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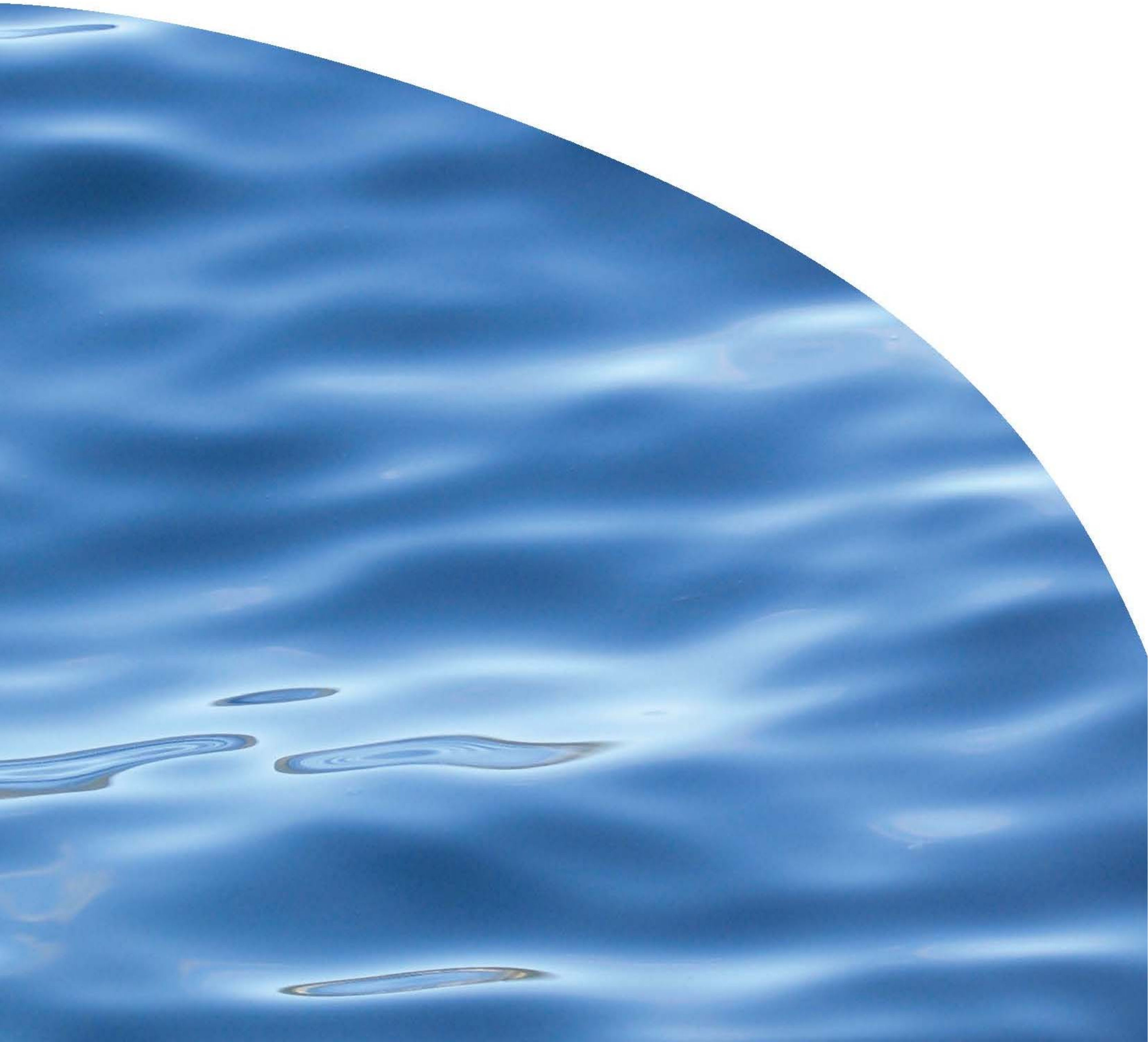
BASELINE BENTHIC ECOLOGICAL SURVEY FOR A PROPOSED WASTEWATER TREATMENT PLANT OUTFALL IN AKAROA HARBOUR



BASELINE BENTHIC ECOLOGICAL SURVEY FOR A PROPOSED WASTEWATER TREATMENT PLANT OUTFALL IN AKAROA HARBOUR

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Prepared for CH2M Beca Limited

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EXECUTIVE SUMMARY

It is proposed that the Akaroa sewerage system will be upgraded, with a new treatment plant to include biological nitrogen removal (BNR) and membrane filtration. It is proposed that the new wastewater treatment plant (WWTP) will be built just north of the township and a new mid-harbour outfall constructed. An ecological investigation of the benthic habitat and communities was undertaken by Cawthron Institute (Cawthron) in the vicinity of the proposed outfall diffuser to assess the sensitivity of the receiving environment and also to serve as a baseline for future monitoring. The benthic survey approach employed 10 sample stations along a 2 km transect, aligned with the axis of prevailing currents in the harbour and running through the proposed diffuser site.

Composite sediment samples were collected from each station and analysed for grain size distribution, organic content and a range of trace metal contaminants. Triplicate infauna core samples were also collected to investigate benthic macrofaunal communities. At five sites along the transect, full-depth water column profiles were recorded for temperature, pH, salinity and dissolved oxygen, and turbidity was measured in surface grab samples. Triplicate samples of the green-lipped mussel (*Perna canaliculus*) were collected for analysis of tissue trace metals and microbiological indicators at two sites south of the transect: Pinnacle Rock (on the eastern shore) and Cape Three Points (on the western shore).

The seabed substrate at all stations was uniformly soft mud with very little variability in texture. Samples were dominated by the silt / clay fraction (63–80% < 63 µm) and had low concentrations of trace metals and moderate concentrations of nutrients and organic enrichment. Variability between stations was very low for all sediment parameters and no clear spatial trends were observed along the sampling transect.

A total of 53 macroinvertebrate taxa were identified from the infauna samples. This assemblage was generally consistent with data from previous studies of Akaroa Harbour. Samples exhibited some variability in terms of macrofaunal abundance and number of taxa but standard indices for diversity and evenness were moderate to high and varied little between stations. The results of multivariate statistical analysis reflected the patchiness of benthic communities over small spatial scales but also indicated no fundamental differences between stations and no clear spatial trends. No taxa or assemblages of special scientific or conservation interest were identified. The benthos was assessed as being typical of shallow protected coastal environments in the region.

The homogeneous nature of the substrate in the vicinity of the proposed outfall means that any monitoring carried out following commissioning will be sensitive with respect to the identification of any changes to the benthic environment arising from the discharge of the treated wastewater.

The shellfish samples contained generally low concentrations of both trace metals and indicator bacteria. Although the limitations of sampling at a single point in time are

acknowledged, there was no apparent influence from relative proximity to the current outfall; nor did the results suggest consistent exposure to significant anthropogenic bacterial sources.

The water column measurements for turbidity, pH, dissolved oxygen and salinity were consistent with available information for Akaroa Harbour. However, all of the full depth profiles featured a distinctly colder benthic layer, but no apparent corresponding change in turbidity or salinity. While stratification of the water column can have implications for the dispersion of a buoyant plume released at the seabed, the frequency or persistence of such a thermocline cannot be inferred from this single instance.

Although nitrogen loading to the harbour receiving environment (as a component of cumulative inputs) is considered to be a key ecological concern, the proposed treatment process (incorporating BNR) will produce a higher quality effluent than the current WWTP. The loading from the discharge was furthermore shown to be relatively small compared to other nitrogen sources, being an order of magnitude lower than both stream and aquaculture inputs and less than 0.05% of that represented by tidal influx. Direct monitoring of the nutrient status of harbour waters is important on the basis of cumulative inputs from all sources. However, the best indication of specific loading and localised water quality effects from the proposed discharge, is likely to be provided by rigorous effluent monitoring in combination with knowledge of the available dilution under reasonable worst-case conditions rather than analysis of water samples collected from the mixing zone edge.

Significant impacts to the mid-habour benthic habitat are considered unlikely in light of the absence of significant effects to the benthic environment identified by a 2006 survey of the immediate vicinity of the current discharge and improved effluent and dispersal conditions for the proposed discharge. Furthermore, the nature of the existing benthos is such that a moderately rapid recovery would be expected from any enrichment effects following cessation of inputs or a significant decrease in environmental loading. The distance from the shoreline of the mid-harbour outfall is considered suitably protective of intertidal and hard substrate habitats in terms of direct plume impingement.

The 2010 Cawthron report on the potential risk to marine mammals from endocrine-disrupting chemicals (EDCs) was reviewed. No new information with a direct bearing on these risks has since become available. Not enough is known about the action of EDCs on marine mammals, or the routes and mechanisms of exposure to quantify the risk to Hector's dolphins represented by the Akaroa WWTP discharge. However, the available evidence suggests that the risk from EDCs contained in the wastewater discharge will be low.

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GLOSSARY

Item	Definition	Type
°C	Degrees Celsius	Unit
µg/L	Micrograms per litre (parts per billion)	Unit
µm	Micron	Unit
ADL	Analytical detection limit	Acronym
AEE	Assessment of Environmental Effects	Acronym
ANZECC	Australia and New Zealand Environment and Conservation Council	Acronym
As	Arsenic	Abbreviation
BNR	Biological nitrogen removal	Acronym
BOD5	Biochemical oxygen demand (5-day)	Acronym
Cd	Cadmium	Abbreviation
cm	Centimetre	Unit
cm/sec	Centimetres per second	Unit
Cr	Chromium	Abbreviation
Cu	Copper	Abbreviation
DIN	Dissolved inorganic nitrogen	Acronym
DO	Dissolved oxygen	Acronym
DRP	Dissolved reactive phosphorus	Acronym
E	East	Acronym
EDC	Endocrine-disrupting chemical	Acronym
g	Grams	Unit
g/m3	Grams per cubic metre	Unit
GPS	Global Positioning System	Acronym
H’	Shannon-Weiner diversity index	Index
Hg	Mercury	Abbreviation
ICP-MS	Inductively coupled plasma-mass spectrometry	Acronym
ISQG	Interim Sediment Quality Guideline	Acronym
J	Pielou’s evenness index	Index
km	Kilometre	Unit
LOI	Loss on ignition	Acronym
m	Metre or Metres	Unit
m/s	Metres per second	Unit
MDS	Multi-dimensional scaling	Acronym
mg/kg	Milligrams per kilogram (parts per million)	Unit
mg/L	Milligrams per Litre (parts per million)	Unit
MIS	Median international standard	Acronym
mm	Millimetres	Unit
MPN	Most probable number	Acronym
MSL	Mean sea level	Acronym
MZE	Mixing zone edge	Acronym
N	Number of individual organisms (density)	Index
n	Number of individuals / replicates in a sample	Variable
Ni	Nickel	Abbreviation
NIWA	National Institute of Water and Atmospheric Science	Acronym
NO_x	Nitrate and nitrite nitrogen	
NTU	Nephelometric turbidity unit	Acronym
NZDT	New Zealand daylight time	Acronym
NZTM	New Zealand Transverse Mercator (map projection)	Acronym
P	Phosphorus	Abbreviation

Item	Definition	Type
Pb	Lead	Abbreviation
PCB	Polychlorinated biphenyl	Acronym
pH	Measure of acidity or basicity	Variable
psu	Practical salinity units	Unit
PVC	Polyvinyl chloride	Acronym
S	Number of species (species richness)	Index
SCUBA	Self-contained underwater breathing apparatus	Acronym
SE	Standard error of the mean	Acronym
SG	Waters managed for shellfish gathering	Acronym
SIMPER	Similarity percentage	Acronym
SVOC	Semi volatile organic compound	Acronym
TN	Total nitrogen	Acronym
TOC	Total organic carbon	Acronym
TP	Total phosphorus	Acronym
TSS	Total suspended solids	Acronym
USEPA	United States Environmental Protection Agency	Acronym
UV	Ultraviolet light	Acronym
WWTP	Wastewater treatment plant	Acronym
Zn	Zinc	Abbreviation

1. INTRODUCTION

1.1. Background

As part of a project to modify and upgrade the wastewater reticulation system for the township of Akaroa and construct a new treatment plant and harbour outfall, Cawthron Institute (Cawthron) was contracted by CH2M Beca to provide a marine ecological assessment for the proposed outfall site.

This ecological assessment was required as part of the 'Investigations and technical assessments' outlined within Stage One (resource consenting) in the Request for Proposals (RFP) dated 9 July 2013. As such, it is intended to be one of a number of technical documents appended to and in support of an overall assessment of effects (AEE) of the upgrade project.

The existing Akaroa wastewater treatment plant (WWTP) is located at the end of Beach Road on the south side of the Akaroa township. It comprises primary, secondary and tertiary treatment processes and discharges the treated wastewater via a 100 m long outfall into Akaroa Harbour offshore from Red House Bay (Figure 1).

The site for the new Akaroa WWTP is located approximately 120 m above sea level near the top of Takamatua Hill on the north side of Akaroa, on Old Coach Road. It is proposed that the WWTP will consist of biological nitrogen removal (BNR) and membrane filtration and the treated wastewater will be discharged via a new harbour outfall pipeline extending approximately 2.5 km out from Children's Bay into the harbour (Figure 1). It is expected that the new WWTP will continue to treat primarily domestic wastewater from the township of Akaroa.

The broader marine receiving environment of Akaroa Harbour has been previously characterised by Fenwick (2004), Hart *et al.* (2009) and Bolton-Ritchie (2013) for ecology, sediments and bathymetry, and water quality, respectively.

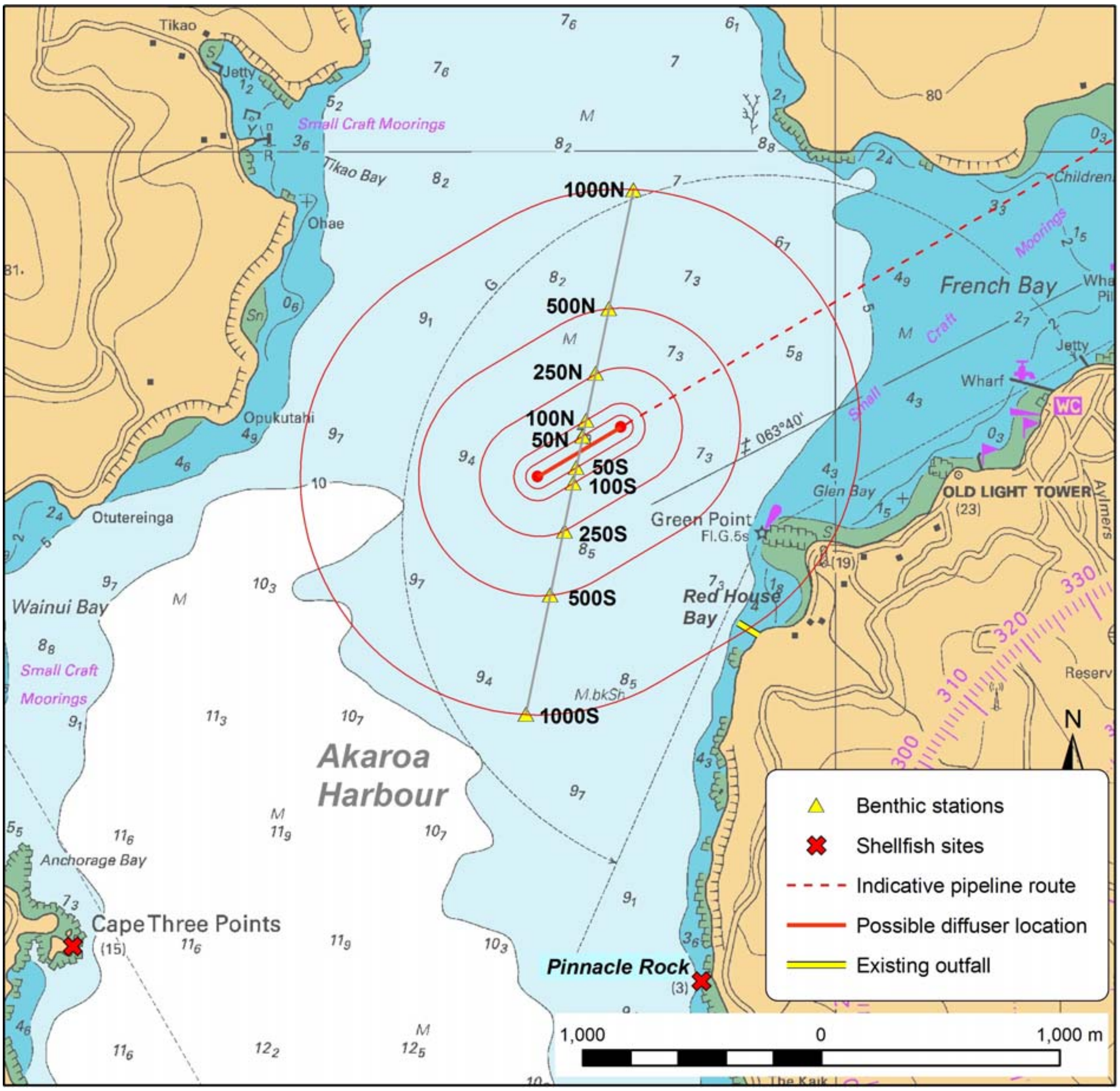

Figure 1. Benthic sampling stations located along a harbour axis transect running through the centre of the possible diffuser location of the proposed outfall along the axis of prevailing currents. Concentric ellipses show contours equidistant from the discharge through each station. Station details are listed in Table 1.

1.2. Approach and scope

While previous ecological investigations in Akaroa Harbour have encompassed both soft sediment benthic areas and hard substrate intertidal habitats over wide spatial areas, it was the intention for this study to focus on the soft sediment habitats within the vicinity of the proposed outfall. In light of the findings of preliminary investigations, distance offshore and expected available dilution (Bell *et al.* 2014), it was considered that further study of potential impacts upon intertidal communities was not warranted for a mid-harbour outfall option.

One of the principal objectives was to provide an effective baseline characterisation of the seabed along a sampling transect aligned with the expected plume dispersion axis (Figure 1). In this way, the results serve as a benchmark of pre-existing conditions against which future (post-commissioning) monitoring data can be effectively compared.

The main focus of the investigation was the soft sediment communities occurring in the vicinity of the proposed outfall, requiring data collection related to:

1. Physico-chemical nature of the substrate
2. Abundance and diversity of benthic macroinvertebrates.

A 2 km transect was considered to provide coverage appropriate for the determination of spatial gradients along the principal axis of dispersion. Such designs are widely used for monitoring coastal outfalls and utilise far-field stations to serve as effective control or reference points (NZWERF 2002).

The field survey also provided the opportunity to collect data on the following additional aspects:

- Shellfish quality (*Perna canaliculus*) at two mid-harbour shoreline locations in regard to bacterial indicators and trace metals.
- A snapshot of water quality in the form of water column profiles for a number of parameters at five points along the 2 km monitoring transect.

An updated summary of the findings of an earlier assessment by Clement (2010) of the effects of wastewater-associated endocrine-disrupting chemicals (EDCs) is also provided.

2. METHODS

The benthic sampling transect was established on a north-northeast / south-southwest (NNE/SSW) orientation so that it bisected the diffuser 'footprint' at the suggested location. This effectively aligned it with the direction of the main tidal flow. The length of the transect was set at 2 km (1 km up- and down-harbour) since effects outside a 1 km radius were not expected, based on projected effluent quantity and quality. By buffering the diffuser coordinates at 50 m, 100 m, 250 m, 500 m and 1,000 m, the sample stations could be located where each locus intersected the transect. Although this pattern made a strict isobath impractical, stations placed along the mid-harbour axis effectively kept them at similar water depths.

The sampling survey was conducted on 14 February 2014, during a period of neap tides and settled weather conditions, using the 7.7 m Canterbury University vessel *Rapaki*. On the day of sampling, low tide (MSL-0.79 m) was at 10:21 NZDT and high tide (MSL+0.74 m) was at 16:25 NZDT. All stations were located in the field using GPS and marked with a shot-line prior to sample collection by SCUBA diver. Location coordinates for each station are listed in Table 1, along with water depth and the time of sample collection.

Table 1. Details of the benthic sample stations depicted in Figure 1 and sampled 14 February 2014. Depths from vessel sounder have been corrected for tidal height.

Station	Location coordinates (NZTM)		Time	Depth
	Easting	Northing	(NZDT)	(m MSL)
1000N	1595130	5150179	13:41	9.9
500N	1595026	5149680	14:31	10.1
250N	1594972	5149409	14:06	10.0
100N	1594931	5149211	15:04	9.9
50N	1594918	5149145	9:37	10.5
50S	1594891	5149013	13:18	10.3
100S	1594877	5148947	12:50	10.4
250S	1594840	5148746	11:29	10.7
500S	1594781	5148478	10:53	11.0
1000S	1594678	5147977	10:18	11.6

2.1. Sediment physico-chemistry

Four replicate 62 mm diameter core samples were collected by divers at each benthic sample station. Perspex™ corers were driven 100–150 mm into the seabed, carefully withdrawn and capped for return to the support vessel. The cores were examined and photographed; then the surficial 5 cm of each was sub-sampled and composited to provide a single analysis sample for each station. Sediment analyses included grain-size distribution, organic content, total nitrogen (TN), total recoverable phosphorus (TP) and the trace metals cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn). Brief analytical method descriptions are listed in Table 2.

Table 2. Summary of analytical methods for Akaroa Harbour benthic sediment samples.

Analyte	Method Number/code	Description
Particle grain size (extended)	Hills Laboratories in-house method	Wet sieved through screen sizes: >2 mm = Gravel <2 mm – >1 mm = Coarse Sand <1 mm - >500 µm = Medium Sand <500 µm - >250 µm = Medium/Fine Sand <250 µm - >125 µm = Fine Sand <125 µm - >63 µm = Very Fine Sand <63 µm = Mud (Silt & Clay) Size classes from Udden-Wentworth scale
Total organic carbon (TOC)		Acid pre-treatment to remove carbonates if present, neutralisation, Elementar combustion analyser
Total recoverable nitrogen (TN)		Catalytic combustion (900°C, O2), separation, Thermal conductivity detector, Elementar combustion analyser
Total recoverable phosphorus (TRP)	USEPA 200.2.	Dried sample, sieved as specified (if required). Nitric / hydrochloric acid digestion, ICP-MS (inductively coupled plasma-mass spectrometry), screen level.
Trace metals: ICP-MS (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	USEPA 200.2	Dried sample, sieved (2 mm, as required). Nitric / hydrochloric acid digestion, ICP-MS, trace level.

2.2. Benthic macroinvertebrate communities

Macrofauna are defined as animals retained on a 0.5 mm sieve mesh. Infaunal communities that live within the sediment matrix are a subset of this group. Although the process of sample collection by sediment corer specifically targets the infauna, species that are more correctly classified as epibenthic (surface-dwelling) are inevitably included. Macrofaunal community analysis is a sensitive tool to evaluate the overall health of benthic sediment ecosystems and identify long-term shifts in community structure resulting from anthropogenic stressors such as contaminants and physical disturbance. Such information is an important marker of degradation or recovery that integrates the sum total of all impacts. In this way, it complements the inferences that can be made on the basis of national and international sediment quality guidelines and ties them to actual biological indices.

Benthic infauna were sampled at each station by divers using three replicate 130 mm internal diameter PVC corers fitted with 0.5 mm nylon mesh bags for sieving. The corers were manually driven approximately 100 mm into the sediment and removed with the core intact. The core was transferred to the mesh bag and returned to the support vessel where the contents were gently washed through the sieve. The residue, containing the infauna, was emptied into a plastic container and preserved in 70% ethanol containing 1% glycoxylate as a fixative prior to transport back to the Cawthron taxonomy laboratory for processing.

In the laboratory, the infauna samples were sorted, identified to the lowest practicable taxonomic level and counted with the aid of a binocular microscope. The raw count data were analysed to provide standard community indices of abundance, species richness, diversity and evenness for each sample. These indices are listed and described in Table 3.

Table 3. Descriptors of macro-invertebrate community indices.

Descriptor	**Equation**	**Description**
No. species (S)	Count (taxa)	Total number of species in a sample.
No. individuals (N)	Sum (n)	Total number of individual organisms in a sample.
Evenness (J')	$J' = H'/\text{Log}_e(S)$	Pielou's evenness: A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa.
Diversity (H' $\log_e$)	$H' = -\text{SUM}(P_i*\log_e(P_i))$	Shannon-Wiener diversity index ($\log_e$ base): A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species (low community complexity) to high values for communities containing many species and each with a small number of individuals. The maximum value is dependent on the number of categories or species sampled for a given data set.

The infauna assemblages described by the count data were further contrasted using non-metric multidimensional scaling or MDS (Kruskal & Wish, 1978) and ordination and cluster diagrams based on Bray-Curtis similarities (Clarke & Warwick. 1994). Sample ordination, via multivariate analysis, attempts to represent samples in a 2-, 3- or multi-dimensional space according to their similarities and differences. If a 2-dimensional representation explains a sufficient proportion of the sample differences observed, these can be assessed spatially on a 2-dimensional plot, where the distance between sample points corresponds to the degree of difference observed between infauna assemblages. A stress statistic provides a measure of how well the plot represents the differences in the data overall.

Abundance data were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each group (by station) were identified using analysis of similarities (SIMPER; Clarke & Warwick 1994). All multivariate analyses were performed with PRIMER v6 software.

2.3. Shellfish samples

A triplicate sample of the green-lipped mussel (*Perna canaliculus)* was collected from each of two sites (at Cape Three Points and Pinnacle Rock) to the south of French Bay and Akaroa township. The selection of these sites (Figure 1) was driven by patterns of recreational and customary shellfish gathering and to supplement historical shellfish quality data. The shellfish were collected by a diver from water depths between the surface and 3 m. Each replicate consisted of approximately 15 individuals, which were wrapped in aluminium foil, placed in pre-labelled polyethylene bags and stored on ice for transport to the laboratory, as per the method outlined in USEPA (1995). Tissues from the shellfish samples were analysed for trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and bacterial indicators (Table 4).

Table 4. Summary of analytical methods for samples of green-lipped mussels *Perna canaliculus* collected from Akaroa Harbour, 14 February 2014.

Analyte	**Method no. / code**	**Description**
Shucking and homogenisation		Removal of tissue from shell. Blending of sample to form homogenous sample fraction
Bacterial indicators (Faecal coliforms, *E. coli*, enterococci).	Compendium 4th edn. 2001	MPN/100 g
Moisture content		Drying for minimum of 24 h at 65°C, gravimetry.
Digestion		Nitric and hydrochloric acid micro-digestion, 85°C for 1 h
Trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)		ICP-MS, trace level

2.4. Water quality measurements

On the day of benthic sample collection, *in situ* water quality profiles were compiled through the deployment of an YSI EXO-2 multi-sensor sonde using a 2 Hz sampling frequency. By lowering and raising the sonde slowly through the full depth of the water column, profiles were generated for temperature, salinity, pH and dissolved oxygen (DO). Such measurements were undertaken at five locations; being the mid-point of the suggested location of the outfall diffuser and at the 500 m and 1000 m benthic stations (north and south) on the sampling transect (Figure 1).

In addition to the profiling measurements, surface samples of seawater were taken and measured for turbidity using a Hach 2000 field nephelometric turbidimeter.

3. RESULTS AND DISCUSSION

3.1. Field observations

Benthic sampling was conducted over the full period of the flood tide, with water profile measurements taken just after the turn of the high tide (Figure 2). The seabed substrate at all stations was observed to be relatively uniform deep soft mud. Core samples were light grey / brown in colour in the surface layers with a diffuse change to slightly darker grey sediments at around 7–10 cm depth in the profile (Appendix 1). As such, there was no distinct apparent redox discontinuity layer[1]. Neither was there any notable hydrogen sulphide odour, indicating no more than moderate organic enrichment.

A noticeable cold water layer was evident at the seabed, but this did not appear to be associated with a distinct benthic turbidity layer.

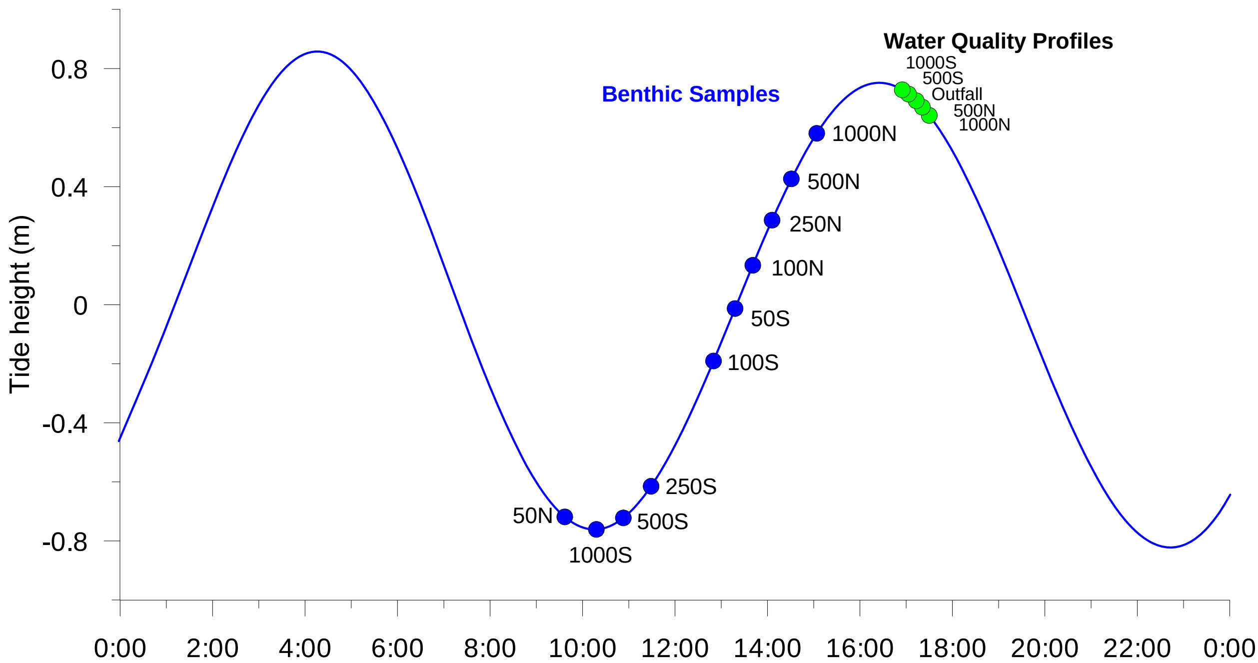

Figure 2. Field sampling carried out in Akaroa Harbour in relation to tidal state, 14 February 2014.

[1] The apparent redox potential discontinuity depth (aRPD) refers to the often distinct colour change, between surface and underlying sediments, brought about by the changing redox environment with depth in the profile. This gradient of colour change is in reality continuous but may be reduced to an average transition point (sediment depth) for descriptive purposes.

3.2. Sediment physico-chemical characteristics

3.2.1. Sediment texture

Grain size profiles for sediments from the 10 benthic stations are shown graphically in Figure 3 and the full data are tabulated in Appendix 2. The samples were dominated by the silt / clay fraction (< 63 µm) that ranged from 63%–80% and averaged 74% over all stations with no clear spatial trends along the sampling transect. Small amounts of very fine, fine and medium sand classes were also consistently present in the composite samples, averaging 7%, 7% and 9%, respectively.

In a NIWA investigation undertaken in 2003, Fenwick (2004) reported benthic sediments in the vicinity of the proposed diffuser site to be finer than was found in the current investigation[2], with approximately 98% finer than 63 µm. The NIWA 'Station 3' was approximately 250 m west of Station 500N in the current study, and the methodology for analysis of grain size distribution was not specified. The breakdown of size classes into five sub-63 µm fractions suggests that a laser-diffraction method may have been used. Significant differences in distribution profile can arise from different grain size analysis methods.

Hart *et al.* (2009) mapped sub-tidal sediment trends in upper Akaroa Harbour (north of Cape Three Points) based on 89 separate samples. Analyses undertaken utilised wet sieving, dry sieving and pipette analysis. At a point on the mid-harbour axis corresponding to the current study area, sediments of 5% sand, 50% silt and 45% clay were reported. This result was in general agreement with the Fenwick (2004) data. It was suggested that the central upper harbour operates as a sink for fine sediments carried into the harbour and for suspended fines swept northward along the central harbour axis.

While the wet sieve grain-size methodology employed in the current study is a standard approach in ecological assessments, the very fine nature of the Akaroa sediments (where the bulk of the material is finer than 63 µm) means that it may not be the best method for monitoring changes that occur within the fine fraction.

All of the relevant data concerning areas adjacent to the current sampling transect support findings of fine soft mud substrate and a high level of spatial uniformity in sediment texture.

[2] Wentworth size classes for Fenwick (2004) (Station 3 sediments): clay (< 4 µm) 59%, v. fine silt (4–8 µm) 22%, fine silt (8–16 µm) 11%, med. silt (16–31 µm) 3%, coarse silt (31–63 µm) 3%, coarse sand (500 µm –1 mm) 2%.

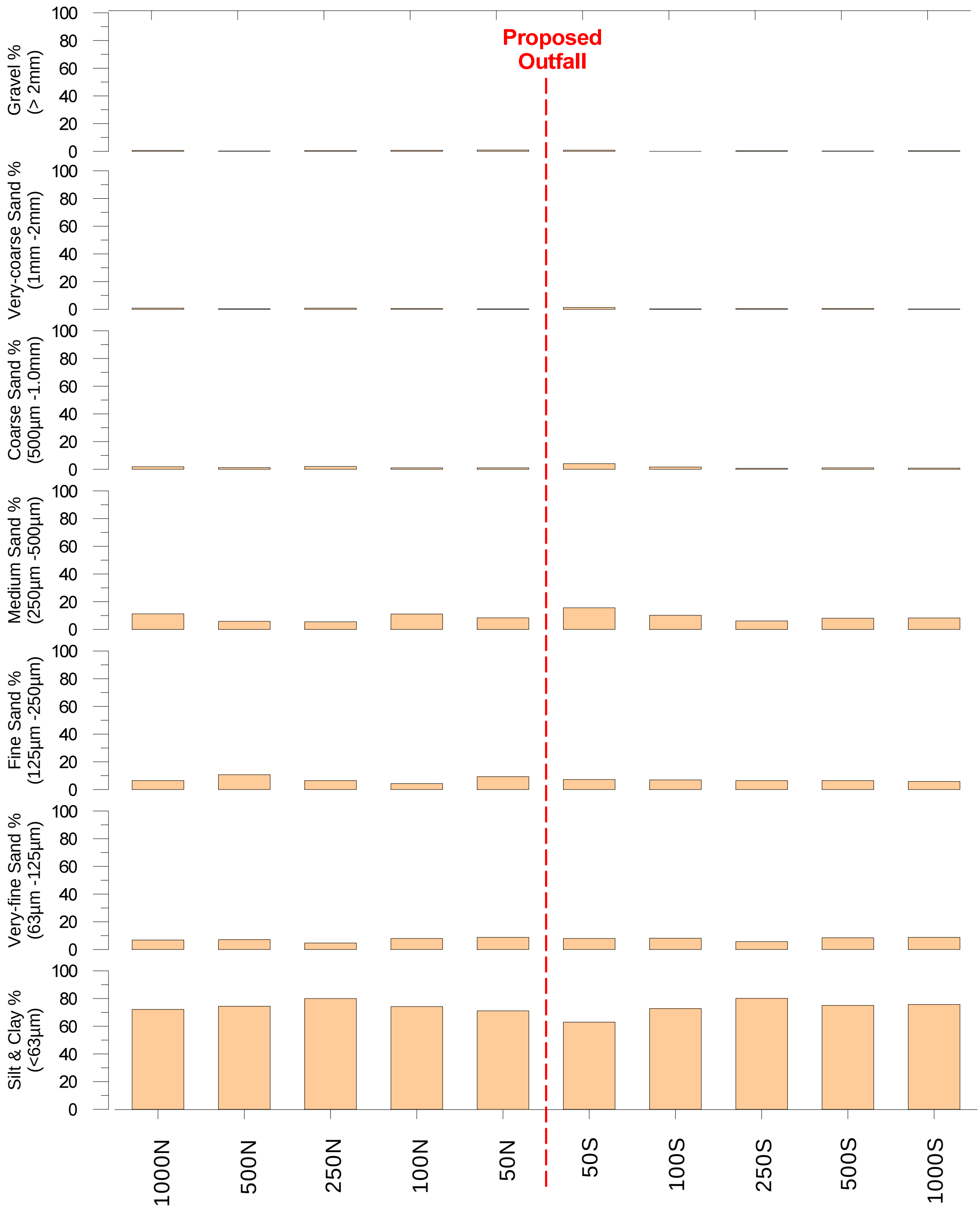

Figure 3. Grain-size distribution for composite sediment samples across the 10 benthic stations.

3.2.2. Sediment nutrients and organic enrichment

The analytical results for sediment nutrients and organic carbon are shown graphically in Figure 4 and are listed in Appendix 2. Very little variation in these parameters was apparent along the 2 km sampling transect.

At 860–950 mg/kg, total recoverable phosphorus was in the upper part of the range typical for coastal sediments. While this probably reflects mineralogy, higher levels may also be expected for very fine sediments that present a high surface area to analytical digestion processes. Fenwick (2004) reported a harbour range for total phosphorus of 590–740 mg/kg and 590 mg/kg for a station adjacent to the current sampling transect. Bolton-Ritchie (2005) reported a range for 10 sites in upper Akaroa Harbour (across Barrys, Duvauchelle, Robinsons and Takamatua Bays) of 390–830 mg/kg.

Total nitrogen ranged 0.10–0.13 g/100 g, in general agreement with values observed by Fenwick (2004) (0.06–0.13 g/100 g) and Bolton-Ritchie (2005) (0.08–0.26 g/100 g).

The organic content of the sediments was at levels fairly typical of fine harbour sediments. Fenwick (2004) reported sediment organic content as weight loss on ignition (LOI or ash-free dry weight), giving a range for the harbour of 2.5–5% and 4% for the station closest to the current sample transect. Although direct conversion between these parameters is generally unreliable, the results indicate consistent ranges in organic enrichment across the two studies.

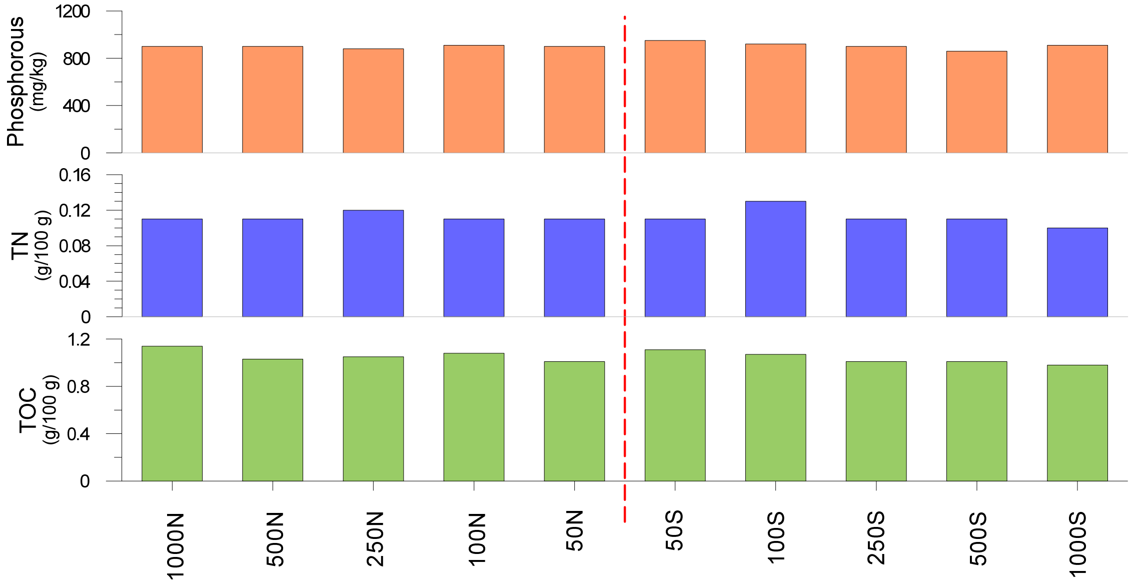

Figure 4. Sediment concentrations of nutrients (total recoverable phosphorus and total nitrogen (TN)) and total organic carbon (TOC) across benthic stations.

3.2.3. Sediment trace metals

Analytical results for sediment trace metals are presented graphically in Figure 5. Similar to results for other sediment physico-chemical parameters, concentrations exhibited generally flat spatial profiles along the 2 km sampling transect.

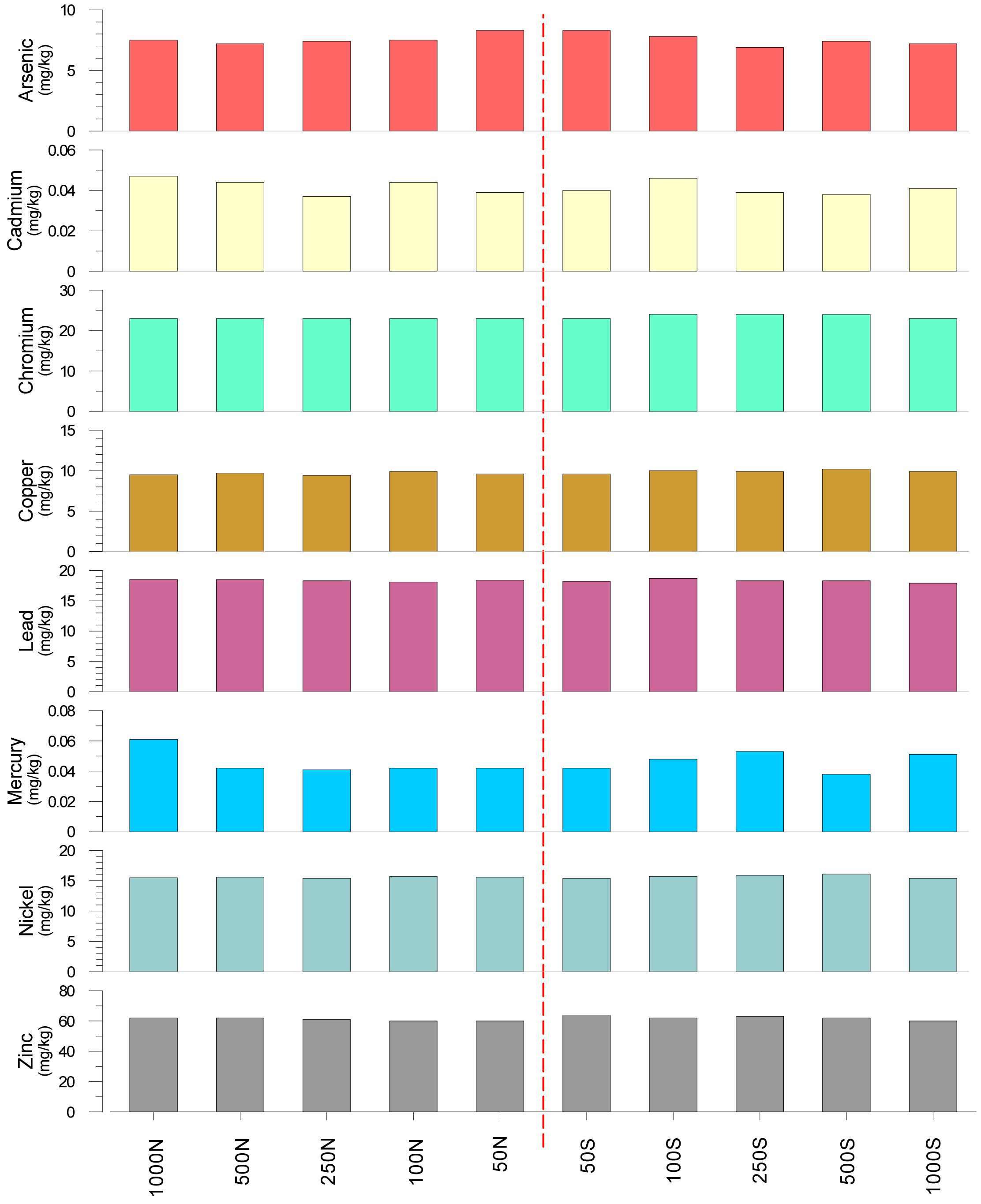

Figure 5. Trace metals (mg/kg) in sediments from the 10 benthic stations in Akaroa Harbour. ANZECC (2000) ISQG-Low triggers for sediments as follows (mg/kg): As, 20; Cd, 1.5; Cr, 80; Cu, 65; Pb, 50; Hg, 0.15; Ni, 21; Zn, 200.

Concentrations for all metal analytes were well below the corresponding ANZECC (2000) ISQG-Low trigger levels[3] for possible ecological effects. As for nutrients and TOC, the data shows almost no effective spatial variation. The slight variability observable for cadmium and mercury can be attributed mainly to overall levels being proportionately much closer to the analytical detection limit (ADL) for these metals.

Fenwick (2004) reported sediment trace metal concentrations for Akaroa Harbour which were in general agreement with those in Figure 5 and found little variation throughout the Harbour. However, a spatial trend was noted for lead (22–38 mg/kg) and zinc (60–76 mg/kg) gradually decreasing towards the harbour entrance.

The generally low concentrations and even spatial distribution of trace metal contaminants in the vicinity of the possible outfall site, suggests that these levels are likely to be representative of the natural background for the harbour. It is concluded that subsequent monitoring surveys, using a similar transect approach, will be able to detect and quantify any future changes that may be attributable to the discharge.

3.3. Macrofaunal community analysis

The macroinvertebrate count data for the 30 infauna samples (three replicates from each of 10 stations) collected along the sampling transect is presented in Appendix 3. The 10 most abundant taxa identified across all stations are listed in Table 5. The samples were characterised by a range of macrofaunal taxa considered fairly typical of fine sediment environments in protected coastal areas. Also typical of such habitats, detrital deposit feeders and epifaunal scavengers were well represented within the benthic community.

[3] Sediment quality criteria outlined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) provide trigger values for contaminants representing two distinct threshold levels above which biological effects are predicted. The lower threshold (ISQG-Low) indicates a *possible* biological effect (10% probability), while the upper threshold (ISQG-High) indicates a *probable* biological effect (50% probability).

Table 5. List of the 10 most abundant macrofaunal taxa identified in infauna samples collected during the February 2014 survey, sorted by mean abundance per 133 cm^2 sample.

Group	Taxa	Common name	Mean abundance
Nematoda	Nematoda	Roundworm	27.0
Gastropoda	*Zeacolpus symmetricus*	Tower snail	13.9
Polychaeta	Paraonidae	Polychaete worms	8.1
Polychaeta	Cirratulidae	Polychaete worms	4.4
Decapoda	*Macrophthalmus hirtipes*	Stalk-eyed Mud Crab	2.8
Oligochaeta	Oligochaeta	Oligochaete worms	2.7
Anthozoa	*Virgularia gracillima*	Sea Pen	2.5
Bivalvia	*Arthritica bifurca*	Small bivalve	2.5
Amphipoda	Phoxocephalidae	Amphipod (family)	2.3
Amphipoda	Amphipoda	Amphipods	1.9

3.3.1. Community indices

The principal macroinvertebrate community indices for each station are plotted in Figure 6 and are listed in Appendix 4. Abundance within the samples was highly variable between stations, but much less so between replicates from a single station. This suggests a degree of patchiness in communities despite the observed uniformity in sediment physico-chemical conditions (see Section 3.2).

Species richness (S) was relatively less variable. Across all sites, 53 individual taxa were recorded, although for individual replicate samples, S varied between 7 and 24 (average 16).

Shannon-Weiner diversity (H') and Pielou's evenness (J) were generally consistent across all sampling stations, exhibiting no apparent spatial trends, although stations 100N and 500S exhibited consistently slightly lower values of both indices. H' ranged from ~1.3–2.7, indicating a medium level of complexity in species composition. Values for J were moderate to high, ranging from ~0.47–0.97 and indicating a fairly uniform distribution of species composition at most stations[4].

[4] The maximum potential value for the Shannon-Weiner diversity index (H) is dependent upon the number of categories or species sampled for a given data set. Values typically range between 0 (indicating low community complexity) and 4 (indicating very high complexity). The evenness value (J) ranges from 0 (highly irregular distribution) to 1 (regular distribution). While a range of values for the Shannon-Weiner diversity index (H') are possible for soft sediment communities in relatively unimpacted marine systems, these typically exceed 1.0. Values of Pielou's evenness (J') less than 0.4 would warrant closer scrutiny.

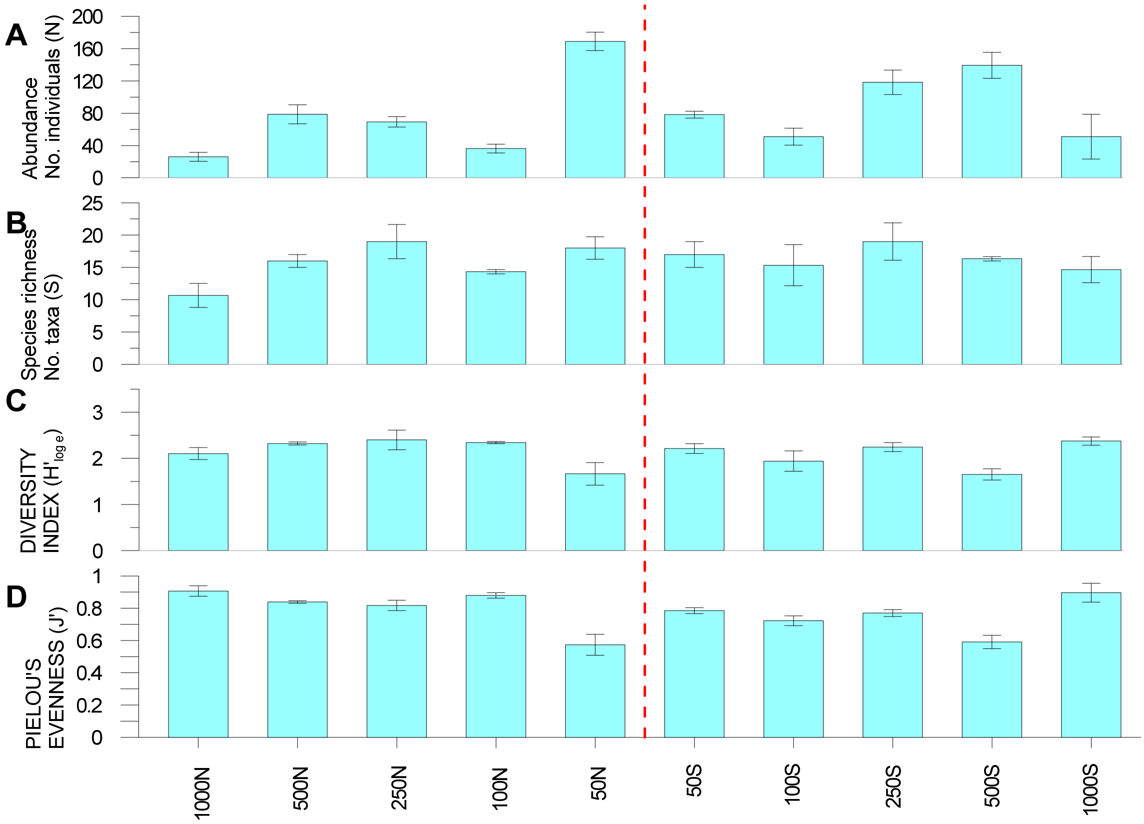

Figure 6. Macrofaunal community indices for the 10 benthic stations sampled on 14 February 2014. Error bars represent ± the standard error (SE) of three replicates.

3.3.2. Distribution of principal taxa

The primary reason for the lower values at stations 50N and 500S was that communities were dominated by high densities of nematode worms (Figure 7). Although nematodes were the most abundant taxa overall (average 27 per sample, Table 5), they were significantly more dominant in communities at these two stations, yielding mean abundances of 94 and 83 per sample at 50N and 500S, respectively. Of other dominant taxa, abundances of the small gastropod *Zeacolpus symmetricus* and paraonid polychaetes also tended to be variable, but less so between stations relative to overall variability between replicates.

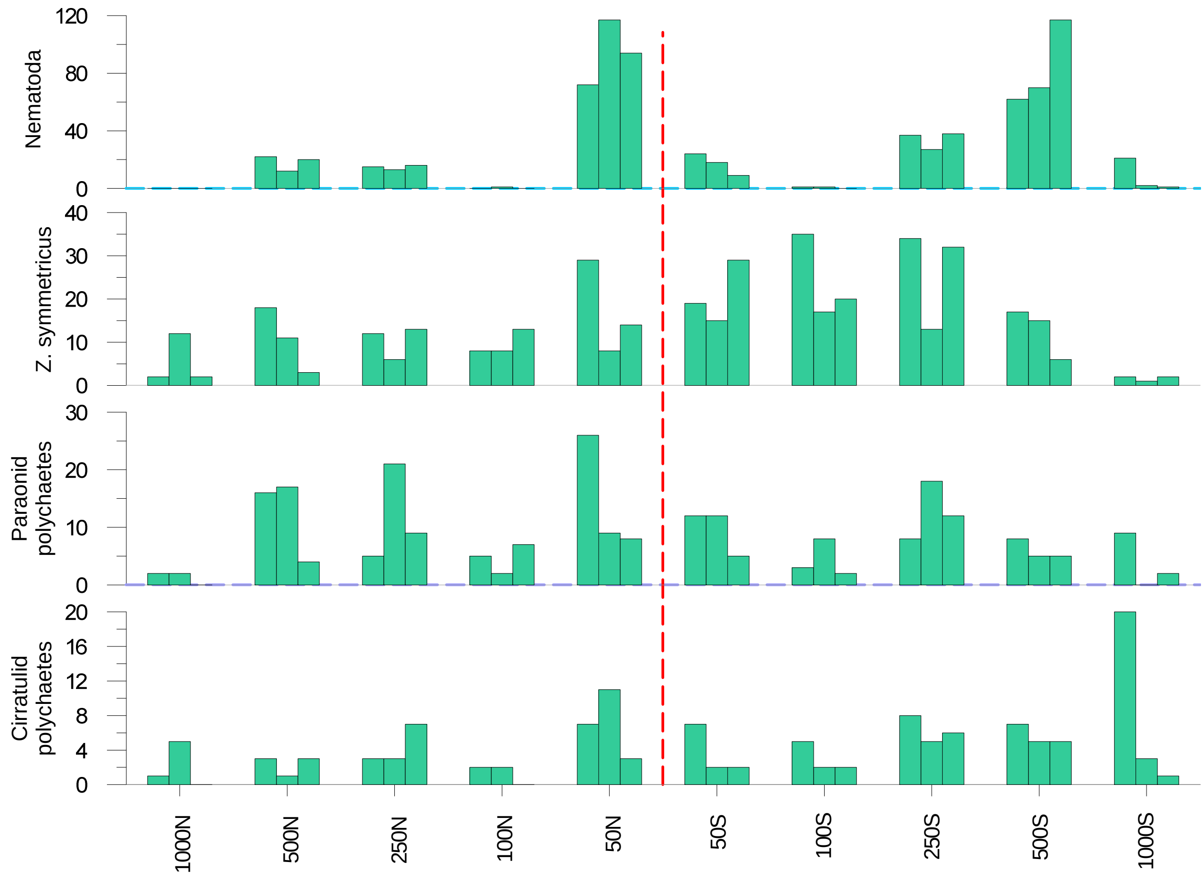

Figure 7. Density distribution (abundance per core sample) of the principal infauna taxa along the sampling transect. Counts from individual 133 cm^2 benthic sample replicates.

With no clear spatial gradients in sediment physico-chemical parameters along the 2 km transect and only a small change in water depth, the absence of overall trends in benthic community distribution is not surprising. The data set therefore represents a suitable baseline against which any future changes in the benthos may be effectively compared.

3.3.3. Comparison to historical data

Fenwick (2004) collected macrofaunal community samples in October 2003 using an anchor-box dredge (0.06 m^2) to 100 mm depth. A total of 136 taxa were identified for triplicate samples from 10 stations throughout the harbour. Taxa richness was found to increase along the central axis of the harbour from 18 to 58 per station. Mean taxa richness was 18 at a mid-harbour station (Station 3) closest to the current sampling transect, which agrees well with the distribution in Figure 6B. However the differences in methodology and taxonomic resolution between the two surveys mean that the two data sets were not directly comparable.

Nematode worms did not feature at all in the 2003 taxa list, but were the most abundant taxa in the current study. Nematoda is a large and diverse phylum of mostly small-bodied worms, assemblages of which are often included in the smaller meiofaunal rather than macrofaunal communities. It is possible, therefore, that they were excluded from the 2003 data set. However, both investigations sieved the samples through the same mesh size (0.5 mm). It is also possible that the difference is seasonal because the 2003 samples were collected in late October. Certainly, free-living marine nematodes can have short generation times and populations respond quickly to changing conditions (Vranken & Heip 1986).

The gastropod *Zeacolpus symmetricus* was also identified by Fenwick (2004) as being dominant at upper harbour stations, with abundances very similar to those observed in the current study.

3.3.4. Multivariate analysis

Multi-dimensional scaling (MDS) and Bray-Curtis cluster analysis of the benthic macrofauna communities represented by the infauna samples are shown in Figure 8. The stress value[5] of 0.22 for the MDS plot indicates that the separation of points on the plot should be interpreted cautiously.

The samples are seen to resolve into five groupings at the 56% level of similarity, with 1000S being the only station where all three replicates are included in a group separate from the main Group 'A'. While 1000S is situated at the southern end of the mid-harbour transect, the pattern of station occurrence across the groups is not otherwise indicative of effects arising from water depth or relative exposure. The tendency for station replicates to be spread over more than one group underlines the fact that differences between stations were generally similar due to small-scale spatial variability within replicates from individual stations.

[5] Distances on the MDS plot have only relative, not absolute, meaning. Thus the stress value is a dimensionless quantity and is a measure of the difficulty involved in compressing the sample relationships into two dimensions. A stress value of < 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation, while a stress value of < 0.2 still gives a potentially useful 2-D picture. Stress values within the range of 0.2 to 0.3 should be treated with a great deal of scepticism, particularly if in the upper half of this range and for sample sizes of < 50.

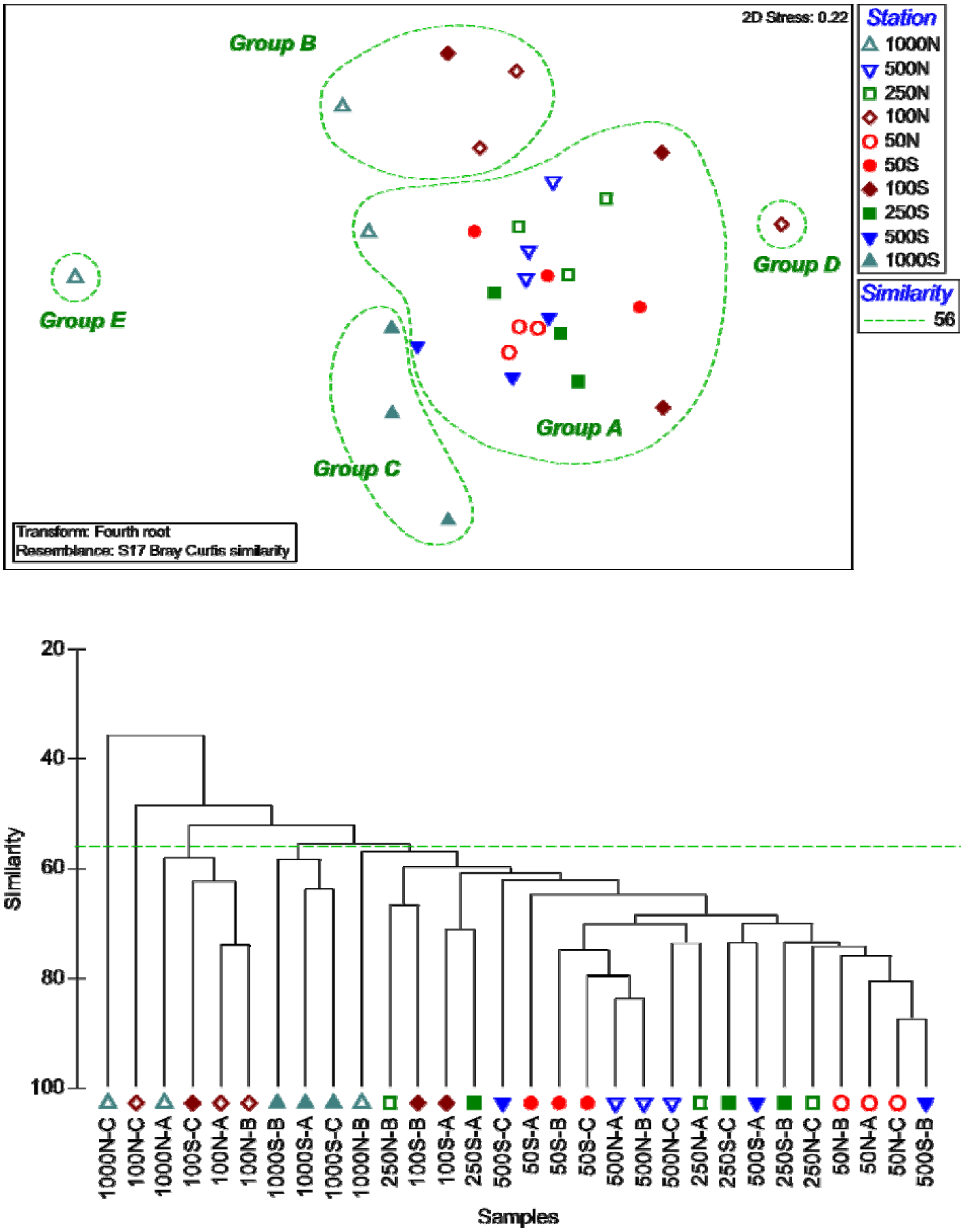

Figure 8. Multi-dimensional scaling (MDS; top) and dendrogram (bottom) plots from multivariate analysis of macroinvertebrate count data for the Akaroa Harbour samples.

The taxa contributing most to the distinctiveness of each grouping shown in Figure 6 are listed in Table 6. Group A was comprised of 21 of the 30 individual samples and included replicates from all stations except 1000S and 100N (which was split across Groups B and D). Group A featured high numbers of nematode worms (except in replicates from 100S) and moderate to high incidence of the gastropod *Zeacolpus symmetricus* and paraonid polychaetes. While these key taxa also occurred across groups B and C, it was the variation in their population density, together with the occurrence of other species, which was responsible for the separation. Table 6 describes the key community differences in the groupings represented along the sampling transect. The type and magnitude of sample dissimilarity is considered typical of such environments. But since the study represents a pre-disturbance baseline, a record of these differences is important in establishing background variability.

Table 6. Summary of the key community characteristics differentiating the sample groupings depicted in the MDS plot (Figure 8). Since most samples occur in Group A, features of the subsequent groups are described relative to the Group A community.

Group	Characteristics of infauna community
Group A: All stations represented except 1000S and 100N	**High numbers** of nematode worms **Moderate to high numbers** paraonid polychaetes and the gastropod *Zeacolpus symmetricus* **Low to moderate numbers** of cirratulid polychaetes and the mud crab *Macrothphalmus hirtipes* **Low numbers** of phoxocephalid amphipods, the sea pen *Virgularia gracillima*, terebellid polychaetes, the capetellid polychaete *Heteromastus filiformis* and the bivalve *Arthritica bifurca.*
Group B: Stn 1000N, Rep A Stn 100N, Reps A & B Stn 100S, Rep C	**Significantly lower numbers** of nematode worms and paraonid polychaetes **Lower numbers** of *Z. symmetricus,* cirratulid polychaetes, *V. gracillima, M. hirtipes* **No incidence** of *Heteromastus filiformis, or oligochaete worms.*
Group C: Station 1000S All reps	**Significantly lower numbers** of nematode worms, *Z. symmetricus* and paraonid polychaetes **Lower numbers** of *M. hirtipes,* phoxocephalid amphipods and *V. gracillima* **Significantly greater numbers** of oligochaete worms **Greater numbers** of cirratulid polychaetes and *H. filiformis.*
Group D: Station 100N Rep C	**No incidence** of Nematode worms, cirratulid polychaetes, *M. hirtipes* and *V. gracillima* **Greater numbers** of the bivalve *Arthritica bifurca.*
Group E: Station 1000N Rep C	**No incidence** of nematode worms, paraonid and cirratulid polychaetes, phoxocephalid amphipods and oligochaetes **Significantly lower numbers** of *Z. symmetricus* **Greater number** of *A. bifurca, H. filiformis.*

3.4. Shellfish analyses

The green-lipped mussel (*Perna canaliculus*) samples were collected from Cape Three Points and Pinnacle Rock at depths from the surface of up to 3 m at neap high water. The populations were in small clusters within crevices and overhangs and were not plentiful at either site. Shell length observed varied up to 150 mm although the collected samples were in the range of approximately 60–100 mm. It is important to note that, although drawn from samples that were temporally and spatially coincident, a separate set of replicate sub-samples was submitted for the analysis of tissue trace metals and bacteriological quality.

3.4.1. Trace metals

Trace metal concentrations for the samples are plotted on a dry weight basis in Figure 9. Although there appear to be differences in mean concentrations for some metals between the two samples, these showed no consistency across analytes. The current WWTP discharge (Figure 1) is closer to the Pinnacle Rock site on the eastern shoreline (1.5 km) than to Cape Three Points (3.1 km), but no clear influence from the outfall was suggested by the mussel tissue metals concentrations[6].

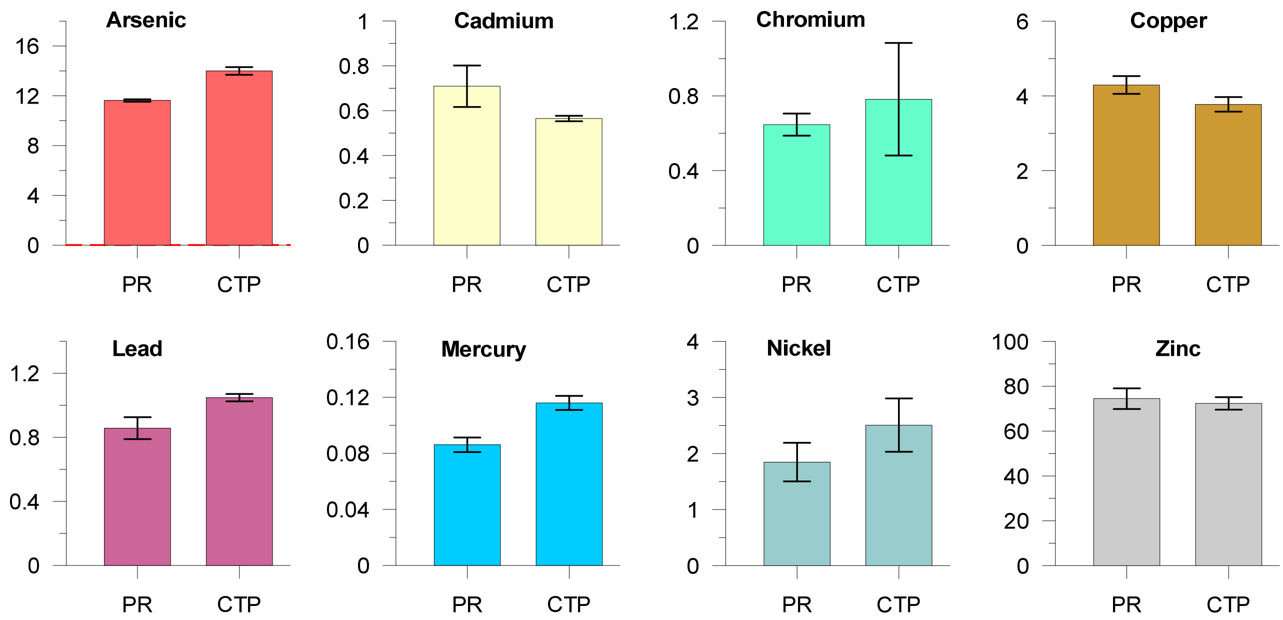

Figure 9. Trace metal concentrations in tissues of green-lipped mussel (*Perna canaliculus)* samples collected from Akaroa Harbour. PR = Pinnacle Rock. CTP = Cape Three Points (Figure 1). Units of mg/kg dry weight.

[6] Although the wastewater outfall at Wainui has the potential to be a confounding influence, its small size (max. 40 m^3/day) suggests that its relative contribution would be less than minor. Christchurch City Council advises that there has been no discharge to the Harbour from the Wainui WWTP since April 2012.

For consideration of implications for shellfish gathering and comparison against food standards, concentrations expressed on the basis of fresh (or wet) weight are more appropriate and these are listed in Table 7.

Table 7. Green-lipped mussel (*P. canaliculus)* tissue metal concentrations (wet weight basis) compared to relevant food standards (Food Standards Australia New Zealand; FSANZ 2013) and guidelines (Rasmussen 2000).

	Pinnacle Rock			**Cape Three Points**			**Guideline / Std**		
Replicate	**A**	**B**	**C**	**A**	**B**	**C**	**FSANZ**	**MIS [c]**	**EDL [d]**
Moisture (g/100g)	82	83	84	87	87	84			
Metals (mg/kg)									
Arsenic	2.100	2.000	1.830	1.740	1.850	2.300	1 [a]	1.4	3.74
Cadmium	0.098	0.147	0.115	0.071	0.073	0.094	2	1.0	0.99
Chromium	0.13	0.09	0.11	0.18	0.06	0.08	-	1.0	0.73
Copper	0.74	0.81	0.64	0.44	0.52	0.63	30 [b]	20	2.28
Lead	0.131	0.150	0.154	0.142	0.132	0.166	2	2.0	1.61
Mercury	0.017	0.013	0.014	0.015	0.014	0.020	0.5	0.5	0.05
Nickel	0.24	0.29	0.40	0.44	0.31	0.28	-	-	0.78
Zinc	12.8	14.2	11.0	9.6	8.7	12.2	290 [b]	70	42.9

a. Applies to inorganic arsenic rather than total arsenic.
b. Generally expected levels (GELs) 90th percentile for molluscs. The value for zinc applies specifically to oysters rather than mussel species.
c. Median international standard compiled for shellfish (Rasmussen 2000).
d. Elevated data level (EDL; 85th percentile) applicable to blue mussel (*Mytilus edulis*) or *California mussel (M*. *californianus*; arsenic only) (Rasmussen 2000).

The information available on background metals levels in *P. canaliculus* (*e.g.* Nielson & Nathan 1972; Fenaughty *et al.* 1988; Larcombe *et al.* 1986) suggests that the samples did not have elevated levels of mercury, copper, lead or zinc. They were also within the (%dry wt) ranges reported for Manukau Harbour by Kelly and McMurtry (2004). A triplicate sample of *P. canaliculus* collected from Battery Point in Lyttelton Harbour returned mean wet weight concentrations slightly higher than those from Akaroa Harbour for a range of metals (mercury 0.027 mg/kg, arsenic 2.83 mg/kg, chromium 0.21 mg/kg, copper 1.10 mg/kg, lead 0.28 mg/kg, zinc 18 mg/kg) (Sneddon 2011).

More data is available for the blue mussel (*Mytilus edulis*) than for *P. canaliculus*, partly due to its international status as a bioindicator species. Kelly and McMurtry (2004) reported that, while oysters and mussels differ in their ability to concentrate trace elements and are therefore not directly comparable, reasonable comparisons can still be made among oyster or mussel species (although slight inter-species variations may still occur). For this reason, data for *M. edulis* is considered useful where information concerning *P. canaliculus* is sparse. Metals concentration ranges reported for *M. edulis* sampled from Wellington Harbour were similar to those of the current study for cadmium, copper and nickel, higher for lead, chromium and zinc, but slightly lower for mercury (Milne 2007).

Relevant food standards and guidelines concerning metals levels include Standard 1.4.1 for Contaminants and Natural Toxicants in Food (FSANZ 2013), which lists the maximum levels (ML) of specified metal and non-metal contaminants and natural toxicants in nominated foods. For the trace metals analysed in shellfish for the current survey, MLs exist for arsenic, cadmium, lead, and mercury (Table 7). In addition, Rasmussen (2000) listed median international standards (MIS) for trace elements in fish and molluscs, providing an indication of what a range of nations considered to be elevated concentrations in terms of human health risk.

Concentrations in the samples were well below both the FSANZ (2013) ML criteria and the MIS for all except arsenic. The observed range of 1.74–2.3 mg/kg wet weight exceeded the FSANZ arsenic ML of 1 mg/kg. However, it is noted that the standard refers explicitly to inorganic arsenic. Arsenic species occurring in seafood are predominantly in organic forms such as arsenobetaine. While metabolic pathways for organic arsenic compounds are not well understood, it is generally accepted that such compounds in seafood are not very toxic in living systems (*e.g.* Sakurai 2002).

As a geologically young country of volcanic origin, New Zealand is relatively rich in minerals, many of which contribute locally to concentrations in coastal environments. These geological influences can lead to relatively large local variations in levels of some metals (Gillespie *et al.* 2011). Arsenic is frequently associated with geology of volcanic origin and, for this reason, elevated arsenic levels are not uncommon in New Zealand environments. Turner *et al.* (2005) cite a study by Robinson *et al.* (1995) that reported arsenic levels in mussels from the mouth of the Waikato River. This river receives large volumes of geothermal, industrial, agricultural and domestic effluent, at over three times the levels for a control estuary (Raglan). However, the Waikato River mouth samples were within the arsenic range reported by Kelly and McMurtry (2004) for mussels from the Manukau Harbour.

Similar to the occurrence of arsenic, it should be noted that, despite its recognised toxicity, mercury is also environmentally ubiquitous and that shellfish contain natural background levels that are not necessarily attributable to any environmental contamination. Turner *et al.* (2005) cite Hoggins and Brooks (1973) as estimating background levels of mercury in *P. canaliculus* in New Zealand at 0.02 mg/kg, a value which is consistent with the results of the current study.

There are no New Zealand guidelines for acceptable concentrations of chromium, copper, nickel or zinc in shellfish tissue. While the risk to human health from copper and zinc is regarded as too low for provision of a criterion, FSANZ provides generally expected levels (GELs) for different food groups, including shellfish. GELs are not legally enforceable and are provided as a benchmark only. Similarly, 85th percentile elevated data levels (EDLs) have been provided for *M. edulis* and *M. californianus* based on extensive monitoring for the California State Mussel Watch programme (Table 7). While they provide useful context, it should be noted that GELs and EDLs are not directly related to potentially adverse human or animal health effects.

3.4.2. Bacterial indicators

Results for microbiological analyses of the mussel samples are presented in Table 8. Except for presumptive enterococci in a single replicate from Cape Three Points, all bacterial counts were below 100 MPN/100 g. This is generally at the lower end of the ranges reported by Bolton-Ritchie (2013a) for shellfish collected at other points in the harbour. The presence of indicator bacteria at these low levels is to be expected from a sheltered coastal inlet receiving inputs from streams and run-off from land supporting a range of feral and domestic animals. As for the metals results, and notwithstanding the 'snap-shot' nature of the samples, there is no suggestion (based on proximity) of an influence from the current outfall.

Table 8. Indicator bacteria in tissues of green-lipped mussel (*Perna canaliculus)* from Akaroa Harbour compared to applicable reference criteria.

	Pinnacle Rock			Cape Three Points			Guideline / std	
Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**FSANZ [a]**	**MoH [a]**
Bacterial indicators (MPN/100 g)								
Faecal coliforms	20	< 20	80	50	20	40	-	230
E. coli	20	< 20	80	50	20	40	230	-
Presumptive enterococci	< 20	< 20	< 20	2,800	70	40	-	-

a. Tolerance of no more than a single exceedance in a batch of five samples.

While there are no formal bacterial or viral limits for shellfish gathered for non-commercial purposes in New Zealand or Australia, FSANZ has promulgated a standard for *E. coli* levels (and norovirus) in commercial shellfish (FSANZ 2012). The criterion for shellfish (other than scallops) is based on *E. coli* counts per 100 g of tissue in five sample replicates. Shellfish quality is considered to pose a risk to human health when more than one replicate is over 230 *E. coli/*100 g, but no replicate is permitted to be above 700 *E. coli /*100 g.

Historically, the MoH (1995) criteria for faecal coliform bacteria in shellfish have been applied. These state that faecal coliform concentrations up to 230 MPN/100 g are acceptable, with up to two samples from the same batch (site) allowed to exceed this level and no sample to exceed 330 MPN/100 g. As for FSANZ (2012), which supersedes them, the MoH (1995) criteria are based on a minimum of five samples for bivalve shellfish, comprising a minimum of 12 individuals per sample.

Although some caution should be applied in comparing the results of the current limited investigation to these guideline criteria, not least because they are based on a higher level of sample replication, the values do not suggest that green-lipped mussels at these points in the harbour are consistently exposed to significant anthropogenic bacterial sources.

3.5. Water quality data

It is acknowledged that water quality sampling is of limited efficacy unless it encompasses significant levels of replication across appropriate time periods. However, this field survey was seen as an opportunity to collect a 'snap-shot' of a number of water quality parameters on the day and to record any stratification occurring within the water column.

The water column profiles were conducted between 16:55 and 17:30 (NZDT) just after the high neap at 16:25 (MSL+0.74 m, Figure 2). The profiles for temperature, pH, salinity and dissolved oxygen are plotted in Appendix 6. A summary of the water quality data is listed in Table 9.

Surface samples taken for turbidity measurements averaged 2.7 NTU over the five sites, ranging from 2.0–2.91 NTU. This is well within the range reported by Bolton-Ritchie (2013a) for measurements made over 2003–4 and 2008–9 for a number of sites within Akaroa Harbour.

The main feature of the profiles (supported by diver observation) was a distinct change in temperature near the seabed, indicating a benthic layer some 1.7°C colder than surface waters. Towards the southern end of the transect, this layer extended further up through the water column but was less well-defined (Table 9, Appendix 6). The depth of the thermocline varied from 1.5–1.8 m from the seabed in the north to nearly 6 m at station 1000S.

While efforts were made to minimise the rate of descent and ascent of the instrument sonde (approximately 12 cm/sec), lag in the sensors resulted in sometimes pronounced hysteresis in the profiles for temperature, salinity and dissolved oxygen. In the case of salinity, temperature-compensation produced sharp upward and downward shifts at the thermocline before equilibration was regained (Appendix 6). Examination of the salinity profiles leads to a conclusion that the temperature effect was the sole cause of variation and that there was in fact negligible change through the water column. The pH, which averaged 8.14, was also consistent throughout the water column and between sites.

Dissolved oxygen concentration was recorded as lower in the benthic cold water layer, decreasing from an average of 8.3 mg/L (above 100% saturation) for the upper water column to 7.4 mg/L (90-94% saturation) near the seabed.

Table 9. Summary data for water quality stations. 'Upper' refers to values averaged for the upper part of the water column. 'Benthic' refers to values averaged for the benthic cold layer. Due to issues with hysteresis, depth ranges over which data were averaged were necessarily subjective.

Station	Time	Depth [a]	Turbidity [b] surface	Temperature		Benthic layer [c]	Dissolved O_2		Salinity [d]	pH
				Upper	Benthic		Upper	Benthic	Mean	Mean
	(NZDT)	(m)	(NTU)	(°C)	(°C)	(m)	(mg/L)	(mg/L)	(psu)	
1000N	17:30	9.7	2.91	17.71	15.98	1.8	8.11	7.51	34.9	8.15
500N	17:21	10.2	2.82	17.60	15.84	1.5	8.11	7.49	34.8	8.16
Outfall site	17:13	10.5	2.81	17.40	15.67	3.0	8.27	7.27	34.8	8.14
500S	17:03	11.1	2.10	17.13	15.49	3.0	8.37	7.33	34.7	8.14
1000S	16:55	11.8	2.83	17.11	15.36	5.7	8.48	7.33	34.6	8.12

a. From YSI EXO2 water quality sonde recorder (Appendix 6). Not corrected for tidal height.
b. Nephelometric turbidity measured using a portable (Hach 2100) field turbidimeter.
c. Distance from seabed estimated from averaging data from descending and ascending components of sonde temperature record.
d. Based on stable sections of the profile record.

4. ASSESSMENT

The ecological characterisation of the new outfall location has been an important component of this investigation. However, since the discharge of Akaroa wastewater is not fundamentally a new activity, the assessment of potential ecological effects may be focussed on specific areas of concern identified from preliminary studies, historical monitoring and prior investigations of the harbour system. The key effluent constituent of nitrogen has been highlighted due to its potential effects as the principal limiting nutrient in estuarine and coastal systems. Specific aspects of effluent dispersion and dilution established by Bell *et al.* (2014) have been considered in the context of potential exposure of marine habitats to effluent plumes. Expected effects on marine ecology have been assessed in the light of predicted effluent quality and dilution, historical effects from the current discharge, and the sensitivity of near-field benthic communities characterised by the field survey.

4.1. Effluent and receiving water quality

Based on the Harrison Grierson (2010) options, assessment and information compiled by Bartram (2013) for historical effluent and receiving water quality, the effluent parameters of primary concern are nutrients (principally nitrogen) and indicator bacteria. The microbiological quality of the effluent has implications mainly for risks associated with shellfish quality and contact recreation. The total cumulative nutrient loadings to the Akaroa Harbour receiving environment from all sources potentially have more far-reaching ecological effects.

Ammoniacal nitrogen (NH_3-N) has the potential for acute toxic effects and is a key parameter both for the control of effluent quality and design of the outfall for maximum dilution. ANZECC (2000) provides a table of ammonia toxicity for freshwater and marine receiving environments based on pH (the main factor determining toxicity via the ionisation of ammonia). The trigger value for NH_3-N at pH 8.0 is 0.910 mg/L, but this decreases to 0.750 mg/L at pH 8.1. The proposed annual 95th percentile trigger value for NH_3-N of 20 mg/L and the expected peak summer effluent concentration for the proposed BNR process (5 mg/L; Table 10) is considered appropriately protective given the modelled initial dilution of greater than 200:1 within the rising plume (Bell *et al.* 2014). The buoyancy of the plume means that, at the edge of the mixing zone, any criteria for NH_3-N would be exceeded first in the surface waters rather than at the seabed.

Compared to the current Akaroa WWTP effluent, the preliminary design report (CH2M Beca 2014) predicts that a reduction in total nitrogen in the discharged effluent will be provided by the BNR process (Table 10). It is accepted that targets or standards based on median values are generally protective concerning impacts related primarily to overall loads (as is the case with eutrophication). The capacity to maintain a high quality effluent over peak summer periods suggests that the risk that the effluent represents in terms of the promotion of algal blooms within the harbour is also small.

Table 10. Values for treated effluent quality. Adapted from the Akaroa Wastewater Preliminary Design Report (CH2M Beca 2014). Mean effluent nutrient concentrations for the period of the existing consent (from Bartram 2013) are listed for comparison.

	Proposed consent limits		Current limits	Design (expected) values		Historical value (May 2008–Feb 2013)
Parameter	**Annual median**	**Annual 95 %ile**	**Annual median**	**Winter dry weather**	**Peak summer**	**Mean**
$CBOD_5$ (mg/L)	20	50	< 30	5	10	-
TSS (mg/L)	20	50	< 30	2	4	-
TN (mg/L)	15	30	-	10	15	29.4
NH_3-N (mg/L)	10	20	-	1	5	6.9
NO_x		-	-	-	-	16.9
DIN (mg/L)			-	-	-	-
TP (mg/L)			-	-	-	6.3
DRP (mg/L)			-	-	-	5.9
Faecal coliform(/100 mL)	500	1,000	< 1,000	10	100	-
Enterococci(/100 mL)	500	1,000	-	10	100	-

4.1.1. Relative significance of effluent nitrogen load

The nitrogen loading from the proposed discharge is not considered to be large, but it is acknowledged that nutrients discharged to Akaroa Harbour have the cumulative potential to change the trophic status of harbour waters. As such, they may promote episodic blooms of phytoplankton or the growth of nuisance macroalgae such as sea lettuce (*Ulva* sp.). It is therefore useful to consider the significance of the nitrogen load from the Akaroa outfall in the context of other inputs such as freshwater streams and runoff, other wastewater outfalls, finfish aquaculture, groundwater and tidal influx.

Streams

Streams flowing into upper and mid Akaroa Harbour are typically from rural catchments. While noting differences in the temporal variability of nutrient loads in both stream and wastewater inputs, Bolton-Ritchie (2013b) calculated that eight monitored streams discharging to Akaroa Harbour contributed up to 7.7 times more total nitrogen (TN) to harbour waters than the current Duvauchelle and Akaroa outfalls combined.

Wastewater

Of the three wastewater treatment plants discharging to the Harbour, the flow of effluent from the Akaroa plant (consented at 2,200 m^3/day) is by far the largest. Flows from Duvauchelle and Wainui are consented at respective maximums of 40 m^3/day and 250 m^3/day. Bolton-Ritchie (2013b) reported that, while there was no available data on nutrient concentrations in Wainui wastewater, mean annual TN loads of 751 kg/year and 1,924 kg/year were calculated for Duvauchelle and Akaroa WWTPs, respectively. It was noted that none of these treatment plants were designed to reduce wastewater nutrient concentrations. It is estimated there will be an annual TN load from the Akaroa outfall of 1.95 tonne/year based on; the 2041 design annual average flow of 130,300 m^3 and a conservative peak summer expected TN concentration of 15 mg/L (Table 10).

Finfish aquaculture

A salmon farming operation, with current production of approximately 200 tonne/year, has been in operation at Wainui for over two decades. Finfish aquaculture is an acknowledged significant source of nitrogen to receiving waters. Assuming a feed rate on the order of 400 tonne/year for this level of production, and based on a typical nitrogen loading of 48 kg TN/tonne feed (pers. comm. N. Keeley, Cawthron Institute), an estimated annual nitrogen loading of 19.2 tonne/year may be calculated. This exceeds the current and projected Akaroa WWTP loadings (~1.9 tonne/year) by an order of magnitude.

Groundwater

There was no data pertaining to nitrogen loads to Akaroa Harbour from groundwater flows. However, Fenwick & Image (2002) concluded that, based on high nitrate-nitrogen concentrations and high aquifer transmissivity, groundwater has the potential to have a significant effect on the productivity and ecology of the Banks Peninsula south coast area at times of high flows and protracted calm weather.. For this reason it was suggested that groundwater discharge may be implicated in phytoplankton blooms in the area.

Tidal influx

Based on 12 samples collected at Akaroa Heads during 2008–2009, a mean value for TN of 0.17 mg/L was derived by Bolton-Ritchie (2013b). With a neap tidal prism for the Harbour of 65 million m^3 (representing 13% of spring low tidal volume; Bell *et al.* 2014), tidal influx of TN may be estimated at 11 tonnes. Using the 2041 design summer average discharge volume of 561 m^3/day (CH2M Beca 2014), and the peak summer expected TN concentration of 15 mg/L (Table 10) gives a nominal effluent loading to the receiving environment of approximately 4.4 kg over a tidal cycle (~12.5 hours), or 0.04% of the value represented by tidal exchange.

4.1.2. Temporal trends in Akaroa Harbour nutrient concentrations

Bolton-Ritchie (2013b) compared nutrient concentrations within harbour waters over three time periods, the early 1990s, late 1990s and 2000s. While appreciable variability in concentrations of ammonia nitrogen, TN, dissolved reactive phosphorus (DRP) and TP was observed, it was concluded that there had not been a significant increase in the concentration of these nutrients in harbour water over time.

4.1.3. Phytoplankton blooms

Fenwick & Image (2002) reported that phytoplankton population data collected for Akaroa Harbour from1999–2002 were very variable between years. Some taxa rarely appeared in abundance; whereas others persisted and bloomed repeatedly. It was noted that marine phytoplankton blooms are characteristically variable from year-to-year because of the large number of variables that influence their development and persistence. It was concluded that the task of linking such occurrences in Akaroa Harbour to particular inputs or causes, requires either very extensive historical data or a combination of targeted sampling combined with hydrodynamic and ecological modelling.

Based on insufficient data to assess phytoplankton blooms in Akaroa Harbour generally, Bolton-Ritchie (2013b) concluded the following:

- the influence on phytoplankton blooms from nutrients in wastewater and stream inputs was unknown and;
- it could not be determined whether there have been changes in the nature and frequency of blooms over time.

While the potential of the proposed Akaroa WWTP discharge to cause algal blooms in the mid to upper Harbour cannot be determined, its nitrogen loading compared to other inputs to the Harbour system strongly suggests that such potential is very low.

Using the Deltares Delft2d hydrodynamic model (tracer module), Bell *et al.* (2014) found that the transitory period to reach a dynamic-equilibrium background harbour concentration (balanced by harbour tidal exchange) was up to around 120 days. While nitrogen is not in this instance a conservative contaminant, this illustrates how relatively steady discharge loads are not accumulative over longer time periods. So a decrease in nitrogen load via improved effluent quality will result in lower harbour-wide concentrations (if all other inputs are constant) and lower risk of nutrient-triggered phytoplankton blooms.

4.1.4. Receiving water limits and monitoring

Bolton-Ritchie (2013b) provided low-risk trigger values for nutrients within receiving waters based on 80th percentile background values as suggested by ANZECC (2000). These were 0.062 mg/L for DIN and 0.018 mg/L for DRP.

When applied as limits at the edge of a mixing zone, such criteria will by definition result in exceedances on at least 20% of occasions, even in the absence of a discharge. Hence such limits must take into account the co-occurring background concentrations in adjacent waters beyond the influence of the outfall. It is also noted that the suggested trigger value for DIN is automatically protective of acute effects from its NH_3-N component.

Direct monitoring of receiving water quality has limited efficacy for the mid-harbour discharge of a high quality treated effluent. This is because water samples would vary in composition depending on their location relative to the plume centre-line. To counter this source of variability, an indication of surface plume direction can be obtained by deployment of drogues. However, where there is a sound knowledge of the available dilution under reasonable worst case conditions (established via a dye study and the existing modeling information), it is believed that a more broadly applicable indication of effects on surface water quality in the vicinity of the discharge can be gained by rigorous effluent monitoring.

4.2. Dilution and dispersion

The water column data collected for this study was generally consistent with available information for Akaroa Harbour and expectations for an inlet of this nature. The one feature of note was the presence, at the time of sample collection, of a colder benthic layer, although this did not appear to be associated with a change in salinity. While the occurrence or persistence of such a layer cannot be inferred from this single instance, it is noted that the presence of a thermocline can have implications for the behaviour of a rising plume discharged at the seabed. Bell *et al.* (2014) noted that, while vertical density stratification (especially from temperature gradients) does occur at times in the Harbour, it was unlikely to have a major influence on effluent concentrations in shallow near-shore coastal sites. This was supported by a model simulation using multiple depth layers that showed only marginal differences with depth in current velocities in the middle Harbour.

The typical behaviour of a buoyant plume from a seabed diffuser with appropriate discharge velocity would see significant dilution achieved by the time it reaches the surface from a depth of 10 m. From the surface 'boil', the plume will tend to spread concentrically as a lower salinity surface layer but the direction and rate of propagation will depend largely upon prevailing currents and wind direction.

Bell *et al.* (2014) investigated near-field initial dilution of the outfall discharge using the CORMIX plume model. It was indicated that most of the initial mixing will be achieved within 50 m of the diffuser, with some further residual initial dilution achieved by 100 m. A cumulative distribution of initial dilutions was generated from a one-year simulation for the suggested outfall diffuser site. This yielded 1st and 10th percentile (worst-case) dilutions of 207:1 and 516:1, respectively.

CORMIX modelling carried out by Kingett Mitchell (2006) for the current outfall, indicated that the simple outfall pipe discharge would not promote effective dispersion, leading to plume attachment to the seabed within 10 m of the outfall. The modelling undertaken by Bell *et al.* (2014) for the proposed mid-harbour outfall diffuser showed that this will not occur. Seabed exposure is therefore expected to be limited to highly diluted plumes at greater distances from the outfall.

The majority of Akaroa Harbour is classified 'SG' (waters managed for shellfish gathering); however, discharge in the mid-harbour region will generally decrease the exposure of benthic organisms to wastewater constituents. This is especially notable for edible shellfish since shoreline contact will no longer occur until the plume has undergone further dispersion along with time-dependent inactivation of potential pathogens (Bell *et al.* 2014). The distances from the suggested outfall site to the nearest shorelines are 700 m to the east (Green Point) and 1,250 m to the west (Opukutahi). Plume travel time from the mid-harbour diffuser to the site of the present outfall near Green Point was calculated to be 15 hours. While the modelling report did not provide physical dilution ratios for individual shoreline receptor sites, it was established that far-field dilution (beyond the mixing zone) would be relatively low at 2- to 3-fold.

4.3. Effects on benthic habitats

Samples collected for this investigation were specific to the soft sediment benthic habitats predominating along the central harbour axis. Apart from general observations at Pinnacle Rock and Cape Three Points during shellfish collection, the shoreline habitats of the harbour were not surveyed. However, some assessment of the potential effects on wider harbour communities can be made based on consideration of historical survey data, effluent quality and expected dispersion and dilution. The 2006 ecological survey of the current outfall site (Golder 2007) is particularly relevant in that the shallower near-shore location represents a worse case for benthic habitat exposure to wastewater constituents.

4.3.1. Sediments

Golder (2007) found no evidence of sediment accumulation of metals within 150 m of the current outfall. Sediment concentrations of copper, lead and zinc were 7.7 mg/kg, 15.4 mg/kg and 49.3 mg/kg, respectively. These were slightly lower than, but comparable to, those found for mid-harbour sediments in the current investigation (Appendix 2). This is likely to be due to the lower mud content of the sediments in shallower water closer to the shore (25–77% dry weight for material < 2 mm). The inshore sediments in the vicinity of the outfall also had lower organic carbon (0.48–0.74% dry weight for material < 2 mm) although nutrient status was not evaluated.

With a buoyant (freshwater) plume rising through the deeper water at the mid-harbour location, benthic habitats in the vicinity will be far less exposed to discharge plumes at low levels of dilution. It is considered very unlikely that, on the basis of present and projected effluent quality, sediment accumulation of discharge-related trace metals will occur to levels of potential concern. While the depositional benthic environment means that there is potential for a slight organic or nutrient enrichment effect near the proposed mid-harbour outfall, such effects are similarly expected to be indiscernible outside a 100 m mixing zone. Neither are discernible shifts in grain size distribution expected since the depositional environment has already resulted in a uniformly very fine substrate and the projected suspended solids load in the discharge is low (< 10 mg/L TSS).

4.3.2. Ecology

The design of the current investigation represents a baseline survey, establishing a suitable 'template' for effective benthic monitoring once the proposed outfall has been commissioned. The results from this study were consistent with earlier studies describing aspects of benthic habitats at the site of the survey transect.

Golder (2007) identified no significant effects on benthic ecology from the current outfall, although it was noted that community assemblages within 25 m of the outfall featured a greater number of taxa, including many that are typically more tolerant of disturbance and organic enrichment. An increase in abundance and species richness without dominance by opportunistic or disturbance-tolerant taxa is characteristic of slight enrichment or increased organic matter mineralisation. As such, the results may be indicative of conditions associated with the first stage of enrichment described by the Pearson-Rosenberg (PR) model (Pearson & Rosenberg 1978). With such low-level effects confined to an area immediately adjacent to the long-term wastewater discharge, benthic community effects within the deeper mid-harbour region would be expected only if such communities were significantly more sensitive.

The seabed in the vicinity of the proposed outfall is homogeneous, and biogenic structures such as beds of macroalgae or dense shellfish are absent. The benthos is largely comprised of small-bodied fauna that are ubiquitous within the Harbour. In the event that sediments close to the outfall became moderately enriched with nutrients and / or organic matter, the affected area would be expected to recover over intermediate timeframes (months to years) if such inputs were to cease. However, in light of the findings of the Golder (2007) survey of the present shallower outfall, the improved quality of the treated wastewater and a suitable diffuser design, significant impacts to the sediment habitat are considered unlikely.

Regarding the ecology of the wider Harbour area, Fenwick (2004) provides the best general context and the following conclusions are considered relevant to the siting of the proposed outfall:

- Intertidal communities varied principally with changing exposure to wave action, and comprised of species that are widely distributed around Banks Peninsula and elsewhere along the east coast of the South Island.
- There is a change in benthic sediments along the harbour mid-line, from almost completely mud fraction in the upper harbour, to very fine sands near the heads (although it is notable that the transition to sand occurs south of the area covered by the current survey).
- Sediments and benthos closer inshore were generally very similar to those along the mid-harbour axis, suggesting that the results from the current study are reasonably representative of soft sediment habitats in the upper to mid-harbour region.
- Total macroinvertebrate diversity and densities in Akaroa Harbour were consistent with those reported for other soft sediment locations around Banks Peninsula. It was noted that Lyttelton Harbour and Akaroa Harbour share many common species.
- Comparison of the benthic community data to other published studies suggested that the sub-tidal benthos in Akaroa Harbour has not been altered greatly by human impacts.

Modelling by Bell *et al.* (2014) indicates that the distance from the shoreline of the mid-harbour outfall is suitably protective of these habitats in terms of direct plume impingement. The largest potential stressor to the wider Akaroa Harbour ecosystem is expected to be in the form of nutrients (principally nitrogen) in the discharge, this being a key factor in the specification of a biological nutrient removal (BNR) process for the new WWTP (CH2M Beca 2014). However, Akaroa treated wastewater is a relatively minor contributor to total nitrogen inputs to the Harbour system, which also includes: other wastewater discharges, finfish aquaculture and agricultural runoff (see Section 4.1.1). While it should be noted that the upgraded and re-sited WWTP and outfall will represent a decrease in overall nitrogen loading, effective monitoring of the Harbour is important for the future management of cumulative inputs.

Future monitoring of benthic sediments and communities is also important, especially since these tend to integrate effects over time. But caution is advised in interpreting general shifts in community structure since these can be a natural feature arising from external influences and natural cycles. Observing strict seasonality in monitoring is important in this regard. Seasonal influences may be of greater or lesser importance depending on the site and the parameters of interest. In some cases, its relative significance may simply be unknown. The significance of seasonality as a factor in the design of monitoring programmes stems from it being essentially controllable; that is, if seasonal variability can be eliminated simply through strict scheduling, then it makes sense to do so.

4.4. Marine mammals

In relation to wastewater discharges, Clement (2010) discussed what was currently known about the potential effects of endocrine-disrupting chemicals (EDCs) and marine mammals. This limited knowledge was then applied specifically to an assessment of risks to marine mammals, particularly Hector's dolphins, in Akaroa Harbour.

Since the 2010 report, there has been no new information available regarding the sensitivity of marine mammals to EDCs. Hence the question as to the levels at which specific EDCs would start to have an effect on Hector's dolphins, remains unanswerable with the current level of understanding. However, it is worth reiterating the following from the 2010 report.

Evaluations of the levels at which EDC body burdens begin to adversely affect the health of marine mammals via immunological and reproductive effects are currently very limited. Even where such studies have been undertaken (*e.g.* Kanaan 2000), predictions of the environmental exposure levels necessary to produce such burdens would require broad assumptions regarding multiple factors:

- composition and provenance of prey items in the diet
- bio-magnification factors (as these differ between species as well as between chemicals)
- lipid content of the diet
- possible movement patterns
- cumulative exposure to various non-point sources.

The significant gaps in current knowledge of (or ability to predict) many of these factors, tends to render such an exercise almost entirely speculative.

Instead, the most precautionary approach that can be taken (until further information is available) is to limit the levels of EDCs from point-source discharges in relation to current ANZECC (2000) 95–99% guideline values[7]. While these receiving environment trigger values may be multiplied by the expected mixing zone dilution factor in order to derive effluent (*i.e.* end-of-pipe) limits, an alternative but much more conservative approach would be to apply such guideline levels directly to effluent concentrations.

The trigger for phenols in marine waters at the 99% level of protection is 270 µg/L (0.27 g/m^3). In the case of the existing Akaroa WWTP, phenol levels in the effluent tested in August 2010 were, at less than 0.001 g/m^3, well-below the 99% trigger level. All other potential EDCs tested as components of the semi-volatile and volatile organic compound (SVOC and VOC) and polychlorinated biphenyl (PCB) analysis suites were also found to be below analytical detection limits (ADL) at the trace level. Two samples of the effluent collected in December 2013 and analysed for a suite of SVOCs (including phenols) similarly returned concentrations generally less than ADL for trace level analysis. The only exceptions were three polycyclic aromatic hydrocarbons (PAHs) in one sample at marginally above ADL.

Of the trace elements analysed, only cadmium, lead and mercury were identified as having the potential to cause immuno-suppression effects, and could therefore indirectly disrupt natural endocrine functions in marine mammals. Of these, only mercury is recognised for its clear tendency to bio-concentrate through food webs. Test results for these three metals within effluent sampled in October 2009 and January 2010, were consistently below both trace level ADL and ANZECC (2000) 99% protection trigger levels.

But for many EDCs, such trigger values are not listed in ANZECC (2000) — especially for marine systems — as there was considered to be insufficient data available to derive them. In these instances, examining the levels of those chemicals that do have trigger levels will help provide some idea of the quality of the effluent as a whole, as well as the level of treatment and original sources of the wastewater.

Clement (2010) noted that seasonal trends in distribution and density of Hector's dolphins within Akaroa Harbour indicate that they are rarely found in the vicinity of the existing outfall except over summer months (mainly January and February) in fairly low densities. This assessment covered the broad area of the mid- to upper Harbour and applies equally to the site of the proposed new outfall.

[7] Under the ANZECC (2000) water quality guidelines, values for four distinct levels of protection are presented for a range of contaminants. These levels (99%, 95%, 90%, 80%) are defined as a nominal percentage of aquatic species that will likely be protected, with 99% being the most conservative and 80% the least. For most contaminants, the 95% level represents the default value applicable to slightly- to moderately-disturbed systems, with the other levels being used for systems which are recognised as varying from this type for specific reasons (*e.g.* 99% protection may apply to pristine areas, such as marine reserves).

Any improvements in the treatment, dilution and dispersion of the wastewater discharge will result in a decreased risk of significant exposure to EDCs for important prey species and therefore to Hector's dolphins.

5. SUMMARY AND CONCLUSIONS

The main focus of the investigation was the soft sediment habitat and benthic communities occurring within the vicinity of the proposed outfall. Samples were collected from 10 stations along a 2 km transect oriented along the harbour axis.

Analysis of sediment samples indicated a generally homogeneous substrate of fine soft mud along the transect. Consistent with data from other studies of the central and upper harbour, grain size was predominantly in the silt / clay fraction (< 63 µm). Sediment concentrations of nutrients, organic matter and trace metal contaminants were similarly uniform and considered likely to reflect relatively unimpacted background conditions.

Overall, 53 macroinvertebrate taxa were identified from the samples, this moderate diversity being consistent with the homogeneous nature of the substrate. Communities were generally consistent with data from previous studies of Akaroa Harbour and no taxa or assemblages of special scientific or conservation interest were identified.

The density of benthic macroinvertebrates and (to a lesser extent) taxa richness were quite variable along the sampling transect. Indices for community diversity and evenness were relatively high and uniform, indicating a healthy community structure with the patchiness often typical of shallow coastal environments; however, slightly lower values at two of the 10 stations resulted from the numerical dominance of nematode worms.

The results of multivariate statistical analysis reflected the patchiness of macroinvertebrate communities over small spatial scales. The observed variability was not attributable to the influence of factors such as water depth or sediment physico-chemical parameters.

The uniformity of the substrate and benthic communities observed during this investigation suggest that subsequent monitoring surveys using a similar transect approach will be able to detect and quantify, via observable spatial gradients, changes which may be attributable to the discharge. In order to minimise the confounding effects of natural temporal variability in benthic communities, strict seasonal timing of such surveys should be observed. The very fine nature of the Akaroa Harbour sediments (where the bulk of the material is finer than 63 µm) means that a method that better characterises this fraction should be considered for future monitoring.

Triplicate samples of the green-lipped mussel (*Perna canaliculus)* collected from Cape Three Points and Pinnacle Rock returned generally low values for trace metals and no apparent influence from relative proximity to the current outfall was identified. Tissue concentrations were below relevant food standards and consistent with available data for this species and the blue mussel (*Mytilus edulis*). Although the limitations of sampling at a single point in time are acknowledged, analyses for indicator bacteria similarly suggested no exposure to significant anthropogenic bacterial sources.

As for the shellfish samples, the field survey was seen as an opportunity to collect depth profiles for a number of water quality parameters at five points along the sampling transect. Values for turbidity, pH, dissolved oxygen and salinity were consistent with available information for Akaroa Harbour and expectations for an inlet of this nature. However, all of the profiles featured a distinctly colder benthic layer, but this stratification did not appear to be associated with a change in either turbidity or salinity. While the frequency or persistence of such a thermocline cannot be inferred from this single instance, it is noted that such a feature can have implications for the behaviour of a rising plume discharged at the seabed.

The proposed treatment process will result in a higher quality effluent than for the current WWTP. Although considered to be a key concern for the discharge, the projected nitrogen loading to the Harbour system will be very small compared to inputs from other sources. And while there is insufficient data to determine the potential for the discharge to cause algal blooms in the mid- to upper Harbour, its relative insignificance strongly suggests that such potential is also correspondingly low. Rather than implementing direct monitoring of receiving water quality, it is believed that a more broadly applicable indication of effects on surface water quality in the vicinity of the discharge can be gained by rigorous effluent monitoring combined with knowledge of the available dilution under reasonable worst-case conditions.

Significant impacts to the mid-harbour benthic habitat are considered unlikely in light of the absence of significant effects to the benthic environment identified by a 2006 survey of the immediate vicinity of the current discharge and improved effluent and dispersal conditions for the proposed discharge. Furthermore, the nature of the existing benthos is such that moderately rapid recovery would be expected from any enrichment effects following cessation of inputs or a significant decrease in environmental loading. The distance from the shoreline of the mid-harbour outfall is considered suitably protective of intertidal and hard substrate habitats in terms of direct plume impingement. This was supported by hydrodynamic modelling of plume propagation.

Not enough is known about the action of EDCs on marine mammals or the routes and mechanisms of exposure to quantify the risk to Hector’s dolphins represented by the Akaroa WWTP discharge. However, the available lines of evidence suggest that the risk is low and it is noted that any improvements in the treatment, dilution and dispersion of the wastewater discharge will result in a decreased risk of significant exposure to EDCs for important prey species.

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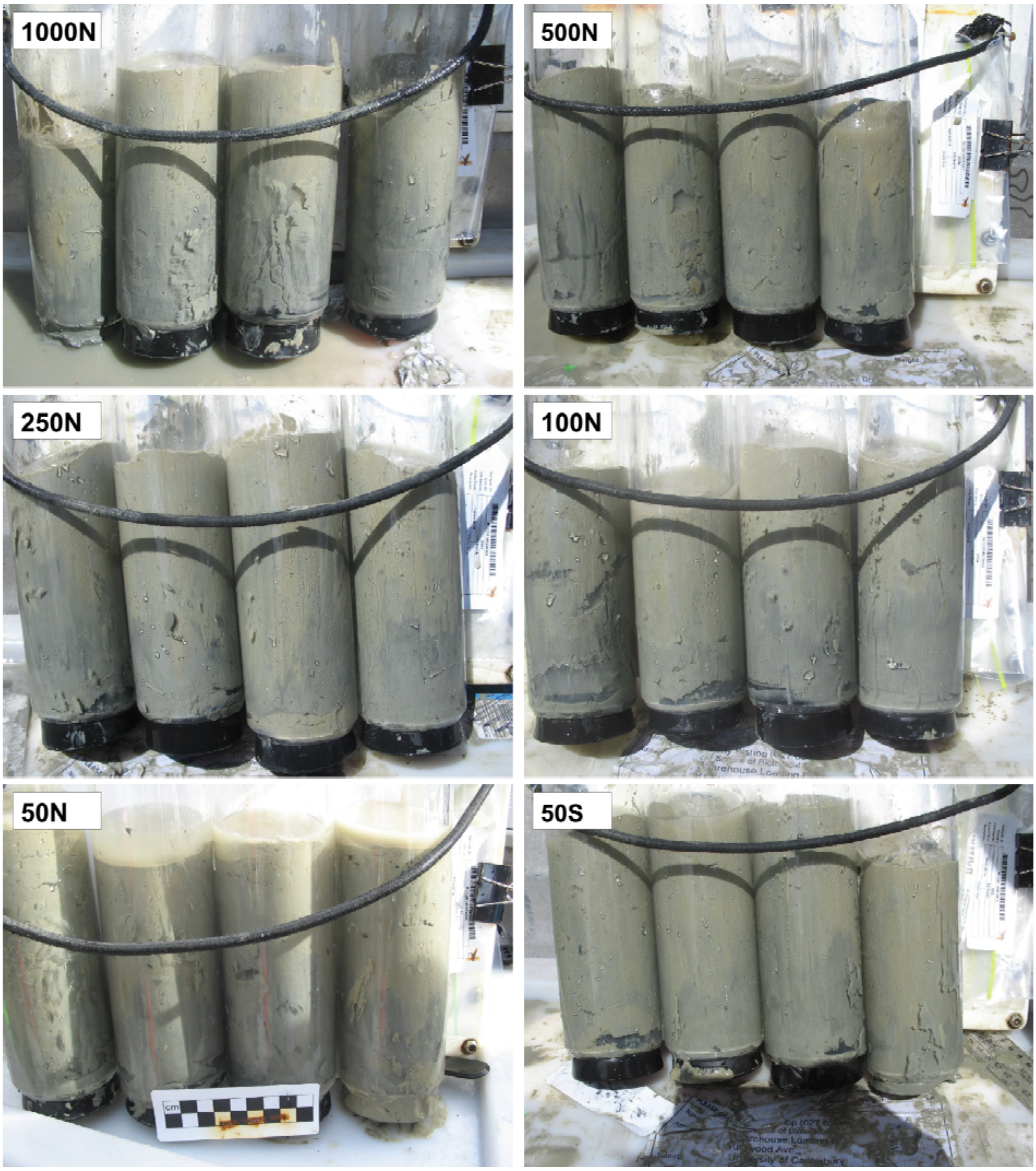
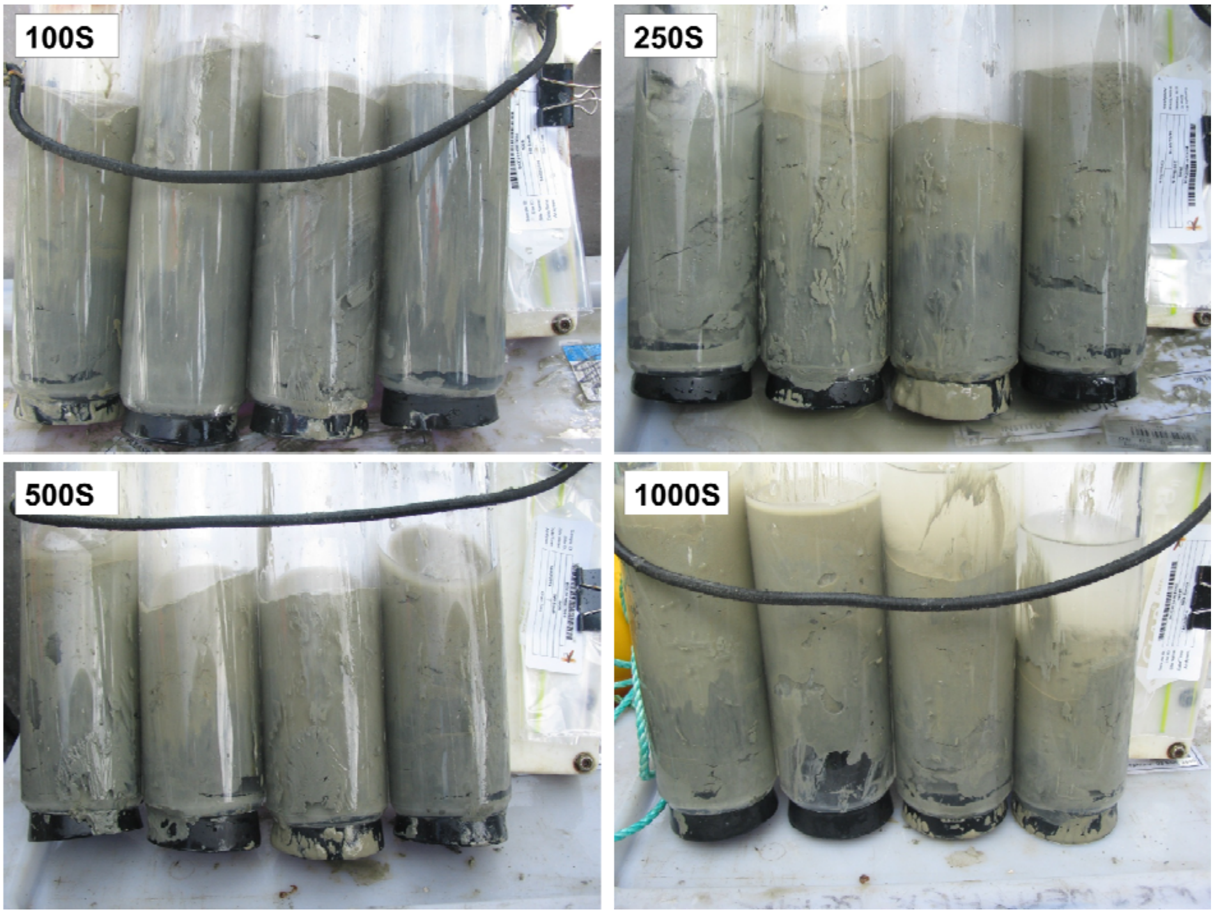
7. APPENDICES

Appendix 1. Photographic record of sediment core samples collected at each Akaroa Harbour benthic station, 14 February 2014.



Appendix 1. (*continued*)



Appendix 2. Physico-chemical properties of sediment samples. Results from laboratory analysis.

Grain size profile (g/100g)

	1000N	500N	250N	100N	50N	50S	100S	250S	500S	1000S
Gravel (> 2 mm)	0.7	0.3	0.6	0.8	1	0.9	< 0.1	0.5	0.3	0.5
Very coarse sand (1 mm–2 mm)	0.8	0.4	0.8	0.6	0.3	1.3	0.3	0.5	0.6	0.2
Coarse sand (500 µm–1.0 mm)	1.8	1.2	2	1	1	4.1	1.6	0.7	1	0.8
Medium sand (250 µm–500 µm)	11.2	5.8	5.5	11.1	8.4	15.6	10.2	6.1	8.1	8.3
Fine sand (125 µm–250 µm)	6.4	10.7	6.4	4.3	9.3	7.3	7	6.4	6.4	5.8
Very fine sand (63 µm–125 µm)	6.9	7.2	4.7	8	8.8	8	8.2	5.7	8.5	8.8
Silt and clay (< 63 µm)	72.1	74.4	80	74.2	71.1	62.9	72.7	80.1	75	75.7

Trace metals (total recoverable, mg/kg)

	1000N	500N	250N	100N	50N	50S	100S	250S	500S	1000S
Arsenic	7.5	7.2	7.4	7.5	8.3	8.3	7.8	6.9	7.4	7.2
Cadmium	0.047	0.044	0.037	0.044	0.039	0.04	0.046	0.039	0.038	0.041
Chromium	23	23	23	23	23	23	24	24	24	23
Copper	9.5	9.7	9.4	9.9	9.6	9.6	10	9.9	10.2	9.9
Lead	18.5	18.5	18.3	18.1	18.4	18.2	18.7	18.3	18.3	17.9
Mercury	0.061	0.042	0.041	0.042	0.042	0.042	0.048	0.053	0.038	0.051
Nickel	15.5	15.6	15.4	15.7	15.6	15.4	15.7	15.9	16.1	15.4
Zinc	62	62	61	60	60	64	62	63	62	60

Nutrients and organic enrichment

	1000N	500N	250N	100N	50N	50S	100S	250S	500S	1000S
Phosphorus (total rec., mg/kg)	900	900	880	910	900	950	920	900	860	910
Total nitrogen (g/100g)	0.11	0.11	0.12	0.11	0.11	0.11	0.13	0.11	0.11	0.1
TOC (g/100g)	1.14	1.03	1.05	1.08	1.01	1.11	1.07	1.01	1.01	0.98

Appendix 3. Raw infauna count data for the February 2014 benthic sampling survey.

	1000N			500N			250N			100N			50N			50S			100S			250S			500S			1000S		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Hydrozoa																														
Hydroida (thecate)					1	1	1		1	1	1						1				1						1			
Anthozoa																														
Virgularia gracillima	1	5	3	8	3	5	5	3	3	2	1		3	1			4	1	1	2		4	4	4	4		3	1		3
Scyphozoa								1																						
Nemertea																						1								
Nematoda				22	12	20	15	13	16		1		72	117	94	24	18	9	1	1		37	27	38	62	70	117	21	2	1
Gastropoda																														
Gastropoda (rissoid like)			2				4						1	1							1							6		
Gastropoda unid. Juv.																			1			1								
Turbonilla sp.													1											1						
Zeacolpus symmetricus	2	12	2	18	11	3	12	6	13	8	8	13	29	8	14	19	15	29	35	17	20	34	13	32	17	15	6	2	1	2
Bivalvia																														
Bivalvia indent.																					1									
Arthritica bifurca	7	1	4	2	1	6	7	1	2	1	3	7	3		5		11	2			2		1	4		1	2	1		
Theora lubrica												1															1			
Oligochaeta							4		1			2	18	4	1							2		2	5	3	12	25	2	1
POLYCHAETA																														
Orbiniidae																			1											
Phylo novazealandiae							1																1					1	1	
Paraonidae																														
Paraonidae	2	2		16	17	4	5	21	9	5	2	7	26	9	8	12	12	5	3	8	2	8	18	12	8	5	5	9		2

	1000N			500N			250N			100N			50N			50S			100S			250S			500S			1000S		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Aricidea sp.																								1						
Cossuridae																														
Cossura consimilis					1			1																1						
Spionidae																														
Prionospio sp.		1	1												2		1		2		1	1			1		1	2		5
Prionospio yuriel						1	3		2			3	4	2	4					1	1	9	5	1		3	4			
Capitellidae																														
Heteromastus filiformis		2	3	4	6				1				2	1	2	1	1	2				3	2	3	1	3	3	5	2	4
Heteromastus sp.																					2									
Maldanidae				1								1																		
Sigalionidae	2	2		1	1		1	1	1	2		1	2	3	2	3	2	1	1			2		2	1	1			1	
Hesionidae				1	1		1				2	1	1		1			2	1		4	1	1	1	1	1		2	2	1
Syllidae																									1		3			
Sphaerosyllis sp.				2		4	1						2	1	2													2		2
Nephtyidae																														
Aglaophamus sp.		1							1									1	2			1		1	1					
Lumbrineridae	1									1			2				1				1	1				1	2			
Cirratulidae	1	5		3	1	3	3	3	7	2	2		7	11	3	7	2	2	5	2	2	8	5	6	7	5	5	20	3	1
Terebellidae	1			5	3	3	2	2	1	1	1		2	1	1	3	1	4			1	5	3	1	4	1		4	1	2
Trichobranchidae																														
Terebellides stroemi							1			1	2	1						1			1				2			1		
Mysidacea		2		2	6	1	2					1					4	2				1		4				1		
Cumacea				1	1	1	1	1	1			3	2		2		2	1	1	1		5				8				2
Tanaidacea																						1								
Isopoda																														
Munna neozelanica																			1											

	1000N			500N			250N			100N			50N			50S			100S			250S			500S			1000S		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Munna schauinslandi										1						1														
Valvifera																			1			2								
Amphipoda																														
Caprellidae	1						1														2									
Haustoridae																														1
Lysianassidae	1																													
Oedicerotidae																		1	1			1								
Phoxocephalidae		2		4	3	5	1	3	2	3	1	3	4	1	4	3	1	2	2	1	1	3	4	5	2	3	3	2		
Amphipoda	3	1		9	1		3		3	4	1	1	1	3	1	2	4	1	5		1	6	3			1		1	2	1
Decapoda																														
Alpheus sp.							1			1	1																			
Macrophthalmus hirtipes	2		2	2	5	4	5	1	3		3		7	3	4	2	2	3	6	1	4	5	3	4	2	6	3		1	1
Nectocarcinus antarcticus													1																	
Pontophilus australis																	1													
Pontophilus sp.	1																													
Decapoda (larvae unid.)								1	1																					
Decapod indet.																1	1				1									
Holothuroidea																														
Heterothyone alba									1			2			1	3		1								1				
Pentadactyla longidentis									1																					

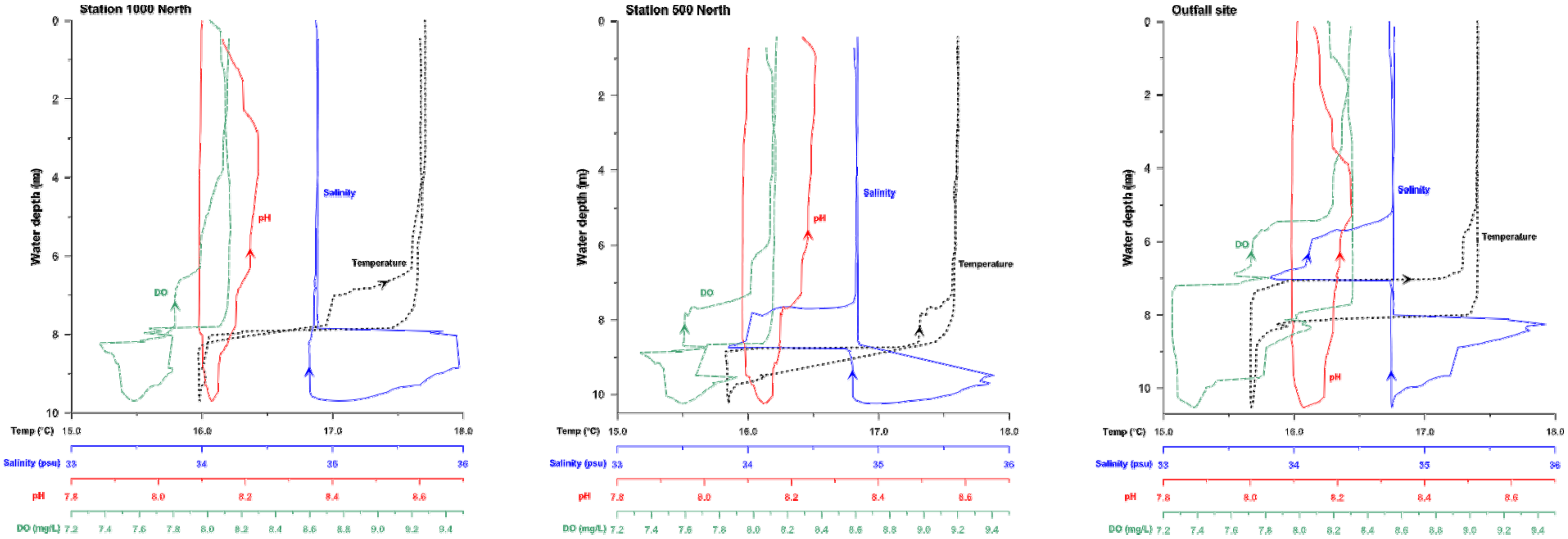
Appendix 4. Macrofaunal community indices for the infauna samples. Mean values for each station in bold blue font.

Station rep	N	S	J'	H'(loge)
1000N-A	25	13	0.905	2.32
1000N-B	36	12	0.851	2.12
1000N-C	17	7	0.963	1.87
1000N	**26.0**	**10.7**	**0.906**	**2.10**
500N-A	101	17	0.829	2.35
500N-B	74	17	0.833	2.36
500N-C	61	14	0.854	2.25
500N	**78.7**	**16.0**	**0.839**	**2.32**
250N-A	80	23	0.872	2.73
250N-B	58	14	0.759	2.00
250N-C	70	20	0.821	2.46
250N	**69.3**	**19.0**	**0.817**	**2.40**
100N-A	33	14	0.892	2.35
100N-B	29	14	0.900	2.38
100N-C	47	15	0.846	2.29
100N	**36.3**	**14.3**	**0.879**	**2.34**
50N-A	190	21	0.694	2.11
50N-B	166	15	0.471	1.28
50N-C	151	18	0.555	1.60
50N	**169.0**	**18.0**	**0.573**	**1.66**
50S-A	81	13	0.791	2.03
50S-B	84	19	0.813	2.39
50S-C	70	19	0.751	2.21
50S	**78.3**	**17.0**	**0.785**	**2.21**
100S-A	70	18	0.685	1.98
100S-B	34	9	0.700	1.54
100S-C	49	19	0.782	2.30
100S	**51.0**	**15.3**	**0.722**	**1.94**
250S-A	142	24	0.767	2.44
250S-B	90	14	0.809	2.14
250S-C	123	19	0.734	2.16
250S	**118.3**	**19.0**	**0.770**	**2.24**
500S-A	119	16	0.640	1.77
500S-B	128	17	0.624	1.77
500S-C	171	16	0.507	1.41
500S	**139.3**	**16.3**	**0.591**	**1.65**
1000S-A	106	18	0.780	2.25
1000S-B	18	11	0.968	2.32
1000S-C	29	15	0.940	2.55
1000S	**51.0**	**14.7**	**0.896**	**2.37**

Appendix 5. Trace metal concentrations (mg/kg) in tissues of green-lipped mussel (*Perna canaliculus*) replicates.

	Pinnacle Rock			Cape Three Points		
	A	B	C	A	B	C
Wet weight basis						
Arsenic	2.1	2	1.83	1.74	1.85	2.3
Cadmium	0.098	0.147	0.115	0.071	0.073	0.094
Chromium	0.13	0.09	0.11	0.18	0.06	0.08
Copper	0.74	0.81	0.64	0.44	0.52	0.63
Lead	0.131	0.15	0.154	0.142	0.132	0.166
Mercury	0.017	0.013	0.014	0.015	0.014	0.02
Nickel	0.24	0.29	0.4	0.44	0.31	0.28
Zinc	12.8	14.2	11	9.6	8.7	12.2
Moisture (g/100 g)	82	83	84	87	87	84
Dry weight basis						
Arsenic	11.7	11.8	11.4	13.4	14.2	14.4
Cadmium	0.54	0.86	0.72	0.55	0.56	0.59
Chromium	0.72	0.53	0.69	1.38	0.46	0.50
Copper	4.1	4.8	4.0	3.4	4.0	3.9
Lead	0.73	0.88	0.96	1.09	1.02	1.04
Mercury	0.09	0.08	0.09	0.12	0.11	0.13
Nickel	1.33	1.71	2.50	3.38	2.38	1.75
Zinc	71.1	83.5	68.8	73.8	66.9	76.3

Appendix 6. Water quality profiles for five locations along the sampling transect in Akaroa Harbour. Data collected 16:55–17:30 NZDT on 14 February 2014. Arrows indicate path representing ascending component of instrument deployment.



Appendix 6. *continued*