Ecological Monitoring of three Tairāwhiti estuaries: Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon

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Executive Summary

Ecological monitoring of three Tairāwhiti estuaries: Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon, has assessed a range of key health indicators. The results provide a reference point for future assessments and aims to contribute to the improved management of estuarine conditions.

The study assessed a range of estuary health indicators through fine-scale monitoring, including sediment quality, grain size, organic carbon, nutrients, metal contaminants, chlorophyll-a and pheophytin-a, epibiota, infaunal macroinvertebrates, shellfish abundance, and indicator taxa.

Kaitawa Estuary exhibited significant environmental stress, characterised by high sediment mud content (50-85% volume) and elevated metal contaminants, that result in low macroinvertebrate diversity and high Mud and Metal Benthic Health Model (BHM) impact scores. In contrast, Tūranganui Estuary, influenced by urban catchment inputs, displayed mixed ecological site-specific differences in sediment quality and macrofauna indicators reflecting varying levels of organic enrichment and muddiness.

Te Wherowhero Lagoon showed infaunal macroinvertebrates were diverse and abundant, with species indicating a moderately stress-tolerant community. There was elevated sediment TOC and TN at Wherowhero 2, and TRP was highest across all sites at Te Wherowhero Lagoon. Mud and Metal BHM scores were moderate, reflecting the lagoon's ecological state compared to other estuarine sites in Aotearoa New Zealand.

This study suggests that each estuary faces unique challenges, from sedimentation and metal contamination at Kaitawa Estuary to urban pressures and localized enrichment at Tūranganui Estuary. Integrated, catchment and estuary management, and targeted mitigation are therefore essential to protect estuary health and associated ecological and cultural values.

1. Background and scope

Monitoring the ecological condition of estuarine habitats is essential to maintain and enhance their values through their effective management. Regional councils in Aotearoa New Zealand undertake estuary monitoring as part of their State of the Environment (SOE) programmes. The estuary monitoring framework used by Gisborne District Council was developed in 2024 by Cawthron Institute (Berthelsen et al., 2024; Berthelsen et al., 2024b; Clark et al., 2024). This framework was then applied to Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon in 2025. It drew on key elements from the National Estuary Monitoring Protocol (NEMP; Robertson et al., 2002) and included the fine-scale monitoring component, which tracked a range of physical, chemical and biological indicators to evaluate sediment quality and the health of biological communities.

This report presents an assessment of the ecological monitoring undertaken in 2025 for Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon, focusing on key indicators of estuarine health, including sediment quality and habitat condition. This report provides a reference point for future assessments and regional comparisons, and contributes to better management of estuarine ecosystems by informing regional policy plans.

2. Study locations

2.1 Kaitawa Estuary

Kaitawa Estuary is located northeast of Tūranganui-a-Kiwa/Gisborne, where the Ūawa River joins the sea at Tolaga Bay. It is classified as a tidal river mouth estuary. Ūawa is home to Te Aitanga-a-Hauiti and is the place of a leading whare wānanga, or focal point of learning, specialising in tribal lore and carving (Ngata, 1930). The Kaitawa Estuary is valued for kaimoana (seafood) gathering, birdwatching, walking, kayaking, holidaying, relaxing, and enjoying nature. Kaimoana is gathered both as a food source and as a way of strengthening connections to the whenua and moana, while passing on important cultural practices. The estuary is surrounded by a relatively large catchment, most of which is covered in exotic forest, grassland and native scrub/shrubland.

Three representative sites were surveyed at Kaitawa Estuary (Figure 1) and were established at suitable benthic habitats. Kaitawa 1 was in the northern end of the estuary, close to the mouth, Kaitawa 2 was located in the middle of the estuary and Kaitawa 3 was positioned at the southern/upper end of the estuary near the Kaitawa Stream inlet. Each survey site measured 60m x 30m and was split into nine plots, each measuring 20m x 10m, to achieve nine replicates per location. The long edge of each site was positioned parallel to the water's edge. Site GPS coordinates can be found in Appendix 1.

Figure 1. Map of Kaitawa Estuary.

2.2 Tūranganui Estuary

Tūranganui Estuary is formed by the joining of the Taruheru and Waimatā Rivers, which flow through the city of Tūranganui-a-Kiwa. Mana whenua in this area includes Ngāi Tāwhiri, Te Whānau a Iwi and Ngāti Oneone. The area surrounding the mouth of the Tūranganui River and the confluence of the Taruheru and Waimatā Rivers, known as Ngā Waiweherua – 'The Waters Split', was originally settled by descendants of the Horouta, Tākitimu, and Te Ikaroa-a-Rauru waka (Spedding., 2006; Salmond et al., 2022).

The estuary is relatively small, dominated by river flows and surrounded by a large catchment, most of which is covered in grassland, exotic forest and native scrub/shrubland. It is classified as a tidal river mouth estuary, having a long, narrow and shallow basin that is dominated by river flows (Clark et al., 2024; Hume et al., 2016). The estuary has very little intertidal area and is usually submerged at all tides.

Tūranganui Estuary had two representative survey sites (Figure 2) that were established at suitable benthic habitats. Tūranganui 1 was located on the Taruheru River and Tūranganui 2 on the Waimatā River with both sites positioned between the estuary margin and the channel. Due to the limited sampling space at both sites, modification of the sampling design was required. Tūranganui 1 measured 60m x 15m and was divided into nine equal plots (each plot measured

20m x 5m), and Tūranganui 2 measured 24m x 10m and was divided into six equal plots (each plot measured 8m x 5m). The size of the sites chosen was smaller than outlined in the NEMP (2002) due to the limited intertidal area accessible at low tide. Site GPS coordinates can be found in Appendix 1.

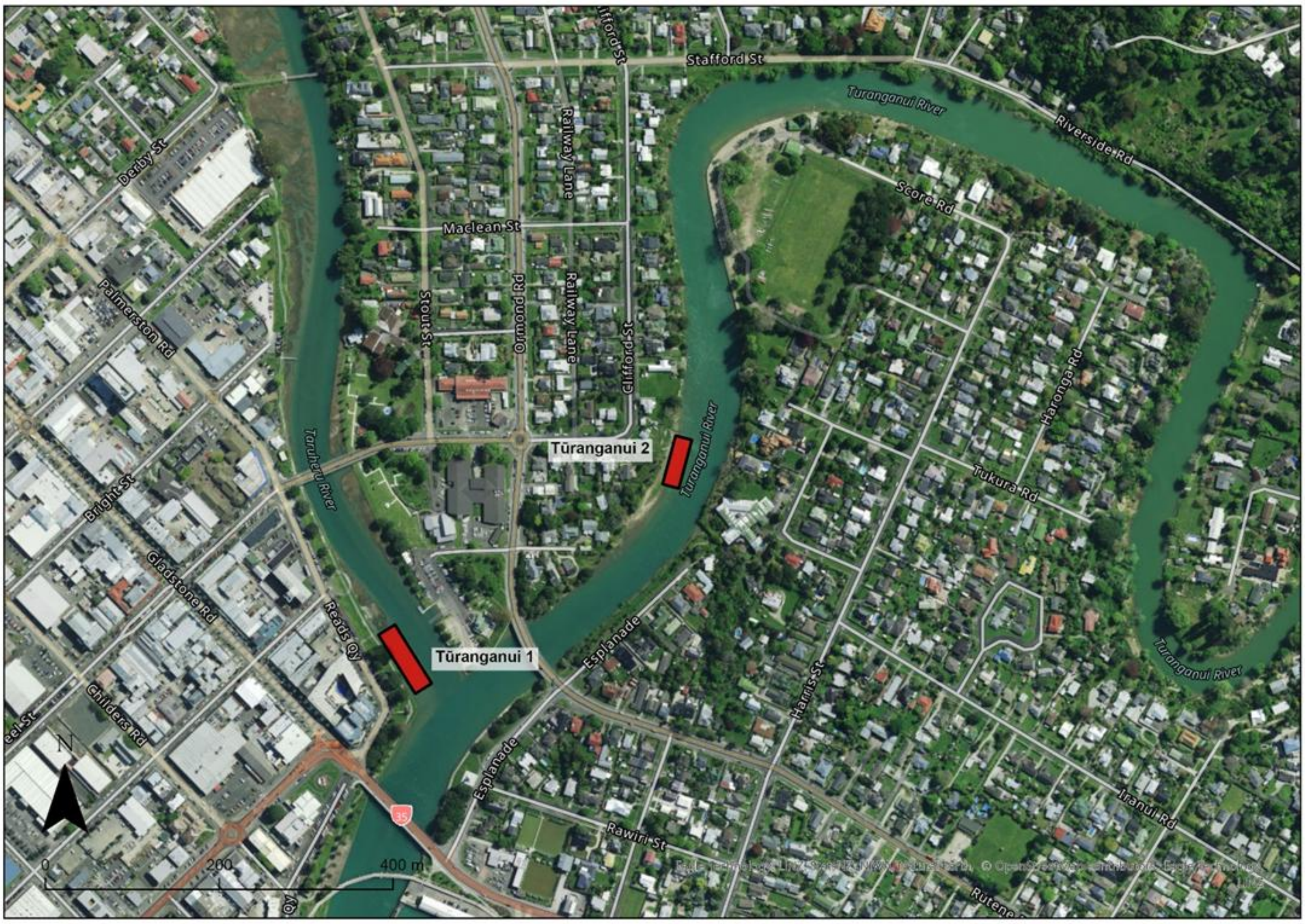

Figure 2. Map of Tūranganui Estuary. Tūranganui 1 on the Taruheru River. Tūranganui 2 on the Waimatā River.

2.3 Te Wherowhero Lagoon

Te Wherowhero Lagoon is on the southeastern coast of Tūranganui-a-Kiwa. Ngāi Tāmanuhiri and Rongowhakaata are mana whenua. Te Wherowhero Lagoon was an early settlement site in the region, where generations of chiefs built pā on the headland, utilising its strategic vantage point (Tāmanuhiri Tūtū Poroporo Trust, 2023)

The lagoon is surrounded by a moderately sized catchment, most of which is covered in grass and cropland, with a small amount of forestry. It is classified as a permanently open tidal lagoon, with an extensive intertidal area and narrow entrance to the sea, separated from the sea by a narrow sandspit. Although the entrance is narrow, these types of estuaries are typically well flushed with salinity levels generally similar to that of seawater. River inflow is minimal compared to tidal exchange, resulting in the lagoon’s hydrodynamics being primarily driven by tide, with most water entering and exiting on the ingoing and outgoing tide (Berthelsen et al., 2024; Hume et al., 2016).

Three representative survey sites were established at Te Wherowhero Lagoon at suitable benthic habitats (Figure 3). Wherowhero 1 was located at the northern/upper end of the lagoon, Wherowhero 2 was located in the north-western/central zone of the lagoon near the Pākōwhai Stream inlet, and Wherowhero 3 was positioned at the southern end of the lagoon closer to the saltwater inlet. Each survey site measured 60m x 30m and was split into nine plots, each measuring 20m x 10m, to achieve nine replicates per location. The long edge of each site was positioned parallel to the water's edge. Site GPS coordinates can be found in Appendix 1.

Figure 3. Map of Te Wherowhero Lagoon.

3. Methodology

The fine-scale and shellfish monitoring methods followed the monitoring protocol outlined by Clark et al. (2024). Fine-scale monitoring was conducted at all three estuaries: Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon, from the 26th March to the 2nd April 2025 inclusive. Timing was chosen to coincide with the lowest tides for sampling. Shellfish monitoring was only conducted at the Tūranganui Estuary due to site feasibility. It was undertaken at the same time as the fine-scale monitoring, and involved quantifying the abundance and size structure of shellfish populations.

Fine-scale monitoring was done as described in Figure 4, which outlines the type of sampling within each site and plot. For Tūranganui Estuary, the approach was amended (outlined in Section 2.2), based on site size limitations.

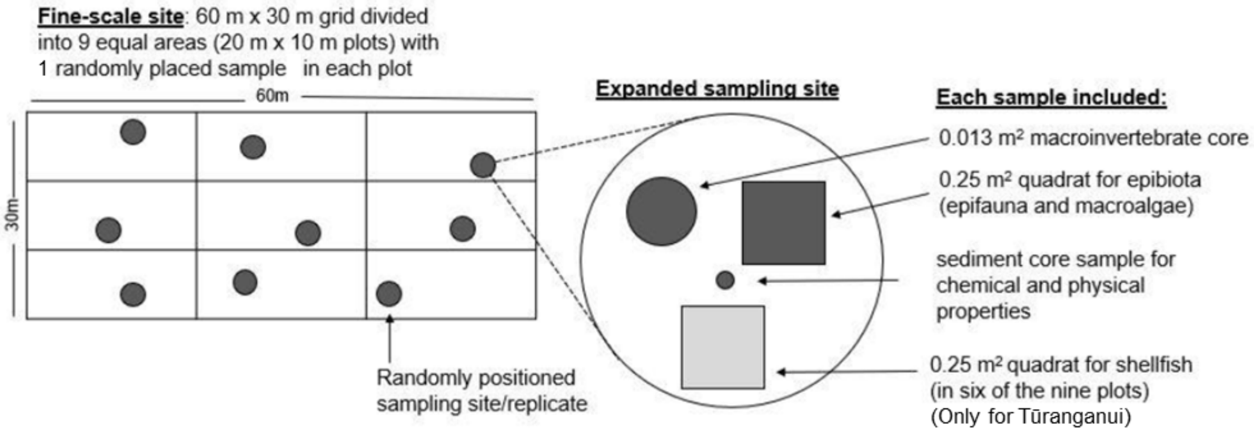

Figure 4. The sampling layout of the fine-scale monitoring. Figure has been adapted from Berthelsen et al. (2024).

3.1 Sediment quality

Sediment nutrients, nitrogen and phosphorus, support plant growth. However, when nitrogen and phosphorus levels are elevated they can drive algal blooms and eutrophication (excessive enrichment) that negatively affect benthic macrofauna (Stevens et al., 2024; Walker et al., 2022). Nutrient levels are influenced by sediment grain size, with finer sediments associated with higher nutrient concentrations (Heap et al., 2001; Sutula, 2011). Organic matter in estuarine sediment is measured as percent Total Organic Carbon (TOC). TOC is an indicator of eutrophication as the decomposition of organic matter can deplete oxygen impacting estuary biota.

The source of metal contaminants in estuaries is from naturally occurring phenomena and human activities, and excess levels can be toxic to biota (plant and animal life). Levels are usually elevated in areas of anthropogenic development, particularly around point sources in urban environments. Copper Cu, lead Pb and zinc Zn are the main contaminants that are associated with urban stormwater input, while arsenic As, mercury Hg, cadmium Cd, chromium Cr and nickel Ni are usually associated with rural land practises (Stevens et al., 2024). Concentrations vary depending on surrounding land use and catchment activities.

Sediment microalgae (chlorophyll-a and pheopigment) contribute to both estuarine primary productivity and carbon fixation, and secondary production by contributing as a food source (Underwood & Kromkamp, 1999). Chlorophyll-a concentrations were analysed as a relative measure of microalgal biomass and pheophytin concentrations represent the pigments formed from the breakdown of chlorophyll. They are measured to identify any major bloom occurrences that may be indicative of eutrophic conditions (Robertson et al., 2002).

A sediment core was collected with a 60mm diameter tube pushed to a depth of at least 150mm into the benthic substrate of each fine-scale site plot. Cores were extruded onto a white tray, sectioned vertically into halves, and then photographed alongside a ruler and identification tag. Sediment colour, texture, smell, stratification and any occurrence of black (anoxic) zones were recorded. If black zones were present, the average depth of the transition layer, known as the redox potential discontinuity (RPD), was measured.

At each plot, the top 20mm of the extracted sediment core was collected. Samples from multiple plots were combined into three composite samples (Table 1). Samples were stored on ice and sent to RJ Hill Laboratories for analysis of grain size (seven grain size profiles), nutrients (total organic carbon (TOC), total nitrogen (TN), total recoverable phosphorus (TRP)), metals (arsenic (As), cadmium (Cd), chlorophyll-a, and pheophytin-a). Laboratory methods and detection limits are provided in Appendix 2.

Sediment quality was then assessed according to existing guidelines: Stevens et al. (2024), Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018), and the Estuary Trophic Index (ETI; Robertson et al., 2016). Sediment default guideline values (DGV) of toxicant concentration levels in sediment are used to assess potential ecological impacts.

Composite samples for each estuary are given in Table 1.

Table 1. Composite samples for each estuary

Survey Site	Sample #	Composite Sample Plots
Kaitawa 1	1	1-3
	2	4-6
	3	7-9
Kaitawa 2	1	1-3
	2	4-6
	3	7-9
Kaitawa 3	1	1-3
	2	4-6
	3	7-9
Tūranganui 1	1	1-3
	2	4-6
	3	7-9
Tūranganui 2	1	1-2
	2	3-4
	3	5-6
Wherowhero 1	1	1-3
	2	4-6
	3	7-9
Wherowhero 2	1	1-3
	2	4-6
	3	7-9
Wherowhero 3	1	1-3
	2	4-6
	3	7-9

3.2 Epibiota

At each fine-scale monitoring site, a $0.25m^2$ quadrat was randomly placed into each plot and the epifauna (surface dwelling organisms) and number of crab burrows were identified and quantified. The placed quadrat was photographed with an identification tag, and observations of number of individuals for each animal taxon and number of crab burrows were recorded. Any visible microalgae were also noted for colour, coverage and thickness.

3.3 Infaunal macroinvertebrates

Core samples were collected using a 130mm diameter and 150mm depth corer from each plot to monitor infaunal macroinvertebrates (organisms living within the sediment). Extracted cores were placed in a plastic zip-lock bag with an identification tag and transported to a location for sieving. Core samples were gently washed with saline water through a 0.5mm mesh to remove any fine sediment, and any retained animals were transferred into 1.5L plastic pottles and preserved with 80% ethanol. Preserved infauna were sent to a taxonomist (MacLean Marine Identifiers) and sorted, identified and checked for quality assurance.

Community metrics

To evaluate infaunal macroinvertebrate communities, univariate community metrics, namely species richness (S), total abundance (N), diversity (H') and evenness (J'), were used. These metrics provide a robust framework for comparative analyses among sites, facilitating the identification of ecological trends in relation to key environmental variables (Table 2).

Table 2. Descriptions of univariate measures for epifaunal and macroinvertebrate communities. Table from Berthelsen et al. (2024).

Index	**Equation**	**Description**
No. species (S)	Count (taxa)	Total number of species in a sample
No. individuals (N)	Sum (n)	Total number of individual organisms in a sample
Diversity (H' loge)	H' = -SUM(Pi*loge(Pi))	Shannon–Wiener diversity index (loge base). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values for communities containing many species with each represented by a small number of individuals. Pi is the number of individuals of the ith species as a proportion of the total number of individuals in the sample
Evenness (J')	J' = H'/Loge(S)	Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates an even distribution, and a low value indicates an uneven distribution or dominance by a few taxa

Benthic Health Models

The National Benthic Health Model (BHM) was applied to assess the estuaries' ecological condition. The Mud BHM was used to evaluate the influence of surface sediment mud content on macrofaunal communities, while the Metals BHM measures the effects of copper, lead and zinc concentrations on macrofaunal communities. Each model produces a BHM score ranging from 1 to 6, where 1 denotes minimal impact from the stressor(s) on macrofaunal communities, and 6 represents the highest impact, relative to other estuarine sites throughout Aotearoa New Zealand (Table 3). One taxon was removed from Kaitawa 1 before modelling according to the procedures outlined in Clark et al. (2022).

Table 3. Descriptive names and boundaries for Benthic Health Model (BHM) score categories

BHM group	Level of impact relative to other estuarine sites in Aotearoa New Zealand	BHM score
1	Very low	0 to < 2
2	Low	2 to < 3
3	Moderate	3 to < 4
4	High	4 to < 5
5	Very high	> 5

Indicator taxa

Infaunal macroinvertebrates are commonly used as indicators to assess the ecological condition of estuarine ecosystems, as these taxa exhibit characteristic responses to environmental changes or disturbances.

A number of infaunal organisms have been selected as 'indicator taxa' (refer to Appendix 3) based on relevant sources (AZTI, 2022; Hewitt et al., 2005, 2009; Robertson et al., 2015; De Silva et al., 2022; Needham et al., 2014). These organisms are known to either be tolerant or intolerant to high mud, organic enrichment and/or sediment pollution levels. These organisms respond to changes in environmental conditions by either increasing or decreasing in number, depending on their tolerance levels.

3.4 Shellfish

Targeted shellfish sampling was only conducted at the two Tūranganui Estuary fine-scale sites. A 0.25m^2 quadrat was randomly placed in each plot. The top 150mm of sediment within the quadrat was dug using a trowel/spade, and the collected sediment was passed through a 4mm mesh size sieve. Any shellfish (cockles/tuangi, pipi, wedge shells/hanikura) that remained on the sieve were removed, placed on a white tray and photographed with a ruler and identification tag.

The number and size of shellfish were recorded. The size of each shellfish was measured across the widest part of individual's shell using photo analysis software, ImageJ.

3.5 Woody debris

To estimate woody debris percentage cover on top of the sediment within a fine-scale site, a 0.25 m² gridded quadrat was placed over woody debris that was present both inside and outside the site boundaries. Each placement was photographed for percentage cover calculations. This procedure was repeated up to 12 times per site. The percentage cover was calculated from grid intersection data in the photographs. Cover was then broadly classified into three categories: 0% (none—no woody debris detected), 0–50% (some), and greater than 50% (lots).

4. Results

4.1 Kaitawa Estuary

4.1.1 Sediment quality

Sediment Core

Kaitawa Estuary had no sulphide odours in any of the sediment core samples. The Kaitawa 1 cores (Figure 5), located nearest to the estuary mouth, were predominantly composed of brown, orange and grey clay with a fine, soft surface layer. In contrast, the Kaitawa 2 cores (Figure 5) had a coarser texture, consisting mainly of sand and fine silt with grey and brown tones. One of these cores featured an RPD layer at a depth of 200mm (Figure 6). Kaitawa 3 cores (Figure 5), taken from the upper estuary margin, were mainly dense brown and grey clay with some samples showing a thin layer of fine sediment on the surface.

Figure 5. Sediment cores from Kaitawa Estuary. Left is an example from Kaitawa 1, middle is an example from Kaitawa 2, and right is an example from Kaitawa 3.

Figure 6. Kaitawa 2 sediment core displaying an RPD layer.

Sediment grain size

Kaitawa 1 and Kaitawa 3 sediment composed of a greater amount of mud than Kaitawa 2 (Figure 7). The sediment mud (Table 4) fell into the "poor" and "very poor" range of LAWA's guidelines at all sites, indicating sediment is having negative impacts on the macrofaunal communities.

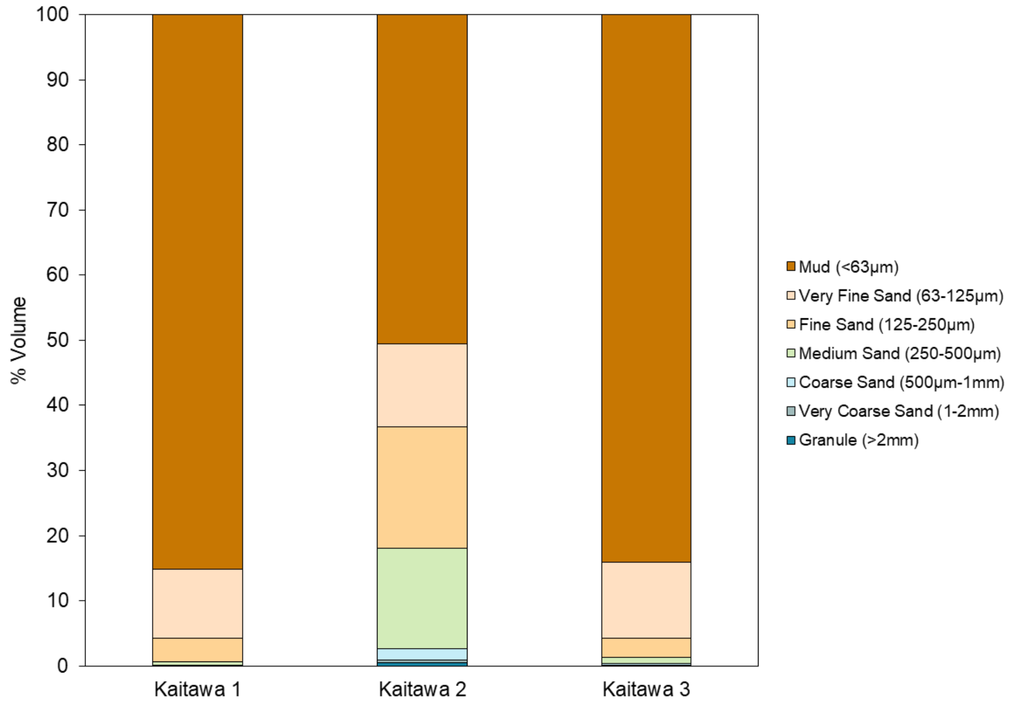

Figure 7. Sediment grain size categories as percentage volume average from composite samples at Kaitawa Estuary.

Table 4. Sediment quality parameters at fine-scale monitoring sites for Kaitawa Estuary, Tūranganui Estuary and Te Wherowhero Lagoon (Mud and TOC in %, TN, TRP As, Cd, Cr, Cu, Pb, Hg, Ni, Zn, Chl-a and Pheo in mg/kg). Values are coloured to reflect condition ratings of

ecological health as per guidelines of Stevens et al. (2024) and ANZG (2018). Rating criteria are not established for TRP, Chl-a or Pheo-a.

Site	Mud	TN	TRP	TOC	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Chl-a	Pheo
Kaitawa 1	85.2	417	420	0.34	5.94	0.028	16.1	9.5	8.0	0.046	23.3	50.3	1.13	1.03
Kaitawa 2	50.6	410	380	0.36	5.19	0.023	10.1	5.1	5.8	0.028	13.1	36.6	3.37	2.73
Kaitawa 3	84.1	743	361	0.66	3.51	0.046	12.0	7.5	7.2	0.037	15.5	47.3	2.70	2.47
Tūranganui 1	61.1	457	306	0.49	3.73	0.054	14.0	7.1	7.8	0.033	14.0	52.6	2.53	2.43
Tūranganui 2	30.7	283	242	0.16	3.34	0.036	9.5	4.8	5.2	0.027	11.8	35.0	0.93	0.83
Wherowhero 1	24.5	360	504	0.23	13.53	0.025	11.8	6.5	7.1	0.039	16.1	39.6	2.47	2.40
Wherowhero 2	71.6	710	483	0.71	10.25	0.051	13.6	9.9	8.7	0.032	18.1	44.4	3.87	3.70
Wherowhero 3	54.0	463	402	0.40	6.46	0.028	15.1	8.5	7.2	0.037	18.0	47.0	2.93	3.97

Condition rating: Very Good | Good | Fair | Poor | Very Poor

Organic Carbon and Nutrients

Sediment concentrations of TN and TOC at Kaitawa Estuary were within the “very good” to “good” quality range (Table 4), suggesting low nutrient enrichment and a healthy organic carbon profile across the sites.

Metal Contamination

Metal concentrations were predominantly in the “very good” to “good” range, except for Ni at Kaitawa 1 in the “poor” quality category.

Chlorophyll-a and Pheophytin-a

Chlorophyll-a ranged from 1.3 mg/kg to 3.3 mg/kg, while pheophytin-a ranged from 1.0 mg/kg to 2.7 mg/kg (Table 4). Kaitawa 1 exhibited the lowest concentrations for both pigments.

4.1.2 Epibiota

Crab burrows were present at all fine-scale sites, with the highest densities recorded at Kaitawa Estuary 2 (114 burrows/m²) and Kaitawa Estuary 3 (103 burrows/m²), as shown in Appendix 7. The most observed epifauna were *Austrohelice crassa* (burrowing mud crab) and *Amphibola crenata* (mud snail). No macroalgae or vascular plants were recorded within quadrats at any site. Although mangroves are present in the upper estuary margin, they were absent from all surveyed locations.

4.1.3 Infaunal Macroinvertebrates

Kaitawa 1 had the lowest macroinvertebrate diversity, with 6 taxa primarily from Arthropoda and Annelida. Kaitawa 2 recorded 13 taxa, mainly Mollusca and Annelida, while Kaitawa 3 had 10 taxa dominated by Annelida and Arthropoda (Appendix 4).

Community Metrics

Univariate indices describing the communities across the Kaitawa sites are shown in Figure 8. The Shannon–Wiener diversity (H’) ranged from 0.28 to 0.90, species richness (S) ranged from 1 to 3 taxa, and abundance (N) ranged from 1 to 6 individuals per core.

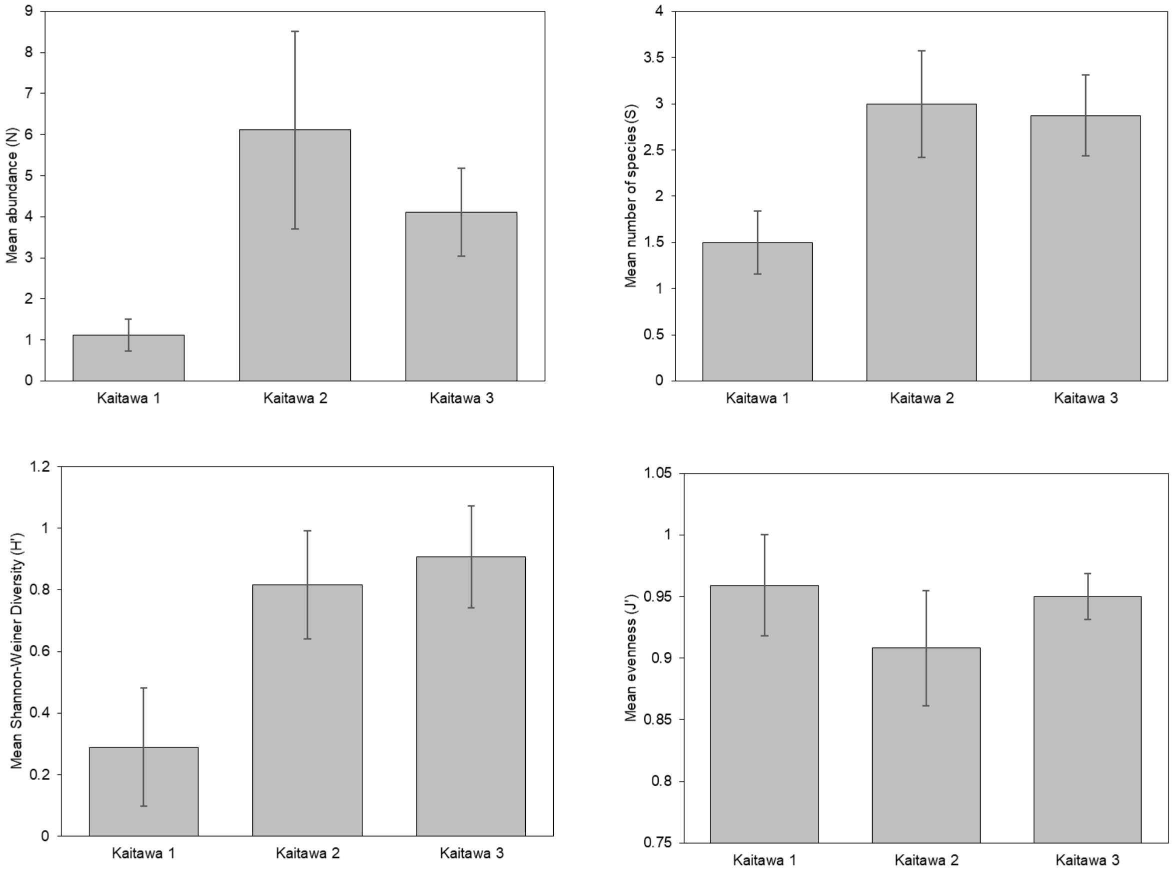

Figure 8. Community indices namely number of macroinvertebrate species (S) and diversity (H’; left) and infauna abundance (N) and evenness (J’; right) for Kaitawa Estuary. Bars indicate standard error.

Benthic Health Models

The Mud BHM scores (Figure 9) for Kaitawa estuarine sites were higher than most estuarine sites across Aotearoa New Zealand and indicate a moderate (Kaitawa 1) to high (Kaitawa 2 and 3) impact from sedimentation on benthic health.

The Metals BHM scores (Figure 10) for Kaitawa estuarine sites were also higher than most estuarine sites in New Zealand and indicate a moderate (Kaitawa 1 and Kaitawa 3) to high (Kaitawa 2) impact from sedimentation on benthic health.

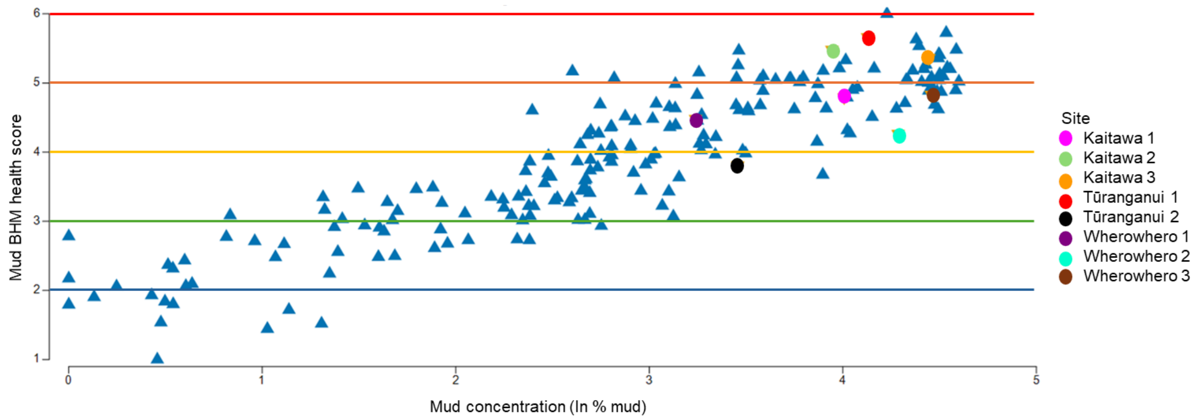

Figure 9. Mud Benthic Health Model (BHM) scores for the fine-scale sites (coloured circles) compared with those from sites used to develop the model (blue triangles). The absolute health boundaries for Metals BHM scores are indicated with the coloured solid lines which indicate the upper value of the boundary: blue is very low impact (<2), green is low impact (2 - <3), yellow is moderate (3 - <4), orange is high (4 - <5), and red is very high impact (5 - <6).

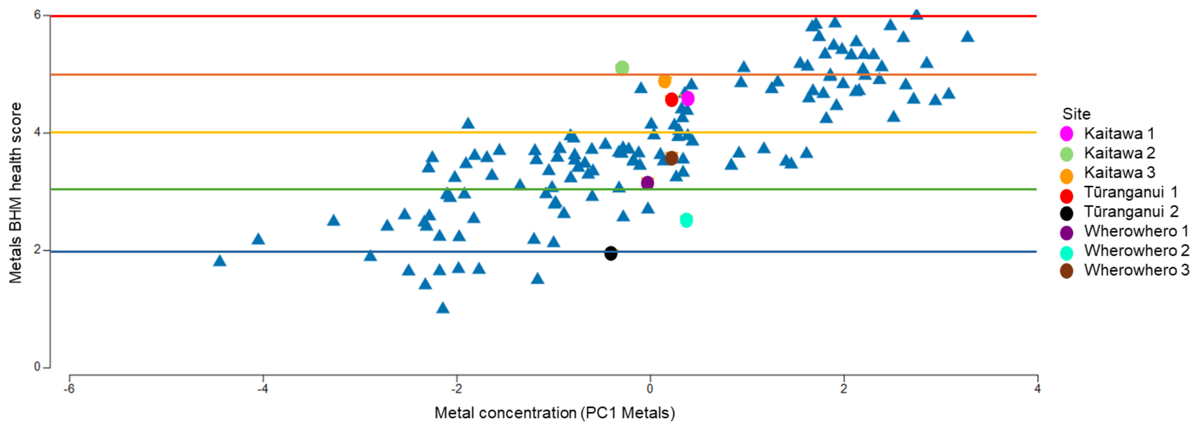

Figure 10. Metal Benthic Health Model (BHM) scores for the fine-scale sites (coloured circles) compared with those from sites used to develop the model (blue triangles). The absolute health boundaries for Metals BHM scores are indicated with the coloured solid lines (the upper value of the boundary): blue is very low impact (< 2), green is low impact (2 - <3), yellow is moderate impact (3 - < 4), orange is high impact (4 - <5), and red is very high impact (5 - <6).

Indicator taxa

The Kaitawa Estuary hosted five indicator taxa, mainly at Kaitawa 2 and Kaitawa 3 (Appendix 4). The Nereididae family were the most abundant, being able to tolerate sediment mud contents of up to 100 percent.

4.1.4 Shellfish

No cockles were found in the infauna samples at Kaitawa 1 or Kaitawa 3, and only one recruit (<5mm) was detected at Kaitawa 2 (Figure 11).

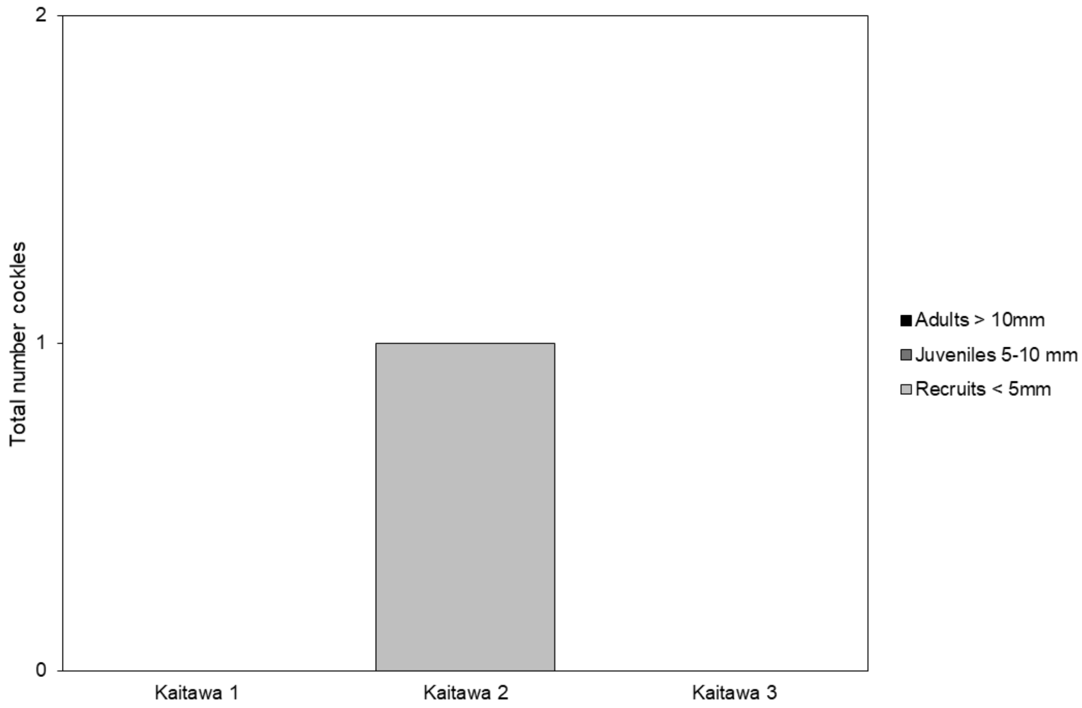

Figure 11. Number of cockles in each size class at Kaitawa Estuary.

4.1.5 Woody debris

Kaitawa sites woody debris ranged from 8% at Kaitawa 3 to 22% at Kaitawa 2 (Figure 12).

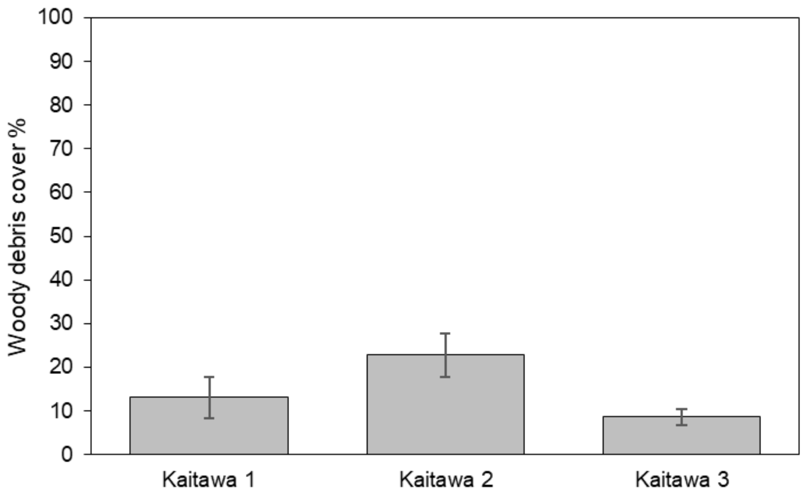

Figure 12. Mean percentage cover of woody debris within quadrats placed on top of the debris inside/outside of the fine-scale sampling sites; Kaitawa 1 (outside), Kaitawa 2 (outside), and Kaitawa 3 (inside).

4.2 Tūranganui Estuary

4.2.1 Sediment quality

Sediment core

Tūranganui 1 had core samples that exhibited sulphide odours. Tūranganui 1 sediment cores consisted of fine, waterlogged silt with a gritty texture due to decomposed shell material. The Tūranganui 2 cores were composed of granulated, sandy sediment with grey and brown hues. No distinct RPD was observed at either site. Example cores are shown in Figure 13.

Figure 13. Sediment core examples from Tūranganui Estuary. Tūranganui 1 on the left and Tūranganui 2 on the right.

Sediment grain size

Sediment grain size composition at Tūranganui 1 was mostly mud and very fine sand, and Tūranganui 2 sediment was composed of less mud and greater very fine sand (Figure 14). The sediment mud at Tūranganui 1 fell into the “very poor” range and Tūranganui 2 fell into the “poor” range of LAWA guidelines, indicating greater negative effects on the macrofaunal communities (Table 4).

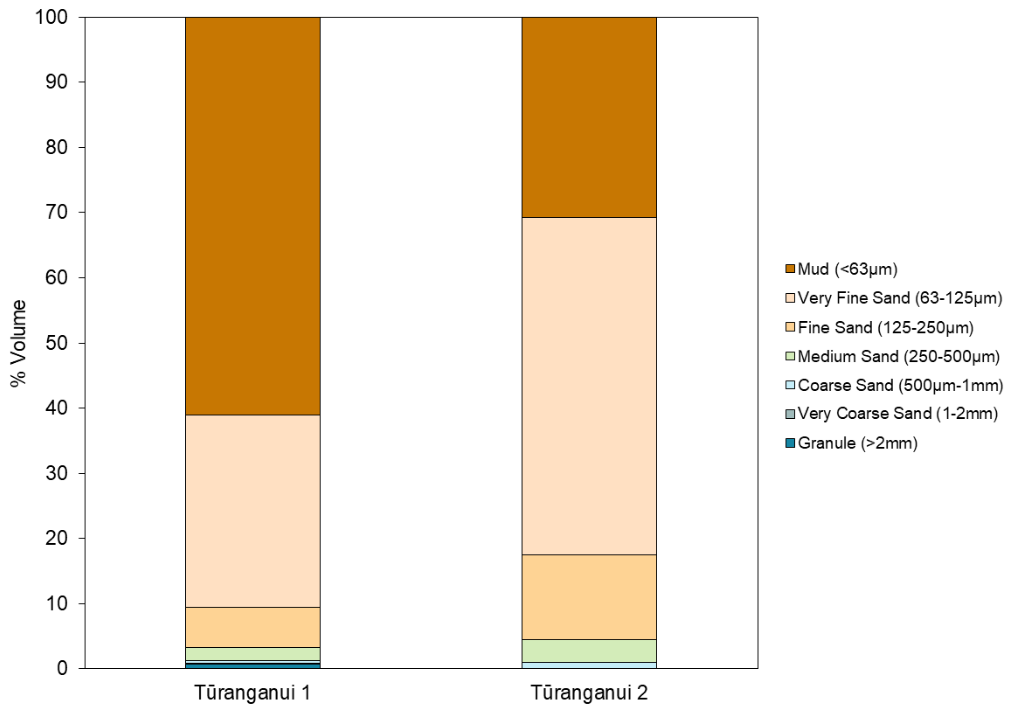

Figure 14. Sediment grain size categories as percentage volume average from composite samples at Tūranganui Estuary.

Organic carbon and nutrients

Sediment concentrations of TN and TOC at Tūrnaganui Estuary were within the “very good” to “good” range (Table 4), suggesting low nutrient enrichment and a healthy organic carbon profile across both sites.

Metal contamination

Metal concentrations were predominantly in the “very good” to “good” range (Table 4), except for Nickel which fell into the “poor” range at both Tūranganui 1 and Tūranganui 2.

Chlorophyll-a and Pheophytin-a

Tūranganui 1 pigment concentrations were 2.5 mg/kg chlorophyll-a and 2.4 mg/kg pheophytin-a. Tūranganui 2 had notably lower values of 0.9 mg/kg chlorophyll-a and 0.8 mg/kg pheophytin-a (Table 4).

4.2.2 Epibiota

Crab burrows were present at both sites. The most frequently occurring epifauna at Tūranganui 1 and the only epifauna present at Tūranganui 2 was the burrowing mud crab (*Austrohelice crassa*), as shown in Appendix 8. No macroalgae or vascular plants were recorded within quadrats at any site.

4.2.3 Infaunal macroinvertebrates

Tūranganui 1 had 19 taxa, with the majority belonging to the Mollusca phylum and Tūranganui 2 had 13 different taxa identified, with the hooded shrimp and estuarine amphipod being the most dominant (Appendix 5).

Community metrics

Univariate indices describing the communities across the Tūranganui sites are shown in Figure 15. On average, Tūranganui 1 had an abundance (N) of 29 individuals, species richness (S) of 6.5 taxa, and Shannon-Wiener diversity (H') of 1.4. Tūranganui 2 had an average abundance (N) of 23.5 individuals, a species richness (S) of 4.5 taxa, and Shannon-Wiener diversity (H') of 0.8.

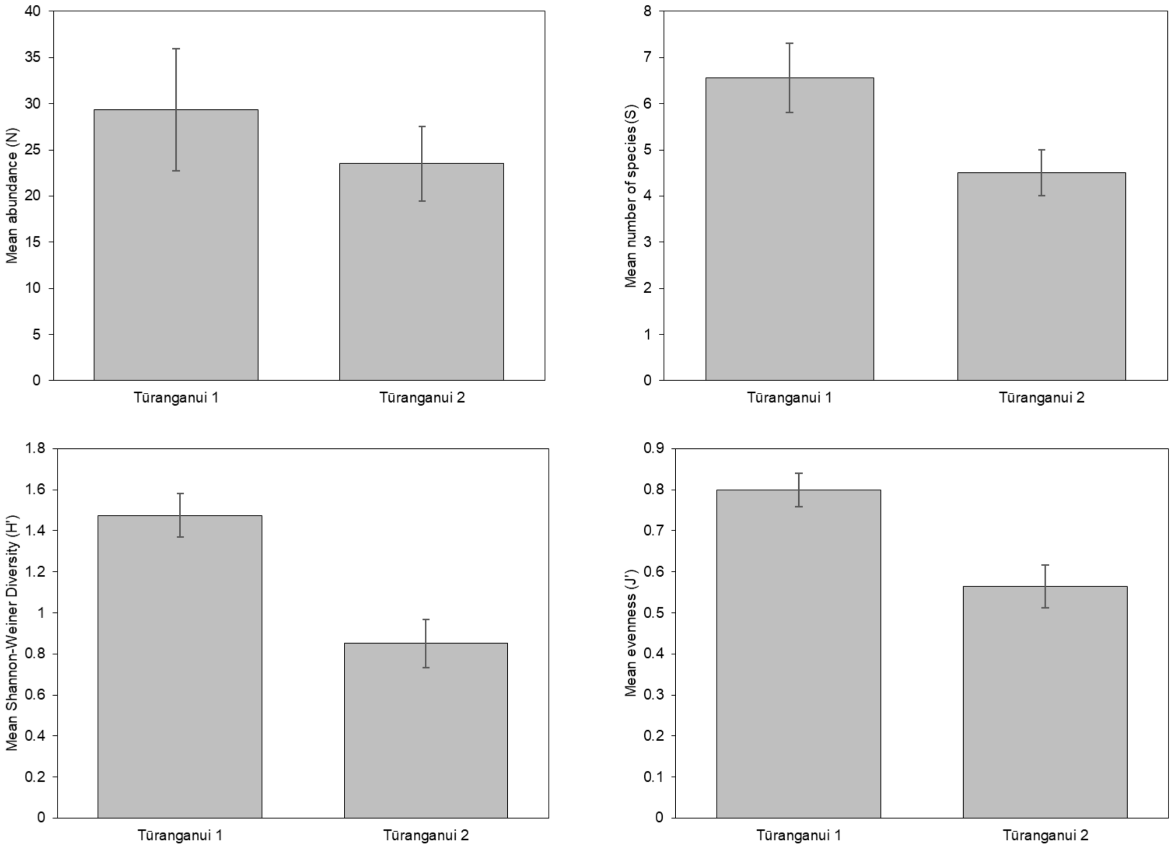

Figure 15. Community indices namely number of macroinvertebrate species (S) and diversity (H'; left) and infauna abundance (N) and evenness (J'; right) for fine-scale sites at Tūranganui Estuary. Bars indicate standard error.

Benthic Health Models

The Mud BHM score (Figure 9) for Tūranganui 1 was higher than most estuarine sites across Aotearoa New Zealand and indicates a very high impact from sedimentation on benthic health. The Mud BHM for Tūranganui 2 had a moderate impact from sedimentation on benthic health.

The Metals BHM score (Figure 10) for Tūranganui 1 was also higher than most estuarine sites in New Zealand and indicates a high impact from metal contaminants on benthic health. Tūranganui 2 Metal BHM score indicates a very low impact from metal contamination on benthic health.

Indicator taxa

Tūranganui 1 presented an abundance of taxa which tolerate moderately muddy, organically enriched sediments, *Arthritica bifurca*, *Austrovenus stutchburyi* and Capitellidae. In contrast, Tūranganui 2 had small numbers of species tolerant indicator taxa, Nereididae, *Potamopyrgus estuarinus*, and a mud sensitive species, *Microspio maori*.

4.2.4 Shellfish

At Tūranganui 1, cockles were predominantly recruits (<5mm), while Tūranganui 2 contained very few recruits (Figure 16). During targeted shellfish sampling (including cockles and pipis larger than 4 mm), six cockles were recorded at Tūranganui 1, but none at Tūranganui 2.

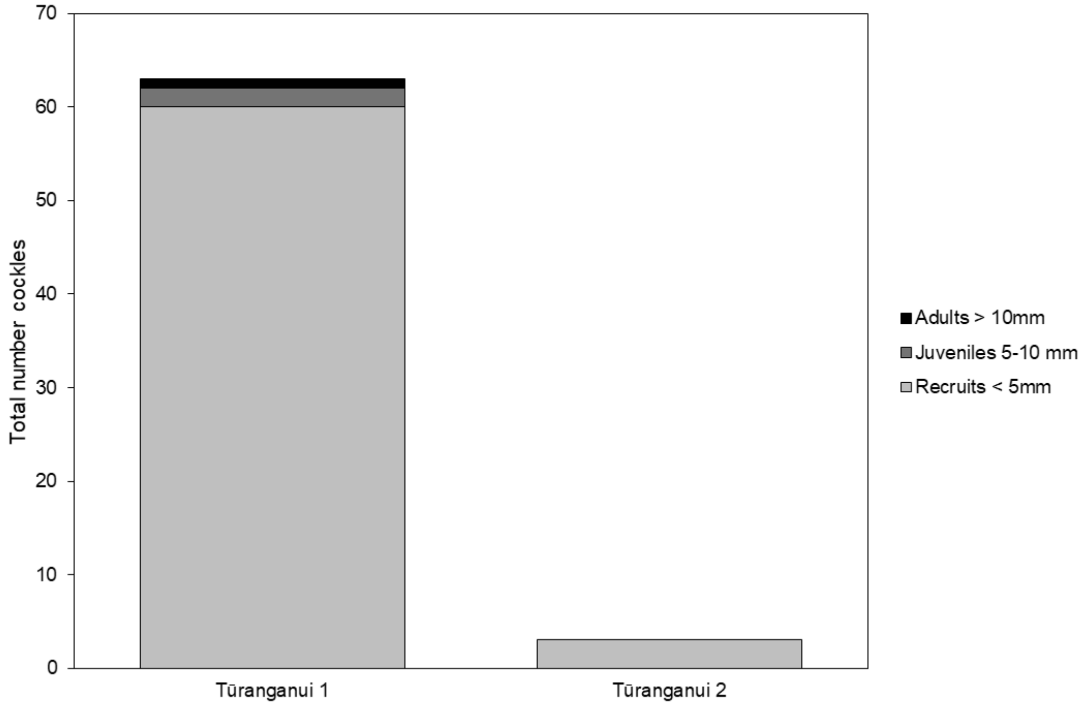

Figure 16. Number of cockles in each size class at Tūranganui Estuary.

4.2.5 Woody debris

Woody debris was absent at Tūranganui 1 (Figure 17), while Tūranganui 2 contained a greater quantity of smaller woody debris (debris size data not shown).

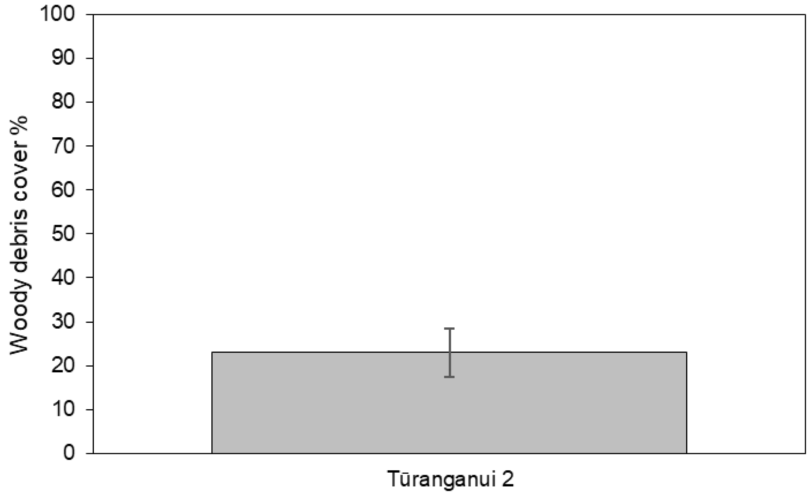

Figure 17. Mean percentage cover of woody debris within quadrats placed on top of the debris outside of Tūranganui 2. Bar show standard error.

4.3 Te Wherowhero Lagoon

4.3.1 Sediment quality

Sediment core

A strong sulphide odour was detected at Wherowhero 3. This is generally a sign of organically enriched and highly anoxic (oxygen deficit) sediment which may have been due to decomposition of woody debris which was abundant at this site. Wherowhero 3, located closest to the lagoon mouth, featured cores primarily composed of a fine grey and brown silt layer in the upper <100mm, followed by a grey and brown clay and silt layer extending to around 150mm depth, beneath which lay a grey coarse sand layer. The other two Te Wherowhero Lagoon sites had surface layers of fine silt, transitioning to sand, silt, clay and then coarser sand at greater depths. Example core samples are provided in Figure 18.

Figure 18. Example sediment cores from Te Wherowhero Lagoon. Left is Wherowhero 1, middle is Wherowhero 2, and right is Wherowhero 3.

Sediment grain size

Wherowhero 2 had the highest percentage of sediment mud (Figure 19), followed by Wherowhero 3 and Wherowhero 1 which had the least, with fine and medium sand contributing to Wherowhero 1 sediment composition. The sediment mud at Wherowhero 2 fell into the "very poor” range, Wherowhero 3 fell into the “poor” range and Wherowhero 1 fell into the “fair” range of LAWA’s guidelines, indicating negative impacts on the macrofaunal communities (Table 4).

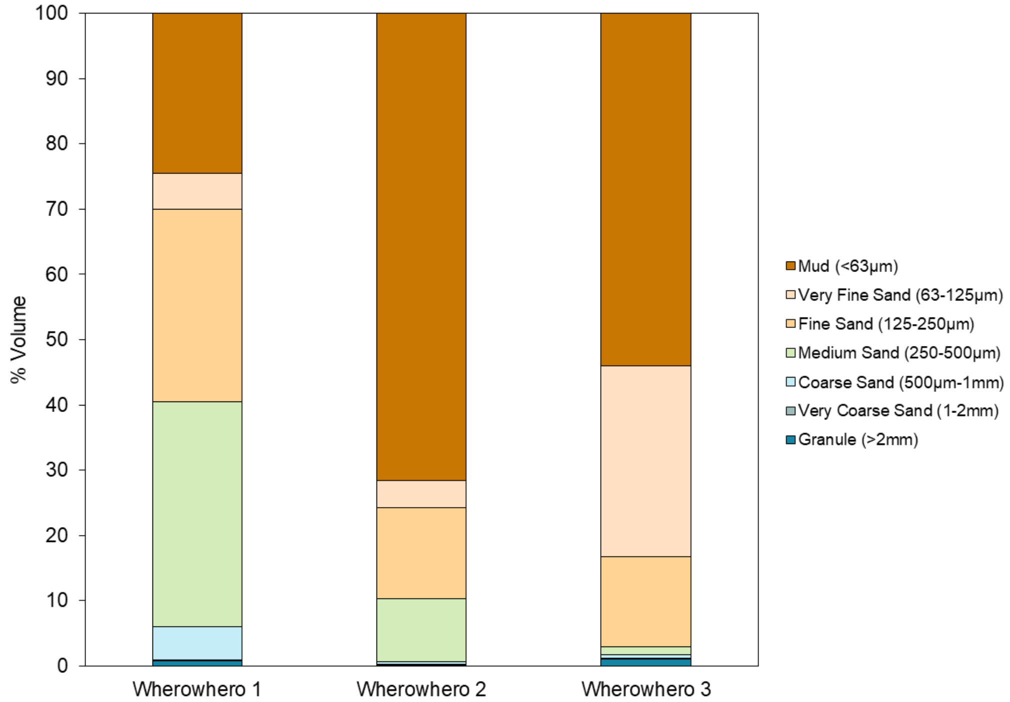

Figure 19. Sediment grain size categories as percentage volume average from composite samples at Te Wherowhero Lagoon.

Organic carbon and nutrients

Sediment concentrations of TN and TOC at Te Wherowhero Lagoon were within the “very good” to “good” range (Table 4), suggesting low nutrient enrichment and a healthy organic carbon profile across the sites.

Metal contamination

Metal concentrations were predominantly in the “very good” to “good” range. Arsenic at Wherowhero 1 and Wherowhero 2 was in the “fair” range, and Nickel at all Te Wherowhero Lagoon sites fell into the “fair” quality category (Table 4).

Chlorophyll-a and Pheophytin-a

Chlorophyll-a ranged from 2.4 mg/kg to 3.9 mg/kg, while pheophytin-a ranged from 2.4 mg/kg to 3.9 mg/kg (Table 4). Wherowhero 1 exhibited the lowest concentrations for both pigments.

4.3.2 Epibiota

Crab burrows were present at all fine-scale sites (epibiota data found in Appendix 9). The most observed epifauna were *Zeacumantus subcarinatus* (spire shell) and *Austrohelice crassa* (burrowing mud crab). No macroalgae or vascular plants were recorded within quadrats at any site.

4.3.3 Infaunal macroinvertebrates

Wherowhero 2 had the lowest macroinvertebrate diversity, with 20 taxa, primarily from Mollusca and Arthropoda. Wherowhero 1 had 25 taxa, with majority being Mollusca, Annelida and Arthropoda. Wherowhero 3 showed the highest diversity, with 31 infauna taxa, primarily from the Annelida and Mollusca phyla.

Community metrics

Univariate indices describing the communities across the eight sites are shown in Figure 20. Wherowhero 3 had the highest abundance per core of 60 (N), and the highest number of species (8.5 (S)), with lower Shannon-Wiener diversity (H') and evenness (J') than the other two Te Wherowhero Lagoon sites.

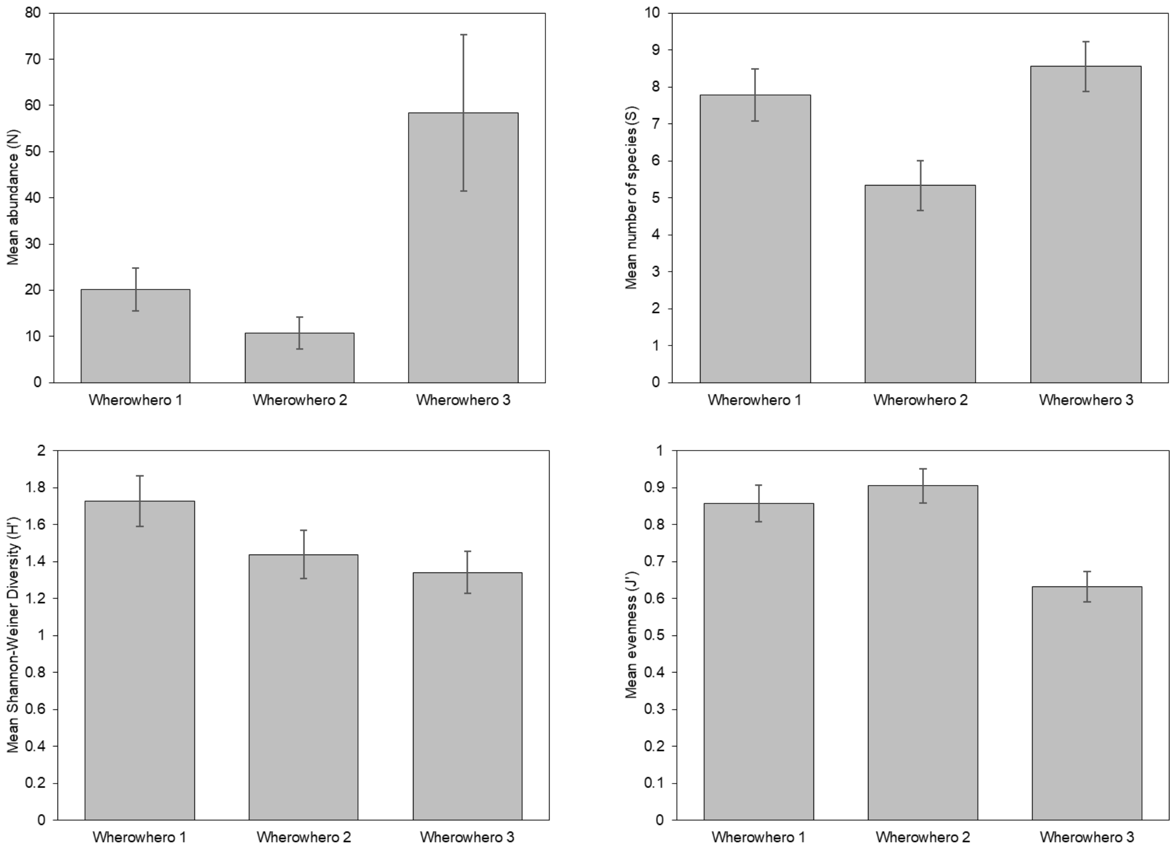

Figure 20. Community indices namely number of macroinvertebrate species (S) and diversity (H'; left) and infauna abundance (N) and evenness (J'; right) for fine-scale sites at Te Wherowhero Lagoon. Bars indicate standard error.

Benthic Health Models

The Mud BHM scores (Figure 9) at Te Wherowhero Lagoon sites were higher than most estuarine sites across Aotearoa New Zealand and indicate a high impact from sedimentation on benthic health.

The Metals BHM scores (Figure 10) at Te Wherowhero Lagoon sites were similar to other estuarine sites across Aotearoa New Zealand and indicate a low to moderate impact from metal contamination on benthic health.

Indicator taxa

The bivalve *Austrovenus stutchburyi* (cockle) was common at all the Te Wherowhero Lagoon sites (Appendices 6), preferring sandy sediments with low mud content. *Prionospio aucklandia* was abundant at Wherowhero 1 and 3, typically found in very muddy habitats. *Arthritica bifurca*, which favours moderately muddy sediment, was abundant at Wherowhero 1.

4.3.4 Shellfish

Te Wherowhero Lagoon had high cockle densities in the infauna samples (Figure 21), consisting of mainly adults (>10mm). Wedge shells (*Macomona Liliana*) were found exclusively at the Te Wherowhero Lagoon sites, with totals ranging from 2 to 4 per site.

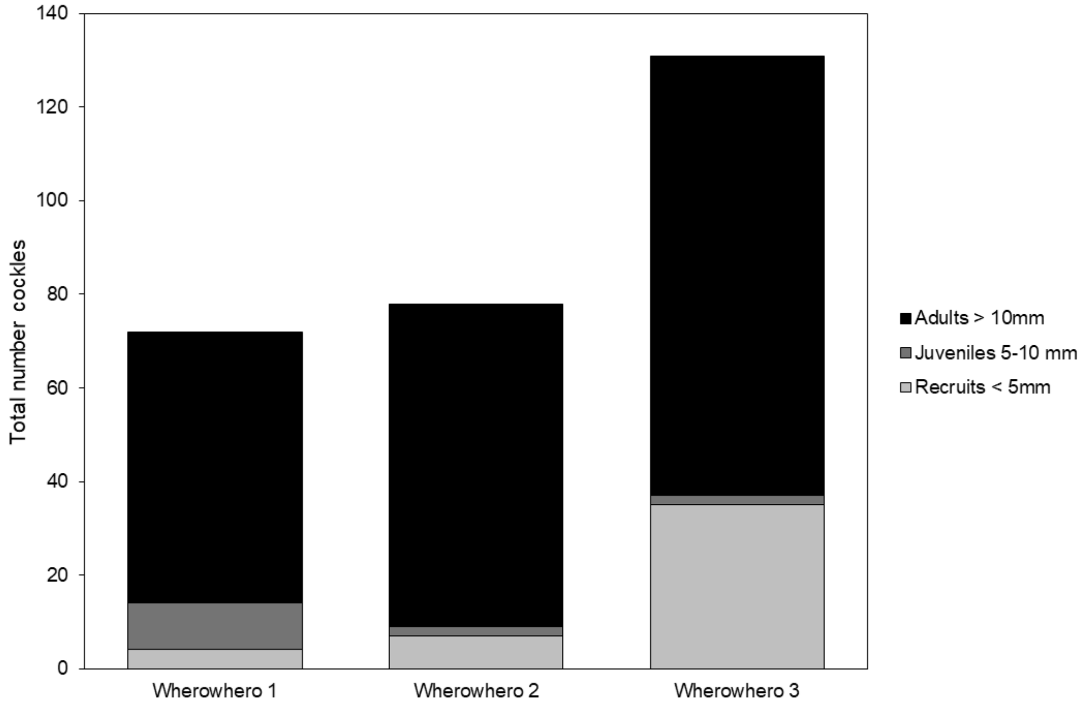

Figure 21. Number of cockles in each size class at Te Wherowhero Lagoon.

4.3.5 Woody debris

Woody debris was absent at Wherowhero 1, and Wherowhero 2 contained mainly larger debris while Wherowhero 3 had both large and small debris (debris size data not shown) (Figure 22).

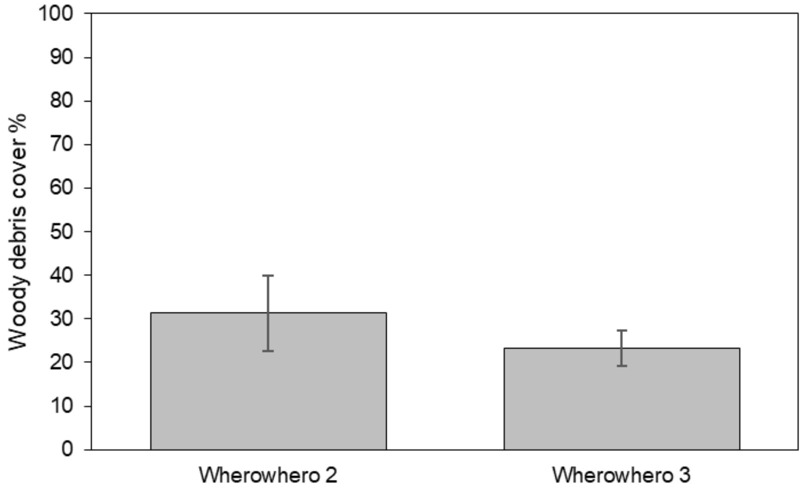

Figure 22. Mean percentage cover of woody debris within quadrats placed on top of the debris inside/outside of sampling sites; Wherowhero 2 (outside), Wherowhero 3 (inside). Bars show standard error.

5. Discussion

The Kaitawa Estuary is experiencing significant environmental stress, evident from multiple indicators. The macrofaunal community has low species richness, abundance, and diversity, likely due to substantial sediment smothering. Recent catchment-scale disturbance events, such as Cyclone Gabrielle, have probably exacerbated sedimentation and erosion, contributing to the high mud content recorded across all sites (Biggs et al., 2025, MBIE, 2024; NIWA, 2023). The presence of tolerant taxa, such as Nereididae polychaetes, further supports the conclusion of moderate to high ecological disturbance (Warwick et al., 1987; Borja et al., 2000).

The cumulative effects of sedimentation, metal contamination, and nutrient enrichment (as indicated by elevated total organic carbon, total nitrogen and total recoverable phosphorus levels, Table 4) pose significant implications for the estuary's ecological health. Restricted flushing and nutrient inputs from the rural catchment may be contributing to these issues. Furthermore, the spread of non-native mangrove species may be altering the estuary's ecology, potentially exacerbating existing stressors. These findings highlight the need for management attention to mitigate the impacts of these stressors and to inform effective conservation strategies.

The Tūranganui Estuary is in intermediate ecological health, shaped by both natural estuarine variability and substantial human pressures, including urban runoff, stormwater discharge, untreated sewage overflows, and upstream agricultural and forestry activities (Gisborne District Council, 2022). Moderate organic enrichment is indicated by the dominance of tolerant taxa such as Capitellidae polychaetes, *Arthritica bifurca*, and *Austrovenus stutchburyi*, with higher metal contamination at Tūranganui 1 likely associated with stormwater and infrastructure runoff (Pearson & Rosenberg, 1978; Grall & Chauvaud, 2002). This site supports a resilient community adapted to fluctuating conditions (Borja et al., 2000), while Tūranganui 2 supports fewer indicator taxa but includes mud-sensitive species such as *Microspio maori* and *Potamopyrgus estuarinus*, reflecting sandier, well-oxygenated sediments with low organic and metal contamination.

The variation in community composition and contamination between sites highlights spatial heterogeneity in anthropogenic pressures and sediment characteristics, a common feature of tidal river estuaries (Berthelsen et al., 2019). These findings underscore the need for targeted management to reduce contaminant and nutrient inputs, improve stormwater and sewage infrastructure, and protect sediment-sensitive habitats. Restoration strategies should focus on mitigating pollutant sources and maintaining habitat diversity to support both tolerant and sensitive species, ensuring the estuary’s long-term ecological resilience.

The results for Te Wherowhero Lagoon exhibited ecological resilience, with high species richness and diversity, and balanced communities. Although moderate mud and metal contamination are as expected, the macrofaunal community remains diverse and abundant, indicating a moderately stress-tolerant community. The lagoon's productive benthic habitats and microalgal communities further suggest a healthy and productive heterogenous ecosystem, consistent with previous research showing strong correlations between organic matter, nutrients, and benthic pigment concentrations (Sandwell et al., 2022).

6. Conclusions

This assessment of Kaitawa Estuary, Tūranganui Estuary, and Te Wherowhero Lagoon highlights the complex and site-specific nature of estuarine health. Kaitawa Estuary is heavily impacted by sedimentation and metal contamination, while Tūranganui Estuary faces mixed pressures from urban activities and localized enrichment. In contrast, Te Wherowhero Lagoon supports relatively diverse and resilient benthic communities. Nevertheless, the presence of potentially toxic contaminants in all the studied estuarine environment highlights a significant risk to estuarine biota and cultural values, emphasizing the need for integrated catchment management, ongoing monitoring, and targeted mitigation. In this direction, the current assessment results aim to contribute to ongoing monitoring to establish a baseline and regional comparisons to inform efficient management of estuarine health in the region.

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8. Appendices

Appendix 1: GPS coordinates for sites

Estuary site name	Site ID	Stake 1	Stake 2	Stake 3	Stake 4
Tūranganui 1	T1	38°40'00.60"S 178°01'43.80"E	38°40'02.20"S 178°01'45.10"E	38°40'02.50"S 178°01'44.60"E	38°40'00.80"S 178°01'43.30"E
Tūranganui 2	T2	38°39'52.80"S 178°01'57.60"E	38°39'53.60"S 178°01'57.70"E	38°39'53.50"S 178°01'57.20"E	38°39'52.70"S 178°01'57.20"E
Te Wherowhero 1	W1	38°43'42.15"S 177°56'09.86"E	38°43'40.13"S 177°56'09.65"E	38°43'40.18"S 177°56'10.80"E	38°43'42.10"S 177°56'11.14"E
Te Wherowhero 2	W2	38°43'52.01"S 177°55'43.74"E	38°43'51.39"S 177°55'41.25"E	38°43'50.45"S 177°55'41.34"E	38°43'51.08"S 177°55'43.87"E
Te Wherowhero 3	W3	38°44'55.55"S 177°56'13.88"E	38°44'57.45"S 177°56'15.46"E	38°44'58.26"S 177°56'13.55"E	38°44'55.69"S 177°56'12.43"E
Kaitawa 1	K1	38°22'42.71"S 178°18'23.30"E	38°22'43.16"S 178°18'25.71"E	38°22'44.02"S 178°18'25.59"E	38°22'43.85"S 178°18'23.22"E
Kaitawa 2	K2	38°22'46.16"S 178°18'41.45"E	38°22'47.37"S 178°18'43.62"E	38°22'48.05"S 178°18'42.66"E	38°22'46.99"S 178°18'40.77"E
Kaitawa 3	K3	38°22'52.28"S 178°18'46.25"E	38°22'50.88"S 178°18'44.80"E	38°22'50.20"S 178°18'45.63"E	38°22'51.73"S 178°18'47.00"E

Appendix 2: Sediment parameters and detection limit

Threat	**Parameter**	**Method**	**Level of detection limit**
Sedimentation	Sediment grain size (Seven Grain Sizes profile)	Drying for 16 hours at 103 °C, gravimetry (free water removed before analysis). Wet sieving with dispersant, as received	0.1 g/100 g dry wt
Nutrient enrichment	Total organic carbon (TOC)	Acid pre-treatment to remove carbonates present, followed by catalytic combustion (O2), separation, thermal conductivity detector [Elementar Analyser]	0.05 g/100 g dry wt
	Total nitrogen (TN)	Catalytic combustion (900 °C, O2), separation, thermal conductivity detector [Elementar Analyser]	0.05 g/100g dry wt
	Total recoverable phosphorous (TPR)	Dried sample, sieved as specified (if required). Nitric / hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2	40 mg/kg dry wt
Contamination	Heavy metals (trace) As, Cd, Cr, Cu, Ni, Pb, Zn, Hg	Dried sample, sieved as specified (if required). Nitric / hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2	0.01–0.8 mg/kg dry wt depending on the metal
	Chlorophyll-a and pheophytin-a	Extraction with 95% Ethanol, Spectroscopy	0.1 mg/kg as rcvd

Appendix 3: Indicator taxa table and their relationship with the stressor

Taxon	**Relationship with stressor**
Polychaete Capitellidae inc. *Heteromastus filiformis*	Dominance of this taxon may indicate high levels of nutrient enrichment. Capitellids tolerate a sediment mud content of up to 95%, with an optimum range of 10-40%. Therefore they are usually found in moderately muddy habitats.
Polychaetes *Microspio maori*	Highly sensitive to mud; presence may indicate low mud levels.
Polychaete *Nicon aestuariensis*	Widely tolerant of sediment mud content; presence may indicate high mud levels
Polychaete Nereididae	Nereidids tolerate a sediment mud content of up to 100%, with an optimum range of 35-60%. Therefore, they are usually most abundant in moderately to very muddy habitats. Nereidids are not sensitive to copper, lead and zinc contamination and can be found in high densities in relatively contaminated sediments. Their abundance often increases in contaminated sediments.
Polychaete Aglaophamus sp.	Generally prefer sandy habitats over muddy ones
Polychaete Glycera lamelliformis	Glycerids tolerate a sediment mud content up to 95%, with an optimum range of 10-15%. Therefore, they are usually most abundant in sandy habitats with some mud content. Glycerids are sensitive to low levels of oxygen, which can occur in organically enriched estuarine sediments.
Polychaete Prionospio aucklandica	Prionospio aucklandica tolerates a sediment mud content of up to 95%, with an optimum range of 20-70%. It is usually found in moderately to very muddy habitats, but is less abundant in extremely muddy areas (>70% mud). Prionospio aucklandica is also sensitive to copper contamination.
Gastropod *Amphibola crenata*	Widely tolerant of sediment mud content; presence may indicate high mud levels. Shell length has been positively correlated with sediment cadmium and zinc concentration
Gastropod *Potamopyrgus estuarinus*	Widely tolerant of sediment mud content; presence may indicate high mud levels
Bivavle *Austrovenus stutchburyi* (cockle/tuangi)	Sensitive to terrestrial sediment and different levels of suspended sediment; presence may indicate tolerable (e.g. low to intermediate - optimal range 0-10%) mud levels. Sensitive to Cu or Cu/Pb/Zn. Sensitive to metals. Cockle moderately sensitive to stormwater contaminants.
Bivavle *Arthritica bifurca*	Somewhat associated with elevated mud. Arthritica bifurca tolerates a sediment mud content of up to 75% with an optimum range of 20-60%. Therefore, it prefers moderately muddy habitats.
Bivalve *Macomona liliana* (wedge shell)	Macomona liliana tolerates mud content up to 75%, with an optimum range of 0-30%. Therefore it prefers sandy habitats with some mud. Macomona liliana is also sensitive to copper contamination.
Bivalve Paphies australis (pipi)	Pipi only tolerate a maximum sediment mud content of 5% and are very sensitive to high turbidity. Therefore, they are usually found in sandy habitats. Pipi are also sensitive to zinc contamination.

Appendix 4: Kaitawa Estuary macroinvertebrate abundance

Site	ID	Replicate	*Amphibola crenata*	*Potamopyrgus antipodarum*	*Potamopyrgus estuarinus*	*Arthritica bifurca*	*Arthritica* sp. 5 [1]	*Austrovenus stutchburyi* (0-5mm)	*Cyclomactra tristis*	*Scolecolepides benhami*	Nereididae (juvenile)	*Nicon aestuariensis*	*Perinereis vallata*	*Hemiplax hirtipes*	*Austrohelice crassa*	Brachyura (true crab, *A.crassa/H. hirtipes*)
Kaitawa	K1	1														
Kaitawa	K1	2														
Kaitawa	K1	3													1	
Kaitawa	K1	4													1	
Kaitawa	K1	5												1		
Kaitawa	K1	6								2						1
Kaitawa	K1	7								1						
Kaitawa	K1	8														
Kaitawa	K1	9					1					1		1		
Kaitawa	K2	1													2	
Kaitawa	K2	2													1	
Kaitawa	K2	3				1			1	1	2	3				
Kaitawa	K2	4	1					1		1						
Kaitawa	K2	5								2				2		1
Kaitawa	K2	6		1		14	5			1		2		1		
Kaitawa	K2	7			5					1					1	1
Kaitawa	K2	8								1	1					
Kaitawa	K2	9								1						1
Kaitawa	K3	1													1	
Kaitawa	K3	2														
Kaitawa	K3	3								1				1		
Kaitawa	K3	4										1			1	
Kaitawa	K3	5			1								1	1		2
Kaitawa	K3	6								2					1	1
Kaitawa	K3	7									3	2				1
Kaitawa	K3	8	1				1			2		2			1	
Kaitawa	K3	9								5		4		1		

Appendix 5: Tūranganui Estuary macroinvertebrate abundance

Site	ID	Replicate	Nemertea	*Amphibola crenata*	*Potamopyrgus estuarinus*	*Potamopyrgus* spp.	*Potamopyrgus antipodarium*	*Zeacumantus lutulentus*	*Arthritica bifurca*	*Arthritica* sp.5	*Austrovenus stutchburyi* (0-5mm)	*Austrovenus stutchburyi* (06-10mm)	*Austrovenus stutchburyi* (16-20mm)	*Cyclomactra tristis*	*Paphies australis*	*Xenostrobus neozelanicus*	Oligochaeta	*Capitella* spp.	*Heteromastus filiformis*	*Microspio maori*	*Scolecolepides benhami*	*Nereididae (juvenile)*	*Nicon aestuariensis*	*Perinereis vallata*	*Hemiplax hirtipes*	*Halicarcinus whitei*	Brachyura (true crab, *A.crassa/ H. hirtipes*)	Cumacea cf. Gynodiastylidae	*Paracorophium excavatum*
Tūranganui	T1	1		2	1				1		9												1						
Tūranganui	T1	2	2	1					2		7	1						1	12		2	1	2		2				
Tūranganui	T1	3		1				1	45		20								1			2	3		2				
Tūranganui	T1	4							8	1	5			1								1	2		2	1			
Tūranganui	T1	5									1		1						5						1				1
Tūranganui	T1	6	1	1					8		2								3			1	4		1				
Tūranganui	T1	7		1					1	6	10	1					1						1		1				
Tūranganui	T1	8							2	7	5			1					1							5			
Tūranganui	T1	9							1										1		1								
Tūranganui	T2	1			1		1										1			1								1	12
Tūranganui	T2	2			3	1					1									2								6	23
Tūranganui	T2	3													1												1	4	17
Tūranganui	T2	4									2									1									32
Tūranganui	T2	5																				1		1				2	13
Tūranganui	T2	6					2									1						1							9

Appendix 6: Te Wherowhero Lagoon macroinvertebrate abundance

Site	ID	Replicate	Nemertea	Ceriantharia	*Cominella glandiformis*	*Diloma subrostratum*	*Potamopyrgus estuarinus*	*Zeacumantus lutulentus*	*Arthritica bifurca*	*Arthritica sp*. 5	*Austrovenus stutchburyi* (0-5mm)	*Austrovenus stutchburyi* (06-10mm)	*Austrovenus stutchburyi* (11-15mm)	Austrovenus stutchburyi (16-20mm)	Austrovenus stutchburyi (21-25mm)	Austrovenus stutchburyi (26-30mm)	Austrovenus stutchburyi (30mm+)	*Macomona liliana* (damaged)	*Macomona liliana* (6-10mm)	*Macomona liliana* (11-15mm)	*Macomona liliana* (16-20mm)	*Macomona liliana* (21-25mm)	*Macomona liliana* (30mm+)	Oligochaeta	*Aglaophamus* sp.	*Capitella* spp.	*Heteromastus filiformis*	*Glycera lamelliformis*	*Boccardia syrtis*	*Microspio maori*	*Scolecolepides benhami*	Nereididae (juvenile or damaged)	*Nicon aestuariensis*	*Perinereis vallata*	*Prionospio aucklandica*	*Prionospio* spp.	*Hemiplax hirtipes*	*Austrohelice crassa*	Brachyura (true crab, *A.crassa/H. hirtipes*)	*Austrominius modestus*	*Exosphaeroma planulum*
Wherowhero	W1	1				1			1							1								4			1				2	2	1		2		3				
Wherowhero	W1	2						1	36		1				1	1								4							3		1			1	4				
Wherowhero	W1	3											1						1	1				4							1	1	1		1		1				
Wherowhero	W1	4						1																1														1	2		
Wherowhero	W1	5			2				13															1							1	1		1							
Wherowhero	W1	6							1		1			1										2							4				1		3				
Wherowhero	W1	7	2	2					6		1		3	1		1								2							2	1	1				3		2		
Wherowhero	W1	8						3			1												1	1							1		1		3		2				
Wherowhero	W1	9						1	4				3	1	1									3			1				1	1	1		1		4				
Wherowhero	W2	1							25		4			1																		2	1	1			1		1		1
Wherowhero	W2	2						1	2		2				1				2								2				1				2						1
Wherowhero	W2	3									1				1		1		1								6														
Wherowhero	W2	4								1																	1					1									
Wherowhero	W2	5			1				2															1			1										1		1		
Wherowhero	W2	6							4					1													1					1	1				2				
Wherowhero	W2	7					1																				1				1	1					1				
Wherowhero	W2	8							1																								1				2				
Wherowhero	W2	9							1																		1				1	2		1			1				
Wherowhero	W3	1	1								15			1	4	1											5										1	1		3	
Wherowhero	W3	2	1		1						2	1		3	7	1									1		6				1	1				1	1			1	
Wherowhero	W3	3												8	4														1				1				1	1			
Wherowhero	W3	4			1						6				7	1											6		1						1	1		1	1		
Wherowhero	W3	5							1		2					1										1	25				1	4			2	1					
Wherowhero	W3	6	1						1		6	1	2		3		1									1	4		3		4						3			4	
Wherowhero	W3	7	4	1							3				2									1			32		3		2	4			4		3	2			
Wherowhero	W3	8			4													2		1	1					6	98	1	2			4	1		15		2				
Wherowhero	W3	9			1			1			1		1	1	1	1		1	1			1		1			109					4	2		7	20					

Appendix 7: Kaitawa Estuary epibiota

Site	ID	Common name	Species ID	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9
Kaitawa	K1	Karahue (Mud snail)	*Amphibola crenata*	1	0	4	0	0	3	4	1	3
Kaitawa	K1	Burrowing mud crab	*Austrohelice crassa*	1	0	0	0	0	0	0	0	0
Kaitawa	K1	Small snail	*Potamopyrgus estuarinu*	0	0	1	0	0	0	0	0	0
Kaitawa	K1	Crab holes		28	45	42	42	49	52	35	53	57
Kaitawa	K2	Mudflat whelk	*Cominella glandiformis*	0	0	0	1 (baby)	0	0	0	0	0
Kaitawa	K2	Karahue (Mud snail)	*Amphibola crenata*	0	0	10	2	10	30	0	0	6
Kaitawa	K2	Small snail	*Potamopyrgus estuarinu*	0	0	0	0	0	0	7	2	0
Kaitawa	K2	Tuangi/cockle	*Austrovenus stutchburyi*	0	0	0	0	0	1	0	0	0
Kaitawa	K2	Pipi	*Paphies australis*	1	0	0	0	0	0	0	0	0
Kaitawa	K2	Crab holes		90	159	95	116	107	81	98	127	160
Kaitawa	K2	Burrowing mud crab	*Austrohelice crassa*	6	15	5	10	4	2	4	2	4
Kaitawa	K3	Spotted whelk	*Cominella maculosa*	1	0	0	1	0	0	0	1	0
Kaitawa	K3	Topshell	*Micrelenchus huttonii*	1	0	0	0	0	0	0	0	1
Kaitawa	K3	Karahue (Mud snail)	*Amphibola crenata*	0	0	0	0	0	2	6	23	0
Kaitawa	K3	Crab holes		39	50	37	68	85	100	170	178	205
Kaitawa	K3	Burrowing mud crab	*Austrohelice crassa*	1	0	0	7	4	2	5	8	5

Appendix 8: Tūranganui Estuary epibiota

Site	ID	Common name	Species ID	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9
Tūranganui	T1	Spire shell	*Zeacumantus lutentus*	0	4	0	0	0	0	0	0	0
Tūranganui	T1	Karahue	*Amphibola crenata*	0	0	1	0	0	0	0	0	0
Tūranganui	T1	Tuangi/cockle	*Austrovenus stutchbury*	0	1	0	3	2	0	0	0	2
Tūranganui	T1	Crab holes		21	41	44	80	56	61	151	161	96
Tūranganui	T1	Borrowing mud crab	*Austrohelice crassa*	0	0	1	5	7	0	14	13	25
Tūranganui	T2	Borrowing mud crab	*Austrohelice crassa*	0	0	0	1	0	0	NA	NA	NA
Tūranganui	T2	Crab holes		0	27	5	30	14	9	NA	NA	NA

Appendix 9: Te Wherowhero Lagoon epibiota

Site	ID	Common name	Species ID	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9
Wherowhero	W1	Mudflat whelk	*Cominella glandiformis*	0	2	2	0	1	0	0	0	0
Wherowhero	W1	Spire shell	*Zeacumantus lutentus*	10	4	15	3	6	6	4	12	8
Wherowhero	W1	Tuangi/cockle	*Austrovenus stutchburyi*	5	2	3	3		2	1	1	3
Wherowhero	W1	Tuatua	*Paphies subtriangulata*	0	0	2	0	0	0	0	0	0
Wherowhero	W1	Crab holes		60	34	29	110	41	42	104	32	33
Wherowhero	W1	Burrowing mud crab	*Austrohelice crassa*	0	0	0	0	0	0	2	1	2
Wherowhero	W2	Mudflat whelk	*Cominella glandiformis*	0	0	7	0	0	0	0	0	0
Wherowhero	W2	Spotted whelk	*Cominella maculosa*	0	0	2	0	1	0	0	0	0
Wherowhero	W2	Spire shell	*Zeacumantus lutentus*	2	5	6	0	3	0	0	0	2
Wherowhero	W2	Trough shell		0	0	0	0	0	0	0	1	0
Wherowhero	W2	Tuangi/cockle	*Austrovenus stutchburyi*	1	17	16	12	12	17	0	1	0
Wherowhero	W2	Crab holes		45	32	14	28	48	21	36	34	18
Wherowhero	W2	Burrowing mud crab	*Austrohelice crassa*	0	0	0	0	0	0	2	1	0
Wherowhero	W3	Mudflat whelk	*Cominella glandiformis*	0	0	0	3	8	0	1	0	2
Wherowhero	W3	Mudflat topshell	*Diloma zelandicum*	0	0	0	0	0	0	2	0	0
Wherowhero	W3	Small spire shell	*Zeacumantus subcarinatus*	0	6	0	0	0	0	0	0	0
Wherowhero	W3	Spire shell	*Zeacumantus lutentus*	12	3	0	2	0	2	0	0	0
Wherowhero	W3	Karahue	*Amphibola crenata*	0	0	0	0	0	0	4	0	3
Wherowhero	W3	Tuangi/cockle	*Austrovenus stutchburyi*	78	32	37	29	16	19	22	12	36
Wherowhero	W3	Crab holes		42	84	79	87	74	67	46	15	0
Wherowhero	W3	Burrowing mud crab	*Austrohelice crassa*	2	0	4	0	2	1	0	1	0