Wairoa Embayment:
Benthic habitats, environmental status and potential future threats

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Wairoa Embayment: Benthic habitats, environmental status and potential future threats

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Executive Summary

In 2000, the Auckland Regional Council (now the Auckland Council) commissioned NIWA to design a State of the Environment Monitoring Programme for the region's marine ecological resources (Hewitt 2000). The first tier of the agreed upon approach entailed spatially constrained but temporally detailed (2-3 monthly) monitoring at sentinel sites in important harbours (Tier I). The second tier involved spatially intense sampling of intertidal and near-shore (<20 m) subtidal areas with the objective of defining geospatial patterns of habitats and describing the ecological communities present at particular points in time (Tier II).

Here we report on a Tier II investigation of the Wairoa Embayment, in the southeastern portion of Tamaki Strait, encompassing the intertidal and subtidal habitats along the inner coastline between the tips of Whakakaiwhara and Koherurahi Points. This relatively small (21.2 km^2) and shallow (<4 m depth) embayment is protected from significant northeasterly swell by Pakihi and Ponui Islands to the northeast and Waiheke Island to the north. Water from a relatively large and predominantly rural catchment flows into the embayment via the Wairoa River. Suspended sediment concentrations in the Wairoa River appear to be high, and the lower Wairoa River channel has thick mangroves on both banks. Mangroves are present in other parts of the upper intertidal zone in the embayment also. There are several intertidal rocky reef outcrops, located mainly on the two flanks of the embayment (Whakakaiwhara and Koherurahi Points). There are extensive sand and shell-dominated intertidal flats in the embayment, particularly north of the Wairoa River channel, with slightly elevated muddiness in the southeastern portion. No seagrass habitat is apparent in the embayment at present.

As part of the Tier II survey, nearly 60 sites were sampled within the embayment, including intertidal rocky reefs and intertidal and subtidal soft-sediment habitats. Nineteen subtidal sites were sampled with a small benthic dredge, whilst the remainder were directly observed and quantified using a minimum of three replicate cores (for the soft-sediment sites) or quadrats (for the intertidal rocky reefs). Seven of the intertidal soft-sediment sites were assessed in terms of their suitability as potential Tier I ecological monitoring sites, with additional sampling conducted to facilitate this assessment (sediment heavy metal concentrations and 12 macrofaunal cores $site^{-1}$).

Multivariate analysis of rocky reef community data revealed that the differences between tidal height zones were much more pronounced than the differences between sites. The high tide zone was dominated by highly resilient species including the brown surf barnacles *Chamaesipho brunnea* and the small banded periwinkle *Austrolittorina antipodum*, along with an unidentified black cyanobacterial crust. In the mid-tide zone, the rock oyster *Saccostrea glomerata* was generally the dominant species, with spiny tube worms *Pomatoceros cariniferus* and algal species such as *Hormosira banksii* (Neptune's necklace) and *Corallina officinalis* (coralline turf) also common. In the lowest rocky intertidal zone, the abundance, richness and diversity of organisms was generally the greatest.

Macrofauna communities sampled in Wairoa's intertidal soft-sediment habitats were very different from macrofaunal communities of the adjacent subtidal zone. The ten species contributing most to the differences between intertidal and subtidal sites were *Nucula hartvigiana, Austrovenus stutchburyi, Prionospio aucklandica, Aonides trifida* and *Macomona liliana* (species that were dominant in the intertidal zone), Sigalionidae, *Paradoneis lyra, Torridoharpinia hurleyi* and *Theora lubrica* (species that were common in the subtidal zone), and *Heteromastus filiformis* (which differed in abundance between the intertidal and subtidal areas).

The intertidal soft-sediment communities contained significantly more individuals and species per core (i.e., higher abundance and taxonomic richness) than the subtidal soft-sediment communities. Groups of macrofauna such as bivalves, suspension feeders and deposit feeders were also significantly more abundant in the intertidal than subtidal. Although the subtidal soft-sediment habitats contained significantly fewer individuals and taxa, the individuals collected were very evenly spread among taxa (i.e., a high degree of evenness, low degree of dominance), resulting in greater Shannon-Wiener diversity index values relative to the intertidal zone.

The percentage of silt in the sediment was correlated with macrofaunal community composition in both intertidal and subtidal zones (Canonical Correspondence Analysis) and the extremely muddy nature of the subtidal environment (up to 84% mud and 30 cm thick in places) appeared to negatively influence the resident macrofauna. For example, the amount of functional redundancy inherent in the macrofaunal communities was low in the subtidal environment, reflected by significantly reduced TBI scores. The TBI is a trial State-of-the-Environment indicator based on macrofaunal taxonomic richness in seven particular functional trait groups. TBI scores were negatively correlated with sediment mud content, and the lowest TBI scores were recorded in the muddiest subtidal habitats.

Other observations of subtidal habitats in the Wairoa Embayment suggested that the area once supported high densities of large, suspension-feeding, structure-forming, coastal bivalves. Large *Cyclomactra ovata* and *Pecten novaezelandiae* shells were observed, in addition to shells of bed-formers such as *Atrina zelandica*, *Perna canalicula* and *Modiolus areolatus*. However, no live specimens from these taxa were observed and the shell material is now generally buried beneath several cm of mud.

In addition to the loading of sediments and the in-filling of the embayment, of which much has already occurred, the Wairoa Embayment faces several other potentially important environmental threats in the future. Some of these relate to the presence of a marine aquaculture farm in the southern part of the Embayment, which may result in the spread of non-indigenous species (Pacific oysters and Asian sea squirts, for example) and organic over-enrichment in the sediments (resulting in smelly black muds beneath the farm). At present, potentially problematic non-indigenous species that are established elsewhere in the greater Waitemata-Tamaki Strait region appear to be absent or in low abundance in the Wairoa Embayment. Development in the catchment, agricultural intensification and climate events could result in elevated runoff of organic matter and nutrients from the land. Overharvesting, particularly of cockle populations, which appear to be abundant at several sites in the Embayment, could result in the loss of mahinga kai and important sandflat ecosystem functions.

As a way of gauging environmental threats and tracking the changes in macrofaunal communities over time, we suggest that five of the seven potential Tier I ecological monitoring sites we assessed may be suitable for a new Wairoa ecological monitoring programme. The seven potential monitoring sites sampled met several important criteria for monitoring sites in that they were mid-intertidal, sand-dominated areas containing (1) a suitable abundance of macrofauna from a variety of functional trait and taxonomic groupings, and (2) several of the “monitored” macrofaunal taxa that are used in other Auckland Council ecological monitoring programmes. However, the multivariate community analysis suggested that a few of the sites were quite similar to one another, and that it might be cost effective to monitor as few as five of the sites (rather than all seven). In particular, two sites on the main sandflat north of the Wairoa River channel, two sites on the sandflat south of the Wairoa River channel, and one site in the potentially sediment-impacted Koherurahi Point flank of the Embayment (Sites 1-int, 3-int, 4-int, 5-int and 6-int) would form a robust monitoring programme.

1 Introduction

1.1 Background

In 2000, the Auckland Regional Council (now the Auckland Council, referred to hereafter as AC) commissioned NIWA to design a State of the Environment Monitoring Programme for marine ecology in the region (Hewitt 2000). The resultant nested design has three tiers for the monitoring of flora and fauna living in and on marine substrates. Tier I involves spatially constrained but temporally detailed (2-3 monthly) monitoring at sentinel sites in important harbours, aimed at detecting benthic ecological trends. Tier II involves spatially intense sampling of intertidal and near-shore (<20 m) subtidal areas with the objective of defining geospatial patterns of habitats and describing the ecological communities present at particular points in time. Areas to be sampled under the Tier II plan were prioritised by the AC and it was envisaged that re-sampling would occur every 16 years, allowing any large changes in habitats or communities to be identified. Tier III involves broad-scale habitat mapping with only limited benthic ecological community sampling in waters deeper than 20 m. The temporally intensive Tier I sampling was designed to provide information on the ecological relevance of changes observed in Tier II and III sampling, while the more extensive spatial coverage from Tier II would provide a broader spatial context to assist with the interpretation of Tier I sentinel site monitoring.

Elements of Tier I monitoring have been in operation since 1987, and have provided important feedback for resource management and State of the Environment reporting (Hewitt et al. 1994, Cummings et al. 2003, Hewitt et al. 2004b, Thrush et al. 2004). Tier II monitoring was initiated in 2003 in the Kaipara Harbour (Hewitt and Funnell 2005). This information has proved to be highly useful for the AC's management of aquaculture. In 2005-6, Tier II monitoring of Kawau Bay was undertaken (Chiaroni et al. 2005), and monitoring of Tamaki Strait was initiated in 2007 (Chiaroni et al. 2007). Both Kawau Bay and Tamaki Strait were chosen as high priority areas by the AC as they are diverse systems with a number of uses, and the pressures on them are forecast to increase.

It is important to note that the original design of Tier II monitoring focused on identifying sites along gradients of predicted anthropogenic activity. Sites were to be sampled intensively one year apart, to give a good spatial resolution of communities at each site and an indication of short-term temporal changes that could be compared to similar Tier I sentinel sites. Return sampling would then be carried out in another 16 years. However, by the time that sampling began in the Southern Kaipara, the AC found that its requirement for general ecological information about areas had increased. In light of this, Tier II objectives were shifted. Ecological habitat types and communities were to be compared across areas of interest by increasing spatial resolution of sampling within an area, decreasing spatial resolution at a site and removing temporal information. The description of habitats and communities for the area were to be developed in the context of biodiversity, ecosystem goods and services, and vulnerability to potential anthropogenic threats.

This change in the objective and sample design does not preclude the ability to determine if change has occurred when a return visit has been made, but does alter the way that change would be assessed. Assessment of change would be predominantly at a large scale, considering changes in communities and habitat types across the area as a whole, or within large subsections. Somewhat less effective site-by-site comparisons could also be made for sediment particle size, species and assemblages, using natural temporal variability apparent from the sentinel monitoring sites (Tier I) in the region to set limits on the magnitude of effects detected. Given the changes to the Tier II programme, this report focuses on determining general similarities between sites and the spatial distribution of habitat types and ecological communities, with the raw data necessary for specific site descriptions contained in GIS files.

1.2 Study area

This report is focused on the Wairoa Embayment, located in the southeastern portion of Tamaki Strait, Auckland. Although a few sites in Wairoa were sampled during the previous Tamaki Strait Tier II mapping project, the embayment was mapped in much greater detail here. The possibility of establishing up to seven long-term ecological monitoring sites in Wairoa was also explored.

Wairoa Embayment comprises part of the north-facing shore between Clevedon and Kawakawa Bay. The embayment is defined by Whakakaiwhara Point on the northwestern side and Koherurahi Point to the east (Figure 3.1). Wairoa Embayment and the entire area in the southeast portion of Tamaki Strait is shallow (generally 2-4 m below chart datum or less). Several islands protect the Wairoa Embayment from significant northeasterly swell (e.g., Pakihi and Ponui Islands to the northeast, Waiheke Island to the north), and it is listed as “sheltered” in the Coastal Explorer GIS classification system[1].

Wairoa is roughly 41% intertidal and 59% subtidal, with a total area of 21.2 km^2. The Wairoa River runs through a valley of farmed pasture land and empties directly into the Wairoa Embayment. The Wairoa River channel appears to be permanently open (there is little beach ridge barrier) and the land adjacent to the coast is classified mainly as Chenier plain (Coastal Explorer). Sediments near the river mouth are classified as muddy, although many different habitat types can be found along the entire length of the shoreline: rocky headlands, mudstone, shelly sand beaches, and sand beaches. There are mangroves near the upper shore in places. There is oyster farming activity near the intertidal-subtidal boundary south of the river outlet.

1.3 Human activities and environmental threats

The major potential threats to the ecology of the Wairoa Embayment are considered to be:

- Increased muddiness of the sediment, the spread of mud into presently sandy habitats, and decreased water clarity associated with climatic and land use changes.

[1] http://wrenz.niwa.co.nz/webmodel/coastal

- Subdivision and incremental development (roading, construction) in a presently rural landscape. Such activities would be associated with increased sewage, gardening-related and storm water contaminant inputs into the environment.

- Non-indigenous species (NIS). The sediments of the greater Waitemata-Tamaki Strait region have been invaded by as many as 66 marine NIS (Hayward 1997, Hayward 2008, Cranfield et al. 1998, Inglis et a. 2005). Marinas and shipping ports (e.g., Pine Harbour Marina, Port of Auckland) are often hubs or conduits for the transport of invasive propagules to new locations.

- Increased area of mangrove dominated habitats. Mangroves will tend to benefit from increased amounts of sediment input associated with climatic and land use changes.

- Effects of sea level rise. While hard to predict, increases in the mean level of the sea could result in reduction in the overall intertidal area and/or intertidal habitat diversity.

- Aquaculture. There is one oyster farm presently operating in the Wairoa Embayment. There is no information about whether the size of this farm will be expanded or whether additional farms will be established.

- Trampling of intertidal communities. Communities on intertidal rock platforms can be strongly affected by human foot traffic (Schiel and Taylor 1999, Chiaroni et al. 2007). On soft-sediment flats, human, horse and vehicle traffic also have impacts, although sediment movement and the small cryptic nature of sandflat organisms makes such impacts difficult to detect and measure.

- Anchoring, boat wakes and propeller wash. Boat anchors can cause considerable damage to areas with diverse epifauna. Several large boats are moored in the lower Wairoa River and must cross the Wairoa Embayment to access areas further afield. The very shallow nature of the Wairoa Embayment subtidal zone makes it vulnerable to propeller scars.

- Shellfish and finfish extraction. While the harvest of shellfish and finfish is not within the jurisdiction of the AC to manage, this type of extraction is still a threat to the communities in the Wairoa Embayment, both intertidally and subtidally. Impacts include the direct disruption of community structure via the removal of critical species and collateral damage caused by mobile fishing gear including nets and dredges (Thrush et al. 1998).

- Marinas. Development and maintenance (including associated dredging) of marinas has a number of potential impacts including location-specific changes to circulation patterns and increased contaminant levels (Turner et al. 1994). Wairoa Embayment does not appear to be well suited for the establishment of a marina, due to its broad shallow subtidal area.

2 General survey methods for intertidal habitats

In October 2010, the distribution and extent of different intertidal habitat types within Wairoa Embayment were determined visually whilst walking the area with a handheld GPS and with the aid of aerial photographs. In the field, waypoints were created and GPS tracks (run lines) were used to define the edges of distinct habitat types. Furthermore, photographs were captured, notes were recorded and sketches on laminated aerial maps were made to detail particular features (including muddy areas and stream and channel boundaries).

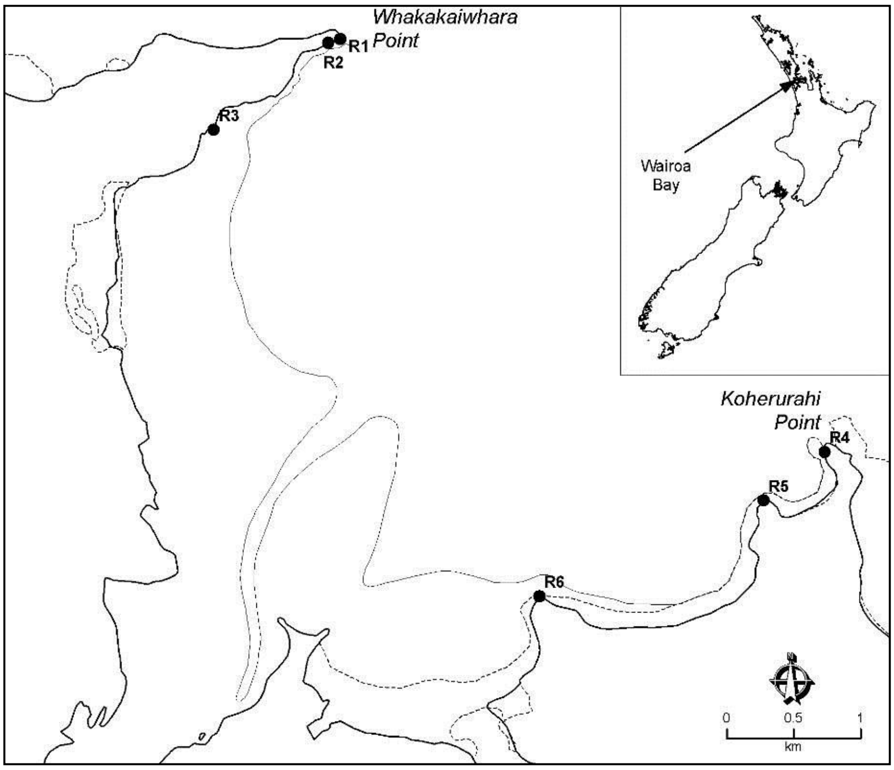
The GPS waypoints and tracks were overlaid onto aerial images (Google Earth). With the aid of all available qualitative and quantitative information (notes, photographs, sketches, samples), the intertidal area was characterised into major habitat types (i.e., mangroves, shell bank, shell hash, firm sand, mud). It is important to note that the entire embayment was not able to be accessed and mapped by foot (mainly due to dense vegetation and time constraints), so aerial photography (2008) and Google Earth imagery (2010) was used to assess the habitat types in some areas. All of the information gathered in the field and from aerial images was imported into ArcGIS 9 software and habitat maps with polygons representing main habitat types within Wairoa Embayment were generated.

3 Intertidal rocky reef sampling methods

Six intertidal rocky reef sites were identified using aerial photographs. Sites selected for monitoring were to be spatially distinct and representative of the range of rocky reef habitats present in Wairoa Embayment (Figure 3.1). For example, although sites R1 and R2 were very close to each other in geographical space, the characteristics of these habitats were distinct enough visually that we felt it was important to sample both.

Figure 3.1

Map of Wairoa Embayment displaying the locations of the rocky reef sites (R1-R6).



At each site, notes were taken describing the characteristics of the area which included assessing the substrate type and size (e.g., bedrock, sand, shingle, pebbles, cobbles, boulders with reference to the Wentworth scale of particle size), slope (e.g., flat, gently sloping, steep), catchment practices (e.g., pastoral, forestry) and anthropogenic influences (e.g., drains and pipes, evidence of trampling, boat ramps). Furthermore, photographs were captured of the surrounding catchment, quadrats and shore profile (see section 8.2).

A tape measure transect was placed perpendicular to the shore, starting at the top of the high tide zone (0 m) and running to the bottom of the low tide zone. A compass bearing was recorded and a GPS position was taken at 0 m to mark the site position (Table 3.1). Three zones (high, mid and low tide) were determined based on elevation and faunal and floral zonation patterns. Within each zone, three 0.25 m^2 quadrats were surveyed to capture the major habitats present. At some sites, it was not possible to access the low tide zone (mainly due to rough weather and sea conditions), so notes on the dominant species were taken from a distance. The position of each quadrat along the transect tape (m) was noted and the percent cover of flora and fauna within each quadrat was recorded. Furthermore, the number and dimensions of rock pools near the transects (within 5 m either side) were recorded. We ranked the rock pools as small, medium or large (longest dimension <30 cm, 30-100 cm and >100 cm, respectively) and depth was recorded as being shallow, medium or deep (< 10 cm, 10-25 cm and > 25 cm, respectively).

Table 3.1

Site location, name, GPS coordinates and the compass bearing of transects sampled at intertidal rocky reef sites R1-R6.

Site Location	Site Name	Latitude	Longitude	Compass Bearing
Whakakaiwhara Point (Duder Regional Park) 1	R1	36 54.0534	175 05.9465	082°
Duder Regional Park 2	R2	36 54.0665	175 05.8882	147°
Duder Regional Park 3	R3	36 54.4303	175 05.3229	143°
Koherurahi Point	R4	36 55.6673	175 08.4298	246°
Mataitai Point	R5	36 55.8686	175 08.1290	290°
Kahuru Point	R6	36 56.2764	175 07.0138	351°

4 Intertidal soft-sediment sampling methods

Sixteen intertidal soft-sediment sites in the Wairoa Embayment were visited to provide (1) general physical and biological descriptions of the Embayment's various soft-sediment habitat types and (2) to provide a context against which changes over time can be compared. For example, changes in site characteristics over time such as an increase in muddiness or disturbance by eagle rays may help explain natural variability in macrofaunal community composition (e.g., Townsend 2010). Description of biological features focused on the presence and abundance of ray pits, gastropods, tube worms, crabs burrows and adult shellfish (e.g., cockles, pipi and wedge shells). Physical features assessed included the type of sediment (e.g., firm sand) and the presence of ripples, the presence and depth (mm) of a surficial mud layer and the species composition of the shell hash. Furthermore, land-use around the site and the presence of man-made structures was also noted.

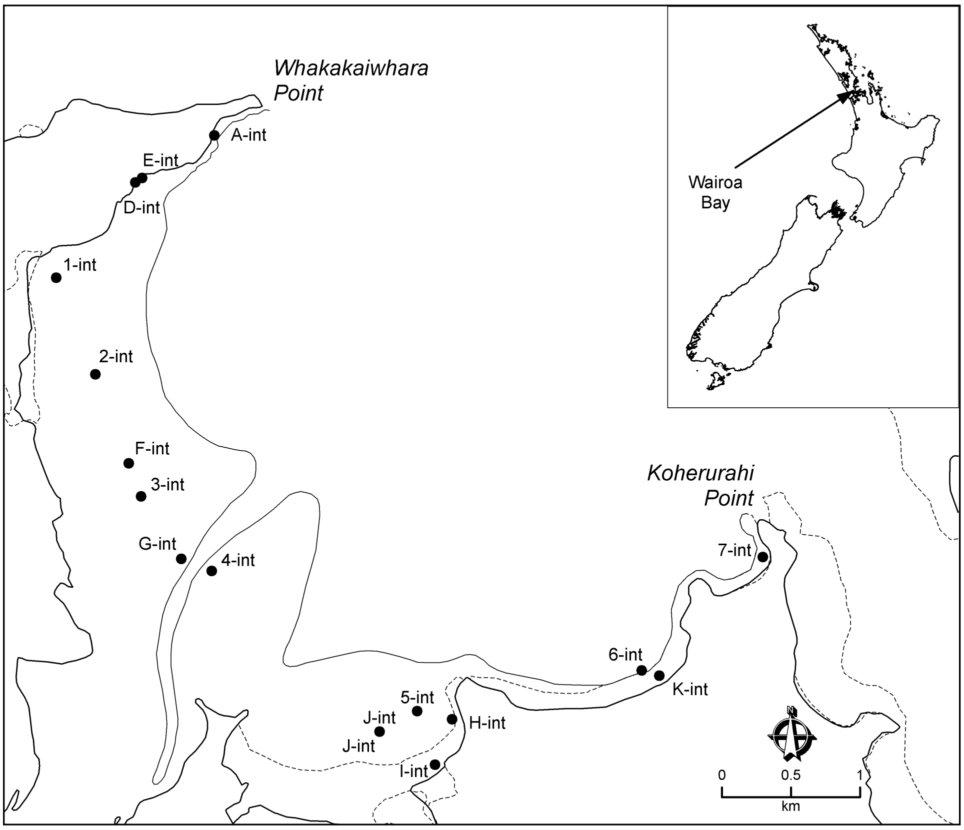
4.1 Sites to be considered for long-term monitoring

The AC expressed interest in establishing long-term ecological monitoring sites in intertidal habitats of the Wairoa Embayment. Seven of the sixteen sites we visited were considered as potential future monitoring sites, with the following selection criteria: (1) the seven sites were to be dispersed across the entire embayment, with individual sites positioned in areas that would reflect the quality of water/sediment discharge from the land, (2) each individual site was to be a sand-dominated, un-vegetated intertidal habitat, lacking mats formed by high densities of tube-dwelling polychaetes, and (3) each site was to be representative of a broad area of intertidal habitat in the portion of the Wairoa Embayment being sampled. Sites were also selected to maximize the potential of detecting environmental change using the methodologies of Tier I ecological monitoring programmes (e.g., Townsend 2010).

The seven potential monitoring sites were visited in October 2010 (Sites 1-7, Figure 4.1, Table 4.1). Sites 1-int to 5-int were defined to be 9,000 m^2 (100 m × 90 m), whilst Sites 6-int and 7-int were slightly smaller (6,300 m^2; 90 m × 70 m) due to smaller width of the intertidal zone in those locations.

Figure 4.1

Map of the Wairoa Embayment displaying the locations of potential monitoring sites (1-int to 7-int) and additional habitat mapping sites (A-int, D-int to K-int).



At each potential monitoring site, a fluorescent stake was positioned and a GPS waypoint was recorded to mark the lower left corner of the site[2]. Each site was divided into 12 equal sectors and one macrofauna core sample (13 cm diameter, 15 cm depth) was taken from a random location within each sector (n=12 replicate macrofauna cores). These samples were sieved over a 500 µm mesh, preserved with 70% isopropyl alcohol and stained with Rose Bengal prior to processing. The macrofauna were then sorted, and the taxa identified to the lowest practical level, enumerated and stored in 50% isopropyl alcohol (as described in Section 6.1).

At six random locations within the site, two small sediment cores (2 cm deep, 2 cm diameter) were collected, one to determine sediment grain-size and organic matter content and the other for chlorophyll *a* analysis. Cores from the six locations within each site were pooled and kept frozen in the dark prior to analysis (as described in Section 6.2 and 6.3).

To establish a baseline indication of stormwater-associated contaminant levels present in the sediments at the potential monitoring sites, 500 g of sediment was collected from each site for analysis of heavy metals (copper, lead and zinc). Analytical details are provided in Section 6.4.

[2] "Lower" refers to the side closest to the sea (i.e., lower intertidal) and "left" refers to the corner on the left-hand side whilst facing the land.

Table 4.1

Site locations, names and GPS coordinates of the seven potential intertidal monitoring sites sampled.

Site Location	Site Name	Latitude	Longitude
Adjacent to North Road 1	1-int	36 54.7503	175 04.9746
Adjacent to North Road 2	2-int	36 55.1250	175 05.1773
Adjacent to North Road 3	3-int	36 55.6000	175 05.4137
Pouto Point	4-int	36 55.8851	175 05.7677
Kauri Bay	5-int	36 56.4163	175 06.7875
Wairoa Bay	6-int	36 56.2350	175 07.8792
Mataitai Point Bay	7-int	36 55.7786	175 08.4562

4.2 Additional sites for habitat mapping

To increase the spatial coverage of sampling in intertidal soft-sediment habitats of the Wairoa Embayment, nine additional sites were sampled. These sites were chosen not necessarily for their “representativeness” but rather to encompass the variability in the types of soft-sediment habitats in the Embayment. These additional sites were also chosen for their potentially differing degrees of anthropogenic impact. The names and positions of the additional nine sites are given in Table 4.2 and on Figure 4.1.

At each of the additional sites, observations of both biological and physical characteristics were noted, photographs were captured, and the sediment was quantitatively sampled. At each site, three macrofauna cores (13 cm diameter, 15 cm depth) were randomly collected. Small sediment cores (2 cm deep, 2 cm diameter) were collected from six random positions per site for grain-size, organic matter and chlorophyll *a* content and bulked prior to analysis (i.e., one “average” value per site). As previously described, the macrofauna cores were sieved, preserved in IPA, sorted and identified and the sediment collected from the smaller cores were pooled and kept frozen and in the dark until analysis was conducted.

Table 4.2

Site locations, names and GPS coordinates of the additional intertidal habitat mapping sites.

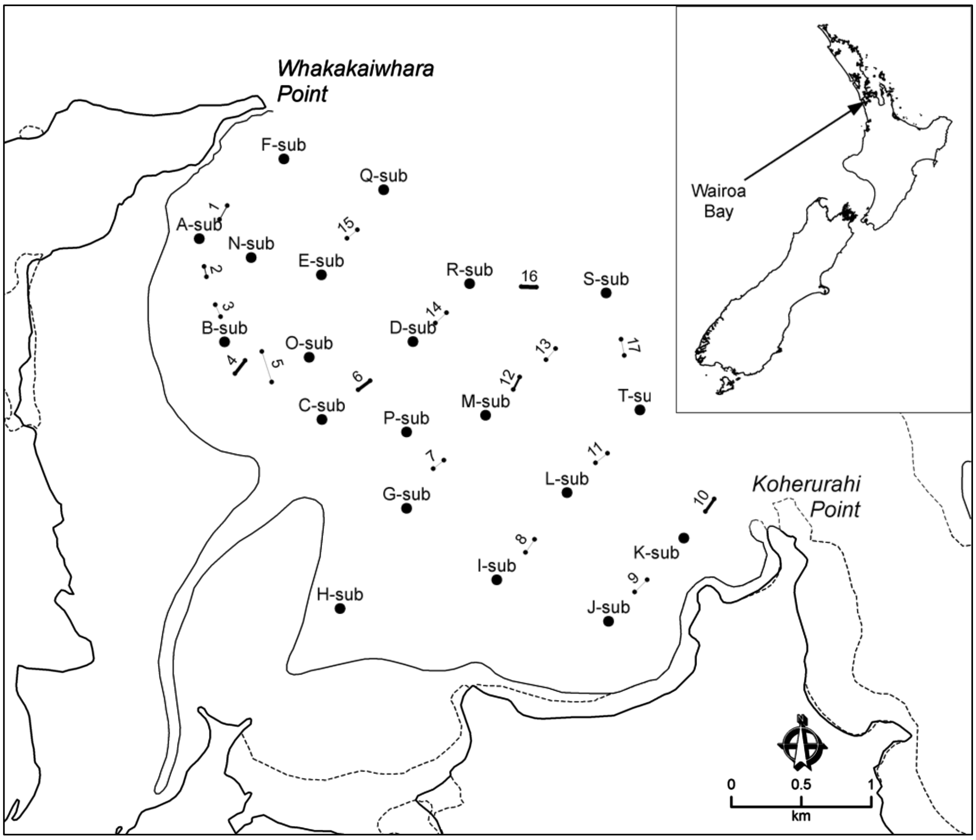
Site Location	Site Name	Latitude	Longitude
Duder Regional Park 1	A-int	36 54.1775	175 05.7296
Duder Regional Park 2	D-int	36 54.3506	175 05.3823
Duder Regional Park 3	E-int	36 54.3688	175 05.3488
Adjacent to North Road	F-int	36 55.4713	175 05.3506
Main Channel (Pouto Point)	G-int	36 55.8410	175 05.6176
Kauri Bay	H-int	36 56.4448	175 06.9593
Kauri Bay	I-int	36 56.6246	175 06.8806
Kauri Bay	J-int	36 56.4994	175 06.6065
Wairoa Bay	K-int	36 56.2540	175 07.9651

5 Subtidal soft-sediment sampling methods

Unlike intertidal areas (where one can walk long distances during low tide periods and observe the spatial configuration of habitats), it was impossible to directly observe habitat transition zones in the subtidal realm. The highly turbid seawater in the Embayment limited the effectiveness of underwater camera deployments, and the shallow mean water depth prevented us from using side-scan sonar to delimit habitats. Thus a regularly spaced grid of sampling points was used (Figure 5.1, Table 5.1), with benthic sledge transects running between the discretely sampled sites.

Figure 5.1

Map of the Wairoa Embayment displaying the locations of the subtidal sites (dots) and additional benthic sledge sites (lines)



5.1 Discrete sampling of subtidal sites

Twenty one subtidal sites were sampled by scuba divers. The sites were spread evenly across the Wairoa Embayment, with distances between nearest neighboring sites of approximately 500-1000 m. At each subtidal site, four large cores of sediment (10 cm internal diameter x 15 cm deep) were collected for later analysis of macrofaunal communities. In addition to the macrofaunal cores, six smaller cores of sediment (3 cm internal diameter x 2 cm deep) were collected and divided equally into two bulked sample containers for later analysis of sediment grain size, organic matter and chlorophyll *a* content. Divers also made observations of general habitat characteristics and features at each site, taking photographs when possible. Photographs were not effective for documenting habitat characteristics in most cases, as visibility was limited (10 - 100 cm).

5.2 Transect sampling of subtidal sites using a benthic sledge

To increase the extent of the sampling area in the subtidal portions of Wairoa Embayment, a small benthic sledge (similar to a scallop dredge) was towed for distances of approximately 100 m in the gaps between discretely sampled subtidal sites. Seventeen benthic sledge tows were completed, with the locations determined based on diver observations at the discretely sampled sites (Figure 5.1). In essence, the sledge was towed in areas where the possibility of detecting habitat transition zones was greatest. With a net mesh size of 4-5 mm, the dredge was capable of detecting the presence of large epifauna (e.g., horse mussels, mytilid mussels, scallops, star fish, crabs, shrimps, etc.), whilst smaller macrofauna and highly mobile organisms (fish) were not likely to be sampled effectively by this method.

After each tow, the contents of the benthic sledge were rinsed thoroughly and emptied into a bin. The amount of shell hash collected with each dredge tow was quantified (by volume, litres) and the shell material was photographed. All large epifauna observed were noted, and several photographs of individual animals were taken. None of the material from the dredge tows was saved for subsequent analysis due to the preponderance of non-living shell material (and its sheer volume).

6 Sample processing methods

6.1 Benthic macrofauna analysis

All macrofaunal samples were identified in the NIWA Hamilton biology laboratory with taxonomy resolved to genus and species whenever possible. Many groups are not well described in New Zealand and resolution to family (or even phylum) was reasonably common. However, in such cases, care was always taken to differentiate forms that appeared to be distinct morpho-species even if the exact taxonomic names were not known. Furthermore, the most common bivalve species, *Austrovenus stutchburyi* and *Macomona liliana*, were placed into size classes according to longest shell dimension (mm). Bivalves in each of the following size classes were tabulated: <1 mm; 1-5 mm; 5-10 mm; 10-20 mm; 20-30 mm; 30-40 mm and >40 mm. Classes are consistent with those used in other Auckland regional monitoring programmes.

6.2 Sediment grain size and organic matter content

Sediment core samples were homogenised, and 5 g subsamples were taken for analysis of grain size and organic matter content. The subsample for sediment grain size analysis was pre-treated with hydrogen peroxide to remove organic matter that can bind particles together. Wet sieving was then used to separate the subsample into size fractions: gravel (particles >2000 µm); very coarse + coarse sand (2000-500 µm); medium sand (500-250 µm); fine + very fine sand (250-63 µm); and mud (particles <63 µm). The mud fraction was subjected to pipette analysis to separate silt (63-9 µm) from clay (<9 µm). All sediment particle size fractions were oven-dried (60^{o} C) until a stable weight was achieved, with particle size distribution determined by the percentage dry weight of each sediment fraction.

The subsample for organic content analysis was dried at 60 °C to a constant weight and combusted for 5.5 hours at 400 °C. Organic content was determined by the difference in the weight of the subsample before and after combustion (% loss on ignition).

6.3 Sediment chlorophyll *a* content analysis

All samples for sediment chlorophyll *a* content analysis (Chl*a*) were kept frozen and in the dark until analysis. Analysis was completed within one month of sample collection. Prior to analysis, samples were freeze dried (to standardize water content and avoid dilution effects), weighed, and homogenized. Sediment Chl*a* was then determined spectrophotometrically after extracting pigments from a 0.5 g subsample by boiling in ethanol and using an acidification step to separate degradation products (e.g., phaeophytin) from Chl*a*. Concentrations of both Chl*a* and phaeophytin (µg per g of sediment) were recorded. Sediment Chl*a* concentration is indicative of the standing stock of fresh food material (microphytobenthos, newly deposited phytoplankton), whereas phaeophytin is indicative of degraded microalgal detritus.

6.4 Sediment heavy metals analysis

Analysis of total recoverable Cu, Pb and Zn in the <500 um sediment fraction was performed on sediment samples collected at 7 intertidal sites (Section 4.1, Table 4.1) using a strong acid digestion in *aqua regia* (HCl/HNO3) at 100–110˚ C. The tests were performed at R J Hill Laboratories Limited (Hamilton, New Zealand) in accordance with International Accreditation New Zealand (IANZ) standards, with detection limits of 2 mg/kg dry wt for copper, 0.4 mg/kg dry wt for lead, and 4 mg/kg dry wt for zinc. A summary of the methods and quality control information for the analysis is provided in the Appendix section.

7 Statistical analysis methods

7.1 Rocky reef communities (intertidal)

The analysis of intertidal rocky reef data was based on data collected from each tidal zone (upper, middle, lower) at each site (R1-R6). The abundance (total number of total individuals), richness (number of distinct taxa), and diversity (Shannon-Weiner H') of communities from each zone at each site were compared, and top three most abundant taxa from each zone at each site were determined.

The similarity of rocky reef community composition among sites and tidal zones was assessed using non-metric multidimensional scaling (MDS), based on a Bray-Curtis dissimilarity matrix developed from square-root transformed data (PRIMER v.6 software). A two-way analysis examining the effects of Site and Tidal Zone (ANOSIM) was used to test for the significance of differences in community composition among sites and zones. The SIMPER procedure was used to examine the contributions of particular taxa to the similarities/differences among sample types.

7.2 Soft-sediment macrofaunal communities (intertidal and subtidal)

To accurately compare macrofaunal communities among all of the soft-sediment sites sampled, we first had to ensure that the data were standardized according to sampling effort and core size.

There was a greater sampling effort at the proposed ecological monitoring sites (12 replicates per site) than there was at the regular mapping sites (3 or 4 replicates for the intertidal and subtidal sites, respectively). Therefore, we randomly selected 3 of the 12 ecological monitoring replicates for analysis. At all 37 soft-sediment sites, macrofauna data were then averaged and standardized to an area of 100 cm^2. [3]

The densities of all macrofauna species present per site were tabulated. In addition, total abundance, taxonomic richness and Shannon-Wiener diversity values were calculated. The richness of suspension and deposit feeding taxa at each site was noted because turbidity and muddiness (environmental issues in Wairoa Embayment) can affect the success of these two groups.

Differences in macrofaunal community structure among sites were assessed using multivariate statistical techniques. First, the SIMPER procedure in Primer v.6 was performed to help us determine the species most responsible for contributing to the differences among sites (based on Bray-Curtis dissimilarities developed from square-

[3] Three intertidal cores will sample an area that is slightly larger than the area sampled by four subtidal cores (398 cm^2 vs 314 cm^2); 100 cm^2 is the approximate area of one "average" core of sediment.

root transformed data). We also used SIMPER to comprehend the broader differences in community composition between intertidal and subtidal areas.

Nonmetric Multi-Dimensional Scaling (MDS, Primer v. 6) plots were created to help us visualise the differences among sites, while the clustering procedure in Primer v.6 was used to determine the significance of site groupings. Like the SIMPER analysis described above, both the MDS and cluster plots were based on Bray-Curtis dissimilarities developed from square-root transformed data. There was one intertidal site (A-int) that appeared to be very distinct from all other sites[4], therefore analyses including and excluding A-int were performed.

Canonical correspondence analyses (CCA) were performed for the intertidal and subtidal regions separately. CCA was used to demonstrate the relationships between environmental variables (e.g., silt, Chl*a* content) and macrofaunal community composition. A Monte Carlo permutation test was first performed to select environmental variables that significantly explained the variability in macrofaunal abundance (α = 0.05 after 1999 permutations). The variance explained by the CCA model was calculated as the sum of eigenvalues axes (Borcard et al. 1992), based on square-root transformed macrofauna data with the rarest taxa (<1% of overall abundance) removed.

Sites that are close to each other in geographical space have the potential to be more similar with regards to macrofaunal community composition. To test this hypothesis, we plotted the geographical distances between all possible site pairs versus the Bray-Curtis dissimilarity values for all possible site pairs. The geographical distances between sites (as the crow flies, in meters) were obtained from the GIS, whilst the Bray-Curtis dissimilarities were obtained from the SIMPER analysis (described above).

State of the Environment indicators

A functional traits based index called the TBI (Lohrer and Rodil 2011, Hewitt et al. 2012) was calculated using macrofaunal data from all of the soft-sediment sites. The TBI is an index based on the summed taxonomic richness in seven particular trait groups ("SUMactual" scores), and a parameter that varies with sample size ("$SUMmax_n$") (Lohrer and Rodil 2011) [5].

The TBI index, which was developed for intertidal sites in the Auckland Region but is theoretically more broadly applicable, has been shown to respond to gradients of mud and heavy metal contaminants (Cu, Pb, Zn). Although this is the first time the TBI index has been calculated for subtidal sites, the broad variation in mud content encompassed by the Wairoa sites provided an opportunity to test the response of the TBI in new areas. The TBI was plotted versus sediment mud content to test whether or not TBI index values (which indicate functional redundancy and resilience potential) would decline with increased mud percent using a combination of intertidal and subtidal sites.

The Benthic Health Model (BHM, Anderson et al. 2002, 2006) was applied to the seven intertidal sites for which there was sediment heavy metal contaminant information (sites

[4] This site was not technically a "soft-sediment" site; it had stones and gravel and no fine particles, Chl*a* or organic material.
[5] Corresponding to our sample size of 3, the $SUMmax_n$ value used was 133.56 (see Table 2 of Lohrer and Rodil 2011).

1-int to 7-int). By entering macrofaunal community data into the model, CAPmud and CAPmetals scores were generated. The CAP scores were then plotted against sediment mud and heavy metal content data (PCA1.500 was used as an index of contamination by Cu, Pb and Zn). Model output from the seven Wairoa sites was compared to other Auckland area sites that have been investigated during the Regional Discharges Project.

7.3 GIS maps

Maps of habitat characteristics were produced for the entirety of the Wairoa Embayment by combining two separate data interpolations: one using data from intertidal sites only, and one using data from subtidal sites only. The habitat characteristics mapped were the mud, sand and shell hash contents of the sediment along with sediment pigments (chlorophyll *a* and phaeophytin) and total organic matter content.

The sharp transition located at the intertidal-subtidal boundary on these maps results from combining the two separate data interpolations. This transition will be more gradual in reality. However, we believe that the techniques we used offered the best presentation of the spatial variability in habitat characteristics within the Wairoa Embayment as a whole. Dummy variables were used in the Wairoa River channel area, as no data were available in that location. The Wairoa River channel area was known to be quite muddy, despite its close proximity to the sandy intertidal sites 3, 4 and G; without dummy variables, the interpolations would have misrepresented this fact.

Maps of macrofaunal distributions, using the variables of total density, richness and diversity per site, were produced. Map layers were also created for twelve individual taxa that were reasonably abundant, made substantial contributions to the Bray-Curtis dissimilarities between intertidal and subtidal sites, or were known to be ecologically or culturally important (e.g., *Austrovenus stutchburyi, Paphies australis, Macomona liliana*). Taxonomic richness in two functional trait groups (deposit feeders and suspension feeders were also mapped.

7.4 Soft-sediment habitat map based on community data

There is a tendency to make habitat maps based strictly on physical characterisations of the environment, particularly when the biological characteristics are cryptic (i.e., small, infaunal, underwater). However, one of main reasons for collecting ecological community data is to better map the biology and to recognize that ecological community types can vary substantially within single physical classifications.

Prompted by the observed differences in the spatial distributions of abundant taxa within the Wairoa Embayment, we were able to identify 8 reasonably distinct community types (4 intertidal and 4 subtidal). The differences among the purported habitat types were tested statistically by combining the macrofauna data from the sites within them and using ANOSIM with pairwise comparisons. Unlike some of the other harbours where Tier II mapping surveys have been undertaken (e.g., Kaipara Harbour), there were no obvious bathymetric or physical demarcations within the Wairoa

Embayment that could be used to define habitat boundaries. Thus the shapes on the map were drawn by hand (statistically similar sites were encircled). Nevertheless, the methodology used was otherwise similar to that used in Figure 17 of Hewitt & Funnell (2005) for the Kaipara Harbour.

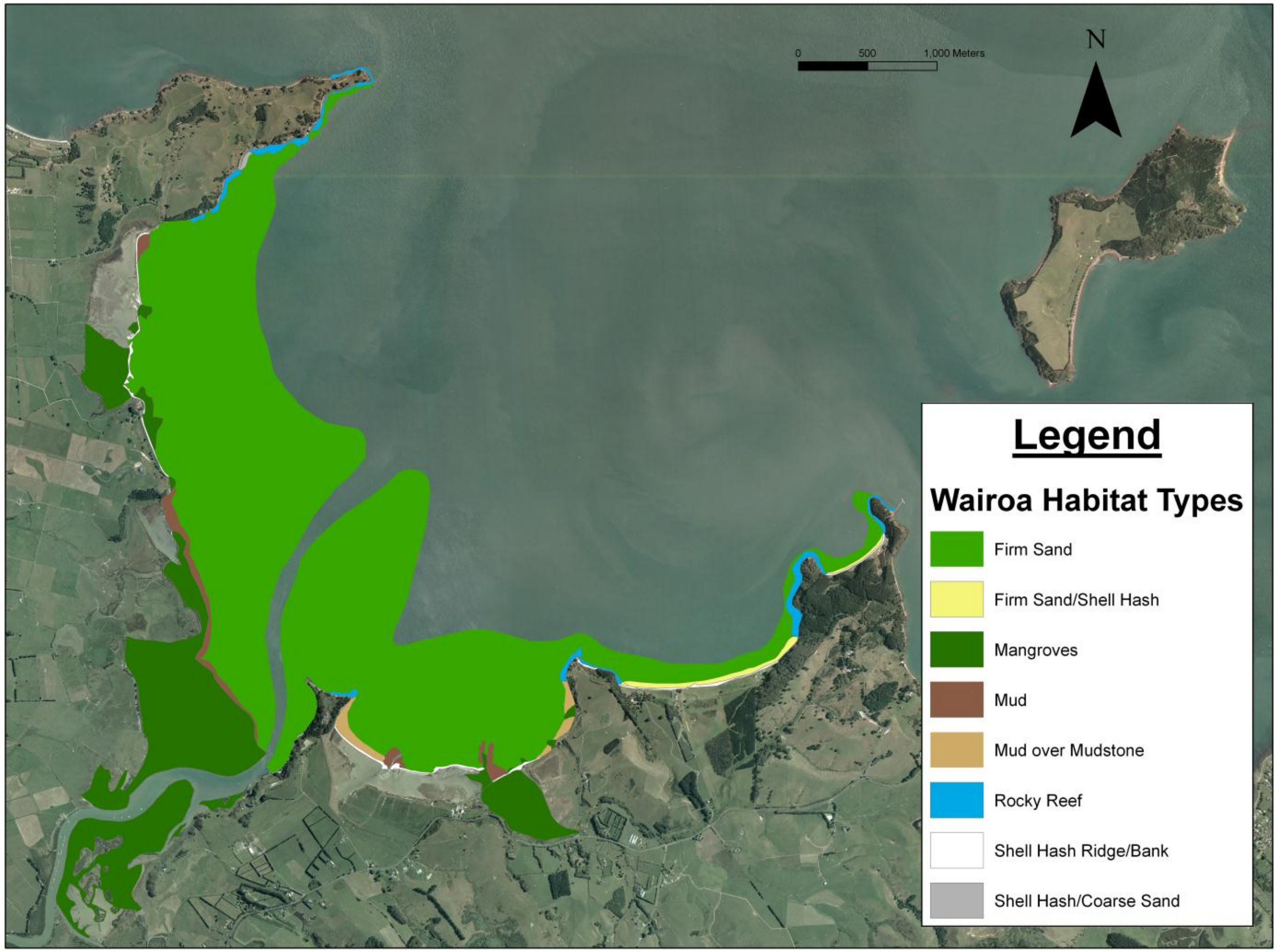
8 Results-General findings and habitat descriptions

8.1 Variety and spatial arrangement of intertidal habitats

A map showing the various types of intertidal habitats throughout the entirety of the Wairoa Embayment, from Whakakaiwhara Point to Koherurahi Point, was developed from the observational data and field notes collected during our site visits (Figure 8.1). The dominant middle and lower intertidal habitat type was firm sandy sediment, with substantial area of mangrove habitat on both banks of the Wairoa River. Mangroves were present in other parts of the upper intertidal zone in the inshore part of the embayment also, whilst there were rocky intertidal reef areas on both flanks of the embayment. No areas of soft-sediment habitat containing seagrass or algal stands were observed.

Figure 8.1

Results of a walking survey of intertidal habitat types in the Wairoa Embayment. GIS shapes indicating habitat types (see colour legend) are overlain atop Google Earth imagery. The Wairoa River can be seen in the bottom left corner of the map. Fine sand habitats dominant the intertidal zone of Wairoa Embayment in terms of area.



8.2 Descriptions of the intertidal rocky reef sites

The six rocky intertidal sites surveyed spanned the types of rocky reef habitats present within the Wairoa Embayment (Figure 3.1). Generally the catchments adjacent to the sites were forested and/or farmed, and all of the sites appeared to be readily accessible by boat or on foot. Biological zonation patterns present at each site were relatively similar between sites, with the high tide zones being dominated by barnacles, small banded periwinkles and black cyanobacterial crusts. The mid-tide zone was dominated by rock oysters and barnacles, and the low tide zone was dominated by large algal species and various other species including gastropods. Below are detailed descriptions of each site visited moving from north to south (R1-R3 on the Whakakaiwhara Point side and R4-R6 on the Koherurahi Point side of the embayment).

Site R1, located on the northwestern flank of Wairoa Embayment at Whakakaiwhare Point (Table 3.1), is a rough rocky outcrop that is gentle to medium (at low tide) sloping (Figure 8.2). The site was situated at the base of a steep grass covered cliff with large jutting rocks and a Pohutukawa tree hanging over the rocky intertidal area. The surrounding catchment forms part of the Duder Regional Park, a recreational coastal farm park managed by the AC, and is primarily pasture with isolated pockets of remnant native bush. The transect had a bearing of 082° and was relatively short, with 25 m surveyed in total. Clear physical zones were identified: high tide zone 0 – 12.2 m, mid-tide zone 12.2 – 18.5 m, and low tide zone 18.5 – 25 m (water’s edge).

Figure 8.2

Photograph taken of site R1 displaying the gentle gradient from the high tide zone (see person in red jacket) to the low tide zone (foreground). The vertical banding of the oysters in the steeper mid-tide zone can also be seen.

Zonation bands seemed to generally correspond with the physical zones defined, based on elevation. The high tide zone was very broad (approximately 19 m) compared to the other zones defined. This zone was characterized by few species that have adapted to living in this harsh environment. Much of the area surveyed was bare rock (up to 99% in one quadrat) with some encrusting black cyanobacteria and a low abundance of the small banded periwinkle (*Austrolittorina antipodum*) (Figure 8.3). The major structuring organism present was the brown surf barnacle (*Chamaesipho brunnea*) with an average percent cover of 68% when present in the quadrats.

Moving down to the mid tide zone, species diversity was greater but the main species structuring this zone was the rock oyster (*Saccostrea glomerata*) covering about 48% of the area on average (Figure 8.3). Other species recorded but with lesser abundances included *Chamaesipho brunnea* (5-20%) and *Corallina officinalis* (1-5%). Other common species present that had a percent cover of less than 1% (within the quadrats) included the snakeskin chiton (*Sypharochiton pelliserpentis*), the oyster borer (*Haustrum scobina*) and plicate barnacles (*Epopella plicatus*).

Moving down to 18.5 m along the transect, the low tide zone consisted of a number of different species, but was dominated by *Corallina officinalis* (maximum of 60% in one quadrat surveyed) (Figure 8.3). Other algal species present included *Codium* sp., *Hormosira banksii* and coralline paint. Gastropods were also well represented and included the predators *Cominella virgata* and *Haustrum scobina* and the grazer *Lunella smaragdus*. The barnacle *Austrominius modestus* was also present with an average percent coverage of 5%.

A total of 36 rocky pools were recorded within 5 m either side of the transect. Twenty-two were classified as small, 10 as medium and 4 large. All were shallow (< 10 cm deep).

Figure 8.3

Photographs of taxa found in the three intertidal zones (high, mid and low) at site R1.

High

Mid

Low

Site R2 was located on the next point south from Site R1, on the northwestern flank of the Wairoa Embayment on Whakakaiwhare Point (Table 3.1). This rocky site was inside Duder Regional Park, with the surrounding catchment consisting of pasture and isolated pockets of remnant native bush. The site was a gentle sloping rocky outcrop and was situated at the base of a steep grass covered cliff and fringed by overhanging Pohutukawa (Figure 8.4). The transect had a bearing of 147° and was relatively short, with 25 m surveyed in total. Clear physical zones were identified: a relatively short high tide zone 0 – 3.5 m, a mid tide zone 3.5 – 27.0 m, and a low tide zone starting at the 27.0 m mark. It was not possible to sample the far end of the low tide zone due to rough seas.

Figure 8.4

Photograph taken of site R2 displaying the gentle gradient from the high tide zone to the top of the low tide zone.

Compared to the other rocky sites, Site R2 had a very narrow high tide zone (approximately 3.5 m). Much of the area surveyed was bare rock (99% in one quadrat), however, this did vary between quadrats. The most abundant taxon recorded within this zone was matted foliose *Ulva* sp. (green alga; average coverage in the three quadrats was 27%) followed by the brown surf barnacle (*Chamaesipho brunnea*; 19%) (Figure 8.5). Other species recorded included the blue-banded periwinkle (*Austrolittorina antipodum*), the brown periwinkle (*Austrolittorina cincta*), black cyanobacterial crust and the snail *Zeacumantus subcarinatus*.

Within the mid tide zone, three species were found in similar abundances: spiny tube worms (*Pomatoceros cariniferus*; average coverage in quadrats 15%), rock oysters (*Saccostrea glomerata*; 15%) and the dominant brown alga *Hormosira banksii* (Neptune's Necklace, 12%) (Figure 8.5). Other species recorded with percent cover less than 1% included the whelks *Haustrum scobina* and *Cominella maculosa*, *Zeacumantus subcarinatus*, the snakeskin chiton (*Sypharochiton pelliserpentis*), barnacles (*Chamaesipho brunnea)* and the branching red algal species *Gigartina clavifera* and *Scytothamnus fasciculatus*.

The low tide zone was partially covered at the time of the survey. The most abundant taxa recorded were tube worms *Pomatoceros cariniferus* (23% cover) and barnacles (*Austrominius modestus*; 23%) (Figure 8.5). The next most abundant taxa recorded was the green-lipped mussel (*Perna canalicula*; 3%). Other species recorded in low percentages included the whelks *Cominella maculosa*, *Cominella virgata* and *Haustrum scobina*, the snail *Buccinulum* sp., hermit crabs *Pagurus* spp. and the algal species *Hormosira banksii*, *Corallina officinalis* and encrusting coralline paint.

Rocky pools were observed within the high and mid tide zones, with 15 shallow (<10 cm) small pools within the high tide zone and 13 shallow pools within the mid tide zone. Of the 13 mid tide zone pools, 8 were small, 4 medium and one large.

Figure 8.5

Photographs of taxa found in the three intertidal zones (high, mid and low) at site R2.

High Mid Low

Site R3 is located within Te Wharau Bay, on the northwestern flank of the Wairoa Embayment on Whakakaiwhare Point (Table 3.1). The site is located in close proximity to a walking track within the Duder Regional Park and, as such, is likely to be accessed by foot traffic. Site R3, situated at base of a steep grassy cliff, is a rough rocky outcrop with a medium to gentle sloping gradient (at low tide) (Figure 8.6). The surrounding catchment is primarily pasture grasses with some patches of remnant native trees and shrubs. The transect had a bearing of 143° and a transect length of 10.5 m. Due to the sea conditions, none of the low tide zone could be observed at the time of survey. However, the zonation between high and mid tide zones was easily identifiable, with a relatively broad high tide zone (0 – 9.5 m).

Figure 8.6

Photograph showing the highest of the three tidal zones at site R3.

The high tide zone in site R3 contained characteristically few species and was mostly dominated by bare rock (up to 99% cover in one quadrat). The major structuring organism, the brown surf barnacle (*Chamaesipho brunnea*; average coverage in quadrats 27%; Figure 8.7), was the most abundant species. Other species present with a coverage of at least one percent (within the quadrats) included the algal species

Apophloea sinclarii, the predatory gastropod *Haustrum scobina* and the blue-banded periwinkle *Austrolittorina antipodum*.

At the 9.5 m mark a clear zonation to the mid tide zone was observed. The mid tide zone was also dominated by bare rock, with an average coverage of 93% observed. The most abundant species within the quadrats was the rock oyster (*Saccostrea glomerata*; average coverage 5%; Figure 8.7). Other species present with coverage of less than one percent (within the quadrats) included the snakeskin chiton *Sypharochiton pelliserpentis*, the barnacle *Chamaesipho brunnea*, the gastropod *Haustrum scobina*, and algal species *Apophloea sinclarii* and *Corallina officinalis*.

Rocky pools were observed within the high tide zone only, with 11 shallow (<10 cm) pools (of these 6 were small, 4 medium and 1 large) and 1 medium depth (10 – 25 cm) large pool.

Figure 8.7

Photographs of taxa found in the upper two intertidal zones (high and mid) at site R3.

High

Mid

<u>Site R4</u>, situated on the far southeastern flank of the Wairoa Embayment at Koherurahi Point, is located within private property owned by ORICA New Zealand (Table 3.1). The site is located within close proximity to access roads and infrastructure, such as machinery, sheds and a boat ramp. The surrounding catchment is pine forest with some small patches of remnant native bush.

Situated at the base of a steep rocky cliff, the transect ran along a rough rocky outcrop with a medium sloping gradient. The transect had a bearing of 246° and was relatively short, with 21.2 m surveyed in total. Clear physical zones were identified: high tide 0 – 12.1 m, mid-tide 12.1 – 16.8 m, and low tide 16.8 – 21.2 m (water's edge).

The high tide zone was broader than the other two zones. Much of the high tide zone was bare rock with some barnacles (*Chamaesipho brunnea*; average coverage in quadrats 15%), black cyanobacteria crust (13%) and *Ulva* sp. (8%) (Figure 8.8). Other species present with less than 1% coverage (within the quadrats) included blue-banded and brown periwinkles (*Austrolittorina antipodum and A. cincta*), rock oysters (*Saccostrea glomerata*), snakeskin chitons (*Sypharochiton pelliserpentis*), and the alga *Apophloea sinclarii*.

Quadrats within the mid-tide zone were dominated by the presence of *Saccostrea glomerata* (average coverage in quadrats 67%), with up to 95% cover in one quadrat (Figure 8.8). *Chamaesipho brunnea* was also present with an average percent coverage of 22%. Other species present with a coverage of 1% or less included *Apophloea sinclarii*, *Corallina officinalis*, *Hormosira banksii* and *Scytothamnus fasciculatus*. The whelks *Haustrum scobina* and *Cominella virgata* were also present, as was the radiate limpet *Cellana radians*.

Further down the transect in the low tide zone, algal species were the most abundant, with *Hormosira banksii* and *Corallina officinalis* present with average percent coverage of 50% and 32%, respectively (Figure 8.8). Other algal species present included *Apophloea sinclarii* and unidentified encrusting coralline reds. The spiny tube worm (*Pomatoceros cariniferus*) was also present with an average percent coverage of 10%.

A total of 36 rock pools were observed within 5 m either side of the transect. Within the high tide zone 21 pools were recorded (of which 20 were shallow and small or medium-sized, and one was of medium depth and size). Five pools were observed within the mid tide zone (of which four were shallow and small or medium-sized, and one was of medium depth and size). At the time of survey, the high tide zone had 10 shallow pools (seven small and three medium-sized).

Figure 8.8

Photographs of taxa found in the three intertidal zones (high, mid and low) at site R4.

High Mid Low

<u>Site R5</u> is located in the southeast of the Wairoa Embayment, at Mataitai Point between Wairoa Bay and Koherurahi Point (Table 3.1). The site is situated at the base of a steep rocky cliff covered mostly in native tree and shrub species. The land surrounding the site is owned by ORICA New Zealand.

The transect consisted predominantly of a rocky platform with some loose rock material and small, shallow rock pools (Figure 8.9). The transect was gentle to medium sloping (at low tide) and had a bearing of 290°. The high tide zone was clearly identified between 0 and 17.4 m on the transect, with the mid-tide zone starting at 17.4 and continuing past 23 m. Water coverage due to rough seas prevented us from assessing the low tide zone.

Figure 8.9

Photograph taken of site R5 looking northwest from the start of the transect out towards the Wairoa Embayment.

Much of the broad high tide zone was bare rock (98% in one quadrat; Figure 8.10), with some encrusting black cyanobacteria and a low abundance of the predatory gastropod *Haustrum scobina*. The structure forming brown surf barnacle (*Chamaesipho brunnea*; average coverage 22%) was the most abundant species within the surveyed quadrats. Also, a single mangrove seedling was observed within the high tide zone.

The most abundant species recorded within the mid-zone quadrats were Neptune's Necklace (*Hormosira banksii*; average coverage in quadrats 42%), *Chamaesipho brunnea* (18%), and spiny tube worms (*Pomatoceros cariniferus*; 15%) (Figure 8.10). Other species included *Corallina officinalis* (10%), and the rock oyster, *Saccostrea glomerata* (9%).

Eighteen rock pools were observed within the high and mid tide zones, with almost all of them shallow small pools.

Figure 8.10

Photographs of taxa found in the high and mid intertidal zones at site R5. The low tide zone was not accessible when site survey was being completed.

High Mid

Site R6 is located in the southern section of the Wairoa embayment on Kahuru Point, between Kauri Bay and Wairoa Bay (Table 3.1). The site is surrounded by a steep-sloping, highly vegetated cliff face containing a mix of native and introduced trees and shrubs. Beyond the cliff lies farm land and scattered rural and life style properties. Site R6 is a gentle sloping, long transect, with a transect length of 131 m and a bearing of 351° (Figure 8.11). Clear physical zones were identified: a relatively broad high tide zone from 0 – 73 m, a mid tide zone from 73 – 114 m, and a low tide zone from 114 to the water's edge.

Figure 8.11

Photograph taken of site R6 looking up the transect from the water's edge at low tide.

Zonation bands seemed to generally correspond with the physical zones defined, based on elevation. The high tide zone was very broad (73 m) and was characterized by low species diversity. The most abundant species within this zone were brown surf barnacles (*Chamaesipho brunnea*; average coverage in quadrats 43%), small mussels *Limnoperna pulex* (17%) and matted foliose green alga *Ulva* sp. (5%) (Figure 8.12).

The mid tide zone was also very broad (41 m) and was characterized by a greater number of taxa and coverage. Within this zone the most abundant species were *Corallina officinalis (*17%), *Hormosira banksii* (15%), and green-lipped mussels (*Perna canalicula*; 10%) (Figure 8.12). Other species recorded included the cushion star *Patiriella regularis* (7%), *Chamaesipho brunnea* (3%) and the blue mussel *Mytilus galloprovincialis* (2%).

Further down the transect in the low tide zone, algal species were the most abundant, with *Corallina officinalis* coverage at 47% (Figure 8.12) and encrusting coralline paint at 10%. Other recorded species included the barnacles *Austrominius modestus* (4%) and *Epopella plicatus* (2%), the grazing gastropod *Lunella smaragdus* (2%) and *Patiriella regularis* (2%).

A large number of small (< 30 cm) rock pools were observed within the high tide zone. Of these, 60 were observed to be small, 10 were medium sized and 4 were large.

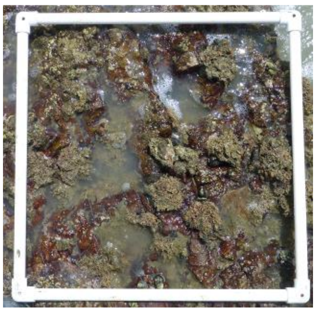
Figure 8.12

Photographs of taxa found in the three intertidal zones (high, mid and low) at site R6.

High

Mid

Low



8.3 Descriptions of the intertidal soft-sediment sites

Site characteristics, including appearance and sediment type, can provide a context against which changes in macrofauna can be described. For this reason, a brief description of site appearance and sediment characteristics are given here. The discussion of these sites will begin with sites near Whakakaiwhara Point in the northwestern portion of the Wairoa Embayment, and will move systematically around the Embayment towards Koherurahi Point.

Sites adjacent to Duder Regional Park (A-int, D-int and E-int)

Intertidal soft-sediment sites A-int, D-int and E-int were positioned in the little embayments flanking the rocky outcrops along this stretch of the coast from Whakakaiwhara Point along to the large intertidal flat adjacent to North Road (Figure 4.1, Table 4.2). The catchments adjacent to all sites were steep and pastoral with small stands of Pohutukawa and Manuka (Figure 8.13). At sites D-int and E-int, the catchment was fenced from the coast, whilst at A-int there was potential for stock to access the site. Each site was gently sloping with small rocky outcrops dispersed from the high tide mark down to the water's edge that housed common rocky shore species such as the rock oyster (*Saccostrea glomerata*) and the brown surf barnacle (*Chamaesipho brunnea*).

At all three of these sites, the sediment was firm under foot and consisted of a mixture of shell hash, coarse sand and pebbles (>40% by weight at sites A-int and E-int) (Figure 8.14). The sediment at D-int was similar to the other two sites, but there was also a notable amount of silty mud at this site (sinking depth approximately 5 cm). No epifauna were obvious at any of these sites, although live pipis (*Paphies australis*) and cockles (*Austrovenus stutchburyi*) were found easily at sites D-int and E-int by digging through the sediment. The density of pipis was >38 individuals per 100 cm^2 at E-int. Apart from these sites, pipis were only observed at one other site in the Wairoa Embayment (37 soft-sediment sites sampled in total). In addition to the pipis and cockles, which were the common large infauna present, sites D-int and E-int contained a variety of small polychaetes and bivalves (e.g., *Aonides trifida, Prionospio aucklandica, Nucula hartvigiana*).

Figure 8.13

Photographs of intertidal soft-sediment sites A-int, D-int and E-int, displaying the gently sloping nature with dispersed rocky outcrops.

A-int

D-int

E-int

Figure 8.14

The sediment surface at sites A-int, D-int and E-int.

A-int

D-int

E-int

Sites on the intertidal flat north of Wairoa River (1-int to 4-int, F-int and G-int).

Moving south towards the Wairoa River mouth, four potential monitoring sites (Table 4.1) were visited along with habitat mapping sites F-int and G-int (Table 4.2). This extensive intertidal flat was readily accessible and surrounded by a pastoral catchment with stands of native (i.e., Manuka and Pohutukawa) and exotic (i.e., pine) vegetation. At the high tide mark there were scattered mangroves, which become thicker stands moving south towards the Wairoa River channel. At all sites along this flat it was common to see foraging seagulls and dotterels, and there is a designated nesting area for dotterels roped off in the adjacent land-beach transition zone.

Site 1-int was characterised by firm sandy sediment with a moderate amount of shell hash on the surface comprised of mainly large cockle and wedge shells, with small fragments dispersed throughout the sediment (Figure 8.15). By weight, the sediment had approximately 14% shell hash, with the dominant sediment particle size fraction being fine + very fine sand (70%). Mud content was low (7.6%). At this site there was a moderate abundance of the gastropod *Zeacumantus lutulentus* on the surface of the sediment (~120 individuals m^{-2}). The dominant infaunal species were spionid polychaetes, *Aonides trifida* and *Prionospio aucklandica*, and cockles, *Austrovenus stutchburyi*.

Figure 8.15

Site 1-int, in broad view looking towards the northwest (left), and looking directly down towards the sediment surface (right). Note the cockle and wedge shell hash in the image on the right.

Site 2-int (images unavailable) was located 750 m south east of Site 1-int and was largely similar in terms of sediment grain size: firm sediment with a moderate to high density of shell hash (8% shell hash, 75% fine+very fine sand, 10% mud). Chl*a* in the sediment at Site 2-int was 2.7 times higher than it was at Site 1-int (27 vs 10 µg g^{-1}, respectively), and there was a greater abundance, richness and diversity of macrofauna at Site 2-int as well. Epifauna including the gastropods *Cominella glandiformis* and *Zeacumantus lutulentus* were scattered atop the sediment surface, along with patches of tube-dwelling polychaete worms. *Prionospio aucklandica, Austrovenus stutchburyi* and *Nucula hartvigiana* were the dominant macrofauna at this site, whilst *Macomona liliana* was not readily apparent (with an average density of <1 individual per macrofaunal core sample).

Moving further south east, Site F-int (images unavailable) was approximately 680 m away from Site 2-int and consisted of a 10 m diameter patch of sediment that was different from the surrounding sandy firm sediment. Inside this patch, a silty surficial layer approximately 3 cm deep overlaid firm sandy sediment (grain size was 13% mud, 79% fine+very fine sand, and 3.6% shell hash). The gastropods *Zeacumantus lutulentus*, *Cominella glandiformis* and *Diloma subrostrata* were all sparsely distributed on the sediment surface at moderate densities. The infauna was dominated by deposit feeding bivalves, *Nucula hartvigiana* and *Macomona liliana* (approximately 75% of the total macrofaunal abundance at Site F-int), with the capitellid polychaete *Heteromastus filiformis* and mud crab *Hemiplax hirtipes* also present at low densities.

Approximately 250 m away to the south east, was the location of Site 3-int (images unavailable). The firm sandy sediment at this site was covered with a moderate density of shell hash consisting of cockle and wedge shells and fragments. Small ripples (5 cm wave length, 1 cm wave height) were prominent and a slight deposition of light coloured terrestrial sediment was present in the troughs. In addition, a slight surficial mud layer (1-2 mm depth) was present and a few small ray pits were sparsely dispersed over the 9,000 m^2 site. Epifauna including *Cominella glandiformis*, *Zeacumantus lutulentus* and *Diloma subrostrata* were present and had approximate abundances of 120, 240 and 120 m^{-2}, respectively. Furthermore, the crab *Austrohelice crassa* was seen but was not as common as the mud crab *Hemiplax hirtipes* (which averaged >1 individual per 100 cm^2 core) [6]. The dominant infauna at Site 3-int were *Nucula hartvigiana* (~32 $core^{-1}$), *Prionospio aucklandica* (~6 $core^{-1}$), *Austrovenus stutchburyi* (~4.2 $core^{-1}$) and *Macomona liliana* (~3.7 $core^{-1}$). Although cockles were not hugely abundant at this site, they were a notable feature of the habitat as a biomass dominant and due to the visibility of the cockle shell hash.

Again moving south east, G-int was located approximately 530 m away from 3-int on the northern bank of the Wairoa River channel. A thick fringe of adult mangroves at the high tide mark was directly west of the site. The sediment was firm and sandy (only 3% mud), although a fine layer of sediment was present in the troughs of prominent sand ripples (5 cm wave length, 1 cm wave height) (Figure 8.16). Small fragments of shell hash were mixed throughout the sediment and *Macomona liliana* feeding tracks (approximately 10 m^{-2}) were evident. Gastropods *Cominella glandiformis* and *Zeacumantus lutulentus* were present in moderate densities and it was common to see large numbers of *Cominella* feeding on dead cockles. Although the sediment had a low component of shell hash (<1% by weight), the abundance of live shellfish was by far the highest of all of the soft-sediment sites (average abundance of 78 bivalves in each 100 cm^2 core: *Nucula hartivigiana*, 46 $core^{-1}$; *Austrovenus stutchburyi*, ~26 $core^{-1}$; *Macomona liliana*, ~6 $core^{-1}$). The dominance by these three species and the relatively low abundances of other types of macrofauna meant that the diversity of community was intermediate-to-low.

[6] Hereafter, units of "$core^{-1}$" will denote the number of individuals per 100 cm^2, which is the approximate average size of the intertidal and subtidal cores. All of the data were standardised to an area of 100 cm^2.

Figure 8.16

Site G-int, displaying the rippled topography of the sediment surface and the relative lack of shell hash material. The lack of shell hash belies an extremely high density of live shellfish including cockles, nut shells and wedge shells.

Across the Wairoa River channel on the southern bank adjacent to Pouto Point, potential monitoring site 4-int was established (Figure 8.17). The sediment at this site was a mixture of coarse sand and shell fragments with some larger cockle and wedge shell fragments lying on the sediment surface (Figure 8.17). The sediment was firm under foot and ripples (10 cm wave length, 4 cm wave height) with terrestrial sediment deposition in the troughs were also notable at this site. Sediment Chl*a* content was relatively low at this site (8.7 µg g^{-1}), and a low abundance of surface grazing snails (*Diloma subrostrata* and *Zeacumantus lutulentus*) was observed. The content of degraded algal material in the sediment, phaeophytin (7.6 µg g^{-1}), was relatively high in comparison to the Chl*a*, judging from the Chl*a*:phaeophytin ratios at the other intertidal soft-sediment sites.

Of all of the intertidal soft-sediment sites, Site 4-int had the highest richness and diversity of macrofauna, although abundance was not particularly high. *Nucula hartvigiana*, *Austrovenus stutchburyi*, *Heteromastus filiformis*, and *Macomona liliana* were common at this site, along with 24 other taxa that were identified in the core samples.

Figure 8.17

Photographs of Site 4-int, in broad view looking north across the Wairoa River channel (left), and looking directly down at the sediment surface (right), displaying the rippled topography of the sediment surface.

Sites in Kauri Bay (5-int, H-int, I-int and J-int).

Kauri Bay is located east of Wairoa River and is flanked by Pouto Point and Kahuru Point. The catchment is moderately steep and partially rural and forested; there are approximately 20 residential properties located there at present. Access to this intertidal flat is easy and potential anthropogenic disturbances may include human and animal access, run off and sedimentation via streams and the Wairoa River, and activity and nutrient loading associated with the large oyster farms located inshore and to the west of the bay (-36.937887,175.106492). An adult mangrove fringe lines the high tide mark and is adjacent to monitoring site 5-int (Table 4.1; Figure 4.1).

Site 5-int was established in the eastern half of Kauri Bay and situated approximately 300 m west of Kahuru Point and the rocky reef. The monitored area was firm sand (Figure 8.18) with prominent ripples on the sediment surface (0.5 cm wave length, 4 cm wave height) and deposits of terrestrial sediment in the ripple troughs. A moderate amount of shell hash was also present on the sediment surface and was comprised of mainly cockle, wedge and pipi shells. Epifauna were evident at this site, notably *Cominella glandiformis*, *Zeacumantus lutulentus* and *Diloma subrostrata*, all with approximate abundances of 150-200 m^{-2}, and there was also a low density of ray feeding pits. Digging down into the sediment, *Austrovenus stuchburyi* and *Nucula hartvigiana* appeared to be abundant, and this was reflected in the quantitative samples (>25 and >13 $core^{-1}$, respectively). Other infauna included the polychaete *Prionospio aucklandica* (1.8 $core^{-1}$) and the wedge shell *Macomona liliana* (1.3 $core^{-1}$).

Figure 8.18

Photographs of Site 5-int, looking west from the fluorescent stake marking the bottom left corner of the monitored area (left), and directly down at the sediment surface (right).

The other three sites (H-int, I-int and J-int) are all smaller sites sampled in the eastern half of the bay and represented habitats distinct from the monitoring site, which was characteristic of most of the bay (Table 4.2). Site J-int was at a similar tidal level to site 5-int, whilst sites H-int and I-int were closer to the high tide line.

Site H-int was located close to the high tide mark fringed with adult mangroves. The sediment was mainly firm and sandy with a small amount of shell hash (mainly cockle and wedge shell) and some rocky areas. The sediment had a greater percentage of coarse + medium sands (30% by weight) than the other sites in the area. A surficial mud layer of 0.5 cm depth was present and was silty to touch (Figure 8.19), although overall mud content was <3%. The surface topography contained small ripples (1 cm wave height, 3-4 cm wave length) and the occasional ray feeding pit. Sediment Chl*a* content was high at this site (26.6 µg g^{-1}). The most abundant macrofaunal organism was the polychaete *Aonides trifida* (>20 $core^{-1}$), whilst *Austrovenus stutchburyi* and *Prionospio aucklandica* were reasonably common (5.5 and 2.8 $core^{-1}$, respectively).

Site I-int was the southern-most site sampled in the bay and was also close to the adult mangroves fringing the foreshore (Figure 8.19). The sediment consisted of firm sandy sediment with cockle shell hash and an overlying surficial sediment layer that was approximately 1 cm deep. Ripples with a 2 cm wave height and a 4-5 cm wave length were present. In the ripple troughs, the surficial mud layer was up to 2.5 cm deep in some areas. Epifauna at this site was scarce, although an average of 3 mud crabs (*Hemiplax hirtipes*) were collected in sediment cores. Live cockles and wedge shells were observed in the sediment, with moderately low densities of cockles quantified (4.0 *Austrovenus stutchburyi* per core). *Nucula hartvigiana* and *Macomona liliana* were relatively scarce (0.5 and 0.25 $core^{-1}$, respectively), whilst the polychaete *Prionospio aucklandica* was abundant (16 $core^{-1}$).

At site J-int, the firm sandy sediment with cockle shell hash was covered with a thick layer of surficial mud, approximately 5 cm deep (Figure 8.19). The percentage mud was 10% by weight (72% fine + very fine sand). The surface dwelling gastropods *Zeacumantus lutulentus* and *Cominella glandiformis* were both present at variable densities of approximately 80 and 20 m^{-2}, respectively. Two crab species, *Austrohelice crassa* and *Hemiplax hirtipes*, were present and could be observed scurrying into burrows. Infaunally, Site J-int was dominated by a variety of polychaete and bivalve species. *Prionospio aucklandica* and *Heteromastus filiformis* were common (17 and 7 $core^{-1}$, respectively), as were cockles and pipis (20 and 2.8 $core^{-1}$ for *Austrovenus* and *Paphies*, respectively).

Figure 8.19

Photographs of the sediment at intertidal soft-sediment sites H-int, I-int and J-int.

H-int

I-int

J-int

Sites in Wairoa Bay (6-int and K-int).

Wairoa Bay is flanked by Kahuru Point to the west and Mataitai Point to the north east (Figure 4.1). The sediment at site 6-int, was characteristic of the sediment at the mid tide level across the entire bay. A monitoring area of 6,300 m^2 was established (90 m running parallel to the water and 70 m running perpendicular) encompassing a broad stretch of similar habitat type (Figure 8.20). The adjacent catchment was primarily pine forest, with some small rural areas. The sediment at this site was sandy and firm underfoot, however there was a small patch of muddy sediment in the top right hand corner of the sample area that was approximately 2-5 cm deep (Figure 8.20). On average, this site was the muddiest of the seven potential ecological monitoring sites (16% mud, ~80% fine + very fine sand), and fine silty deposits could be seen in surficial depressions. Sediment Chl*a* content was moderately high (26 $\mu g.g^{-1}$) at Site 6-int, although the epifauna at this site was dominated by predator/scavengers rather than grazers: *Cominella glandiformis* were present in low abundance, and small crabs (*Halicarcinus whitei*) and cushion stars (*Patiriella regularis*) were also observed. As for the infauna, *Nucula hartvigiana* and *Heteromastus filiformis* were dominant (~13 and ~6 $core^{-1}$, respectively), whilst the paraonid polychaete *Paradoneis lyra* was present at an average density of 1 individual per core. The key bivalves *Austrovenus stutchburyi* and *Macomona liliana* were absent or scarce.

Figure 8.20

Photographs of Site 6-int. A broad view, looking west across the monitored area (left) and a close-up view of the sediment surface in the muddy corner of the designated sampling area (right).

Site K-int was located 130 m south east of 6-int and was a very muddy area close to the high tide mark. This area was quite different from much of the habitat in the bay. The muddy sediment sat on top of mudstone and was approximately 10 cm deep in most places (Figure 8.21). The mud fraction at this site was >68% by weight, which was more than 4 times higher than any of the other intertidal soft-sediment sites sampled in the Wairoa Embayment. The fluid-like mud was silty and smooth. Much of this muddy sediment was deposited and seemed to have collected between small rocky reef outcrops. The surface topography contained ripples with a wave height of 1-2 cm and a wave length of approximately 5 cm. Occasionally *Cominella glandiformis* was observed in low abundance, with a random, sparse distribution. Mud crabs (*Hemiplax hirtipes*) were present and approximately 15 crab burrows m^{-2} were observed. There were ~3 mud crabs per sediment core, on average, and other mud tolerant species were noted in the sediment cores as well (e.g., *Heteromastus filiformis*, 14 $core^{-1}$; *Theora lubrica*, 1.2 $core^{-1}$). Although a few scattered cockles were noted at the site, no *Austrovenus stutchburyi* or *Macomona liliana* were recorded in the sediment cores.

Figure 8.21

Photograph of the sediment surface at site K-int, displaying the rippled topography and muddy nature of the habitat.

Site in Mataitai Point Bay (7-int).

Site 7-int was established in the small bay flanked by Mataitai Point and Koherurahi Point (Figure 4.1, Table 4.1). The soft intertidal area was not as broad as the other intertidal areas sampled, so a 6,300 m^2 area (the same as 6-int) was established for potential monitoring (Figure 8.22). The surrounding catchment was primarily pine forest and is private property owned by ORICA New Zealand. Jetty rocks are present on the foreshore to the east of the bay, and the bay is halved by a small rocky reef. The area established for potential monitoring at site 7-int was characteristic of the sediment along the entire bay at the mid-tide level. The surface topography contained ripples (1 cm wave height, 5-7 cm wave length) and a surficial mud layer of approximately 1-2 mm was present in the ripple troughs (Figure 8.22). The sediment was predominately fine sand (10% mud, 87% fine + very fine sand) mixed with a few broken shell fragments (0.2% shell hash). Sediment Chl*a* content at this site was 37.4 $\mu g.g^{-1}$, the highest level observed among all of the intertidal soft-sediment sites. *Cominella glandiformis* was the dominant epifaunal gastropod at the site, with an approximate abundance of 10 m^{-2}, and cushion stars (*Patiriella regularis*) were also observed. *Nucula hartvigiana* was the dominant infaunal bivalve (~22 $core^{-1}$), with *Macomona liliana* more rare (0.8 $core^{-1}$) and *Austrovenus stutchburyii* not present in the cores.

Figure 8.22

Photographs of Site 7-int looking south from the fluorescent stake marking the bottom left hand corner of the monitored area (left), and looking directly down at the sediment surface (right).

8.4 Descriptions of the subtidal soft-sediment sites

The subtidal parts of the Wairoa Embayment were much muddier than the intertidal areas, apart from isolated muddy areas in the upper intertidal zone (e.g., mangrove and channel-edge habitats). This was by far the most obvious and striking difference between the subtidal and intertidal parts of the Wairoa Embayment. With the exception of K-int (discussed in section 8.3), mud content was 0-16% for the intertidal sites and 36-84% for the subtidal sites (Table 8.1). In the subtidal zone, there was no significant tendency for the shallower sites to be less muddy than the deeper ones, although two shallow sites near the intertidal-subtidal transition zone (H-sub and B-sub) were among the least muddy at 36 and 50%, respectively. The sites in the southeastern half of the embayment (near Koherurahi Point; sites J-sub, K-sub and U-sub) were the muddiest.

As light availability is greater in intertidal areas than it is in subtidal areas, it is not uncommon for sediment Chl*a* content to be less in the subtidal zone. In the Wairoa embayment, intertidal sites had 17.7 µg Chl*a* per g sediment on average, whereas there was 3.8 $\mu g.g^{-1}$ at the subtidal sites (less than a quarter of the intertidal values). The ratio of fresh-to-degraded pigments, as indicated by the Chl*a*:phaeophytin ratio, was also much less for the subtidal sites (averaging <1:1 in the subtidal, relative to >4:1 in the intertidal).

There was a weak positive relationship between sediment mud content and sediment Chl*a* content within both the intertidal and subtidal zones. However, overall, sediment mud content values were much greater in the subtidal zone, and Chl*a* content was much reduced, relative to the intertidal zone.

Although the underwater visibility was extremely limited, the sites are discussed below in terms of their geographical positions, their basic appearance as noted by the divers (thickness of mud layer, type and amount of shell material mixed into the sediment), and information obtained from the subtidal dredge transects that ran between the subtidal sites. Evidence of biological activity was sometimes observed by the divers (i.e., holes and burrows likely inhabited by crustaceans), although the animals themselves were not always seen. There was also evidence of vibrant biological life in the past, with layers of shell material buried beneath the sediment-water interface at most sites.

Table 8.1

Sediment characteristics at 37 soft-sediment sites in the Wairoa Embayment. Percent contributions of gravel, sand and mud (by weight), organic matter content (% dry weight combusted) and pigments ($\mu g.g^{-1}$) to the sediment are presented.

	Site	Latitude	Longitude	Depth (m at MLW)	Shell and Gravel (>500 µm)	V.coarse + coarse sand (500-250 µm)	Medium sand (250-125 µm)	Fine + v.fine sand (125-63 µm)	Silt (63-9 µm)	Clay (<9 µm)	Total Sand (500-63 µm)	Mud (silt+clay) (<63 µm)	Organic matter content (%)	Chl*a* (µg/g sediment)	Phaeo. (µg/g sediment)
Intertidal	1-int	36 54.7503	175 04.9746	.	13.82	3.87	4.71	69.98	4.16	3.46	78.56	7.62	1.44	9.86	5.91
Monitorin	2-int	36 55.1250	175 05.1773	.	7.95	4.73	2.20	75.14	5.44	4.54	82.07	9.98	1.41	27.06	3.51
	3-int	36 55.6000	175 05.4137	.	5.16	0.56	2.97	85.57	2.65	3.09	89.10	5.74	1.49	20.40	2.29
	4-int	36 55.8851	175 05.7677	.	3.05	14.73	26.11	54.04	0.41	1.66	94.88	2.07	1.40	8.71	7.64
	5-int	36 56.4163	175 06.7875	.	4.08	5.08	2.41	84.67	3.77	0.00	92.15	3.77	1.64	13.52	4.46
	6-int	36 56.2350	175 07.8792	.	0.86	0.45	2.61	79.42	11.83	4.84	82.48	16.66	2.67	26.60	3.17
	7-int	36 55.7786	175 08.4562	.	0.20	0.53	2.26	87.05	4.64	5.31	89.85	9.95	2.21	37.37	4.61
Intertidal	A-int	36 54.1775	175 05.7296	.	23.41	56.21	16.72	3.60	0.00	0.00	76.54	0.00	1.50	0.46	0.20
Mapping	D-int	36 54.3506	175 05.3823	.	11.33	17.04	31.61	25.61	7.73	6.68	74.26	14.41	2.56	11.69	6.24
	E-int	36 54.3688	175 05.3488	.	12.14	34.06	28.67	24.34	0.00	2.38	87.07	2.38	1.62	3.73	4.53
	F-int	36 55.4713	175 05.3506	.	3.67	1.52	2.48	79.19	6.02	7.11	83.20	13.13	2.17	18.34	4.08
	G-int	36 55.8410	175 05.6176	.	0.50	0.68	5.02	90.65	1.35	1.80	96.35	3.15	1.60	23.84	1.84
	H-int	36 56.4448	175 06.9593	.	5.52	11.41	19.71	60.88	0.00	2.89	92.01	2.89	2.12	26.60	2.10
	I-int	36 56.6246	175 06.8806	.	6.15	4.58	2.59	72.83	4.26	9.58	80.01	13.84	2.63	15.59	7.78
	J-int	36 56.4994	175 06.6065	.	7.51	6.33	3.38	72.56	7.06	3.16	82.26	10.22	2.52	20.86	5.51
	K-int	36 56.2540	175 07.9651	.	0.00	0.07	0.35	30.66	49.44	19.48	31.08	68.92	5.32	19.71	4.52
Subtidal	A-sub	36 54.5739	175 05.6549	1.62	0.64	0.54	0.64	26.98	60.32	10.88	28.2	71.20	4.95	3.78	3.52
	B-sub	36 54.9717	175 05.7892	1.57	1.84	0.54	0.29	47.02	42.96	7.34	47.9	50.30	3.33	2.87	4.92
	C-sub	36 55.2629	175 06.2678	1.92	0.67	0.44	0.91	27.67	54.09	16.23	29.0	70.31	4.49	3.21	3.59
	D-sub	36 54.9531	175 06.6969	3.67	0.56	0.85	0.22	38.31	45.21	14.85	39.4	60.06	5.24	3.90	4.16
	E-sub	36 54.7028	175 06.2476	4.17	1.82	0.16	0.18	38.74	44.32	14.77	39.1	59.09	4.09	2.87	4.76
	F-sub	36 54.2575	175 06.0534	4.02	6.62	0.62	0.40	21.85	56.96	13.56	22.9	70.52	5.49	1.03	8.81
	G-sub	36 55.5989	175 06.6857	3.27	0.04	0.23	0.14	27.29	60.09	12.21	27.7	72.30	4.35	3.55	5.32
	H-sub	36 55.9928	175 06.3771	2.42	0.24	0.09	0.18	63.17	30.59	5.74	63.4	36.32	3.29	9.28	3.36
	I-sub	36 55.8671	175 07.1292	2.17	0.00	0.30	0.39	26.32	59.04	13.96	27.0	73.00	5.47	4.70	5.20
	J-sub	36 56.0171	175 07.6725	1.77	0.00	0.45	0.24	14.39	64.54	20.38	15.1	84.92	5.50	4.70	7.64
	K-sub	36 55.6880	175 08.0258	5.67	0.00	0.38	0.31	19.92	50.63	28.77	20.6	79.40	5.08	4.13	2.97
	L-sub	36 55.5235	175 07.4570	5.47	0.00	0.17	0.17	32.67	48.18	18.80	33.0	66.98	3.94	4.58	2.98
	M-sub	36 55.2315	175 07.0554	5.32	2.17	1.05	0.48	36.71	45.57	14.02	38.2	59.59	3.78	2.87	4.72
	N-sub	36 54.6424	175 05.9071	3.67	0.00	0.00	0.02	35.89	46.07	18.03	35.9	64.10	3.66	4.70	4.42
	O-sub	36 55.0228	175 06.1989	3.22	0.82	0.20	0.11	49.59	37.21	12.07	49.9	49.28	2.79	3.55	4.17
	P-sub	36 55.3039	175 06.6761	2.87	1.96	0.69	0.44	33.39	46.38	17.14	34.5	63.52	3.35	4.01	4.60
	Q-sub	36 54.3673	175 06.5383	3.72	0.00	0.00	0.04	36.40	43.91	19.64	36.4	63.55	3.76	1.83	5.27
	R-sub	36 54.7235	175 06.9634	2.42	4.95	0.36	0.30	48.74	32.27	13.38	49.4	45.65	3.77	2.87	4.72
	S-sub	36 54.7466	175 07.6223	2.32	3.51	1.47	0.60	27.77	34.52	32.14	29.8	66.66	4.19	2.75	4.49
	T-sub	36 55.1960	175 07.7981	1.67	9.30	1.22	0.55	33.27	34.14	21.52	35.0	55.66	3.85	4.01	6.91
	U-sub	36 55.3969	175 08.2723	3.17	0.00	0.05	0.07	15.63	51.63	32.61	15.8	84.25	4.72	4.93	9.01

Table 8.2

Abundance of twelve macrofaunal taxa (average number of individuals per 100 cm^2) at thirty-seven soft-sediment sites in the Wairoa Embayment. Summary variables of total abundance, taxonomic richness, Shannon-Wiener diversity, and bivalves are also presented. The TBI scores are an index of the functional redundancy present at each site (scores will be near to 0 at completely defaunated sites and near 1 at pristine ones).

	Site	*Aonides trifida*	*Austrovenus stutchburyi*	*Hemiplax hirtipes*	*Heteromastus filiformis*	*Nucula hartvigiana*	*Paradoneis lyra*	*Prionospio aucklandica*	Siglionidae	*Theora lubrica*	*Torridoharpinia hurleyi*	*Macomona liliana*	*Paphies australis*	Average Richness	Average Abundance	S-W Diversity	Average # of bivalves	TBI Score
Intertidal	1-int	16.32	6.28	0.75	0.25	0.00	0.00	8.79	0.00	0.00	0.00	0.00	0.00	20	40.68	1.902	6.28	0.37
Monitoring	2-int	0.75	15.57	1.00	2.01	12.81	0.00	21.10	0.00	0.00	0.00	0.75	0.00	27	75.34	2.268	29.13	0.52
	3-int	0.00	4.27	1.26	0.50	31.89	0.00	5.78	0.00	0.00	0.00	3.77	0.00	20	59.27	1.829	39.93	0.37
	4-int	0.00	6.03	0.00	2.26	17.33	0.00	1.00	0.00	0.00	0.00	1.76	0.00	28	46.96	2.449	25.11	0.58
	5-int	0.50	25.62	0.25	0.50	13.31	0.00	1.76	0.00	0.00	0.00	1.26	0.00	20	51.23	1.669	40.18	0.43
	6-int	0.00	0.00	1.00	5.78	13.31	1.00	0.00	0.00	0.00	0.00	0.50	0.00	24	30.89	2.144	13.81	0.55
	7-int	0.00	0.00	0.75	3.26	21.60	0.25	0.50	0.00	0.00	2.01	0.75	0.00	15	33.65	1.458	22.35	0.30
Intertidal	A-int	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	1.76	0.683	0.00	0.04
Mapping	D-int	6.78	16.83	1.51	0.75	16.07	0.00	29.63	0.00	0.00	0.00	1.00	4.77	26	88.65	2.104	38.68	0.53
	E-int	23.86	9.04	0.00	0.25	6.78	0.00	0.50	0.00	0.00	0.00	0.00	38.68	21	97.44	1.840	54.50	0.41
	F-int	0.25	0.50	1.00	3.52	38.17	0.00	0.50	0.00	0.00	0.00	2.01	0.00	23	53.74	1.384	40.68	0.52
	G-int	0.25	25.87	0.25	0.75	46.71	0.00	0.25	0.00	0.00	0.25	5.78	0.00	20	87.14	1.365	78.35	0.44
	H-int	21.35	5.53	0.50	0.25	0.00	0.00	2.76	0.00	0.00	0.00	1.51	0.00	12	34.66	1.350	7.03	0.23
	I-int	1.51	4.02	3.26	0.00	0.50	0.00	16.83	0.00	0.00	0.00	0.25	0.00	16	36.41	1.818	4.77	0.31
	J-int	0.00	20.34	0.50	7.03	4.77	0.00	17.08	0.00	0.00	0.00	0.50	2.76	22	66.05	2.080	28.38	0.36
	K-int	0.00	0.00	2.76	14.06	2.01	0.00	0.50	0.00	1.51	0.50	0.00	0.00	18	28.13	1.897	3.52	0.40
Subtidal	A-sub	0.00	0.00	2.23	0.00	0.32	0.64	0.00	0.32	0.00	0.64	0.00	0.00	13	8.59	2.290	0.32	0.32
	B-sub	0.00	0.00	0.32	3.82	0.00	4.77	0.00	1.27	0.32	0.95	0.00	0.00	22	25.78	2.587	0.32	0.55
	C-sub	0.00	0.00	2.55	0.64	0.32	0.95	0.00	1.59	0.00	0.95	0.00	0.00	15	10.82	2.429	0.32	0.37
	D-sub	0.00	0.00	1.27	1.27	0.00	0.64	0.00	0.64	0.00	1.59	0.00	0.00	15	9.55	2.517	0.00	0.36
	E-sub	0.00	0.00	0.00	0.95	0.00	0.64	0.00	0.64	0.95	0.95	0.00	0.00	8	5.41	2.008	0.95	0.17
	F-sub	0.00	0.00	0.32	0.00	0.00	1.91	0.00	0.64	0.64	0.95	0.00	0.00	8	5.41	1.846	0.64	0.19
	G-sub	0.00	0.00	0.32	0.64	0.32	0.00	0.00	1.27	0.00	1.91	0.00	0.00	8	5.41	1.795	0.32	0.17
	H-sub	0.00	0.64	0.32	2.55	1.27	0.95	0.00	0.64	0.00	0.95	0.00	0.00	14	20.05	1.865	1.91	0.28
	I-sub	0.00	0.00	0.00	0.00	0.00	1.27	0.00	2.23	0.00	0.64	0.00	0.00	5	4.77	1.339	0.00	0.13
	J-sub	0.00	2.55	0.32	0.32	0.00	0.00	0.00	0.64	0.00	0.95	0.00	0.00	7	6.68	1.647	2.55	0.14
	K-sub	0.00	0.00	0.32	0.64	0.00	0.64	0.00	0.95	2.55	1.27	0.00	0.00	11	8.28	2.120	2.55	0.25
	L-sub	0.00	0.00	0.32	0.32	0.00	2.55	0.32	0.95	0.95	2.86	0.00	0.00	10	9.87	1.941	0.95	0.22
	M-sub	0.00	0.00	0.95	0.32	0.00	2.86	0.00	1.91	0.64	0.95	0.00	0.00	12	10.82	2.159	0.64	0.29
	N-sub	0.00	0.00	0.64	3.82	0.00	2.23	0.00	0.95	0.95	0.64	0.00	0.00	21	19.42	2.692	0.95	0.47
	O-sub	0.00	0.00	1.91	0.32	0.95	0.00	0.00	2.86	0.95	0.00	0.00	0.00	12	14.01	2.317	1.91	0.27
	P-sub	0.00	0.00	1.27	1.91	0.32	1.59	0.00	1.91	0.95	1.27	0.00	0.00	12	11.78	2.298	1.27	0.26
	Q-sub	0.00	0.00	1.59	0.00	0.00	1.27	0.00	5.73	1.59	0.32	0.00	0.00	12	19.42	2.172	1.59	0.29
	R-sub	0.00	0.00	0.95	1.27	0.00	0.64	0.00	1.59	1.27	0.64	0.00	0.00	11	8.91	2.266	1.27	0.22
	S-sub	0.00	0.00	0.64	19.10	0.00	0.32	0.00	1.91	0.95	0.32	0.00	0.00	30	48.38	2.374	0.95	0.73
	T-sub	0.00	0.00	0.00	4.46	0.64	4.46	0.00	1.27	2.55	1.27	0.00	0.00	16	20.69	2.352	3.18	0.40
	U-sub	0.00	0.00	0.00	1.27	0.00	0.32	0.00	2.55	4.46	3.18	0.00	0.00	9	13.05	1.711	4.46	0.22

Subtidal sites M-sub, R-sub, S-sub and T-sub

In the central part of the embayment, well beyond the mouth of the Wairoa River channel, there were four subtidal sites with relatively thin layers of mud and evidence of epifaunal life on top of dense shell material (Figure 8.23).

At S-sub and T-sub, the shell material in the sediment consisted of large infaunal bivalves (e.g., *Cyclomactra ovata*) and occasional horse mussels, scallops and mussels (*Atrina zelandica, Pecten novaezelandiae, Perna canalicula*; Figure 8.24). However, no live specimens of these shell-forming species were observed. At both of these sites, there was sparse epifauna attached to the shell materials, including large orange-lined anemones and unstalked solitary ascidians (Figure 8.25). Also notable at S-sub and T-sub (and found nowhere else) were large tube-building terebellid polychaetes, whose tentacles extended 5-10 cm in a deposit-feeding posture. The dominant infaunal species collected at Site S was *Heteromastus filiformis* (19 $core^{-1}$), followed by the polychaete Sigalionidae and the bivalve *Theora lubrica*. The total abundance of macrofauna at S-sub (48 $core^{-1}$) was more than 2 times higher than it was at the next closest subtidal site (which was T-sub).

At site T-sub, the polychaetes *Heteromastus filiformis* and *Paradoneis lyra* were co-dominant (4.5 $core^{-1}$), followed by *Theora lubrica*, Sigalionidae and the amphipod *orridoharpinia hurleyi*.

At site M-sub, there was at least 5 cm of silty mud containing numerous large and small crustacean burrows on top of the layer of shell material. In places where the shell material was closer to the sediment surface, tufts of filamentous red/brown algae were observed along with large orange-lined anemones (Figure 8.25). Infaunal cores at M-sub revealed the small paraonid polychaete *Paradoneis lyra* to be the most common species (~2.9 $core^{-1}$), with mud crabs (*Hemiplax hirtipes*) and other mud tolerant species (*Theora lubrica, Heteromastus filiformis*) present along with Sigalionidae and *Torridoharpinia hurleyi*.

R-sub had an even thicker muddy layer atop the shell (up to 8 cm of mud thickness), although the shell hash content of this surficial sediment remained relatively high (~5%). There was less evidence of epifauna at this site, and the average number of macrofaunal individuals collected per core (i.e., total abundance) was less than 9.

There were four subtidal dredge transects where copious shell material was collected (#6, #12, #16 and #10, each with ≥17.5 litres of shell), and these four dredge transects were in close proximity to sites M-sub, R-sub, S-sub and T-sub. However, other dredge tows that were predominantly mud-filled (#7, #11, #13, #14, #17; indicative of thicker mud layers and deeply buried shell), were also in close proximity to M-sub, R-sub, S-sub and T-sub. Thus, the middle of the Wairoa Embayment was likely a spatially heterogenous mosaic of habitat patches rather than one contiguous large habitat of thin mud and high shell content.

Figure 8.23

A map showing roughly approximated groupings of subtidal sites based on (1) the type and amount of shell material observed by divers and in dredge tows and (2) the depth of the mud layer atop the shell material. The shaded red colour indicates the presence of large shell material (e.g., *Atrina, Pecten, Perna, Cyclomactra, Modiolus* etc.), whilst the shaded yellow colour indicates the presence of venerid bivalve shell hash (e.g., *Austrovenus, Protothaca, Ruditapes*). The abundance of epi- and infaunal macroinvertebrates tended to be greatest in the locations with copious shell material and relatively thin layers of mud: sites M-sub, R-sub, S-sub and T-sub (blue outline) and A-sub, B-sub and N-sub (green outline), although there was considerable habitat heterogeneity.

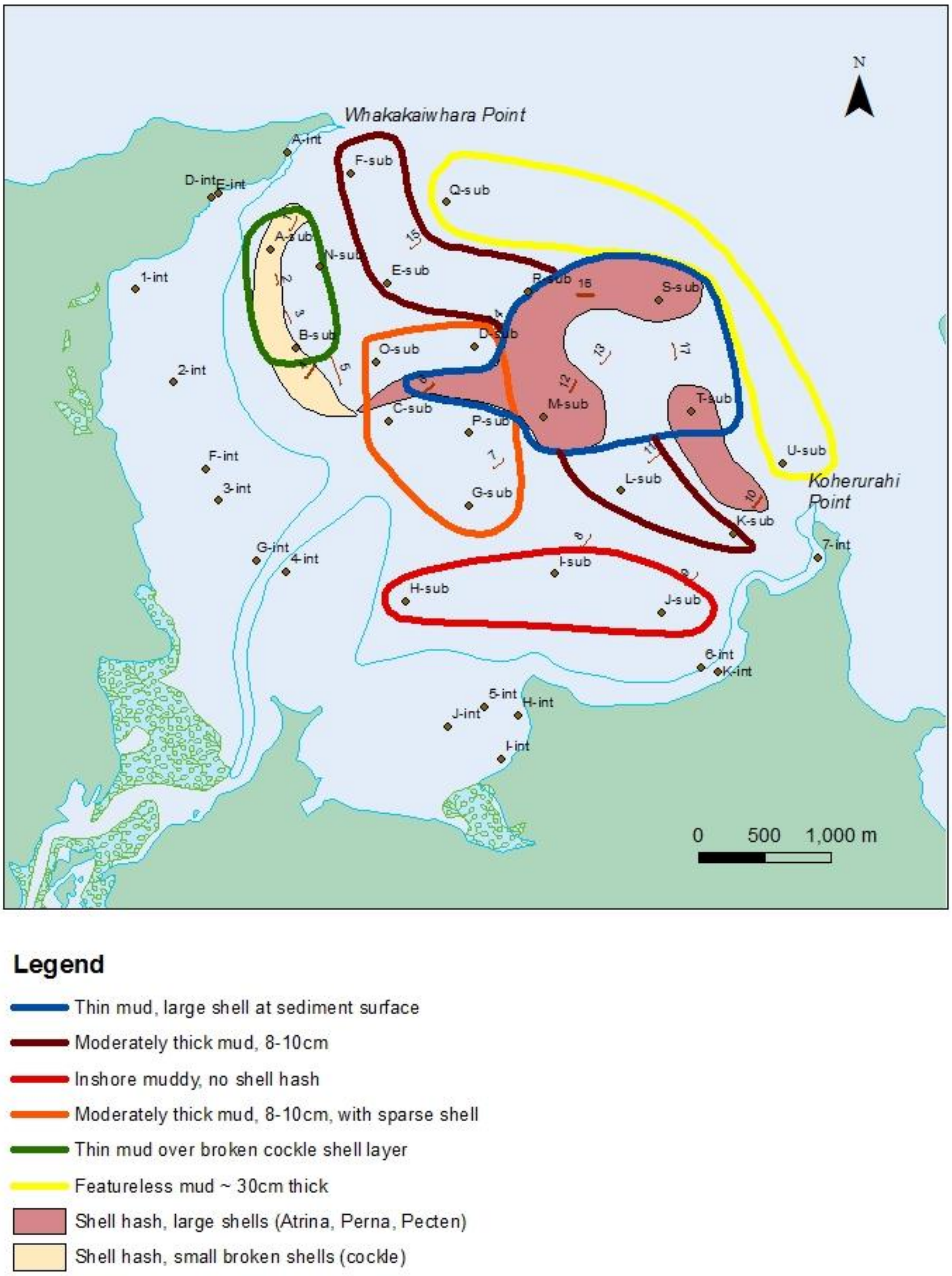


Figure 8.24

Pictures of large shell hash material collected in dredge tows #10 (top) and #16 (bottom), similar to the type of material observed by divers at subtidal sites S-sub and T-sub. Note the presence of epifauna (ascidians) in the upper image.

Figure 8.25

Image of the orange-lined anemone, unidentified, in situ (top) and after collection (middle). Bottom panel shows the non-stalked solitary ascidian, possibly *Asterocarpa coerulea* or *Cnemidocarpa bicornuta*.

Sites A-sub, B-sub, and N-sub

Sites A-sub, B-sub, and N-sub were on the Whakakaiwhara Point side of Wairoa embayment, directly east of sandy intertidal habitats (e.g., sites 1-int, E-int and D-int). All three of these subtidal sites had shell hash that was covered with a relatively thin layer of mud. The shell hash collected in the vicinity of Sites A-sub, B-sub and N-sub consisted mainly of cockle shells, with smaller shell pieces than those observed near to M-sub, R-sub, S-sub and T-sub (Figure 8.26).

Site B-sub had the thinnest covering of mud (<1 cm) and a sediment grain size distribution indicating 50% silt+clay, whereas Sites A-sub and N-sub had thicker mud (up to 4 cm) and 64-71% silt+clay. The dredge tow south of Site B-sub had 25 litres of shell hash (relative to 1 and 5 litres in tows closer to Sites A-sub and N-sub).

Site B-sub also seemed to have slighter richer biology, as chaetopterid and terebellid polychaetes and occasional sponges were observed by divers at B-sub. Epifaunal organisms present in dredge tow #4 (south of B-sub) included cushion stars and crabs (*Patiriella regularis* and *Hemiplax hirtipes*) (Figure 8.26). Macrofaunal samples from B-sub averaged 26 individuals and 19 taxa per core, relative to 9-19 individuals and 13-21 taxa at A-sub and N-sub. *Paradoneis lyra* was the most abundant macrofaunal organism at B-sub (4.8 $core^{-1}$), *Heteromastus filiformis* was the most abundant macrofaunal organism at N-sub (3.82 $core^{-1}$), whilst mud crabs (*Hemiplax hirtipes*) were the most common creatures at A-sub (2.2 $core^{-1}$).

Figure 8.26

Shell material collected in dredge tow #4, south of site B-sub, in the subtidal zone. Note the cockle-dominated shell hash and the ventral sides of two cushion stars, *Patiriella regularis.*

Sites E-sub, F-sub, K-sub, L-sub

The common feature of all of these subtidal sites was the preponderance of muddy sediments (69% mud, on average), and the lack of a shallow shell layer underneath the mud. If a discrete shell layer was present, it tended to be at least 8-10 cm beneath the sediment-water interface.

Evidence of epifauna at these sites was limited to the presence of variously sized holes and burrows (mud crabs, most likely). These sites had a relatively low abundance and richness of macrofauna (averaging <11 individuals and taxa per core). *Theora lubrica*, *Torridoharpinia hurleyi* and *Paradoneis lyra* were the commonest species at these sites, whilst *Hemiplax hirtipes* and *Heteromastus filiformis* were also each present at three of the four sites.

Sites C-sub, D-sub, G-sub, O-sub, P-sub

Inshore (south) of subtidal sites E-sub and F-sub, were five sites at the mouth of the Wairoa River channel: C-sub, D-sub, G-sub, O-sub and P-sub. These sites were characterised as having shell material sparsely mixed throughout the muddy sediment, with no distinctive shell layer present (at least in the top 10+ cm). The percentage mud at these sites averaged 63%, with <1% shell.

Site G-sub, with the highest sediment mud content (72%), had the lowest abundance and richness of macrofauna (8 taxa $core^{-1}$) of the five sites in this grouping. Sites C-sub and D-sub averaged 15 taxa per core, whilst sites O-sub and P-sub averaged 12 taxa per core. Sigalionid polychaetes and mud crabs, followed by phoxocephalid amphipods (*Torridoharpinia hurleyi*) and capitellid polychaetes (*Heteromastus filiformis*), were the most common macrofaunal taxa at these sites.

Sites H-sub, I-sub and J-sub

Furthest inshore, in the southern-most part of the embayment, were three muddy sites with very little shell material observed. Site H-sub, with 0.24% shell hash, was the closest of the three sites to the intertidal zone and had the lowest sediment mud content (36%). Sites I-sub and J-sub, to the east and slightly deeper, were progressively more muddy at 73% and 84% mud, respectively. There was no shell hash (0%) recorded at I-sub or J-sub.

Site H-sub, with slightly firmer sediment and almost twice as much sediment Chl*a* than sites I-sub and J-sub (9.3 versus 4.7 $\mu g\ g^{-1}$), had a higher abundance and richness of macrofauna as well, with Sites I-sub and J-sub among the most depauperate sites sampled in the entire Wairoa Embayment (averaging <7 individuals and taxa per core). Interestingly, because sites H-sub to J-sub were very shallow and close to the intertidal-subtidal boundary, a few “intertidal” species were present there, including *Austrovenus stutchburyi* and *Nucula hartvigiana* (Figure 8.27).

Figure 8.27

Image showing the small pieces of shell hash and the relatively small amount of shell material collected in dredge tow #9 (between J-sub and K-sub). Note that a number of live *Austrovenus stutchburyi* were collected in this tow and at site J-sub.

Sites Q-sub and U-sub

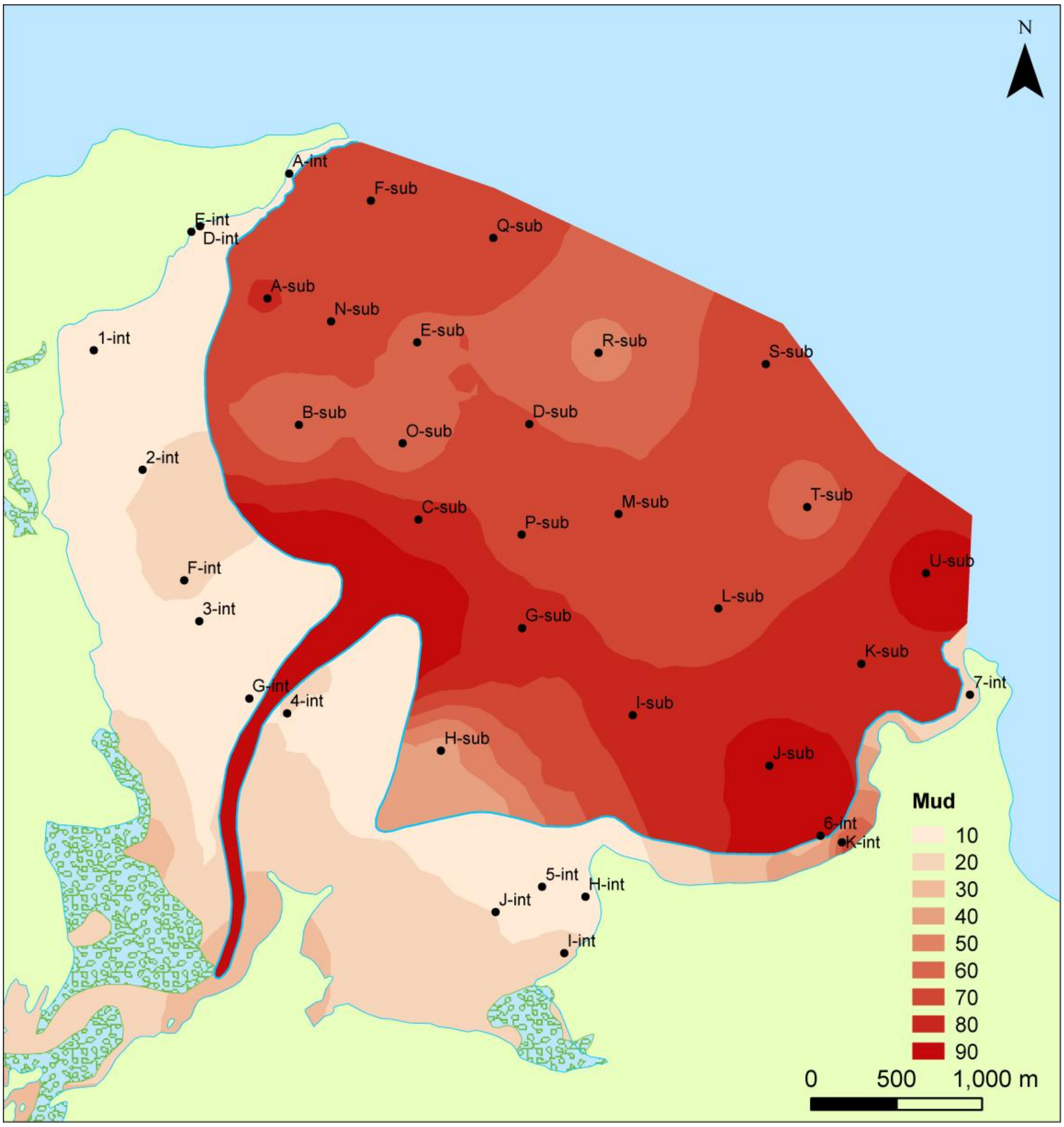
Sites Q-sub and U-sub were offshore and adjacent to Whakakaiwhara and Koherurahi Points, respectively. These two sites were the least interesting from an epifaunal standpoint, consisting of almost featureless mud. At site U-sub, the layer of soft mud (84% by weight) was estimated to be up to 30 cm deep. Although a few medium sized crustacean burrows were seen at Site Q-sub (63% mud), no shell hash or any other of type of epifauna was recorded.

An average of 13-19 individuals from 9-12 macrofaunal taxa were present at these two sites. Consistent with the observation of crustacean burrows at Q-sub, mud crabs (*Hemiplax hirtipes*) were recorded in the macrofaunal cores collected at this site (1.6 core^{-1}). Q-sub was dominated by Sigalionidae (5.7 core^{-1}), with *Theora lubrica* and mud crabs each averaging 1.6 core^{-1}. U-sub, in contrast, was dominated by *Theora lubrica* (4.5 core^{-1}) and *Torridoharpinia hurleyi* (3.2 core^{-1}), followed by Sigalionidae (2.6 core^{-1}) and *Heteromastus filiformis* (1.3 core^{-1}).

9 Map and interpolation results

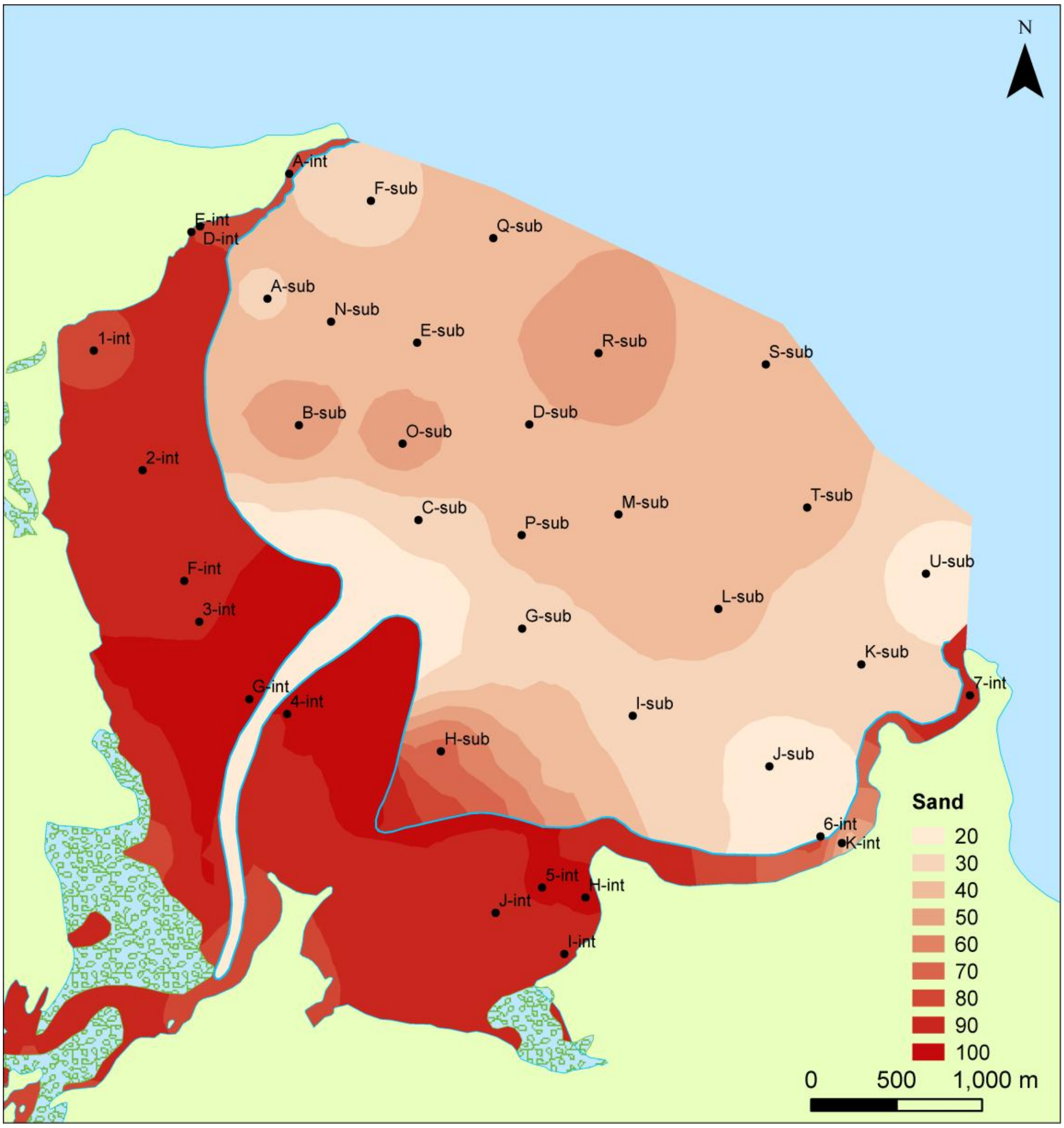
Map 1

GIS interpolation of sediment mud content (percent, by weight, of particles in the 0-63 µm size range (silt + clay)). Intertidal and subtidal data were interpolated separately and then pieced together to form a single map.



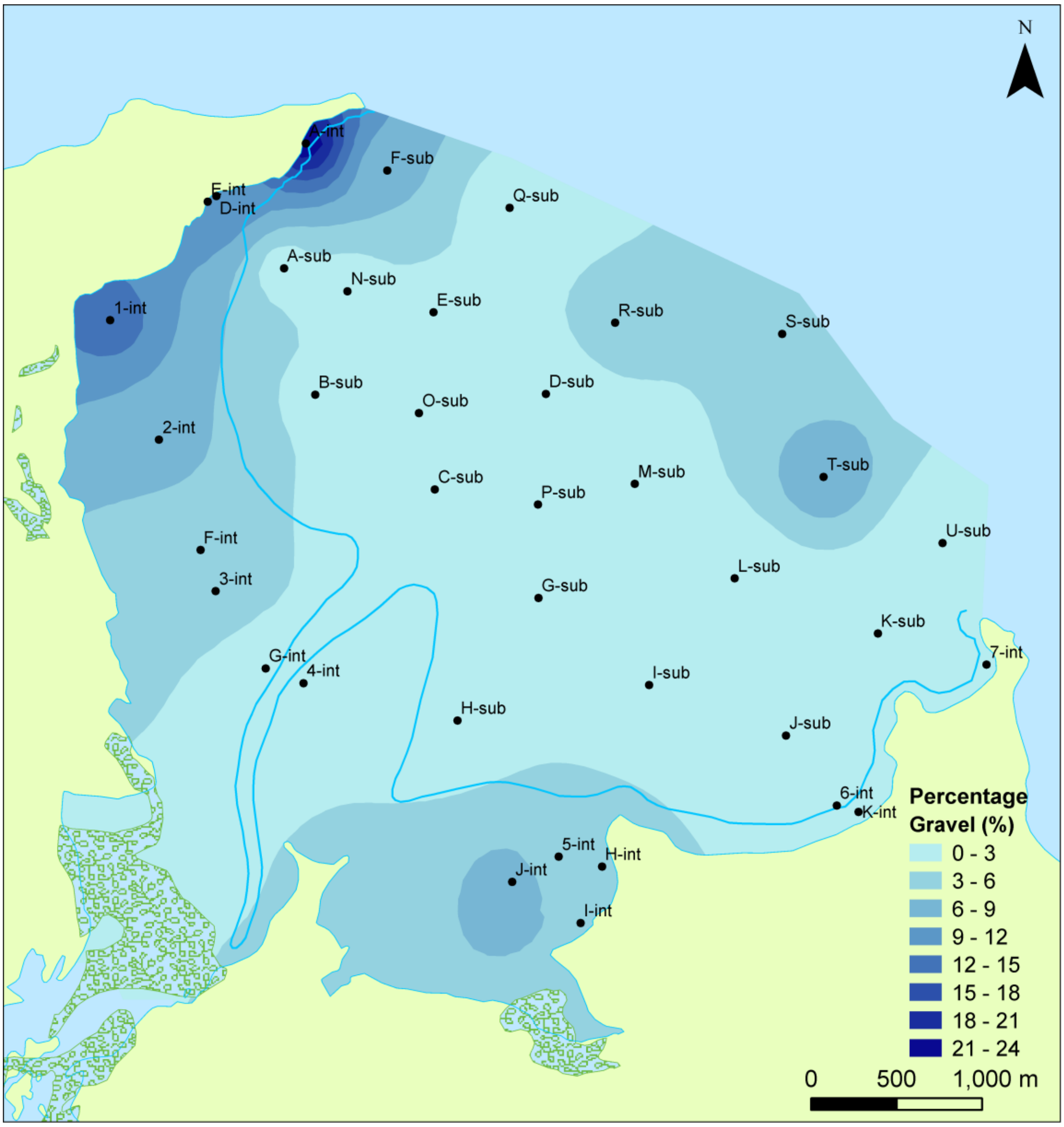
Map 2

Sediment sand content (percent, by weight, of particles in the 63-500 µm size range). Intertidal and subtidal data were interpolated separately and then pieced together to form a single map.



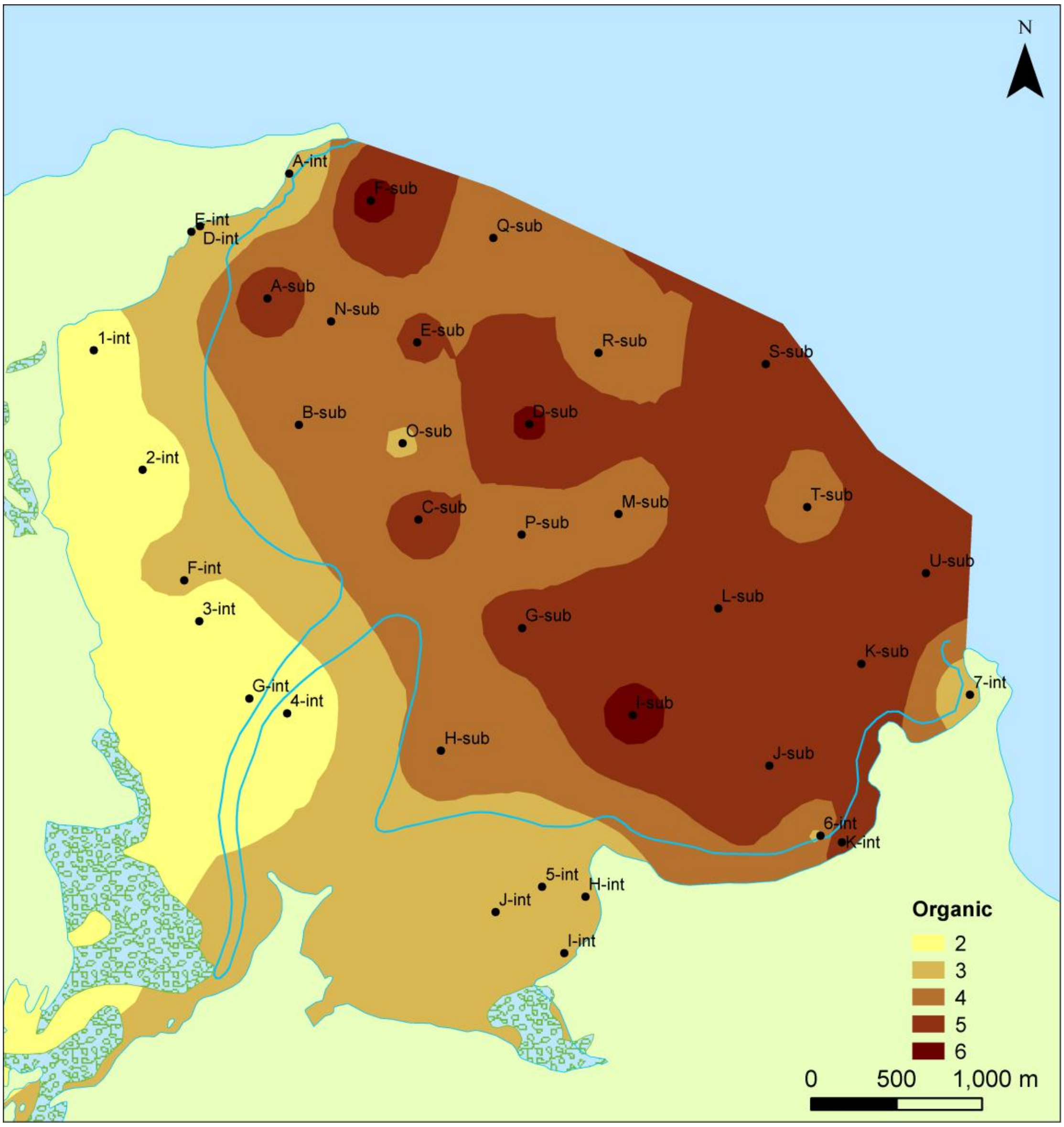
Map 3

Sediment “gravel” content, which generally indicates the presence of shell hash. Data are percent, by weight, of particles >500 µm. A single interpolation using data from all intertidal and subtidal sites (shown on map) was used.



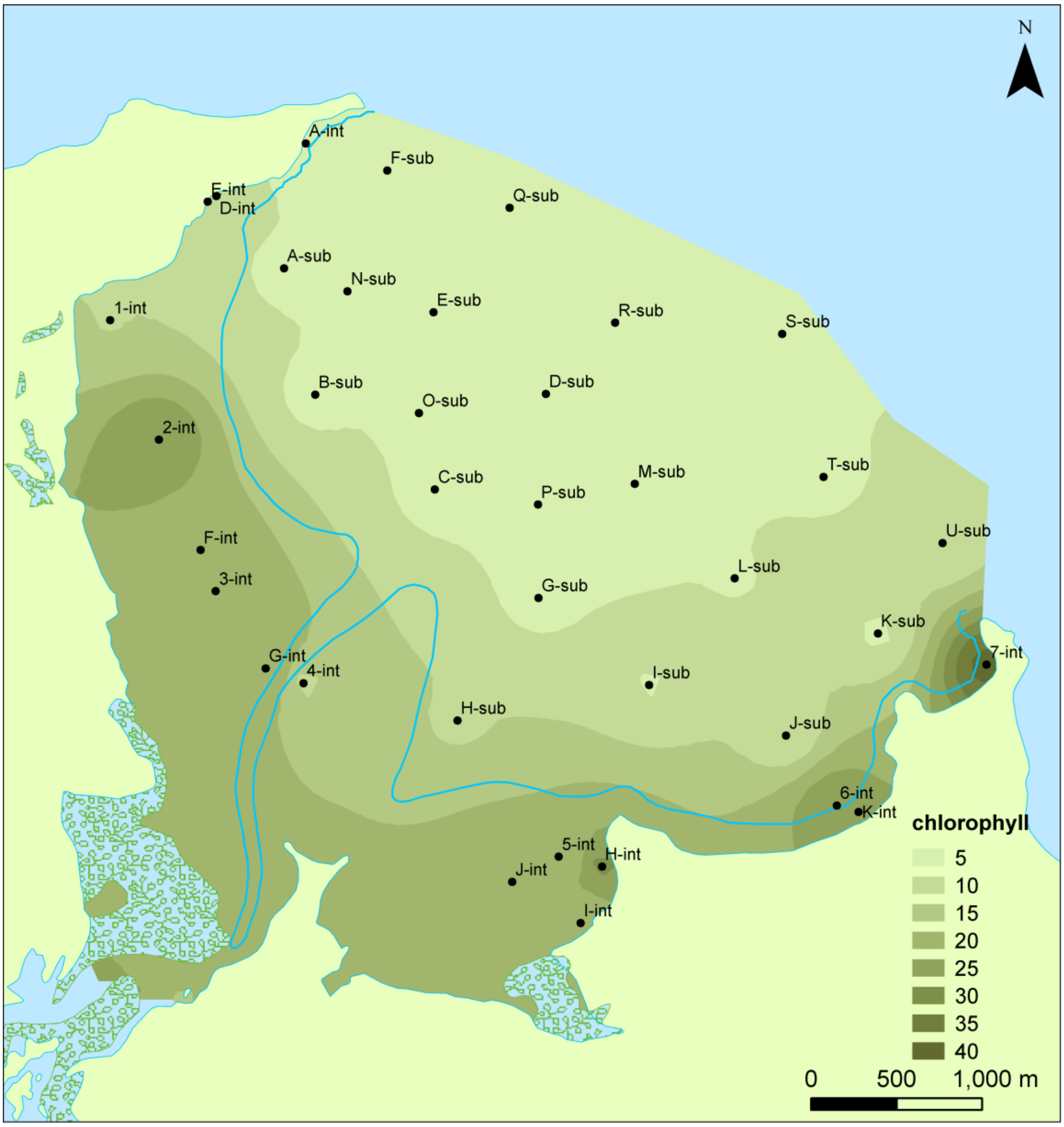
Map 4

Sediment organic matter content (% of dry mass lost during combustion at 400º C for 24 hr). A single interpolation using data from all intertidal and subtidal sites (shown on map) was used.



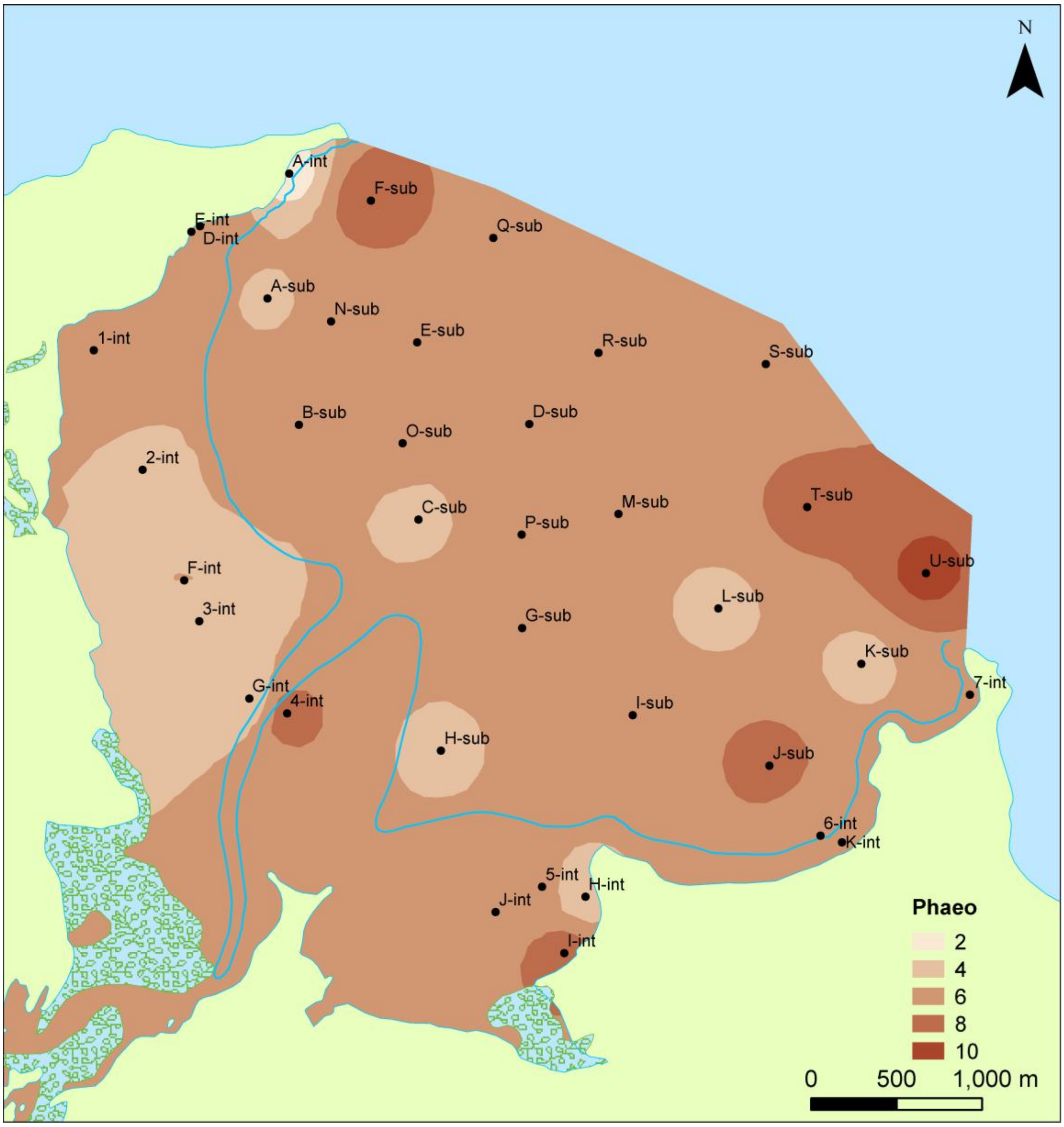
Map 5

Sediment chlorophyll *a* content (µg Chl*a* per g of dry sediment). A single interpolation using data from all intertidal and subtidal sites (shown on map) was used.



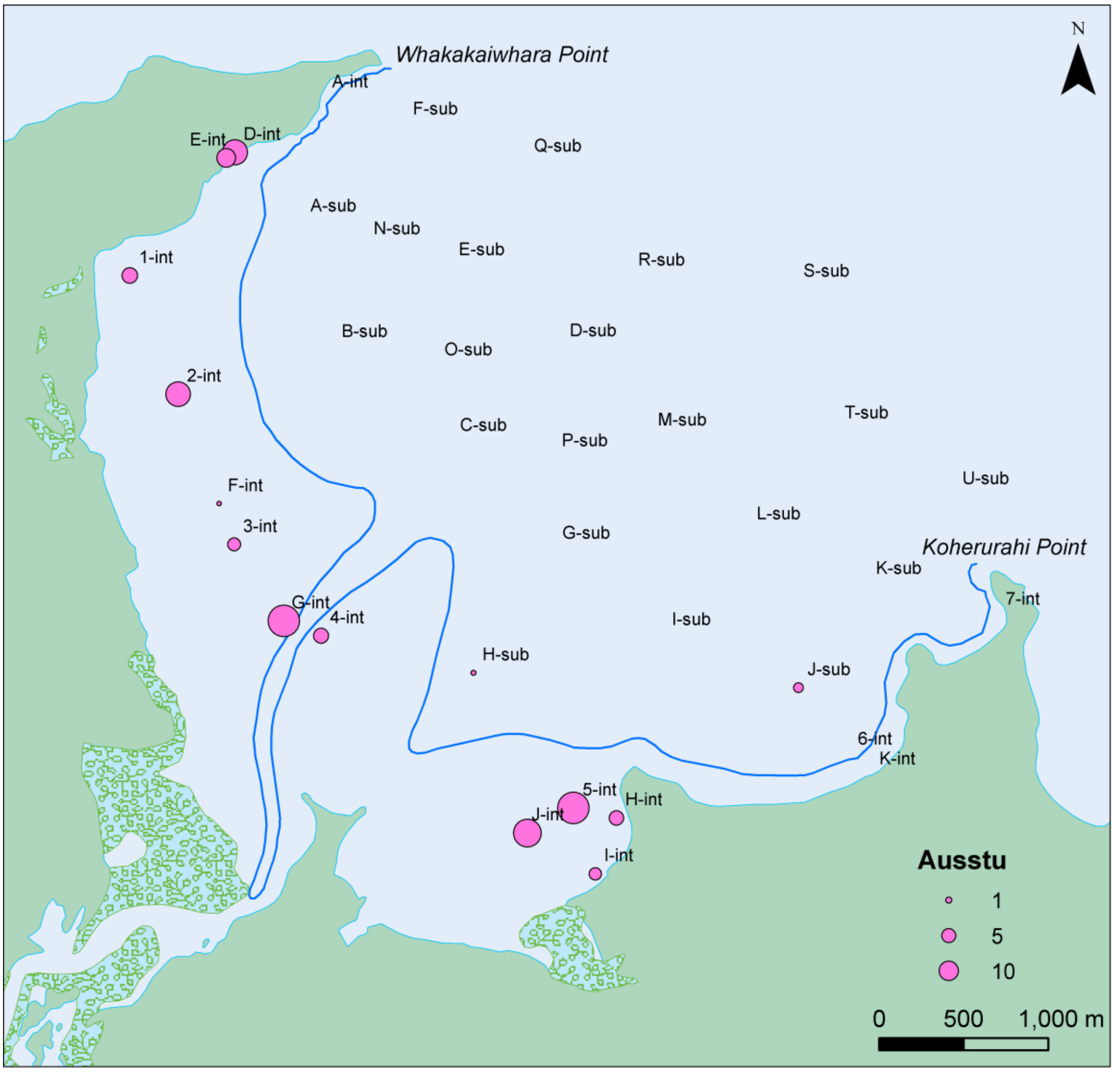
Map 6

Sediment phaeophytin content (µg phaeophytin per g of dry sediment). A single interpolation using data from all intertidal and subtidal sites (shown on map) was used.



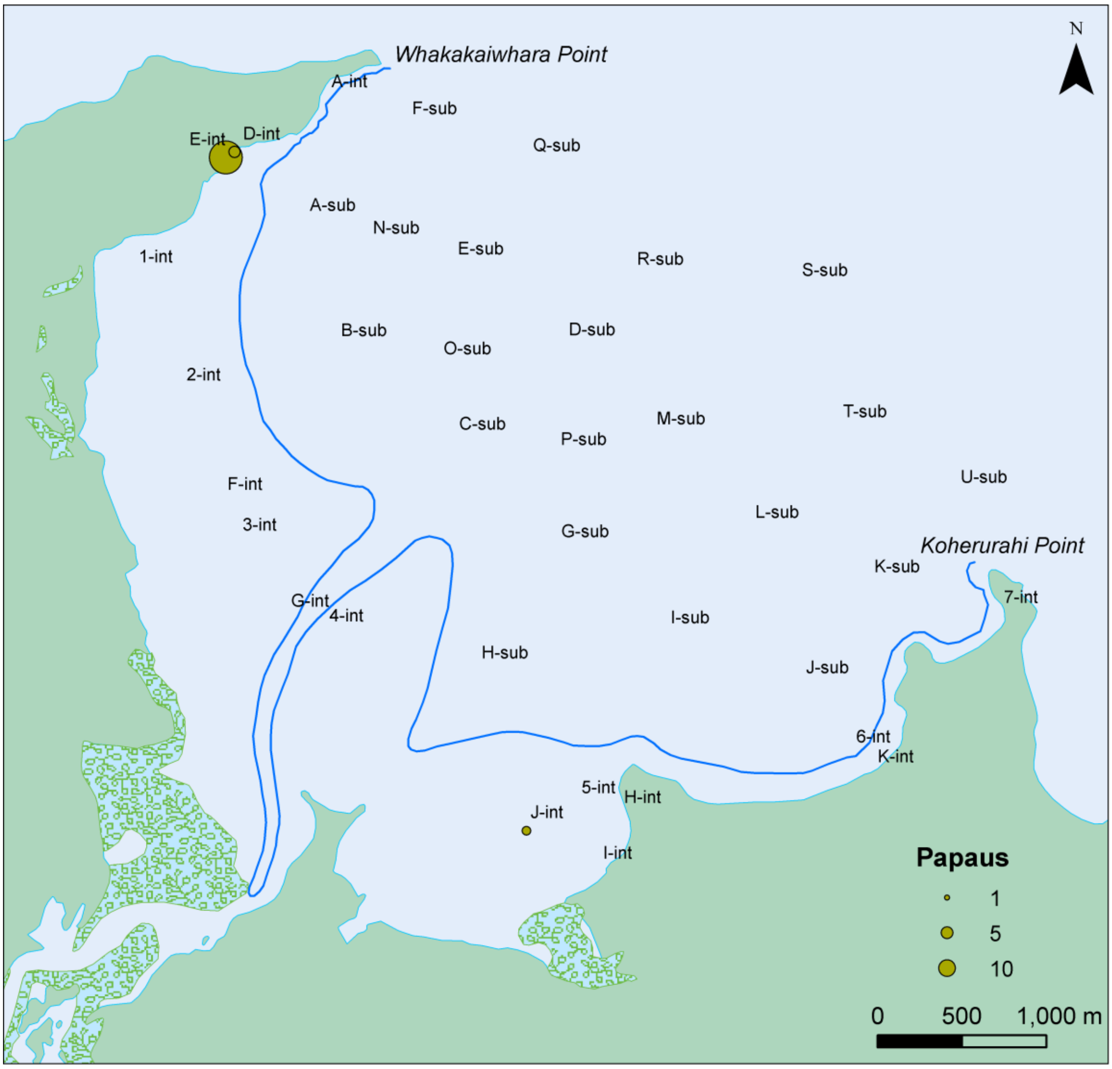
Map 7

Relative abundance (average number of individuals per 100 cm^2) of the large suspension-feeding bivalve, *Austrovenus stutchburyi* (cockle), at sites in the Wairoa Embayment. Cockles were common to abundant at several intertidal soft-sediment sites, including potential monitoring sites 1-int to 5-int (but not 6-int or 7-int).



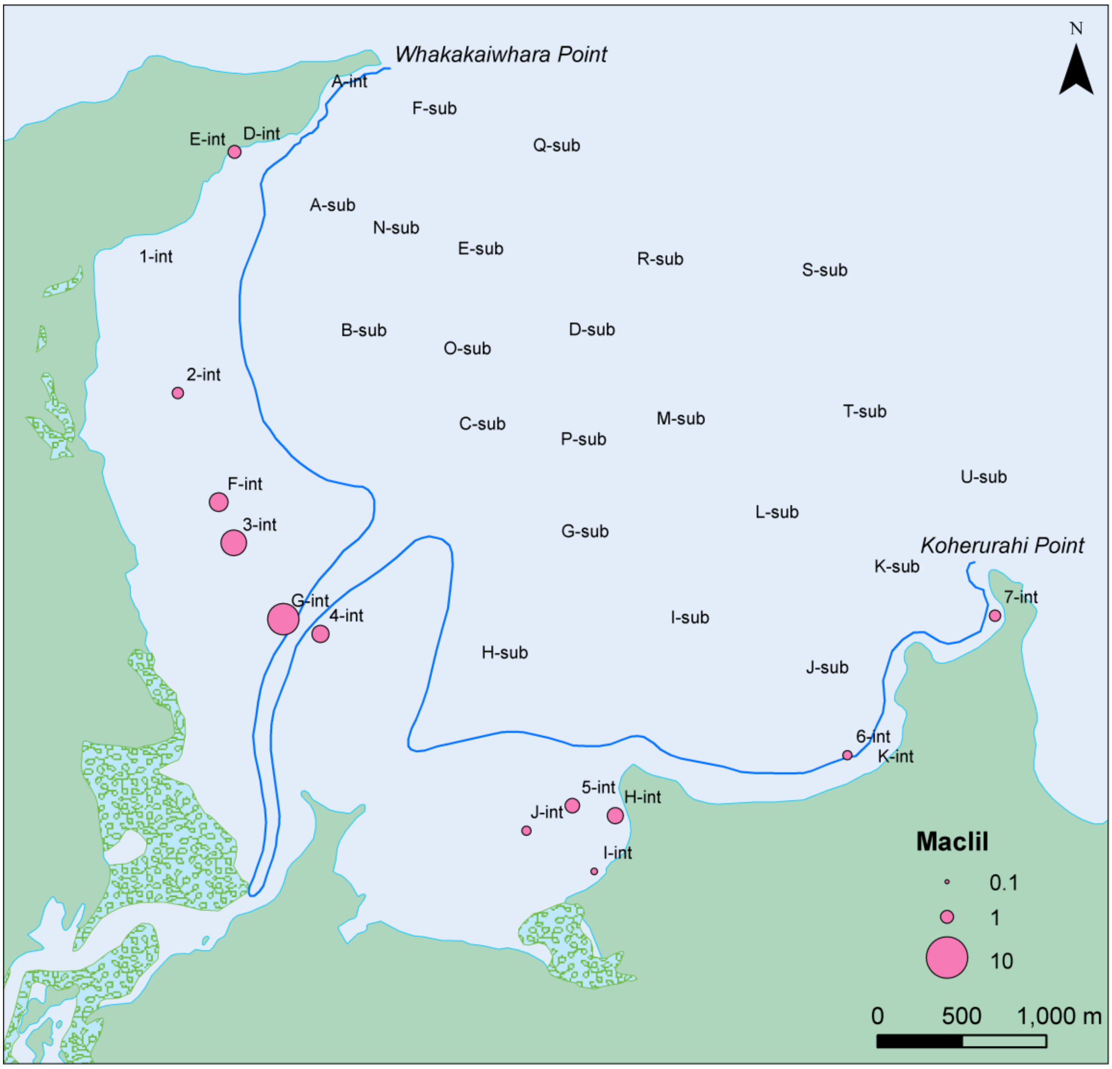
Map 8

Relative abundance of the large suspension-feeding bivalve, *Paphies australis* (pipi), at sites in the Wairoa Embayment. Although there was a high abundance of pipis at intertidal soft-sediment site E-int (with an average of 39 individuals per 100 cm^2), it was absent at 34 of 37 soft-sediment sites.



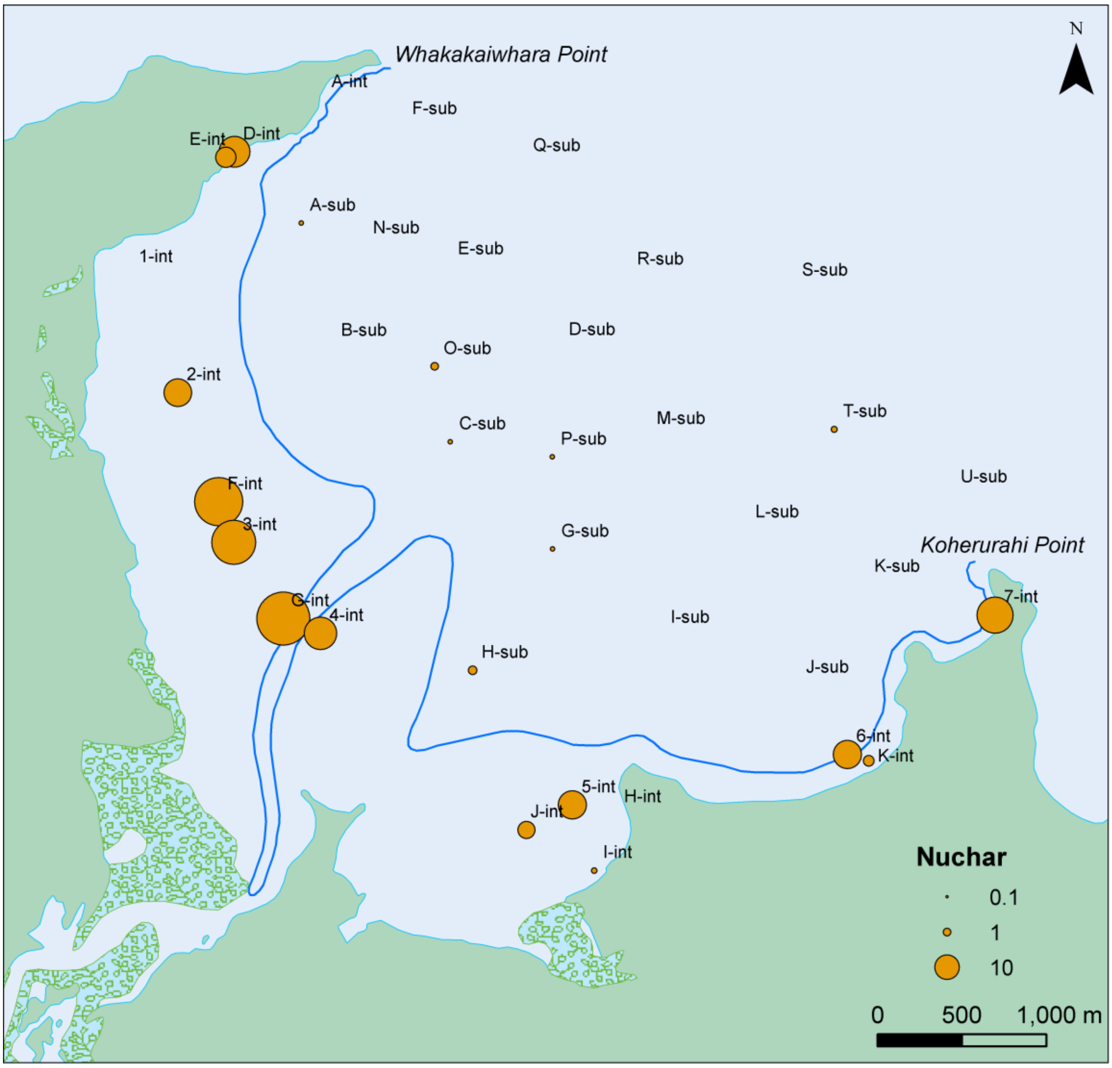
Map 9

Relative abundance of the large deposit-feeding bivalve, *Macomona liliana* (wedge shell), at sites in the Wairoa Embayment. Wedge shells were present at most of the intertidal soft-sediment sites. Maximum abundance was approximately 6 individuals per 100 cm^2.



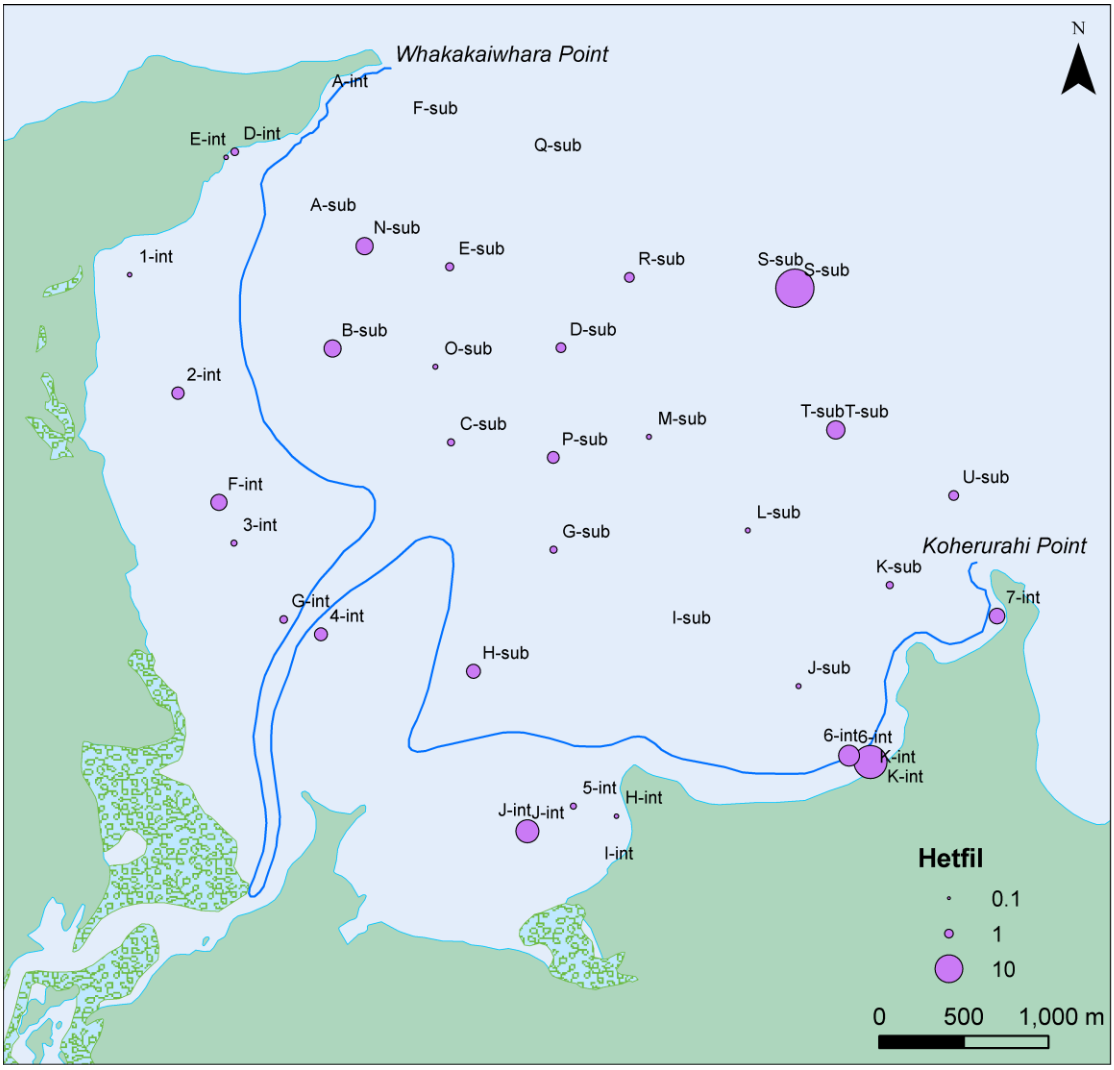
Map 10

Relative abundance of the small deposit -feeding bivalve, *Nucula hartvigiana* (nut shell), at sites in the Wairoa Embayment. This species was numerically dominant at several intertidal sites (up to 46 individuals per 100 cm^2), and was found in low abundance at several subtidal sites as well.



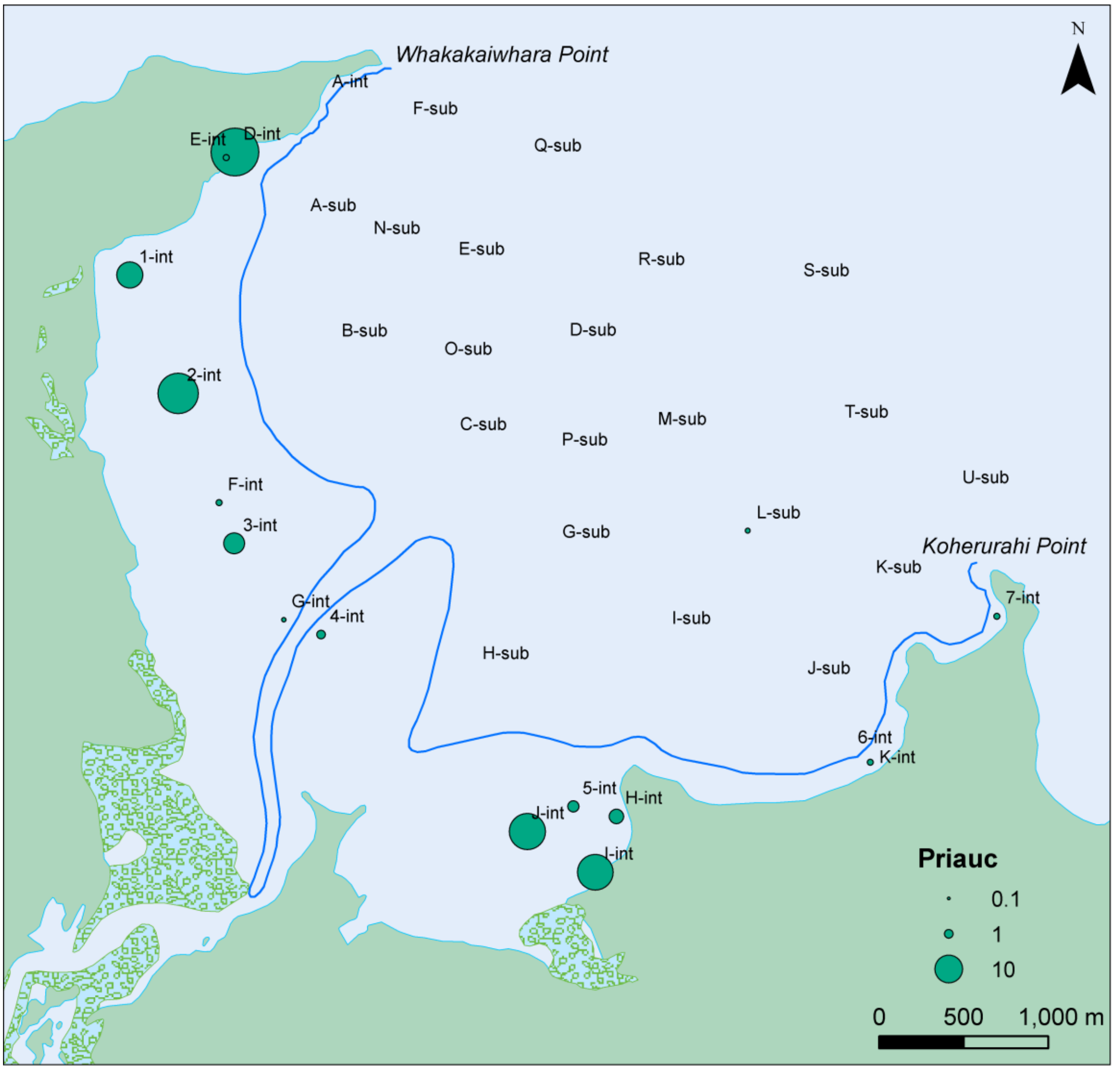
Map 11

Relative abundance (average number of individuals per 100 cm^2) of the common capitellid polychaete, *Heteromastus filiformis*, at sites in the Wairoa Embayment. This species is considered to have broad environmental tolerances and was found in moderate abundance at both intertidal and subtidal soft-sediment sites.



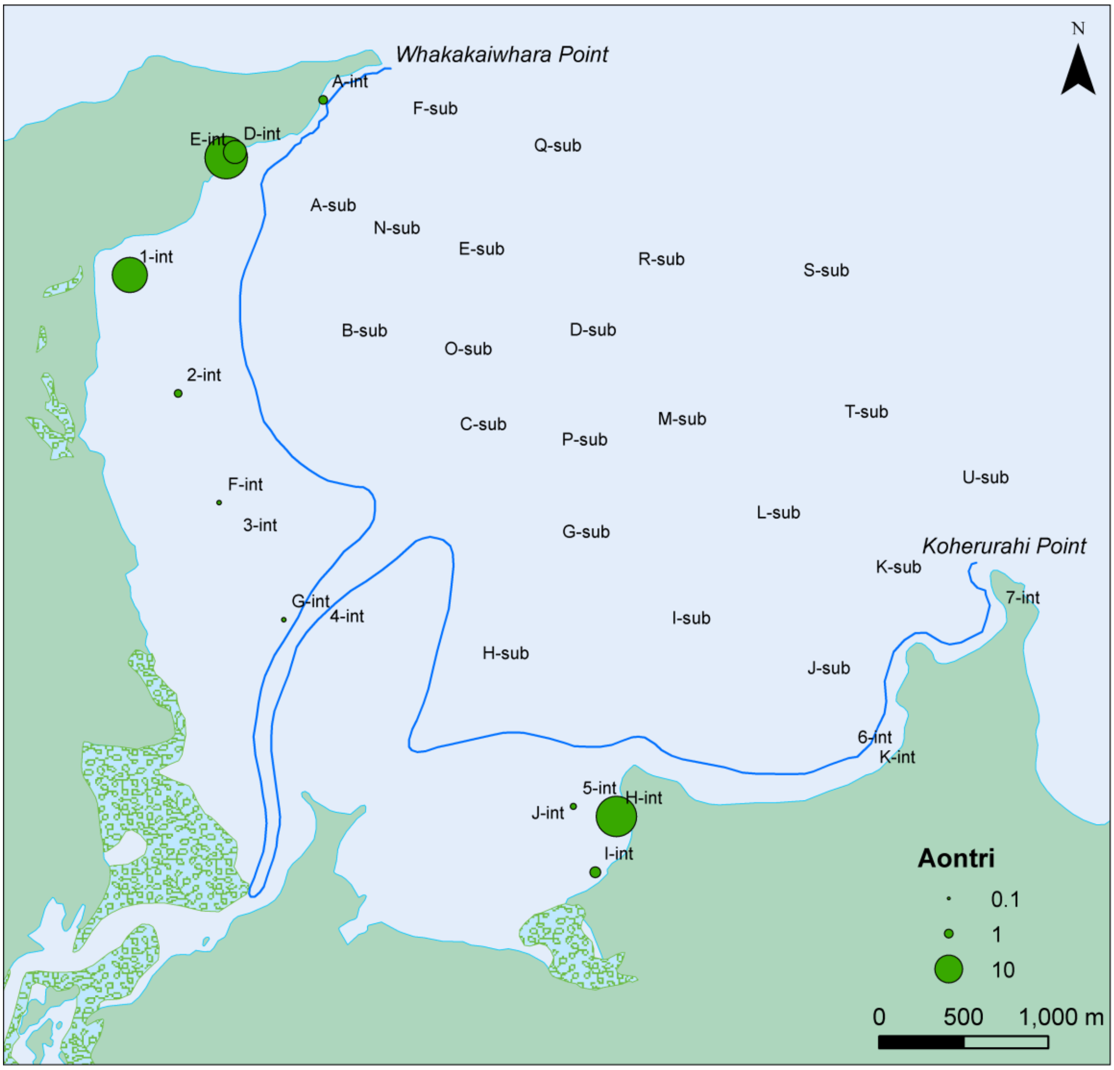
Map 12

Relative abundance of the common spionid polychaete, *Prionospio aucklandica*, at sites in the Wairoa Embayment. This species occurred at all but two of the intertidal soft-sediment sites, although its abundance varied considerably, even among sites in close proximity. Sites D-int and E-int had averaged 29.6 and 0.5 individuals per 100 cm^2, respectively.



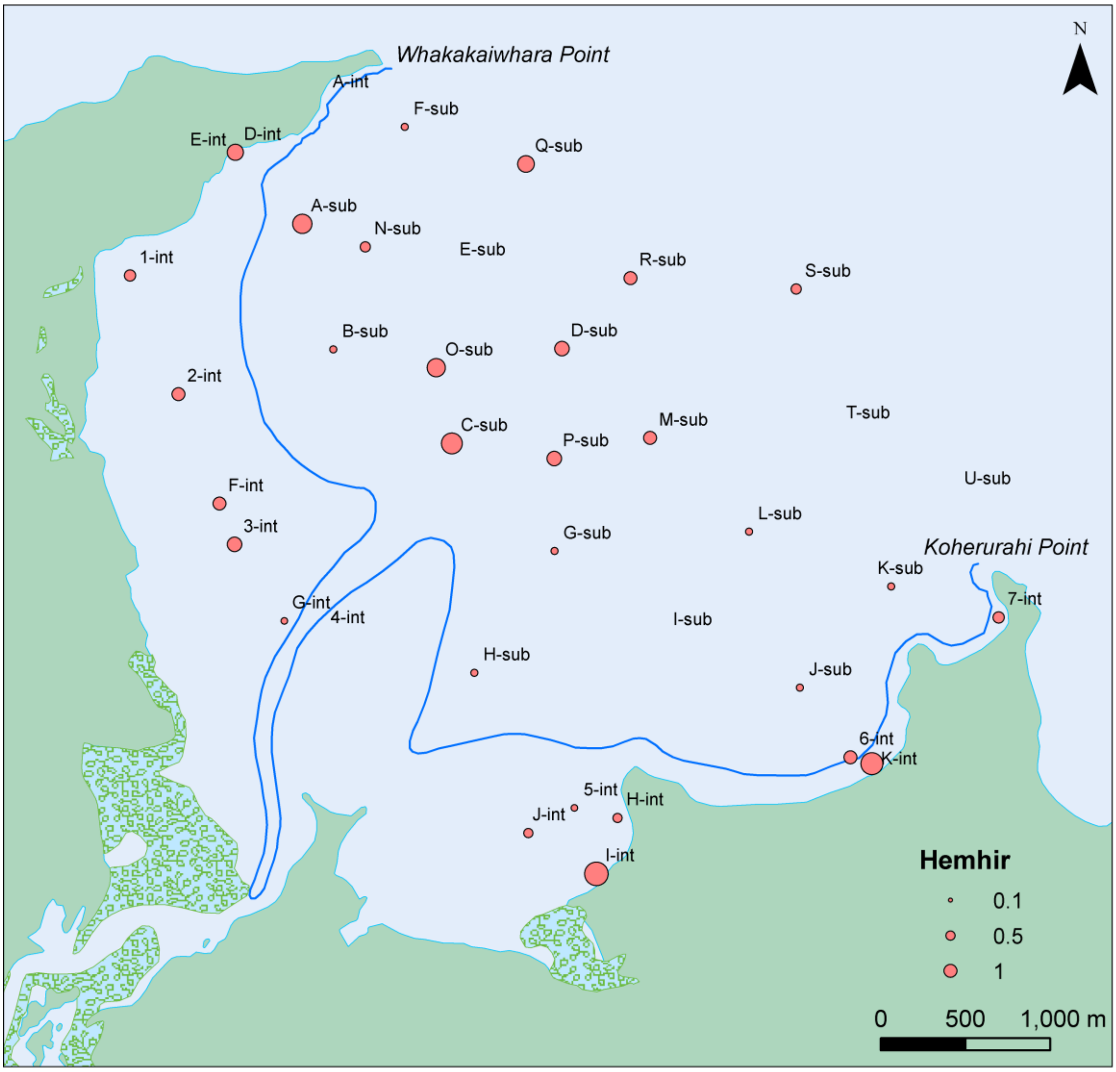
Map 13

Relative abundance of the spionid polychaete, *Aonides trifida*, at sites in the Wairoa Embayment. Although this species was common-to-abundant at four of the intertidal soft-sediment sites (6-24 individuals per 100 cm^2), it was absent or rare (≤1 individual per 100 cm^2) at all other sites.



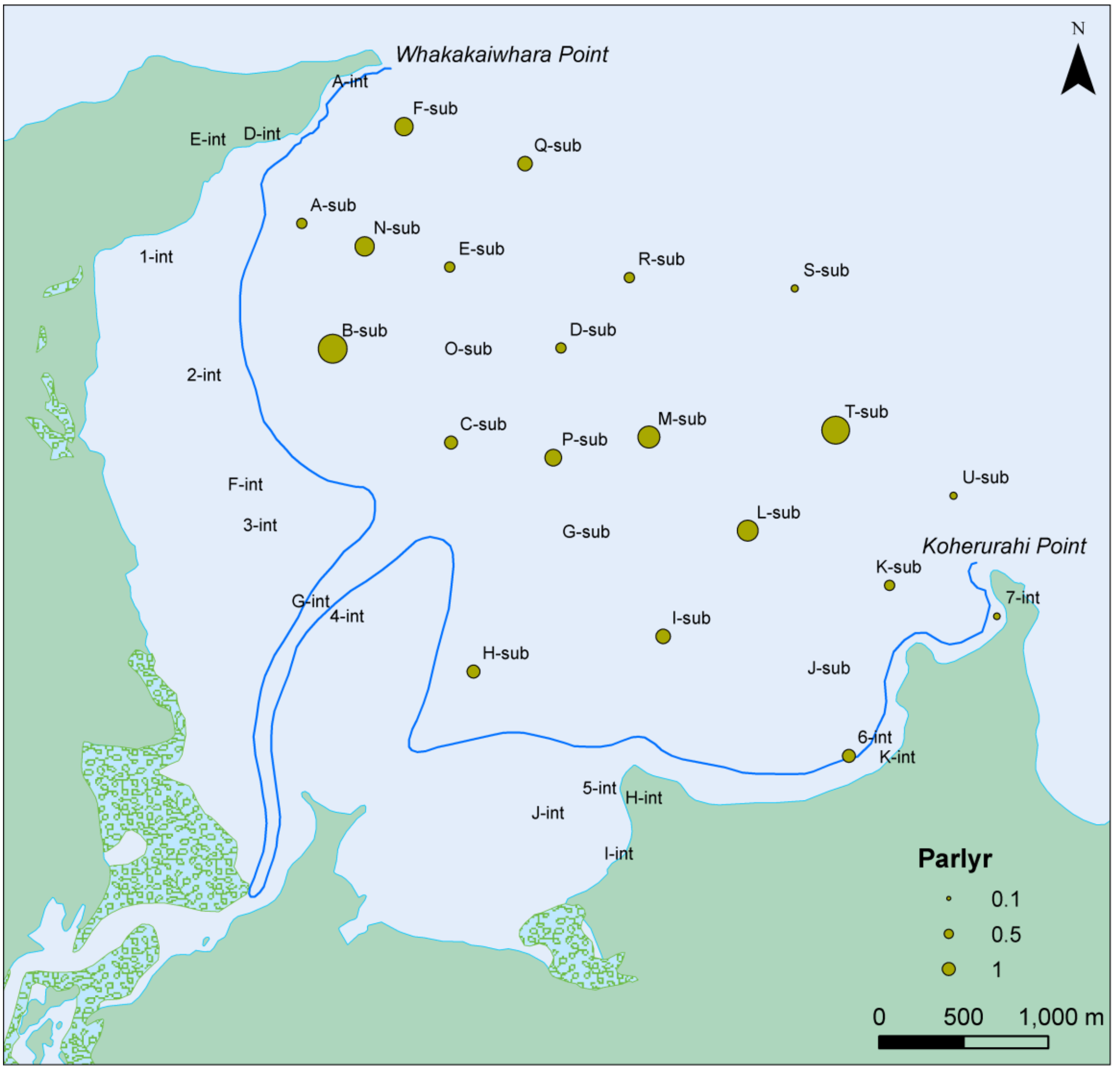
Map 14

Relative abundance (average number of individuals per 100 cm^2) of the ocypodid mud crab, *Hemiplax hirtipes*, at sites in the Wairoa Embayment. This species is known to occur both intertidally and subtidally, and it was found in low abundance at nearly all sampling sites.



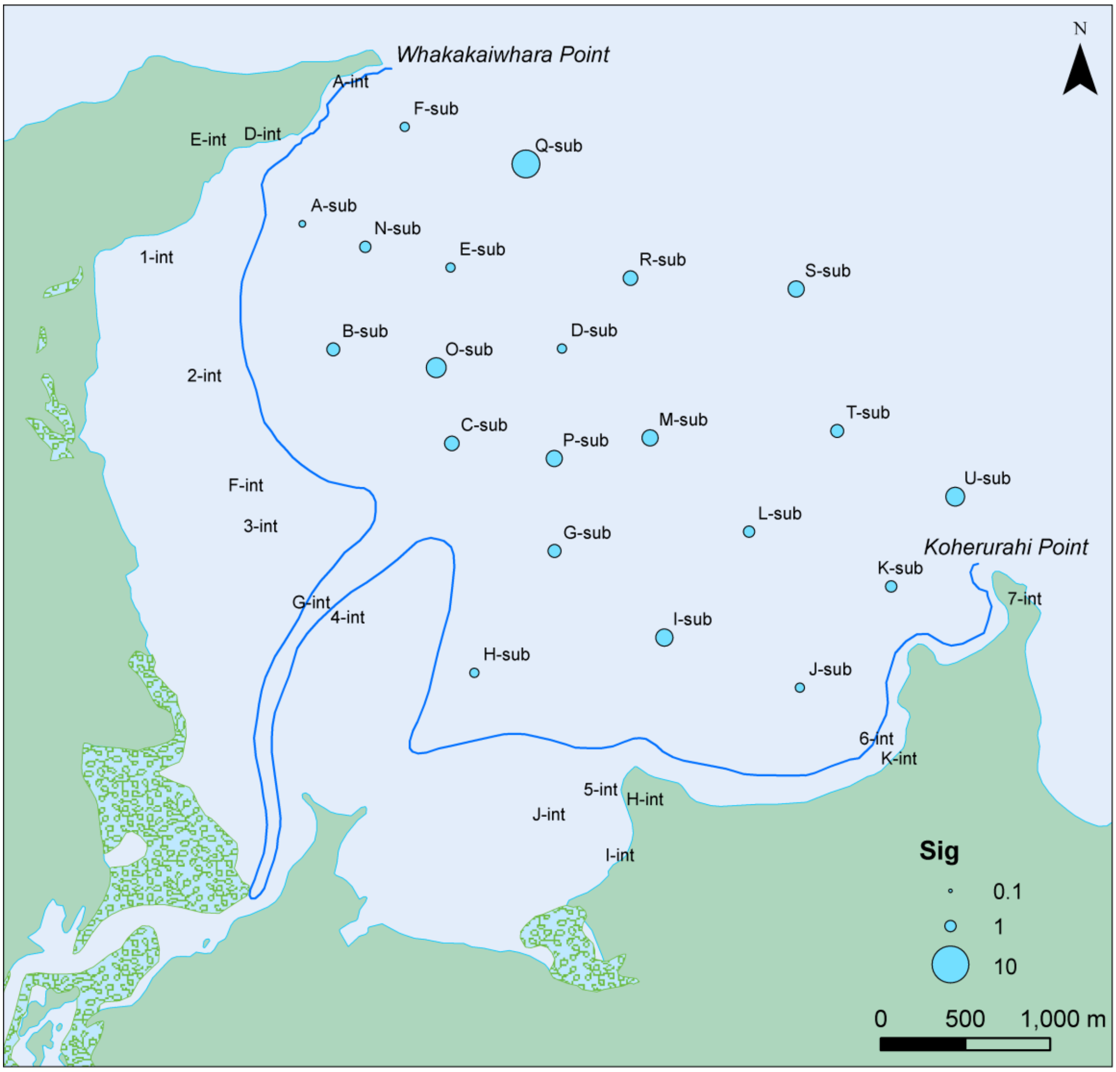
Map 15

Relative abundance of the paraonid polychaete, *Paradoneis lyra*, at sites in the Wairoa Embayment. This species was largely restricted to the subtidal zone, although it was present at intertidal sites 6-int and 7-int. The maximum abundance of this species was <5 individuals per 100 cm^2, although it was the most common species at three subtidal sites.



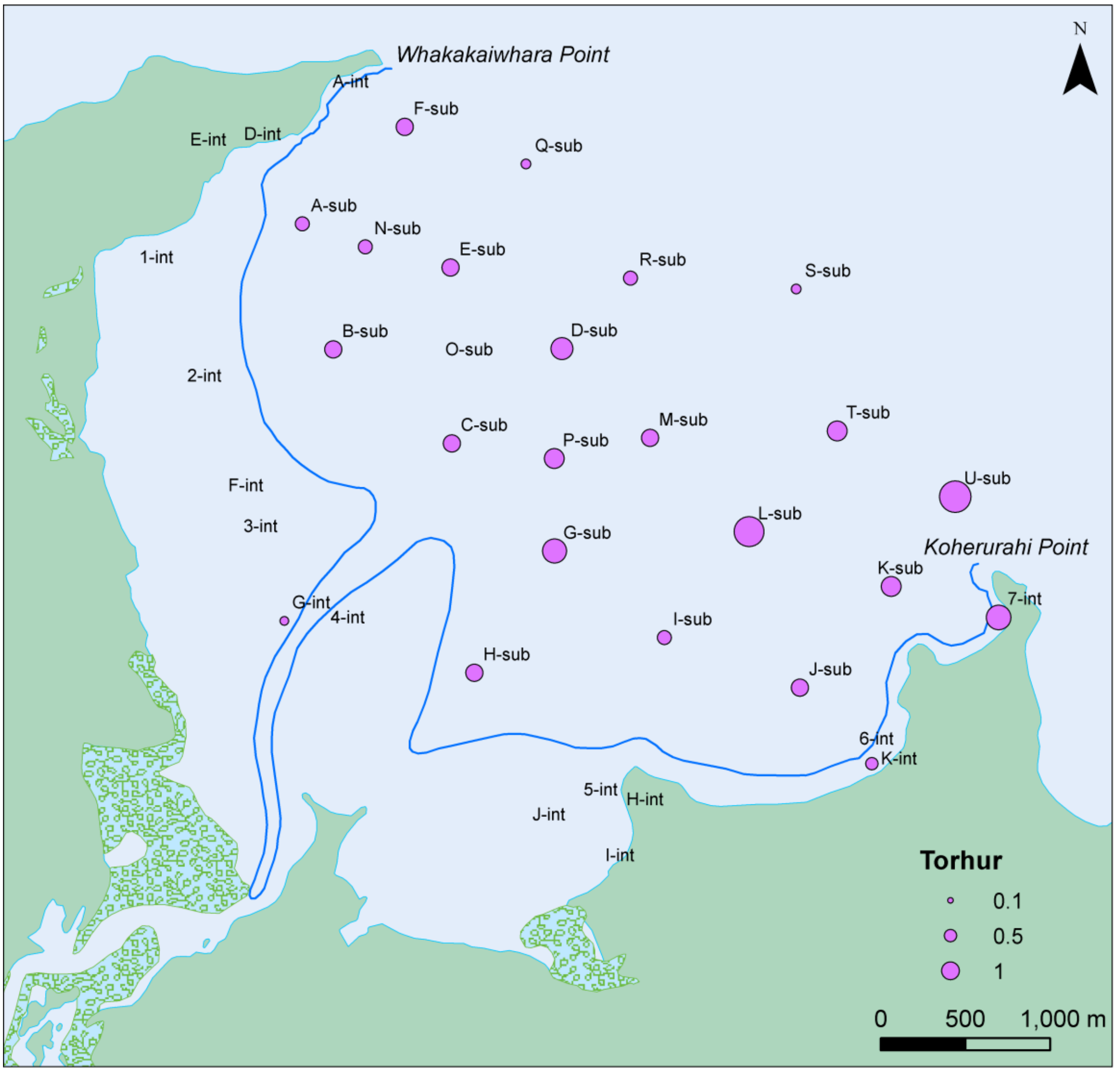
Map 16

Relative abundance of a scale worm from the family Sigalionidae at sites in the Wairoa Embayment. Similar to the pattern for *Paradoneis* (previous figure), sigalionids were largely restricted to the subtidal zone, with a maximum abundance of 5.7 individuals per 100 cm^2. Sigalionids were the most common macrofaunal taxon at four of the subtidal sites.



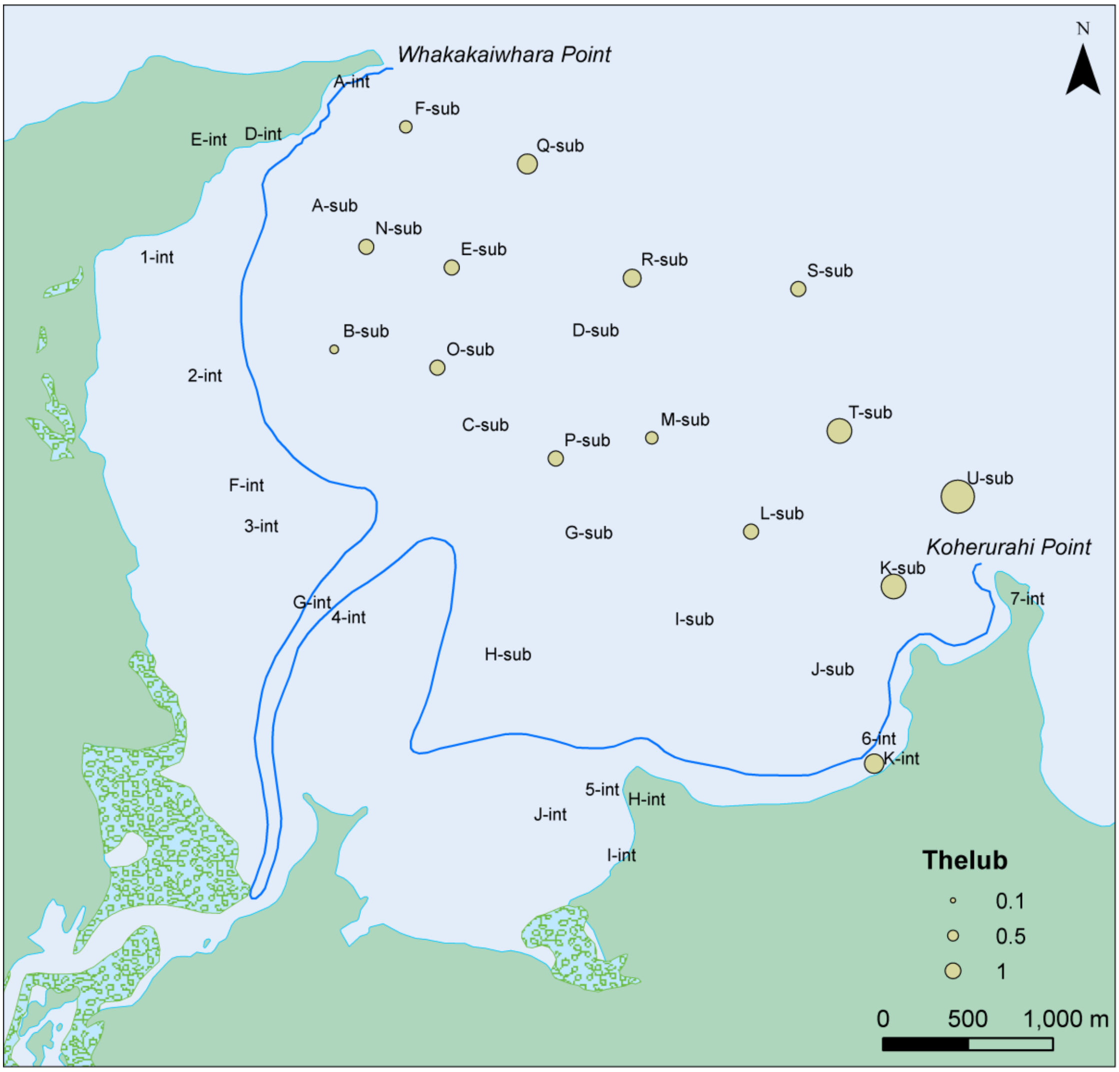
Map 17

Relative abundance of the phoxocephalid amphipod, *Torridoharpinia hurleyi*, at sites in the Wairoa Embayment. This species occurred at all but one of the subtidal soft-sediment sites and, although its maximum abundance was low (<3.2 individuals per 100 cm^2), it was the most common species at 3 depauperate subtidal sites.



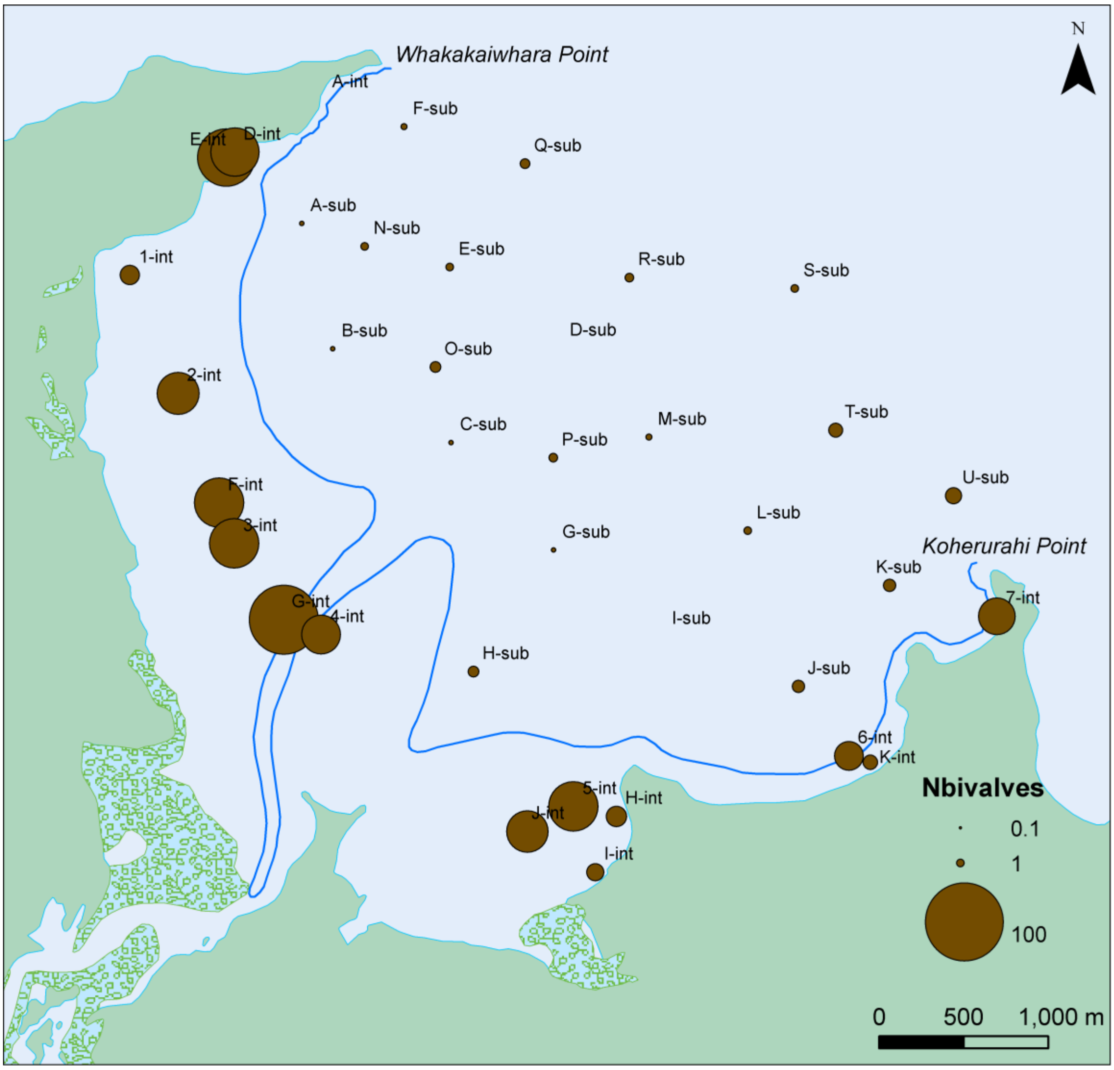
Map 18

Relative abundance of the small, thin-shelled, non-indigenous bivalve, *Theora lubrica*, at sites in the Wairoa Embayment. This bivalve was the most abundant species at two of the muddiest subtidal sites (K-sub, U-sub) and the muddiest intertidal site (K-int). Overall, however, abundance was relatively low (≤4.5 individuals per 100 cm^2) and its distribution was predominantly subtidal.



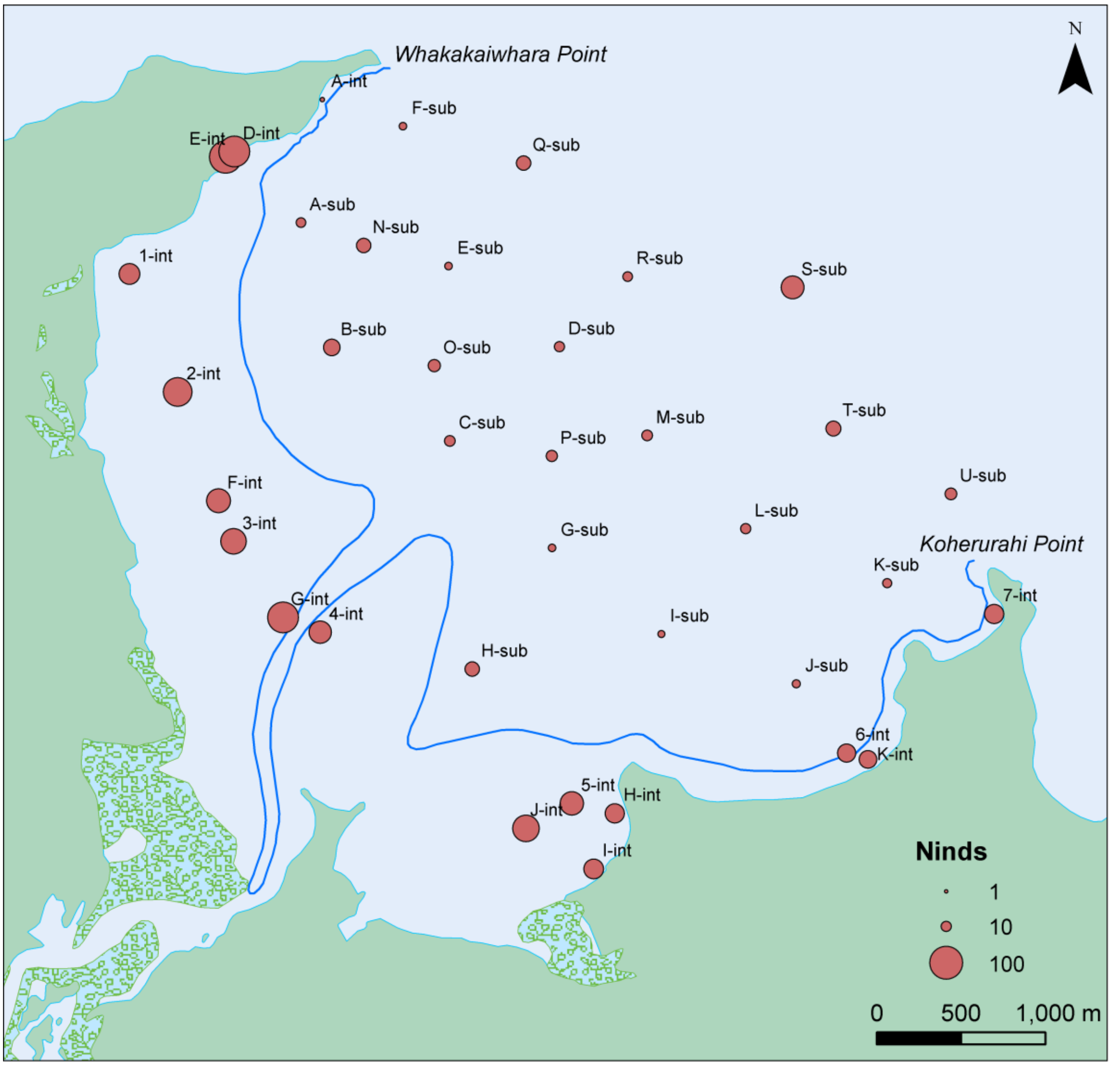
Map 19

Relative abundance of all bivalves collected in macrofaunal cores. Data are averages per site (per 100 cm^2). Bivalves were dominant in intertidal habitats, but relatively scarce subtidally.



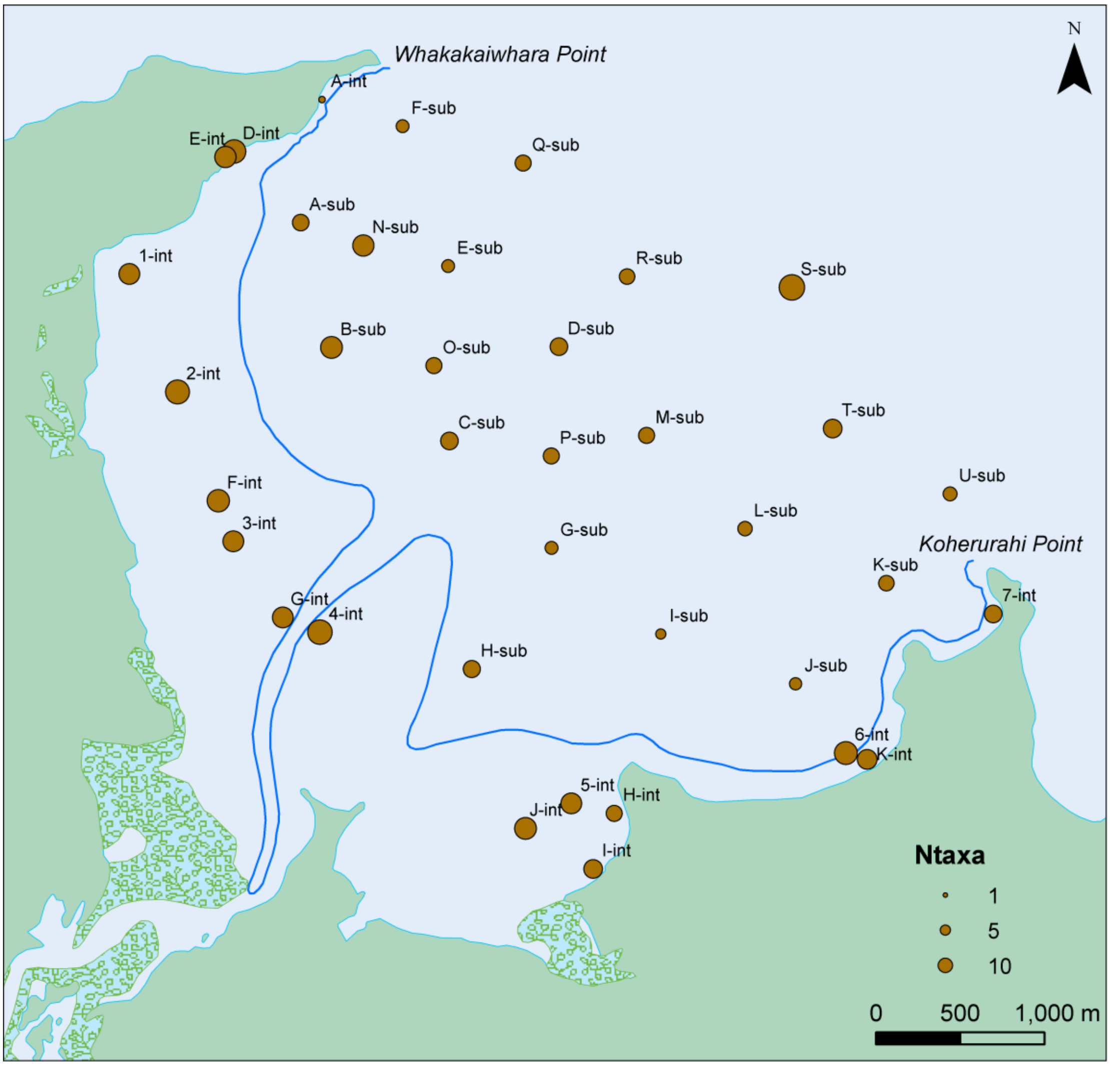
Map 20

Total abundance of macrofauna collected in macrofaunal cores. Data are averages per site (per 100 cm^2). Macrofaunal abundance was significantly greater in the intertidal zone than it was subtidally.



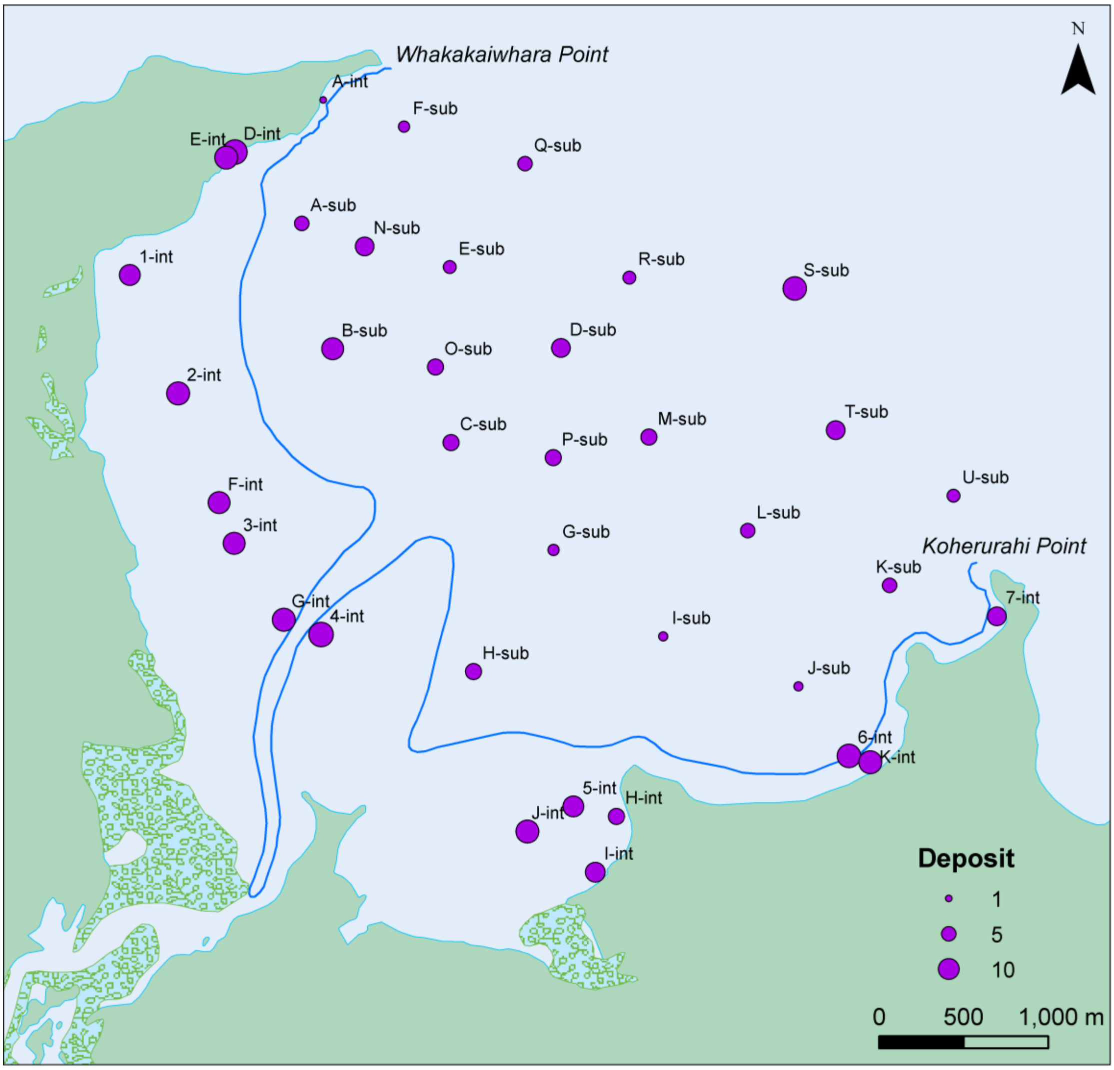
Map 21

The taxonomic richness of macrofauna identified in macrofaunal cores. Data are averages per site (per 100 cm^2). Overall, macrofaunal richness was significantly greater in the intertidal zone than it was subtidally, although richness at subtidal site S-sub was the highest among all sites.



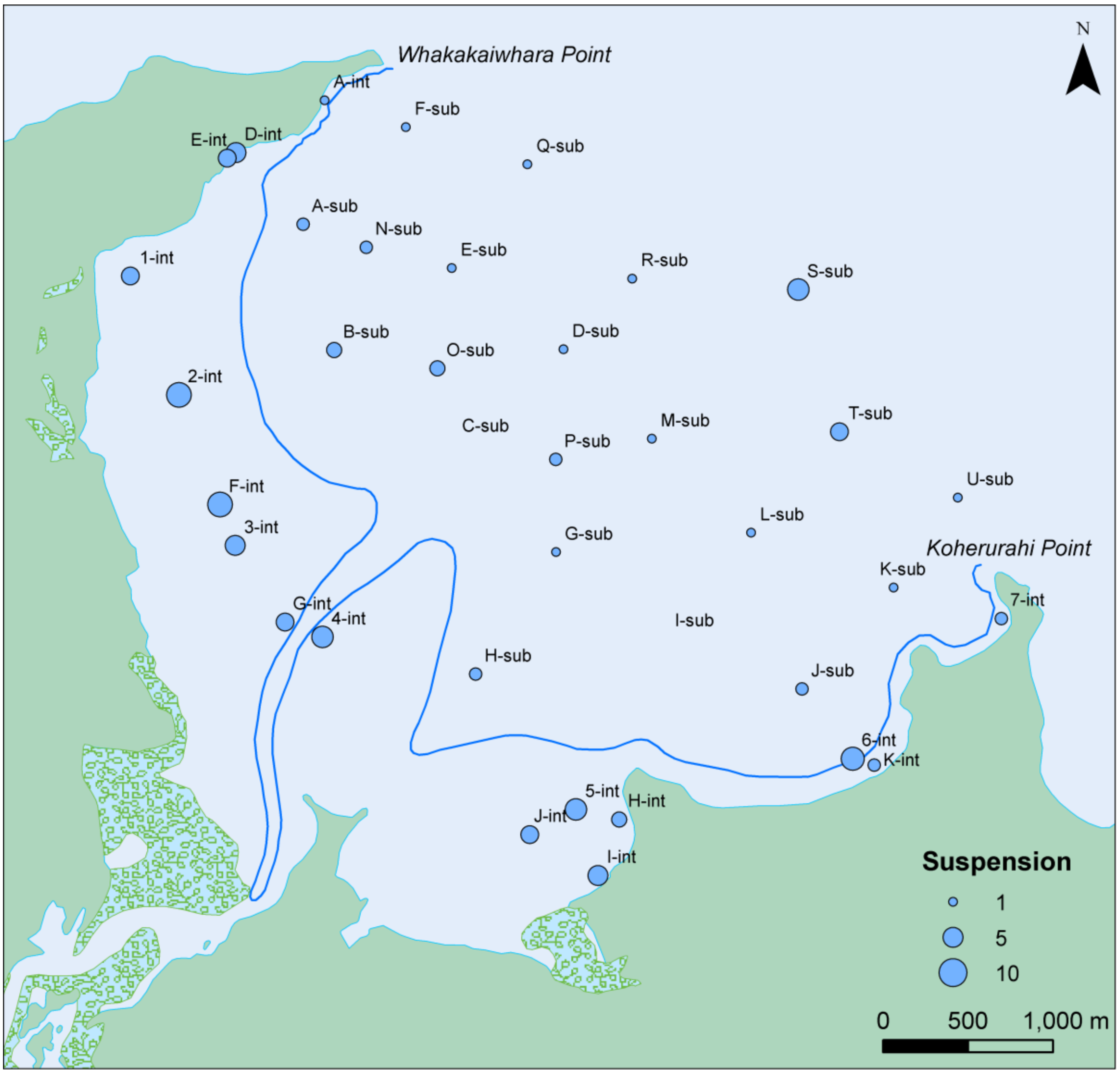
Map 22

The richness of deposit-feeding taxa identified in macrofaunal cores. Data are averages per site (per 100 cm^2). The richness of deposit-feeders was significantly greater in the intertidal zone than it was subtidally, although the richness at subtidal site S-sub was comparable to that found at several intertidal sites.



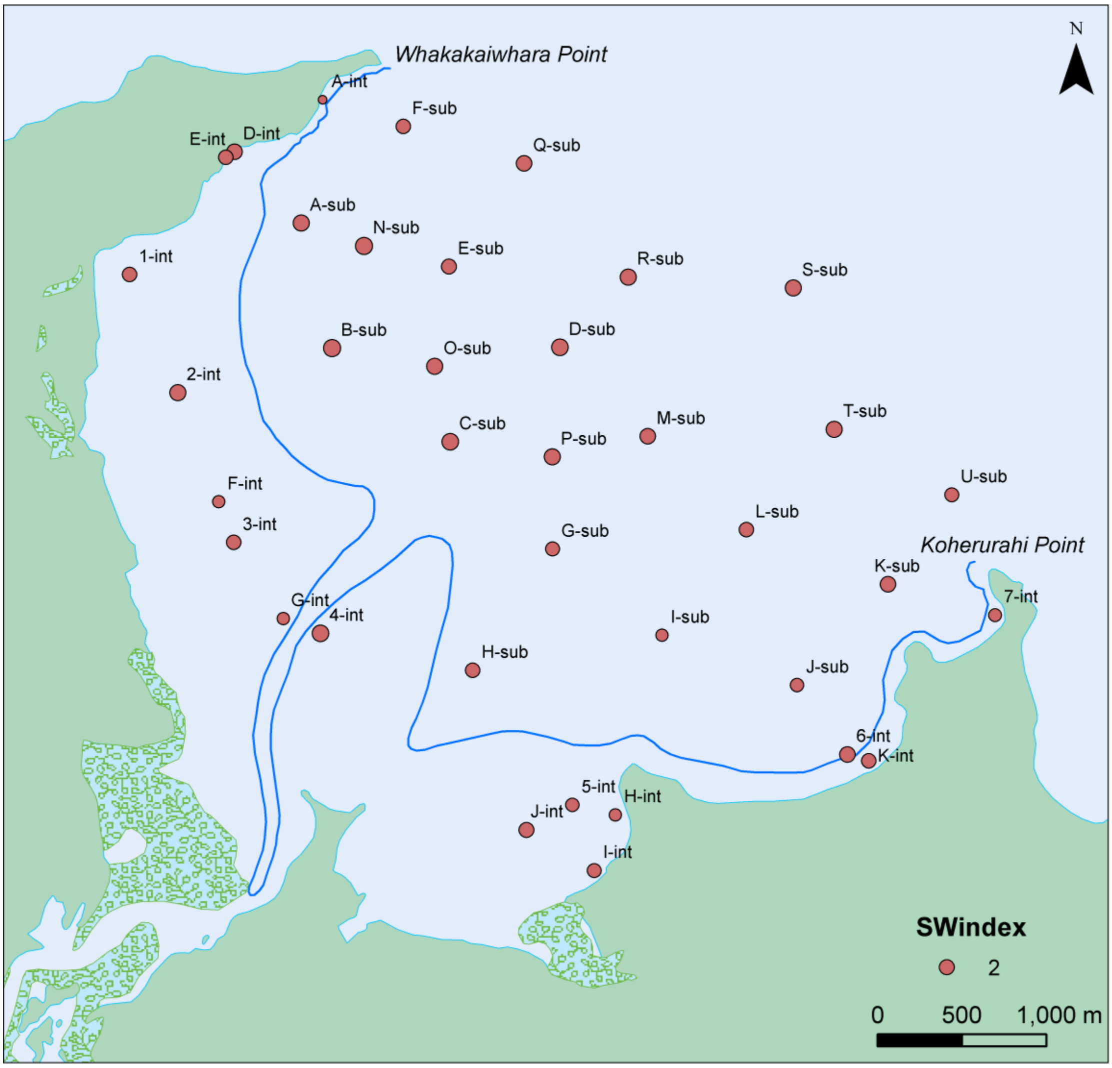
Map 23

The richness of suspension-feeding taxa identified in macrofaunal cores. Data are averages per site (per 100 cm^2). The richness of suspension feeders was significantly greater in the intertidal zone than it was subtidally, although the richness at subtidal site S-sub was comparable to that found at several intertidal sites.



Map 24

Macrofauna diversity (Shannon-Wiener H' index value) at soft-sediment sites in the Wairoa Embayment. Data are averages per site. Diversity was slightly greater in the subtidal zone, despite fewer total individuals and species. One or two individuals from each of 8-12 species per subtidal site was often recorded; this high degree of evenness resulted in higher Shannon-Wiener H' index values in the subtidal zone.



10 Macrofaunal community analysis results

10.1 Rocky shore

In general, the abundance, taxonomic richness and diversity of rocky shore organisms at sites in Wairoa Embayment increased progressively moving down shore, from the upper intertidal zone to the lower part of the shore (Figure 10.1). This reflects the strong physical gradients associated with tidal inundation time (which relates to desiccation stress, the time available for feeding, and exposures to predators). Obviously, there is variation between sites due to differing steepness profiles and wave exposure regimes (which affects the “splash” zone). However, the MDS plot and related ANOSIM analysis revealed that the differences between tidal height zones were much more pronounced than the differences between sites (Figure 10.2).

Across the rocky intertidal sites, the types of dominant species were relatively similar, with the high tide zone dominated by highly tolerant species including the brown surf barnacles *Chamaesipho brunnea* and the small banded periwinkle *Austrolittorina antipodum*, along with black cyanobacterial crust. The matted foliose green alga *Ulva* sp. was present at three of the sites and was the most abundant upper intertidal species at site R2. Across sites, the communities within the high tide zone were 57% similar to each other, with the brown surf barnacle (*Chamaesipho brunnea*) contributing most to the similarity (70%).

In the mid-tide zone, the rock oyster *Saccostrea glomerata*, was generally the dominant species. Across sites, samples from the mid-tide zone were 42% similar to each other, with *S. glomerata* the main contributor to the similarity (31%). Other common mid-zone species were the spiny tube worms *Pomatoceros cariniferus* and algal species such as *Hormosira banksii* (Neptune’s necklace) and *Corallina officinalis* (coralline turf). *Perna canalicula* was occasionally found in this zone and extending into the low tide zone. In fact, many of the most common lower zone species were also found in the mid-tide zone, although the percent coverage of these species was almost always greater in the lower intertidal zone. Coralline turf contributed the most to the 46% similarity of the low tide zone samples across sites (34%).

Figure 10.1

Average number of individuals (top panel), taxa (middle panel), and Shannon-Wiener diversity (lower panel) within the high tide zone (H), mid-tide zone (M) and low tide zone (L) at each rocky reef site R1–R6 (± SE). ND denotes no data available for this site due to poor weather conditions and inaccessibility to the zone.

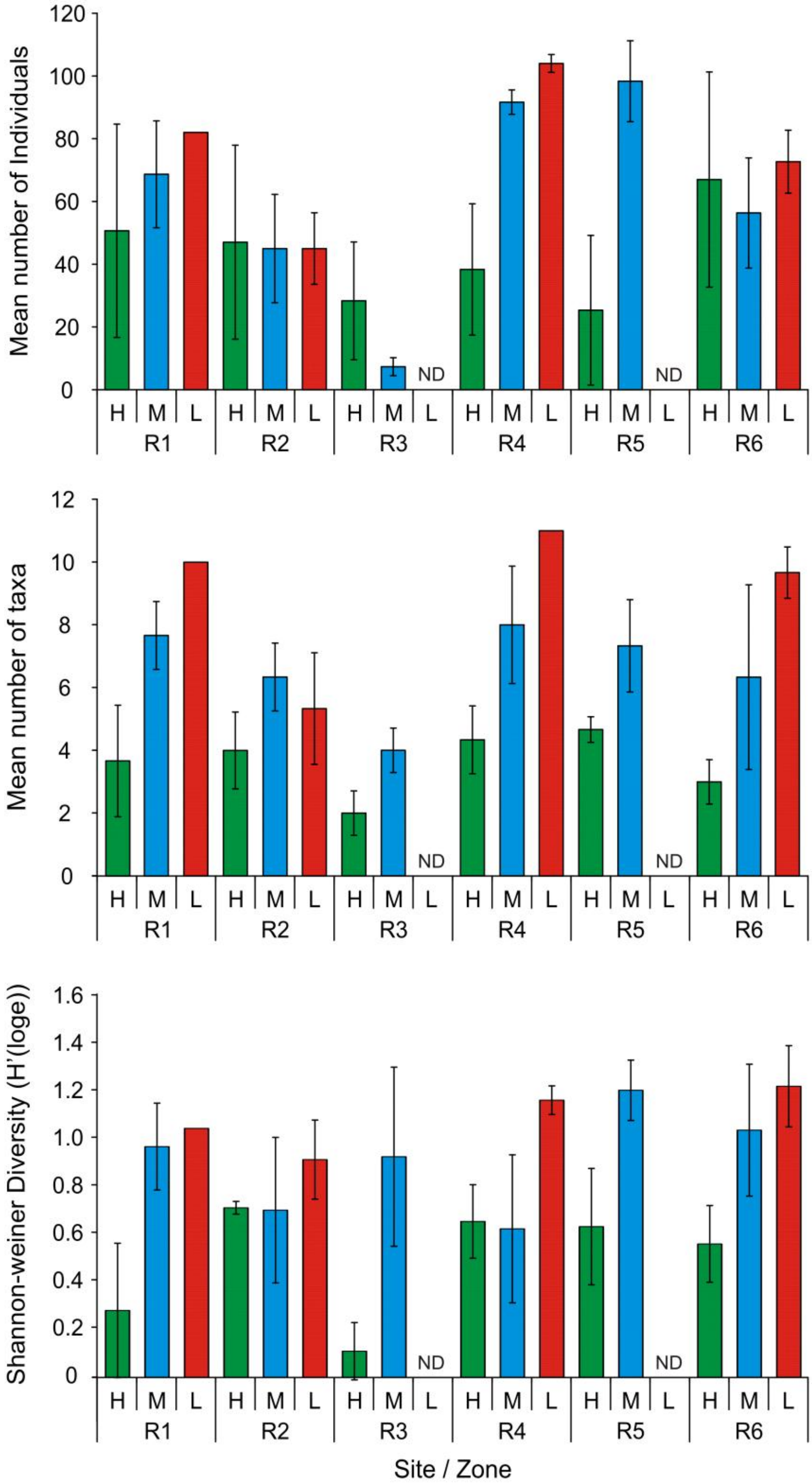
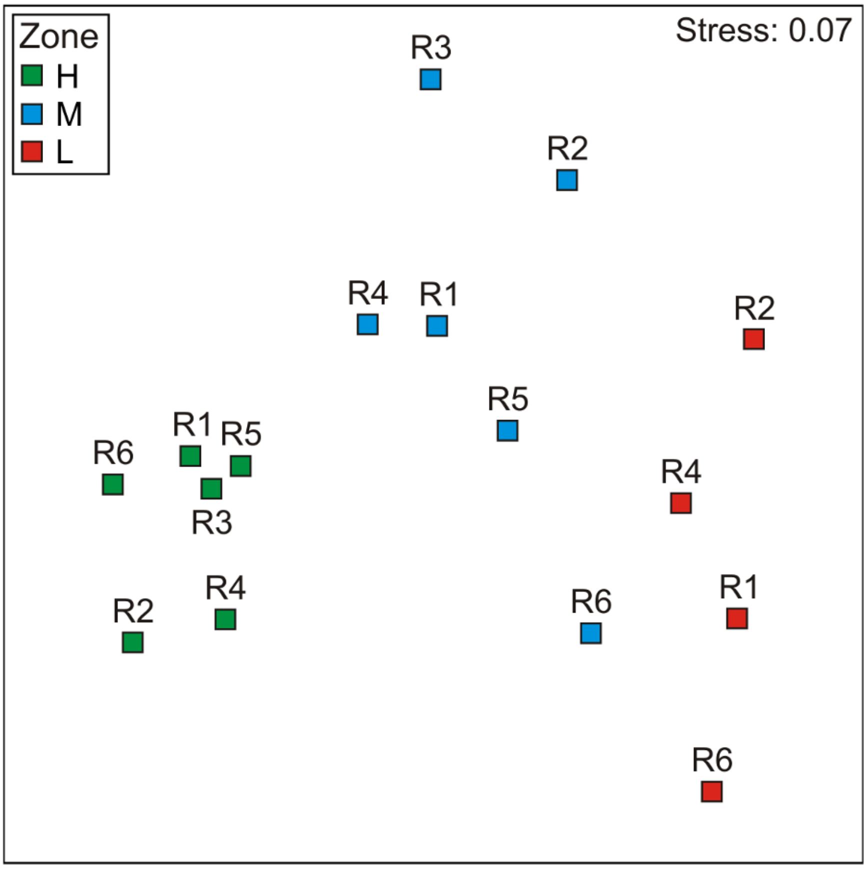


Figure 10.2

Non-metric multidimentional scaling (MDS) ordination plot of rocky reef community structure within each tidal height zone (H = high, M = mid, L = low) at each site (R1-R6). Points that are close together in ordination space represent samples that are similar in terms of community composition. The low stress level (0.07) suggests that the two-dimensional ordination is a reasonably accurate representation of the relative differences in the community data.



10.2 Intertidal and subtidal soft-sediments

Macrofauna communities sampled in Wairoa Embayment intertidal soft-sediment habitats were very different from macrofaunal communities of the adjacent subtidal zone (average Bray-Curtis dissimilarity of 85%) (Figures 10.3 and 10.4).

Figure 10.3

Non-metric multidimentional scaling (MDS) ordination plot of macrofaunal community structure at thirty-seven soft-sediment sites in the Wairoa Embayment. Points that are close together in ordination space represent samples that are similar in terms of community composition. The low stress level (0.11) suggests that the two-dimensional ordination is a reasonably accurate representation of the relative differences in the community data.

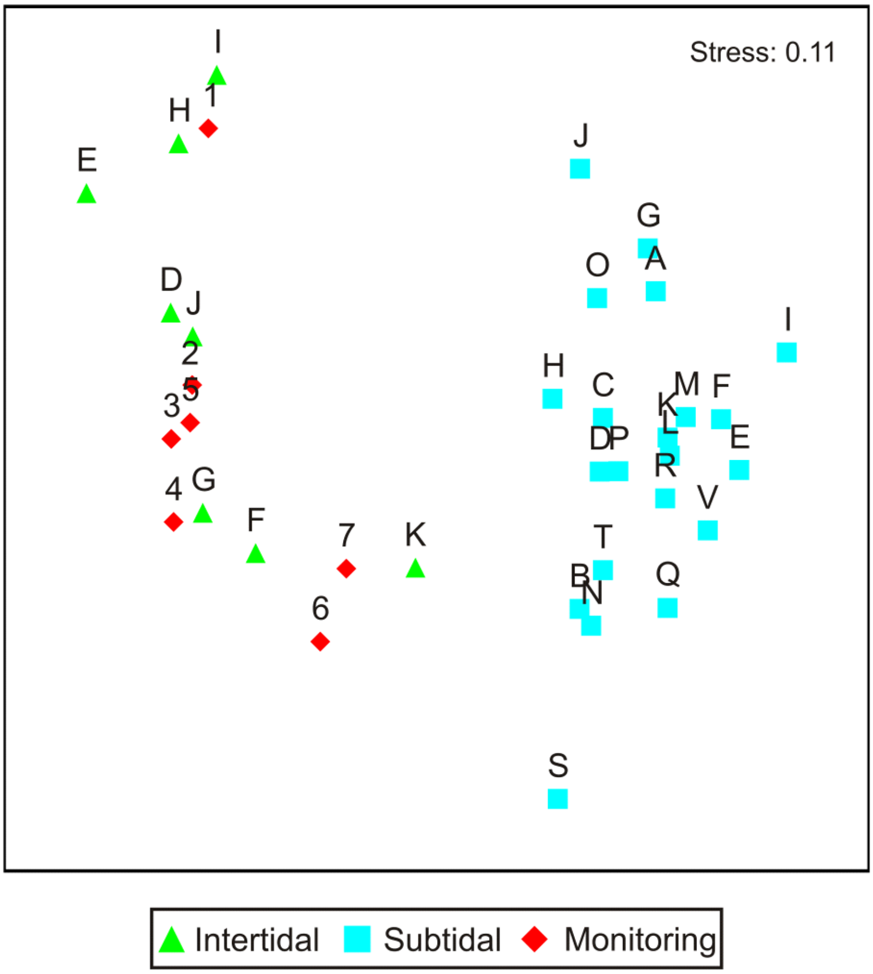
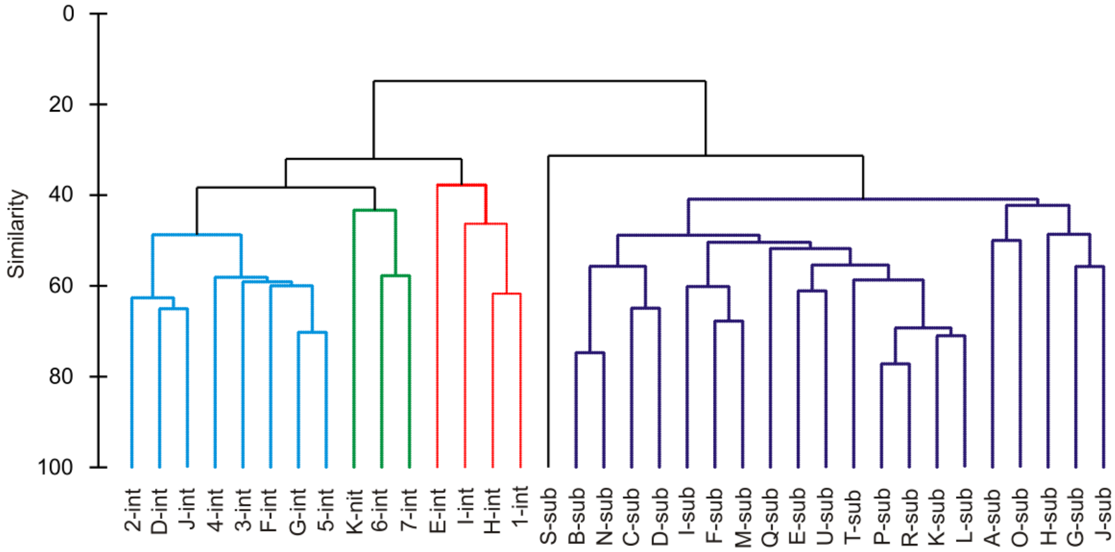


Figure 10.4

A dendrogram depicting groupings among thirty-seven soft-sediment sites in the Wairoa Embayment. Sites that group together are more similar in terms of macrofaunal community composition (average, square-root transformed data based on 3 or 4 replicates per site). There were three distinct groupings of intertidal sites (noted in light blue, green and red). All of the intertidal sites were distinct from the subtidal sites. Subtidal site S-sub was distinct from the rest of the subtidal sites, although no other significant groupings among the subtidal sites were found.



The ten species contributing most to the differences between intertidal and subtidal sites were *Nucula hartvigiana, Austrovenus stutchburyi, Prionospio aucklandica, Aonides trifida* and *Macomona liliana* (species that were dominant in the intertidal zone), Sigalionidae, *Paradoneis lyra, Torridoharpinia hurleyi* and *Theora lubrica* (species that were common in the subtidal zone), and *Heteromastus filiformis* (which was common both intertidally and subtidally). These ten species contributed nearly 50% to the total Bray-Curtis dissimilarity between the intertidal and subtidal sites.

The percentage of silt in the sediment was correlated with macrofaunal community composition in both intertidal and subtidal zones (p=0.005 and 0.03, respectively, Canonical Correspondence Analysis). Other correlates with community composition were the percentage of shell hash and coarse sand (in the intertidal zone) and sediment Chl*a* content (in the subtidal zone).

One exposed site near the tip of Whakakaiwhara Point (intertidal site A-int, dominated by coarse sand and gravel) was excluded from the analyses after confirming that its distinctness was caused by a scarcity of macrofauna (density <2 relative to 28-98 at all other intertidal sites). Subtidal site S-sub, another potential outlier, was left in the analyses given its average of 48 individuals from 30 taxa.

The cluster analysis confirmed the distinctness of S-sub, indicating that it was 69-91% dissimilar to all other subtidal sites (Figure 10.4). S-sub had a particularly high density of *Heteromastus filiformis* and non-bivalve individuals and taxa (e.g., worms such as Sigalionidae). However, apart from the separation of S-sub, there were no statistically significant clustering patterns among the rest of the subtidal sites (Figure 10.4).

As for the intertidal sites, there appeared to be three distinct groupings based on the macrofaunal community data (Figure 10.4):

- Sites 1-int, E-int, H-int and I-int. These sites were spread throughout the Wairoa Embayment (two in the northwest portion, two in the southern portion). The sites were dominated by *Aonides trifida* or *Prionospio aucklandica*, with moderately low densities of *Austrovenus stutchburyi*.

- Sites 2-int to 5-int, D-int, F-int, G-int and J-int. These sites were spread throughout the Wairoa Embayment and had moderately high densities of the bivalves *Austrovenus stutchburyi*, *Macomona liliana*, or *Nucula hartvigiana*.

- Sites 6-int, 7-int and K-int. All three of these sites were all located on the eastern side of Wairoa Embayment. All three were dominated by *Heteromastus filiformis* and *Nucula hartvigiana*, with *Austrovenus stutchburyi* absent.

There was at least one monitoring site (i.e., 1-int to 7-int) contained within each of the three distinct groupings of intertidal sites (Figure 10.5). The monitoring sites that were the most similar to each other—based on the three replicates from each site that were randomly selected for analysis—were 2-int to 5-int (50% similar on average). Sites 6-int and 7-int were 45% similar. Site 1-int was the most distinctive of the monitoring sites, averaging just 25% similarity to the other six sites.

Further analysis of the similarities among the potential monitoring sites was conducted using all twelve replicates collected per site (Figures 10.5 and 10.6). The results confirmed the distinctiveness of 1-int from the others (2-int to 7-int). Sites 6-int and 7-int were very similar to each other, and distinct from the rest of the monitoring sites. Sites 2-int and 5-int were very similar to each other, and somewhat similar to Sites 3-int and 4-int (which were moderately distinct from each other).

Figure 10.5

Non-metric multidimentional scaling (MDS) ordination plot of macrofaunal community structure at the seven potential ecological monitoring sites only. The ordination is based on square-root transformed macrofaunal community data from all 12 core samples collected per site. Points that are close together in ordination space represent samples that are similar in terms of community composition. The low stress level (0.01) suggests that the two-dimensional ordination is an accurate representation of the relative differences in the community data at the different sites.

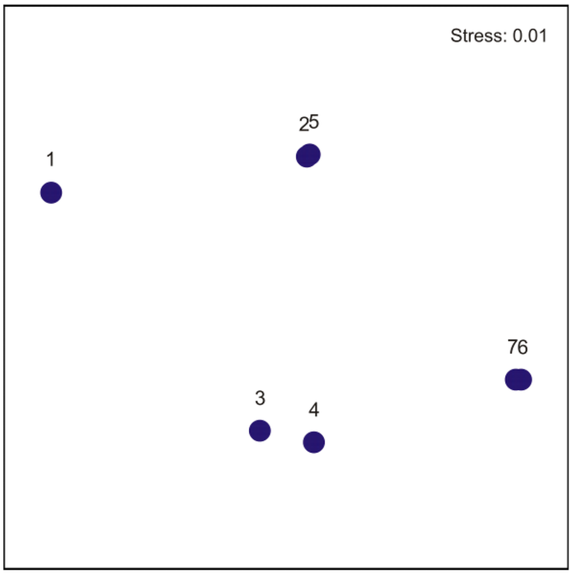
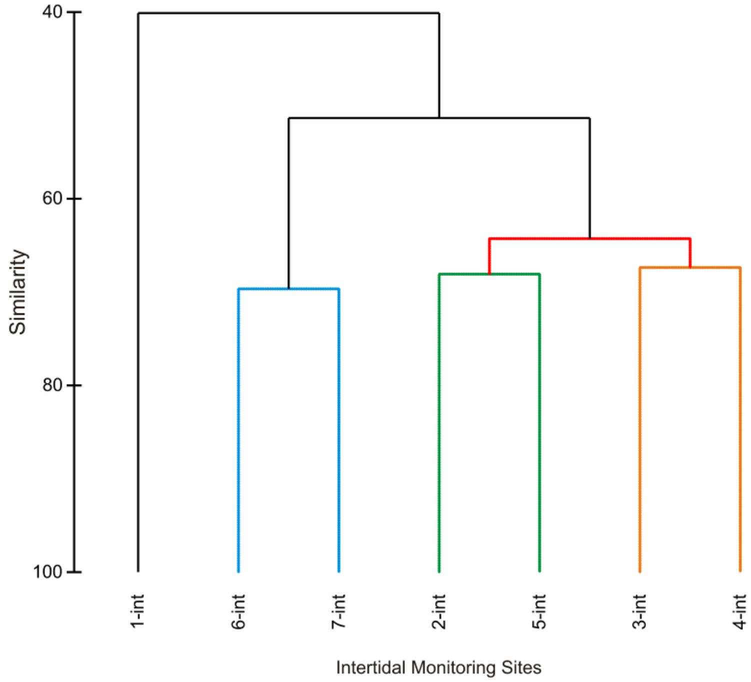


Figure 10.6

A dendrogram depicting groupings among seven potential ecological monitoring sites in the Wairoa Embayment. Sites that group together are more similar in terms of macrofaunal community composition (average, square-root transformed data from 12 replicate cores per site). Site 1-int was distinct from all other sites. Sites 6-int and 7-int grouped together, but the grouping was distinct from all other sites. Sites 2-int to 5-int were not significantly different in terms of community composition, although 2-int was most similar to 5-int, and 3-int was most similar to 4-int.



Univariate measures of soft-sediment macrofauna

In the case of Wairoa Embayment, the differences between intertidal and subtidal soft-sediment communities can be summarized reasonably well with univariate statistics. The intertidal communities contained significantly more individuals and species per core (i.e., higher abundance and taxonomic richness). Groups of macrofauna such as bivalves, suspension feeders and deposit feeders were also significantly more abundant in the intertidal than subtidal (Figure 10.7).

Although the subtidal habitats contained significantly fewer individuals and taxa, the individuals collected were very evenly spread among taxa (i.e., a high degree of evenness, low degree of dominance). This resulted in greater Shannon-Wiener diversity index values in the subtidal habitats, relative to the intertidal zone (Figure 10.7).

Of the seven potential ecological monitoring sites, Sites 2-int and 3-int had the greatest abundance of macrofauna (average number of individuals per core, averaged from all 12 replicates). The abundance at 2-int and 3-int was significantly greater than abundances at 1-int, 6-int and 7-int. The differences in taxonomic richness were less pronounced, although sites 3-int and 4-int had richness values greater than or equal to the richness values at the other sites. Site 4-int had the highest Shannon-Wiener H’ diversity value, significantly greater than the values at Sites 3-int, 5-int, 6-int and 7-int (Figure 10.8).

Figure 10.7

Comparisons of macrofaunal community variables at intertidal and subtidal soft-sediment sites. With the exception of Shannon-Wiener diversity, all variables were significantly greater at intertidal sites.

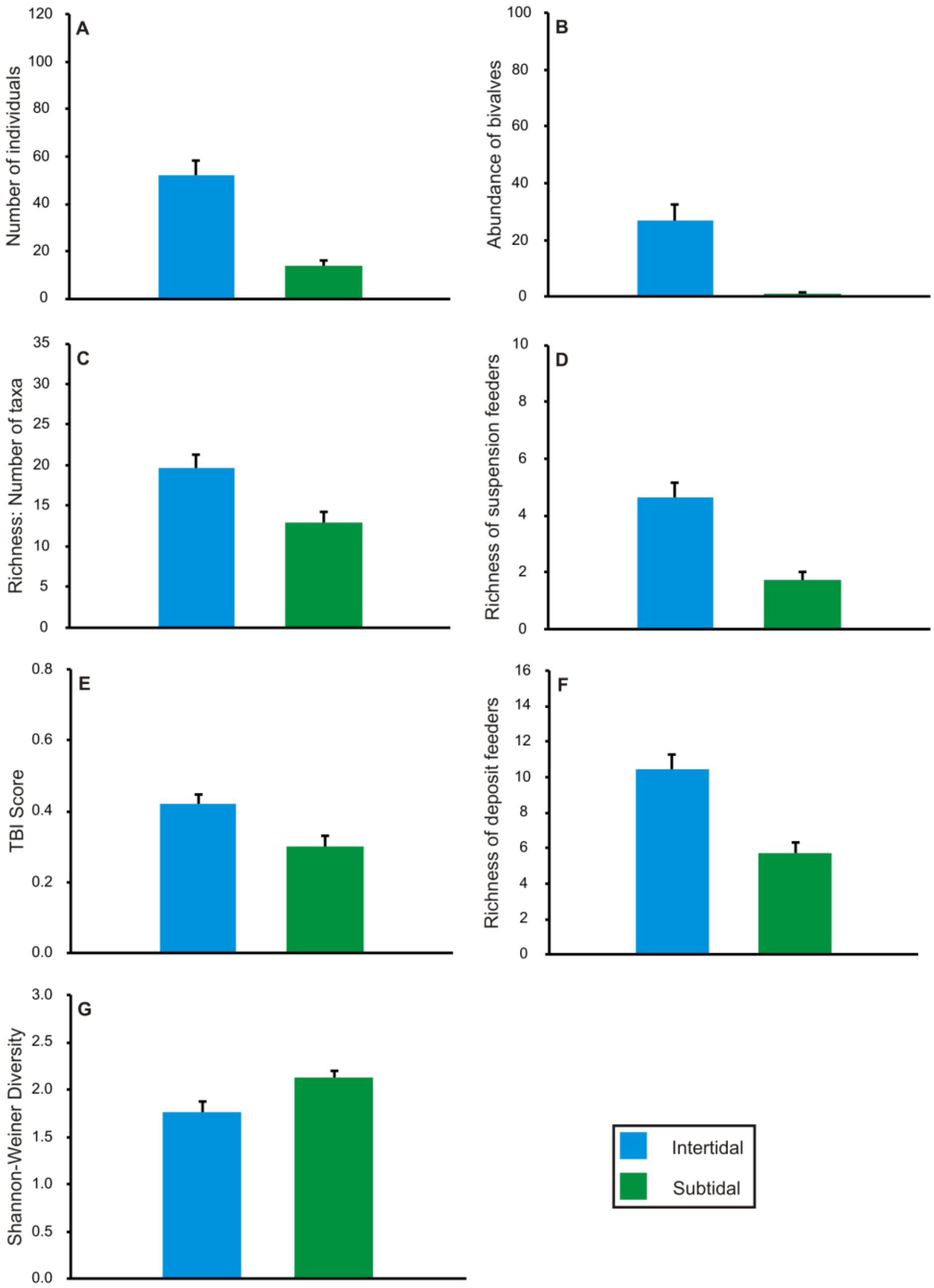
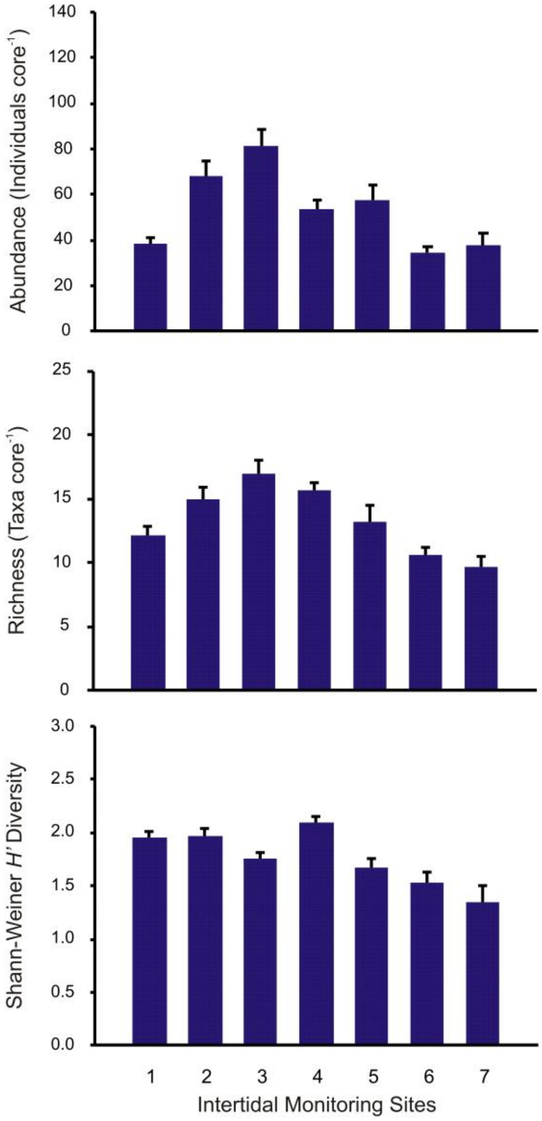


Figure 10.8

Average macrofaunal abundance, richness and diversity at each of the seven potential intertidal monitoring sites. Bars show averages (+ 1 SE) based on 12 macrofaunal core samples per site.

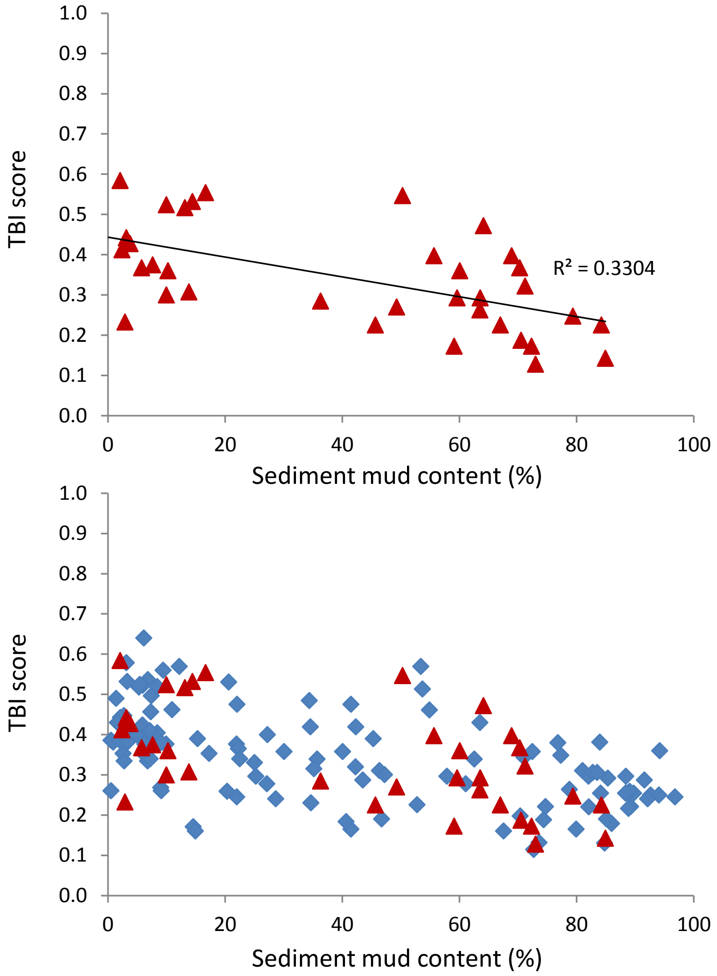


State of the Environment indicators

The amount of functional redundancy inherent in the macrofaunal communities was greater in the intertidal soft-sediment habitats, relative to the subtidal. This was reflected by the significantly higher TBI scores in the intertidal zone (average of 0.42), relative to the subtidal (average of 0.30). Note, the TBI functional traits index is supposed to be inversely correlated with increases in sediment mud content and, indeed, the soft-sediment habitats with the lowest TBI scores were present in the muddiest parts of Wairoa Embayment (Figure 10.9, upper panel). Additionally, TBI values from sites in the Wairoa were consistent with those from the RDP data set (original 95 sites) and sites investigated by Lohrer and Rodil (2011) (Figure 10.9, lower panel). The spread of the TBI values at the Wairoa sites was consistent with the other data sets across the entire range of mud content values observed.

Figure 10.9

Values of the functional traits based State-of-the-Environment indicator, the TBI, plotted relative to sediment mud content (% by weight). This index runs between 0 and 1, with low values indicating degraded sites with reduced functional redundancy. The upper panel shows data from Wairoa only. The cluster of sites on the right hand side of the plot (with higher mud contents and lower TBI scores) were all from the subtidal zone. Two outlying data points (A-int, S-sub) were removed prior to plotting. The percent variability explained using a linear least-squares fit was ~33% (r^2 = 0.3304). The lower panel shows the Wairoa data (red triangles) along with data from 95 RDP sites and 22 additional sites used to verify the TBI (Lohrer and Rodil 2011) (blue diamonds).



The seven intertidal sites investigated as potential long term ecological monitoring sites were the only sites for which both mud and metals data were available. With 12 macrofaunal replicates per site available, BHM ratings and TBI scores were able to be calculated (results presented in Table 10.1).

According to the CAPmetal and CAPmud scores of the BHM, Site 5-int was the healthiest of the seven sites. Five groupings of relative health have been determined based on CAPmetal scores, and Site 5-int falls into the BHM's top "Group 1" category (Figure 10.10). Sites 3-int and 4-int had the next best CAPmetal and CAPmud scores, but fit into the "Group 2" category. Sites 1-int and 2-int had somewhat reduced CAPmetal and CAPmud scores but were still retained in the "Group 2" category.

Site 6-int and 7-int, with relatively low macrofaunal abundance, richness and diversity, had the highest sediment mud percentages and the highest sediment heavy metal concentrations. Copper, lead and zinc concentrations at these two sites were ≥4, ≥10 and ≥48 mg kg^{-1} for each of the three metals, respectively (Table 10.1). BHM scores were not particularly low at Site 6-int (Group 2), however Site 7-int had the slightly more unhealthy rating of Group 3 (Figure 10.10).

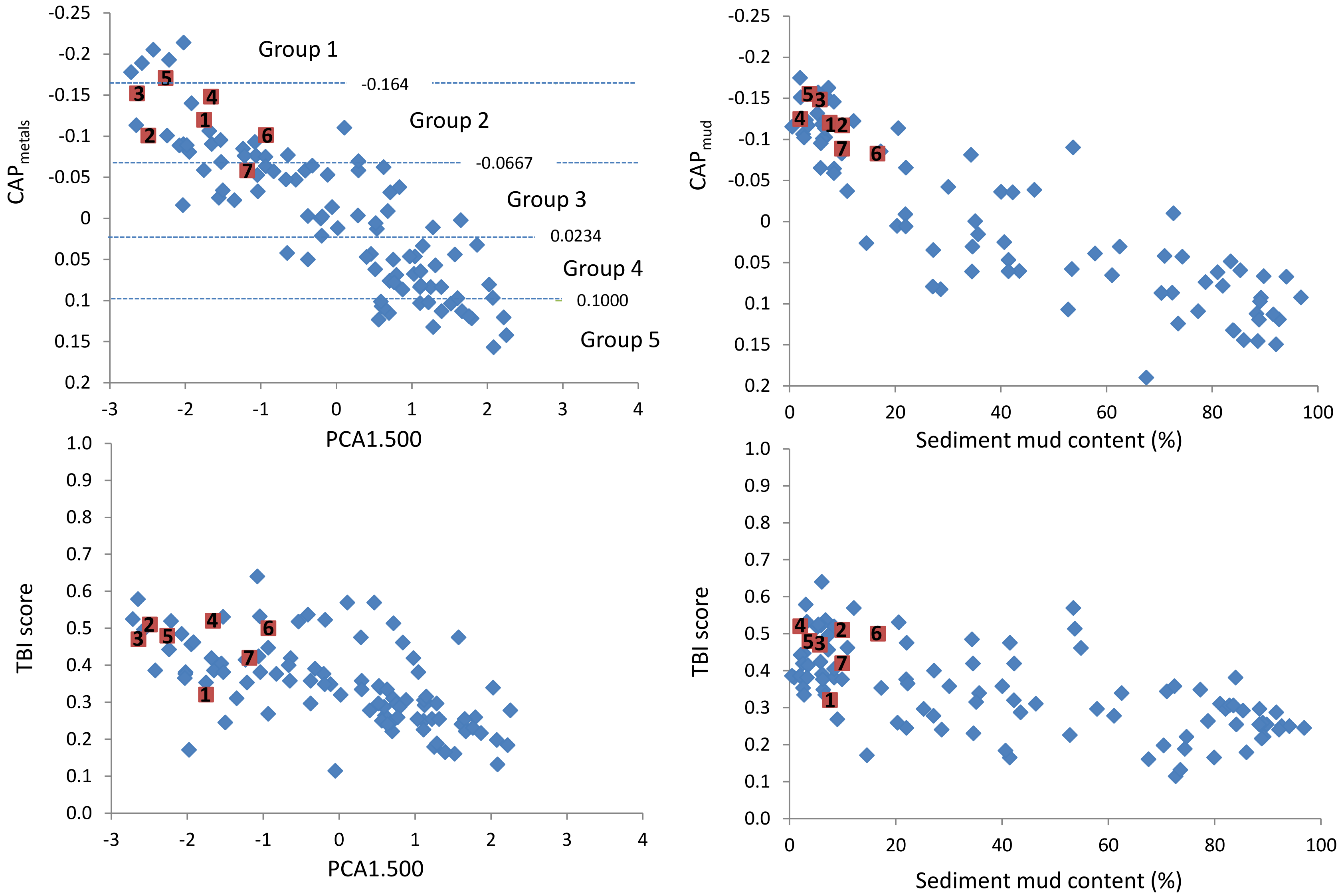
Table 10.1

Sediment characteristics at the seven potential ecological monitoring sites in the Wairoa Embayment (intertidal soft-sediment habitats). The percent mud content at each site and the concentrations of copper, lead and zinc (mg/kg dry wt in the <500 µm fraction) are given. CCU and PCA1.500 scores are related to combinations of metals (see references in Lohrer and Rodil 2011). CAPmetal and CAPmud scores are Benthic Health Model outputs. BHM and TBI calculations were based on twelve macrofaunal core samples per site. BHM metals groupings are given in parentheses after the CAPmetal scores.

Site	Mud %	Cu	Pb	Zn	CCU	PCA 1.500	CAP metal	CAP mud	TBI
Int-1	7.6	3.0	6.0	41.0	0.59	-1.75	-0.1199 **(2)**	-0.1201	0.32
Int-2	10.0	1.5	5.2	27.0	0.41	-2.49	-0.1008 **(2)**	-0.1169	0.51
Int-3	5.7	1.5	4.3	25.0	0.37	-2.64	-0.1521 **(2)**	-0.1485	0.47
Int-4	2.1	2.0	8.5	53.0	0.73	-1.66	-0.1482 **(2)**	-0.1247	0.52
Int-5	3.8	1.5	5.5	39.0	0.52	-2.26	-0.1706 **(1)**	-0.1554	0.48
Int-6	16.7	5.0	11.3	53.0	0.89	-0.93	-0.1012 **(2)**	-0.0827	0.50
Int-7	10.0	4.0	10.2	48.0	0.79	-1.18	-0.0584 **(3)**	-0.0886	0.42

Judging from CAP scores and TBI scores, the intertidal monitoring sites at Wairoa seemed relatively healthy, particularly when compared to the majority of RDP sites (Figure 10.10). There were subtle differences between the CAP scores and the TBI scores. For example, Sites 5-int had the best CAP scores of the seven sites for both mud and metals, but only the 4^{th} highest TBI score. Site 1-int had the worst TBI score, but had average CAP scores. Site 7-int was somewhat more consistent, being the second worst in terms of both TBI score and CAPmud score. The low CAPmetal score at Site 7-int placed it in BHM Group 3.

Figure 10.10. CAPmetal (upper left), CAPmud (upper right), and TBI scores (lower panels) plotted versus levels of sediment heavy metal contamination (PCA1.500, left hand panels) and mud content (%, right hand panels). Scores at Sites 1-int to 7-int in the intertidal zone of Wairoa embayment are plotted with red squares; scores from RDP sites (n=95) are given as blue diamonds. Group 1 is the healthiest BHM grouping. The Wairoa sites plotted here were mainly Group 2.



11 Discussion

The Wairoa Embayment is a small, relatively wave-protected embayment in the southeastern portion of Tamaki Strait. Relative to the size of the embayment (21.2 km^2), the catchment area is rather large (311 km^2). A majority of the once-forested catchment has now been converted to farmland, particularly along the Wairoa River valley and in the surrounding hills.

The Wairoa River appears to have high suspended sediment concentrations (judging from its muddy colour) and mangroves have almost completely colonised the intertidal flats on either side of the meandering main tidal channel (Swales et al. 2008). Whilst there are extensive areas of diverse sandy habitat and a few rocky reefs in the intertidal zone of the Wairoa Embayment, the entire subtidal area of the Wairoa Embayment appears to be in-filled and extremely muddy (up to 84% mud, 30 cm deep, in places). The highly in-filled state of Wairoa Embayment (average depth during low tide of approximately 3 m) has perhaps compromised its capacity to act as a sink for terrigenous sediments, and a substantial quantity of the annual catchment sediment load is likely exported to the open coastal environment (Swales et al. 2002, 2008). However, at least some terrigenous sediment is still likely deposited in the sheltered subtidal waters immediately beyond the mouth of the Wairoa River (Swales et al. 2008).

The observations of subtidal habitats throughout the Wairoa Embayment made during our investigation suggested that the area once supported high densities of large, suspension-feeding, structure-forming, coastal bivalves. Large *Cyclomactra ovata* and *Pecten novaezelandiae* shells were observed, in addition to shells of bed-formers such as *Atrina zelandica*, *Perna canalicula* and *Modiolus areolatus*. However, this shell material was usually buried beneath several cm of mud, and was often relatively free of epibionts such as algae or bryozoans or ascidians (with exceptions at Sites M-sub, R-sub, S-sub and T-sub).

A patch of live *Atrina zelandica* was noted in the vicinity of S-sub more than 10 years ago, (R. Budd, personal communication). However, although *Atrina* shell material was noted at this site during our fieldwork, no live *Atrina* (or standing dead shells) were noted in 2011. The site in closest geographical proximity to S-sub, (T-sub, 870 m away) was the most similar to it in terms of seabed appearance and macrofaunal community composition (30% similarity). These two sites had relatively thin coverage of mud atop a layer of large shells, and these sites had the most abundant and rich macrofaunal life as well.

Visually, and to some to extent geographically, the subtidal soft-sediment sites were able to be grouped based on the presence/absence of distinct shell hash layers and the thickness of mud layers atop the shell. For example, sites to the east of the Wairoa River mouth (on the Koherurahi Point side of the Embayment) had the least amount of shell and greatest percentage of mud. However, macrofaunal community structure was rather homogeneous in the subtidal zone, and multivariate clustering techniques did not reveal any significant data-based groupings. Sites that were further apart from one another in geographical space were only slightly more likely to differ from one another in terms of community composition (with Bray-Curtis dissimilarity increasing by <1% per km, $r^2 = 0.04$).

There was much more habitat-level variation in the intertidal zone of the Wairoa Embayment. Firstly, although no seagrass was found anywhere in the Embayment, there were rocky reef sites and mangrove areas in addition to soft-sediment sites dominated variously by muds and sands mixed with shell material. Several of the sites were dominated by high densities of ecologically and culturally important bivalves, such as cockles, pipis and wedge shells. In fact, bivalves comprised more than 50% of the total macrofaunal abundance at several of the intertidal sites (E-int, F-int, G-int, 4-int, 5-int, 7-int). This contrasted with the subtidal environment, where the only common bivalve was the non-indigenous species *Theora lubrica*.

In the soft-sediment sites of the Wairoa Embayment, there were twice as many deposit-feeding taxa, on average, as there were suspension-feeding taxa. In fact, in the subtidal zone, there was an average of 3.7 deposit-feeding taxa for every suspension-feeding taxon. Nevertheless, some of the intertidal sites were dominated by suspension feeders (e.g., cockles *Austrovenus stutchburyi*) in terms of abundance and biomass. Theoretically, suspension-feeders will have difficulty in depositional environments and in highly turbid water, as they must spend time and energy to cleanse their filter-feeding structures of fine particles that can clog them and interfere with respiration and food capture. The lack of *Austrovenus* at intertidal sites 6-int, 7-int and K-int in the eastern part of the Wairoa Embayment (near Koherurahi Point) may reflect the slightly muddier more turbid waters, generally speaking, on this side of the embayment.

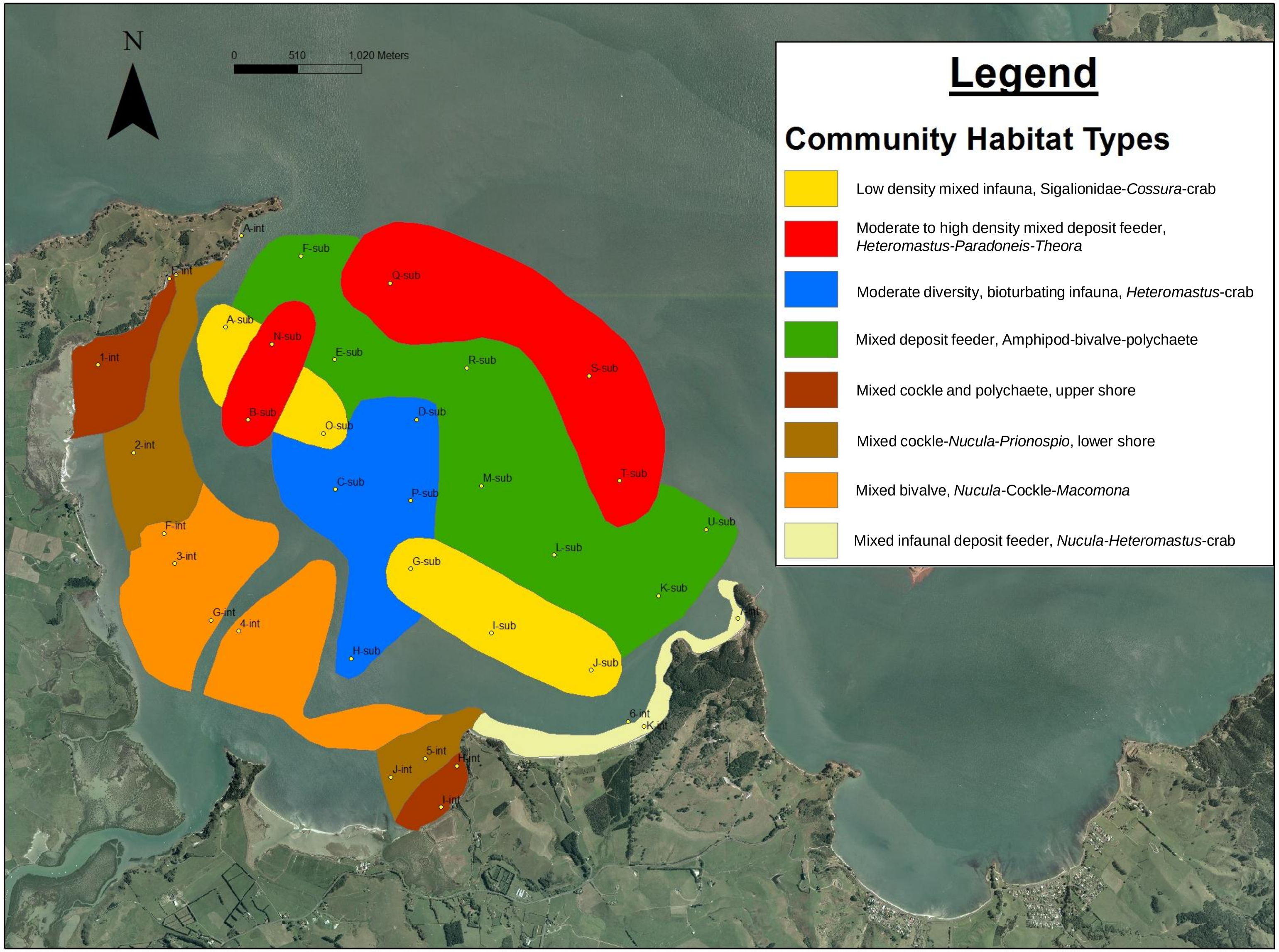
11.1 Soft-sediment habitat map based on community data

There is a tendency to make habitat maps based strictly on physical characterisations of the environment, particularly when the biological characteristics are cryptic (i.e., small, infaunal, underwater). Examples of physical or mostly-physical habitat maps of the Wairoa embayment are given in Figures 8.1 (intertidal) and 8.23 (subtidal). However, one of main reasons for collecting ecological community data is to better map the biology and to recognize that ecological community types can vary substantially within single physical classifications.

Figure 10.11 depicts eight ecological community types present in the Wairoa Embayment. All of the habitat types drawn were statistically distinct from one another (pairwise tests $p < 0.05$), with the exception of the blue and yellow areas in the shallow subtidal zone.

The sandier intertidal zone was dominated by bivalves such as *Austrovenus* and *Nucula*, although proximity to the Wairoa River channel and tidal height appeared to influence macrofaunal community structure. The lower shore near the Wairoa River

Figure 10.11. Map of soft-sediment habitat types based on all available information including macrofaunal community data.



channel was dominated mainly by bivalves (*Nucula*, *Austrovenus* and *Macomona*), whereas polychaetes (e.g., *Prionospio* and *Aonides*) became more common away from the river channel and towards the upper shore. The light coloured intertidal zone in the southeast corner of the map (containing Sites 6-int, 7-int, K-int) stood out as being more influenced by mud and dominated by deposit-feeders including *Nucula*, *Heteromastus* and *Hemiplax*. Macrofaunal densities in this portion of the embayment were lower than those in the other three intertidal habitat types, though they were still higher than those of all adjacent subtidal areas.

There was an area of moderate diversity in the subtidal zone located where the Wairoa river discharged (shown in blue). This habitat was characterised by the presence of mud tolerant worms and crabs (*Heteromastus* and *Hemiplax*). Further away from the river discharge were mixed assemblages characterised by low macrofaunal density and diversity (shown in yellow). Despite the low density and diversity, this habitat contained predator/scavengers (sigalionid polycheates), deposit feeders (cossurid polychaetes) and bioturbatory species (mud crabs). The largest grouping of sites in Wairoa's subtidal zone was classified as a mixture of deposit feeders containing amphipods, bivalves and polychaetes (shown in green). Finally, there was an area of moderate-to-high diversity that was associated with the presence of shell hash (shown in red). Apart from the shell hash, the main component of the sediment at these sites was mud; the infaunal species present here were mud tolerant deposit feeders including *Heteromastus*, *Paradoneis* and *Theora*.

11.2 Functional indicators and responses to elevated mud

Values of the new functional traits index being trialed as a State-of-the-Environment indicator, the TBI (Lohrer and Rodil 2011), suggest that the intertidal sites in the Wairoa Embayment have a reasonably high level of functional redundancy (average TBI score of 0.42). TBI scores theoretically range between zero and one ("zero" represents a completely defaunated site, whilst "one" represents a perfectly pristine site), although calculations based on real data typically fall between 0.2 and 0.6. Of the seven potential ecological monitoring sites we sampled in the Wairoa Embayment, four had TBI scores ≥0.50 (based on the full 12 replicates). A similar range of TBI scores has been noted for intertidal monitoring sites in Manakau and Mahurangi Harbours (October 2010)7.

The TBI scores in the Wairoa subtidal zone were markedly lower than scores from the intertidal zone, averaging 0.30, with low scores of 0.13 and 0.14 at Sites I-sub and J-sub. Although it is correlative evidence only, it appears that the elevated muddiness of the subtidal sites has contributed to reductions in abundance, richness and functional redundancy (as indicated by the TBI score) of the resident macrofaunal communities. The major factor that seems to positively affect macrofauna in the subtidal zone appears to be shell material in the upper part of the sediment column (e.g., S-sub and T-sub, B-sub and N-sub; Hewitt et al. 2005, Thrush et al. 2006). Thus, the lack of large

[7] Manukau: AA=0.48; CB=0.65 & CH=0.40. Mahurangi: HL=0.38; DC=0.40; MH=0.47; TK=0.44; CB=0.49; JB, a heterogeneous site, = 0.93 (Hailes & Hewitt 2011 Draft report; Halliday & Cummings 2011 Draft report).

shell-forming bivalve species in the subtidal zone at present, in combination with thick mud and highly turbid water, suggests minimal likelihood of biotic recovery of the Wairoa subtidal zone in the near to medium term.

As an aside, the application of the TBI to benthic soft-sediment data from the Wairoa Embayment was useful for independently testing this index. The magnitude and variability of Wairoa's TBI values were consistent with calculations made at sites across a broad range of sedimentary mud content (Figure 10.9; Lohrer and Rodil 2011). This was true for the predominantly sandy sites in the intertidal and for the significantly muddier sites in the subtidal. The match of the subtidal sites was particularly encouraging, as this was the first application of the TBI to subtidal data.

11.3 Environmental threats other than elevated mud

It is likely that increased muddiness of the sediment, the spread of mud into presently sandy habitats, and increasingly turbid water associated with climatic and land use changes will continue to be the main environmental threat in the Wairoa Embayment in the near to medium term. Unfortunately, it appears that much of the damage to the subtidal environment has already been done. Time will tell if conditions have deteriorated to the extent that new recruitment by habitat modifying calcifying bivalves (*Atrina, Perna, Cyclomactra, Modiolus*) is being inhibited. In the meantime, steps should be taken to minimise sediment impacts and additional compounding stressors such as those outlined in the following paragraphs.

Hypoxia in the bottom water above muddy sediments can occur naturally due to the high bacterial counts and correspondingly high benthic oxygen demand. However, additional loadings of nutrients and organic matter have exacerbated this problem and produced large anoxic dead zones in many estuaries worldwide. The shallow water of Wairoa Embayment is unlikely to experience problems of this magnitude, yet controlling the discharge of sewage, organic matter, agricultural effluent and inorganic nutrients into the Wairoa River would be prudent for maintaining oxygenated bottom waters and sediments in the Embayment. The oyster farm in the southern part of the Embayment (discussed below) is a potential point source of organic enrichment (faeces and pseudo-faeces) and elevated nutrients (ammonium, phosphate).

The catchment surrounding Wairoa Embayment is mainly rural, not urban, so heavy metal contaminants linked to automobile traffic were not expected to be high. The levels of Cu, Pb and Zn averaged 2.6, 7.3 and 40.9 mg kg dry weight, respectively, which is lower than moderately contaminated sites in the Central Waitemata Harbour including Pollen Island, Coxes Bay and Hobson Bay (Lohrer and Rodil 2011). However, the metal contaminant concentrations were notably higher than at nearby Whitford, which had 1.6, 3.0, 16 mg kg^{-1}, respectively, for the same three metals. The source of the contaminants to the Wairoa Embayment is likely to be from the Wairoa River. However, it is possible that contaminated particles also arrive following long-distance transport in the water column, perhaps from urbanised areas closer to central Auckland. Metal contaminants were not measured at all of the intertidal and subtidal survey sites, just Sites 1-int to 7-int. According to the BHM, and compared to the majority of RDP sites, these sites were in relatively healthy state (clustered in Group 2 for the most part).

There are a large number of non-indigenous species (NIS) already established in the greater Waitemata-Tamaki Straight region, thus the colonisation of the Wairoa Embayment by NIS is a concern. NIS larvae are probably abundant in the water column at certain times of year and may reach the Wairoa Embayment in a state competent for settlement. Less likely is the introduction of species via hull fouling or ballast water, as Wairoa Embayment has no marina or moorings and seems to attract little vessel traffic.

At present, it appears that Wairoa Embayment is relatively free of NIS non-indigenous marine species, including the notable invaders *Styela clava, Musculista senhousia, Charybdis japonica* and *Nassarius burchardi*. Apart from the Pacific Oyster (*Crassostrea gigas*, which is farmed in the embayment), the most abundant non-indigenous species was *Theora lubrica*, a small thin-shelled bivalve often found in muddy, organically enriched sediments. Compared to soft-sediment habitats in Waitemata Harbour, Rangitoto Channel and Tamaki Strait (Hayward et al. 1997, Lohrer et al. 2008, Chiaroni et al. 2007), the densities of *Theora lubrica* were relatively low in Wairoa Embayment. *Musculista senhousia* and *Limaria orientalis* (other non-indigenous bivalves from Asia) were absent in all of the cores collected and analysed. The polychaete *Boccardia syrtis* was found in low densities (averaging <0.5 core^{-1}) at the eight sites where it was present.

There is currently one oyster farming operation in the Wairoa Embayment (inshore of subtidal Site H-sub). Marine farming operations may contribute to a number of environmental problems. In this particular case, the current farm constitutes a local source population of a non-indigenous species, *Crassostrea gigas*, which is an oyster native to Asia. This oyster has outcompeted native species of shellfish for food and space in many parts of the world, and now exists “wild” on many rocky outcrops in New Zealand as a result of culturing operations. The extent to which it has modified rocky shorelines in New Zealand is not well understood, although Hayward et al. (1997) believe this to be a significant change in the ecology of the Waitemata Harbour that has occurred in the last 70-80 years. *C. gigas* also has the potential to develop into extensive oyster reefs in muddy soft-sediment areas, which altering the habitat considerably and can affect tidal channel formation, hydrodynamics and ecology.

Marine aquaculture farms can provide a large amount of attachment area to support additional non-indigenous epiflora and fauna (e.g., *Undaria pinatifida, Styela clava, Sabella spallanzanii*)(e.g., Floc’h et al. 1996; Hewitt et al. 2004a). Once established in an aquaculture area, the NIS are likely to have increased fertilisation success and spread to natural areas beyond the borders of the farm.

Another environmental issue associated with marine aquaculture farms is the settlement of organic rich faeces and pseudofaeces in a relatively localised area beneath the farm. The rain of particles from the farm to the sediment surface can smother small organisms living at the sediment-water interface, including the microphytobenthos (sediment dwelling primary producers). The sediments beneath a farm are often shaded by racks, further reducing photosynthesis at the sediment-water interface. This, coupled with elevated benthic oxygen demand due to organic enrichment, reduces the depth of the redox discontinuity layer in the sediment and increases the chances of having smelly, black, anoxic sediments. Finally, high densities of bivalves can excrete significant quantities of inorganic nitrogen and phosphorus, which can elevate water column nutrient concentrations.

There are several other potential threats to Wairoa Embayment that are more difficult to quantify without further data: trampling, marinas, shellfish overharvesting, boat anchoring/propeller damage, sea-level rise and altered climate.

Most of the intertidal area in the Wairoa Embayment is readily accessible to the public, and, in fact, the Duder Regional Park directly abuts several of the rocky and soft-sediment intertidal sites we sampled. Thus, there is a potential for heavy foot traffic to result in the trampling of some of the more sensitive organisms. Although this does not seem to be particularly likely, it is difficult to assess this threat without better information on visitor numbers. Horses, quadbikes, trucks and tractors could cause damage to the upper shore line and other soft-sediment areas, depending on the frequency and speed at which they travel across the sand.

The threat of physical damage to the subtidal seabed from anchors and boat propellers will obviously depend on the number of boats that traverse and anchor in the Embayment. We have no data on this. The shallow depth of the embayment, and the number of trips across the embayment by boats moored in the lower Wairoa River, could elevate the threat of propeller damage, although local boaters tend to know how to avoid the shallow areas. The embayment does not appear to be a popular fishing spot, so anchor damage may be limited. It is doubtful that Wairoa Embayment will ever be the site of a marina, given its shallow depth and its likelihood of in-filling, and given the availability of moorings and boat ramps in the Wairoa River and nearby Kawakawa Bay.

Overharvesting is a potentially important problem for various intertidal and subtidal species in the Wairoa Embayment and elsewhere in the greater Tamaki Strait area. The removal of intertidal species like pipis and cockles can influence the long-term viability of culturally important harvesting practices and can seriously affect the diversity and functioning of the habitats these species come from. For example, pipis and cockles can stabilise sandflat sediments when present at high densities, provide shell hash that has a positive impact on macrofaunal species, influence benthic-pelagic coupling by filtering particles, bioturbating sediments and excreting inorganic nutrients, and can act as a long-term sink of atmospheric carbon via the incorporation of calcium carbonate. The widespread removal of these species will lead to the loss of these services. Overharvesting of cockles and declines in the quality of the water in which they feed are already considered to be problems in the adjacent embayment, Kawakawa Bay (personal communication with local kaitiaki).

The effects of overharvesting in the subtidal zone may have been significant in the past, as there appears to have been dredging for oysters and mussels in this area as early as 1840. Dredging likely affected the targeted shellfish populations, but also the delicate epifaunal species living atop the bivalves (sponges, bryozoans, hydroids, soft-corals); epifauna such as this are known to provide food and refugia for a variety of fish and invertebrate species. The effect of the removal of subtidal predators (e.g., snapper, crayfish) may also have caused substantial change to these habitats, but it is effectively impossible to assess these historical impacts retrospectively.

The linked threats of climate change and sea-level rise are also likely to influence the ecology of Wairoa Embayment. Climate change could result in changes to air and sea water temperatures, increased or decreased rain fall, storm frequency, wind speed and wave height. Thus, the only certainty is change; some species will benefit, while others will not. Although the effects of climate change are uncertain, the associated problem of sea-level rise could result in a net loss of species in the Wairoa Embayment, particularly if the present-day intertidal area is converted into habitats similar to the present-day subtidal zone (which is highly muddy and generally species poor). The unknown part of the analysis is how the upper intertidal and supra-littoral zone will change as it becomes converted into lower and middle intertidal habitat.

11.4 Selection of potential ecological monitoring sites

Given the proven value of ecological monitoring data for understanding the short-term variability and long-term trends in functionally important soft-sediment systems, we sampled seven sites in the Wairoa Embayment for consideration as potential Auckland Council ecological monitoring sites for State of the Environment monitoring.

The seven potential monitoring sites sampled met several important criteria for monitoring sites in that they were mid-intertidal, sand-dominated areas containing (1) a suitable abundance of macrofauna from a variety of functional trait and taxonomic groupings, and (2) several of the “monitored” macrofaunal taxa that are used in other AC ecological monitoring programmes. However, the multivariate community analysis suggested a few of the sites were quite similar to one another, and that it might be cost effective to monitor as few as five of the sites (rather than all seven). The sites most similar to each other were 2-int and 5-int, and 6-int and 7-int, and we suggest that sites 2-int and 7-int could be dropped. This would leave five sites total (1-int, 3-int, 4-int, 5-int and 6-int), with two sites on the main sandflat north of the Wairoa River channel, two sites on the sandflat south of the Wairoa River channel, and one site in the potentially sediment-impacted Koherurahi Point flank of the Embayment. If funding was only available for four sites total, 4-int could also potentially be dropped. However, 4-int was somewhat distinct from 3-int in terms of macrofaunal community composition, would provide data from a site near the Wairoa River channel, and was the closest site to the marine farming operation.

12 Acknowledgements

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14 Appendix

Heavy metals analysis report, summary of methods and detection limits for Wairoa Sites 1-int to 7-int (which correspond to samples 8-14, respectively, in the table below). On the following page, the quality assurance information provided by the analytical laboratory (R J Hills Laboratories Limited) is given.

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ANALYSIS REPORT

Page 1 of 2

Client:	NIWA Corporate	**Lab No:**	861068 SPv3
Contact:	Julia Simpson	**Date Registered:**	20-Jan-2011
	C/- NIWA Corporate	**Date Reported:**	08-Jun-2012
	PO Box 11115	**Quote No:**	43358
	Hillcrest	**Order No:**	
	HAMILTON 3251	**Client Reference:**	Sieving & Heavy metals
		Submitted By:	Julia Simpson

Amended Report

This report replaces an earlier report issued on the 27 Jan 2011 at 4:24 pm
A QC report is now attached.

Sample Type: Sediment

	Sample Name:	1 10-Jan-2011	2 10-Jan-2011	3 10-Jan-2011	4 10-Jan-2011	5 10-Jan-2011
	Lab Number:	861068.1	861068.2	861068.3	861068.4	861068.5
Total Recoverable Copper	mg/kg dry wt	8	4	< 2	4	2
Total Recoverable Iron*	mg/kg dry wt	17,700	16,000	12,100	13,200	12,100
Total Recoverable Lead	mg/kg dry wt	9.4	4.1	1.8	2.9	2.0
Total Recoverable Zinc	mg/kg dry wt	45	31	21	28	24

	Sample Name:	6 10-Jan-2011	7 10-Jan-2011	8 10-Jan-2011	9 10-Jan-2011	10 10-Jan-2011
	Lab Number:	861068.6	861068.7	861068.8	861068.9	861068.10
Total Recoverable Copper	mg/kg dry wt	2	5	3	< 2	< 2
Total Recoverable Iron*	mg/kg dry wt	14,100	13,500	12,400	8,000	6,900
Total Recoverable Lead	mg/kg dry wt	2.7	2.8	6.0	5.2	4.3
Total Recoverable Zinc	mg/kg dry wt	23	25	41	27	25

	Sample Name:	11 10-Jan-2011	12 10-Jan-2011	13 10-Jan-2011	14 10-Jan-2011	
	Lab Number:	861068.11	861068.12	861068.13	861068.14	
Total Recoverable Copper	mg/kg dry wt	2	< 2	5	4	-
Total Recoverable Iron*	mg/kg dry wt	14,400	9,700	17,300	14,400	-
Total Recoverable Lead	mg/kg dry wt	8.5	5.5	11.3	10.2	-
Total Recoverable Zinc	mg/kg dry wt	53	39	53	48	-

Analyst's Comments

Appendix No.1 - QC report

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Samples
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-14
Total Recoverable Copper	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	2 mg/kg dry wt	1-14
Total Recoverable Iron*	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-14
Total Recoverable Lead	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	0.4 mg/kg dry wt	1-14
Total Recoverable Zinc	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	4 mg/kg dry wt	1-14

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The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

Client: *NIWA*
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Contact: *Simpson, Julia*

Laboratory No: *861068QC*
Date Registered: *20/01/2011*
Page Number: *1 of 2*

Client's Reference: Sieving & Heavy metals

Quality Control Report for 861068

This report includes quality control data for the following analytes:

Trace Elements - Soil
Total Recoverable Metals
(Copper,Iron, Lead and Zinc)

- *Procedural Blank*
- *Certified Reference Material (CRM)*
- *Duplicate Sample Analysis*

Client: *NIWA* **Laboratory No:861068**QC

Sample Type: Environmental Solids, Soil

Note 1: The CRM Certified Range for AGAL 10 below are presented as the reference value ± the standard deviation (SD). The CRM In House Limits are the 99% confidence limit ranges.

Quality Control Data for Samples 861068.1-14 (ESTR 5858)

Sample Name	Lab No	Total Recoverable Iron (mg/kg dry wt)	Total Recoverable Lead (mg/kg dry wt)	Total Recoverable Zinc (mg/kg dry wt)
Procedural Blank		<40	<0.4	<4
CRM (AGAL 10)		16100	46.18	50.1
CRM Certified Range (AGAL 10)		20000 ± 1170	40.4 ± 2.7	57 ± 4.2
CRM In House Limits (AGAL 10)		13855 - 21568	33.87 - 49.71	46.1 - 65.4
Duplicate Sample 1 *	860738.3	32500	21.64	97.3
Duplicate Sample 2 *	860738.3	31100	22.77	100.1

* No duplicate was analysed for this job. The data presented is that of a job on the same batch of samples.

Quality Control Data for Samples 861068.1-14 (ESTR 5862)

Sample Name	Lab No	Total Recoverable Copper (mg/kg dry wt)
Procedural Blank		<2
CRM (AGAL 10)		22.1
CRM Certified Range (AGAL 10)		23.2 ± 1.9
CRM In House Limits (AGAL 10)		18.4 - 28.4

Find out more: phone 09 301 0101, email
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aucklandcouncil.govt.nz and knowledgeauckland.org.nz

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