff Read.
	Asychis asychis-B	0	7		
	Macroclymenella stewartensis	22	0		Voucher specimens of *Macroclymenella stewartensis* and *Maldane theodori* could be checked by Geoff Read.
	Maldane theodori	376	0		

		Abundance (total number)			
	taxa	**2006, 2011, 2016**	**2020**	**notes**	**Recommendations**
	Nicomache nicomache-A	0	15	These three Maldanid polychaetes were combined in the 2020 analysis as Maldanidae spp. ID of *Nicomache nicomache*-A was confirmed by Geoff Read. *Macroclymenella stewartensis* was found at EB2 only.	
	Goniada echinulata	17	0		Voucher specimens could be checked by Geoff Read, however numbers are low so this taxa may not have been expected to be found in 2020 by chance.
	Glycinde trifida	3	20	ID was confirmed by Geoff Read.	
	Goniada sp.	0	5	ID was confirmed by Geoff Read.	
	Polynoidae sp. #1	153	0		Voucher specimens of Polynoidae sp. #1 and Polynoidae sp. #2 could be checked by Geoff Read to determine whether either is the *Harmothoe* sp. taxa found in 2020.
	Polynoidae sp. #2	41	0		
	Harmothoe sp.	0	71		
Sipunculid	Sipunculid *sp. #1*	3832	0	Combined as Sipunculid in the analysis.	Voucher specimens could be examined by Geoff Read to assign names to sp. #1, 2 and 3. While not essential, this is recommended due to the very high numbers of individuals found pre-2020.
	Sipunculid *sp. #2*	10	0		
	Sipunculid *sp. #3,*	1	0		
	Sipunculus mundanus	11	0		
	Sipuncula	0	7		
Sabellidae spp.	*Megalomma suspiciens, Sabellidae sp. #1.*	28	0	Combined as Sabellidae spp. in the analysis. 2020 ID's were confirmed by Geoff Read.	Voucher specimens could be examined by Geoff Read to confirm ID, enabling the taxa to be separated in future analyses.
	Euchone limnicola, Euchone pallida, Parasabella aberrans, Sabellidae	0	6		

Appendix C Taxa unique to EB2 in 2020.

Phyla	Class/Order	Family	Taxa
Annelida	Polychaete	Capitellidae	*Barantolla lepte*
Annelida	Polychaete	Capitellidae	*Notomastus* spp.
Annelida	Polychaete	Dorvilleidae	*Schistomeringos* spp.
Annelida	Polychaete	Eunicidae	*Marphysa* sp.
Annelida	Polychaete	Glyceridae	*Glycera ovigera*
Annelida	Polychaete	Glyceridae	*Hemipodia simplex*
Annelida	Polychaeta	Goniadidae	*Glycinde trifida*
Annelida	Polychaeta	Maldanidae	*Euclymene insecta*
Annelida	Polychaeta	Opheliidae	*Armandia maculata*
Annelida	Polychaete	Orbiniidae	*Leodamas cylindrifer*
Annelida	Polychaeta	Oweniidae	*Owenia petersenae*
Annelida	Polychaete	Spionidae	*Boccardia syrtis*
Annelida	Polychaete	Spionidae	*Prionospio australiensis*
Annelida	Polychaete	Terebellidae	*Terebellidae* spp.
Crustacea	Decapoda	Hymenosomatidae	*Halicarcinus varius*
Crustacea	Decapoda	Upogebiidae	*Upogebia hirtifrons*
Chordata	Tunicata		*Tunicata* spp.
Echinodermata	Holothurian	Chiridotidae	*Taeniogyrus dendyi*
Echinodermata	Ophiuroidea	Amphiuridae	*Amphipholis squamata*
Mollusca	Bivalvia	Psammobiidae	*Hiatula siliquens*
Mollusca	Bivalvia	Veneridae	*Dosinia lambata*
Mollusca	Bivalvia	Veneridae	*Venerupis largillieti*
Mollusca	Chitonida	Acanthochitonidae	*Acanthochitona zelandica*
Mollusca	Gastropoda	Calyptraeidae	*Sigapatella tenuis*
Mollusca	Gastropoda	Mangeliidae	*Neoguraleus murdochi*
Mollusca	Gastropoda	Pyramidellidae	*Turbonilla zealandica*
Mollusca	Gastropoda	Trochidae	*Roseaplagis artizona*
Mollusca	Gastropoda	Turritellidae	*Maoricolpus roseus*
Phoronida			Phoronida
Porifera	Demospongiae	Suberitidae	*Suberites cupuloides*

Appendix D Amalgamated taxa and data set updates.

Log of changes made when merging data from pre-2020 and 2020 taxa lists. Pre-2020 includes monitoring years 2006, 2011 and 2016.

Dataset Updates

1. Split 2020 data into Wellington and Porirua datasets "All_WH file and "All_POR" file.
2. Added Site/Year/Replicate header to WH 2020 data

Checking against WH 2020 data and "WH All benthos 2006_2016_NIWA edits"

Confirmed all sites present and combined sheets from previous years (checking all row names the same), removing sites not sampled in 2020. Transferred all to "WH_all_old" tab in "All_WH" file.

To merge old WH datasets only:

- "Polychaeta: unknown" in EB2B sites, not present in other sites. Added into species list to standardise
- Enchytraeidae and Gastropod sp. #1 not present in AQ/LB site data. Added into species list to standardise
- *Pectinaria australis* rows added into AQ/LB and EB dataset.
- unid tunicate (?*Asterocarpa coerulea*), Turbellarian unid, Mysid shrimp, *Sagitta* sp., *Patiriella regularis*, Unid microgastropod, *Cominella maculosa* not present in WH dataset. Add into species list to standardise
- Polychaeta sp.#2, *Scintillona zelandica*, Corophiidae sp.#1 not present in WH or EB dataset. Add into species list to standardise
- Ampeliscidae sp. #1 (WH) and Ampeliscidae sp. #1 AND Crustacea: Ampeliscidae sp. #1 (AQ/LB and EB). Add into species list to standardise
- Axiidae sp. #1 (WH) and Axiidae sp. #1 AND Crustacea: Axiidae sp. #1 (AQ/LB and EB). Add into species list to standardise

To merge the past and current datasets from Wellington Harbour:

All rows with 0 species removed.
Added in Phyla, Class/order, Family columns to both datasets.
Old dataset: *Pripulopsis australis.* Spelling error. Updated to *Priapulopsis australis*
Old dataset: *Chirodota nigra*. Spelling error. Updated to *Chiridota nigra*
Old dataset: *Paelemon affinis*. Spelling error. Updated to *Palaemon affinis*

To combo:

- Echiurid sp. #1 and *Urechis novaezealandiae*. Combined to Echiurid spp.
- *Aphrodita talpa* and *Aphrodita* sp. Combined to *Aphrodita* spp.
- *Notomastus* sp. #1 and *Notomastus* sp. Combined to *Notomastus* spp.
- *Aphelochaeta* sp. #1 and *Aphelochaeta* sp. Combined to *Aphelochaeta* spp.
- *Schistomeringos* sp. #1 (old), *Schistomeringos* sp. (2020) and Dorvilleidae (2020). Combined to: *Schistomeringos* spp. and Dorvilleidae (2020) retained.
- *Glycera lamelliformis* (old) and *Glycera* ?*lamelliformis* (2020). Combined as *G. lamelliformis*
- *Abyssoninoe galatheae* and *Lumbricalus aotearoae* (old) and Lumbrineridae (2020). Combined as Lumbrineridae spp.
- *Asychis* sp.#1 and *Asychis asychis*-B (2020). Combined to *Asychis asychis*-B (c.f. Geoff Read).
- *Axiothella* sp. #1 and *Axiothella axiothella*-B. Combined as *A. axiothella* -B.
- *Macroclymenella stewartensis*, *Maldane theodori* (old) and Maldanidae, *Nicomache nicomache*-A (2020). Combined to Maldanidae spp.
- Nereidae sp.#1 and Nereididae. Combined to Nereididae spp.
- *Drilonereis* sp. #1 (old) and Oenonidae (2020). Combined to Oenonidae spp.
- *Aricidea* sp.#1 and *Aricidea* sp. Combined as *Aricidea* spp.
- *Paradoneis* sp. #1 and *Paradoneis lyra*. Combined to *Paradoneis* spp.
- *Pilargis* sp. #1 and *Pilargis pilargis*-A. Combined to *Pilargis* spp.
- *Lepidonotus* sp .#1 and *Lepidonotus* sp. Combined to *Lepidonotus* spp.
- *Megalomma suspiciens*, Sabellidae sp. #1 (old) and *Euchone limnicola*, *Euchone pallida*, *Parasabella aberrans*, Sabellidae (2020). Combined to Sabellidae spp.
- *Boccardia* (*Paraboccardia*) *syrtis* and *Boccardia syrtis.* Combined to *Boccardia syrtis.*
- *Paraprionospio* sp.#1 and *Paraprionospio* cf *pinnata.* Combined to *Paraprionospio* spp.
- Syllidae sp. #1 (old) and Exogoninae, Syllidae (2020). Combined all to Syllidae spp.
- Terebellidae sp. #1 (old) and *Pista pegma* (2020). Combined to Terebellidae spp.
- *Sipunculus mundanus*, Sipunculid sp. #1, Sipunculid sp. #2, Sipunculid sp. #3 (old) and Sipuncula (2020). Combined all to Sipunculida spp.
- Ampeliscidae sp. #1, Crustacea: Ampeliscidae sp.#1 (old) and *Ampelisca chiltoni* (2020). Combined all to Ampeliscidae spp.

- Phoxocephalidae sp. #1, Phoxocephalidae sp.#2, Amphipod sp. # 9 (*Torridoharpina hurleyi*) (old) and *Torridoharpinia hurleyi* (2020). *Torridoharpina hurleyi* combined. Phoxocephalidae sp. #1, Phoxocephalidae sp.#2, kept separate.
- Amphipod sp. #3 (Oedicerotidae) (old) and *Bathymedon* cf *neozelanicus* (2020). Combined to Oedicerotidae spp.
- Amphipod sp. #1, Amphipod sp. #2, Amphipod sp. #4 (unid), Amphipod sp. #6, Amphipod sp. #7, Amphipod sp. #8 in old dataset. *Amphilochus* sp. 1, *Bemlos*? sp. 1, *Liljeborgia* sp. 1 in 2020 dataset. All combined to Amphipoda spp.
- Copepod sp. #1, Copepod sp. #3 (old) and Harpacticoid copepod (2020). Combined to Copepoda spp.
- *Diastylis* sp.#1, Cumacean sp. #1 (old) and *Cyclaspis* cf *similis*, *Hemileucon* sp., *Leucon* sp. (2020). Combined to Cumacea spp.
- *Jaxea novaezealandiae* and *Jaxea novaezealandiae* (larvae) both in old and 2020 datatset. Combined to *Jaxea novaezealandiae*.
- *Macrophthalmus hirtipes* synonymised (and combined with 2020) to *Hemiplax hirtipes*.
- *Natatolana* sp. #1 (old) and *Natatolana* cf *aotearoa*, *Natatolana rossi*, *Natatolana* sp. (2020). Combined as *Natatolana* spp.
- Gnathiidae sp. #1 (old) and *Gnathia* sp. (2020). Combined as Gnathiidae spp.
- Ostracoda sp. #1-#12 (old) and Ostracoda sp. (2020). Combined to Ostracoda spp.
- Tanaid sp. #1 (old) and *Apseudes* "*novaezealandiae*", *Paratanais paraoa* (Bird, 2011), *Pseudotanais* "*erysarthron*" (2020). Combined to Tanaidacea spp.
- *Scintillona zelandica* (old) and *Scintillona* sp. (2020). Combined to *Scintillona zelandica*
- *Arthritica* sp. (old) and *Arthritica bifurca* (2020). Combined to *Arthritica* spp.
- *Leptomya retiara retiara* and *Leptomya retiara*. Combined to *Leptomya retiara*.
- *Dosina zelandica* (old) and *Dosinia greyi*, *Dosinia lambata* (both), *Dosinia* sp. (2020). *Dosinia greyi*, *Dosinia lambata* kept and *Dosina zelandica* and *Dosinia* sp. combined to *Dosinia* spp.
- *Maoricolpus roseus* and *Maoricolpus roseus roseus*. Combined to *Maoricolpus roseus.*
- Nemertea sp #1-#12 (old) and Nemertea (2020). Combine to Nemertea spp.
- unid tunicate (?*Asterocarpa coerulea*) (old) and Tunicata (2020). Combine to Tunicata spp.

Additional changes once Bruce Marshall Had ID's the bivalve and gastropod vouchers:

Cantharidus sp. changed to *Roseaplagis artizona*.
Nucula nitidula and *Linucula hartvigiana* combined and renamed *Linucula* sp. 1.
Thyasiridae (voucher from samples WH04B.2, WH05B.1) and *Montacuta* (voucher from WH017B) ID

as *Mysella hounselli*
Nozeba sp. updated to *Nozeba emarginata* (and combined with old data)
Philine sp. updated to *Philine auroformis* (and combined with old data)
Turbonilla sp. updated to *Turbonilla zealandica*
82 *Thracia vitraea* specimens confirmed as *T. vitrea* (and combined with old data)
Zalipasis lissa updated to *Hyalogyrina* sp. aff. *glabra*.
Unlogged single specimen found at WH1B.6 and added to datasheet as *Eulimella coena*.
Venerupsis largillierti in WH03B.3 and WH03B.8 is *Neolepton* sp. (2 indiv total). All the others *Venerupsis largillierti* (21 indiv. total). No change to previous years ID.

Same taxa names in 2020 data and prior data set, so combined:

Ampharete kerguelensis
Heteromastus filiformis
Cossura consimilis
Glycinde trifida
Ophiodromus angustifrons unaccepted. Changed to Oxydromus angustifrons and combined
Euclymene insecta
Aglaophamus verrilli
Onuphis aucklandensis
Armandia maculate
Phylo novazealandiae
Owenia petersenae
Labiosthenolepis laevis
Carazziella phillipensis
Prionospio yuriel
Terebellides narribri
Jaxea novaezealandiae
Hemiplax hirtipes
Upogebia hirtifrons
Neommatocarcinus huttoni
Echinocardium cordatum
Pentadactyla longidentis
Amphiura rosea
Pratulum pulchellum
Corbula zelandica
Zenatia ainaces
Neilo australis
Ennucula strangei
Linucula hartvigiana
Hiatula siliquens
Theora lubrica
Zemysina globus
Dosinia greyi
Dosinia lambata
Venerupis largillieti
Xymene plebeius

Nematoda
Priapulopsis australis

Other Taxa name changes

Notomithrax sp. Mis-labelled as “Annelida Polychaeta”. Relabelled to “Arthropoda Decapoda” (2020).
Polychaeta: unknown (old) think we just have to leave this one as is!
Goniada sp. Mis-labelled as Crustacea Decopoda (2020), Relabelled to Annelida Polychaeta.
Periclimenes yaldwyni labelled as Echinodermata Holothurian. Relabelled as Crustacea Decapoda (2020).
Leionucula strangei (old) updated to *Ennucula strangei* and combined
Soletellina siliquens updated to *Hiatula siliquens* and combined
Diplodonta globus updated to *Zemysina globus* and combined
Ruditapes largillierti updated to *Venerupis largillierti* and combined
Trochidae and Turritellidae (2020) labelled as Bivalvia, changed to Gastropoda

Appendix E Spearman's rho correlation coefficients and probability values for the relationship between sediment characteristics and time at each site in Wellington Harbour.

Values in **purple** indicate strong correlations (Rho >0.9), blue indicates moderate correlations (Rho 0.7-0.9) and values in orange indicate weak correlations (Rho 0.5-0.7). Values <0.5 (in black) are unlikely to be ecologically significant (Hewitt 2019). Italicised and bolded p-values indicate statistically significant correlations. N=4 sampling times for all WH sites (2006, 2011, 2016, 2020), N=3 for AQ and LB sites (2011, 2016, 2020).

Site		10-63 µm sediments	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	PAH	HMW PAH	TOC
WH1	Rho	0.80	**-0.95**	***-1.00***	0.80	-0.40	0.00	0.00	0.80	-0.40	-0.60	-0.20	***-1.00***
	Pr > |r|	0.2000	0.0513	***<.0001***	0.2000	0.6000	1.0000	1.0000	0.2000	0.6000	0.4000	0.8000	***<.0001***
WH2	Rho	0.80	0.40	-0.80	0.00	-0.80	***-1.00***	-0.40	-0.32	-0.40	-0.60	-0.20	***-1.00***
	Pr > |r|	0.2000	0.6000	0.2000	1.0000	0.2000	***<.0001***	0.6000	0.6838	0.6000	0.4000	0.8000	***<.0001***
WH3	Rho	0.00	***1.00***	-0.20	0.80	-0.40	-0.80	-0.40	0.60	-0.40	0.00	0.00	-0.80
	Pr > |r|	1.0000	***<.0001***	0.8000	0.2000	0.6000	0.2000	0.6000	0.4000	0.6000	1.0000	1.0000	0.2000
WH4	Rho	***-1.00***	-0.60	-0.40	-0.20	***-1.00***	***-1.00***	-0.40	-0.40	-0.80	-0.80	0.40	-0.80
	Pr > |r|	***<.0001***	0.4000	0.6000	0.8000	***<.0001***	***<.0001***	0.6000	0.6000	0.2000	0.2000	0.6000	0.2000
WH5	Rho	0.80	-0.60	-0.80	0.00	-0.40	-0.63	-0.40	-0.80	-0.40	-0.60	-0.20	-0.80
	Pr > |r|	0.2000	0.4000	0.2000	1.0000	0.6000	0.3675	0.6000	0.2000	0.6000	0.4000	0.8000	0.2000
WH9	Rho	0.80	0.00	***-1.00***	-0.40	-0.40	-0.80	-0.80	0.00	-0.40	-0.80	-0.60	-0.80
	Pr > |r|	0.2000	1.0000	***<.0001***	0.6000	0.6000	0.2000	0.2000	1.0000	0.6000	0.2000	0.4000	0.2000
WH10	Rho	0.80	-0.40	-0.40	0.63	-0.40	-0.40	-0.40	0.00	0.20	-0.80	0.80	-0.63
	Pr > |r|	0.2000	0.6000	0.6000	0.3675	0.6000	0.6000	0.6000	1.0000	0.8000	0.2000	0.2000	0.3675
WH13	Rho	0.40	-0.74	-0.40	-0.80	-0.40	**-0.95**	-0.80	0.00	-0.40	-0.80	0.40	-0.40
	Pr > |r|	0.6000	0.2621	0.6000	0.2000	0.6000	0.0513	0.2000	1.0000	0.6000	0.2000	0.6000	0.6000
WH15	Rho	***1.00***	-0.20	-0.40	0.00	-0.80	-0.60	0.40	0.40	0.40	0.00	0.20	0.00

Site		10-63 μm sediments	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	PAH	HMW PAH	TOC
	Pr > |r|	*<.0001*	0.8000	0.6000	1.0000	0.2000	0.4000	0.6000	0.6000	0.6000	1.0000	0.8000	1.0000
WH17	Rho	-0.40	***-1.00***	0.40	0.00	-0.80	-0.40	0.60	-0.80	-0.40	-0.40	-0.20	-1.00
	Pr > |r|	0.6000	*<.0001*	0.6000	1.0000	0.2000	0.6000	0.4000	0.2000	0.6000	0.6000	0.8000	*<.0001*
AQ1	Rho	***-1.00***	0.50	***-1.00***	-0.50	0.50	-0.50	-0.50	0.50	0.50	0.50	0.50	***-1.00***
	Pr > |r|	*<.0001*	0.6667	*<.0001*	0.6667	0.6667	0.6667	0.6667	0.6667	0.6667	0.6667	0.6667	*<.0001*
AQ2	Rho	0.50	***-1.00***	-0.50	-0.50	***1.00***	***-1.00***	***1.00***	***-1.00***	0.50	0.50	0.50	***-1.00***
	Pr > |r|	0.6667	*<.0001*	0.6667	0.6667	*<.0001*	*<.0001*	*<.0001*	*<.0001*	0.6667	0.6667	0.6667	*<.0001*
LB1	Rho	***1.00***	0.50	***-1.00***	0.50	***1.00***	0.50	***1.00***	0.50	***1.00***	-0.50	-0.50	***1.00***
	Pr > |r|	*<.0001*	0.6667	*<.0001*	0.6667	*<.0001*	0.6667	*<.0001*	0.6667	*<.0001*	0.6667	0.6667	*<.0001*
LB2	Rho	-0.50	***1.00***	***-1.00***	-0.50	***-1.00***	0.50	-0.50	0.00	-0.50	0.50	0.50	-0.50
	Pr > |r|	0.6667	*<.0001*	*<.0001*	0.6667	*<.0001*	0.6667	0.6667	1.0000	0.6667	0.6667	0.6667	0.6667
Strong increase		2	2	0	0	2	0	2	0	1	0	0	1
Strong decrease		2	2	5	0	2	3	0	1	0	0	0	5