Te Awarua-o-Porirua Harbour subtidal sediment quality monitoring

Results from the 2020 survey

Prepared for Greater Wellington Regional Council

December 2021

Prepared by:
Vonda Cummings
Jane Halliday
Greg Olsen
Rachel Hale
Barry Greenfield
Sarah Hailes
Judi Hewitt

For any information regarding this report please contact:
Vonda Cummings
Principal Scientist - Marine Ecology
+64-4-386 0602
vonda.cummings@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No:	2021309WN
Report date:	September 2021
NIWA Project:	WRC20304

Quality Assurance Statement		
	Reviewed by:	Drew Lohrer
	Formatting checked by:	Jess Moffat
	Approved for release by:	Judy Sutherland

Contents

Tables

Figures

Executive summary

In 2020, the Greater Wellington Regional Council (GWRC) contracted NIWA to collect, prepare and process marine sediment samples from five subtidal sites in Te Awarua-o-Porirua Harbour as part of a long-term assessment of benthic community health and sediment quality.

Samples were collected at sites in the Pāuatahanui (PAH) and Onepoto (POR) Arms of Porirua Harbour in November 2020. PAH1 is located off Browns Bay, PAH2 is near Duck Creek and PAH3 off Camborne. POR1 and POR2 are in the inner Onepoto Arm. Sediments were analysed to determine benthic infaunal community composition, particle size distributions and concentrations of selected metal and metalloid contaminants, total organic carbon (TOC) and nutrients (total phosphorus, total nitrogen, total sulphur).

Mud constituted 66-97% of the sediment at the two sites in the Onepoto Arm (POR1 and POR2) and at two sites in the Pāuatahanui Arm (PAH1 and PAH2), while a mixture of mud and fine sand was found at the third Pāuatahanui Arm site (PAH3, 41% mud and 59% fine sand). Organic matter content was very similar across sites, ranging from 4.6-8.0%.

Analysis of a variety of metal and metalloid sediment contaminants revealed that no sites exceeded guideline concentrations for arsenic, cadmium, chromium, nickel or mercury, although mercury was close to exceeding default guideline values (DGV) at the two Onepoto Arm sites (POR1 and POR2). These two sites exceeded the Auckland Regional Council (ARC) Amber guideline concentrations for lead and zinc. The ARC Amber copper guideline was also exceeded at POR1 and it was very close to exceedance levels at POR2. No guidelines were exceeded at sites within the Pāuatahanui Arm.

Mean total organic carbon (TOC), nutrient (total nitrogen and total phosphorus) and percentage mud content of the sediments in 2020 was evaluated against the New Zealand Estuary Trophic Index (ETI) eutrophication guidelines and the Estuary Condition Risk Indicator (ECRI) Ratings for intertidal sites. TOC concentrations varied around the harbour, with the highest levels recorded in the two Onepoto Arm sites. PAH3 had the lowest percentage of TOC and was rated 'good' on the ETI and 'low risk' on the estuary condition rating. TOC ratings at PAH1, PAH2 and POR2 were 'fair'/'moderate risk', and POR1 was 'poor/high risk'. Sediment phosphorus levels were 'poor'/'high risk' at the Onepoto Arm sites and at Pāuatahanui Arm Site 1, but 'fair/moderate risk' at PAH2 and PAH3. Sediment nitrogen levels were 'fair'/'moderate risk' at all five sites. All sites are considered 'poor/high risk' relative to their percent mud content (all >>25% guideline).

A total of 66 taxa were identified across Te Awarua-o-Porirua Harbour in 2020; 57 were collected from the Pāuatahanui Arm, and 41 from the Onepoto Arm. The number of taxa was very similar across sites, ranging from 14-18 per core on average. The dominant taxa were mostly polychaetes and bivalves, with amphipod crustaceans and tanaids also common at some sites. While many of the same taxa were found across the different sites, each of the five sites had compositionally distinct communities. Numbers of individuals were about twice as high at the Onepoto Arm sites (average of 297 and 239 individuals per core at POR1 and POR2, respectively) than at the Pāuatahanui Arm sites (106-185 per core). Shannon diversity index (an index reflective of taxa richness and evenness) was lower at sites in the Onepoto Arm than in the Pāuatahanui Arm, and highest overall at PAH3.

Benthic health assessments designed for use in intertidal situations were used to assess the relative health status of the shallow subtidal invertebrate communities at the different sites. The Traits Based Index (TBI), based on biological traits of the benthic taxa, classified two of the Pāuatahanui Arm sites

(PAH1, PAH3) and one Onepoto Arm site (POR1) as having ‘high’ functional redundancy health scores in 2020. PAH2 had an ‘intermediate’ health score and POR2, the northern site in the Onepoto Arm, was on the borderline between ‘intermediate’ and ‘low’ functional redundancy.

Although high mud content is generally associated with low taxa richness and concomitantly low TBI scores in intertidal habitats, some of the muddiest subtidal seafloor habitats in Porirua Harbour support a relatively high abundance and diversity of macrofauna (e.g. POR1, 93% mud) and have TBI scores reflective of high functional redundancy. Other very muddy sites with similar diversity and abundance (e.g. POR2, 97% mud) have low/intermediate TBI scores. It is probably unwise to put too much weight on the TBI scores reported here until the applicability of this index can be tested and validated in the subtidal zone (work that is ongoing at NIWA at present).

Two benthic health models (BHM) used to track the health of New Zealand’s intertidal estuarine benthic communities in response to sedimentation (‘BHMmud’), and contamination with lead, copper and zinc (‘BHMmetal’) were trialled on this subtidal sampling programme. The BHMmud classified PAH1, PAH3 and POR2 as ‘moderately healthy’ and one site in each arm – PAH2 and POR1 – as in ‘poor health’ based on the mud content recorded. The BHMmet model indicated that while PAH1 was in ‘moderate health’ in 2020, the four remaining sites were in ‘poor health’. The Porirua BMH scores fit well with their measured environmental variables; when the BHMmud scores were checked against the actual percent mud concentrations measured at each of the benthic sites, PAH3 and POR2 displayed good fits and the remaining sites reasonable fits. For the BHMmet scores all sites displayed good fits with the measured concentrations of copper, lead and zinc. Nevertheless, the fact that PAH2 and PAH3 sites scored ‘poor’ for BHMmet when neither exceeded guideline concentrations, indicates that these models require validation for subtidal communities.

Two linear models were used to investigate correlations of sediment characteristics with benthic community composition in 2020. TOC was consistently identified as having a strong influence, explaining ~23% of the variation in community composition. Several other sediment variables were also important, but a number of them were strongly correlated with each other, which influenced the final models and their interpretability. The first model revealed that total sulphur, TOC and percentage mud together explained 83% of the variation in community composition between sites. The Pāuatahanui Arm sites were influenced by total sulphur, while the Onepoto Arm sites were influenced by mud (each constituted >90%). In the second model, arsenic, TOC and total phosphorous together explained 87% of the variation in community composition.

In general, the two sites in the Onepoto Arm were in poorer health than those in the Pāuatahanui Arm, due to their exceedances of contaminant and nutrient level guidelines and their very high concentrations of muddy sediments. However, the benthic communities at all sites contained a mix of taxa types (around 15 taxa per core), from taxa sensitive to mud and organic enrichment to mud-loving species.

Benthic community composition has changed at all sites since the sampling began 17 years ago, with the temporal patterns similar across sites and the communities remaining distinct from each other. This indicates that long-term (since monitoring began) pressures on the harbour are general in nature and do not appear to be localised in a particular region or Arm. The numbers of individuals are more variable over time than the number of taxa, particularly at PAH1 and PAH2. We are unable to comment on short term changes at specific sites (e.g. resulting from rainfall or storm events) due to the infrequent sampling.

Concentrations of fine sediments (10-63 µm) have decreased slightly (improved) over time at PAH3, POR1 and POR2. Average concentrations of lead have also declined at these sites, as have copper in sediments at PAH1, PAH3 and POR1. While there is difficulty with statistically comparing changes over time with only a few data points (at least 10 are recommended, cf. six available here to date) and no strong conclusions can be drawn, these declines are encouraging.

Recommendations

- The monitoring programme should continue with its present methodologies, with one exception. The size of the benthic faunal cores collected from the 'benthic circle' should be reduced to enable cores to be collected using a remote corer, and to become more in line with the smaller sizes of subtidal samples collected in other harbours. This will require adjusting of sample sizes in future analyses to ensure comparability between years.
- Sampling should occur more frequently and at regular intervals. At least one site, and preferably two (i.e. one site in each of the Onepoto and Pāuatahanui Arms) should be sampled annually. Inclusion of these sentinel sites will provide greater temporal resolution and thus strengthen the ability of the monitoring programme to detect change over time.
- All five sites should be sampled at least every four years and ideally every three years. Sampling could also be aligned with timing of Wellington Harbour subtidal monitoring and/or Porirua intertidal monitoring.
- Voucher specimens from previous sampling years should be examined by taxonomic experts to confirm their identifications, enabling the taxa lists across the monitored period to be better aligned and reducing the loss of taxonomic resolution when the data sets from different years are combined. Better taxonomic resolution will result in fewer datapoints being lost when datasets are aligned. Taxa to be resolved include a number of polychaetes, as well as amphipods and oligochaetes.
- Analysis of benthic community characteristics should use amalgamated species lists for temporal comparison. Each full data set should be utilised for benthic health assessments, where diversity information is particularly important.
- A formal analysis should be undertaken to understand the relationship between the results of sediment particle sizes determined using two methods in 2020: laser particle size analyser and wet sieving. In previous years sediment particle size was determined only using the laser particle size analyser. On future sampling dates wet sieving will be the preferred method as different analyser machines are in use over time and may not produce comparable results. This comparison will enable any limitations of the laser-derived data from early years to be understood and confidently used in evaluations of sediment size changes over time.

1 Introduction

Greater Wellington Regional Council (GWRC) commissioned NIWA to conduct a subtidal survey of sediments and benthos from Te Awarua-o-Porirua Harbour (Porirua Harbour). This survey, which was conducted in November 2020, monitors benthic faunal community health and sediment quality within the harbour. It forms part of a long-term State of the Environment assessment of Porirua Harbour by GWRC.

This work includes sampling at specified sites in the Pāuatahanui and Onepoto Arms of Porirua Harbour, using collection and processing methods employed by Stephenson et al. (2008) for the same study on five previous occasions. This report presents the results of the sixth survey of Porirua Harbour subtidal sediment quality; previous surveys were undertaken in May 2004, October 2005, November 2008, November/December 2010, and November 2015 (Williamson et al. 2005, Stephenson & Mills 2006, Milne et al. 2009, Oliver & Conwell 2014, Conwell et al. 2017).

This report describes the sampling methods used to quantify the benthic community, along with a brief description of methods used for determining particle size and contaminant concentrations of associated sediments. It then provides an evaluation of the health status of the Te Awarua-o-Porirua Harbour subtidal benthos and sediment in 2020, and of changes over time and recommendations for future monitoring.

2 Methods

2.1 2020 Sample Collection

Subtidal sediment samples were collected from five Porirua Harbour sites by NIWA divers, on 12th and 20th November 2020 (Figure 2-1, Table 2-1). Three sites are located in the Pāuatahanui Arm (PAH1, PAH2, PAH3) and two in the Onepoto Arm (POR1, POR2).

Figure 2-1: Map of Porirua Harbour showing locations of the subtidal sites sampled in November 2020. Sites in the Pāuatahanui Arm are indicated using the prefix 'PAH' and sites in the Onepoto Arm using 'POR'.

Site	Location	Date	Position (NZTM coordinates)		Depth[1] (m)
			Easting	Northing	
PAH1 PAH1B	Pāuatahanui Arm, off Browns Bay	12/11/2020 12/11/2020	1758157 1758136	5448052 5448074	2.0
PAH2 PAH2B	Pāuatahanui Arm, off Duck Creek	12/11/2020 12/11/2020	1759727 1759759	5448139 5448116	1.7
PAH3 PAH3B	Pāuatahanui Arm, off Camborne	20/11/2020 20/11/2020	1758151 1758154	5449206 5449222	1.7
POR1 POR1B	Onepoto Arm South	20/11/2020 20/11/2020	1754864 1754834	5445871 5445890	2.0
POR2 POR2B	Onepoto Arm North	20/11/2020 20/11/2020	1755179 1755158	5446506 5446538	2.8

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

B = Benthic fauna collection area

Sampling procedures followed prescribed methodologies previously used for sampling in Porirua Harbour in 2004, 2005, 2008, 2010 and 2015 (Olsen et al. 2017). Some modifications to the methods had been implemented by GWRC in 2015, including (i) the analysis of three replicate sediment samples (reduced from five replicates in previous years) and (ii) addition of analysis for Total Nitrogen, Total Sulphur and Total Phosphorus.

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.

From each quadrant of the **benthic circle**, two 200 mm diameter x 250 mm deep cores were taken for benthic fauna (total of eight cores per site) (Figure 2-1). One sediment core (50 mm diameter x 120 mm deep) was also collected for particle size analysis (Figure 2-1). The sediment corers consisted of a screw-top polyethylene bottle, with the bottom cut off and replaced with a plastic insert.

Within the 20 m **sediment circle**, a total of fifteen 50 mm diam. x 120 mm deep sediment cores were collected (three or four cores from each quadrant; Figure 2-1). All sediment cores were kept upright in a specially designed crate and brought to the surface (Figure 2-4), where they were then placed in an insulated bin containing icepacks for transport to the laboratory.

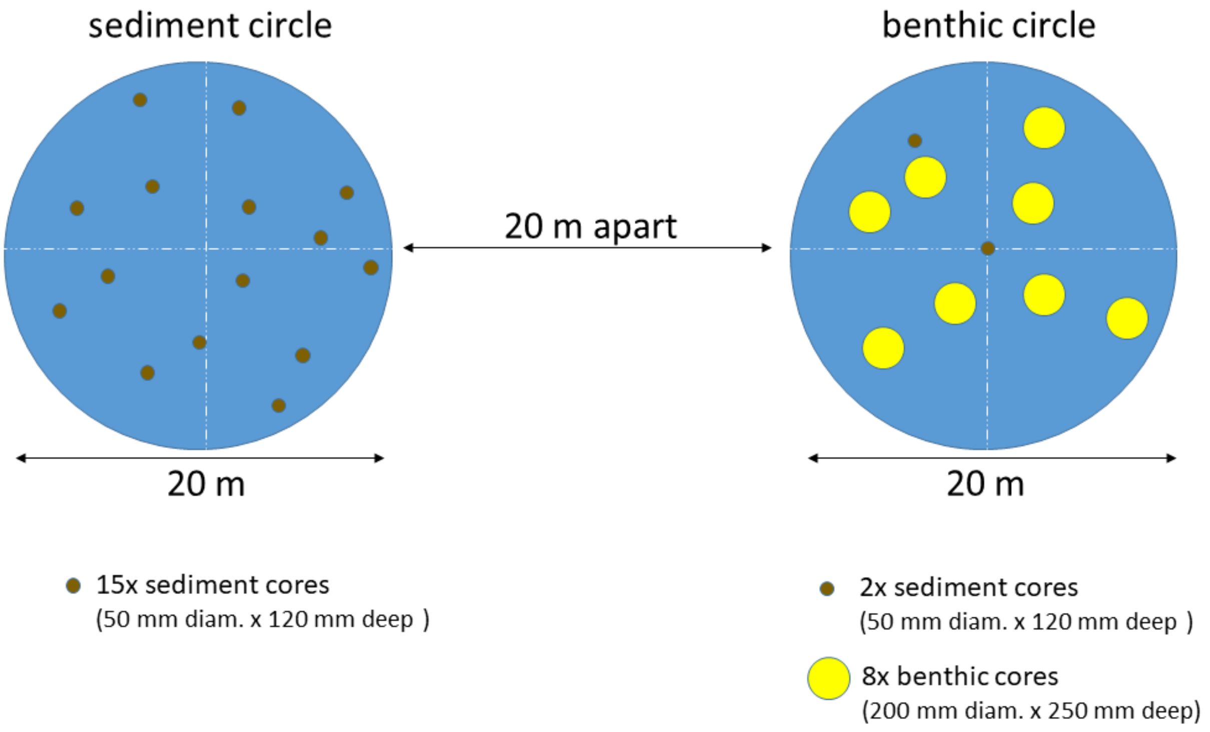

Figure 2-2: Schematic of subtidal sampling methodology followed for collection of sediment chemistry and benthic faunal samples from Porirua Harbour in 2020. Not to scale.

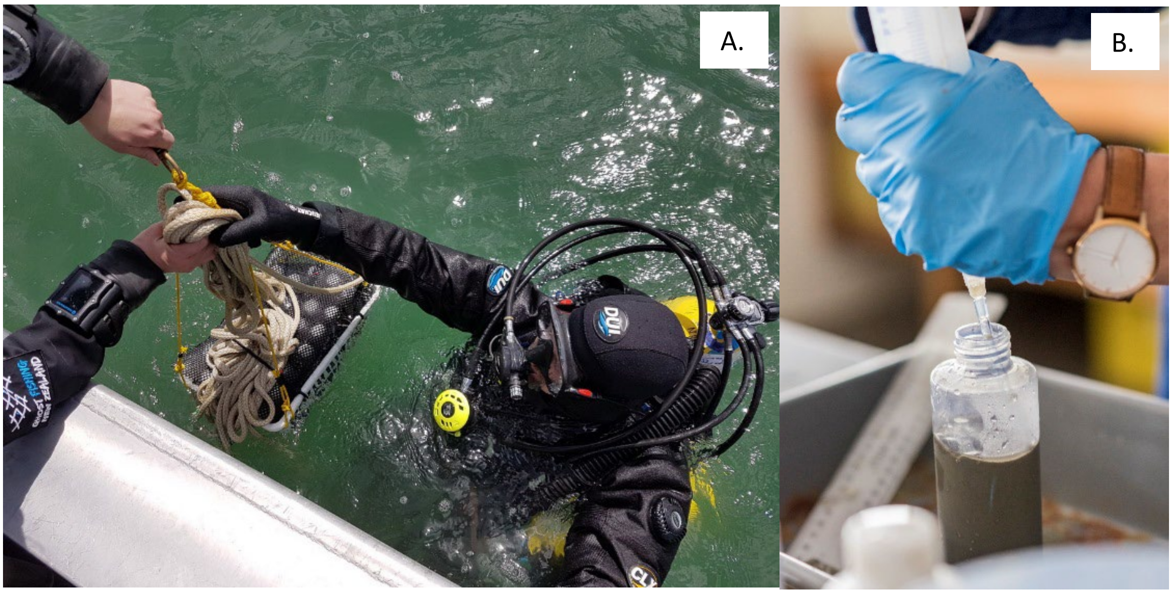

Figure 2-3: Examples of sediment cores collected from Wellington Harbour. A. Crate of sediment cores being transported to the boat by diver after collection (photo: Peter Marriott, NIWA); B. Seawater being carefully syringed off the core surface prior to extrusion and sectioning (photo: Dave Allen, NIWA). Only the top 30 mm of sediment was collected for sediment chemistry and particle size analyses.

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 (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 these counts and identifications were checked in one sample from every site by another staff member.

Voucher specimens of each taxa were retained from a number of sites. All voucher specimens were given to specialist taxonomists to confirm their identification. Voucher specimens were then set aside for long term preservation and research with the NIWA National Invertebrate Collection, and a set of photos taken of each taxa. The taxonomic vouchers and photos will 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 2-4).

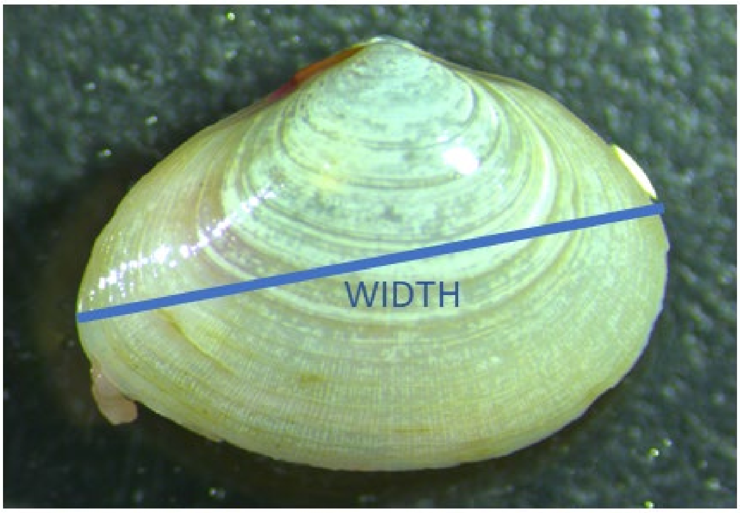

Figure 2-4: **Bivalve measurements.** Bivalves were measured as shown by the blue line overlaid on this image of the bivalve *Leptomya retiaria* (photo: Barry Greenfield).

2.2.2 Sediment characteristics

Sediment cores were stored upright in a refrigerator at 4°C for a minimum of 12 hours after collection 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 from each core was collected. The 15 **sediment circle** samples from each site were randomly divided into three sets of five cores. These groups became the three replicate composite samples for that site and the composite samples were frozen in polyethylene bags. The **benthic circle** sample was similarly frozen in a polyethylene bag.

Frozen sediments from all five 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 an Elkay 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. For Porirua Harbour subtidal sediments, ≥99% of the sample was <500 µm. In this case, sieving reduces the variability associated with the presence of any large debris, which can be significant in some samples, while retaining sufficient original sample to allow analysis of the contaminants.

The sediment circle samples were analysed for particle size, total recoverable metals, total organic carbon (TOC) and nutrients. The benthic circle samples were analysed for particle size and total 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 2004, 2005, 2008, 2010 and 2015 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 matter 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.

Total Nitrogen (TN), Total Sulphur (TS) and Total Phosphorus (TP) concentrations in sediment

Total Nitrogen (TN), Total Sulphus (TS) and Total Phosphorus (TP) concentrations were determined from three replicate <500 µm fraction sediment samples at each of the five chemistry sites. TS was also determined for the single sample of freeze-dried <500 µm sieved sediment from each of the five biology sites. TN and TP were analysed by Hill Laboratories and TS was analysed by SGS Waihi (subcontracted by Hill Laboratories).

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[1]:

- The default guideline values (DGV) (formerly ANZECC ISQG-Low, TEL[2] 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[3] 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 – 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;

[1] http://www.waterquality.gov.au/anz-guidelines
[2] 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).
[3] 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).

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

The 2020 data set was merged with data from previous years (i.e. 2004, 2005, 2008, 2010, and 2015). Modifications were made to the taxa list to ensure that, if comparisons were made between the different reports/years, that the same level of taxonomic resolution was compared over time. This was necessary due to the different approaches/expertise from the three different teams that have conducted identifications since the monitoring programme was initiated in 2004. This involved merging several species to higher taxonomic levels (e.g. amphipods), as detailed in a separate summary document supplied to GWRC (Appendix C). All of the univariate and multivariate analyses were conducted on this 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), taxa 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 Bray-Curtis similarities of untransformed and square root transformed[4] count data. Spatial differences between sites were analysed using analysis of similarities (ANOSIM). The individual taxa contributing to the community differences between sites were identified using the similarity percentages procedure, SIMPER (Clarke et al. 2014).

Environmental correlates 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 2015 data (Hewitt

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

2019) we used forward selection with Akaike's Information Criterion (AIC) as the stopping criterion, 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 matter content; see also Table 3-1 below) and chemical contaminants (metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc) along with TOC, TS, TP and TN; see also Table 3-2. With only five sites, only three variables at a time could be tested and used in the analysis. Similar to the analysis in Hewitt (2019), the highly correlated variables copper, lead and zinc, were replaced by the first axis of a PCA ordination which represented 98.5% of the variability.

Communities over time

Changes in numbers of taxa and individuals, Shannon diversity and selected taxa at each site, were examined graphically across the four years of the sampling programme. Community composition over 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 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 (Appendix C). An index based on the sensitivities of different trait groups 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).

The TBI was developed from intertidal estuarine data in the Auckland Region and 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.

Although the TBI has not been explicitly validated in the subtidal realm yet, TBI scores can be calculated using subtidal macroinvertebrate community data sets. Here we use it as an indication of the relative health status of the different sites sampled in Porirua Harbour, noting also that the subtidal sites in this harbour are very shallow (<3 m at mean low water neap tide; Table 2-1).

Benthic Health Model (BHM). Benthic health models have been developed to track the health of New Zealand estuarine intertidal benthic communities in response to two key coastal stressors: terrestrial sedimentation and heavy metal contamination (Clark et al. 2020). The outputs of the BHMs can be simplified into a five-category health score system, 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. As described in Section 2.4.1, separate calculations were made using the full 2020 data set and the combined 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

2.4.1 Sediment health

GWRC requested an evaluation of the Porirua sites against the New Zealand Estuary Trophic Index (ETI) (Robertson et al. 2016a, b), and the Estuary Condition Risk Indicator (ECRI) Rating (Robertson & Stevenson 2015). These indices have been developed for intertidal conditions and their applicability to subtidal sites is unknown; however, equivalent indices for subtidal sites do not yet exist.

Nutrient concentrations (TN, TP), along with percent mud, were evaluated against levels classified for intertidal areas using the ETI and the ECRI Rating). The ETI provides guidelines on where an estuary is positioned on an eutrophication gradient, and classifies the sediments as 'very good', 'good', 'fair' or 'poor', while the ECRI rates the sediments from 'low' to 'high' risk. Along with the general indicator variables TN, TP and percent mud evaluated in this report, other secondary variables (e.g. redox layer depth, the coastal marine benthic index AMBI) are also usually included to determine the ETI. Redox layer depth was not measured for these subtidal samples and we instead adopted the indicator bands used for Porirua Harbour intertidal sites in Forrest et al. (2020). These bands were based on site specific thresholds as described in Robertson et al. (2016b), that had been refined for percent mud as described by Robertson et al. (2016c). There are currently no available risk ratings set out for TS.

2.4.2 Sediment characteristics over time

Changes in sediment characteristics (total metals, TOC, and 10-63 μm sediment particles determined via laser analyser) were examined over time using Spearman rho correlation analysis, conducted in SAS (PROC CORR; SAS 9.4). Nutrients were not included in this analysis as they were only introduced into the monitoring programme in 2015.

The potential for overall changes in sediment characteristics was also assessed by comparing the pattern of dissimilarity (Euclidian dissimilarity matrices) between the sites in 2004 and 2020, 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

In 2020 the sediment particle size (determined by wet sieving) in the biology sampling circle was predominantly mud at four sites, ranging from 66-97% (Table 3-1). A mixture of mud and fine sand was recorded at PAH3 (41% and 59%, respectively) (Table 3-1). The mud at these sites comprised 34-77% silt and 7-20% clay (Table 3-1). Organic matter content was high and similar across sites, ranging from 4.6-8.0% (Table 3-1).

The same description of the sediment particle size holds for the chemistry circles at each site determined by wet sieving (Table 3-1). PAH3 sediments were a mixture of mud and fine sand (48% and 50%, respectively), while the remaining sites were predominantly mud (61-94%) (Table 3-1). Organic matter content was high and similar across the chemistry sites (4.0-8.1%) (Table 3-1).

This comparison confirms that sediment conditions were similar across both 20 m diam. sampling circles, which were located 20 m apart (Figure 2-2).

Table 3-1: Summary of particle size distributions from all the biology (identified with 'B' suffix, N=1) and sediment chemistry (no suffix, N = 3) sampling circles at each Porirua Harbour site in 2020. Particle sizes were determined using wet sieving. Data modified from Tables 3-9 and 3-10 in Olsen et al. (2021).

GWRC Site	Grain size distribution (µm) % composition							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									
PAH 1B	13.00	53.36	25.47	7.19	0.74	0.23	0.00	6.7	66.4
PAH 2B	20.29	61.56	16.95	0.87	0.09	0.26	0.00	7.9	81.9
PAH 3B	6.67	33.95	44.95	13.51	0.75	0.17	0.00	4.6	40.6
POR 1B	20.31	72.07	6.49	0.78	0.18	0.17	0.00	5.6	92.4
POR 2B	19.11	77.41	2.64	0.68	0.09	0.07	0.00	8.3	96.5
B. Sediment chemistry circle									
PAH 1	11.08	49.48	29.21	9.06	0.95	0.14	0.08	6.2	60.6
PAH 2	20.53	63.47	14.99	0.84	0.14	0.04	0.00	7.7	84.0
PAH 3	10.52	37.73	37.79	11.85	1.10	0.24	0.77	4.0	48.3
POR 1	18.05	74.18	6.37	1.18	0.12	0.09	0.02	8.1	92.2
POR 2	20.43	73.87	3.96	1.05	0.10	0.06	0.53	6.8	94.3

3.1.2 Sediment contaminants

There were no guideline exceedances for any of the metal and metalloid contaminants in sediments at the three sites within the Pāuatahanui Arm of Porirua Harbour (Table 3-2).

Both Onepoto Arm sites exceeded ARC amber concentrations for lead and zinc, and POR1 sediments also exceeded copper guidelines (Table 3-2); POR2 was very close to exceeding copper guidelines

(Table 3-2). Lead contamination is derived from stormwater run-off from urban environments or industry point sources but was removed from fuel 25 years ago. Zinc is typically derived from galvanised roof run-off and tyre wear on vehicles, and copper is mainly from brake linings and treated timbers.

No sites exceeded any of the guidelines for arsenic, cadmium, chromium, nickel or mercury (Table 3-2). However, sediment mercury concentrations at the Onepoto Arm sites (0.12 and 0.11 mg/kg, at POR1 and POR2, respectively) were close to the DGV level of 0.15 mg/kg (Table 3-2). We are unsure of the sources of the slightly elevated levels of mercury at these sites, though industry polluted urban soils and coastal reclamation fills are known sources of mercury in estuarine environments overseas (Mirlean et al. 2009). Also unknown is how much of this mercury is in its most toxic form, methylmercury.

Table 3-2: Chemical contaminant guidelines and their exceedances in subtidal sediments at Porirua 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. 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.

Site	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	No. of exceedances
ARC amber				19	30			124	
ARC red				34	50			150	
DGV	20	1.5	80	65	50	0.15	21	200	
GV-High	70	10	370	270	220	1	52	410	
PAH1	9.0	0.04	16.8	10.4	18.1	0.08	11.6	77	0
PAH2	8.3	0.06	16.1	11.5	18.3	0.08	11.2	78	0
PAH3	9.1	0.04	15.1	7.9	13.6	0.05	10.6	69	0
POR1	10.5	0.13	18.6	20.7	34.3	0.12	12.1	196	3
POR2	12.1	0.05	20.2	18.2	31.3	0.11	13.5	149	2

ETI health bands were specified based on threshold concentrations of the indicator variables shown in Table 3-3. TOC concentrations varied among sites in Porirua Harbour, with higher levels in the two Onepoto Arm sites (1.85 and 2.22%) than in the three Pāuatahanui Arm sites (0.95-1.78%). PAH3 had the lowest percent TOC and rated 'good' on the ETI and 'low' risk for estuary condition. Sediment TOC at PAH1, PAH2 and POR2 indicated 'fair/moderate' risk, and POR1 was 'poor/high' risk. Sediment TP levels were highest at the Onepoto Arm sites, which were classified as 'poor' on the ETI guidelines, and 'high' risk on the ECRI rating (Table 3-3). TP levels at Pauahatanui Arm Site 1 also indicated 'poor/high' risk, but indicated 'fair/moderate' risk at Pāuatahanui Arm Sites 2 and 3. Sediment TN levels indicated 'fair/moderate' risk at all five sites. Pāuatahanui Arm Site 3, at 1,000 mg/kg TN, was right on the borderline between 'moderate' and 'low' risk (Table 3-3). All sites were considered 'poor/high' risk relative to their percent mud content (all >>25% guideline). TS concentrations were lowest at POR2, but all other sites were very similar to each other (0.17-0.18 g/100g; Table 3-3).

Table 3-3: New Zealand Estuary Trophic Index (ETI) guidelines and Estuary Condition Risk Indicator Ratings (ECRI), and their exceedances in subtidal sediments at the Porirua Harbour sites in 2020. Only a selection of the variables included in the ETI are included. The guideline bands are the general indicator thresholds derived from the New Zealand Estuarine Tropic Index, taken from Table 3 in Forrest et al. (2020). TOC = Total organic carbon, TN = total nitrogen, TP = total phosphorus, TS = total sulphur.

	ETI guidelines* (and ECRI ratings#)				Pāuatahanui Arm			Onepoto Arm	
	Very good*	Good* (low risk#)	Fair* (moderate risk#)	Poor* (high risk#)	PAH1	PAH2	PAH3	POR1	POR2
% TOC	< 0.5	0.5 to < 1	1 to < 2	≥ 2	1.32	1.78	0.95	2.22	1.85
TN (mg/kg)	< 250	250 to < 1000	1000 to < 2000	≥ 2000	1300	1600	1000	1700	1600
TP (mg/kg)		100 - 300	> 300 - 500	> 500 - 1000	535	498	476	560	610
% mud	< 5	5 to <10	10 to <25	≥ 25	66.4	81.9	40.6	92.4	96.5
TS (g/100g)	No guidelines	No guidelines	No guidelines	No guidelines	0.17	0.18	0.17	0.18	0.12

3.2 Benthic ecology in 2020

3.2.1 Biodiversity

Average number of taxa and individuals recorded at each site in 2020 are shown in Figure 3-1 and Table 3-4. The number of taxa was very similar across sites, ranging from 14-18 on average, while the number of individuals were lower at the Pāuatahanui Arm sites (average of 106-185 per core) than at the Onepoto Arm sites (297 and 239 individuals per core at POR1 and POR2, respectively).

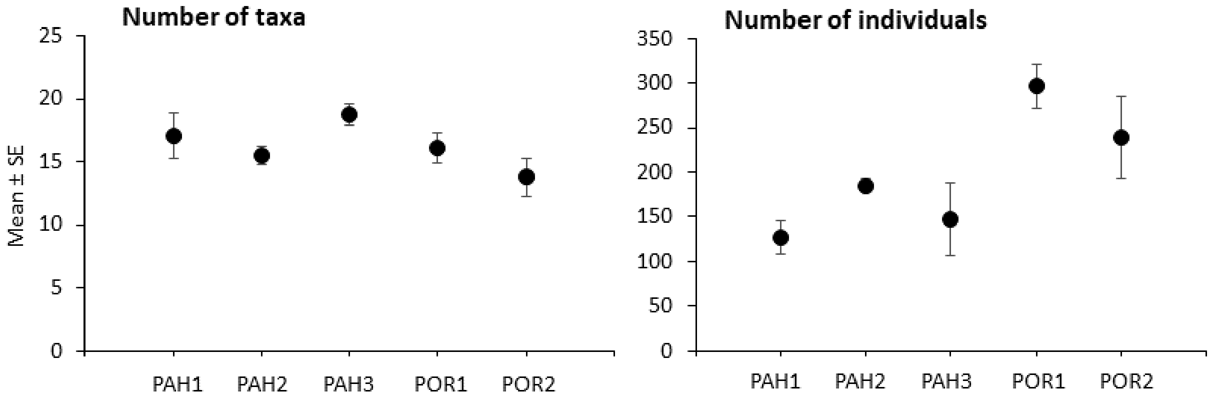

Figure 3-1: Total number of taxa and individuals found at each site in 2020. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

Taxa richness (the number of species at the site), species evenness (relative abundance of the different species) and Shannon diversity (an index reflective of richness and evenness) were all higher at sites in the Pāuatahanui Arm than those in the Onepoto Arm, and highest overall at PAH3 (Table 3-5). PAH3 appears to be in a less urbanised part of the harbour and further from contaminant input points than the other sites (Figure 2-1), perhaps accounting for its slightly higher richness/diversity.

Table 3-4: Average diversity indices for each site in 2020.

Site	Number of individuals	Number of species	Taxa richness (Margalef)	Evenness	Shannon diversity
PAH1	127	17	3.32	0.72	2.03
PAH2	185	16	2.78	0.74	2.02
PAH3	106	18	3.78	0.79	2.3
POR1	297	16	2.66	0.61	1.68
POR2	239	14	2.38	0.66	1.66

3.2.2 Community composition and sediment characteristics

Each site contains a mix of taxa that, in intertidal areas, have a range of tolerances to mud and organic enrichment. Only PAH1 and PAH2 contain a dominant taxa (*Linucula hartvigiana*) considered sensitive to enrichment (Norkko et al. 2001, Ellis et al. 2017, Robertson et al. 2016c).

Pāuatahanui Site 1 (PAH1), located off Browns Bay (Figure 2-1), had sediments comprised of 66% mud and was dominated by deposit feeders including the bamboo worm *Asychis asychis*-B (26 ind. core^{-1}) and two species of small bivalve, *Linucula hartvigiana* (31 ind. core^{-1}) and *Arthritica* spp. (12 ind. core^{-1}) (Figure 3-2). *Theora lubrica* (8 ind. core), a non-indigenous surface deposit feeding bivalve known to be common in muddy and organically enriched environments (Lohrer et al. 2013, and references therein), were also common. *A. asychis*-B is a tube-building maldanid polychaete whose response to elevated sediment mud content and organic enrichment is unknown. *Linucula* is considered to be sensitive to mud (Norkko et al. 2001, Ellis et al. 2017) and organic enrichment (Robertson et al. 2016c) although it can be found across a range of sediment types from muds to sands (authors' pers. obs.), while *Arthritica* and *Theora* are mud-loving/enrichment tolerant species (Robertson et al. 2016). On the ETI scale and ECRI rankings this site is 'fair'/'moderate' risk for TOC and TN, and is 'poor'/'high risk' for TP and percent mud. Metal and metalloid contaminants did not exceed sediment quality guidelines.

Pāuatahanui Site 2 (PAH2), the inner most site in this arm of the harbour, closest to Duck Creek (Figure 2-1), had the highest mud content and organic matter content of the three Pāuatahanui sites (82% and 6.9%, respectively). The benthic community featured each of the polychaetes *Cossura consimilis* (43 ind. core^{-1}) and *Heteromastus filiformis* (40 ind. core^{-1}), and 17 ind. per core of *Asychis asychis*-B amongst the dominant taxa (Figure 3-2). As at PAH1, the small bivalves *Arthritica* spp. (36 ind. core) and *Linucula hartvigiana* (21 ind. core) were also very common. Three of these taxa are mud/enrichment tolerant (*Heteromastus, Arthritica, Cossura*), while *Linucula* are mud-sensitive and the tolerance of *Asychis* is unknown. The ETI scale and ECRI risk rankings for this site were 'fair'/'moderate risk' for TOC, TN and TP, and 'poor'/'high risk' for percentage mud. Metal and metalloid contaminants did not exceed sediment quality guidelines.

Arthritica spp. (26 ind. core^{-1}) was the dominant taxa at **Pāuatahanui Site 3** (PAH3 off Camborne; Figure 2-1). Although the mud content at PAH3 was lowest of the three Pāuatahanui Arm sites (40.6%), this is still a "muddy" site with a considerable proportion of mud mixed with coarser grains. This site had the lowest total number of individuals in this area of the harbour, and the highest taxa richness and Shannon diversity, perhaps owing to the more heterogenous sediments (less mud, more sands). Several polychaetes were found in reasonable numbers at this site*:* bamboo worms (*Asychis asychis*-B; 16 ind. core), *Cossura consimilis* (12 ind. core^{-1}) and *Heteromastus filiformis* (8 ind. core^{-1}) and Ostracoda spp. (9 ind. core). Neried polychaetes *Nicon aestuariensis* (3 ind. core^{-1}) and Phoxocephalidae spp. amphipods (mud/enrichment indifferent; 6 ind. core^{-1}) also featured amongst the most common taxa (Figure 3-2). Three of these taxa are mud/enrichment tolerant taxa (*Cossura, Heteromastus, Nicon*), and while Phoxocephalidae are indifferent they are considered sensitive to disturbance; the tolerance of *Asychis* to these stressors is unknown (Norkko et al. 2001, Ellis et al. 2017, Robertson et al. 2016c). Sediment TOC was ranked 'good'/'low risk' using the ETI and ECRI, TP and TN levels were 'fair'/'moderate risk', and mud was 'poor'/'high risk'. As at PAH1 and PAH2, metal and metalloid contaminants did not exceed sediment quality guidelines.

The **Onepoto Arm site POR1** (the uppermost site in this arm, near Porirua City centre; Figure 2-1) had extremely muddy sediments (92.4%) and the highest number of individuals of all sites in Porirua

Harbour. Total abundance can be very high at polluted sites, with pollution limiting the abundance of persistent species and allowing highly opportunistic/tolerant species to proliferate (Pearson-Rosenberg 1978). This appeared to be the case at POR1: very high numbers of mud/enrichment tolerant *Arthritica* spp. (147 ind. core^{-1}), and many bamboo worms (*Asychis asychis*-B; 55 ind. core^{-1}), were found at this site. Polychaete species common at the other sites (*Heteromastus filiformis*, 31 ind. core^{-1}; *Cossura consimilis*, 17 ind. core^{-1}; *Nicon aestuariensis* 9 ind. core^{-1}) were also found here (Figure 3-2). With the exception of *Asychis*, all of these taxa are considered to be mud/enrichment tolerant species (Norkko et al. 2001, Ellis et al. 2017, Robertson et al. 2016c). The ETI and ECRI classified POR1 as 'poor'/'high risk' for TOC, TP and percent mud, and 'fair'/'moderate risk' for TN. Sediment here exceeded the ARC amber guidelines for copper, lead and zinc, and levels of mercury were close to exceeding the DGV guidelines (0.12 mg/kg cf. guideline concentrations of 0.15 mg/kg).

At the second **Onepoto Arm site, POR2**, sediments were the muddiest of all five monitoring sites (96.5%) and organic matter content was also high (8.3%). The tanaid *Apseudes "novaezealandiae"* was extremely abundant, with 101 ind. core^{-1} found. The bamboo worm *Asychis asychis*-B, and *Arthritica* spp. were also very common at 43 and 45 ind. core^{-1}, respectively (Figure 3-2). In 2020, the tube-mat building spionid polychaete *Boccardia syrtis* (16 ind. core^{-1}) was abundant only at this site. These four taxa have a range of tolerances to mud and organic enrichment: tanaids are considered to be highly sensitive to mud and organic enrichment, *Arthritica* are mud/enrichment tolerant, *Boccardia* is indifferent and found in a variety of sediment types, and the tolerance of *Asychis* is unknown (Norkko et al. 2001, Ellis et al. 2017, Robertson et al. 2016c). The presence of high numbers of *Apseudes "novaezealandiae"* is at odds with what we know of its preferences; however, this type of crustacean, a burrowing and tube building detritovore, is known for its variable seasonal abundances which are likely related to reproduction (Graham Bird, pers. comm.). It is also found in the muddy subtidal sediments of Mahurangi Harbour (D. Lohrer, pers. comm.). It was not found in any other sites in 2020. The ETI and ECRI found 'fair'/'moderate risk' for TOC and TN, and 'poor'/'high risk' for TP and percent mud. Sediment lead and zinc levels exceeded ARC amber guidelines, and concentrations of mercury (0.11 mg/kg) and copper (18.2 mg/kg) were both very close to the DGV levels (0.15 and 19.0 mg/kg, respectively).

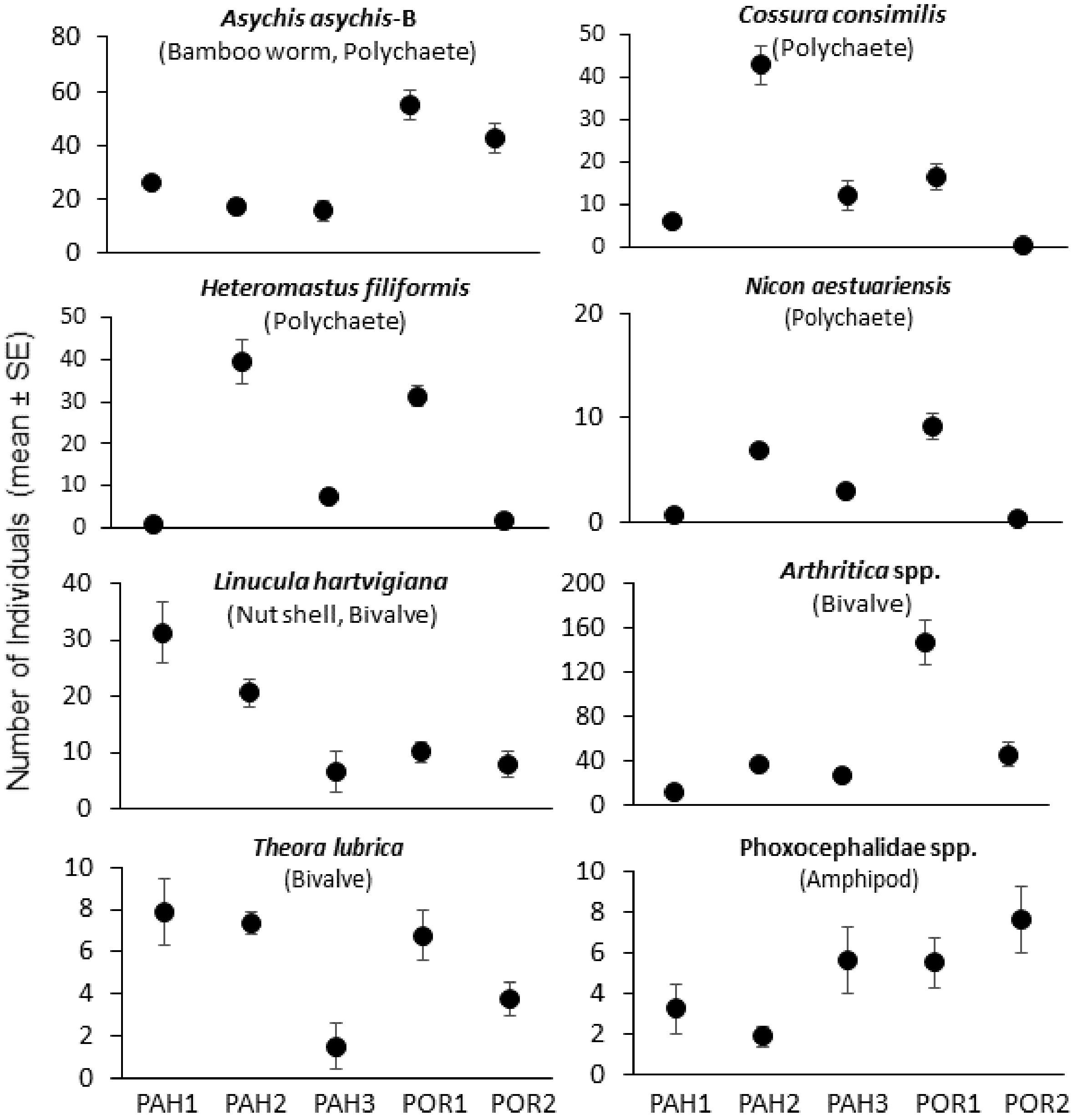

Figure 3-2: Total number of selected common taxa found at each site in 2020. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

The relative differences and similarities in benthic community composition at the different sites in 2020 is illustrated in the ordination diagram in Figure 3-2. Each site has a community that is distinct from the other sites, with little overlap between sites. In the transformed MDS (Figure 3-3B), PAH2 and POR1 are very tightly clustered in the ordination space with high similarity between their respective replicate cores. These sites are also more similar to each other than to any of the other sites (Figure 3-2). PAH3 and POR2 both have replicates which are compositionally different to the majority of the replicates at the site, as shown by their separation in ordination space on the MDS ordination diagram (Figure 3-2). The spatial arrangement of all five sites was similar between the untransformed and square root transformed ordinations, with tighter clustering of cores within sites in the latter, reflecting the differences in rare taxa between sites. There were strong significant differences between Porirua Harbour sites in 2020 [detected by ANOSIM: p = 0.001 (0.1%), R-statistic = 0.704 (untransformed); p = 0.001 (0.1%), R-statistic = 0.695 (square root transformed data)].

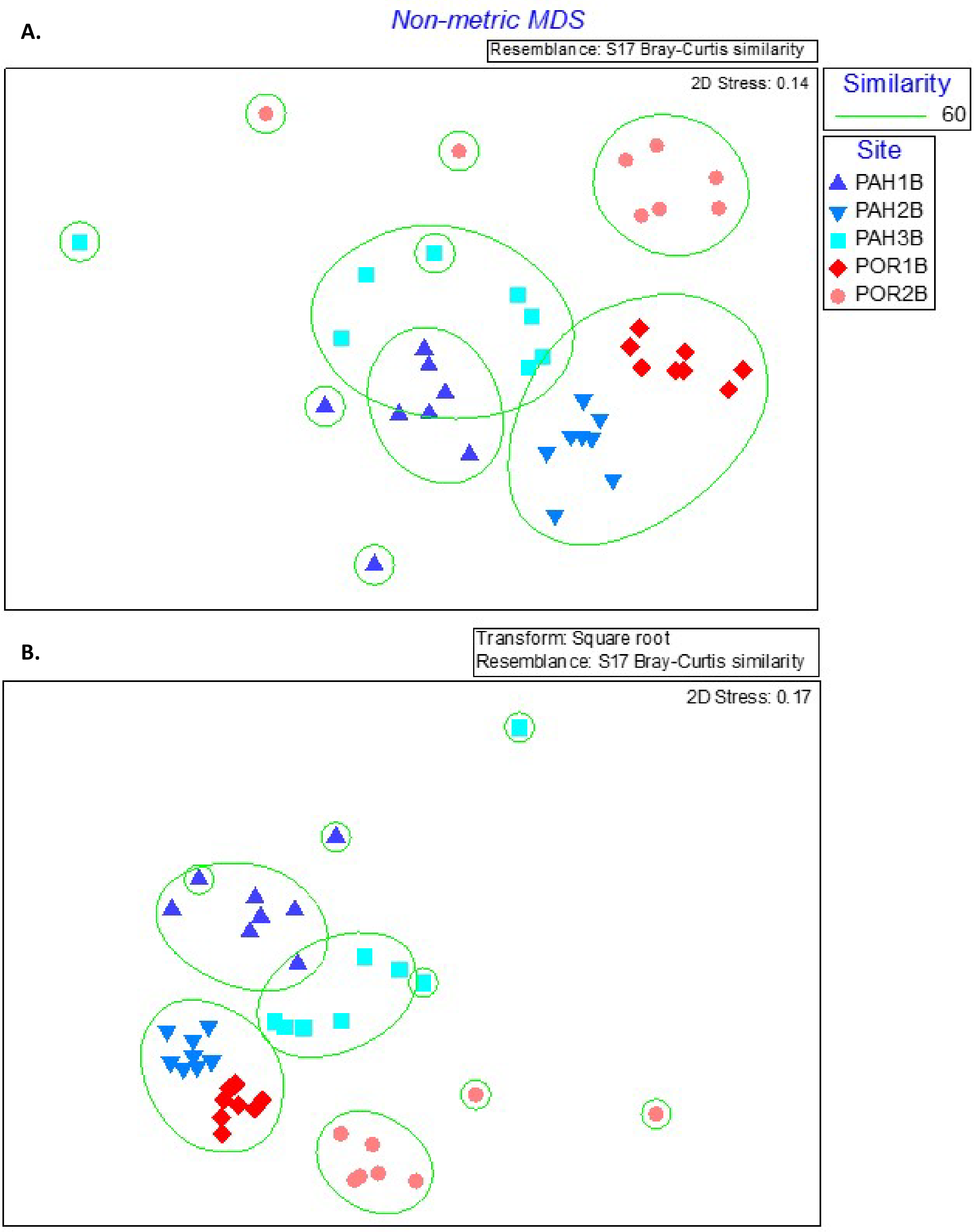

Figure 3-3: Non-metric multidimensional scaling ordination diagram of benthic community similarity amongst Porirua Harbour sampling sites in 2020. Data are untransformed (A) and square root transformed (B) abundance values from benthic macro-infauna core samples. Distances represent Bray–Curtis similarities among sites. Overlaid on the plots are the 60% similarities determined by cluster analysis. All eight cores (each 20 cm diam.) are represented from each site.

3.2.3 Bivalve 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 D.

By far the most common bivalve in Porirua Harbour is the tiny *Arthritica bifurca,* a taxon considered in the intertidal to be tolerant to muddy sediments and organic enrichment. *Arthritica* was found at all five sites and was particularly abundant in the Onepoto Arm. While the majority of the *Arthritica* found in 2020 were <2 mm in size (Figure 3-4), some individuals in the 2-5 mm size class were found too, at all sites except PAH1. For a naturally very small species like *Arthritica* (generally smaller than 6 mm in width; Powell 1979) 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.

Linucula hartvigiana (nut shell) were the next most abundant taxa in 2020 and were common at all five sites. *Linucula* are small bivalves, which attain a maximum size of ~8 mm (Powell 1979). Individuals from the 5-10 mm size class were found at all sites except POR1, likely indicating the presence of reproductive adults at those sites (Figure 3-4). *Linucula* are classified in intertidal data sets as mud-sensitive, however, all of the sites in Porirua Harbour contain a minimum of 41% mud (at PAH3), and over 90% at the two Onepoto Arm sites.

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) sediments. 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. At all five sites, the dominant size class was 5-10 mm, with larger 10-20 mm individuals found at PAH2 and the two Onepoto Arm sites (POR1, POR2) (Figure 3-4). *Theora* were least abundant at PAH3, where their sizes ranged from 2-10 mm (Figure 3-4), again potentially indicating that PAH3 was a slightly healthier site overall.

The remaining bivalve species that were measured include the wedge shell *Macomona liliana*, the cockle *Austrovenus stutchburyi* and the mud clam, *Cyclomactra* spp. (Figure 3-4). *Austrovenus* and *Macomona* are both intertidal species that are not common in the subtidal. In contrast, *Cyclomactra* are only found subtidally, in shallow waters. With the exception of *Macomona* at PAH1 where a total of seven individuals were collected, all three species were found in extremely low abundances (≤4 individual in total at any one site). The *Cyclomactra* were in the 20-40 mm size class (Figure 3-4). As adults they can attain sizes of 80-100 mm. None of these species were collected at POR2.

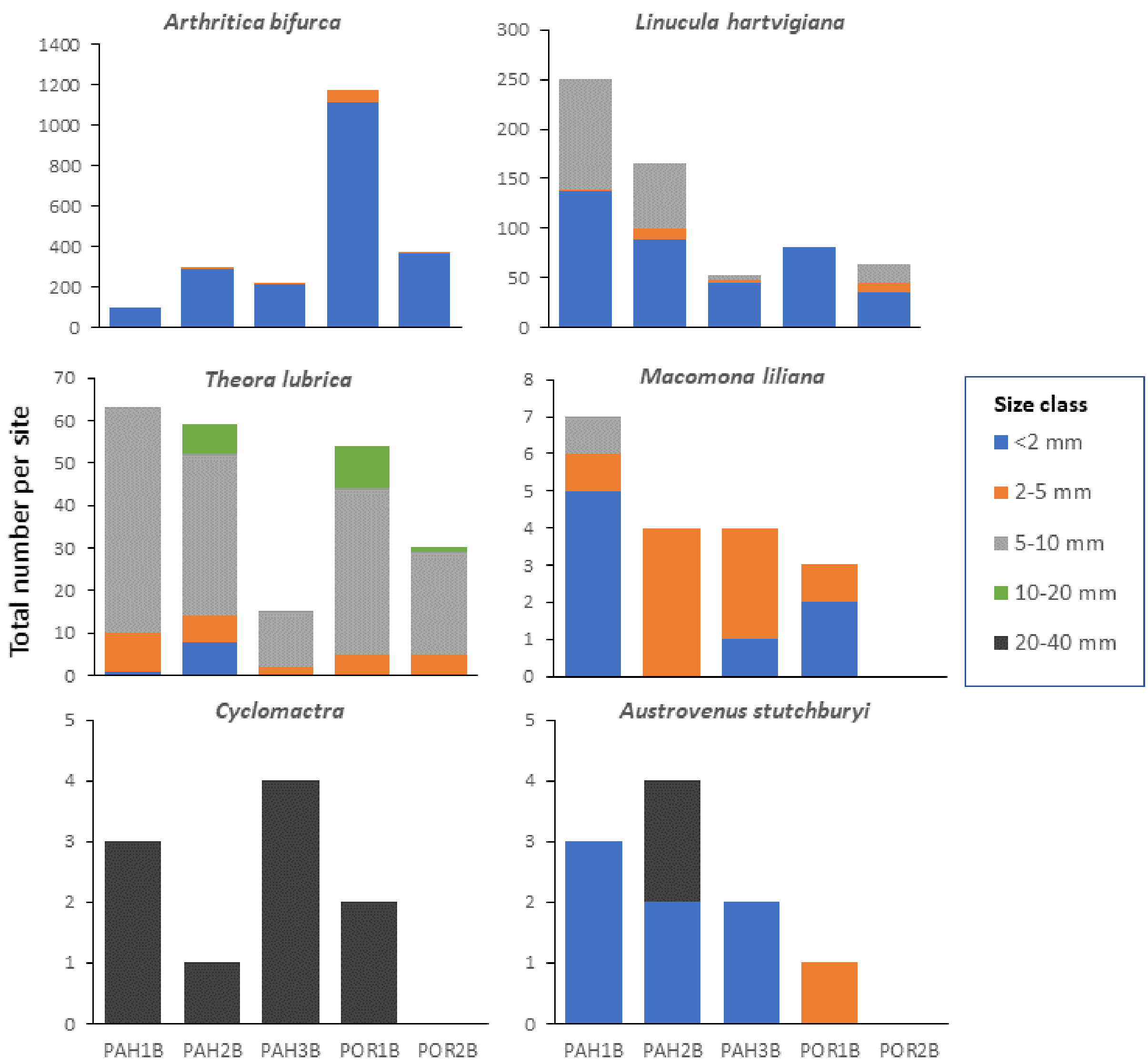

Figure 3-4: Total number of bivalves found in each size class at each site in 2020. Values presented are totals from all benthic cores (eight 20 cm diam. cores).

3.2.4 Benthic Health

Traits Based Index

Most of the taxa identified in Porirua Harbour were able to be matched to taxa in the NIWA traits database. There were a number of cases where there was no exact match, so some educated guesses were made (usually based on higher order similarities, e.g. the same family).

Two of the Pāuatahanui Arm sites (PAH1, PAH3) and one Onepoto Arm site (POR1) were classified as having 'high' functional redundancy health scores in 2020. PAH2, located off Duck Creek (Figure 2-1), had an 'intermediate' health score, and POR2, the northern site in the Onepoto Arm, was on the borderline between 'intermediate' and 'low' functional redundancy. These scores did not change depending on whether the condensed data set (i.e. where some taxa had been amalgamated to a lower taxonomic level) or the full data set were used in the calculations (Table 3-5).

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 are relatively influential (positively) 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, surface 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. One of the reasons for the slightly higher than expected TBI scores at the muddy and metal contaminated Porirua Harbour sites (given the known inverse relationship between the TBI and mud/metals concentrations) may have been the commonness of *Asychis*, *Boccardia* and *Nicon*. Also note that the capitellid *Heteromastus* is a somewhat atypical capitellid species (i.e., less tolerant to pollution than other capitellids, and with a higher TBI weighting).

Table 3-5: Health status of Porirua Harbour benthic ecology in 2020. Health scores are based on the Traits-based index (TBI), for the condensed data set and the full data set. TBI scores <0.3 = low levels of functional redundancy and highly degraded sites, 0.3-0.4 = intermediate conditions, >0.4 = high functional redundancy and resilience.

	Condensed 2020 data set		Full 2020 data set	
Site	TBI score	Health score	TBI score	Health score
PAH1B	0.44	High	0.44	High
PAH2B	0.35	Intermediate	0.35	Intermediate
PAH3B	0.49	High	0.50	High
POR1B	0.41	High	0.41	High
POR2B	0.30	Low/Intermediate	0.30	Low/Intermediate

Benthic Health Models

Only five taxa were found in Porirua Harbour that did not form part of the existing BHM model data set. This probably contributed to the reasonable fit of the Porirua BMH scores to their measured environmental variables.

The BHM mud scores were checked against the actual percent mud concentrations measured at each of the benthic sites, with PAH3 and POR2 displaying good fits and the other three displaying reasonable fits (Figure 3-5). The BHMmet scores were checked against the actual concentrations of copper, lead and zinc (converted to a PCA score) measured at each of the benthic sites (see equation below), with all sites displaying good fits (Figure 3-6). The PCA axis score was calculated from the equation given in the model information and supplementary information contained in Clark et al. (2019):

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)

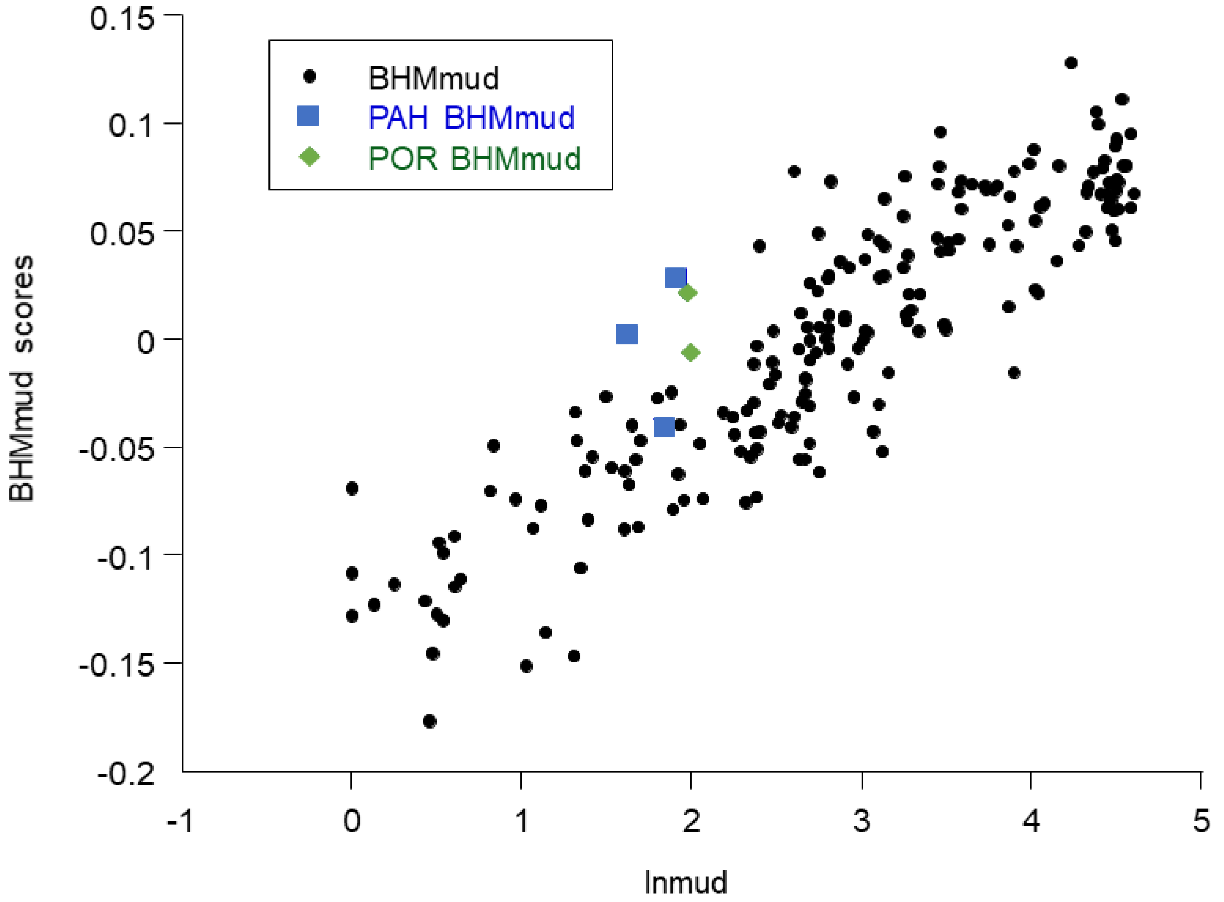

Figure 3-5: Relationship between the Mud Benthic Health Model (BHM) scores and the actual percent mud content of the sediments measured at each site. Blue squares are the Pāuatahanui Arm (PAH) BHMmud scores and green diamonds are the Onepoto Arm (POR) BHMmud scores, for the model run with subtidal species included and allocated to the same group as the most similar intertidal species on the list. Black symbols are the relationship for a range of intertidal sites around New Zealand.

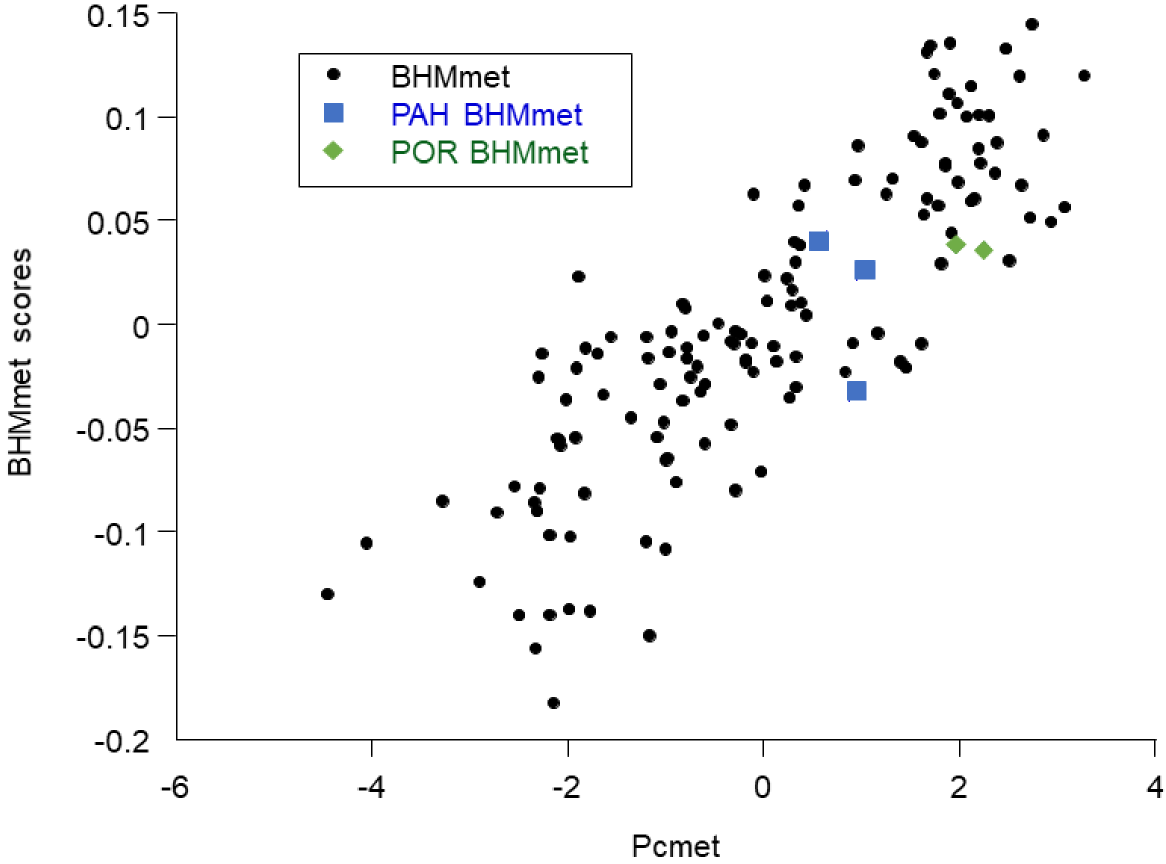

Figure 3-6: Relationship between the Metals Benthic Health Model (BHM) scores and PCmet (i.e. the PCA axis 1 scores from the PCA on the copper, lead and zinc concentrations). Blue squares are the Pāuatahanui Arm BHMmet scores and green diamonds are the Onepoto Arm BHMmet scores, for the model run with subtidal species included and allocated to the same group as the most similar intertidal species on the list. Black symbols are the relationship for a range of intertidal sites around New Zealand.

BHM Mud

The correlation between BHMmud scores calculated on the two slightly different datasets (i.e. with the subtidal species included and excluded) was strong (Pearson's correlation coefficient r = 0.98). This high correlation is likely driven by the low number of species known to be exclusively subtidal in Porirua Harbour (five taxa).

BHMmud scores indicated moderate health for PAH1, PAH3 and POR2 and poor health for PAH2 and POR1 (Table 3-5). Inclusion/exclusion of subtidal taxa did not alter these findings (Table 3-6).

Table 3-6: Scores and health category ratings for the BHMmud model at the Porirua Harbour sites. Health category ratings range from 1 (least impacted) to 6 (most impacted).

	Subtidal species included		Subtidal species excluded	
	BHM mud	Mud group	BHM mud	Mud group
PAH1	3.16	3 (moderate)	3.20	3 (moderate)
PAH2	4.27	4 (poor)	4.27	4 (poor)
PAH3	3.85	3 (moderate)	3.94	3 (moderate)
POR1	4.15	4 (poor)	4.20	4 (poor)
POR2	3.71	3 (moderate)	3.71	3 (moderate)

BHM Metals

As for BHMmud, the overall correlation between the two sets of BHMmet scores calculated was very high (Pearson's r = 0.98) and no effect on health category was observed when subtidal species were excluded (Table 3-7). PAH1 was in moderate health in 2020, while the four remaining sites were in poor health with respect to metal content (Table 3-6).

Table 3-7: Scores and health category ratings for the BHMmetal model at the Porirua Harbour sites. Health category ratings range from 1 (least impacted) to 6 (most impacted). *included and assigned attributes of the nearest/most similar intertidal species.

	Subtidal species included*		Subtidal species excluded	
	BHM metals	Metal health rating	BHM metals	Metal health rating
PAH1	3.17	3 (moderate)	3.22	3 (moderate)
PAH2	4.08	4 (poor)	4.08	4 (poor)
PAH3	4.32	4 (poor)	4.31	4 (poor)
POR1	4.25	4 (poor)	4.24	4 (poor)
POR2	4.27	4 (poor)	4.27	4 (poor)

3.2.5 Sediment characteristics correlated with benthic community composition

With only five sites, only three variables at a time could be tested and used in the analysis. Because this low number of sites results in less reliable p-values, we instead focus on the percent explained by the variables. Statistical power depends on sample size, so with low sample size, there is a relatively high chance of the statistical results finding "no effect" when in fact there may be one. In this case it is best not to put too much weight on whether $p<0.05$ or $p>0.05$, because the chance of a Type II error is unacceptably high. (Type II error is when one accepts a null hypothesis that is actually false). Forwards selection resulted in a model with TS, TOC and mud together explaining 83% of the variation between sites (Table 3-7; Figure 3-7A). The Pāuatahanui Arm sites were influenced by TS, while the Onepoto Arm sites were influenced by mud (each had > 90% mud; Table 3-3), However, a second model where TS was removed (by forcing the model to choose the next most important variable as its starting position) resulted in a model with As, TOC and TP explaining 87% (Table 3-7; Figure 3-7B). This result was partly driven by the high correlations (Pearson's r > 0.90) between a number of variables (Table 3-7). The high correlations mean that one variable can mask the effects of other variables. For example, TOC reduces the influence of mud in the model, and mud and TOC reduce the influence of TN (to the point where TN is eliminated from the model entirely).

Table 3-8: Results of the DISTLM model. Results of the first model (A), the second model with TS removed (B), and the variables that are highly correlated (C), are shown.

A. First Model	% explained
TS	39
TOC	23
%mud	21
B. Second Model	**% explained**
As	38
TOC	23
TP	26
C. Highly correlated variables	
%mud, TOC, TN	
TOC, Cu, TN	
As, Cr	
PCA, Cr, Hg, TOC	
TP, Cr	

Marginal tests show TS and As are the most important variables, followed by Cr and TP (Table 3-9).

Combining the forwards selection with the marginal tests, this suggests that TOC is consistently important, explaining ~23% of the variation. TS and As are also important, but As is highly correlated with Cr and the combined Cu-Pb-Zn variable. TP and mud are important but, similar to As, with only five data points, it is difficult to separate their effects from TOC, As and Cr.

Table 3-9: Results of marginal tests for each variable, listed in decreasing order of importance. The percentage explained is the explanatory power of the single variable alone.

Variable	Proportion explained
TS	0.39
As	0.39
Cr	0.33
TP	0.32
PCA	0.25
Mud	0.25
TOC	0.23
TN	0.23
Hg	0.22
%Organics	0.19
Cd	0.19

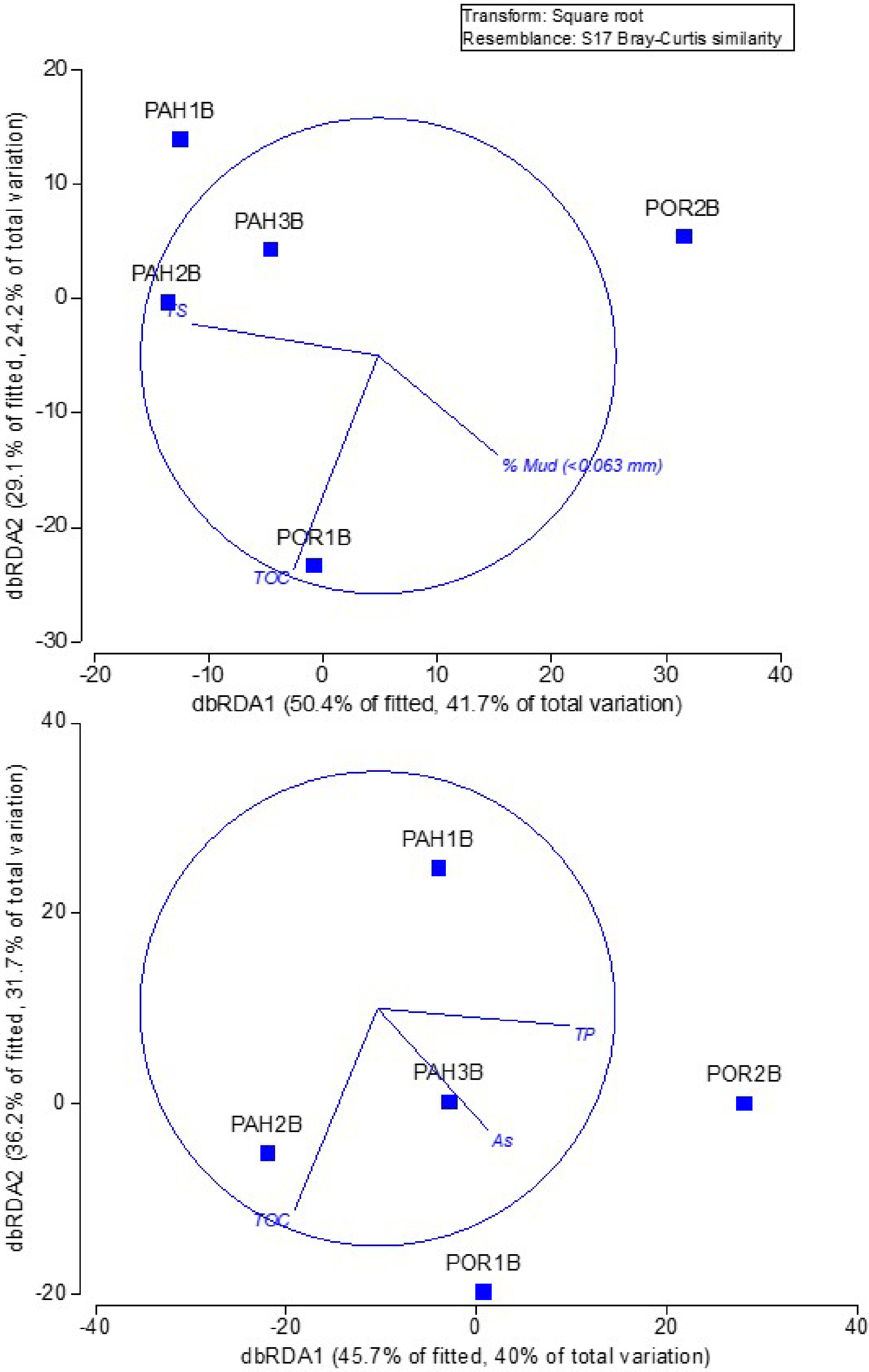

Figure 3-7: A constrained ordination of benthic faunal data and sediment characteristics. A. initial model, with TS, TOC and %mud together explaining 83% of the variation between sites. B. second model, with As, TOC and TP explaining 87% of the variation between sites. The blue lines indicate the strength and direction of the forward selected sediment characteristics as drivers of benthic community similarities between sites. TS = total sulphur, TOC = total organic carbon, TP = total phosphorus, As = Arsenic.

3.3 Reconciling benthic invertebrate data sets collected over the monitoring programme

A total of 101 invertebrate voucher specimens were collected during the identifications of the 2020 samples. Specialist taxonomists identified 66 unique taxa from these vouchers.

For the combined data set, a total of 64 taxa were identified across Porirua Harbour in 2020: 57 were collected from the Pāuatahanui Arm, and 41 from the Onepoto Arm. The dominant taxa were mostly polychaetes and bivalves, with amphipods, crustaceans and ostracods also common at some sites (Figure 3-2; Appendices B and C).

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 A). 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 B. 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 2004-2015 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, Tanidacea), and polychaete groups (Paraonidae, *Boccardia syrtis* and Maldanids) (Appendix B). For taxa that are difficult to identify (e.g. due to lack of taxonomic expertise in NZ) or that occur only in low numbers, we recommend combining at a higher taxonomic level (Appendix B).

3.4 Sediment characteristics over time

There was no change in the overall spatial pattern of sediment characteristics (metals, TOC and 10-63 µm sediment particles) over time between 2004 and 2020 (rho = 0.697, p = 0.084; RELATE), indicating that sites have not changed much relative to each other. Below we discuss temporal patterns in sediment particle size, TOC, metals and/or metalloid contaminants.

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 3-8. There have not been any large changes or clear trends in concentrations of this sediment class across the years of monitoring. Correlation analysis indicates a moderate, negative and non-significant relationship with sampling year at PAH3, POR1 and POR2 (Table 3-10). In other words, concentrations have decreased slightly (improved), though there are not enough data points to perform a formal trends analysis from which to draw strong conclusions.

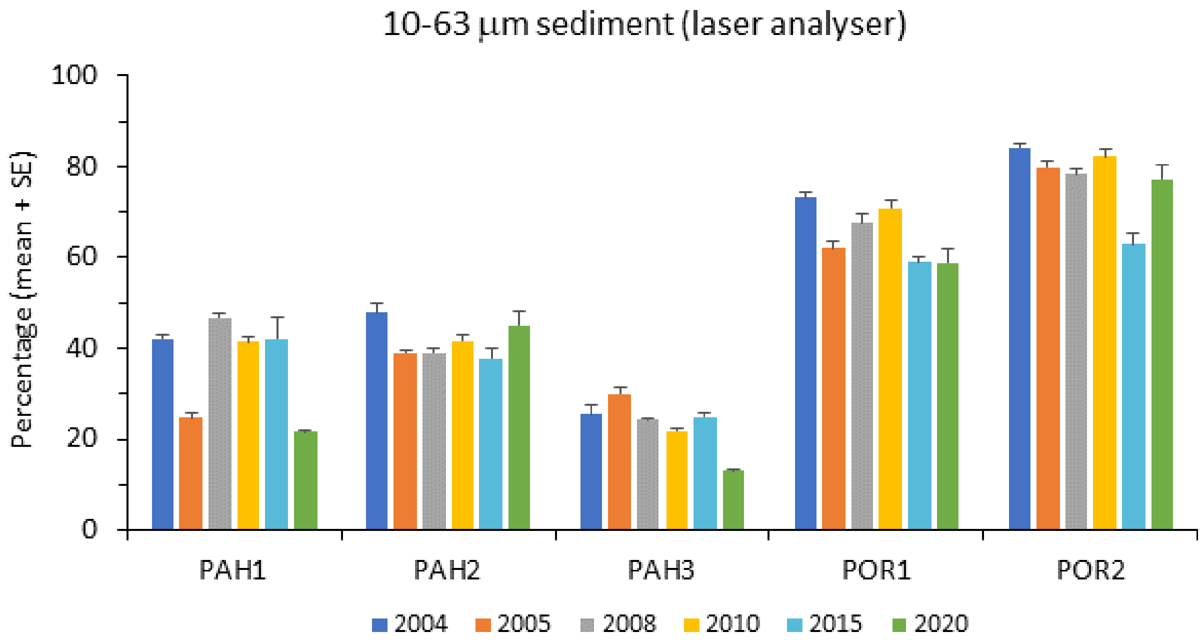

Figure 3-8: Concentration of fine sized sediments at each site on each monitoring occasion. Percentage of sediment particles in the 10-63 µm particle size range determined using laser analyser (N=3; sediment chemistry circle).

For comparison we have included percent mud content determined by wet sieving (Figure 3-9). These values were used in the analyses of the 2020 benthic indices because they are a true percent mud value, incorporating clay (<3.9 µm) and silt (3.9-63 µm) sediment fractions. Although the percent mud was considerably higher than the laser-derived 10-63 µm measurements for 2020 in all cases, the mud values reflect the patterns noted for the laser analysis – e.g. concentrations are highest at POR 1 and 2 and lowest at PAH3.

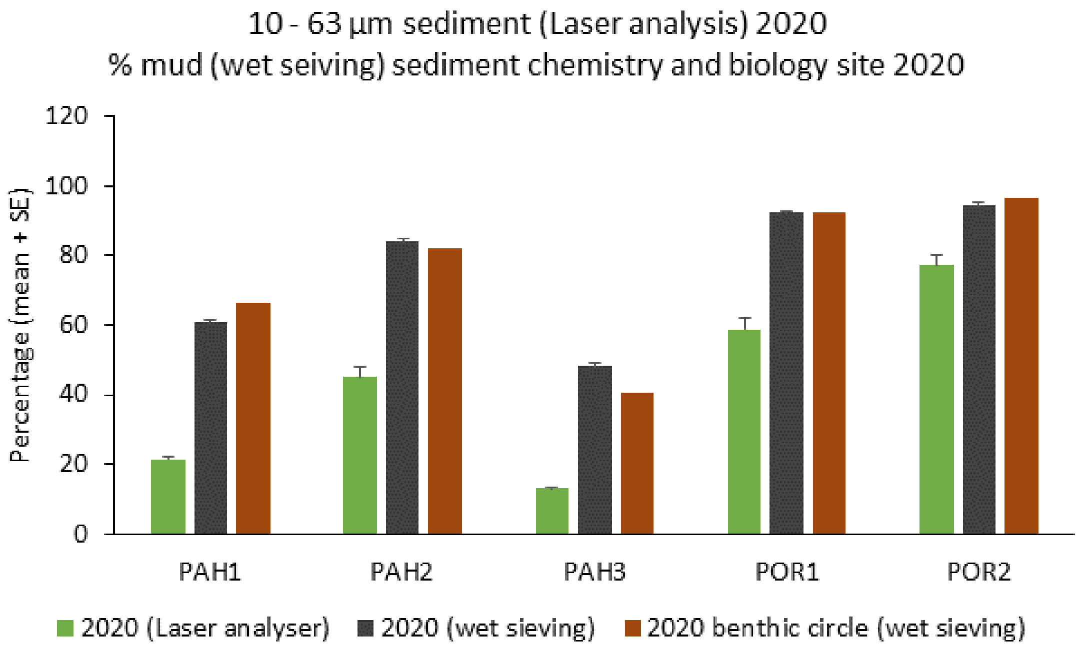

Figure 3-9: Concentration of finer sediments in 2020 determined using laser analysis and wet sieving. Plot shows the percentage of 10-63 m sediments determined from the sediment circle using the laser analyser (N=3; green bars), and of mud sized particles (0-63 m) using wet sieving analysis (N=3; black bars). Also shown are the percentage of mud from the benthic circle (N=1; brown bars).

Statistically significant negative correlations in average concentrations with time were detected for lead at three sites: PAH3 (moderate), POR1 (strong) and POR2 (moderate), and for copper at POR2 (moderate; Table 3-10). Moderate but non-significant negative correlations were also detected for copper at all other sites except PAH2 (Table 3-10). The change detected for copper at POR2 is driven by the high value at the very beginning of the time sequence (Figure 3-10).

Moderate negative correlations were detected for copper at PAH1, PAH3, POR1 (rho = -0.77 at each site), but these were not statistically significant (Table 3-10). Only seven positive correlations were noted; all were weak and non-significant (Table 3-10).

These results suggest that concentrations are decreasing over time, although there is difficulty with statistically comparing changes over time with only a few data points. At least 10 data points 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) and increasing the sampling frequency would provide more robust trend analysis.

Table 3-10: Spearmans rho correlation coefficients and probability values for the relationship between sediment characteristics and time, at each site in Porirua 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=6 sampling times.

Site		10-63 µm sediments	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	TOC
PAH1	Rho	-0.26	-0.66	0.03	-0.37	-0.77	-0.52	-0.14	-0.64	-0.20	-0.71
	Pr > |r|	0.6228	0.1562	0.9537	0.4685	0.0724	0.2946	0.7872	0.1731	0.7040	0.1108
PAH2	Rho	-0.20	0.14	-0.58	-0.03	-0.37	-0.44	0.37	0.46	0.37	-0.32
	Pr > |r|	0.704	0.7872	0.2307	0.9572	0.4685	0.3832	0.4685	0.3542	0.4685	0.5379
PAH3	Rho	-0.77	0.26	-0.51	0.41	-0.77	-0.59	0.20	-0.89	0.17	-0.60
	Pr > |r|	0.0724	0.6228	0.3046	0.4247	0.0724	0.2213	0.704	***0.0188***	0.7417	0.208
POR1	Rho	-0.77	-0.66	-0.49	-0.43	-0.77	-0.21	-0.26	-0.94	-0.35	0.46
	Pr > |r|	0.0724	0.1562	0.3206	0.3965	0.0724	0.686	0.6228	***0.0048***	0.4993	0.3542
POR2	Rho	-0.77	-0.35	0.00	-0.43	-0.88	-0.46	-0.26	-0.83	-0.31	-0.31
	Pr > |r|	0.0724	0.4993	1.0000	0.3965	***0.0198***	0.3542	0.6228	***0.0416***	0.5441	0.5441

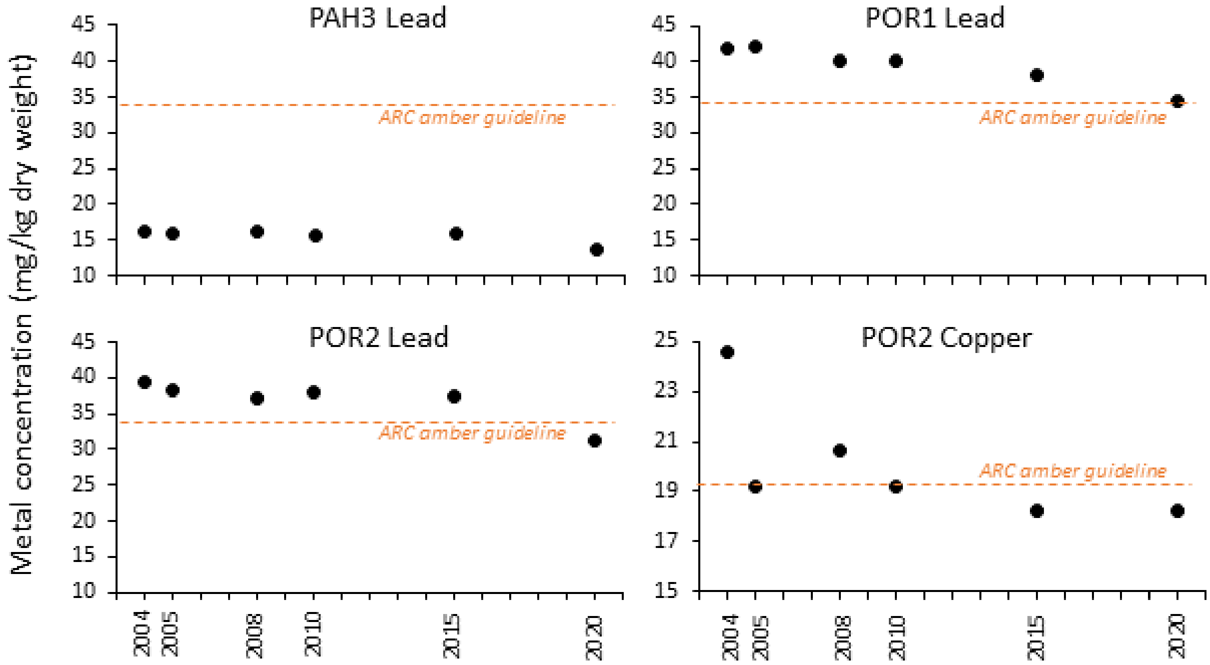

Figure 3-10: Concentrations of metals over time. Only metals and sites for which statistically significant correlations were detected are presented.

3.5 Benthic ecology over time

3.5.1 Biodiversity

The total number of taxa track very closely over time for all sites (Figure 3-11). The number of individuals is more variable over time, particularly at PAH1 and PAH2. All sites exhibited an increase in numbers of individuals between 2015 and 2020, but these increases are not out of the ordinary in light of fluctuations observed over the six sampling dates (Figure 3-11). The Shannon diversity index declined at POR2 in 2020 to its lowest of all six sampling dates, reflecting the high number of a single taxa (tanaids) found at the site.

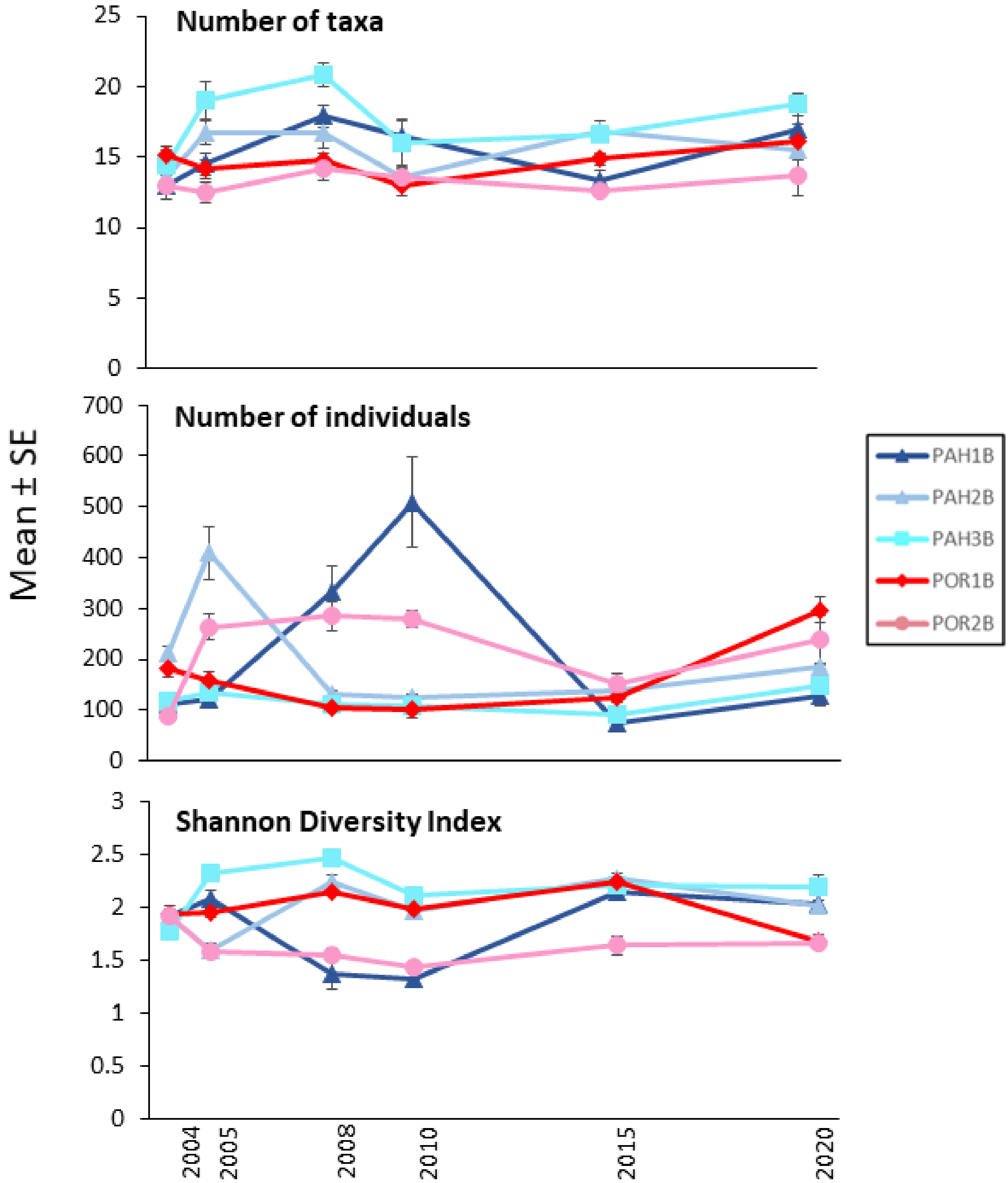

Figure 3-11: Total number of taxa and individuals, and the Shannon diversity index at each Porirua Harbour site on the six sampling occasions. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

3.5.2 Community composition

Benthic community composition has changed since the sampling began in 2004 (17 years ago), with all sites tracking in the same direction, and maintaining similar (and distinct) relative positions in ordination space between 2004 and 2020 (Figure 3-12), indicating that since monitoring began sites have not changed much relative to each other. The largest shifts in community composition at the various sites occurred between 2010 and 2015, and 2015 and 2020 (Figure 3-12). Given the frequency of the sampling, short term changes at specific sites resulting from rainfall or storm events, are unlikely to be identified.

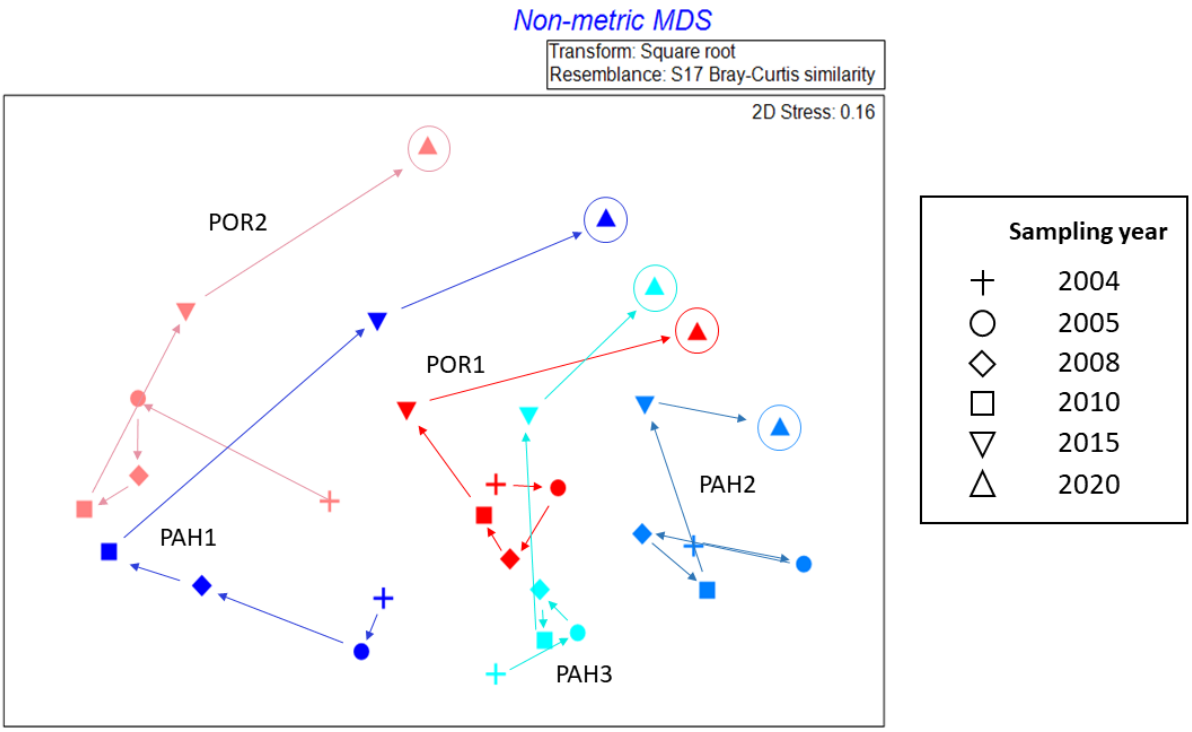

Figure 3-12: Non-metric multidimensional scaling ordination diagram of benthic community similarity amongst Porirua Harbour sampling. sites for all years of the sampling sites for all years of the sampling programme (2004, 2005, 2008, 2010, 2015 and 2020). Data are square root transformed abundance values from benthic macro-infauna core samples. Only the centroids of the site replicates are plotted; each year is shown with a different symbol, and the positions of the communities in 2020 are highlighted with a circle. PAH = Pāuatahanui Arm, POR = Onepoto Arm of Porirua Harbour.

SIMPER analysis detected a number of species that were 'influential' in producing the temporal patterns, including *Arthritica* sp. 1, *Terebellides narribi*, *Linucula hartvigiana* and *Heteromastus filiformis*. Phoxcocephalidae spp., Oligochaete sp. 1, and Tanidacea sp. 1 were also influential species (Appendix E, F), although this may be largely driven by the taxonomic issues highlighted in Appendix B and may be resolved once voucher specimens are checked. Mud and organic enrichment tolerant oligochaetes were most abundant at all sites in 2005, found in low numbers on other sampling dates and absent in 2020. Tanaidacea sp. 1 was found at PAH1 in 2008 and 2010, and the tanaid *Apseudes* in 2020. Graham Bird (tanaid expert) has seen variations in abundance with season in similar tanaid taxa elsewhere. He suggests these fluctuations are not a response to any environmental factor – rather that they are likely to be reproduction linked.

The terebellid polychaete *Terebellides narribi* appeared for the first time in 2015 at all sites except PAH1, albeit sometimes in low numbers (1-10 ind. core^{-1}) and was found at POR1 only in 2020 (~2 ind. core^{-1}).

Some taxa increased in abundance at one or both of the Onepoto Arm sites in 2020 (*Arthritica bifurca, Theora lubrica*, *Asychis asychis*-B*, Nicon aestuariensis, Boccardia syrtis;* (Figure 3-13). *Theora*, the nerieid polychaetae *Nicon* and particularly *Arthritica* are considered to be tolerant of mud and organic enrichment. The spinonid polychaete *Boccardia* is ‘indifferent’ (neither prefers nor dislikes mud/enrichment), and the preference of the maldainid *Asychis* is unknown.

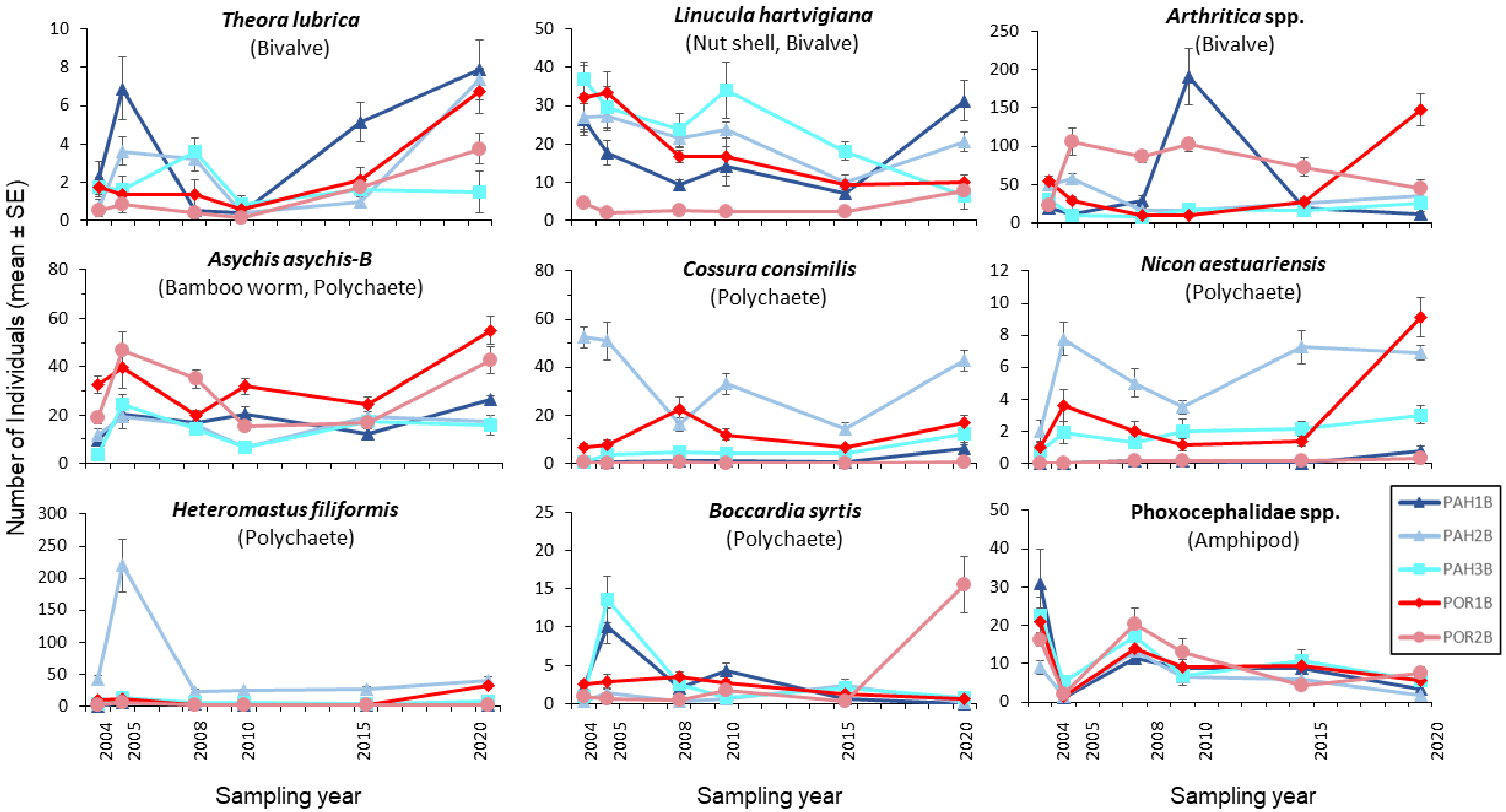

Figure 3-13: Total number of individuals of the common taxa at each site over all sampling dates. Values presented are mean (± standard error) per 20 cm diam. core. N=8.

4 Summary

Sediments collected in 2020 were predominantly muddy at four sites, ranging from 66-97% mud, while a mixture of mud and fine sand was recorded at PAH3 in the Pāuatahanui Arm (41% and 59%, respectively). Organic matter content was very similar across sites, ranging from 4.6-8.0%.

Analysis of a variety of metal and metalloid sediment contaminants revealed that no sites exceeded any of the guidelines for arsenic, cadmium, chromium, nickel or mercury. There were no guideline exceedances for any of these contaminants in sediments at the three sites within the Pāuatahanui Arm. Both of the Onepoto Arm sites (POR1 and POR2) exceeded ARC amber guideline concentrations in lead and zinc. POR1 sediments also exceeded ARC amber copper guidelines, and POR2 sediments were very close to exceedance levels for copper. Sediment mercury concentrations at the Onepoto Arm sites were close to DGV levels.

Mean total organic carbon (TOC), nutrient (TN, TP) and percent mud content of the sediments were evaluated against the New Zealand Estuary Trophic Index (ETI) eutrophication guidelines and the Estuary Condition Risk Indicator (ECRI) Rating. TOC concentrations varied around the harbour, with higher levels in the two Onepoto Arm sites than in the three Pāuatahanui Arm sites. PAH3 had the lowest % TOC and was rated ‘good’ on the ETI and ‘low risk’ on the ECRI rating. Sediments at PAH1, PAH2 and POR2 were ‘fair’/‘moderate risk’, and POR1 was ‘poor’/‘high risk’. Sediment TP levels were ‘poor’/‘high risk’ at the Onepoto Arm sites and at Pāuatahanui Arm Site 1, but ‘fair’/‘moderate risk’ at PAH2 and PAH3. Sediment TN levels were ‘fair’/‘moderate risk’ at all five sites, although Pāuatahanui Arm Site 3, at 1,000 mg/kg TN, was bordering the ‘moderate’ and ‘low’ risk categories. All sites were considered ‘poor’/‘high risk’ relative to their percent mud content (all >>25% guideline). TS concentrations were lowest at POR2, and all other sites were very similar to each other.

A total of 64 different taxa were identified across Te Awarua-o-Porirua Harbour in 2020; 57 were collected from the Pāuatahanui Arm, and 41 from the Onepoto Arm. The mean number of taxa was very similar across sites, ranging from 14-18 per core on average. The dominant taxa were mostly polychaetes and bivalves, with amphipod crustaceans and tanaids also common at some sites. While the dominant taxa were found across all sites, each of the five sites had a community compositionally distinct from the other sites. The number of individuals was about twice as high at the Onepoto Arm sites (297 and 239 ind. per core at POR1 and POR2, respectively) than at the Pāuatahanui Arm sites (average of 106-185 ind. per core).

Benthic health assessments were used to assess the relative health status of the different sites in 2020. The Traits-based index, based on biological traits of the benthic taxa, classified two of the Pāuatahanui Arm sites (PAH1, PAH3) and one Onepoto Arm site (POR1) as having ’high’ functional redundancy health scores in 2020. PAH2, located off Duck Creek, had an ‘intermediate’ health score and POR2, the northern site in the Onepoto Arm, was on the borderline between ‘intermediate’ and ‘low’ functional redundancy. The BHMmud model classified PAH1, PAH3 and POR2 as ‘moderately’ healthy and one site in each arm - PAH2 and POR1 – in ‘poor’ health. The BHMmet model indicated that while PAH1 was in ‘moderate’ health in 2020, the remaining sites were in ‘poor’ health. The Porirua BMH scores fit well with their measured environmental variables; when the BHMmud scores were checked against the actual percent mud concentrations measured at each of the benthic sites, PAH3 and POR2 displayed good fits and the remaining sites reasonable fits. For the BHMmet scores all sites displayed good fits with the measured concentrations of copper, lead and zinc (converted to a PCA score).

Although high mud content is generally associated with low taxa richness and concomitantly low TBI scores in intertidal habitats, some of the muddiest subtidal seafloor habitats in Porirua Harbour support a relatively high abundance and diversity of macrofauna (e.g. POR1, 93% mud) and have TBI scores reflective of high functional redundancy. Other very muddy sites with similar diversity and abundance (e.g. POR2, 97% mud) have low/intermediate TBI scores. It is probably unwise to put too much weight on the TBI scores reported here until the applicability of this index can be tested and validated in the subtidal zone (work that is ongoing at NIWA at present). It is also worth noting that diversity can increase at intermediate levels of disturbance (Connell, 1978; Huston, 1979).

Two models were used to investigate sediment characteristics correlated with benthic community composition in 2020. TOC was consistently identified as having a strong influence on explaining ~23% of the variation in community composition. Several other sediment variables were also important, but a number of them were strongly correlated, which strongly influenced the final models and their interpretability. The first model revealed that total sulphur, TOC and percent mud together explained 83% of the variation in community composition between sites. The Pāuatahanui Arm sites were influenced by total sulphur, while the Onepoto Arm sites were influenced by percent mud (each had > 90%). In the second model, arsenic, TOC and total phosphorous explained 87% of the variation in community composition.

In general, when comparing across sites, the two sites in the Onepoto Arm are in poorer health than those in the Pāuatahanui Arm, due largely to the metal contaminant and nutrient level exceedances. Nevertheless, the benthic communities at these sites are reasonably diverse (around 15 taxa) and did not contain taxa indicative of highly impacted sites. A combined health index (Greenfield et al. 2019) was not calculated because these are not yet validated for subtidal sites.

Benthic community composition has changed at all sites since the sampling began 17 years ago, with the temporal patterns similar across sites and the communities remaining distinct from each other. This indicates that long-term (since monitoring began) pressures on the harbour are general in nature and do not appear to be localised in a particular region or Arm. The numbers of individuals is more variable over time than the number of taxa, particularly at PAH1 and PAH2. We are unable to comment on short term changes at specific sites (e.g. resulting from rainfall or storm events) due to the infrequent sampling.

Correlation analysis has suggested that concentrations of fine sediments (10-63 μm) have decreased slightly (improved) over time at PAH3, POR1 and POR2. Average concentrations of lead have also declined at PAH3, POR1 and POR2, as has copper in sediments at PAH1, PAH3 and POR1. While there is difficulty with statistically comparing changes over time with only a few data points (at least 10 are recommended, cf. six available here to date) and no strong conclusions can be drawn, these declines are encouraging.

4.1 Recommendations

- Analysis of benthic community characteristics should be conducted on the combined taxa lists to enable temporal comparisons to be made with aligned data sets. We also recommend that the full data set is utilised for benthic health assessments each year.

- Voucher specimens from previous sampling years should be examined by taxonomic experts to confirm their identifications, enabling the taxa lists across the monitored period to be better aligned and reducing the loss of taxonomic resolution when the data sets from different years are combined. Taxa to be examined include a number of polychaetes, as well as amphipods and oligochaetes.

- The methods used in this monitoring programme should continue in their 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 the 13.6 cm diam. KC Denmark HAPS corer available at NIWA would be appropriate. This was successfully trialled in Wellington Harbour in November 2021. This will require adjusting of sample sizes in future analyses to ensure comparability between years.

- Sampling should occur more frequently and at regular intervals. At least one site, and preferably two (i.e. one site in each of the Pāuatahanui and, especially the Onepoto Arms) should be sampled annually. Inclusion of these sentinel sites will provide greater temporal resolution and thus strengthen the ability of the monitoring programme to detect change over time.

- All five sites should be sampled at least every four years and ideally every three years. Sampling could also be aligned with timing of Wellington Harbour subtidal monitoring and/or Porirua intertidal monitoring.

- Formal analysis should be undertaken to determine the relationship between the results of sediment particle sizes determined using two methods: laser particle size analyser and wet sieving. In 2020, 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). 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.

5 Acknowledgements

Many thanks to NIWA boat skippers and divers; Chazz Marriott, Pete Notman, Serena Cox, Jeff Forman, Roberta D'Archino, and Owen Anderson for field sampling. Mark Fenwick, Dean Stotter, Diana MacPherson (all NIWA) and Laura Bornemann (NIWA student intern) assisted with sieving benthic core samples. Thanks to Grady Petersen, Kelly Carter, Michal Ferries and Nichola Salmond for help with sorting and identifications. Specialist taxonomic assistance was provided by NIWA colleagues Kareen Schnabel (decapods), Nikki Davey (Holothuroidea), Jeff Forman (Mysids), Michelle Kelly (Sponges), Rachel Peart (Crustaceans) and Sadie Mills (Ophiuroids). External specialists Geoff Read (Polychaeta), Graham Bird (Tanaidacea) and Bruce Marshall (Mollusca) are also thanked for their help with taxonomic identifications. Drew Lohrer (NIWA), Megan Melidonis and Megan Oliver (both GWRC) are thanked for providing constructive comments during their reviews of this report.

6 Glossary of abbreviations and terms

AIC	Akaike's Information Criterion
ANZG	Australia and New Zealand Guidelines
ANOSIM	Analysis Of Similarities
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
GV-high	Guideline Value-High
ECRI	Estuary Condition Risk Indicator
ERC	Environmental Response Criteria
ETI	Estuary Trophic Index
GPS	Global Positioning System
GWRC	Greater Wellington Regional Council
Hg	Mercury
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
nMDS	Non-metric Multi-Dimensional Scaling
Ni	Nickel
NZ ETI	New Zealand Estuary Trophic Index
Pb	Lead
PCA	Principal Component Analysis
PERMANOVA	Permutational Multivariate Analysis Of Variance
SIMPER	Similarity Percentages

TBI	Traits Based Index
TOC	Total organic carbon
TN	Total Nitrogen
TP	Total Phosphorous
TS	Total Sulphur
QA	Quality assurance
QC	Quality control
Zn	Zinc

7 References

ANZG (2018a) *Australian and New Zealand guidelines for fresh and marine water quality*. https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

Conwell, C., Oliver, M.D., Robertson, B. (2017) Te Awarua-o-Porirua Harbour subtidal sediment quality survey: Results from the 2015 survey. *Greater Wellington Regional Council*, Publication GW/ESCI-T-17/106, Wellington.

Clark, D.E., Hewitt, J.E., Pilditch, C.A., Ellis, J.I. (2020) The development of a national approach to monitoring estuarine health based on multivariate analysis. *Marine Pollution Bulletin,* 150: 110602. https://doi.org/10.1016/j.marpolbul.2019.110602

Ellis, J. I., Clark, D., Atalah, J., Jiang, W., Taiapa, C., Patterson, M., Sinner, J., Hewitt, J. (2017). Multiple stressor effects on marine infauna: responses of estuarine taxa and functional traits to sedimentation, nutrient and metal loading. *Scientific Reports*, 7(1). doi:10.1038/s41598-017-12323-5

Forrest, B.M., Stevens, L.M., Rabel, H. (2020) Fine Scale Intertidal Monitoring of Te Awarua-o-Porirua Harbour. *Salt Ecology Report,* 044, prepared for Greater Wellington Regional Council, August 2020: 33.

Greenfield, B.L., McCartain, L.D., Hewitt, J.E. (2019) Manukau Harbour intertidal ecology monitoring 1987 to February 2018. Prepared by NIWA for Auckland Council. *Auckland Council technical report*, TR2019/025.

Hewitt, J.E. (2019) Wellington Harbour subtidal sediment quality monitoring: Results from the 2016 survey. *NIWA Client report* 2019009HN, prepared for Greater Wellington Regional Council.

Hewitt, J.E., Lohrer, A.M., Townsend, M. (2012) Health of estuarine soft-sediment habitats: continued testing and refinement of state of the environment indicators. *Auckland Council Technical Report*, TR2012/012.

Lohrer, A.M., Rodil, I.F., Townsend, M., Chiaroni, L.D., Hewitt, J.E., Thrush, S.F. (2013). Biogenic habitat transitions influence facilitation in a marine soft-sediment ecosystem. *Ecology,* 94: 136–145.

Mirlean, N., Calliari, L., Baisch, P. *et al.* (2009) Urban activity and mercury contamination in estuarine and marine sediments (Southern Brazil). *Environmental Monitoring and Assessment,* 157: 583–589.

Norkko, A.; Talman, S.; Ellis, J.; Nicholls, P.; Thrush, S. (2001b) Macrofaunal sensitivity to fine sediments in the Whitford embayment. Prepared for Auckland Regional Council. NIWA Client Report ARC01266/2.

Olsen, G., Cummings, V., Halliday, J., Ovenden, R., Rendle, D., Petersen, G. (2021) *Te Awarua-o-Porirua Harbour subtidal sediment quality monitoring 2020.* Sediment chemistry, particle size and QA/QC data report. Prepared for Greater Wellington Regional Council, May.

Powell, A.W.B. (1979) *New Zealand mollusca - marine land and freshwater shells.* Collins Auckland.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T., Oliver, M. (2016a) NZ Estuary Trophic Index Screening Tool 1: Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420: 47.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T., Oliver, M. (2016b) NZ Estuary Trophic Index Screening Tool 2: determining monitoring indicators and assessing estuary trophic state. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract C01X1420: 68.

Robertson, B.P., Savage, C., Gardner, J.P.A., Robertson, B.M., Stevens, L.M. (2016c) Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. *Ecological Indicators,* 69: 595-605.

Rodil, I.F., Lohrer, A.M., Hewitt, J.E., Townsend, M., Thrush, S.F., Carbines, M. (2013) Tracking environmental stress gradients using three biotic integrity indices: advantages of a locally-developed traits-based approach. *Ecological Indicators,* 34: 560-570.

Stephenson, G., Milne, J.R., Sorensen, P. (2008) Wellington Harbour Marine Sediment Quality Investigation. *NIWA Client Report* WGN-DOCS-#496552-V3, GW/EM-T-08/83.

Williamson, B., Olsen, G., Green, M. (2004) Greater Wellington Regional Council Long-Term Baseline Monitoring of Marine Sediments in Porirua Harbour. *NIWA Client Report* HAM2008-075.

Appendix A Amalgamated taxa and data set updates – log of changes made when merging data from 2004 to 2020.

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 POR 2020 data

Confirmed all sites present and combined sheets from previous years (checking all row names the same), removing sites not sampled in 2020.

To merge the past and current datasets from Porirua Harbour:

Removed rows with 0 records.
Added in Phyla, class/order and Family columns to 2020 and earlier data.

The follow taxonomic name changes were made to combine the early data with the 2020 data:

- Hesionidae sp.#1, Hesionidae sp.#2, Hesionidae sp.#3 (old) and *Oxydromus angustifrons* (2020) combined to Hesionidae spp.
- *Asychis* sp.#1 (old) and *Asychis asychis*-B (2020) combined to *Asychis asychis*-B.
- *Aricidea* sp.#1 (old) and *Aricidea* sp. (2020) combined to Aricidea spp.
- Paraonidae sp.#1, Paraonidae sp.#2 (old) and *Paradoneis lyra* combined to Paraonidae spp.
- *Euchone* sp.#1 (old) and *Euchone* sp. (2020) combined to *Euchone* spp.
- *Sphaerodoropsis* sp.#1 (old) and *Sphaerodoropsis* (2020) combine to *Sphaerodoropsis* spp.
- *Prionospio aucklandica* (old, 2020), *Prionospio multicristata* (2020), and *Prionospio* sp.#1, *Prionospio* sp.#2 (old). Keep *P. aucklandica*, combined others to *Prionospio* spp.
- Terebellidae sp.#1 (old) and *Pseudopista rostrata* (2020) combine to Terebellidae spp.
- *Edwardsia* sp.#1 (old) and *Edwardsia* sp. (2020) combine to *Edwardsia* spp.
- Phoxocephalidae sp.#1, Phoxocephalidae sp.#2 (old) and Phoxocephalidae indet, *Torridoharpinia hurleyi* (2020) combine to Phoxocephalidae spp.
- Amphipoda sp. #1-#4 (old). Combined (including Bathymedon neozealanicus and Hippomedon (2020) to Amphipoda spp.
- Copepoda sp.#1, Copepoda sp.#2, Copepoda sp.#3 (old) and Harpacticoid copepod (2020) combined all to Copepoda spp.
- *Macrophthalmus hirtipes* synonymised (and combined with 2020) to *Hemiplax hirtipes*.
- Ostracoda sp #1-#7 (old) and Ostracoda (2020) combined to Ostracoda spp.
- *Arthritica* sp.#1 (old) and *Arthritica bifurca* (2020) combined to *Arthritica* spp.

- *Nucula hartvigiana* updated to *Linucula hartvigiana* and combined. All *Nucula* are *L. hartvigiana* according to Bruce's ID checks.
- Nemertea sp.#1-#4 (old) and Nemertea (2020) combined to Nemertea spp.
- Nematoda sp.#1 (old) and Nematoda (2020) combined to Nematoda spp.
- Sipunculida sp.#2 (old) and Sipuncula (2020) combined to Sipuncula spp.
- *Glycera lamellipodia* and *Glycera lamelliformis* merged.

Same species found in the old data set and the 2020 data set so 2020 data added to existing data:

Heteromastus filiformis
Cossura consimilis
Glycinde trifida
Nicon aestuariensis
Perinereis vallata
Armandia maculate
Phylo novazealandiae
Priapulopsis australis
Boccardia syrtis
Scolecolepides benhami
Terebellides narribri
Hemiplax hirtipes
Paracaudina chilensis
Cyclomactra ovata
Linucula hartvigiana
Theora lubrica
Macomona liliana
Austrovenus stutchburyi
Xymene plebeius
Halicarcinus varius

Bruce Marshall's updates:

Nucula nitidula and Linucula hartvigiana combined as L. hartvigiana
Turbonilla sp. updated to Turbonilla zealandica

Other Updates made after clarification with taxonomists:

- Eusiridae (Amphipoda) specimens from POR and PAH, not listed on original spreadsheet –ID confirmed with Rachael Peart, new taxa added to dataset.
- The ID staff labelled a PAH2B.1 specimen as 'Cirratulidae', Geoff Read IDed as *Timarete anchylochaeta*. No Cirratulidae present on dataset, only 2 Aphelochaeta specimens found in PAH2B.1 – change all Aphelochaeta to *T. anchylochaeta* – and combined with Old *T. anchylochaeta*
- Voucher PAH3B.7 Serpulidae (Hamilton) ID'ed as *Serpula* sp. (Geoff Read) not present in dataset – added *Serpula* sp. to dataset.

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 2004, 2005, 2008, 2011 and 2015.

Group	Taxa	Abundance (total number)		notes	Recommendations
		Pre-2020	2020		
Amphipod	Amphipod sp. #1, sp. #2, sp. #3, sp. #4	39	0	Combined in the 2020 analysis as Amphipoda spp.	Voucher specimens of Amphipod sp. #1-4 are examined by Rachael Peart.
	Bathymedon cf *neozelanicus* and *Hippomedon* sp.	0	11	Combined in the 2020 analysis as Amphipoda spp. (vouchers confirmed)	
	Phoxocephalidae sp. #1	1202	0	Combined in the 2020 analysis as Phoxocephalidae spp.	Voucher specimens of Phoxocephalidae sp. #1 and sp. #2 are examined by Rachael Peart.
	Phoxocephalidae sp. #2	964	0		
	Phoxocephalidae	0	45	Combined in the 2020 analysis as Phoxocephalidae spp. (vouchers confirmed)	
	Torridoharpinia hurleyi	0	146		
Tanaid	Tanaidacea sp. 1	6495	0	Two main tanaid taxa were found in 2004-2015 only (Tanaidacea sp. 1 and sp. 2). Tanaidacea sp. 1. was found at four sites and was very common at PAH1 and POR2 on some occasions. *Apseudes "novaezealandiae"* was found in large numbers at POR2 in 2020.	Vouchers of Tanaidacea sp. 1 are checked by Graham Bird to determine whether they are *Apseudes "novaezealandiae"*.
	Tanaidacea sp. 2	49	0		Vouchers of Tanaidacea sp. 2 are checked by Graeme Bird.
	Apseudes "novaezealandiae"	0	810	Vouchers have been confirmed by Graeme Bird.	
	Araphura whakarakaia	0	2	Vouchers have been confirmed by Graeme Bird.	
Polychaete (Trichobranchids)	*Terebellides* sp. 1	117	0	Two Trichobranchidae taxa have been found in the past (*Terebellides* sp. 1 and *Terebellides narribri*). Only *Terebellides narribri* was found in the 2020 samples, suggesting a change over time.	Vouchers of both taxa could be checked by Geoff Read *OR* the taxa could be combined at genus level.
	Terebellides narribri	191	19		

Group	Taxa	Abundance (total number)		notes	Recommendations
		Pre-2020	2020		
	Terebellidae sp. 1	8	0	Combined in the 2020 analysis as Terebellidae spp.	No action required, given the low numbers of these taxa.
	Pseudopista rostrata	0	2		
Annelid (Oligochaete)	Oligochaete sp. 1	1661	0	Two oligochaete taxa (sp. 1 and sp. 2) were found in 2004-2015, one oligochaete family was found in 2020 (Naididae; ID confirmed).	Oligochaete sp 1 and sp 2 vouchers could be checked by Geoff Read *OR* the taxa could be combined at family level.
	Oligochaete sp. 2	3	0		
	Naididae	0	116		
Polychaete (Goniadids)	*Glycinde* sp. 1	419	0	In 2004-2011 all Goniadidae were *Glycinde* sp. 1, while in 2015 and 2020 all were *Glycinde trifida* (ID confirmed).	Glycinde sp. 1 and *Glycinde trifida* vouchers could be checked by Geoff Read *OR* the taxa could be combined at genus level.
	Glycinde trifida	117	47		
Polychaete (Paraonids)	Paraonidae sp.#1	471	0	Paraonidae sp.#1, Paraonidae sp.#2. and *Paraoneis lyra* were all combined as Paraonidae spp.	Voucher specimens of sp.#1 and #2 are examined by Geoff Read to determine whether they are *Paradoneis lyra.*
	Paraonidae sp.#2	7	0		
	Paradoneis lyra	0	82		
Polychaete (Spionids)	*Carazziella phillipensi*	0	105	*Carazziella phillipensi* was found in 2020 for the first time. It is an extremely small polychaete. This ID was confirmed by Geoff Read.	No action required.
	Boccardia syrtis	491	136		Vouchers of *Boccardia syrtis* are examined by Geoff Read to determine whether some may be *Carazziella phillipensi* or whether *C. phillipensi* is a new ID from this harbour.
Polychaete (Maldanids)	*Euclymene* sp. #1	43	0	*Euclymene* sp. 1 and *Asychis* sp. #1 were found in 2004-2015. *Asychis asychis-B* was the dominant maldanid in 2020 and it was assumed *Asychis* sp #1	Vouchers of *Euclymene* sp. #1 could be checked by Geoff Read to confirm species name.
	Asychis asychis-B	0	1256		

Group	Taxa	Abundance (total number)		notes	Recommendations
		Pre-2020	2020		
	Asychis sp. #1	4005	0	and *Asychis asychis-B* were the same taxa (combined in the analysis). *Euclymene* sp.#1 was only found in 2004-2015, suggesting a change in taxa may have occurred over time.	Vouchers of *Asychis* sp.#1 could be checked by Geoff Read to confirm it is distinct from *A. asychis-B*.
Polychaete (Exogonids)	Exogoninae	0	15	This 2020 Exogoninae (subfamily) sample ID was confirmed by Geoff Read. *Sphaerosyllis hirsuta* is also an Exogoninae, and was retained in the analysis, but it does not occur in New Zealand waters.	ID Exogoninae to subfamily level only, and combine these two taxa in future analyses.
	Sphaerosyllis hirsuta	16	0		
Cumacean	*Colurostylis lemurum*	17	0	*Colurostylis lemurum* was found in 2004-2015, but not in 2020.	Vouchers of *C. lemurum* could be checked by Rachael Peart see if a species change has occurred over time. *OR* as they are rare, combine all cumaceans to genus level.
	Colurostylis whitireia	0	8		
	Colurostylis castlepointensis	0	1		
	Leptostylis sp.	0	1		
Gastropod*	*Turbonilla zealandica*	0	31	This taxon is distinct in morphology from the other gastropod taxa on the list, and the ID has been confirmed by Bruce Marshall.	No action required.
Gastropod*	*Cominella glandiformis*	12	0	Although this taxon was not found in 2020, it was rare in 2004-2015.	No action required.
Bivalve	*Arthritica* sp. #1	8324	0	Combined as *Arthritica* spp. for the analyses in this report.	Vouchers of *Arthritica* sp. #1 could be examined by Bruce Marshall to determine whether they are *Arthritica bifurca.*
	Arthritica bifurca	0	2125		
Ostracoda	Ostracoda sp. #1, sp. #2, sp. #3, sp. #4, sp. #5, sp. #6, sp. #7	194	0	Ostracods in 2004-2015 were split into seven morphotaxa, but in 2020 they were combined at Class level. Because NZ does not have an Ostracod expert,	ID Ostracoda to class level only and combine all ostracods in future analyses.

Group	Taxa	Abundance (total number)		notes	Recommendations
		Pre-2020	2020		
	Ostracoda	0	132	many are epibenthic or pelagic rather than benthic, and there is no information on their habitat preferences we consider that combining them at Class level makes ecological sense, even though it reduces diversity counts. They were amalgamated for the analyses in this report.	
Nemertea	Nemertea sp. #1, sp. #2, sp. #3, sp. #4	88	0	Nemertea in 2004-2015 were split into four morphotaxa, but in 2020 they were ID as the phylum Nemertea only. They were amalgamated for the analyses in this report. As noted for Ostracods above, NZ does not have a nemertean expert.	ID Nemertea to phylum level.

*Two gastropods, the mud whelk *Cominella glandiformis* (collected 2004-2015 only; 12 individuals) and the small pyramidellid *Turbonilla zealandica* (collected 2020 only; 31 individuals) are easily identifiable. *Cominella glandiformis* are very abundant in the intertidal but are not commonly found subtidally. The majority of the *Turbonilla* were found at PAH2.

Appendix C Functional groups used in the Traits Based Index (TBI) calculations.

Functional Category	Functional Group
Living position *	Attached
	Deeper than 2 cm
	Surface epifauna
	Top 2 cm
Sediment topography feature created *	Permanent burrow
	Erect structure / tube
	Simple hole or pit
	Mound
	Trample marks
	Trough
Direction of sediment particle movement *	Depth to depth
	Depth to surface
	Surface to depth
	Surface to surface
Degree of motility	Freely motile on or in sediment
	Limited movement, usually in sediment
	Sedentary / movement in a fixed tube
	Semi-pelagic
Feeding behaviour *	Deposit feeder
	Grazer
	Predator
	Scavenger
	Suspension feeder
Body size	Large
	Medium
	Small
Body shape	Streamlined (length 3-10x width)
	Round/Globulose (length 1-3x width)
	Worm-shaped (length 10-100x width)
Body hardness	Soft-bodied
	Rigid (chitonous endo- or exo-skeleton)
	Calcified (fully calcified shell; molluscs)

Appendix D Bivalve sizes, Porirua Harbour November 2020.

Site and taxa	<2 mm	2-5 mm	5-10 mm	10-20 mm	20-40 mm	>40 mm
Pāuatahanui Site 1 (PAH1B)	**241**	**12**	**165**		**3**	
Arthritica bifurca	94					
Austrovenus stutchburyi	3					
Cyclomactra ovata					3	
Linucula hartvigiana	137	2	111			
Macomona liliana	5	1	1			
Solemya parkinsonii	1					
Theora lubrica	1	9	53			
Pāuatahanui Site 2 (PAH2B)	**384**	**22**	**104**	**8**	**3**	
Arthritica bifurca	285	2				
Austrovenus stutchburyi	2				2	
Cyclomactra ovata					1	
Leptomya retiaria				1		
Linucula hartvigiana	89	10	66			
Macomona liliana		4				
Theora lubrica	8	6	38	7		
Pāuatahanui Site 3 (PAH3B)	**258**	**9**	**19**		**4**	
Arthritica bifurca	210	1				
Austrovenus stutchburyi	2					
Cyclomactra ovata					4	
Linucula hartvigiana	45	3	5			
Macomona liliana	1	3				
Solemya parkinsonii			1			
Theora lubrica		2	13			
Onepoto Arm Site 1 (POR1B)	**1202**	**63**	**39**	**10**	**2**	
Arthritica bifurca	1117	56				
Austrovenus stutchburyi		1				
Cyclomactra ovata					2	
Linucula hartvigiana	81					
Macomona liliana	2	1				
Mactra sp.	1					
Theora lubrica		5	39	10		
Zemysina globus	1					
Onepoto Arm Site 2 (POR2B)	**397**	**15**	**43**	**1**		
Arthritica bifurca	362	1				
Linucula hartvigiana	35	9	19			
Theora lubrica		5	24	1		

Appendix E PRIMER output of SIMPER analysis for the untransformed 2020 Porirua Harbour data set.

This output shows the taxa found at each site in November 2020. This analysis was conducted on the untransformed combined data set, Bray Curtis data with a 70% cutoff for low contributions.

SIMPER

Similarity Percentages - species contributions
One-Way Analysis

Data worksheet

Name: POR_2020_PRIMER
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters

Resemblance: S17 Bray-Curtis similarity
Cut off for low contributions: 70.00%

Group PAH1B

Average similarity: 59.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Asychis asychis-B	26.25	20.06	3.24	33.77	33.77
Linucula hartvigiana	31.25	18.59	3.97	31.29	65.06
Arthritica spp.	11.75	5.71	1.81	9.61	74.68

Group PAH2B
Average similarity: 76.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cossura consimilis	42.75	19.09	4.74	24.99	24.99
Heteromastus filiformis	39.50	16.51	3.49	21.62	46.60
Arthritica spp.	35.88	14.56	2.17	19.06	65.66
Linucula hartvigiana	20.63	8.98	4.00	11.76	77.42

Group PAH3B
Average similarity: 47.89

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica spp.	26.00	11.77	1.18	24.57	24.57
Asychis asychis-B	15.88	8.66	1.48	18.08	42.65
Cossura consimilis	12.00	5.72	1.37	11.95	54.60
Ostracoda spp.	8.50	5.06	3.69	10.58	65.17
Heteromastus filiformis	7.63	4.18	1.41	8.74	73.91

Group POR1B
Average similarity: 75.89

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica spp.	146.63	37.16	5.20	48.97	48.97
Asychis asychis-B	55.00	16.07	5.29	21.18	70.16

Group POR2B
Average similarity: 55.25

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	100.75	21.35	1.28	38.63	38.63
Asychis asychis-B	42.63	14.49	2.16	26.23	64.86
Arthritica spp.	45.38	9.92	1.75	17.96	82.82

Groups PAH1B & PAH2B
Average dissimilarity = 58.77

	Group PAH1B	Group PAH2B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	0.88	39.50	12.50	2.78	21.27	21.27
Cossura consimilis	5.88	42.75	12.03	2.74	20.47	41.74
Arthritica spp.	11.75	35.88	8.38	1.65	14.25	56.00
Linucula hartvigiana	31.25	20.63	4.30	1.05	7.31	63.31
Asychis asychis-B	26.25	17.25	3.59	1.91	6.11	69.42
Carazziella phillipensis	12.88	0.00	3.11	0.38	5.29	74.71

Groups PAH1B & PAH3B
Average dissimilarity = 60.19

	Group PAH1B	Group PAH3B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Linucula hartvigiana	31.25	6.63	12.14	1.70	20.17	20.17
Arthritica spp.	11.75	26.00	8.23	1.40	13.67	33.84
Asychis asychis-B	26.25	15.88	6.64	1.30	11.03	44.87
Carazziella phillipensis	12.88	0.25	3.98	0.39	6.61	51.48
Cossura consimilis	5.88	12.00	3.92	1.06	6.52	58.00
Theora lubrica	7.88	1.50	3.06	1.53	5.08	63.08
Heteromastus filiformis	0.88	7.63	2.96	1.68	4.92	68.00
Ostracoda spp.	6.75	8.50	2.24	1.21	3.72	71.71

Groups PAH2B & PAH3B
Average dissimilarity = 56.41

	Group PAH2B	Group PAH3B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	39.50	7.63	11.21	2.06	19.88	19.88
Cossura consimilis	42.75	12.00	11.00	1.88	19.50	39.38
Arthritica spp.	35.88	26.00	7.65	1.23	13.57	52.94
Linucula hartvigiana	20.63	6.63	6.10	2.08	10.81	63.76
Asychis asychis-B	17.25	15.88	3.51	1.16	6.22	69.98
Ostracoda spp.	0.13	8.50	2.72	1.92	4.82	74.79

Groups PAH1B & POR1B
Average dissimilarity = 68.50

	Group PAH1B	Group POR1B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	11.75	146.63	31.09	3.41	45.39	45.39
Heteromastus filiformis	0.88	31.13	7.58	2.87	11.06	56.45
Asychis asychis-B	26.25	55.00	6.83	2.06	9.96	66.41
Linucula hartvigiana	31.25	10.13	5.16	1.38	7.53	73.94

Groups PAH2B & POR1B
Average dissimilarity = 47.34

Species	Group PAH2B Av.Abund	Group POR1B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	35.88	146.63	21.98	2.47	46.44	46.44
Asychis asychis-B	17.25	55.00	7.88	2.48	16.64	63.08
Cossura consimilis	42.75	16.50	5.57	1.80	11.77	74.85

Groups PAH3B & POR1B
Average dissimilarity = 63.36

Species	Group PAH3B Av.Abund	Group POR1B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	26.00	146.63	29.47	2.52	46.51	46.51
Asychis asychis-B	15.88	55.00	10.01	2.09	15.80	62.31
Heteromastus filiformis	7.63	31.13	6.36	2.07	10.03	72.34

Groups PAH1B & POR2B
Average dissimilarity = 70.30

Species	Group PAH1B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.00	100.75	24.17	1.88	34.38	34.38
Arthritica spp.	11.75	45.38	8.93	1.75	12.70	47.09
Linucula hartvigiana	31.25	7.88	8.10	1.13	11.52	58.61
Asychis asychis-B	26.25	42.63	6.69	1.82	9.51	68.12
Boccardia syrtis	0.00	15.50	3.91	1.85	5.56	73.69

Groups PAH2B & POR2B
Average dissimilarity = 71.87

Species	Group PAH2B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.00	100.75	20.87	1.85	29.03	29.03
Cossura consimilis	42.75	0.50	11.09	2.13	15.43	44.46
Heteromastus filiformis	39.50	1.88	9.87	1.88	13.73	58.19
Arthritica spp.	35.88	45.38	6.87	1.26	9.56	67.75
Asychis asychis-B	17.25	42.63	6.71	2.25	9.34	77.09

Groups PAH3B & POR2B
Average dissimilarity = 71.02

Species	Group PAH3B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.25	100.75	25.48	1.90	35.87	35.87
Asychis asychis-B	15.88	42.63	9.40	1.51	13.23	49.11
Arthritica spp.	26.00	45.38	9.36	1.41	13.18	62.29
Boccardia syrtis	0.75	15.50	4.04	1.96	5.69	67.98
Cossura consimilis	12.00	0.50	3.94	0.97	5.54	73.52

Groups POR1B & POR2B
Average dissimilarity = 61.98

Species	Group POR1B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	146.63	45.38	20.66	1.53	33.33	33.33
Apseudes "novaezealandiae"	0.25	100.75	17.00	1.75	27.44	60.77
Heteromastus filiformis	31.13	1.88	6.11	2.12	9.86	70.63

Appendix F PRIMER output of SIMPER analysis for the square root transformed 2020 Porirua Harbour data set.

This output shows the taxa found at each site in November 2020. This analysis was conducted on square root transformed combined data set, with a 70% cutoff for low contributions.

SIMPER
Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: SqRtAbund2
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray-Curtis similarity
Cut off for low contributions: 70.00%

Group PAH1B
Average similarity: 62.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Asychis asychis-B	5.11	13.57	4.83	21.54	21.54
Linucula hartvigiana	5.47	13.14	5.70	20.86	42.40
Arthritica spp.	3.25	6.98	3.59	11.08	53.47
Theora lubrica	2.66	5.65	2.72	8.96	62.43
Ostracoda spp.	2.47	5.45	2.94	8.65	71.08

Group PAH2B
Average similarity: 78.43

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cossura consimilis	6.48	13.74	8.15	17.52	17.52
Heteromastus filiformis	6.18	12.71	6.45	16.20	33.72
Arthritica spp.	5.84	11.66	3.81	14.87	48.59
Linucula hartvigiana	4.49	9.36	8.98	11.94	60.52
Asychis asychis-B	4.08	8.37	9.66	10.67	71.20

Group PAH3B
Average similarity: 57.58

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica spp.	4.62	8.60	2.10	14.94	14.94
Asychis asychis-B	3.72	7.70	2.37	13.38	28.31
Cossura consimilis	3.20	6.34	3.00	11.01	39.33
Ostracoda spp.	2.79	6.23	8.13	10.82	50.15
Heteromastus filiformis	2.53	4.89	1.61	8.50	58.65
Phoxocephalidae spp.	2.08	3.64	1.32	6.33	64.98
Nicon aestuariensis	1.60	3.22	1.66	5.59	70.56

Group POR1B
Average similarity: 76.94

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica spp.	11.90	20.83	8.69	27.07	27.07
Asychis asychis-B	7.36	13.72	7.93	17.83	44.90
Heteromastus filiformis	5.55	10.46	6.22	13.60	58.50
Cossura consimilis	3.94	6.63	5.43	8.62	67.12

Nicon aestuariensis	2.97	5.25	4.67	6.82	73.94

Group POR2B
Average similarity: 64.41

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	9.18	14.92	2.20	23.17	23.17
Asychis asychis-B	6.37	13.52	4.02	20.99	44.16
Arthritica spp.	6.28	10.92	3.47	16.96	61.11
Boccardia syrtis	3.57	5.58	1.61	8.66	69.77
Phoxocephalidae spp.	2.63	5.08	3.11	7.88	77.65

Groups PAH1B & PAH2B
Average dissimilarity = 48.76

	Group PAH1B	Group PAH2B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	0.57	6.18	7.17	3.34	14.71	14.71
Cossura consimilis	2.30	6.48	5.32	2.97	10.91	25.63
Arthritica spp.	3.25	5.84	3.53	1.67	7.25	32.88
Ostracoda spp.	2.47	0.13	2.93	2.88	6.01	38.89
Nicon aestuariensis	0.60	2.61	2.59	2.48	5.31	44.20
Turbonilla zealandica	0.00	1.63	2.06	1.85	4.23	48.43
Linucula hartvigiana	5.47	4.49	1.62	1.13	3.32	51.75
Naididae	1.37	0.56	1.58	1.06	3.24	54.99
Asychis asychis-B	5.11	4.08	1.52	1.85	3.13	58.11
Paraonidae spp.	0.92	0.93	1.47	1.02	3.02	61.13
Carazziella phillipensis	1.39	0.00	1.44	0.42	2.95	64.08
Phylo novazealandiae	1.11	0.00	1.34	1.52	2.74	66.82
Phoxocephalidae spp.	1.44	1.23	1.30	1.46	2.67	69.49
Priapulopsis australis	0.93	0.00	1.14	1.38	2.33	71.83

Groups PAH1B & PAH3B
Average dissimilarity = 51.44

	Group PAH1B	Group PAH3B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Linucula hartvigiana	5.47	2.04	5.17	1.87	10.06	10.06
Arthritica spp.	3.25	4.62	3.14	1.53	6.11	16.16
Theora lubrica	2.66	0.68	2.97	1.79	5.78	21.95
Heteromastus filiformis	0.57	2.53	2.90	1.79	5.63	27.58
Asychis asychis-B	5.11	3.72	2.42	1.19	4.71	32.29
Cossura consimilis	2.30	3.20	1.97	1.24	3.83	36.12
Phoxocephalidae spp.	1.44	2.08	1.97	1.25	3.83	39.95
Naididae	1.37	1.46	1.79	1.27	3.48	43.43
Carazziella phillipensis	1.39	0.25	1.76	0.49	3.43	46.86
Nicon aestuariensis	0.60	1.60	1.59	1.50	3.09	49.95
Nemertea spp.	0.55	1.40	1.54	1.35	3.00	52.95
Glycinde trifida	0.43	1.29	1.48	1.46	2.88	55.83
Phylo novazealandiae	1.11	0.00	1.47	1.48	2.86	58.70
Paraonidae spp.	0.92	0.48	1.36	0.76	2.65	61.35
Aricidea spp.	0.00	0.97	1.33	2.11	2.58	63.93
Ostracoda spp.	2.47	2.79	1.28	1.34	2.49	66.42
Priapulopsis australis	0.93	0.00	1.25	1.35	2.44	68.86
Xymene plebeius	0.89	0.13	1.18	1.34	2.28	71.14

Groups PAH2B & PAH3B
Average dissimilarity = 47.59

Species	Group PAH2B Av.Abund	Group PAH3B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	6.18	2.53	4.76	1.94	10.01	10.01
Cossura consimilis	6.48	3.20	4.28	1.82	8.99	19.00
Linucula hartvigiana	4.49	2.04	3.58	2.04	7.53	26.53
Ostracoda spp.	0.13	2.79	3.28	3.83	6.89	33.42
Arthritica spp.	5.84	4.62	2.94	1.19	6.18	39.61
Theora lubrica	2.70	0.68	2.74	2.09	5.77	45.37
Turbonilla zealandica	1.63	0.25	1.82	1.68	3.82	49.19
Asychis asychis-B	4.08	3.72	1.70	1.11	3.56	52.75
Phoxocephalidae spp.	1.23	2.08	1.63	1.47	3.44	56.19
Naididae	0.56	1.46	1.57	1.45	3.30	59.48
Nicon aestuariensis	2.61	1.60	1.37	1.23	2.88	62.36
Glycinde trifida	0.60	1.29	1.25	1.41	2.62	64.98
Aricidea spp.	0.00	0.97	1.20	2.23	2.53	67.50
Nemertea spp.	1.15	1.40	1.13	1.28	2.38	69.88
Paraonidae spp.	0.93	0.48	1.01	1.26	2.13	72.01

Groups PAH1B & POR1B
Average dissimilarity = 52.34

Species	Group PAH1B Av.Abund	Group POR1B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	3.25	11.90	10.01	3.41	19.11	19.11
Heteromastus filiformis	0.57	5.55	5.90	3.54	11.27	30.39
Linucula hartvigiana	5.47	3.09	2.81	1.57	5.38	35.76
Nicon aestuariensis	0.60	2.97	2.81	2.27	5.38	41.14
Asychis asychis-B	5.11	7.36	2.62	2.12	5.01	46.15
Ostracoda spp.	2.47	0.25	2.59	2.40	4.95	51.11
Cossura consimilis	2.30	3.94	2.06	1.66	3.93	55.04
Paraonidae spp.	0.92	1.27	1.70	1.20	3.25	58.29
Naididae	1.37	1.16	1.52	1.19	2.90	61.18
Phoxocephalidae spp.	1.44	2.26	1.48	1.43	2.82	64.01
Carazziella phillipensis	1.39	0.00	1.34	0.42	2.57	66.57
Phylo novazealandiae	1.11	0.00	1.24	1.50	2.37	68.94
Nemertea spp.	0.55	1.33	1.12	1.38	2.14	71.08

Groups PAH2B & POR1B
Average dissimilarity = 32.85

Species	Group PAH2B Av.Abund	Group POR1B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	5.84	11.90	6.40	2.52	19.50	19.50
Asychis asychis-B	4.08	7.36	3.54	2.59	10.78	30.27
Cossura consimilis	6.48	3.94	2.78	1.88	8.47	38.75
Linucula hartvigiana	4.49	3.09	1.60	1.43	4.86	43.61
Turbonilla zealandica	1.63	0.25	1.55	1.67	4.72	48.33
Heteromastus filiformis	6.18	5.55	1.23	1.41	3.75	52.08
Naididae	0.56	1.16	1.21	1.16	3.68	55.76
Paraonidae spp.	0.93	1.27	1.14	1.47	3.47	59.23
Phoxocephalidae spp.	1.23	2.26	1.14	1.38	3.47	62.69
Terebellides narribri	0.00	0.95	1.00	0.92	3.03	65.72
Glycinde trifida	0.60	0.89	0.74	1.23	2.26	67.98
Xymene plebeius	0.72	0.13	0.74	1.14	2.24	70.23

Groups PAH3B & POR1B
Average dissimilarity = 47.14

Species	Group PAH3B Av.Abund	Group POR1B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Arthritica spp.	4.62	11.90	8.60	2.18	18.24	18.24
Asychis asychis-B	3.72	7.36	4.31	1.85	9.14	27.38
Heteromastus filiformis	2.53	5.55	3.67	1.90	7.78	35.17
Ostracoda spp.	2.79	0.25	2.92	2.97	6.19	41.36
Theora lubrica	0.68	2.53	2.37	2.10	5.02	46.37
Linucula hartvigiana	2.04	3.09	2.05	1.66	4.36	50.73
Cossura consimilis	3.20	3.94	1.77	1.38	3.76	54.48
Nicon aestuariensis	1.60	2.97	1.70	1.35	3.60	58.09
Naididae	1.46	1.16	1.40	1.36	2.96	61.05
Paraonidae spp.	0.48	1.27	1.30	1.23	2.77	63.81
Phoxocephalidae spp.	2.08	2.26	1.28	1.38	2.72	66.53
Aricidea spp.	0.97	0.00	1.11	2.19	2.36	68.89
Terebellides narribri	0.25	0.95	1.08	1.00	2.29	71.18

Groups PAH1B & POR2B
Average dissimilarity = 57.84

Species	Group PAH1B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.00	9.18	11.17	2.70	19.32	19.32
Linucula hartvigiana	5.47	2.46	4.39	1.25	7.60	26.91
Boccardia syrtis	0.00	3.57	4.35	2.23	7.51	34.43
Arthritica spp.	3.25	6.28	4.20	1.73	7.27	41.70
Cossura consimilis	2.30	0.43	2.56	1.60	4.43	46.12
Ostracoda spp.	2.47	0.72	2.50	1.48	4.32	50.44
Asychis asychis-B	5.11	6.37	2.50	2.07	4.32	54.76
Naididae	1.37	1.53	2.00	1.25	3.46	58.22
Phoxocephalidae spp.	1.44	2.63	1.98	1.37	3.43	61.65
Theora lubrica	2.66	1.78	1.81	1.13	3.13	64.77
Paraonidae spp.	0.92	1.10	1.63	1.05	2.82	67.59
Carazziella phillipensis	1.39	0.00	1.50	0.41	2.59	70.18

Groups PAH2B & POR2B
Average dissimilarity = 57.97

Species	Group PAH2B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.00	9.18	10.24	2.77	17.66	17.66
Cossura consimilis	6.48	0.43	7.45	3.29	12.86	30.52
Heteromastus filiformis	6.18	1.11	6.32	2.53	10.91	41.43
Boccardia syrtis	0.13	3.57	3.89	2.35	6.70	48.13
Asychis asychis-B	4.08	6.37	3.06	2.62	5.28	53.41
Nicon aestuariensis	2.61	0.25	2.94	2.88	5.06	58.48
Arthritica spp.	5.84	6.28	2.87	1.25	4.95	63.43
Linucula hartvigiana	4.49	2.46	2.81	1.16	4.85	68.28
Turbonilla zealandica	1.63	0.00	1.99	1.73	3.44	71.72

Groups PAH3B & POR2B
Average dissimilarity = 57.59

Species	Group PAH3B Av.Abund	Group POR2B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.25	9.18	10.90	2.56	18.93	18.93
Arthritica spp.	4.62	6.28	3.88	1.38	6.74	25.67
Asychis asychis-B	3.72	6.37	3.87	1.66	6.71	32.38
Boccardia syrtis	0.75	3.57	3.73	2.60	6.48	38.87
Cossura consimilis	3.20	0.43	3.70	1.70	6.42	45.29
Ostracoda spp.	2.79	0.72	2.84	1.71	4.93	50.22

Heteromastus filiformis	2.53	1.11	2.36	1.56	4.09	54.31
Linucula hartvigiana	2.04	2.46	2.29	1.36	3.98	58.29
Theora lubrica	0.68	1.78	1.92	1.65	3.34	61.63
Nicon aestuariensis	1.60	0.25	1.87	1.79	3.25	64.88
Naididae	1.46	1.53	1.85	1.38	3.22	68.10
Phoxocephalidae spp.	2.08	2.63	1.65	1.27	2.87	70.96

Groups POR1B & POR2B
Average dissimilarity = 50.18

	Group POR1B	Group POR2B				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Apseudes "novaezealandiae"	0.25	9.18	9.24	2.53	18.41	18.41
Arthritica spp.	11.90	6.28	6.71	1.44	13.38	31.79
Heteromastus filiformis	5.55	1.11	5.14	2.66	10.24	42.03
Cossura consimilis	3.94	0.43	3.96	2.63	7.90	49.93
Boccardia syrtis	0.48	3.57	3.38	2.17	6.74	56.67
Nicon aestuariensis	2.97	0.25	3.12	2.51	6.22	62.89
Asychis asychis-B	7.36	6.37	1.67	0.71	3.33	66.22
Linucula hartvigiana	3.09	2.46	1.61	1.08	3.21	69.43
Naididae	1.16	1.53	1.56	1.30	3.10	72.54