East Coast Estuaries Ecology State and Trends in Tāmaki Makaurau / Auckland to 2023

State of the Environment Reporting

Tarn P. Drylie

June 2025

Technical Report 2025/10

aucklandcouncil.govt.nz

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ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-991377-70-8 (PDF)

The Peer Review Panel reviewed this report
Review completed on 13 June 2025 Reviewed by two reviewers
Approved for Auckland Council publication by:
Name: Paul Klinac Position: General Manager, Engineering, Assets and Technical Advisory
Recommended for approval/publication by:
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Date: 13 June 2025

Recommended citation

Drylie, T. P. (2025). East coast estuaries ecology state and trends in Tāmaki Makaurau / Auckland to 2023. State of the environment reporting. Auckland Council technical report, TR2025/10

Cover image credit
Sandflat and mangrove seedlings in Whangateau Harbour. Photograph by Jonathan De Villiers.

Acknowledgement
The author wishes to acknowledge the many people that have contributed to collecting and analysing field samples for this programme over the decades, and the peer reviewers (Dr Harry Allard and Dr Kala Sivaguru) for their time and feedback which improved this report.

Executive summary

Estuaries that are healthy provide benefits to people in the form of ecosystem services. These services include climate regulation, food production, nutrient and water cycling and opportunities for cultural and recreational fulfilment. A healthy estuary is also resilient to disturbances, whether natural (from storms, for example) or man-made (such as pollution). This report provides technical information describing the current state (or 'health') of small estuaries along Tāmaki Makaurau / Auckland's east coast and how estuary health has changed over time.

The East Coast Estuaries Ecology monitoring programme was initiated in 2000 and monitors 77 sites across eight of the region's smaller estuaries: Whangateau Harbour, Pūhoi River, Waiwera River, Ōrewa River, Ōkura River, Mangemangeroa Creek, Tūranga Creek and Waikōpua Creek. The programme was designed to monitor any changes in the estuaries resulting from population growth and development in their surrounding catchments.

According to the Combined Health Score, only 28 per cent of the intertidal sandflat sites were in 'Excellent' or 'Good' health whereas 71 per cent were 'Fair' or 'Marginal' in 2023. Only one site, PUH10, had 'Poor' overall health (one per cent). The distribution of sites among Combined Health Score categories had degraded since the last regional assessment in 2019; fewer sites were in 'Excellent' (three per cent, down from 11 per cent) or 'Good' health (25 per cent down from 34 per cent) and more were in 'Poor' health (one site in 2023 compared to no sites in 2019). On average, 23 species of macrofauna (invertebrates larger than 0.5 mm) were found at each site, and 56 per cent of sites had 'High' functional resilience according to the Traits-Based Index.

The ecological health of monitoring sites tended to be better in the lower estuary close to the estuary mouth and poorer in the upper estuary close to freshwater inflows. Exceptions occurred where sites in the lower estuary were located in sheltered, low energy areas where the flushing potential is likely to be low and pollutants (such as sediment and metal contaminants) are more likely to settle, or where the natural hydrodynamics of the estuary were altered (for example at Waiwera and Whangateau where causeways may have disrupted tidal flows and impacted health).

Excess land-derived sediment (fine silts and clays) was the most prevalent stressor of ecological health over the monitoring period, impacting every estuary to some degree. Whangateau Harbour exhibited the fewest long-term trends consistent with sedimentation while Mangemangeroa, Ōkura and Waikōpua exhibited the most. Some recent changes in indicators that might suggest contemporary (as opposed to legacy) impacts from sedimentation were also found in most estuaries. These included an increase in the concentration of very fine sediments, a degradation in the health group assigned by the Benthic Health Model for mud or a change in the abundance of indicator species that occurred within the last five years. Notably, potential recovery from sedimentation impacts was evident at sites in the Tūranga and Waikōpua Creeks (in the form of improving health indices and increasing abundances of sediment-sensitive species). Results from sediment accretion monitoring were presented alongside the ecology data for the first time, which aided the interpretation of trends related to sediment impacts.

There was some evidence of metal contamination having caused stress to benthic communities over the monitoring period, though this was often difficult to separate from the impacts of sedimentation, and there was little evidence to suggest that metals impacted ecological health in any estuary over the last five years. Effective indicators of nutrient enrichment are lacking from the East Coast Estuaries Ecology monitoring programme given the focus on terrestrial sediment impacts, however at more than one site in Ōrewa River and Waikōpua Creek, potential symptoms of excess nutrients were observed. Co-occurring increases in the concentration of organic content and chlorophyll a may indicate a nutrient enrichment issue and it is recommended this is investigated via a survey of sediment nutrient concentrations.

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1 Introduction

Estuaries are semi-enclosed coastal systems found at the end of freshwater catchments where streams and rivers meet and mix with seawater (Pritchard, 1967). There are several estuary types including beach streams (such as Waitākere River at Te Henga / Bethells Beach), deep subtidally dominated estuaries (like North Cove on Kawau Island) and shallow intertidally dominated estuaries (like Waitematā Harbour or Ōkura Estuary) (Robertson et al., 2016). Tāmaki Makaurau / Auckland houses roughly 50 estuaries along its 3100km coastline. Shallow intertidally dominated estuaries are the most common type and represent the largest estuaries in the region, though there are numerous deep subtidally dominated estuaries particularly associated with the Hauraki Gulf islands (such as Waiheke Island and Aotea / Great Barrier Island) (NIWA, 2021).

While the west coast of the region is dominated by the vast Kaipara and Manukau Harbours, the east coast is punctuated with numerous smaller harbours and estuaries that are sheltered by the Hauraki Gulf. The East Coast Estuaries Ecology monitoring programme focuses on eight of these smaller estuaries: Whangateau Harbour, Pūhoi River, Waiwera River, Ōrewa River, Ōkura River, Mangemangeroa Creek, Tūranga Creek and Waikōpua Creek. The programme was initiated in 2000 in response to increasing population densities and land use change (including urbanisation) along the east coast and recognition of the potential threat associated with increased inputs of terrestrial (land-derived) sediment to the estuaries. For instance, elevated sediment loads can reduce water clarity and interfere with suspension feeding animals and photosynthesising algae, and when deposited they can smother the plants and animals living on the sandflats and cause the habitat to shift from sand to mud (Gibbs & Hewitt, 2004; Pratt et al., 2014).

It is important that Tāmaki Makaurau / Auckland's estuaries remain in good ecological condition because a healthy, well-functioning estuary supports ecosystem services such as climate regulation, food production, nutrient and water cycling, and provision of opportunities for culture and recreation (Snelgrove et al., 2014; Thrush et al., 2013). A healthy estuary is also resilient to disturbances, whether natural or anthropogenic (i.e. man-made) (Drylie et al., 2020; Thrush et al., 2003). Many of the ecosystem services are underpinned by ecological processes and functions that are mediated by the plants and animals living on and in the soft sediment habitats of the estuaries (Hillman et al., 2020; Karlson et al., 2021; Lohrer et al., 2016; Thrush et al., 2006). The distribution of these animals (called macrofauna) is controlled by various physical (e.g. substrate type, salinity, temperature) and biological (e.g. competition, recruitment) characteristics and the interactions between them, which can be altered by the input of excess terrestrial sediment (Pratt et al., 2014). It is therefore possible to assess the health of a given location in an estuary by studying certain features of the sandflat (such as the amount of mud present or the rate of sediment deposition) and the community of macrofauna that are present (Anderson et al., 2006; van Houte-Howes & Lohrer, 2010). Indices based on the entire macrofaunal community are common and well-developed for Tāmaki Makaurau /

Auckland, and changes in the abundance of macrofauna with known sediment preferences (e.g. sand versus muddy sand) or sensitivities to contaminants (such as certain metals) can also signal a change in the environment (Greenfield et al., 2016; Norkko et al., 2001).

1.1 Report purpose and objectives

The primary objective of this report is to provide technical information describing the current state of ecological health and how this has changed over the monitoring period in estuaries along Tāmaki Makaurau / Auckland's east coast. This forms part of a series of technical reports collectively addressing the ecological health of the large harbours (Drylie, 2025), marine sediment contaminants (Allen, 2025) and coastal water quality (Kamke & Gadd, 2025) to comprehensively assess the state of the marine environment across the region.

Te Kaunihera ō Tāmaki Makaurau / Auckland Council's marine ecology monitoring programmes support the following national and regional objectives:

- Satisfy council's obligations under section 35 of the Resource Management Act 1991 (as amended) to monitor and report on the state of the environment.
- Provide evidence of how the council is protecting and enhancing the coastal environment (Local Government (Auckland Council) Act 2009) and specifically, evidence for the Environment and Cultural Heritage component of the Auckland Plan 2050.
- Support Māori in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).
- Help monitor the effectiveness of regional policy initiatives and strategies.
- Assist with the identification of large scale and/or cumulative impacts of land use activities on estuary health.
- Provide baseline and regionally representative data to support sustainable management through the resource consent process and associated compliance monitoring for coastal environments.
- Provide robust data on estuary health to national environmental reporting initiatives.
- Continuously increase the availability of information for Aucklanders and promote awareness of estuary health issues in the region.

These objectives are provided for by the Auckland Unitary Plan (AUP) (Operative in Part) which provides direction to guide Auckland's growth and development while addressing challenges of population growth and environmental degradation. The main challenges and directions were unchanged following a revision of the Plan in 2022, though greater emphasis was placed on the impacts from and strategic approach to climate change, among other narrative changes.

1.2 Supporting information

This report is one of a series of technical publications prepared in support of *Te oranga o te taiao o Tāmaki Makaurau – The health of Tāmaki Makaurau Auckland's Natural Environment in 2025: a synthesis of Auckland Council State of the Environment reporting*.

All related reports (past and present) are published on the Knowledge Auckland website.

All data supporting this report can be requested through our Environment Auckland Data Portal and interactive dashboards of various regional council monitoring data, including estuary health data, can be found at the Land, Air, Water Aotearoa website.

Reports pertaining to the coastal environment include:

- *Beach change in the Auckland region: current state and trends,* TR2025/13
- *Coastal and estuarine water quality state and trends in Tāmaki Makaurau / Auckland 2024,* TR2025/19
- *East coast estuaries ecology state and trends in Tāmaki Makaurau / Auckland to 2023,* TR2025/10
    - the present report.
- *Marine ecology state and trends in Tāmaki Makaurau / Auckland to 2023,* TR2025/15
    - this report contains a regional summary of all marine ecology monitoring including the East Coast Estuaries and Regional Sediment Contaminants programmes.
- *Marine sediment contaminant state and trends in Tāmaki Makaurau / Auckland 2004-2023,* TR2025/12
- *Tāmaki Makaurau / Auckland east coast subtidal reef monitoring report: 2007 to 2024,* TR2025/24
- *Tāmaki Makaurau / Auckland intertidal reef monitoring report: 2011 to 2024,* TR2025/25

2 Methods

2.1 Programme overview

Monitoring began with Ōkura Estuary and was gradually expanded to include a total of eight estuaries and 77 sites (Table 1 and Figure 1). We focus on benthic environments (those associated with the seafloor rather than the water column) in the intertidal zone (the area that is periodically covered and uncovered by the tides) because they often have high ecological value and impacts from pollutants such as sediment are conspicuous and readily sampled (in terms of surface sediment characteristics and responsive macrofaunal communities).

There are 10 monitoring sites within each estuary (except Whangateau which has seven) that are arranged in a gradient design from the upper reaches (site 10) to the estuary mouth (site 1) encompassing low- and high-energy areas. Sites are typically rectangular (50 m x 20 m) but vary in dimension depending on, for example, the presence of vegetated habitats or the shape of the sandflat.

A temporally nested sampling design is employed to monitor 'core' sites with high frequency (twice per year in April and October) and 'rotational' sites periodically (every five to 10 years) allowing a robust and cost-effective way of monitoring temporal changes in benthic ecology without sacrificing spatial representativeness (Hewitt, 2000). The core sites were selected to represent good coverage from the upper to the lower estuary (Table 1). In response to increasing trends in 'very fine sediment + mud' at some locations and several estuaries being due for sampling in full, all sites in every estuary were sampled between October 2021 and October 2022.

Table 1. Estuaries monitored in the East Coast Estuaries monitoring programme. The year estuaries were added to the programme and the sites that are sampled with high frequency ('core' sites) are shown.

Estuary	Sampling started	Core sites
Ōkura	2001	OKR3, OKR7, OKR9
Pūhoi	2002	PUH1, PUH4, PUH7
Waiwera	2002	WWR1, WWR3, WWR8
Ōrewa	2002	ORW1, ORW4, ORW8
Mangemangeroa	2002	MNG3, MNG5, MNG6
Tūranga	2004	TRN1, TRN4, TRN7
Waikōpua	2004	WKP1, WKP3, WKP6
Whangateau	2009	WNG1, WNG4, WNG7

Figure 1. Location of estuaries and sites featured in this report.

2.2 Data collection and analysis

2.2.1 Surface sediment characteristics

Composite samples of surface sediments were collected to characterise the site according to sediment grain size, organic content and chlorophyll *a* concentration (a proxy for the abundance of benthic microalgae). Small cores (2 cm diameter, 2 cm deep) were collected randomly from across the site (adjacent to cores collected for macrofauna) and split into two sample jars (one for grain size and organic content analyses, the other for chlorophyll *a*). Samples were then stored frozen in the dark prior to the following laboratory analyses.

Grain size

Samples were homogenised before taking a 5 g subsample and digesting in 6 per cent hydrogen peroxide to remove organic matter. Wet sieving and pipette analysis were used to separate size fractions, before drying at 60 °C until a constant weight (Gatehouse, 1971). The results are presented as percentage composition of gravel/shell hash (>2 mm), coarse sand (500-2,000 μm), medium sand (250-500 μm), fine sand (125-250 μm), very fine sand (62.5-125 μm), silt (3.9-62.5 μm) and clay (<3.9 μm). Mud content is the sum of silt and clay content. Proportions of mud and very fine sand were combined as an indicator of sedimentation because very fine sand increased in most estuaries and is thought to have similar ecological effects to mud, therefore including this sediment fraction increased our ability to detect ecologically relevant changes.

Organic content

Approximately 5 g of sediment was placed in a dry, pre-weighed foil tray and dried at 60 °C until a constant weight was reached. The sample was then combusted at 400 °C for 5.5 h and reweighed (Mook & Hoskin, 1982). The results are presented as a percentage composition.

Chlorophyll a

Within one month of sampling, the full sample was freeze-dried, weighed, then homogenised, and a 0.5 g subsample was taken for analysis. Pigments were extracted by boiling the sediment in 90 per cent ethanol (using an acidification step to separate chlorophyll *a* from degradation products), and the extracts were processed using a spectrophotometer (Sartory & Grobbelaar, 1984). The results are presented as the concentration of chlorophyll *a* per gram of dry weight sediment: μg/g dw sediment.

Assessing the state of sediment characteristics

The relationship between sediment mud content and macrofauna has been well researched in Aotearoa / New Zealand and empirically derived thresholds were used to assess the state of sediment quality relative to this regional indicator (Table 2). The thresholds in this report differ slightly from those in Drylie (2021) and were revised to match the categories used in the Land, Air, Water Aotearoa website's Estuary Health topic. The LAWA categories were more conservative (for instance the poorest category in Drylie (2021) was >80 per cent mud content and this was lowered to >60 per cent) which could result in an apparent decline in sediment quality: such cases are highlighted.

Table 2. Thresholds for assessing state in relation to sediment mud content (as per Land, Air, Water Aotearoa).

Threshold	Rationale
≤3%	A small amount of mud is beneficial because the fine particles contain organic matter, which some macrofauna feed on. This means the most diverse macrofaunal communities are often found when there is around 3% mud content, but diversity starts to decline beyond this (Douglas et al., 2019).
3–10%	Macrofaunal communities are most resilient when mud content is less than 10% (Rodil et al., 2013).
10–30%	There are major declines in the resilience of macrofaunal communities between 10 and 25% mud content (Rodil et al., 2013), and communities are described as impoverished around 30% (Robertson et al., 2016).
30–60%	Macrofaunal communities are “unbalanced” (characterised by a reduced abundance of sensitive species and an increased abundance of tolerant species) when mud content is greater than 30% (Robertson et al., 2016).
>60%	Macrofaunal communities are degraded beyond 60% mud content (Rodil et al., 2013).

Suitable thresholds for assessing state according to sediment organic content (measured via loss on ignition techniques) or chlorophyll *a* concentrations were not available (Stevens et al., 2024), though these indicators provide useful information about the availability of food for the macrofaunal community and changes in their quantities can provide an indication of excess nutrients. A simultaneous increase in organic content and chlorophyll *a* may be caused by excess nutrients (provided light is not limiting) as nutrients fuel primary production and increase the amount of plant and algal material in the sediment.

2.2.2 Sediment accretion

Rates of sediment accretion (or erosion) were monitored at three sites in each estuary and were calculated from measurements of sediment depth relative to buried sediment plates (one per site), largely following the method of Hunt (2019a). Sediment accretion sites and core sites were not necessarily aligned. Briefly, plates (concrete pavers 30 cm x 30 cm) were buried roughly 15 cm beneath the sediment, and measurements were taken periodically of the depth between the sediment surface and the top of the plate using measuring rods. Changes in the depth of the sediment overlying the plate determined the rate at which sediment was accreting or eroding. To minimise the influence of variations in sediment level on depth measurements (for example, from crab burrows or sand ripples), five measuring rods were used simultaneously to obtain replicate measurements that were averaged to obtain a sediment plate depth (note that since 2023, the number of replicate measurements was increased from five to ten). The rods were inserted through the sand until they contacted the plate. Replicates were distributed as widely as possible across the plate, and all rods were left in place until every replicate was positioned to ensure a good spread of the measurements.

The sediment accretion rate for each site was estimated from the linear trend line fitted to the sediment level data over time (as per Hunt (2022)). First, the five replicate depth measurements were averaged to obtain a single sediment depth for each plate at each sampling occasion. The average plate depth was then zero-adjusted relative to the depth of the first sample in the time series; for instance, if the first averaged sample was 153 mm and the second was 160 mm, then they became 0 mm and 7 mm. A linear regression model was then applied to the time series of zero-adjusted sediment depths, and the sediment accretion rate was defined by the slope of the fitted line. This provided an estimate of the rate in mm/day, which was converted to mm/year (mm/y) for comparison to ecological guidelines. The 95 per cent confidence interval for the fitted line was calculated to demonstrate confidence in the linear fit (i.e. this did not allow for variability in the replicates).

Assessing state of sediment accretion

A default guideline value for chronic estuary sedimentation was developed by Townsend and Lohrer (2015) for the Australia & New Zealand Guidelines for Freshwater & Marine Water Quality (ANZG; previously ANZECC) that would ensure the major adverse biophysical effects of excess sedimentation were avoided. The guideline drew on research relating to effects from event-based (i.e. acute) sediment deposition and was set at 2 mm/y above the natural annual sedimentation rate (defined as the rate under native-forested catchment) at either an estuary or part-estuary scale.

Natural sedimentation rate data were available for very few estuaries in Auckland (Mahurangi, Tāmaki, and Mangemangeroa) and may not have provided a representative summary of natural sedimentation across the region. Nevertheless, an estimated guideline value based on the average of the Sediment Accumulation Rate (SAR) data from these locations was 2.4 mm/y (comparable to the guideline of 2.2 mm/y defined for the Waikato Region (Hunt, 2019b)) and was applied to provide a preliminary assessment of where ecological impacts were likely.

2.2.3 Macrofauna

For analysis of macrofauna, six large cores (13 cm in diameter x 15 cm deep) were collected at each site and sieved *in situ* over a 500 μm mesh. The material remaining on the sieve was washed into sample jars, stored in 70 per cent isopropyl alcohol, and stained with Rose of Bengal solution prior to sorting, identification, and enumeration. A random sampling approach was used to ensure samples were not within a 5 m radius of each other or any samples from the preceding 12 months.

The entire community was identified and enumerated from the samples collected in October to enable full community analyses (including assessment of species richness) and calculation of benthic health indices (see Section 2.2.4). For each estuary, macrofaunal community data were plotted using non-metric multi-dimensional scaling (nMDS) ordinations to visualise the (dis)similarities in community composition between sites. Data from the last 10 years were plotted to identify recent changes in the composition of the community and highlight whether sites had become more alike (thus indicating an estuary-wide driver of change). Ordinations were based on square roottransformed data to reduce the influence of dominant species and Bray-Curtis similarity matrices. Trajectories showing the direction of change through time were overlaid for each site, and in some instances, vectors representing the Pearson correlation coefficient of environmental variables with the nMDS axes were overlaid to demonstrate the correlation between environmental variables (proportions of different sediment grain sizes, organic content and chlorophyll *a* concentrations) and community composition. When large shifts in community composition were apparent from the nMDS plots, a Similarity Percentage (SIMPER) analysis was performed to measure the contribution of individual species to the difference between years and identify those driving the shift. All plots were created using the software PRIMER (v7) following Anderson et al. (2008).

As this programme was designed specifically to track effects of increased terrestrial sediment entering the estuaries, reporting focussed on a small number of indicator species with defined responses to sedimentation ("monitored species"):

- Crabs (a group consisting of species in the *Austrohelice*, *Hemigrapsus* and *Hemiplax* genera), Nereididae and Corophiidae, which prefer a small amount of mud
- *Anthopleura aureoradiata*, which prefers sand
- *Paphies australis*, *Colurostylis* spp., *Waitangi brevirostris* and *Aonides trifida*, which have a strong preference for sand.

There were seven additional species that are functionally important with known sediment preferences that were common across the East Coast Estuaries and each of the Harbour Ecology programmes; these are referred to as "common species" and enable regionwide trends in biodiversity (which may be driven by regionwide stressors) to be assessed. These are:

- the bivalves *Austrovenus stutchburyi*, *Macomona liliana* and *Linucula hartvigiana* (all prefer sand)
- the polychaetes *Aonides trifida* (strongly prefers sand), *Aricidea* sp. and *Prionospio aucklandica* (both prefer some mud)
- the gastropod *Notoacmea scapha* (strongly prefers sand).

2.2.4 Health indices

Benthic Health Models

Regional Benthic Health Models (BHMs) were developed to assess the health of macrofaunal communities relative to stormwater contaminants (total sediment copper, lead and zinc; BHMmetals) and sediment mud content (BHMmud) (see Anderson et al. (2006) and Hewitt and Ellis (2010)). The models are based on data from 95 unvegetated intertidal sites across the Auckland region encompassing tidal creeks, estuaries and harbours (but not exposed beaches) with a range of contaminant concentrations and mud content. Multivariate analyses of the variation in macrofaunal community composition related to each environmental variable were used to define scores relative to that variable. The composition of new samples is compared to the model data to obtain a score which is then allocated to one of five groups related to health. An increase in BHM score represents a degradation of health. As the BHMs were developed based on data from unvegetated sites, they are not suitable for assessing the health of sites dominated by seagrass or other vegetation.

Traits-Based Index

The functioning of benthic ecosystems is directly affected by benthic biodiversity (Belley & Snelgrove, 2016; Snelgrove et al., 2014; Thrush et al., 2006). To help understand these interactions, macrofauna can be categorised according to characteristics (traits) that are likely to influence function, e.g. their feeding mode (such as deposit or suspension feeding), mobility, size, living habit (such as free-living or tube dwelling), and so on. The Traits-Based Index (TBI) was developed based on the richness (count) of species exhibiting seven particular traits important for benthic ecosystem function: living in the top 2cm of sediment, having an erect structure or tube, moving sediment around within the top 2cm of the sediment column, being sedentary or only moving within a fixed tube, being a suspension feeder, being of medium size, or being worm shaped (Hewitt et al., 2012; Lohrer & Rodil, 2011; van Houte-Howes & Lohrer, 2010). Index values range from zero to one, with TBI scores less than 0.3 indicating low levels of functional redundancy and highly degraded sites, scores of 0.3 to 0.4 indicating intermediate conditions, and scores greater than 0.4 indicating high levels of functional redundancy. A site with a high level of functional redundancy is considered 'healthy' as environmental changes that affect the macrofaunal community tend to have a lesser impact on ecosystem function than a site with low functional redundancy.

Combined Health Score

The BHMs and TBI were combined into a single index, the Combined Health Score, to provide a complementary assessment of health (see Hewitt et al. (2012) for details). This index ranges from zero to one and an increase in score represents a degradation in health. The score assigned to the monitoring sites cannot be generalised to the whole estuary, which may have locations with better or worse health.

2.2.5 Identifying changes over time

Trend analysis

Changes in sediment characteristics, total species and the abundance of monitored and common species were analysed for each site to identify statistically significant trends over the monitoring period. Trends were analysed for core sites only as they were sampled frequently and had an uninterrupted time series. In all cases, the complete time series was analysed to maximise the potential of detecting cycles and patterns in the data that may have influenced trends. Details of the statistical approaches are given in Appendix 2: Trend analysis method and outlined briefly here.

Initially, scatterplots were inspected to identify suspected linear or non-linear trends, step changes, or other patterns. Only monotonic trends were investigated to focus on continuous, long-term change. Ordinary least squares (OLS) regression was used to analyse trends in datasets where the assumptions of OLS were met, whereas generalised least squares (GLS) regression was used if the assumption of homoscedasticity was violated. The slope of the regression indicated the trend magnitude (expressed in the units of the given variable), and the associated p-value was used to determine whether this was statistically significant ($p < 0.15$). For statistically significant trends, plots of residuals were inspected for any bias that might indicate multi-year cycles rather than long-term change and, in combination with scatterplots, used to identify the start and end of trends that occurred over only a portion of the time series. All trend analysis steps were performed in R Studio v4.3.1 (Posit team, 2025) using the R programming language (R Core Team, 2021).

Statistically significant trends were assigned a certainty score based on the regression p-value and the presence of multi-year cycles as follows:

- If $p < 0.05$ and no multi-year cycles are observed, the trend is considered “certain” and is assigned a score of 1.
- If p is between 0.05 and 0.1 OR $p < 0.05$ but multi-year cycles are observed, the trend is “less certain” and assigned a score of 0.5.
- If p is between 0.1 and 0.15 the trend is “uncertain” and assigned a score of 0.25.

This approach allowed potential emerging trends to be highlighted while acknowledging there was a lack of certainty associated with them.

Recent changes

Due to the relatively low level of replication of macrofaunal cores in the East Coast Estuaries Ecology programme, assignation of sites to benthic health categories varied randomly by 12 to 15 per cent. Although this was less than a health category and therefore did not affect our ability to assign a health status at a given time, it precluded analyses of trends through time as the ability to detect changes were vastly reduced. Instead, benthic health scores from the last five years are presented to depict recent changes in health.

Throughout this report qualitative comparisons are made to the results of Drylie (2021) to identify short-term changes that may represent an early warning of environmental degradation.

3 Results and Discussion

3.1 Whangateau

Whangateau Harbour is the largest of the estuaries monitored in this programme (7.5 km^2) and drains part of the North East Consolidated Receiving Environment. The catchment is roughly 42 km^2 and is dominated by rural land use types such as exotic grassland and short rotation cropland. A mixture of native and exotic forest can be found north of the harbour while Ōmaha and Point Wells are predominantly urban. There was very little change in land use over the last five years (Auckland Council, 2025).

The harbour is characterised by two major branches, one draining the Ōmaha River and another larger arm that drains several small streams and is intersected by causeway access to Ōmaha. The core monitoring sites are WNG1, WNG4 and WNG7 and are spread evenly along the larger branch of the harbour. Sediment accretion monitoring was initiated at several sites in 2023 and once a baseline is developed (in roughly five years), should provide additional understanding of sediment dynamics in the harbour to support interpretation of the ecological data.

Sediment characteristics

In 2022 and 2023, sediment mud content was less than 3 per cent at WNG1, WNG2 and WNG4 and at such levels is unlikely to impact ecological health (Figure 2). Mud content was slightly elevated at WNG3 and WNG5 and moderately high at WNG6 and WNG7; at levels such as these, mud content is likely to reduce the diversity and resilience of the macrofaunal community. Long-term median values of very fine sand + mud were high at WNG5 and WNG6, and at most sites there was substantial temporal variability (indicated by standard deviation) over the monitoring period (Table 3).

Between 2009 and 2023, the only trends in very fine sand + mud were decreases (at WNG1 and WNG4) suggesting sedimentation pressure was minimal at the core sites (Table 4). Sediment organic content, an indicator of food availability and potential nutrient enrichment, increased at WNG4 and WNG7. These increases are not necessarily concerning because they were not accompanied by complementary increases in chlorophyll *a* (a proxy for the abundance of microscopic algae living in the sandflats) which would also be expected to increase in response to excess nutrients. Indeed, the only significant trend in chlorophyll *a* was a decrease at WNG7 (Table 4 and Appendix 3: Figure A1).

Figure 2. Sediment mud content at Whangateau Harbour monitoring sites in 2022 and 2023.

Table 3. Median values and temporal variation (standard deviation) of surface sediment characteristics at Whangateau monitoring sites between 2009 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
WNG1	13.13	9.89	0.80	0.18	5.10	1.12
WNG2	4.53	5.14	0.45	0.09	5.22	0.67
WNG3	18.42	14.36	1.27	0.19	11.22	0.51
WNG4	8.84	11.81	0.89	0.40	9.06	1.28
WNG5	43.91	9.51	1.72	0.64	7.56	1.63
WNG6	37.93	13.55	2.09	0.59	9.06	2.21
WNG7	19.28	7.07	1.28	0.49	8.71	1.98

Table 4. Direction of statistically significant trends in sediment characteristics at core Whangateau sites between 2009 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in Drylie (2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (μg g^{-1} dw sediment)
WNG1	▼		
WNG4	▼ New	▲ New	
WNG7		▲ New	▼ New

Benthic health

Sites in Whangateau Harbour had 'Good' or 'Fair' overall health in 2022/2023 (Figure 3). Sites with 'Fair' health were in the more sheltered and poorly flushed parts of the harbour, including site WNG3 which is alongside the causeway, WNG5 which is in the transitional reaches of the Ōmaha River, and sites WNG6 and WNG7 that respectively sit downstream of Coxhead Creek and Birdsalls Stream. In contrast, sites with 'Good' health tended to be in areas where the adjacent land cover was dominated by native vegetation or low intensity land uses (e.g. WNG1 and WNG2) and where there was high tidal energy (e.g. WNG4).

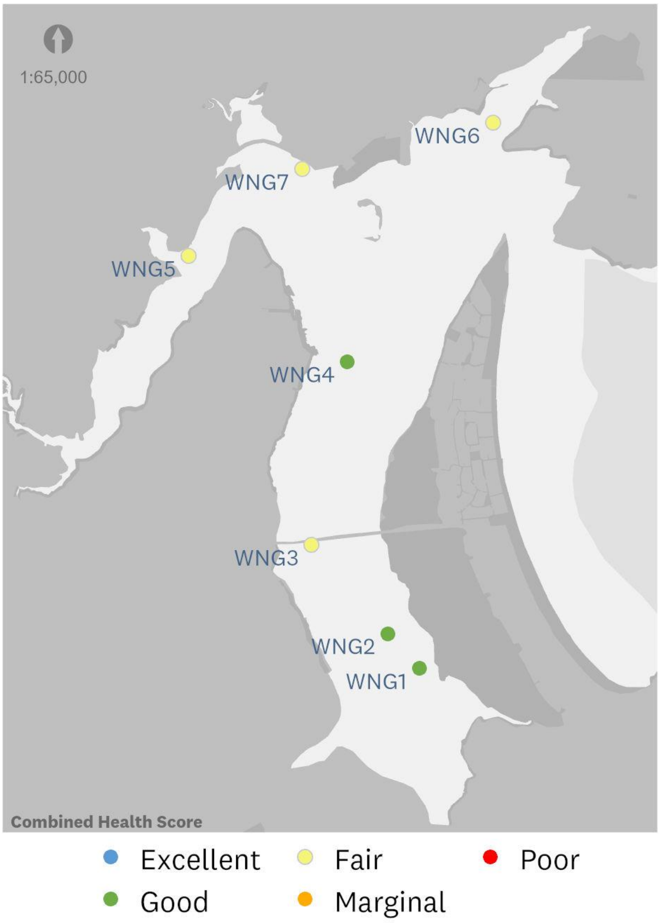

Figure 3. Combined Health Scores at Whangateau Harbour monitoring sites in 2022 and 2023.

There were no concerning changes in benthic health indices at core sites over the last five years (Table 5). At WNG1 and WNG4 health in relation to mud and metals remained 'Good', and functional resilience according to the Traits-Based Index (TBI) was 'High' across all core sites. There was more variability at WNG7 as health in relation to mud flickered between 'Fair' and 'Good'; prior to 2018 BHMmud was consistently 'Good' at this site but since 2018 it mostly scored 'Fair', suggesting a decline in health despite no trend in very fine sand + mud (Table 4).

Table 5. Benthic health groups at core Whangateau sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low.

Index	Year	WNG1	WNG4	WNG7
BHMmud	2019			
	2020			
	2021			
	2022			
	2023			
BHMmetals	2019			
	2020			
	2021			
	2022			
	2023			
TBI	2019			
	2020			
	2021			
	2022			
	2023			

Macrofaunal community

Species richness measures the taxonomic diversity of a site and usually declines, i.e. there is a reduction in the number of species present, in response to stressors such as pollution (Hewitt & McCartain, 2017; Lundquist et al., 2003). No sites in Whangateau Harbour had low species richness and diversity was relatively high at WNG4 (31 species) (Figure 4). Species richness decreased significantly at WNG7 from an average of 36 species over the first five years of the monitoring period (2009–2013) to 33 species in the last five years (2019–2023) (Appendix 4: Figure A15). This trend was "less certain" ($p = 0.056$) and should be revisited as more data become available.

The non-metric multi-dimensional scaling (nMDS) plot for Whangateau Harbour had moderate to high stress and was useful for identifying patterns but not detailed interpretation. The core sites had distinct macrofaunal community compositions over the last 10 years, as shown by the clear separation between their representative data points (Figure 5). Community composition was quite variable at all core sites (evidenced by the distance and trajectory between individual points) and especially so at WNG1. As there was no change in sediment characteristics or benthic health indices at WNG1, this variability is not of concern.

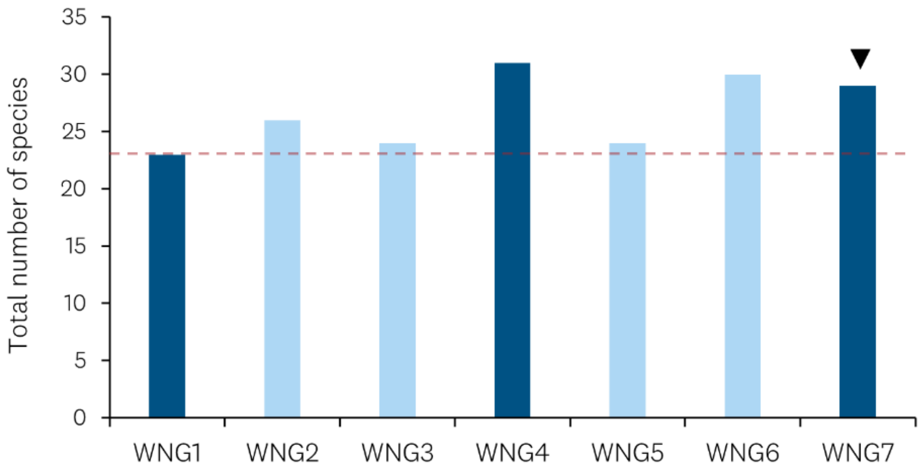

Figure 4. **Species richness at Whangateau monitoring sites in 2022 and 2023.** The dashed line shows the median species richness for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (no trend analysis). The direction of statistically significant trends (2009–2023) are shown: ▲ represents an increase and ▼ a decrease.

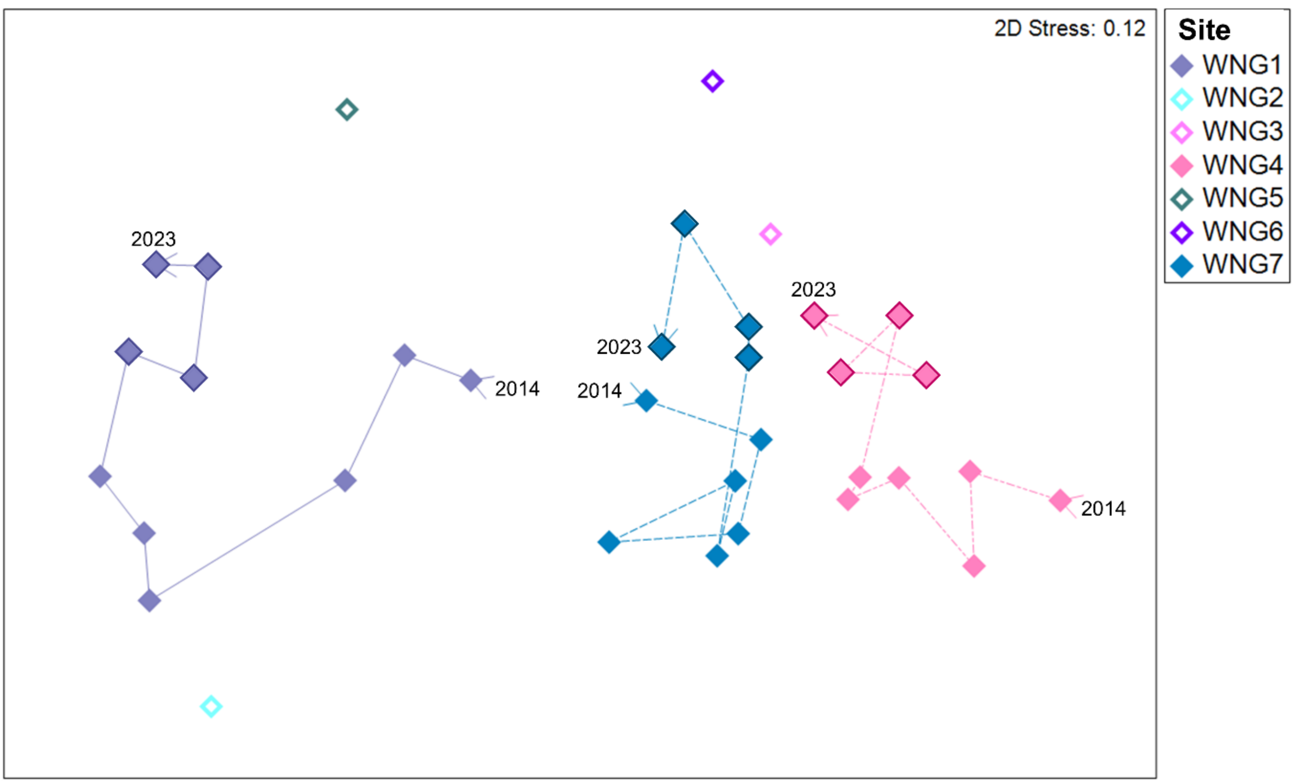

Figure 5. **The similarity in macrofaunal community composition between Whangateau sites and changes over the last 10 years (2014 to 2023) for core sites.** Symbols for core sites are outlined to highlight new data since Drylie (2021).

Indicator species

Analysing trends in the population abundances of particular species can provide greater insight about the extent and cause of ecological changes in benthic environments. In Whangateau Harbour, significant long-term declines in the abundance of the bivalve shellfish *Linucula hartvigiana* at all core sites may indicate widespread impacts from sedimentation, given this species prefers sandy habitats (though it is also sensitive to copper contamination) (Table 6). More recent decreases in the abundance of *Macomona liliana*, another bivalve shellfish with similar sediment preferences, also occurred at all core sites (since 2018 at WNG7 and 2020 at WNG1 and WNG4). This may indicate more recent stress from sedimentation (or stormwater contaminants), and it will be important to monitor whether the decreased abundances persist. Notably, the abundance of Crabs (a group known to prefer habitats with some mud) increased at WNG7 since 2021; the combination of decreasing *Linucula hartvigiana* and *Macomona liliana* and increasing Crabs may explain the declining BHMmud score at this site (Table 5).

At WNG4, the trends indicative of sedimentation impacts seem to contradict the decreasing trend in very fine sand + mud (Table 4). It is possible for the macrofaunal community to be stressed by sedimentation even when sediment mud content is low and there is no evidence of very fine sand + mud increasing because these indicators do not provide robust information about the impacts of acute sediment deposition events, i.e. the smothering of sandflats with terrestrial silts and clays following heavy rainfall. Sediment plate data will improve our ability to understand these kinds of phenomena in the future.

Table 6. Trends in the abundance of monitored and regionally common species at core Whangateau sites between Oct. 2009 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	WNG1	WNG4	WNG7
Crabs	M		▼	▲ *
Nereididae	M	▲ MY	▼	
Corophiidae	M			
Anthopleura aureoradiata	S			
Paphies australis	SS	Not present		
Colurostylis spp.	SS			
Waitangi brevirostris	SS	▲ MY		▼
Aonides trifida	SS		▼ MY	
Regionally common species				
Aricidea sp.	M		▲* MY	
Prionospio aucklandica	M			
Austrovenus stutchburyi	S	▲ MY	*	▲ MY
Linucula hartvigiana	S	▼ Step – 2018	▼*	▼ MY
Macomona liliana	S	*	*	*
Notoacmea scapha	SS			
Trends consistent with sedimentation		2	3	3
Trends consistent with metals		1	2	1

Summary

In summary, sites in Whangateau Harbour had 'Good' or 'Fair' health overall and all core sites exhibited 'High' functional resilience. There were no concerning changes in sediment characteristics between 2009 and 2023, however benthic health in relation to mud appeared to degrade at WNG7 and species richness declined at this site. There were generally few long-term trends in indicator species, though some recent changes in the abundance of indicator species were observed that may signal sedimentation stress at WNG7 and WNG4.

In future monitoring of Whangateau Harbour it is recommended that WNG5 be included as a core site given it had the highest concentration of very fine sand + mud and the poorest health in relation to mud (not presented). Due to its location, this site also provides the most robust assessment of any impacts from Ōmaha River, which is the largest freshwater input to the harbour.

3.2 Pūhoi

The Pūhoi River estuary is a winding estuary within the Hibiscus Coast Consolidated Receiving Environment that is sheltered by a large sandspit (Wenderholm Regional Park). The estuary is small (covering an area of 1.7 km^2) relatively to its catchment (43 km^2) which is dominated by exotic grassland (Auckland Council, 2025). Indigenous and exotic forest are common and there are small pockets of urban area in the Pūhoi township and along the Wenderholm spit. Analysis of changes in land use showed harvesting of exotic forest occurred in the catchment since Drylie (2021) and transport infrastructure had been developed along the top of the estuary (the Ara Tūhono – Pūhoi to Warkworth project on State Highway 1). The core monitoring sites are PUH1, PUH4 and PUH7 and all other sites were sampled in 2022.

Sediment characteristics

In 2022 and 2023, sediment mud content was less than 3 per cent at PUH1 and PUH7 and at all other sites was elevated to levels where impacts on the macrofaunal community would be expected (Figure 6). Instances where there seems to be large differences in sediment mud content between sites that are close together (i.e., PUH1 and PUH3 as well as PUH7 and PUH8) are due to the sites being on opposite sides of the main drainage channel, demonstrating how strongly sedimentation is influenced by the specific flow and tidal dynamics of a site. There was less variation between sites when considering the long-term median values of very fine sand + mud (which ranged from 30 to 55 per cent at all except PUH1 and PUH4, where median values were substantially lower) (Table 7).

Between 2004 and 2023, very fine sand + mud increased significantly at PUH4 and decreased at PUH1 (due to consistently low values since 2019 (Appendix 3: Figure A2)), and an increasing trend that was previously reported for PUH7 has since disappeared due to declines in mud content since 2018 (Table 8). The increases at PUH4 seem driven by large increases in fine sediments since 2021 (Appendix 3: Figure A2). Organic content also increased significantly at PUH4 (fine sediments and organic content often increase in tandem if originating from terrestrial soils which are usually rich with clay, silt and organic matter) and chlorophyll *a* decreased (Table 8). Together these trends identify a potentially concerning trajectory for PUH4 with increasing muddiness and organic enrichment and declining primary productivity.

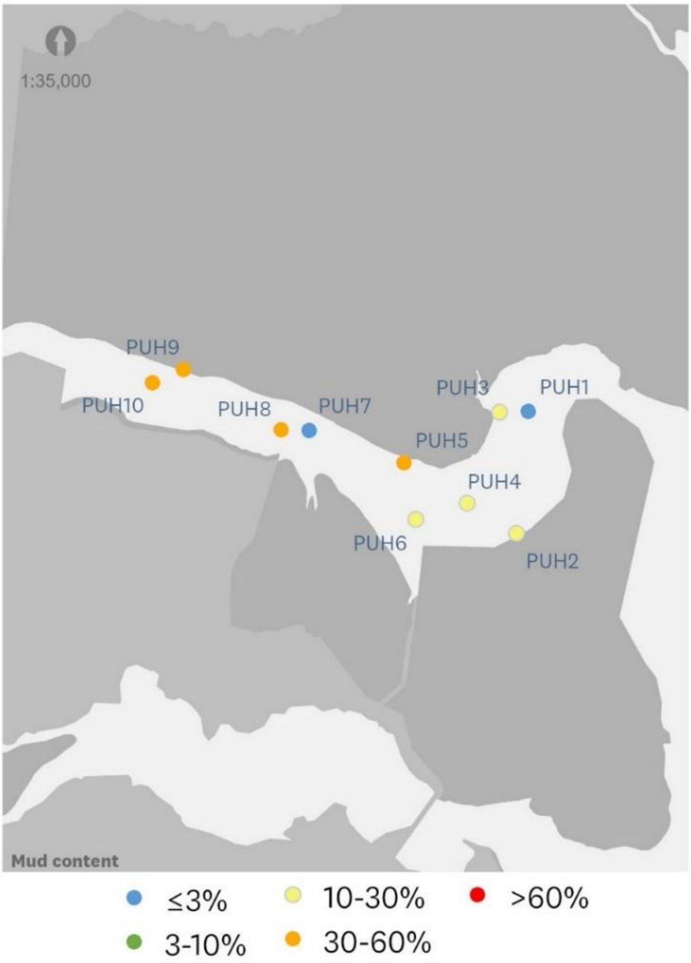

Figure 6. Sediment mud content at Pūhoi monitoring sites in 2022 and 2023.

Table 7. Median values and temporal variation (standard deviation) of surface sediment characteristics at Pūhoi monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
PUH1	6.26	3.36	0.94	0.73	2.41	2.41
PUH2	44.86	13.89	1.57	0.98	7.84	3.02
PUH3	29.97	9.97	1.27	0.84	5.27	1.78
PUH4	15.63	13.84	1.13	0.79	4.36	2.01
PUH5	55.01	13.61	1.93	1.81	10.16	1.86
PUH6	40.62	11.76	1.12	0.69	5.83	1.25
PUH7	33.53	16.19	1.40	0.79	6.35	2.24
PUH8	48.53	19.94	0.95	1.23	7.94	1.49
PUH9	52.30	11.37	2.01	1.14	6.84	1.54
PUH10	35.97	21.35	0.41	1.31	6.19	0.39

Table 8. Direction of statistically significant trends in sediment characteristics at core Pūhoi sites between 2004 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in (Drylie, 2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g^{-1} dw sediment)
PUH1	▼ New	Lost – previously ▼	
PUH4	▲ New	▲ New	▼ Maintained
PUH7	Lost – previously ▲		▼ New

Sediment accretion monitoring occurred at PUH1, PUH4 and PUH9. The last measurement at PUH1 was in 2021 and it has not been possible to locate the plate since. The plate at PUH4 was scoured and lost between 2017 and 2021 before being replaced in October 2021; the few measurements that have been taken since suggest this plate is scouring again and may not be suitable for ongoing sedimentation monitoring. The sediment accretion rate (Table 9) estimated from the trend line fitted to the sediment level data (Figure 7) indicated there was significant accretion at PUH1 and erosion at PUH4 and PUH9. The rate of accretion at PUH1 was much greater than the ANZG guideline value of 2.4 mm/y estimated for the Auckland Region. The 95 per cent confidence intervals show that there was variability around the average linear sediment accretion rate although this did not change the overall assessment of sediment accretion at each plate relative to the ANZG guideline value, e.g., PUH1 still exceeded the guideline at the lower 95 per cent interval, and PUH4 and PUH9 did not even when considering the upper 95 per cent interval.

Table 9. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Pūhoi monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
PUH1	7.41	<0.001	4.24	10.58	2009–2021
PUH4	-11.69	<0.001	-16.19	-7.2	2009–2017
PUH9	-4.11	<0.001	-6.04	-2.19	2009–2023

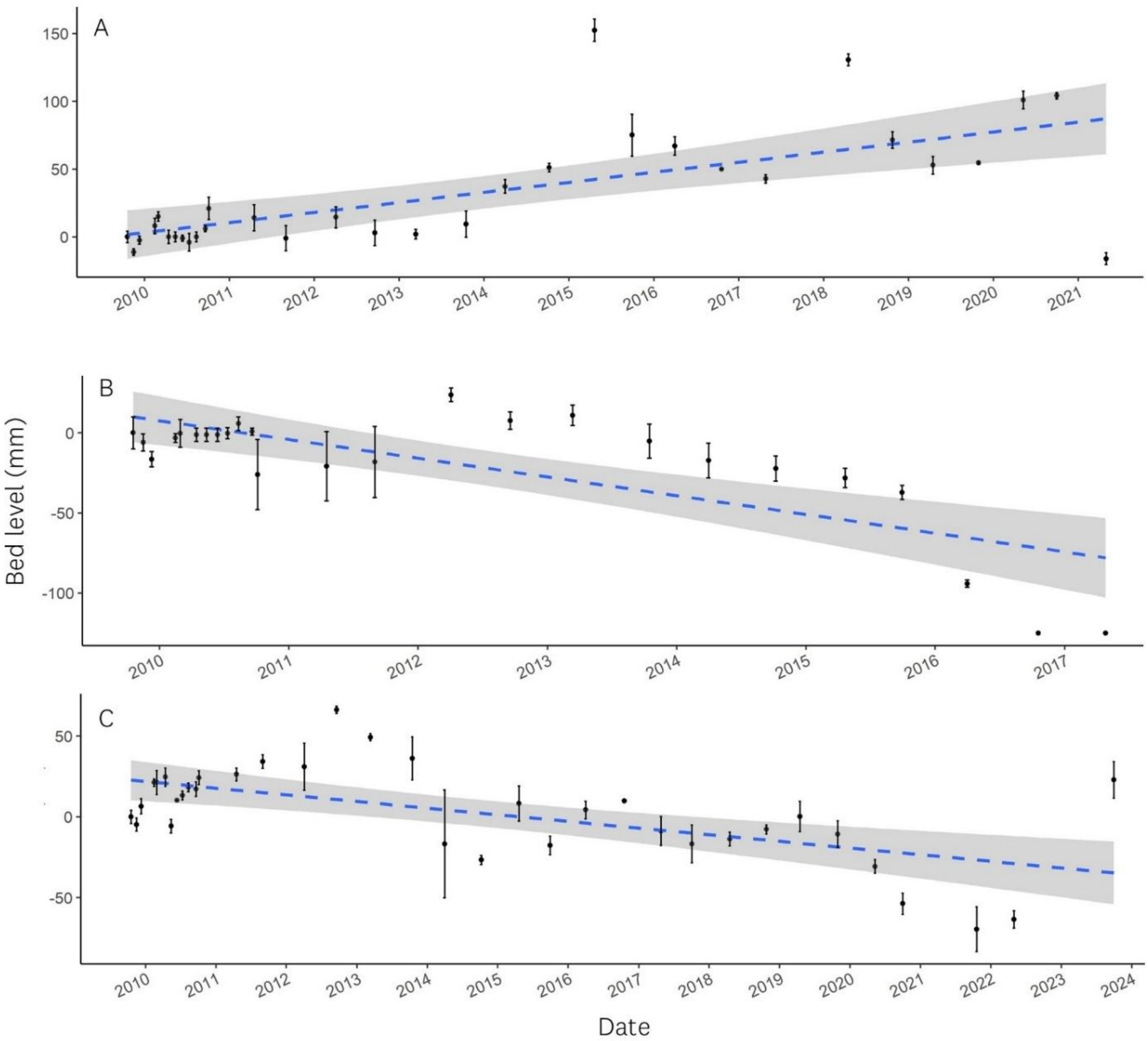

Figure 7. **Sediment levels (relative to buried sediment plate) at A) PUH1, B) PUH4 and C) PUH9.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Initially it appears that the sediment accretion rates contradict trends in very fine sand + mud for PUH1 and PUH4, however there are numerous ways that sediment deposition/erosion might interact with sediment grain size (i.e. the texture of the sediment). At PUH1, mud content was very low in 2023 and a decreasing long-term trend was detected for very fine sand + mud despite significant accretion, suggesting this site has accreted fine or coarse sand and not very fine sand or mud (though the period over which very fine sand + mud trends and sediment accretion were assessed differed). If sedimentation at PUH1 is driven by the deposition of coarse rather than fine sediments, the ecological impact may not be as severe as might be predicted from the ANZG guideline. At PUH4, an increasing long-term trend was detected for very fine sand + mud despite indications of significant and high rates of erosion, however sediment accretion data were only available up to 2017 while the large increases in fine sediments that drove the increasing trend occurred beyond 2021.

Benthic health

The overall health of sites in Pūhoi Estuary ranged from 'Good' to 'Poor', though most had 'Fair' or 'Marginal' health and there was only a slight tendency for health to improve towards the estuary mouth (Figure 8). Since the last report, health in relation to mud (BHMmud) degraded from 'Excellent' to 'Good' at the core sites PUH1 and PUH4 (Table 10). Although PUH7 scored 'Fair' in 2019 and this remained in 2023, in the intervening years it consistently scored 'Good'. The scores for PUH7 were close to the boundary between BHMmud groups, so this site might tend to move between groups arbitrarily. Although PUH4 also scored close to the BHMmud group boundary, the degradation at this site was more likely a genuine sedimentation effect given the large increases in fine sediments since 2021. The change at PUH1 appeared to be a sustained degradation given this site consistently scored 'Good' since 2019 and may reflect impacts from significant sediment accretion (Figure 7 and Table 9).

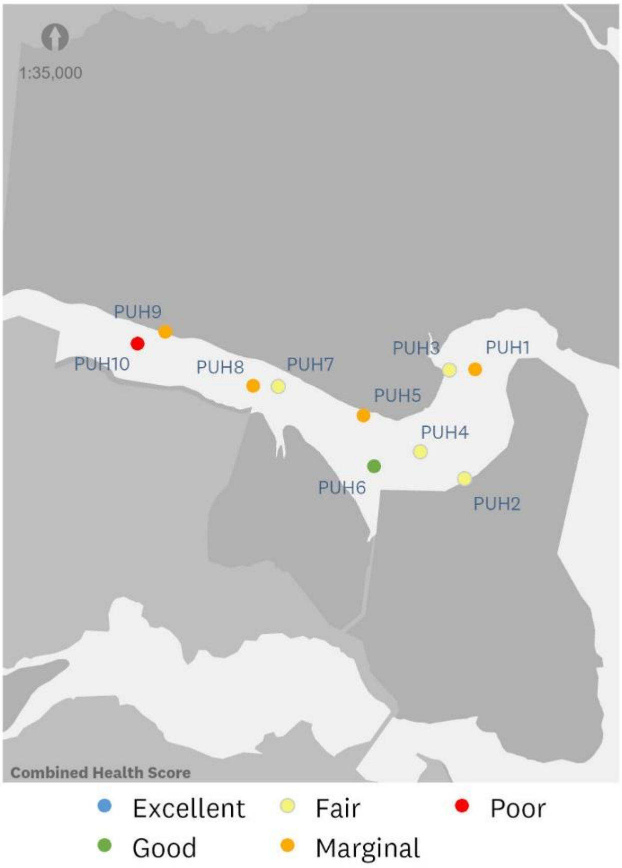

Figure 8. Combined Health Scores at Pūhoi sites in 2022 and 2023.

Health in relation to metals was 'Good' or 'Excellent' and has remained largely stable at the core sites over the last five years. Functional resilience was stable at PUH1 ('Low') and PUH7 ('High') between 2019 and 2023 and oscillated between 'Intermediate' and 'High' at PUH4 (Table 10). Notably, functional resilience was 'Intermediate' at PUH4 following the large increases in very fine sediments in 2021, and the 'Low' functional resilience at PUH1 makes this site vulnerable to disturbance.

Table 10. Benthic health groups at core Pūhoi sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	PUH1	PUH4	PUH7
BHMmud	2019	Excellent	Excellent	Fair
	2020	Good	Good	Good
	2021	Good	Excellent	Good
	2022	Good	Good	Good
	2023	Good *	Good *	Fair
BHMmetals	2019	Good	Good	Good
	2020	Excellent	Excellent	Good
	2021	Good	Good	Good
	2022	Good	Good	Good
	2023	Good	Good	Good
TBI	2019	Low	Intermediate	High
	2020	Low	High	High
	2021	Low	High	High
	2022	Low	Intermediate	High
	2023	Low	Intermediate	High

Macrofaunal community

Species richness in 2022 and 2023 was low at PUH1 (explaining the low functional resilience of this site), PUH8, PUH9 and PUH10 (Figure 9). At all other sites, species richness was close to the average for East Coast Estuaries sites (23 species). Species richness decreased significantly at PUH1 over the monitoring period (Appendix 4: Figure A9).

The nMDS plot for Pūhoi Estuary had moderate stress and an acceptable fit for interpretation. Sites were organised in the plot space according to their position along the estuary, with PUH1 to the left of the plot and PUH8, PUH9 and PUH10 to the right (Figure 10), suggesting macrofaunal community composition transitioned gradually from the upper to the lower estuary. This highlights that although total species diversity was similar at PUH1 and PUH8, PUH9 and PUH10, the composition of species at these sites were very different and resulted at least partly from differences in sediment characteristics (vectors representing highly correlated environmental variables showed sampling occasions to the right of the plot were associated with higher amounts of very fine sand and mud whereas sites to the left of the plot had higher proportions of fine sand).

In the last 10 years, there appeared to be two distinct community composition phases at PUH1 caused by a reasonably large shift between 2018 and 2019. The species making the greatest contribution to the dissimilarity in community composition pre- versus post-2019 were the bivalve *Paphies australis* (greater abundances since 2019) and the barnacle *Austrominius modestus* (largely absent since 2019). This habitat-forming barnacle is known to be transient and can vastly modify the macrofaunal community by forming mats anchored to hard substrates in the estuary (such rocks or oyster reef remnants). There was also a large shift in community composition at PUH7 between 2022 and 2023 such that the composition in 2023 was dissimilar to any other time in the last 10 years. According to SIMPER analysis, this shift was driven by a sharp increase in Amphipods and a decrease in *Austrovenus stutchburyi* and likely underpins the decline in BHMmud group from 'Good' in 2022 to 'Marginal' in 2023.

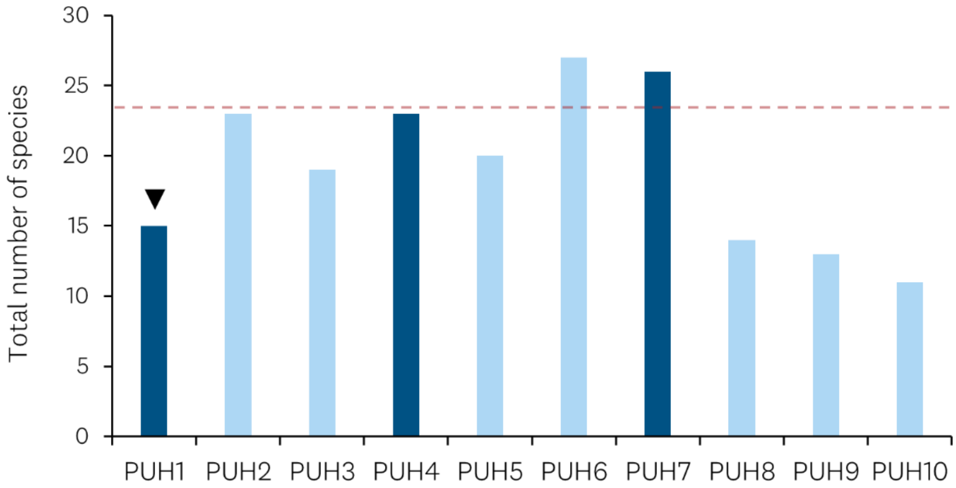

Figure 9. **Species richness at Pūhoi monitoring sites in 2022 and 2023.** The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2004–2023) are shown: ▲ represents an increase and ▼ a decrease.

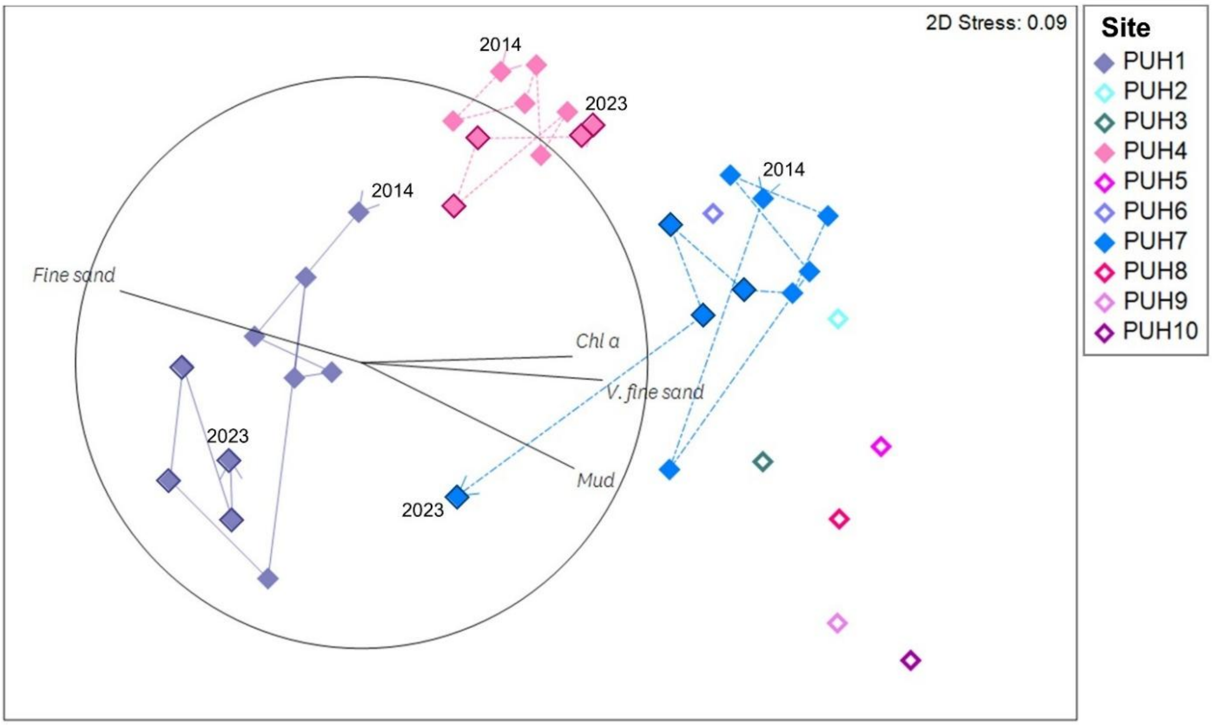

Figure 10. **The similarity in macrofaunal community composition between Pūhoi sites and changes over the last 10 years (2014 to 2023) for core sites.** Symbols for core sites are outlined to highlight new data since Drylie (2021). Vectors representing environmental variables with a Pearson correlation coefficient >0.7 are shown.

Indicator species

Numerous trends in indicator species were consistent with sedimentation impacts at the core sites (especially PUH4 and PUH1) (Table 11). *Waitangi brevirostris*, an amphipod with a strong preference for sand, decreased at all core sites suggesting widespread sedimentation impacts. However, this species has been effectively absent from PUH7 since 2007 and PUH4 since 2012 and is no longer a meaningful indicator at these sites.

There were very few recent changes in indicator species abundances, although as mentioned above the abundance of the sand-preferring bivalve *Austrovenus stutchburyi* decreased at PUH7 since 2021 (from 544 individuals in October 2021 to 137 in October 2022 and only 13 in October 2023), and another bivalve that has a strong preference for sand, *Paphies australis*, decreased in abundance at PUH4 since 2017.

Very few trends consistent with metal contamination were detected at PUH1 and PUH7, though three were found at PUH4 (Table 11). Sites in Pūhoi were last sampled for metal contaminant concentrations in 2016 and the results suggested effects on the macrofaunal community would be unlikely as concentrations of copper, lead and zinc were below the Environmental Response Criteria threshold where ecological impacts are possible (Mills & Allen, 2021). Each of the species that decreased in abundance are also sensitive to mud, so it is likely that sedimentation (rather than metal contamination) caused their declines given the other indications of sediment impacts (i.e. recent increases in very fine sand + mud).

Table 11. Trends in the abundance of monitored and regionally common species at core Pūhoi sites between Oct. 2002 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	PUH1	PUH4	PUH7
Crabs	M			▲ MY
Nereididae	M	▲ MY		
Corophiidae	M	▼ MY		
Anthopleura aureoradiata	S			▲ MY
Paphies australis	SS		▼ * MY	
Colurostylis spp.	SS		▼ MY	▼ MY
Waitangi brevirostris	SS	▼ MY	▼ MY	▼
Aonides trifida	SS		▼	▲ MY
Regionally common species				
Aricidea sp.	M	▲		
Prionospio aucklandica	M		▲ MY	▲ MY
Austrovenus stutchburyi	S		▲ MY	▲ * MY
Linucula hartvigiana	S	▼	▼ Step – 2012	
Macomona liliana	S	▼ MY		
Notoacmea scapha	SS			
Trends consistent with sedimentation		5	6	4
Trends consistent with metals		2	3	1

Summary

Overall health in Pūhoi Estuary ranged from 'Good' to 'Poor' in 2022 and 2023 and generally improved with increasing distance from the Pūhoi River mouth. Sedimentation impacts were observed throughout the estuary, though there was little evidence of metal contamination or excess nutrients.

Some concerning changes occurred at PUH4 that suggested ongoing sedimentation issues, including large increases in very fine sand + mud driven since 2021 which coincided with a degradation in BHMmud from 'Excellent' in 2019 to 'Good' in 2023. Similarly, health in relation to mud degraded at PUH7 and coincided with a large shift in community composition between 2022 and 2023 that was caused by an increase in amphipods and a decrease in *Austrovenus stutchburyi*. These changes contrast the physical characteristics of the site given sediment mud content decreased between 2018 and 2023 and was very low in 2023, so it will be important to monitor the community closely over the next few years.

Species richness and functional resilience was low at PUH1 in 2023 and health in relation to mud degraded from 'Excellent' in 2019 to 'Good' in 2023, despite significant long-term decreases in very fine sand + mud and a very low mud content in 2023. It is hypothesised that the high rate of sediment accretion at this site (which exceeds ANZG guidelines) has caused substantial physical disturbance to the ecological community and is more likely due to the shifting of sediments within the estuary (coarse, marine sands) as opposed to new, land-based sediments (fine silts and clays) arriving at the site, given sediment mud content remained low.

3.3 Waiwera

The Waiwera River estuary is within the Hibiscus Coast Consolidated Receiving Environment. The estuary is very small (1 km^2) relative to its catchment (38 km^2) which comprise large areas of exotic grassland, indigenous forest and indigenous scrub/shrubland (Auckland Council, 2025). There are small areas of exotic forest and an urban area near the estuary mouth at Waiwera Beach. Some small changes in land use occurred throughout the catchment since the last report, often due to the conversion of exotic grassland to indigenous scrub/shrubland or occasionally exotic grassland and some areas of exotic forest becoming harvested forest. The core sites are WWR1, WWR3 and WWR8 and represent a spread from the lower to the upper estuary.

Sediment characteristics

In 2022 and 2023, sediment mud content was less than 3 per cent at WWR3 and at all other sites was elevated to levels where impacts on the macrofaunal community would be expected, particularly at WWR1 where mud content was greater than 60 per cent (Figure 11). The long-term median values of very fine sand + mud were highly variable between sites, though this was generally quite low (≤30 per cent at all sites except WWR1) (Table 12).

The very high mud content at WWR1 in 2023 (65 per cent) was unusual given the long-term median of very fine sand + mud was only 44 per cent (with a standard deviation of 12 per cent) (Table 12) and may reflect a temporary increase from a deposition event, for example. Very fine sand + mud increased at WWR1 over the long term, though this trend ended around 2013 and measurements were generally stable until 2023 (Appendix 3: Figure A3). There was a similar pattern in organic content which increased significantly over the long-term and exhibited a large increase in 2023 (Appendix 3: Figure A3). Very fine sand + mud has been very low and decreased significantly at WWR3 over the monitoring period (Table 13), probably due to the high energy location of this site on a sandbank in the centre of the main estuary channel.

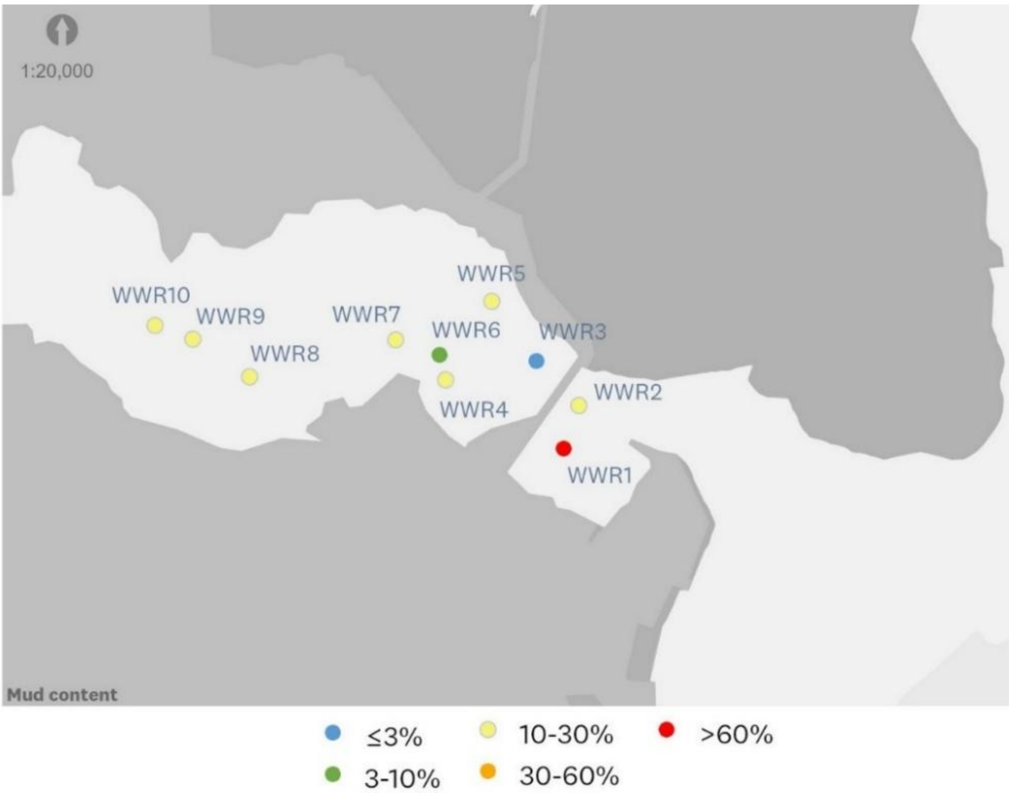

Figure 11. Sediment mud content at Waiwera monitoring sites in 2022 and 2023.

Table 12. Median values and temporal variation (standard deviation) of surface sediment characteristics at Waiwera monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
WWR1	44.44	11.91	2.90	1.47	10.66	2.31
WWR2	30.62	10.46	1.52	2.48	4.70	1.42
WWR3	2.13	5.29	0.85	0.55	4.22	1.23
WWR4	28.39	10.13	0.47	8.76	5.33	N/A
WWR5	28.24	9.53	1.43	2.45	7.39	1.04
WWR6	9.29	6.99	0.79	3.18	2.75	0.79
WWR7	16.63	13.33	0.36	1.25	10.28	2.70
WWR8	6.71	7.14	1.42	0.84	8.19	2.42
WWR9	18.41	10.86	1.34	0.86	6.42	1.23
WWR10	27.83	14.84	0.32	1.34	7.10	N/A

Table 13. Direction of statistically significant trends in sediment characteristics at core Waiwera sites between 2004 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in (Drylie, 2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g^{-1} dw sediment)
WWR1	▲ Maintained	▲ New	
WWR3	▼ New		
WWR8		Lost – previously ▼	

Sedimentation monitoring occurred at WWR2 (near the estuary mouth) and WWR6 (in the mid-estuary), although the last measurement at WWR6 was in 2019 and it has not been possible to locate the plate since. A plate was installed at WWR8 in 2009 but since then it has been exposed and reburied several times and does not have a robust long-term time series for analysis; this site is likely unsuitable for sedimentation monitoring.

The sediment accretion rate (Table 14) estimated from the trend line fitted to the sediment level data (Figure 12) indicated there was significant accretion at WWR2 and erosion at WWR6. The rate of accretion at WWR2 was much greater than the ANZG guideline value of 2.4 mm per year estimated for the Auckland Region and exhibited little variability around the average, as indicated by the narrow 95 per cent confidence intervals. There was greater variability around the average linear sediment accretion rate for WWR6, although the upper 95 per cent confidence interval still indicated erosion at this site.

Table 14. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Waiwera monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
WWR2	9.96	<0.001	8.95	10.97	2009–2023
WWR6	-9.62	<0.001	-12.21	-7.03	2009–2019

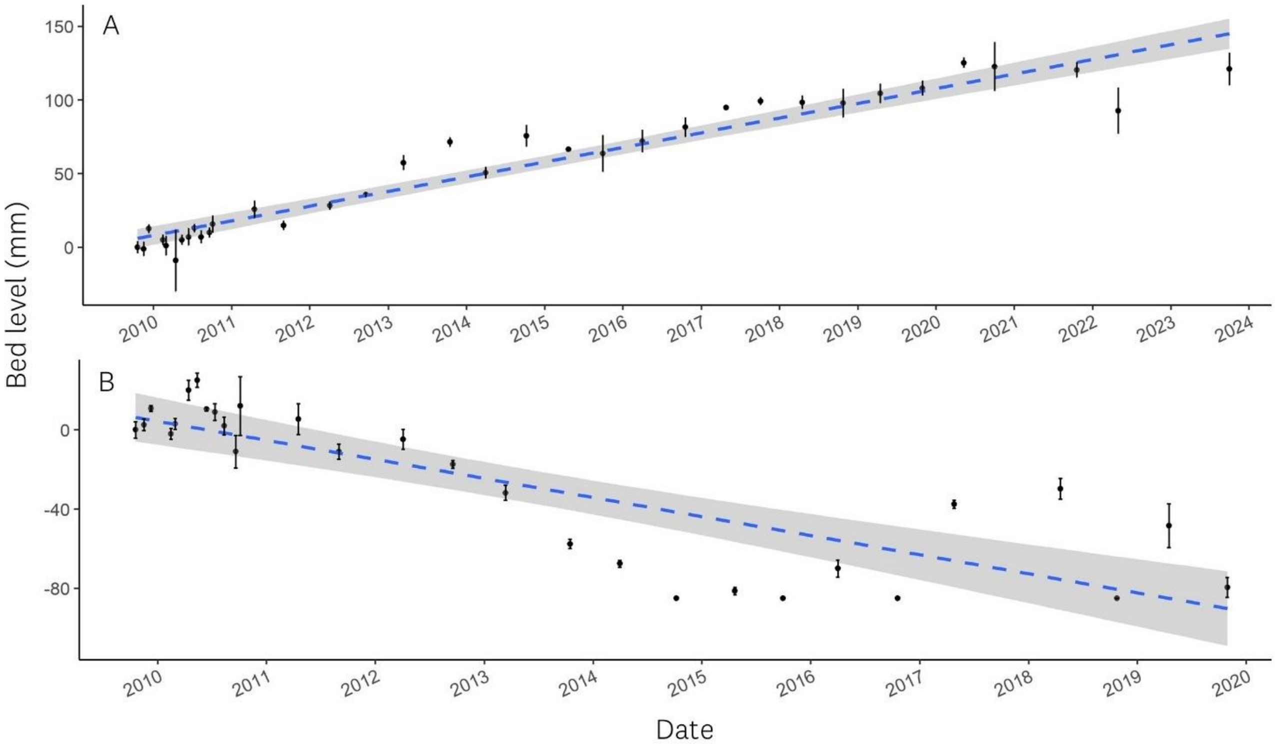

Figure 12. **Sediment levels (relative to buried sediment plate) at A) WWR2 and B) WWR6.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

The overall health of sites in Waiwera Estuary ranged from 'Good' to 'Marginal' in 2022 and 2023, with 50 per cent of sites being 'Marginal' (Figure 13). Health did not follow a typical spatial pattern of improving towards the estuary mouth, as the sites scoring 'Good' health were in the upper half of the estuary. This may be due to changes in the natural hydrodynamics of the lower estuary caused by the Hibiscus Coast Highway causeway which runs across the estuary mouth.

Slight changes in benthic health indices occurred at WWR1 over the last five years though these were all improvements (BHMmud shifted from 'Marginal' to 'Fair' and TBI increased from 'Intermediate' to 'High') (Table 15). It does not appear that the large increase in sediment mud content at WWR1 in 2023 resulted in a degradation in health, though this effect could be delayed. Contrastingly, health in relation to mud and metals degraded at both WWR3 and WWR8 since the last report (Table 15). While this seemed to be an artifact caused by the benthic health scores being close to the boundary between groups for WWR3, the same explanation could not be given for WWR8. Functional resilience (indicated by TBI) was consistently 'Low' at WWR3 and decreased from 'High' to 'Intermediate' at WWR8, which in combination with the degrading BHM groups is concerning.

Figure 13. Combined Health Scores at Waiwera monitoring sites in 2022 and 2023.

Table 15. Benthic health groups at core Waiwera sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	WWR1	WWR3	WWR8
BHMmud	2019	Marginal	Excellent	Good
	2020	Fair	Good	Excellent
	2021	Fair	Excellent	Excellent
	2022	Fair	Good	Excellent
	2023	Fair	Good *	Marginal *
BHMmetals	2019	Fair	Excellent	Good
	2020	Fair	Good	Excellent
	2021	Fair	Excellent	Excellent
	2022	Fair	Good	Excellent
	2023	Fair	Good *	Fair *
TBI	2019	Intermediate	Low	High
	2020	High	Low	High
	2021	High	Low	High
	2022	High	Low	Intermediate
	2023	High	Low	Intermediate *

Macrofaunal community

Species richness diversity in 2022 and 2023 was relatively high at WWR6, WWR7 and WWR9 and very low at most other sites (Figure 14). Of the core sites, WWR3 had the lowest species diversity (only 14) which explains the 'Low' functional resilience observed here. This is typical for WWR3 where species richness has consistently been less than 20, likely due to the low availability of organic matter (a food source for the macrofaunal community) caused by the high energy location of the site in the centre of the main estuary channel (Table 12). Species richness was also low at WWR8 in 2023 at only 15 species, however this was a departure from an average of 24 species over the monitoring period and explains the recent reduction in functional resilience. There were no significant trends in species richness at any of the core sites however the recent declines at WWR8 may be of concern if they persist.

The nMDS plot for Waiwera Estuary had moderate stress and an acceptable fit for interpretation. The macrofaunal community composition at the core sites were highly distinct from one another and have exhibited differing amounts of variability over the last 10 years (Figure 15). There was little variability at WWR1, which aligns with the stable benthic health indices at this site (Table 15). There was a large shift in community composition at WWR3 between 2018 and 2020 though this was not sustained, and there was no evidence of a maintained directional shift that might be cause for concern. The greatest variability occurred at WWR8 and there was a large shift in community composition between 2022 and 2023, which underpinned the degradation in BHM groups (Table 15). Results of SIMPER analysis identified these community shifts were caused by an increase in the abundance of the amphipod family Corophiidae and a decrease in the cumacean *Colurostylis* spp. (which has a strong preference for sand habitats and is sensitive to lead contamination). It is also notable that *Austrovenus stutchburyi* (which prefers sand habitats and is sensitive to stormwater contaminants) was lower in abundance in 2023 than 2021 and 2019.

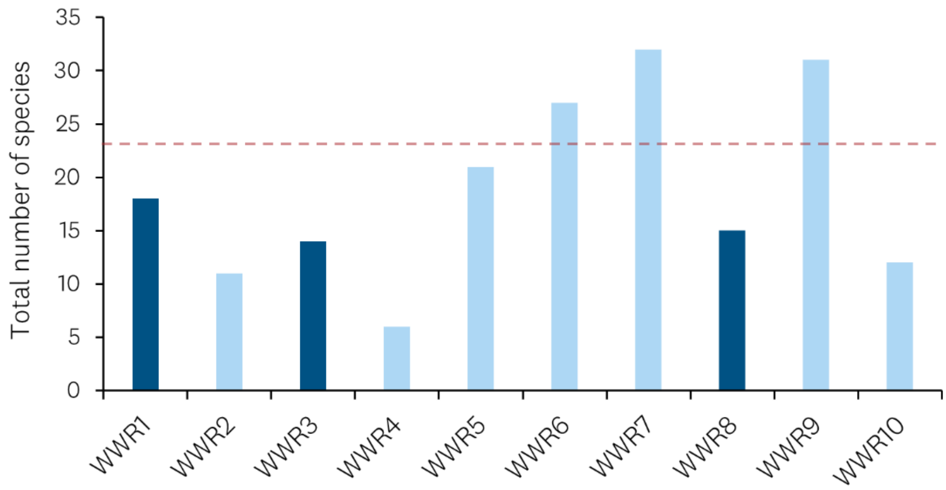

Figure 14. Species richness at Waiwera monitoring sites in 2022 and 2023. The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed).

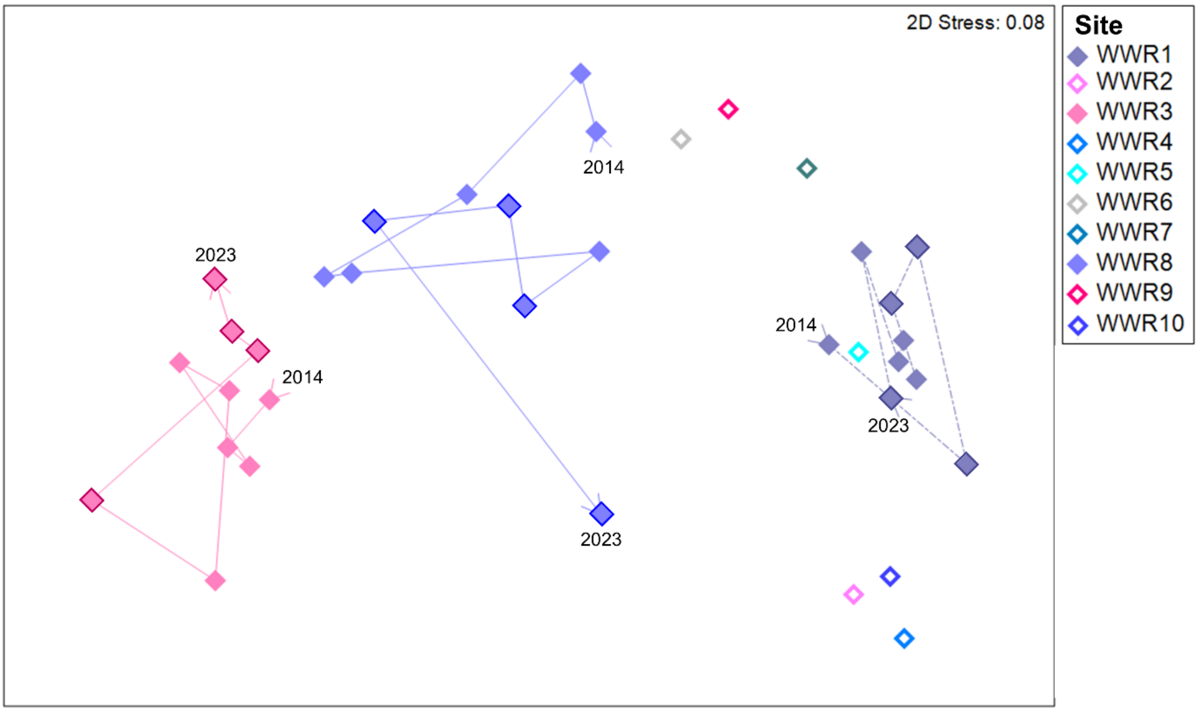

Figure 15. The similarity in macrofaunal community composition between Waiwera sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021).

Indicator species

There were a reasonably high number of trends associated with sedimentation impacts at all sites, though especially WWR3 and WWR8 (Table 16). Population abundances of the strongly sand-preferring bivalve *Paphies australis* and amphipod *Waitangi brevirostris* declined at all core sites, though these trends were partly driven by natural, multi-year cycles. Declines in the abundance of *Colurostylis* spp. (which also has a strong preference for sand habitats) occurred at WWR3 and WWR8 and although these trends may be due partly to multi-year cycles, large decreases at WWR8 since 2018 may be of particular concern as other sand-preferring species also decreased in abundance over a similar timeframe (*Macomona liliana* decreased since 2020 and *Notoacmea scapha* decreased since 2018). These changes in indicator species suggest a recent sedimentation issue that aligns with the degrading benthic health indices at WWR8. Very few trends occurred at the core sites that were consistent with metal contamination.

Table 16. Trends in the abundance of monitored and regionally common species at core Waiwera sites between Oct. 2002 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	WWR1	WWR3	WWR8
Crabs	M		▼ MY	▲ MY
Nereididae	M	▼		▲ MY
Corophiidae	M			▼ No longer present
Anthopleura aureoradiata	S			
Paphies australis	SS	▼ MY	▼ MY	▼ MY
Colurostylis spp.	SS		▼ MY	▼* MY
Waitangi brevirostris	SS	▼ No longer present	▼	▼
Aonides trifida	SS			
Regionally common species				
Aricidea sp.	M		▲	
Prionospio aucklandica	M			
Austrovenus stutchburyi	S			▲ MY
Linucula hartvigiana	S		▼ MY	
Macomona liliana	S	▼ MY		*
Notoacmea scapha	SS	▼		▲* MY
Trends consistent with sedimentation		4	5	5
Trends consistent with metals		1	2	1

Summary

In 2022 and 2023, sites in Waiwera Estuary most commonly had 'Marginal' overall health. There was an unusual spatial pattern with sites in the upper estuary tending to have better health than those near the estuary mouth, which may be due to the causeway that crosses the lower part of the estuary disrupting the estuary hydrodynamics. For instance, significant sediment accretion occurred at WWR2 (near the estuary mouth and adjacent to the causeway) which exceeded the ANZG guideline and would be expected to negatively impact the ecological community, whereas significant erosion occurred at WWR6 in the mid-estuary.

There were some changes of concern at each of the core sites that require close attention in the next few years. The greatest change occurred at WWR8 where sediment mud content jumped from 2 per cent in 2022 to 18 per cent in 2023 and was accompanied by a large shift in community composition, a decrease in species richness, some recent changes in indicator species abundances, and degraded benthic health indices. Sediment mud content was also unusually high at WWR1 in 2023 but did not appear to trigger a response in the macrofaunal community, so it will be important to see if this shift in mud content persists or is a temporary fluctuation and whether there is a delayed impact to the health of the site.

Benthic health scores were variable at WWR3 and had degraded since 2019, however this appears to be an artifact of the site scoring close to the boundary between benthic health groups as sediment mud content was very low, previous fluctuations in community composition appear to have stabilised, and there were no recent concerning changes in species abundances.

3.4 Ōrewa

The Ōrewa River estuary is also within the Hibiscus Coast Consolidated Receiving Environment and is small (1.3 km^2) compared to the size of its catchment (24 km^2, based on the combined areas of the Ōrewa River East and Ōrewa River West Freshwater Management Tool sub-catchments). The catchment is dominated by exotic grassland and urban areas, with patches of indigenous forest and scrub/shrubland and exotic forest (Auckland Council, 2025). Some change in land use occurred in the Ōrewa River West sub-catchment since the last report and took various forms. For example, there were several examples of exotic grassland becoming urban area, indigenous scrub/shrubland or exotic scrub/shrubland, and of exotic forest becoming harvested forest or exotic scrub/shrubland.

The three core sites represent the outer (ORW1), middle (ORW4) and upper (ORW8) parts of the estuary. Due to the main estuary channel shifting and making ORW4 increasingly subtidal and difficult to sample, this site was shifted to a slightly higher position on the intertidal flat since 2021. Paired sampling was conducted at the new and old site locations for three years between 2021 and 2023 to ensure the sediment characteristics and macrofaunal communities were comparable before deciding to cease sampling at the original site since April 2023.

Sediment characteristics

In 2022 and 2023, sediment mud content was relatively low across Ōrewa Estuary with most sites having less than 10 per cent mud content (Figure 16). The exceptions were ORW6 and ORW10 which are in more sheltered, mangrove dominated parts of the estuary, and ORW7 which had 17 per cent mud content in 2022.

Very fine sand + mud increased significantly at ORW4 and ORW8 between 2009 and 2010 (step increase), and since 2020 there have been slight increases at ORW4 (Appendix 3: Figure A4). The previously reported increasing trend at ORW1 could no longer be detected due to consistently low measurements since 2019. Organic content increased at all core sites since 2019, resulting in new significant increasing trends at ORW1 and ORW4 and the cessation of a decreasing trend at ORW8. Importantly, at sites ORW1 and ORW4 these increases were accompanied by increasing chlorophyll *a* concentrations which may suggest an excess nutrients issue.

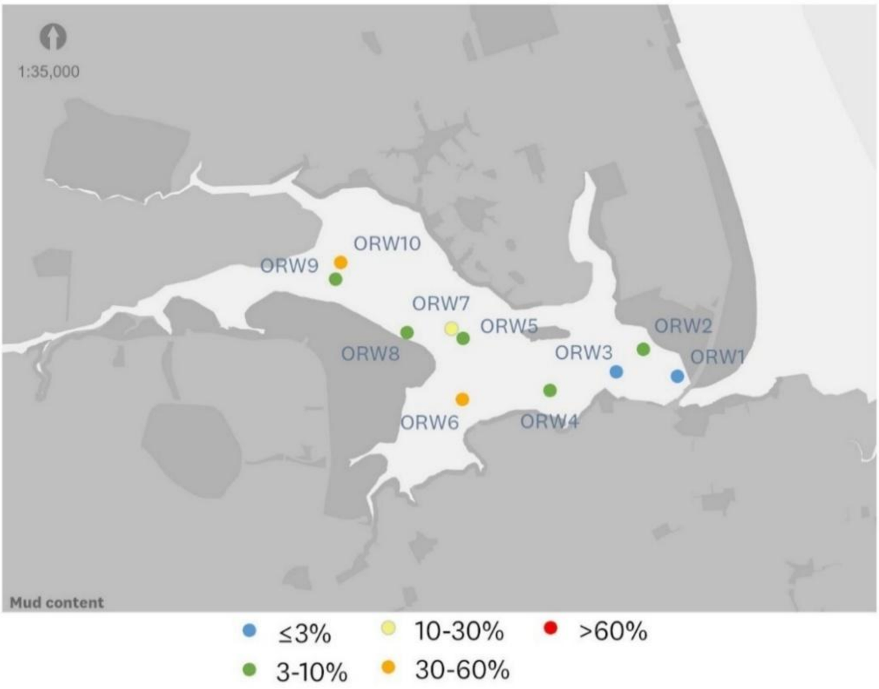

Figure 16. Sediment mud content at Ōrewa monitoring sites in 2022 & 2023.

Table 17. Median values and temporal variation (standard deviation) of surface sediment characteristics at Ōrewa monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
ORW1	14.86	11.90	0.67	0.52	4.41	0.92
ORW2	41.21	23.48	0.97	0.63	8.12	2.80
ORW3	9.98	9.48	0.67	0.41	6.22	1.89
ORW4	52.67	18.79	1.12	0.72	4.56	1.30
ORW5	36.67	22.74	1.11	0.65	5.94	0.55
ORW6	70.79	18.72	1.82	1.03	7.22	0.91
ORW7	22.37	19.26	0.28	0.73	6.01	1.09
ORW8	66.40	18.96	1.32	0.75	4.63	1.06
ORW9	41.08	14.93	0.63	0.92	3.96	1.61
ORW10	61.42	20.47	0.70	2.41	11.70	0.49

Table 18. Direction of statistically significant trends in sediment characteristics at core Ōrewa sites between 2009 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in (Drylie, 2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g^{-1} dw sediment)
ORW1	Lost – previously ▲	▲ New	▲ New
ORW4	▲ Maintained	▲ New	▲ New
ORW8	▲ Maintained	Lost – previously ▼	▼ Maintained

Sedimentation monitoring occurred at ORW1, ORW4 and ORW8. The plate at ORW1 was scoured and lost between 2013 and 2022 and was replaced in October 2023 to reinitiate the timeseries, however there are not enough recent data to include here. The last measurement at ORW4 was in 2021 as, since then, the estuary channel shifted making it increasingly difficult to access the site at low tide (this site has since been moved up-shore). The plate at ORW8 was lost after 2020 and a replacement was installed in 2023.

The sediment accretion rate (Table 19) estimated from the trend line fitted to the sediment level data (Figure 17) indicated there was significant accretion at ORW8 and less certain erosion at ORW4. The rate of accretion at ORW8 was much greater than the ANZG guideline value of 2.4 mm/y estimated for the Auckland Region. The 95 per cent confidence intervals show that there was moderate variability around the average linear sediment accretion rate for ORW4, and very low variability for ORW8. Although the upper 95 per cent interval for ORW4 indicated accretion, this remained below the ANZG guideline value. The combination of increased very fine sand + mud and high rates of sediment accretion suggests ORW8 experiences substantial pressure from sedimentation.

Table 19. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Ōrewa monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
ORW4	-1.58	0.08	-3.38	0.22	2009–2021
ORW8	15.24	<0.001	13.53	16.94	2009–2020

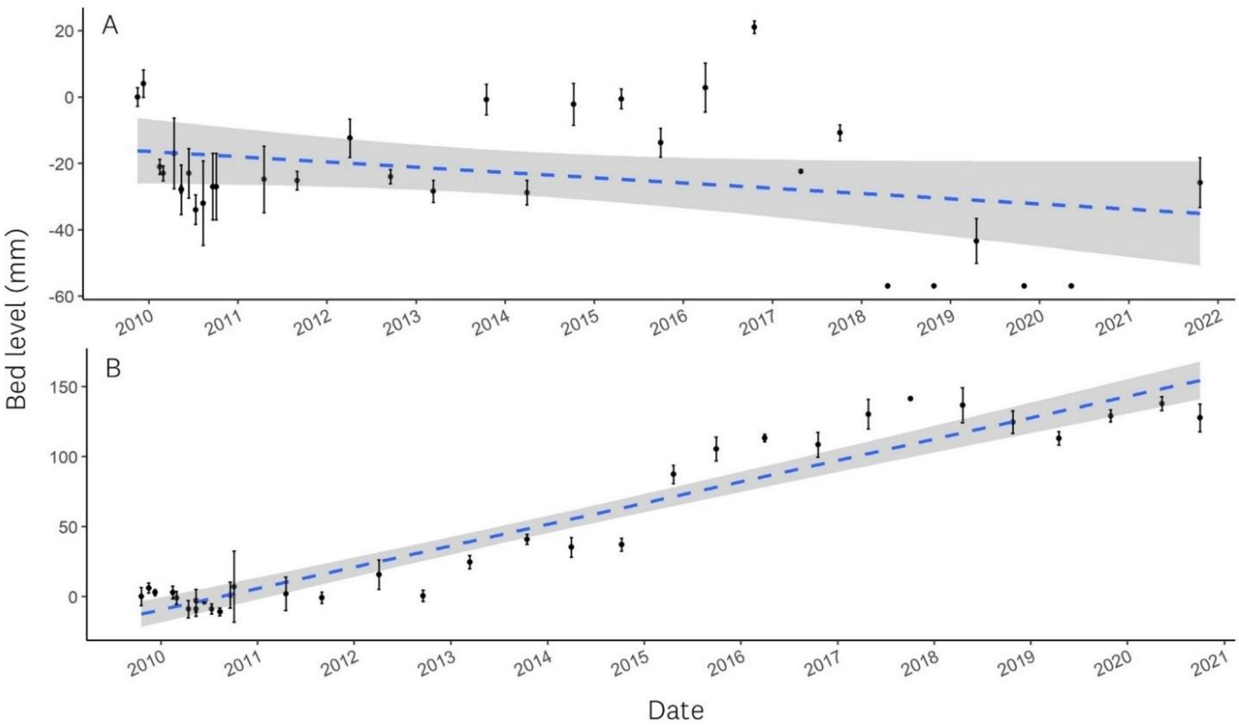

Figure 17. **Sediment levels (relative to buried sediment plate) at A) ORW4 and B) ORW8.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

The overall health of sites in Ōrewa Estuary ranged from 'Excellent' to 'Marginal', with 'Fair' being the most common health group (Figure 18). All the sites with 'Excellent' or 'Good' health were in the lower half of the estuary, although health at ORW1 and ORW4 was lower than might be expected from their location alongside near the estuary mouth and is likely caused by the influence of low TBI scores (see Table 20).

At all core sites, health in relation to mud was 'Good' or 'Fair' and degraded since the last report (Table 20). The decline in health was most pronounced for ORW4 where BHMmud dropped two health groups (from 'Excellent' to 'Fair'); this seems to coincide with the increases in very fine sand + mud (and organic content) that occurred since 2020. A very similar pattern was observed in functional resilience (according to TBI) which was 'Low' at all core sites and had degraded since the last report. Again, the most severe changes occurred at ORW4. Health in relation to metals was 'Excellent' or 'Good' at the core sites and did not change over the last five years.

Figure 18. Combined Health Scores at Ōrewa monitoring sites in 2022 and 2023.

Table 20. Benthic health groups at core Ōrewa sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	ORW1	ORW4	ORW8
BHMmud	2019	Excellent	Excellent	Good
	2020	Excellent	Good	Good
	2021	Good	Good	Fair
	2022	Excellent	Good	Good
	2023	Good *	Fair *	Fair *
BHMmetals	2019	Excellent	Good	Good
	2020	Excellent	Good	Good
	2021	Excellent	Good	Good
	2022	Excellent	Good	Good
	2023	Excellent	Good	Good
TBI	2019	Intermediate	High	Intermediate
	2020	Low	Low	Low
	2021	Low	Low	Low
	2022	Low	Low	Low
	2023	Low *	Low *	Low *

Macrofaunal community

At most sites in 2022 and 2023 species richness was close to the average for the East Coast Estuaries (23 species), but low diversity was recorded at all the core sites (Figure 19). The increasing trend at ORW4 ended in 2018 and species richness declined since 2020 (Appendix 4: Figure A10). Persistently low diversity was also recorded at ORW8 since 2020, and there was a significant long-term decrease in species richness at this site.

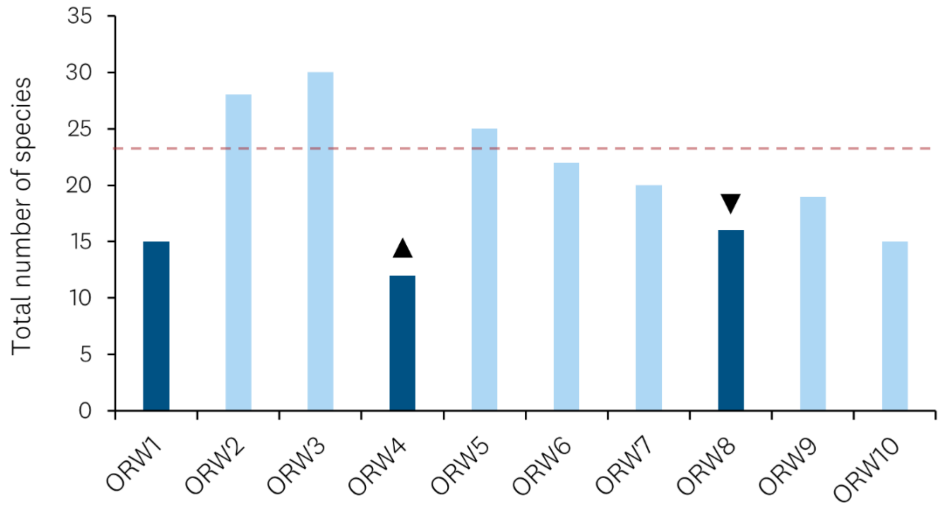

Figure 19. Species richness at Ōrewa monitoring sites in 2022 and 2023. The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2002–2023) are shown: ▲ represents an increase and ▼ a decrease.

The nMDS plot for Ōrewa Estuary had moderate to high stress and was useful for identifying patterns but not detailed interpretation. The sites were separated across the plot space according to their position from the upper to the lower estuary, suggesting gradual changes in community composition along the estuary (Figure 20). For example, ORW10, ORW9 and ORW8 were clustered to the left of the plot while ORW1 was to the right; by overlaying vectors of environmental variables that had a high correlation with the nMDS axes, it was revealed that sites to the left of the plot were associated with higher amounts of very fine sand and mud whereas sites to the right of the plot had higher proportions of medium and fine sand.

The core sites ORW1 and ORW8 did not show much variability over the last 10 years although there was some evidence of directional movement over time; the direction of this change was not correlated with any of the measured environmental characteristics (including sediment grain size, organic content and chlorophyll *a* concentrations) (Figure 20). A large, sustained shift in community composition occurred at ORW4 between 2019 and 2020 that coincided with degrading BHMmud and TBI groups (Table 20). *Austrovenus stutchburyi* has been the dominant species in terms of abundance at ORW4 over the last 10 years, though changes in the next most dominant species occurred pre- and post-2020. For instance, between 2014 and 2019 *Prionospio aucklandica* was the second most abundant species, yet between 2020 and 2023 it did not feature in the top five (Table

21). The changes in dominant species may be related to the encroachment of the estuary channel into the site around 2020, and the change in site location in 2021.

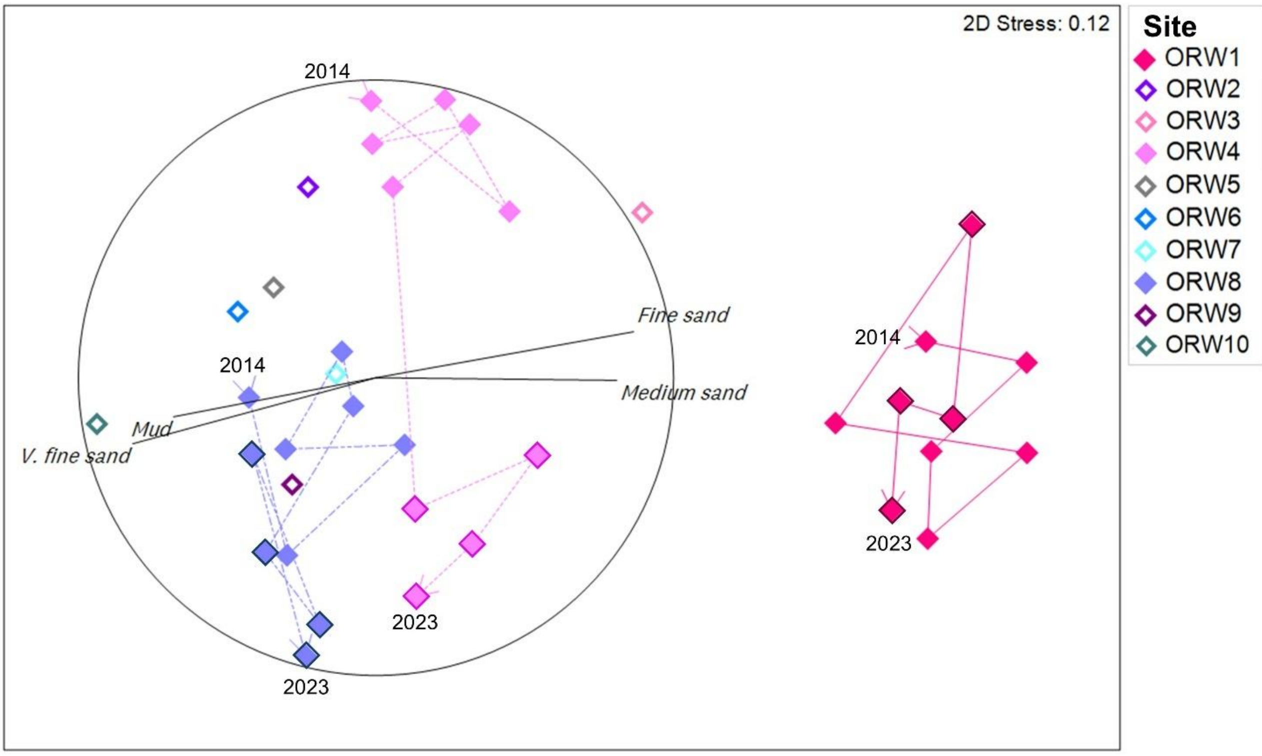

Figure 20. The similarity in macrofaunal community composition between Ōrewa sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021). Vectors representing environmental variables with a Pearson correlation coefficient >0.7 are shown.

Table 21. Dominant species at ORW4 before and after a major shift in community composition between 2019 and 2020. Dominance is based on average abundances from October sampling occasions in the last 10 years (as per nMDS). Where species are equally dominant, they are given the same rank.

Rank	2014–2019	2020–2023
1	*Austrovenus stutchburyi*	*Austrovenus stutchburyi*
2	*Prionospio aucklandica*	Capitellid + Oligochaetes
3	*Austrominius modestus* *Notoacmea scapha*	*Paphies australis* *Austrominius modestus* Corophiidae
4	*Colurostylis* spp. *Anthopleura aureoradiata*	

Indicator species

At each of the core sites, there were four indicator species trends that were consistent with sedimentation (Table 22). The bivalve *Paphies australis* decreased in abundance at all sites, the amphipod *Waitangi brevirostris* decreased at ORW1 and ORW4, and the bivalve *Macomona liliana* decreased at ORW1 and ORW8.

Declines in the abundance of *Prionospio aucklandica* (sensitive to copper) and *Macomona liliana* (sensitive to stormwater contaminants generally) at ORW1 and ORW8 were also indicative of metal contamination. However, the abundance of *Prionospio aucklandica* was always very low at both sites (10 or fewer) and the polychaete worm *Aonides trifida* (which is very sensitive to copper) increased in abundance at ORW1, so it is not likely that copper was a genuine stressor at this site. *Aonides trifida* decreased at ORW8 though this trend ended in 2010 and health in relation to metals was consistently 'Good' between 2019 and 2023 (Table 20), such that copper contamination may have been an issue at this site but does not seem to be currently.

Table 22. Trends in the abundance of monitored and regionally common species at core Ōrewa sites between Oct. 2002 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	ORW1	ORW4	ORW8
Crabs	M		▲ MY	
Nereididae	M			▼ MY
Corophiidae	M		▼	
Anthopleura aureoradiata	S		▲ MY	
Paphies australis	SS	▼ MY	▼ MY	▼ MY
Colurostylis spp.	SS			
Waitangi brevirostris	SS	▼	▼	
Aonides trifida	SS	▲		▼ MY
Regionally common species				
Aricidea sp.	M			
Prionospio aucklandica	M	▼ MY	▲	▼ MY
Austrovenus stutchburyi	S		▲ MY	▲ MY
Linucula hartvigiana	S		▲*	
Macomona liliana	S	▼	▲ MY	▼ MY
Notoacmea scapha	SS		▲	
Trends consistent with sedimentation		4	4	4
Trends consistent with metals		2	0	3

Summary

The overall health of sites in Ōrewa Estuary in 2022 and 2023 varied significantly but was most often 'Fair' or 'Marginal'. Evidence of widespread sedimentation impacts was found as sediment mud content was elevated at most sites, trends in indicator species occurred at all the core sites and very fine sediments increased significantly at ORW4 and ORW8 (and high rates of sediment accretion were observed at ORW8). In the short term, the BHMmud group degraded between 2019 and 2023 at all core sites.

Organic content increased at all core sites since 2019 and at ORW1 and ORW4, this was accompanied by increasing chlorophyll *a* concentrations which may suggest a nutrient enrichment issue. This needs further investigation via sampling of sediment nutrient concentrations. Metal contamination (specifically copper) may have previously caused stress to the ecological community at ORW8, though this does not seem to be an ongoing issue.

Several concerning changes were identified at ORW4 over the last five years with increasing very fine sand + mud, organic content and chlorophyll *a*, declining species richness, shifts in community composition and the most drastic changes in benthic health groups. In the coming years it will be important to determine whether these represent genuine ecological degradation or are an effect of the channel encroaching onto the site and it being moved up-shore.

3.5 Ōkura

The Ōkura River estuary is within the Hibiscus Coast Consolidated Receiving Environment and is within the Long Bay–Ōkura Marine Reserve. The estuary is small (1.4 km^2) with a relatively large catchment (23 km^2, based on the combined areas of the Ōkura and Ōkura North Freshwater Management Tool sub-catchments). Exotic grassland dominates the catchment with large areas of indigenous forest and scrub/shrubland, especially to the south, and a concentrated area of exotic forest at the head of the estuary (Weiti forestry block) (Auckland Council, 2025). There is a small urban area associated with the Ōkura residential area. There was minimal change in catchment land use since the last report and where change did occur this was often from exotic grassland to indigenous and exotic scrub/shrubland, or indigenous forest. The core monitoring sites are OKR3, OKR7 and OKR9.

Sediment characteristics

In 2023, sediment mud content was less than 3 per cent at OKR1 and at all other sites was elevated to levels where the macrofaunal community may experience negative impacts (Figure 21). Organic content and chlorophyll *a* concentrations were also consistently low at OKR1 (likely due to it being in a high energy location near the estuary mouth) which indicates there may be limited food availability for the macrofaunal community (Table 23). Very fine sand + mud was highest at OKR2, OKR8, OKR9 and OKR10 over the monitoring period, and exhibited the most temporal variability at the sites in the upper estuary (Table 23).

Very fine sand + mud increased significantly at all core sites over the monitoring period with step increases in 2010 at OKR3 and OKR9 and little change being observed since, whereas the trend at OKR7 started in 2009 and had not ended in 2023 (Table 24 and Appendix 3: Figure A5). A new (though uncertain) trend of increasing organic content at OKR7 coincided largely with the increases in very fine sediments (Appendix 3: Figure A5), and an increasing trend was maintained at OKR9 (Table 24). Neither of these trends were accompanied by increases in chlorophyll *a*, so are not currently cause for concern with regards to nutrient enrichment.

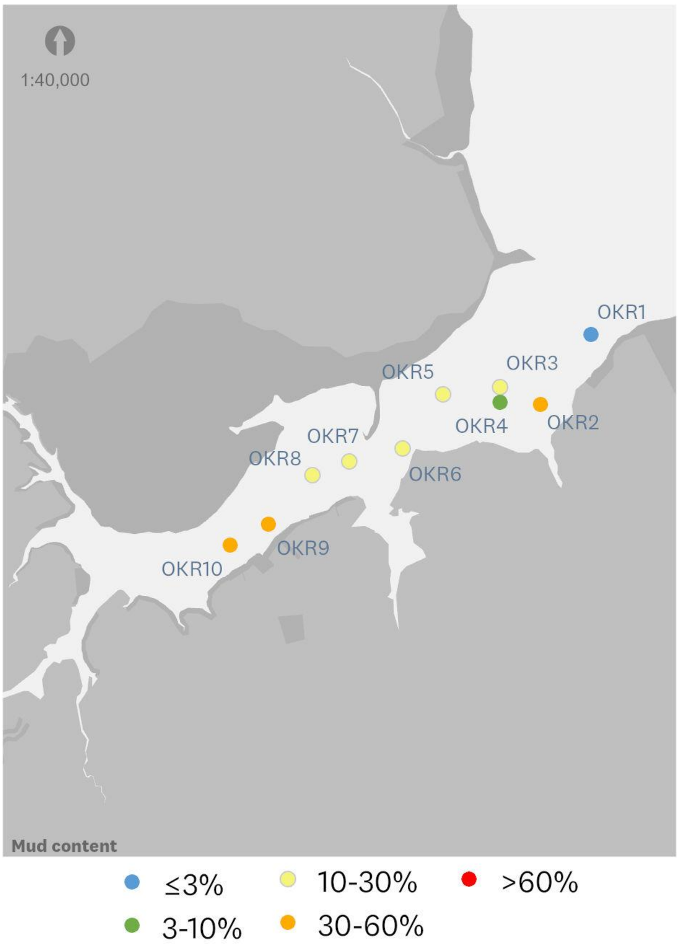

Figure 21. Sediment mud content at Ōkura monitoring sites in 2023.

Table 23. Median values and temporal variation (standard deviation) of surface sediment characteristics at Ōkura monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (μg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
OKR1	15.22	12.08	0.64	0.86	7.10	2.52
OKR2	65.81	15.95	2.29	1.96	16.78	2.91
OKR3	29.61	16.10	1.29	1.10	12.64	3.90
OKR4	21.12	12.39	1.02	0.93	9.17	2.17
OKR5	23.34	7.75	0.95	1.26	8.05	2.05
OKR6	33.67	17.17	1.23	1.73	10.04	3.00
OKR7	27.83	13.90	1.34	1.09	10.58	2.62
OKR8	61.78	19.43	1.60	1.88	10.20	3.55
OKR9	78.15	20.66	1.96	2.92	12.80	3.28
OKR10	70.77	22.69	2.17	2.29	13.76	3.10

Table 24. Direction of statistically significant trends in sediment characteristics at core Ōkura sites between 2004 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in (Drylie, 2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (μg g^{-1} dw sediment)
OKR3	▲ Maintained		
OKR7	▲ Maintained	▲ New	
OKR9	▲ Maintained	▲ Maintained	▼ New

Sedimentation monitoring occurred at OKR3, OKR7 and OKR9. The plate at OKR7 was reburied in April 2011 and as there were too few measurements between 2009 and 2011 to robustly merge the datasets, a new timeseries was initiated from September 2011. The sediment accretion rate (Table 25) estimated from the trend line fitted to the sediment level data (Figure 22) indicated there was significant accretion at all three sites and that the rate of accretion exceeded the ANZG guideline value of 2.4 mm/y estimated for the Auckland Region. The highest rates occurred at OKR7. The 95 per cent confidence intervals show that there was some variability around the average linear sediment accretion rate and that this changed the assessment of sediment accretion relative to the ANZG guideline value for OKR3, i.e., at the lower 95 per cent interval this site would no longer exceed the guideline.

Table 25. **Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Ōkura monitoring sites.**

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
OKR3	2.74	<0.001	1.42	4.06	2009–2023
OKR7	12.9	<0.001	8.84	16.96	2011–2023
OKR9	7.42	<0.001	4.94	9.89	2009–2023

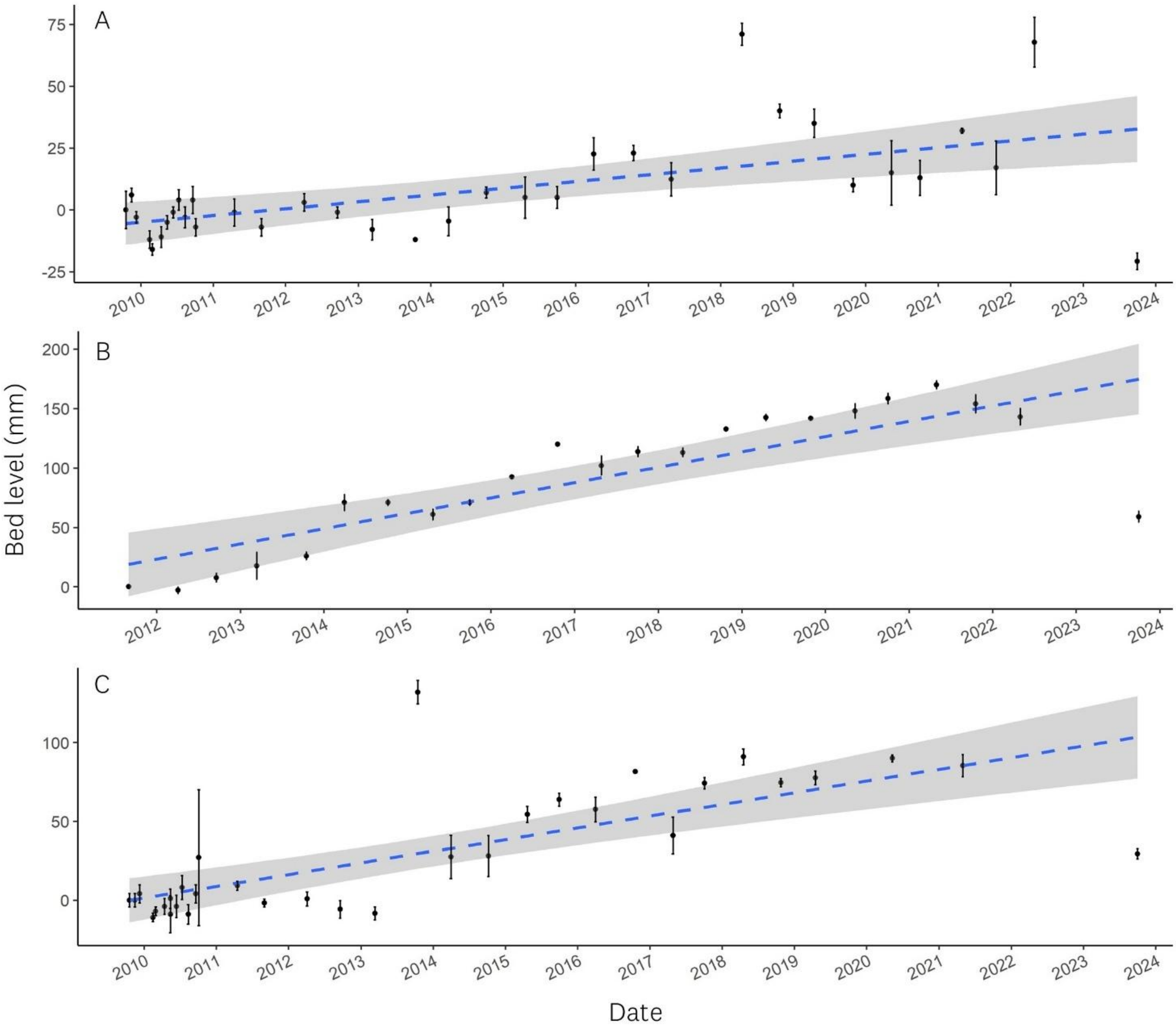

Figure 22. **Sediment levels (relative to buried sediment plate) at A) OKR3, C) OKR7 and B) OKR9.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

In 2023, 50 per cent of the monitoring sites in Ōkura Estuary had 'Good' overall health and the other 50 per cent were either 'Fair' or 'Marginal' (Figure 23). Sites with the poorest health tended to be in the upper estuary (OKR8 and OKR10) where the concentrations of very fine sediments were highest.

Some concerning changes occurred at the core sites OKR7 and OKR9 over the last five years. Health in relation to mud (BHMmud) degraded by one health group at both sites since the last report and health in relation to metals also degraded at OKR9 (Table 26). Despite these changes, functional resilience according to TBI remained 'High' at OKR7 and increased at OKR9 from 'Intermediate' to 'High'. In 2023, OKR3 had 'Good' health in relation to mud and metals and 'High' functional resilience, and although the BHM groups alternated between 'Good' and 'Excellent' since 2019 this did not represent a meaningful change in health (as the site scores close to the boundary between groups).

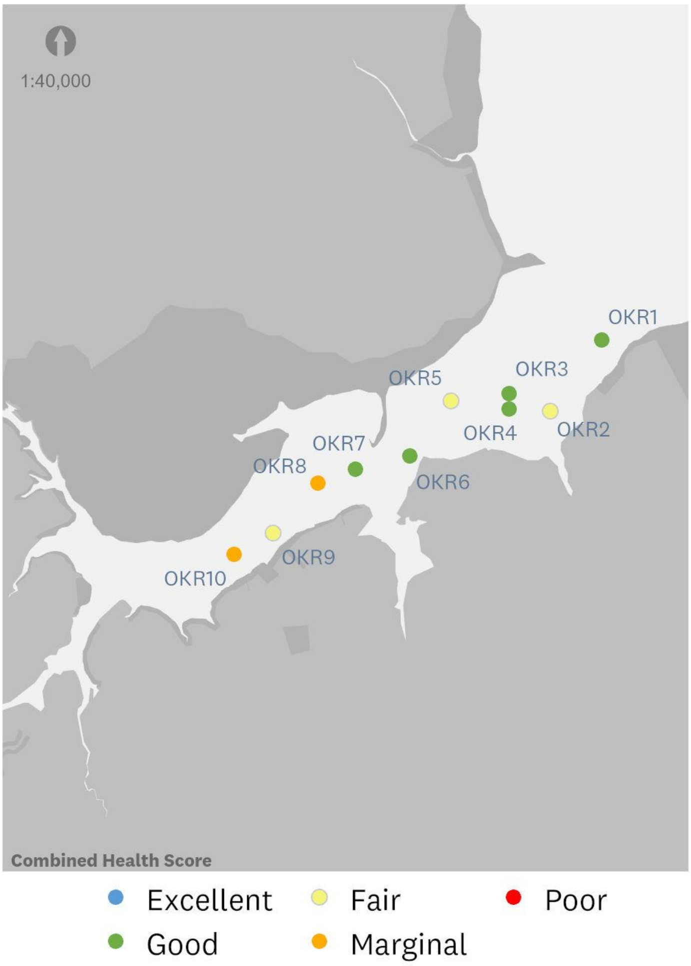

Figure 23. Combined Health Scores at Ōkura monitoring sites in 2022 and 2023.

Table 26. Benthic health groups at core Ōkura sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	OKR3	OKR7	OKR9
BHMmud	2019	Good	Excellent	Fair
	2020	Good	Good	Fair
	2021	Good	Good	Fair
	2022	Excellent	Excellent	Marginal
	2023	Good	Good *	Marginal *
BHMmetals	2019	Good	Good	Good
	2020	Excellent	Good	Fair
	2021	Good	Good	Fair
	2022	Excellent	Excellent	Fair
	2023	Good	Good	Fair *
TBI	2019	High	Intermediate	Intermediate
	2020	High	High	High
	2021	High	High	High
	2022	High	High	Intermediate
	2023	High	High	High

Macrofaunal community

In 2023 species richness at most sites in Ōkura Estuary was at or above the average for the East Coast Estuaries (Figure 24). Diversity was particularly high at OKR4, OKR3 and OKR6 (32 to 34 species) and was lowest at OKR8, OKR10 and OKR1 (16 to 18 species). The lower diversity at OKR8 and OKR10 likely reflects impacts from sedimentation, whereas at OKR1 this is more likely due to the low food availability at this well-flushed site where mud, organic content and chlorophyll *a* were all low (Figure 21 and Table 23). Over the course of the monitoring period, species richness increased at OKR3 (though this is a low certainty trend) and decreased at OKR9 (though this trend appeared to end around 2019) (Appendix 4: Figure A11).

The nMDS plot for Ōkura Estuary had moderate to high stress and was useful for identifying patterns but not detailed interpretation. The macrofaunal community composition at OKR1 and OKR10 was very different to all other sites, likely owing to their distinct positions in the high energy estuary mouth and sheltered upper estuary, respectively (Figure 25). The remaining sites were organised and clustered according to their position along the estuary, except OKR2 which was more similar to OKR9 than any other site. This similarity in community composition seems unusual given the distance between OKR2 and OKR9, however they had very similar sediment conditions (high mud content, high very fine sand + mud (Figure 21 and Table 23)). Community composition at OKR3 was similar in 2023 and 2014 indicating minimal change over the last 10 years. There was some minor directional movement at OKR7 and OKR9 since the last report (highlighted by the outlined symbols) which aligned with the changes observed in BHM groups at these sites, though there was not any evidence of large, sudden shifts in community composition.

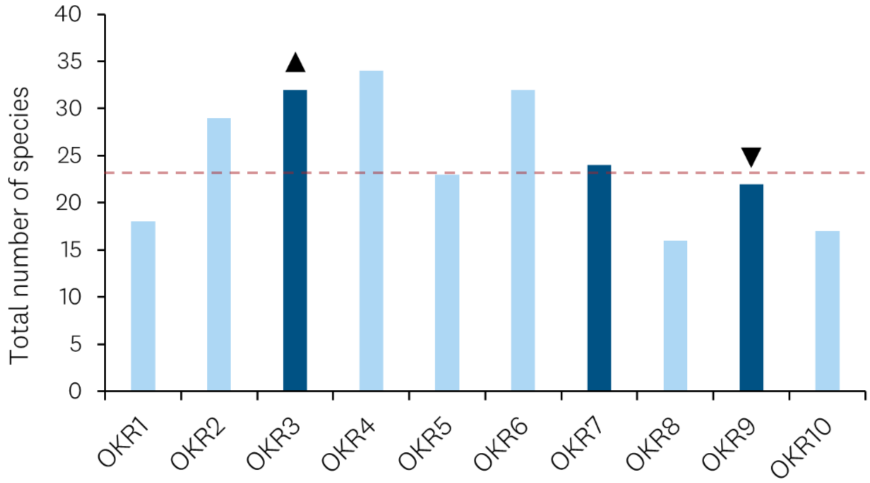

Figure 24. Species richness at Ōkura monitoring sites in 2023. The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2001–2023) are shown: ▲ represents an increase and ▼ a decrease.

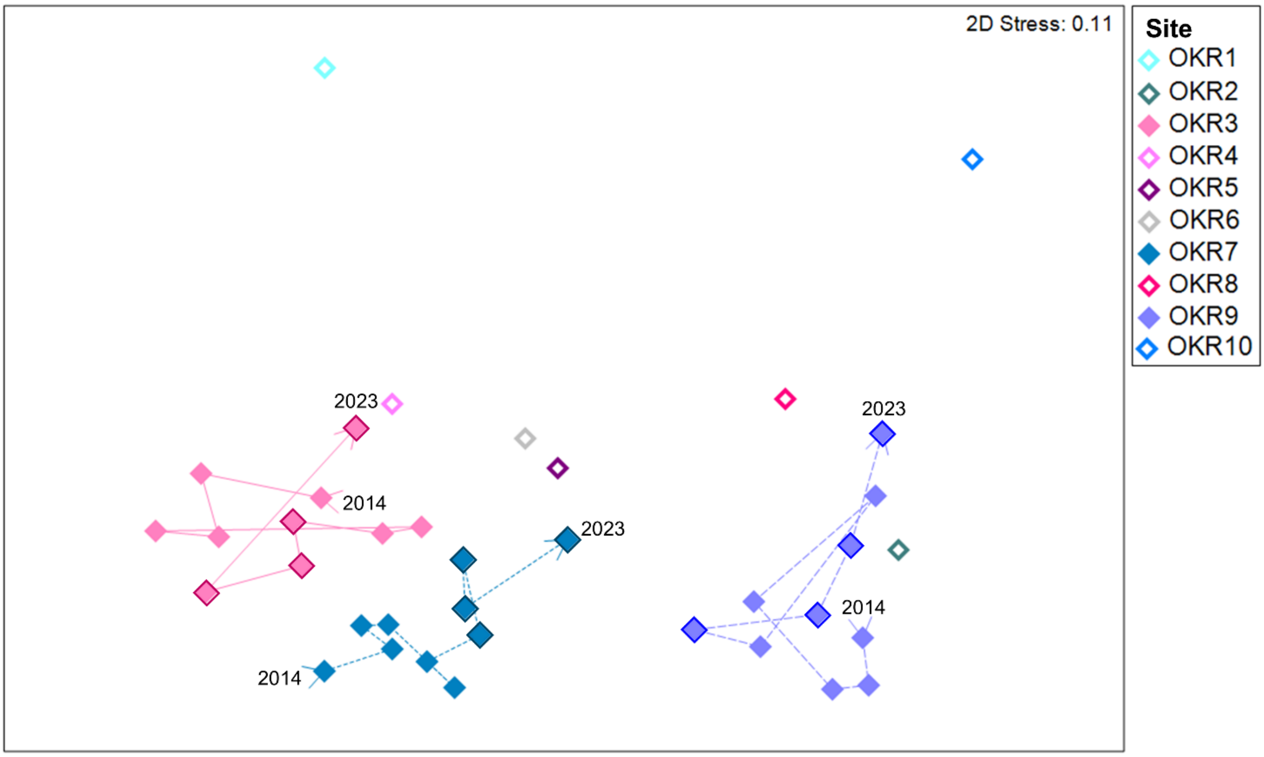

Figure 25. The similarity in macrofaunal community composition between Ōkura sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021).

Indicator species

There were a high number of long-term trends in the abundance of indicator species that suggested sedimentation impacts at OKR9, and a moderate number at OKR7 and OKR3 (Table 27). Estuary-wide decreases in several sand-preferring species occurred, including the polychaete *Aonides trifida*, amphipod *Waitangi brevirostris*, cumacean *Colurostylis* spp., and bivalves *Paphies australis* and *Linucula hartvigiana*. These decreases in mud-sensitive species coincided with significant increases in very fine sand + mud and high rates of sediment accretion at each of the core sites (Table 24 and Table 25).

Table 27. Trends in the abundance of monitored and regionally common species at core Ōkura sites between Oct. 2001 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	OKR3	OKR7	OKR9
Crabs	M			
Nereididae	M	▲ MY	▲ MY	
Corophiidae	M	▲ MY	▼	▼ MY
Anthopleura aureoradiata	S			▼ MY
Paphies australis	SS	▼ MY		▼
Colurostylis spp.	SS		▼ MY	▼ MY
Waitangi brevirostris	SS	▼ MY	▼	▼
Aonides trifida	SS	▼ MY	▼ MY	▼
Regionally common species				
Aricidea sp.	M			
Prionospio aucklandica	M		▲ MY	▲* MY
Austrovenus stutchburyi	S	▲*	▲ MY	▼ MY
Linucula hartvigiana	S		▼ MY	▼ Step – 2012
Macomona liliana	S			▼
Notoacmea scapha	SS	▲ MY		
Trends consistent with sedimentation		5	6	9
Trends consistent with metals		1	3	5

Trends indicative of metal contamination were also quite high at OKR9 (Table 27). Most of the species that decreased in abundance are particularly intolerant of copper (*Anthopleura aureoradiata*, *Aonides trifida*, *Linucula hartvigiana*), though *Colurostylis* spp. is known to be sensitive to lead and

Macomona liliana is sensitive to stormwater contaminants generally. It is notable that all the metal-sensitive species that exhibited significant decreasing trends (at all of the core sites) were also sensitive to sedimentation, so it is likely the significant increases in very fine sediments that occurred at the core sites could be confounding these results. Sites in Ōkura were last sampled for metal contaminant concentrations in 2016 and at that time, concentrations of copper, lead and zinc were below the Environmental Response Criteria threshold where ecological impacts are likely (Mills & Allen, 2021)

Recent changes occurred at OKR3 where *Austrovenus stutchburyi* abundances decreased since around 2018 (Figure 26). This suggests a degradation in environmental conditions, however there was a rapid increase in abundance between 2012 and 2018 such that the recent decreases are not necessarily concerning and may simply be the population returning to pre-2012 abundances. A recent change also occurred at OKR9 where the mud-preferring polychaete *Prionospio aucklandica* decreased since around 2018, which suggests a potential improvement in environmental conditions.

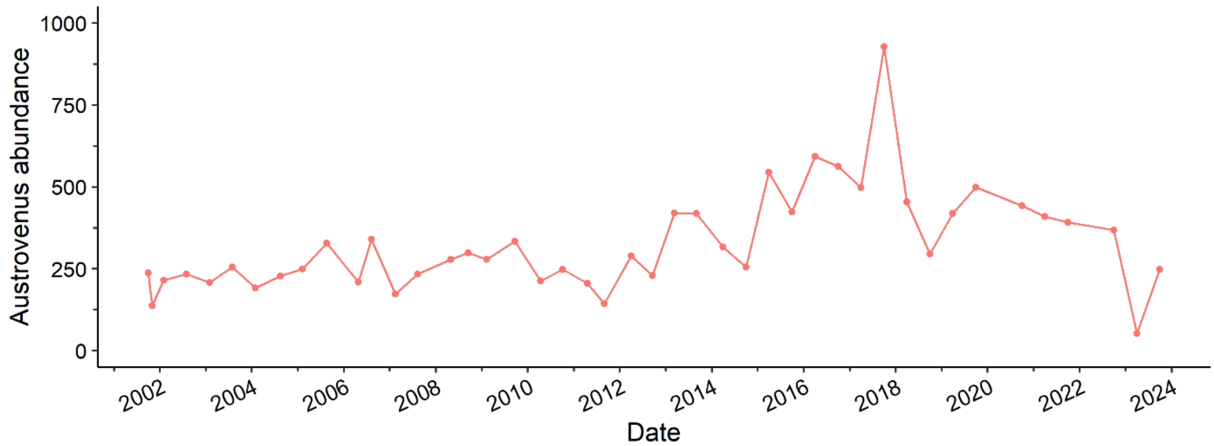

Figure 26. Total abundance (from six replicate cores) of *Austrovenus stutchburyi* at OKR3 over the monitoring period.

Summary

The overall health of monitoring sites in Ōkura Estuary was most commonly 'Good' in 2023, however muddy upper estuary sites had 'Marginal' health. Sedimentation caused increases in very fine sand + mud and high rates of sediment accretion over the monitoring period, which resulted in estuary-wide declines in sediment-sensitive species and increases in mud-tolerant species. There was some evidence of potential metal contamination, however this may have been confounded by the impacts of sedimentation. There was no evidence of excess nutrient issues.

Some recent changes in BHM groups were of concern at OKR7 (BHMmud degraded from 'Excellent' in 2019 to 'Good' in 2023 and was accompanied by a continuing trend of increasing very fine sand + mud) and OKR9 (BHMmud and BHMmetals degraded between 2019 and 2023) and minor directional shifts in macrofaunal community composition were observed at both sites, although functional resilience remained high and there were no recent changes in sediment characteristics or the abundance of indicator species that were cause for concern.

3.6 Mangemangeroa

The Mangemangeroa Creek estuary is a very small estuary (0.6 km^2) within the Tāmaki Consolidated Receiving Environment that discharges to the Whitford Embayment and drains a catchment of 9 km^2. The dominant land use in the catchment is exotic grassland, with large areas of indigenous forest and smaller patches of indigenous and exotic scrub/shrubland (Auckland Council, 2025). Small urban areas are dotted through the catchment with the largest occurring at the head of the estuary (a low-density residential area). Most of the change in catchment land use since the last report occurred in the upper catchment and was from exotic grassland to indigenous forest or exotic scrub/shrubland, though there was little change overall. The core sites in Mangemangeroa are MNG3, MNG5 and MNG6 and cover the lower-mid estuary.

Sediment characteristics

In 2021 and 2023, sediment mud content was intermediate or high at all sites except MNG1, which is beyond the estuary mouth in the Whitford Embayment (Figure 27). Very fine sand + mud was highest at MNG5, MNG6, MNG9, and MNG10 over the monitoring period and exhibited reasonably high temporal variability at all sites (Table 28). Organic content varied considerably between sites and was very low at MNG1, MNG2 and MNG8 and relatively high at sites where very fine sediments were also high.

Very fine sand + mud increased significantly at all core sites over the monitoring period (Table 29). The trends at MNG5 and MNG6 were maintained from the previous report whereas this was a new (uncertain) trend for MNG3, driven by notable increases in very fine sand + mud since 2020 (Appendix 3: Figure A6). New significant increasing trends for organic content were identified at MNG3 and MNG6 as large increases occurred at both sites between 2017 and 2020. These trends were not accompanied by increases in chlorophyll *a* and the increase at MNG6 seemed to follow increases in very fine sediments mud content, so may reflect inputs from land rather than a response to excess nutrients.

Figure 27. Sediment mud content at Mangemangeroa monitoring sites in 2021 and 2023.

Table 28. Median values and temporal variation (standard deviation) of surface sediment characteristics at Mangemangeroa monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g⁻¹ dw sediment)	
	Med	SD	Med	SD	Med	SD
MNG1	17.72	15.97	0.24	0.50	11.12	N/A
MNG2	27.81	11.99	0.53	0.73	14.79	4.17
MNG3	24.64	11.43	2.07	2.05	16.28	3.36
MNG4	47.39	13.86	0.93	5.98	17.20	N/A
MNG5	75.89	18.90	2.58	1.42	17.89	3.08
MNG6	60.88	20.45	2.28	1.64	15.23	2.93
MNG7	51.54	19.70	1.54	1.97	15.82	2.69
MNG8	53.64	13.99	0.39	1.64	16.50	N/A
MNG9	69.26	19.52	2.33	2.51	20.38	2.51
MNG10	61.87	16.25	2.07	1.69	15.36	2.56

Table 29. Direction of statistically significant trends in sediment characteristics at core Mangemangeroa sites between 2009 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in Drylie (2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g^{-1} dw sediment)
MNG3	▲ New	▲ New	
MNG5	▲ Maintained		
MNG6	▲ Maintained	▲ New	

Sedimentation monitoring occurred at MNG3, MNG6 and MNG9. The sediment accretion rate (Table 30) estimated from the trend line fitted to the sediment level data (Figure 28) indicated there was significant accretion at all three sites, though the trend line was only statistically significant for MNG9 (and 'less certain' for MNG3). The rate of accretion did not exceed the ANZG guideline value of 2.4 mm/y estimated for the Auckland Region at any site. The 95 per cent confidence intervals show that there was some variability around the average linear sediment accretion rate and that this changed the assessment of sediment accretion relative to the ANZG guideline value for MNG6 and MNG9, i.e., at the upper 95 per cent interval these sites would exceed the guideline.

Table 30. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Mangemangeroa monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
MNG3	0.48	0.08	-0.07	1.02	2009–2023
MNG6	0.64	0.57	-1.6	2.87	2009–2023
MNG9	1.59	0.02	0.27	2.9	2009–2023

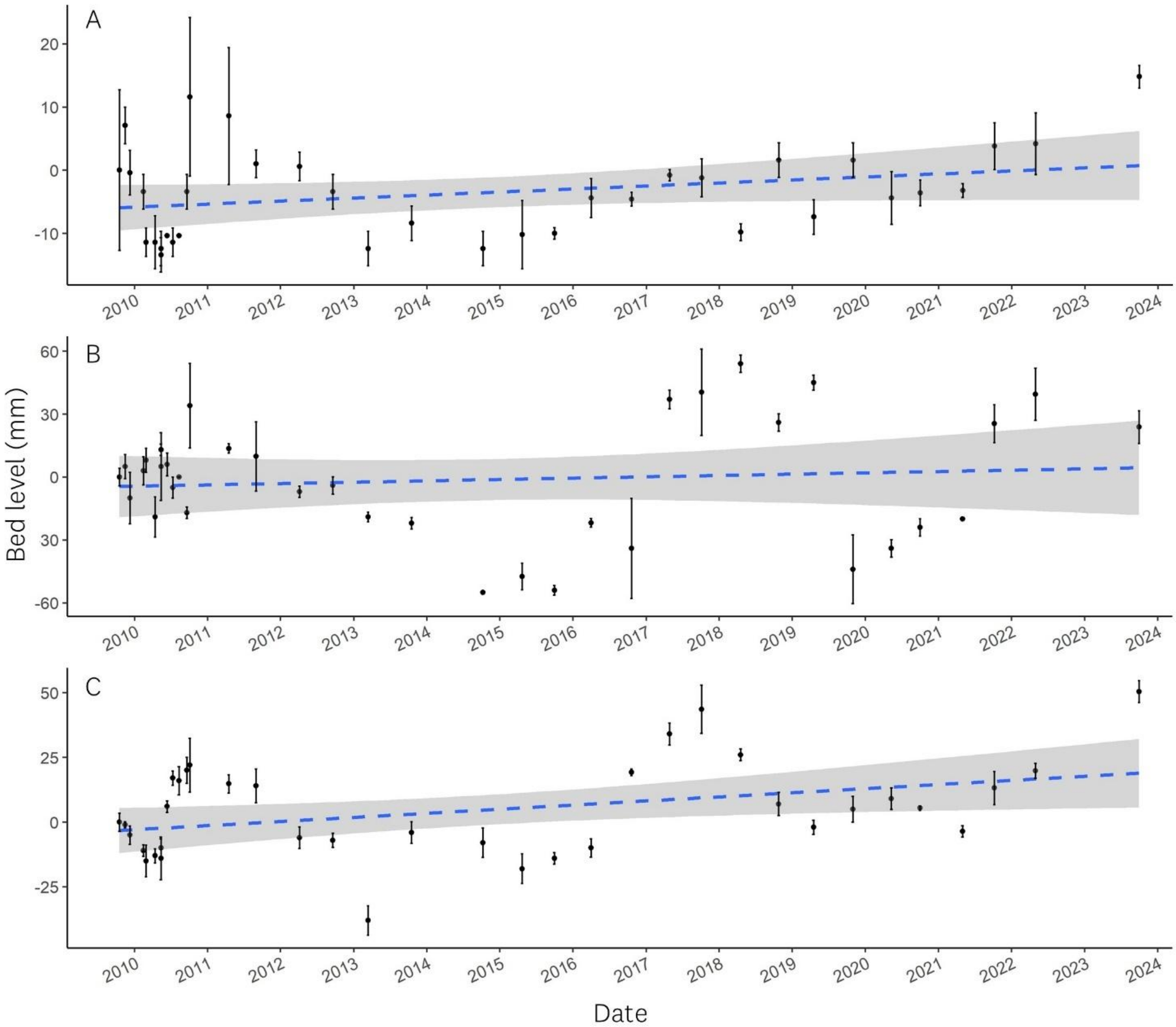

Figure 28. **Sediment levels (relative to buried sediment plate) at A) MNG3, C) MNG6 and B) MNG9.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

In 2021 and 2023, 90 per cent of sites in Mangemangeroa Estuary had 'Fair' or 'Marginal' overall health with only MNG1 scoring 'Good' (Figure 29). Sites in the upper parts of the estuary were generally in worse health. Health in relation to mud (BHMmud) was 'Fair' at MNG3 and 'Marginal' at MNG5 and MNG6 in 2023, and this represented a degradation in health since 2019 for MNG3 and MNG6 (Table 31). The decline in health at MNG3 coincided with the increased very fine sand + mud since 2020, though there was no clear driver of the sustained decline at MNG6. Health in relation to metals (BHMmetals) was 'Fair' at MNG3 and 'Marginal' at MNG5 and MNG6 and has been stable over the last five years. Despite the generally low overall health of the core sites, functional resilience (TBI) remained 'High' at MNG3 and MNG6 and was 'Intermediate' at MNG5 (though was frequently 'High' in the last five years).

Figure 29. Combined Health Scores at Mangemangeroa monitoring sites in 2021 and 2023.

Table 31. Benthic health groups at core Mangemangeroa sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	MNG3	MNG5	MNG6
BHMmud	2019	Good	Marginal	Fair
	2020	Good	Marginal	Marginal
	2021	Fair	Marginal	Marginal
	2022	Good	Marginal	Marginal
	2023	Fair *	Marginal	Marginal *
BHMmetals	2019	Good	Fair	Fair
	2020	Good	Fair	Fair
	2021	Good	Fair	Fair
	2022	Good	Fair	Fair
	2023	Good	Fair	Fair
TBI	2019	High	Low	High
	2020	High	High	High
	2021	High	High	High
	2022	High	High	High
	2023	High	Intermediate	High

Macrofaunal community

In 2021 and 2023 species richness clearly increased from the upper estuary sites to the lower estuary sites, and was at or above the average for the East Coast Estuaries at all sites except MNG8, MNG9 and MNG10 (Figure 30). Species richness was very high at MNG3 (44 species) and above average at MNG6 (29 species) in 2023, explaining the high levels of functional resilience at these sites. Species richness decreased significantly at MNG5 and MNG6 over the monitoring period and while this was characterised by reasonably steady decrease at MNG5, a more cyclical pattern occurred at MNG6 where periods of higher species richness occurred every few years (Appendix 4: Figure A12).

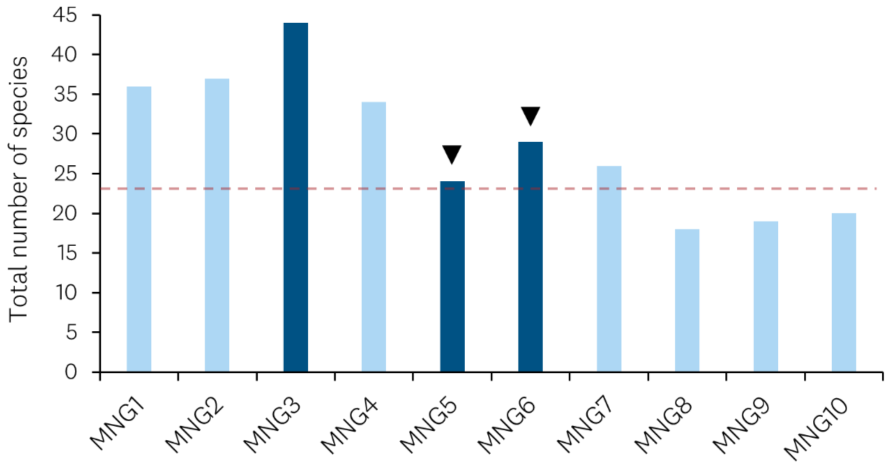

Figure 30. Species richness at Mangemangeroa sites in 2021 and 2023. The dashed line shows the median for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2002–2023) are shown: ▲ = increase and ▼ = decrease.

The nMDS plot for Mangemangeroa Estuary had moderate to high stress and was useful for identifying patterns but not detailed interpretation. Two distinct groups could be identified from the nMDS plot, suggesting there were two broad types of macrofaunal community present in Mangemangeroa Estuary: MNG1, MNG2 and MNG3 were clustered to the left of the plot (sites with the lowest median very fine sand + mud content (Table 28)) and all other sites (where median very fine sand + mud content was notably higher) were clustered to the right of the plot.

Community composition at MNG3 was less variable over the last 10 years than at MNG5 and MNG6, though a slight shift does seem to have occurred since 2019 (highlighted by the outlined symbols) which coincides with the increased very fine sand + mud since 2020 and the degradation in BHMmud between 2019 and 2023 (Figure 31). A large shift occurred in community composition at MNG5 between 2022 and 2023, and the variability at MNG6 was also quite high in the last four years resulting in the communities at these two sites becoming more similar in 2023. According to SIMPER analysis, the shift at MNG5 was caused by an increase in predominantly mud-preferring species between 2022 and 2023, including 'Capitellids + Oligochaetes', '*Heteromastus* + *Barantolla*', *Prionospio aucklandica* and *Arthritica bifurca*, however these changes have not underpinned any change to the BHMmud group of this site (Table 31).

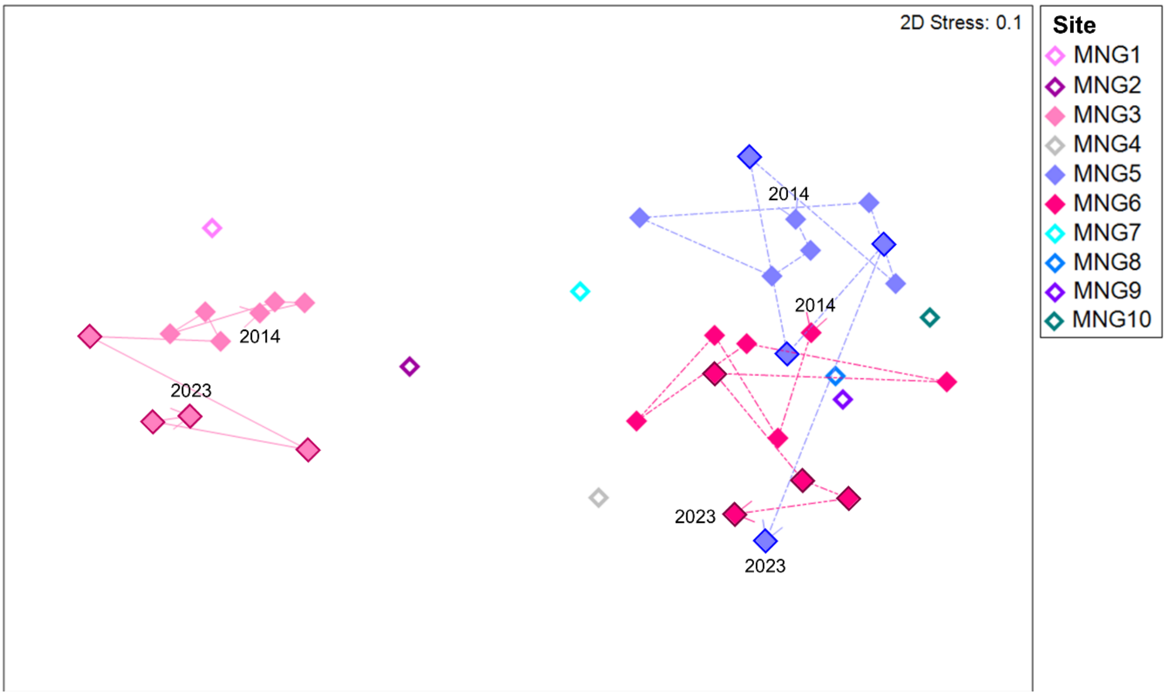

Figure 31. The similarity in macrofaunal community composition between Mangemangeroa sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021).

Indicator species

There were a high number of long-term trends in the abundance of indicator species that suggested sedimentation impacts at all core sites, and especially MNG6 (Table 32). Estuary-wide decreases in several sand-preferring species occurred, including *Waitangi brevirostris*, *Linucula hartvigiana* and *Macomona liliana*, and the mud-preferring polychaete *Prionospio aucklandica* also increased at all core sites. These changes in indicator species coincided with significant increases in very fine sand + mud and sediment accretion at the monitoring sites (Table 29 and Table 30).

Several trends in indicator species were also indicative of metal contamination, particularly from copper and lead (e.g. *Linucula hartvigiana*, *Anthopleura* aureoradiata and *Aonides trifida* are sensitive to copper, *Colurostylis* spp. is sensitive to lead and *Macomona liliana* is sensitive to stormwater contaminants generally) (Table 32). Each of these species is also sensitive to sedimentation so it is possible the significant increases in very fine sediments at the core sites were the main drivers of their decreased abundances. No notable changes in indicator species abundances were detected in the last five years that would suggest impacts from a recent, abrupt change in environmental conditions.

Table 32. Trends in the abundance of monitored and regionally common species at core Mangemangeroa sites between Oct. 2002 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	MNG3	MNG5	MNG6
Crabs	M			
Nereididae	M	▼ MY	▼ MY	▼ MY
Corophiidae	M			▲
Anthopleura aureoradiata	S	▲ MY	▼ MY	▼ MY
Paphies australis	SS	▼		▼
Colurostylis spp.	SS	▼ MY		▼ MY
Waitangi brevirostris	SS	▼ No longer present	▼ No longer present	▼ No longer present
Aonides trifida	SS	▼ Step – 2011		▼
Regionally common species				
Aricidea sp.	M			
Prionospio aucklandica	M	▲ MY	▲	▲
Austrovenus stutchburyi	S	▲ MY	▼ MY	
Linucula hartvigiana	S	▼ Step – 2014	▼MY	▼ Step – 2012
Macomona liliana	S	▼ MY	▼	▼ MY
Notoacmea scapha	SS			
Trends consistent with sedimentation		7	6	9
Trends consistent with metals		4	3	5

Summary

The overall health of monitoring sites in Mangemangeroa Estuary was predominantly 'Fair' or 'Marginal' in 2021 and 2023. Despite this, species richness and functional resilience remained high at most sites. Sediment conditions declined at the core sites over the monitoring period, with significant increases in very fine sand + mud and evidence of sediment accretion (though this did not exceed the ANZG guideline value). This resulted in numerous estuary-wide changes in the abundance of indicator species that were consistent with sedimentation. There was some evidence of potential metal contamination, however this may have been a consequence of metal-sensitive species responding to sediment impacts. There have not been any changes in the population abundances of indicator species that suggest recent stress from excess sediment (or metals).

Some observations require continued attention in the next few years:

- the increases in very fine sand + mud since 2020 at MNG3 caused a shift in community composition and degradation in BHMmud (from 'Good' in 2019 to 'Fair' in 2023) and it will be important to monitor the persistence of these changes.
- increases in the abundance of several mud-tolerant species caused a shift in the community composition at MNG5 between 2022 and 2023, despite no increase in very fine sediments or degradation in BHMmud group.
- the increases in organic content at MNG3 and MNG6 between 2017 and 2020 (which resulted in new significant increasing trends) are not thought to represent a nutrient enrichment issue currently, but it would be beneficial to monitor any further changes to organic content or chlorophyll *a* concentrations at these sites.

The current configuration of core sites may not provide meaningful information about the entire estuary given MNG3, MNG5 and MNG6 are so close together, so investigation of the potential to include site MNG7 or MNG9 (to eventually replace one of the existing core sites) is recommended.

3.7 Tūranga

The Tūranga Creek estuary is situated just south of Mangemangeroa in the Tāmaki Consolidated Receiving Environment and discharges to the Whitford Embayment. The estuary is small (1.5 km^2) relative to its catchment (28 km^2) which is dominated by exotic grassland (Auckland Council, 2025). Small areas of indigenous and exotic scrub/shrubland and forest occur throughout, and an urban area can be found at the head of the estuary associated with the Whitford township. A moderate amount of change in catchment land use occurred since the last report. This change was often characterised by exotic grassland becoming exotic or indigenous scrub/shrubland, though there were also instances of exotic forest becoming harvested forest and exotic grassland becoming urban/bare area. The three core sites are TRN1, TRN4 and TRN7 and these are spread evenly from the upper to the lower estuary.

Sediment characteristics

In 2021 and 2023, sediment mud content ranged from very high to very low in Tūranga Creek and followed a clear pattern of decreasing towards the estuary mouth (Figure 32). The three sites beyond the estuary mouth in the Whitford Embayment (TRN1, TRN2 and TRN3) were the only sites with less than 3 per cent mud content, though very fine sand + mud had been high over the monitoring period at TRN1 (median of 47 per cent) (Table 33).

Long-term increasing trends in very fine sand + mud could still be detected at all core sites (Table 34). Organic content was previously found to be decreasing at TRN1 and TRN7, but these trends were not detected due to slight increases in organic content since 2019 (Appendix 3: Figure A7). Additionally, a new increasing (but uncertain) trend developed at TRN4 reflecting increases in organic content since 2015. Although these changes indicate an estuary-wide increase in organic content, the lack of any accompanying trends in chlorophyll *a* suggest the cause is unlikely to be nutrient enrichment.

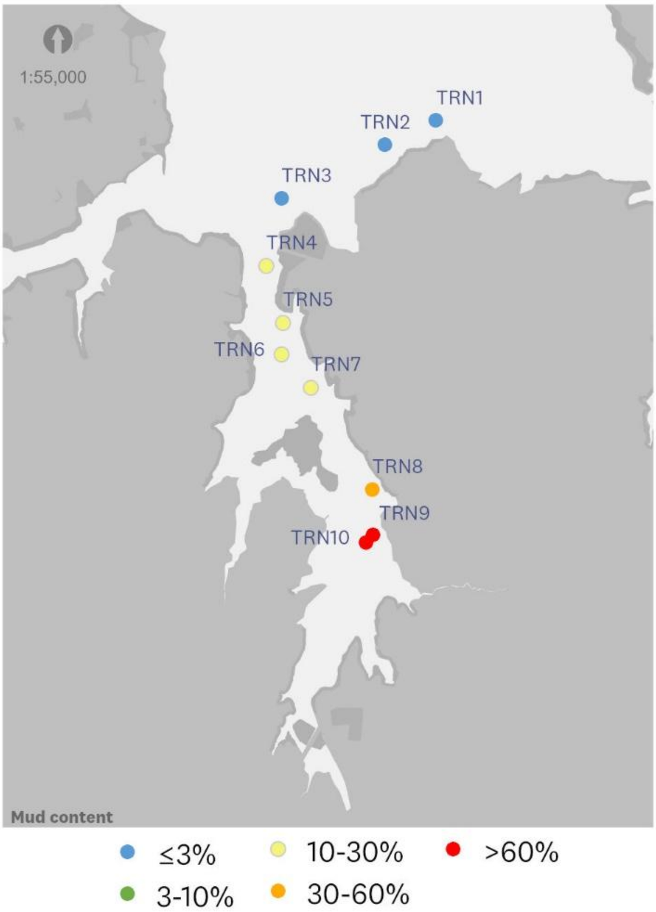

Figure 32. Sediment mud content at Tūranga sites in 2021 and 2023.

Table 33. Median values and temporal variation (standard deviation) of surface sediment characteristics at Tūranga monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (μg g^{-1} dw sediment)	
	Med	**SD**	**Med**	**SD**	**Med**	**SD**
TRN1	47.35	18.88	0.63	2.43	4.40	0.72
TRN2	15.85	13.49	0.25	0.66	3.67	N/A
TRN3	22.85	15.40	0.36	0.48	4.99	1.84
TRN4	82.94	22.96	1.68	1.03	12.74	4.25
TRN5	60.05	11.30	0.55	1.57	16.16	N/A
TRN6	51.06	19.36	1.15	1.24	17.19	6.22
TRN7	70.74	20.43	1.99	6.82	17.65	3.58
TRN8	72.05	18.14	2.98	2.25	14.38	7.61
TRN9	61.72	20.25	1.35	5.55	12.73	N/A
TRN10	69.37	22.99	3.71	4.56	18.12	3.91

Table 34. Direction of statistically significant trends in sediment characteristics at core Tūranga sites between 2009 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in (Drylie, 2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g⁻¹ dw sediment)
TRN1	▲ Maintained	Lost – previously ▼	
TRN4	▲ Maintained	▲ New	
TRN7	▲ Maintained	Lost – previously ▼	

Sedimentation monitoring occurred at TRN3, TRN4 and TRN7. No data are presented for TRN4 as the plate at this site was reburied in 2011 and became scoured and lost by 2017, such that only five years of data were available. A new plate was installed in 2023, however this site might prove to be unsuitable for sedimentation monitoring if issues of plate scouring continue.

The sediment accretion rate (Table 35) estimated from the trend line fitted to the sediment level data (Figure 33) indicated there was significant accretion at TRN7. There was erosion at TRN3, though this was not statistically significant. The rate of accretion at TRN7 was much greater than the ANZG guideline value of 2.4 mm/y estimated for the Auckland Region and exhibited little variability around the average, as indicated by the narrow 95 per cent confidence intervals. There was greater variability at TRN3, and although the upper 95 per cent confidence interval indicated accretion, this remained below the ANZG guideline.

Table 35. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Tūranga monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
TRN3	-0.13	0.73	-0.93	0.66	2009–2023
TRN7	7.94	<0.001	7.12	8.76	2009–2023

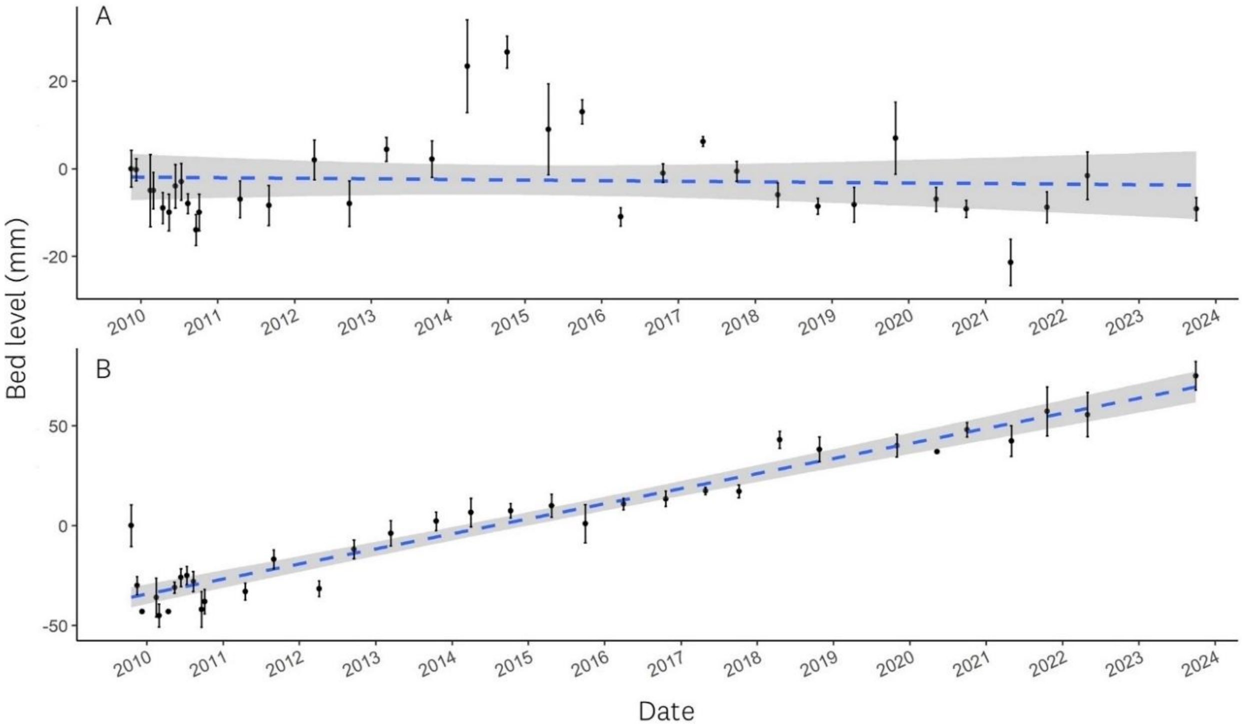

Figure 33. **Sediment levels (relative to buried sediment plate) at A) TRN3 and B) TRN7.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

In 2021 and 2023, 80 per cent of sites in Tūranga Estuary had 'Fair' or 'Marginal' overall health and only TRN1 and TRN2 scored 'Good' and 'Excellent' (Figure 34). There was a clear improvement in health with increasing distance from the freshwater input of Tūranga Creek.

There were no concerning changes in BHMmud health groups at the core sites in the last five years. Health in relation to mud was 'Excellent' at TRN1 and 'Fair' at TRN4 and TRN7 in 2023, with some fluctuating between 'Fair' and 'Marginal' apparent at TRN4. Health in relation to metals (BHMmetals) was stable at TRN4 and TRN7 for the last five years but degraded at TRN1 from 'Excellent' to 'Good' between 2019 and 2023. Functional resilience was 'High' at TRN4 and TRN7 and 'Intermediate' at TRN1 in 2023, and while there was no change in TBI group since the last report, both TRN1 and TRN4 had scored lower in the last five years.

It appears that the alternating between ecological states at TRN1 and TRN4 is indicative of a transitioning into the higher health groups and an improvement in health, rather than a gradual decline, given these sites were previously more stable and tended to score in the lower health groups (see Drylie (2021) where data from 2015 to 2019 are presented).

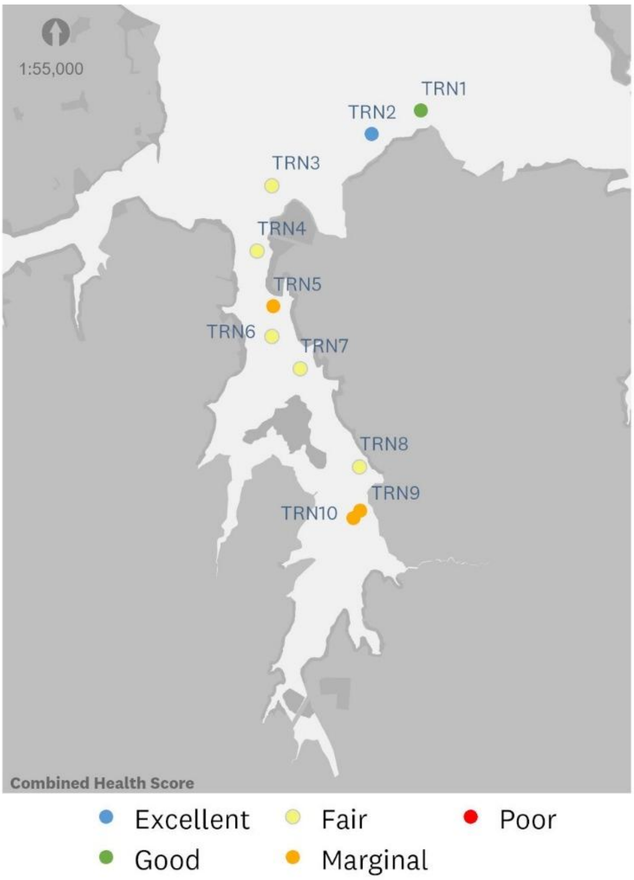

Figure 34. Combined Health Scores at Tūranga monitoring sites in 2021 and 2023.

Table 36. Benthic health groups at core Tūranga sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	TRN1	TRN4	TRN7
BHMmud	2019	Excellent	Fair	Fair
	2020	Excellent	Marginal	Good
	2021	Excellent	Fair	Fair
	2022	Excellent	Marginal	Fair
	2023	Excellent	Fair	Fair
BHMmetals	2019	Excellent	Fair	Good
	2020	Excellent	Fair	Good
	2021	Good	Fair	Good
	2022	Excellent	Fair	Good
	2023	Good *	Good	Good
TBI	2019	Intermediate	High	High
	2020	Low	Intermediate	High
	2021	Intermediate	High	High
	2022	Low	Intermediate	High
	2023	Intermediate	High	High

Macrofaunal community

In 2021 and 2023 species richness was low in the upper estuary (TRN9 and TRN10 had only 13 and 12 species, respectively) and high in the lower estuary (TRN4, TRN6 and TRN7 had between 28 and 35 species) (Figure 35). Significant decreases in species richness occurred at TRN1 and TRN7 over the monitoring period, and the outputs of the linear regression suggest this trend started at TRN1 in 2018 (Appendix 4: Figure A13).

The nMDS plot for Tūranga Estuary had moderate stress and an acceptable fit for interpretation. Sites clustered into three groups according to their position in the estuary and sediment mud content, suggesting there were three broad types of macrofaunal community represented by the monitoring sites in 2021 and 2023 (Figure 36). For instance, TRN1, TRN2 and TRN3 clustered together to the left of the plot (low mud content sites), TRN4, TRN5, TRN6 and TRN7 are grouped in the centre (intermediate mud content sites), and TRN8, TRN9 and TRN10 are clustered together to the right (high mud content sites).

There was little change in community composition over the last 10 years at TRN7 but considerable variability at TRN1 and TRN4 (Figure 36). Particularly large shifts occurred at TRN4 in the last four years such that in 2023 the community composition at this site was similar to TRN7. These shifts have been driven by fluctuations in the abundance of *Austrominius modestus* (a barnacle species) and the bivalve *Austrovenus stutchburyi* between years. These changes in community composition likely underpin the variability observed in benthic health indices at both TRN1 and TRN4 (Figure 34).

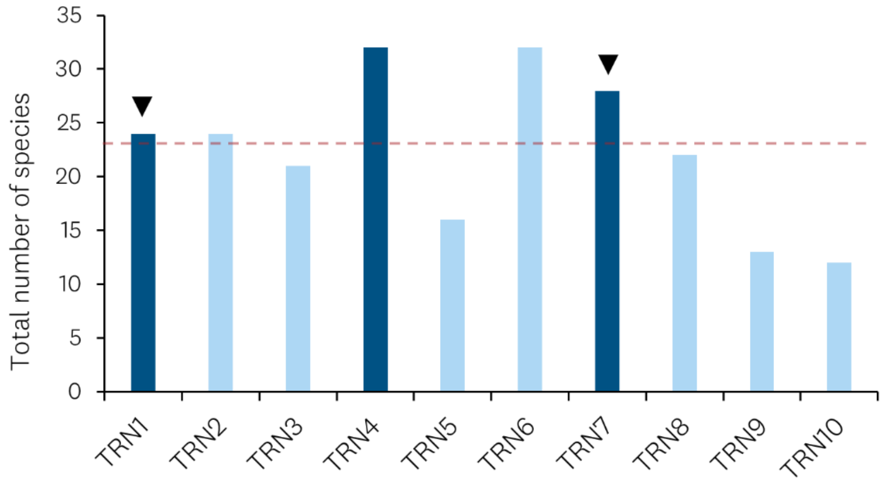

Figure 35. **Species richness at Tūranga monitoring sites in 2021 and 2023.** The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2004–2023) are shown: ▲ represents an increase and ▼ a decrease.

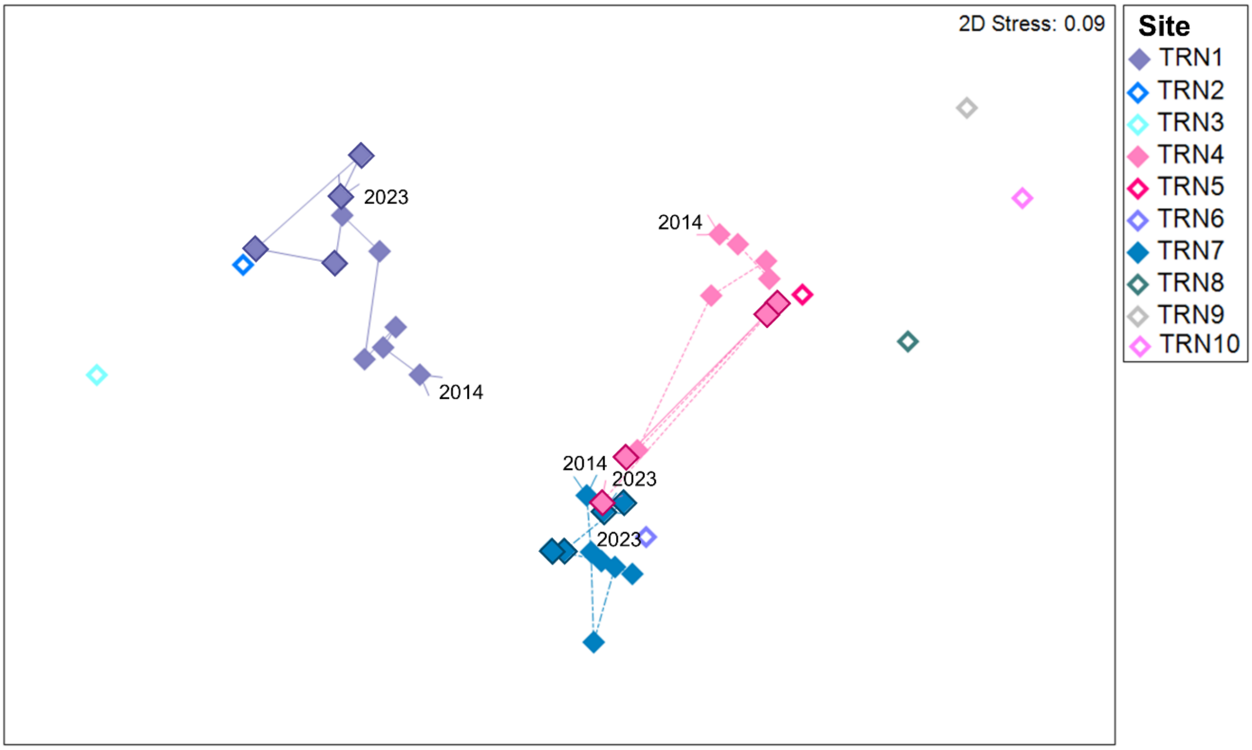

Figure 36. The similarity in macrofaunal community composition between Tūranga sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021).

Indicator species

There were a high number of long-term trends in the abundance of indicator species that were consistent with sedimentation at TRN7, which explains why this site had the lowest BHMmud group of the core sites ('Fair' in 2023) (Table 37). However, there were no changes in species abundances in the last few years that might indicate recent sedimentation stress. TRN1 and TRN4 had very few long-term trends in indicator species that were consistent with either sedimentation or metal contamination, and *Austrovenus stutchburyi* increased at TRN4 since 2020 which implies an improvement in environmental conditions.

Table 37. Trends in the abundance of monitored and regionally common species at core Tūranga sites between Oct. 2004 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	TRN1	TRN4	TRN7
Crabs	M			▼ MY
Nereididae	M	▼ MY		▼
Corophiidae	M			
Anthopleura aureoradiata	S	▲ MY	▲ MY	▲ MY
Paphies australis	SS	▼		▼
Colurostylis spp.	SS			▼ MY
Waitangi brevirostris	SS		Not present	▼
Aonides trifida	SS			
Regionally common species				
Aricidea sp.	M			
Prionospio aucklandica	M	▼	▲ MY	▲ MY
Austrovenus stutchburyi	S	▲ MY	▲* MY	▲ MY
Linucula hartvigiana	S	▼ MY		▼
Macomona liliana	S			▼ MY
Notoacmea scapha	SS		▲	
Trends consistent with sedimentation		2	1	6
Trends consistent with metals		2	0	3

Summary

In 2021 and 2023, the overall health of sites in Tūranga Estuary was generally low (usually 'Fair' or 'Marginal') unless considering sites beyond the estuary mouth. Patterns of health closely resembled patterns in sediment mud content, with higher mud content and poorer health tending to occur in the upper estuary. Recent estuary-wide increases in organic content should be monitored closely for the next few years, though this is not currently thought to reflect a nutrient enrichment issue.

Sediment conditions declined at the core sites over the monitoring period, with significant increases in very fine sand + mud and significantly high sediment accretion at TRN7. This resulted in numerous changes in the abundance of indicator species that were consistent with sedimentation at TRN7 and a 'Fair' BHMmud health group, though there was little evidence that recent changes in sedimentation were causing ecological stress at any site.

The ecological state of TRN1 and TRN4 fluctuated over the last five years though it appears this represented a gradual improvement in health as opposed to a decline, which was supported by the increased abundances of the sand-preferring bivalve *Austrovenus stutchburyi* that were observed at TRN4 since 2020.

3.8 Waikōpua

The Waikōpua Creek estuary is within the Tāmaki Consolidated Receiving Environment and discharges to the Whitford Embayment alongside the Mangemangeroa and Tūranga Creek estuaries. Of the three estuaries, Waikōpua has the largest ratio of estuary to catchment area (i.e. the estuary is relatively large (1.7 km^2) compared to the size of its catchment (15 km^2)). The core sites are WKP1, WKP3 and WKP6 and stretch from the mid to the outer estuary. Monitoring sites extend out into the Whitford Embayment such that sites WKP1 to WKP5 are quite exposed and likely to experience high tidal energy and flushing (see Figure 37).

The catchment is dominated by exotic grassland, especially in the lower parts next to the estuary, and large areas of exotic forest occur in the upper catchment interspersed with small patches of indigenous forest. There is an area of artificial bare surface (associated with the Whitford Landfill) in the upper catchment and some small areas of cropping/horticulture (Auckland Council, 2025). A large area in the upper catchment changed from harvested exotic forest to exotic forest since the last report, and some much smaller areas of exotic forest were harvested. Closer to the estuary, there were several small areas of exotic forest becoming exotic grassland and exotic grassland becoming indigenous or exotic scrub/shrubland.

Sediment characteristics

Sediment mud content was between 10 and 30 per cent at most sites in 2021 and 2023, a range where the diversity of the macrofaunal community is expected to be reduced and less resilient to disturbance, and there was a tendency for mud content to decrease towards the estuary mouth (Figure 37). The long-term median values for very fine sand + mud followed a similar pattern, except for the especially high values at WKP6 (63 per cent) and WKP3 (51 per cent) in the mid and lower estuary (Table 38).

Long-term increasing trends in very fine sand + mud were still detected at all core sites (Table 39). New significant increasing trends in organic content were detected at WKP3 and WKP6 and a previously reported declining trend at WKP1 could no longer be detected due to increases in organic content at all sites since 2020 (Appendix 3: Figure A8). Concerningly, increasing trends in chlorophyll *a* were also detected at WKP3 and WKP6 which suggests there may be an excess nutrients issue driving these changes in sediment characteristics.

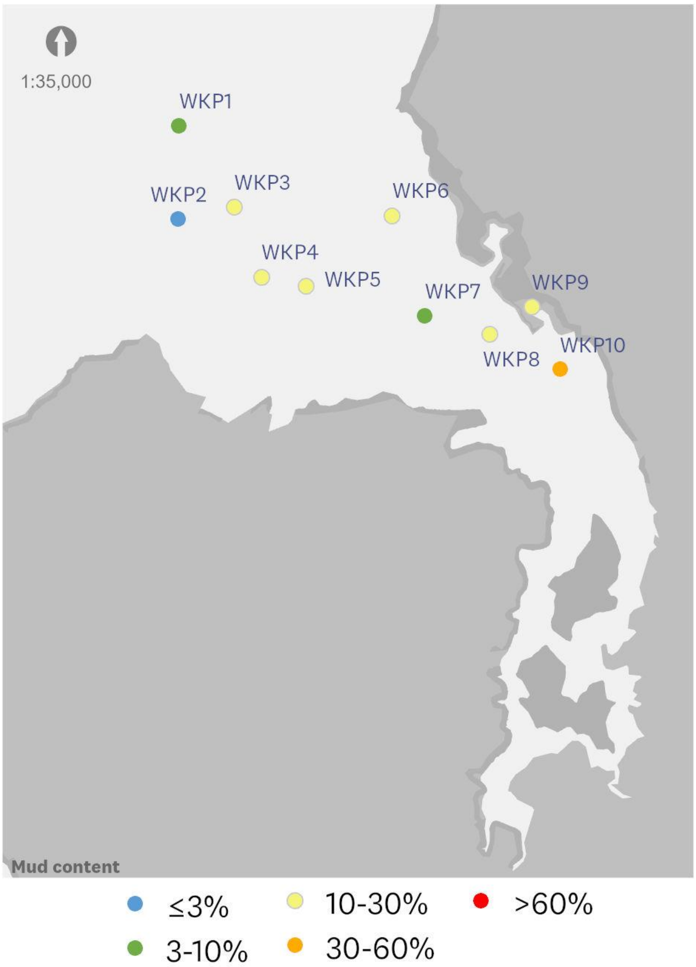

Figure 37. Sediment mud content at Waikōpua monitoring sites in 2021 and 2023.

Table 38. Median values and temporal variation (standard deviation) of surface sediment characteristics at Waikōpua monitoring sites between 2004 and 2023.

	Very fine sand + mud (%)		Organic content (%)		Chl *a* (µg g^{-1} dw sediment)	
	Med	SD	Med	SD	Med	SD
WKP1	18.79	11.09	0.84	0.58	5.96	1.88
WKP2	21.77	10.35	0.18	0.28	4.78	0.23
WKP3	50.75	16.65	1.05	1.21	9.76	2.09
WKP4	44.36	21.74	0.69	0.64	8.23	2.52
WKP5	35.19	21.02	0.76	0.93	6.43	3.05
WKP6	62.99	18.13	1.38	0.83	12.50	2.41
WKP7	31.85	20.62	1.09	0.93	9.17	2.22
WKP8	54.79	19.69	1.37	0.84	9.40	1.89
WKP9	61.07	15.48	1.91	1.16	9.01	2.25
WKP10	50.60	15.29	0.40	2.84	11.35	NA

Table 39. Direction of statistically significant trends in sediment characteristics at core Waikōpua sites between 2009 and 2023. ▲ represents an increase and ▼ a decrease. Grey cells indicate trends that are less certain or uncertain. New = this trend was not previously detected in Drylie (2021), Maintained = this trend was previously detected, Lost = a previously detected trend no longer occurs.

	Very fine sand + mud (%)	Organic content (%)	Chl *a* (µg g^{-1} dw sediment)
WKP1	▲ Maintained	Lost – previously ▼	
WKP3	▲ Maintained	▲ New	▲ New
WKP6	▲ Maintained	▲ New	▲ New

Sedimentation monitoring occurred at WKP3, WKP6 and WKP8. The last measurement at WKP3 was in 2020 and it has not been possible to locate the plate since. The sediment accretion rate (Table 40) estimated from the trend line fitted to the sediment level data (Figure 38) indicated there was erosion at all three sites, with the highest and most significant rates occurring at WKP6. The 95 per cent confidence intervals show that there was some variability around the average linear sediment accretion rate and that according to the upper 95 per cent interval, WKP3 and WKP8 would be accreting. This would not change the assessment of sediment accretion relative to the ANZG guideline, however, as both values remained below the 2.4 mm/y guideline estimated for the Auckland Region.

Table 40. Summary of sediment accretion (mm/y) estimated from the trend line fitted to sediment depth data at Waikōpua monitoring sites.

	Sediment accretion rate (mm/y)	Significance (p-value)	Lower 95% confidence interval	Upper 95% confidence interval	Period
WKP3	-0.74	0.47	-2.82	1.34	2009–2020
WKP6	-5.74	<0.001	-7.56	-3.92	2009–2023
WKP8	-0.47	0.67	-2.69	1.75	2009–2023

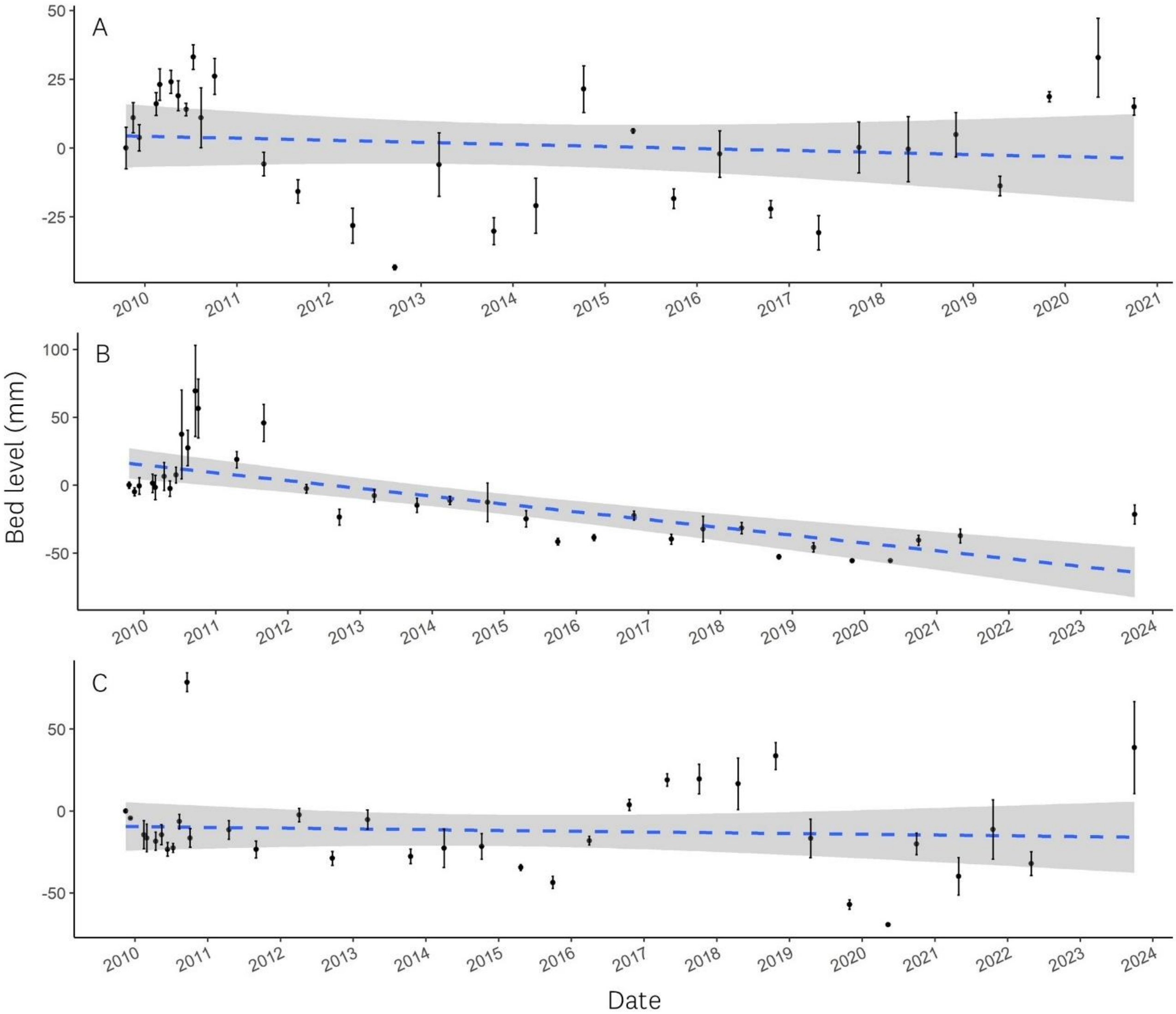

Figure 38. **Sediment levels (relative to buried sediment plate) at A) WKP3, B) WKP6 and C) WKP8.** Average values are plotted and error bars show the standard deviation of replicate (n = 5) measurements. The blue dashed lines represent the linear trend on which the sediment accretion rate is based, and the grey shading shows the 95% confidence interval of the trendline.

Benthic health

In 2021 and 2023, the overall health of monitoring sites ranged from 'Good' to 'Marginal' but was most commonly 'Fair', and health tended to increase towards the estuary mouth (Figure 39). Between 2019 and 2023, health in relation to mud and metals (BHMmud and BHMmetals) alternated between 'Good' and 'Fair' at the core sites, while functional resilience (TBI) was consistently 'High' (Table 41). There was a decline in health group at WKP3 since the last report, as BHMmud degraded from 'Good' to 'Fair'. Health also seemed to decline at WKP1 in recent years, as this site had predominantly 'Good' health in relation to mud and metals in Drylie (2021) and now more frequently scored 'Fair'. In contrast, WKP6 had predominantly 'Fair' health in relation to mud and metals in Drylie (2021) and now more frequently scores 'Good'.

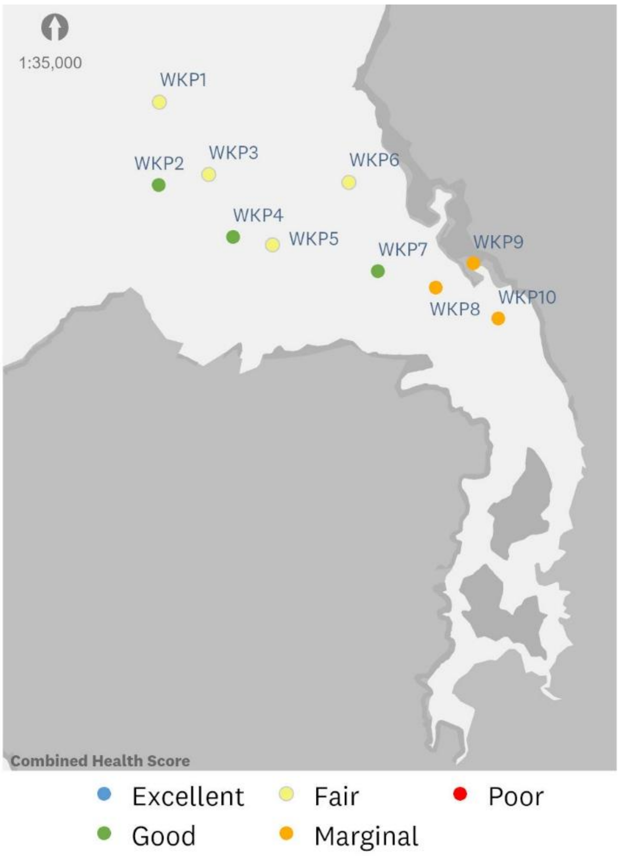

Figure 39. Combined Health Scores at Waikōpua monitoring sites in 2021 and 2023.

Table 41. Benthic health groups at core Waikōpua sites over the last five years. Benthic Health Models (BHM): Excellent, Good, Fair, Marginal, Poor; Traits-Based Index (TBI): High, Intermediate, Low. An asterisk (*) indicates there has been a degradation in benthic health group since last reported.

Index	Year	WKP1	WKP3	WKP6
BHMmud	2019	[yellow]	[green]	[yellow]
	2020	[yellow]	[green]	[green]
	2021	[yellow]	[green]	[green]
	2022	[yellow]	[yellow]	[green]
	2023	[yellow]	[yellow] *	[yellow]
BHMmetals	2019	[green]	[yellow]	[yellow]
	2020	[green]	[green]	[green]
	2021	[yellow]	[green]	[green]
	2022	[yellow]	[green]	[green]
	2023	[green]	[yellow]	[yellow]
TBI	2019	[blue]	[blue]	[blue]
	2020	[blue]	[blue]	[blue]
	2021	[blue]	[blue]	[blue]
	2022	[blue]	[blue]	[blue]
	2023	[blue]	[blue]	[blue]

Macrofaunal community

In 2021 and 2023 species richness ranged greatly among the sites in Waikōpua Estuary with a very high number of species found at the lower estuary sites WKP1 and WKP3 (40 species at both sites) and very few at the upper estuary sites WKP8, WKP9 and WKP10 (only 9 to 13 species) (Figure 40). Trends over the monitoring period also varied, with significant increases at WKP3 and decreases at WKP6 (Figure 40 and Appendix 4: Figure A14).

The nMDS plot for Waikōpua Estuary had moderate stress and an acceptable fit for interpretation. Two distinct groups could be identified from the nMDS plot, suggesting there were two broad types of macrofaunal community present: WKP8, WKP9 and WKP10 (upper estuary sites that had 'Marginal' overall health) were clustered to the right of the plot and all other sites (which had 'Good' or 'Fair' overall health) were to the left, slightly separated according to their position along the estuary (Figure 41). Overlaying vectors of environmental variables that had a high correlation with the nMDS axes revealed that sites in the upper right of the plot had macrofaunal community compositions that reflected higher sediment mud and organic matter content. There was very little change in community composition at WKP6 but large, directional shifts occurred at WKP1 and WKP3 over the last 10 years which were correlated with decreasing proportions of fine sand and increasing proportions of very fine sand and chlorophyll *a* concentrations. This suggests the trend of increasing very fine sand + mud caused a change in the composition of the macrofaunal community that underpinned the decline in health indicated by the BHMs (especially the BHMmud).

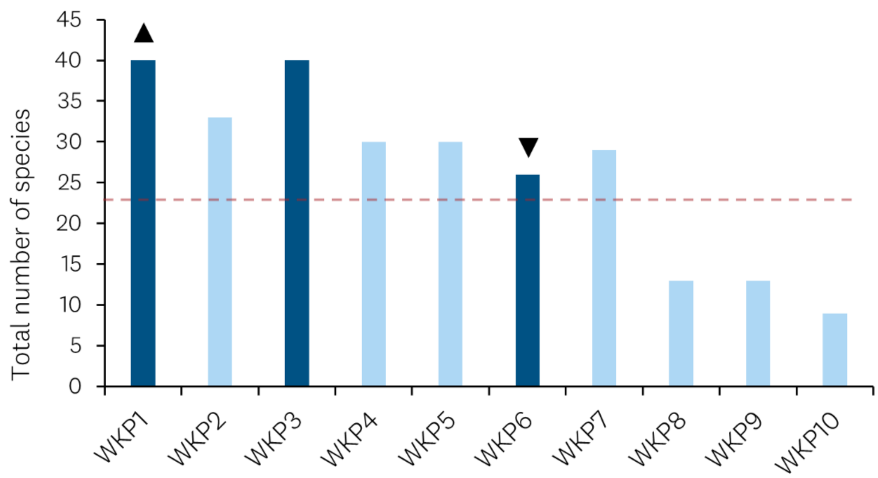

Figure 40. Species richness at Waikōpua monitoring sites in 2021 and 2023. The dashed line shows the median total species for all East Coast Estuaries sites based on the latest available data. Dark blue bars = core sites (trend analysis performed); light blue bars = rotational site (trend analysis not performed). The direction of statistically significant trends (2004–2023) are shown: ▲ = increase and ▼ = decrease.

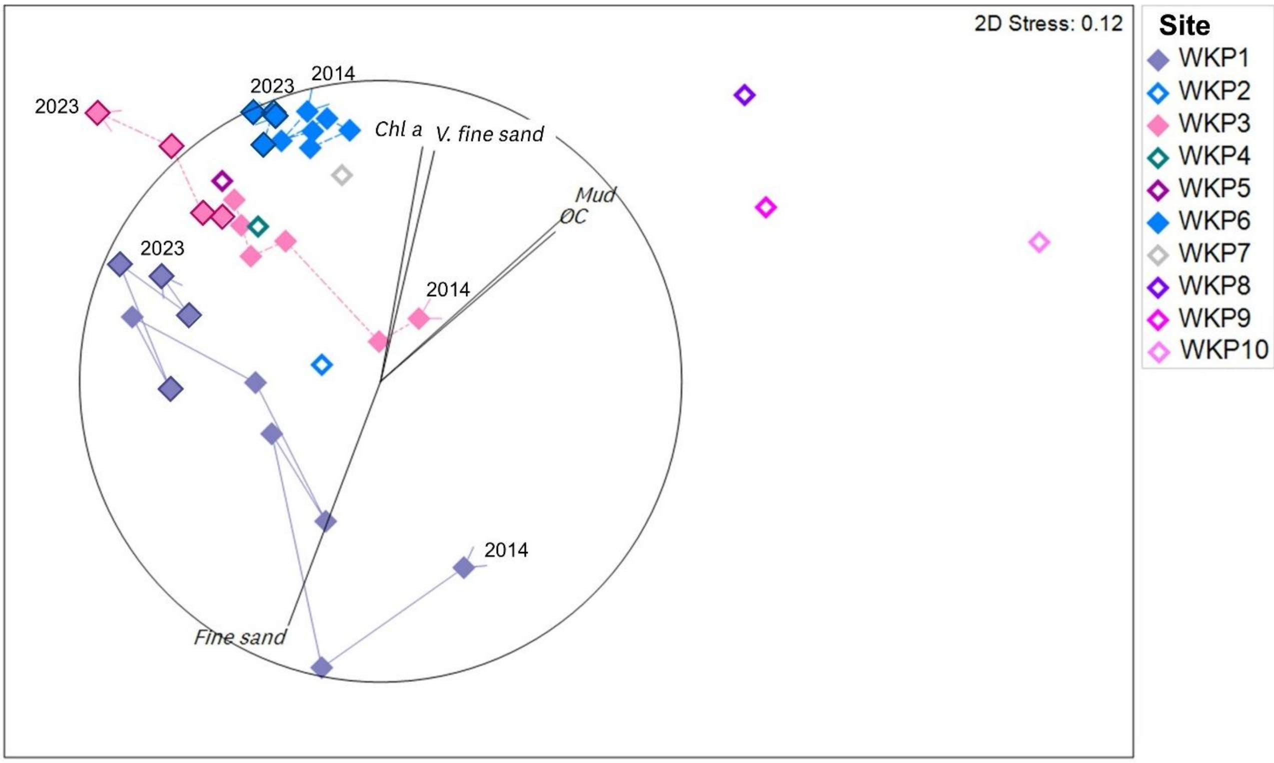

Figure 41. The similarity in macrofaunal community composition between Waikōpua sites and changes over the last 10 years (2014 to 2023) for core sites. Symbols for core sites are outlined to highlight new data since Drylie (2021). Vectors representing environmental variables with a Pearson correlation coefficient >0.7 are shown.

Indicator species

There were numerous long-term trends in the abundance of indicator species that were consistent with sedimentation at all core sites (Table 42). There were generally few trends in indicator species that were consistent with metal contamination and where these did occur, the species were also sensitive to sedimentation. Estuary-wide decreases in the abundance of *Paphies australis* and *Waitangi brevirostris* (which both have strong preferences for sand) and increases in *Prionospio aucklandica* (which prefers slight mud) provide evidence of widespread impacts from sedimentation.

There were also several long-term trends that suggested improvements in the ecological condition of the core sites: the sand-preferring bivalve *Austrovenus stutchburyi* increased at all core sites, the mud-sensitive limpet *Notoacmea scapha* increased at WKP1 and WKP3, and the mud-preferring polychaete Family Nereididae decreased at WKP3 and WKP6 (Table 42). The only recent changes in species abundances have also indicated an easing of sedimentation stress. For instance, at WKP3 the abundance of the mud-preferring polychaete *Aricidea* sp. decreased markedly since 2018 and there were large increases in the abundance of *Austrovenus stutchburyi* 2020.

Table 42. Trends in the abundance of monitored and regionally common species at core Waikōpua sites between Oct. 2004 and Oct. 2023: ▲ = an increasing trend; ▼ = a decreasing trend. Arrows are coloured to highlight trends consistent with a particular stressor: sedimentation, metal contamination, or both. Grey cells indicate trends that are less certain or uncertain and sites exhibiting multi-year cycles (MY) are shown. An asterisk (*) indicates a recent change (within the last five years) has occurred. Pref = sediment preference; SS = strong preference for sand, S = prefers sand, M = prefers some mud but not in high percentages, MM = strong mud preference, - = unknown.

Monitored species	Pref	WKP1	WKP3	WKP6
Crabs	M	▲ MY		
Nereididae	M	▲ MY	▼ MY	▼
Corophiidae	M	▲ MY		
Anthopleura aureoradiata	S		▲ MY	
Paphies australis	SS	▼	▼	▼
Colurostylis spp.	SS			▼
Waitangi brevirostris	SS	▼ MY	▼	▼
Aonides trifida	SS	▼ MY		▼ Step – 2011
Regionally common species				
Aricidea sp.	M		▲*	
Prionospio aucklandica	M	▲ MY	▲ MY	▲ MY
Austrovenus stutchburyi	S	▲ MY	▲* MY	▲ MY
Linucula hartvigiana	S	▲* MY	▼ MY	▼
Macomona liliana	S	▲ MY	▼ Step – 2016	▼ MY
Notoacmea scapha	SS	▲ MY	▲ MY	
Trends consistent with sedimentation		7	6	7
Trends consistent with metals		0	2	3

Summary

In 2021 and 2023, the overall health of sites in Waikōpua Estuary ranged from 'Marginal' in the upper estuary to 'Fair' or 'Good' in the mid and lower reaches, and the functional resilience of all core sites was 'High'. There was clear evidence of widespread impacts from excess sediment with elevated mud content at most sites and significant increases in very fine sand + mud at the core sites, which caused long-term decreases in the abundance of sand-preferring species and increases in the abundance of mud-preferring species. However, there were also numerous trends and recent changes in indicator species that suggested recovery from sedimentation impacts (particularly at WKP3). This seemingly contradicts observations of declining health (BHMmud) over the last five to ten years at WKP1 and WKP3, which coincide with large shifts in the community composition at these sites. It will be important to continue monitoring these benthic health changes and see whether they persist.

The development of a potential nutrient enrichment issue at WKP3 and WKP6 (indicated by new increasing trends in organic content and chlorophyll *a*) is of concern and should be investigated via sampling of sediment nutrient concentrations. This information might also provide further insight into the possible causes of the unexplained changes in community composition and health at the core sites.

4 Regional summary

The East Coast Estuaries Ecology programme monitors the ecological health of 77 intertidal sandflat sites across eight estuaries in Tāmaki Makaurau / Auckland. Between 2021 and 2023 all 77 sites were sampled at least once to enable a comprehensive assessment of health in the region, and three sites within each estuary ('core' sites) were sampled at a consistent, high frequency to develop a dataset suitable for analysing trends over time. Between 2021 and 2023, roughly one third of sites were in 'Excellent' or 'Good' health and almost three quarters were 'Fair' or 'Marginal' according to the Combined Health Score (Figure 42). Only one site had 'Poor' overall health. On average, 23 macrofaunal species were found per site (ranging from six to 44) which resulted in most sites having high functional resilience (56 per cent).

In each estuary, monitoring sites are distributed from the upper to the lower estuary to track spatial patterns in health. The ecological health of monitoring sites tended to be better in the lower estuary close to the estuary mouth and poorer in the upper estuary close to the freshwater inflows, which is consistent with previous reporting for this programme and national studies of estuary health (Broekhuizen et al., 2024; Drylie, 2021; Lohrer et al., 2023). Exceptions occurred where sites in the lower estuary were located in sheltered, low energy areas where the flushing potential is likely to be low and pollutants (such as sediment and metal contaminants) are more likely to settle or where modification of the estuary altered the natural hydrodynamics (e.g., at Waiwera and Whangateau where it is suspected causeways have disrupted tidal flows and impacted benthic health). Instances also occurred where sites in the lower estuary had poorer health than might be expected from the very low sediment mud content observed (e.g. ORW1, MNG1 and TRN3). In these cases the availability of organic content and chlorophyll *a* (food sources for the macrofaunal community) were often equally low, and this was probably an effect of physical disturbance from high tidal energy as opposed to an anthropogenic stressor.

The distribution of sites among health categories in 2023 was degraded compared to the previous assessment based on data up to 2019 (Figure 42). In 2019, 11 per cent of sites were in 'Excellent' overall health compared to only three per cent in 2023, and no sites were 'Poor'. The proportion of sites in 'Fair' or 'Marginal' health also increased between 2019 (55 per cent) and 2023 (71 per cent), while the proportion of sites with 'Good' health decreased (from 34 per cent in 2019 to 25 per cent in 2023). This regionwide shift to lower Combined Health Scores identifies an overall decline in the ecological condition of Tāmaki Makaurau / Auckland's East Coast Estuaries.

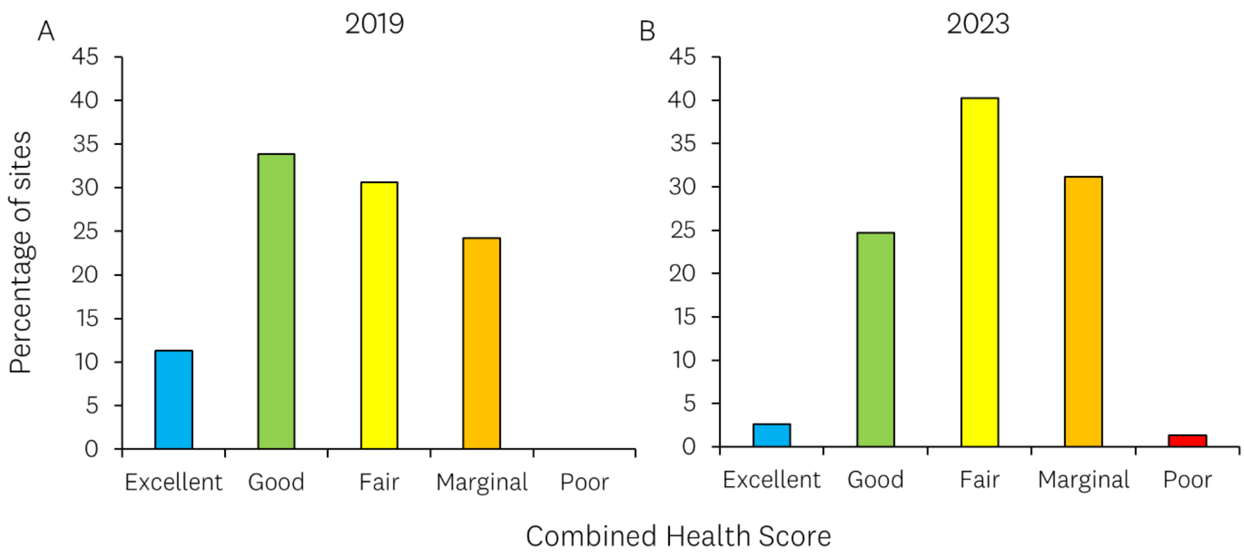

Figure 42. Comparison of the distribution of East Coast Estuary sites among Combined Health Scores in A) 2019 versus B) 2023.

Excess sedimentation was the most prevalent stressor of ecological health over the monitoring period, impacting every estuary to some degree. Whangateau Harbour exhibited the fewest long-term trends consistent with sedimentation while Mangemangeroa, Ōkura and Waikōpua exhibited the most. Changes in indicators that might suggest recent (as opposed to legacy) impacts from sedimentation were also found in most estuaries. For instance, an increase in the concentration of very fine sediments, a degradation in the BHMmud group or a change in the abundance of indicator species that occurred within the last five years. However, there was evidence of recovery at core sites in Tūranga (in the form of improving benthic health indices and increasing abundances of sediment-sensitive species) and possibly Waikōpua.

There was some evidence of metal contamination having caused stress to benthic communities over the long term, though this was often difficult to separate from the impacts of sedimentation given the co-sensitivity of most indicator species. There was little evidence to suggest that metals impacted ecological health in any estuary over the last five years, and metal concentrations in east coast estuary sediments have been persistently low (Allen, 2025).

It was noted in Drylie (2021) that effective indicators of nutrient enrichment are lacking from Auckland Council's marine ecology monitoring programmes. Nonetheless, at more than one site in Ōrewa and Waikōpua potential symptoms of excess nutrients were observed, namely co-occurring increases in the concentration of organic content and chlorophyll *a*. It is recommended that a survey of sediment nutrient concentrations is undertaken at both estuaries to detect excess nutrients directly and determine whether this is the driver of the trends and represents a genuine ecological issue.

5 Conclusions

The current approach to monitoring Tāmaki Makaurau / Auckland's east coast estuaries provides sufficient and robust data to assess the state of ecological health and trends over time. Sampling core sites (a minimum of three) twice per year and conducting 'health checks' for all sites roughly every 10 years provides the consistency needed to analyse long-term trends and the flexibility to focus sampling on estuaries as the need arises. For example, if multiple concerning changes occur at the core sites of a given estuary, then full sampling may be implemented in that estuary the following year. Indicators of estuary health have been selected to provide a meaningful assessment of benthic health and the stressors that are most relevant to Tāmaki Makaurau / Auckland, though it remains difficult to identify early warning signs of nutrient enrichment. Catchment-wide indicators such as land use change statistics provide helpful clues to identify local drivers of change (for example, Auckland Council (2025)) yet suitable indicators of global drivers (e.g. climate change) will become increasingly important as warmer sea and air temperatures influence benthic ecology (Douglas et al., 2024; Lam-Gordillo et al., 2025).

Continuously improving our ability to identify drivers of ecological health is crucial for the effective management of estuaries. For the first time results from long-term monitoring of sediment accretion were presented alongside the ecology data to improve the characterisation of sedimentation dynamics that might be affecting the benthic community. This dataset proved helpful for reinforcing and providing further detail about previously identified sediment impacts, as well as challenging assumptions about the interactions between sediment deposition and sediment grain size that helped to explain otherwise confusing trends in benthic health (at PUH1, for example).

Defining an ecologically relevant threshold for sediment accretion (i.e., at what rate of sediment accretion do we anticipate ecological impacts?) is challenging. Here, the ANZG guideline of 2 mm/y above the natural annual sedimentation rate (Townsend & Lohrer, 2015) was applied to provide a preliminary assessment of where ecological impacts would be expected, although the Ministry for the Environment is currently undertaking a project to revisit the utility of a national guideline and potentially revise the existing guideline given its basis on studies of event-based rather than chronic sediment deposition. The east coast estuaries tend towards naturally high sediment accretion rates given they have a low estuary to catchment area ratio (Swales et al., 2008), and ecological communities in estuaries across the region are already impacted by the vastly elevated sediment loads that have occurred since the arrival of Europeans in Aotearoa / New Zealand (as evidenced in this and previous state and trend reports e.g., Drylie (2021), Hewitt and McCartain (2017) and Hewitt et al. (2015)). Guideline values based on sedimentation rates from the Late European settlement period (post 1940) may therefore be more appropriate for assessing contemporary sedimentation impacts, and regionally representative sedimentation rate data are available from this period. The estimated guideline value based on these later sedimentation rate data from Auckland would be 7.2 mm/y (compared to 2.4 mm/y estimated for the ANZG guideline). The different options for assessing the impact of sediment accretion at a regional and national level should be considered as further advice on a national guideline is developed.

Three specific recommendations are made for future monitoring in the East Coast Estuaries programme:

- Conduct sampling of sediment nutrient concentrations in Ōrewa and Waikōpua to investigate potential nutrient enrichment issues.
- Include site WNG5 as a core site for Whangateau Harbour to improve the spatial coverage of the sites and better capture the influence of Ōmaha River on the estuary.
- Investigate the potential to include site MNG7 or MNG9 as a core site in Mangemangeroa to improve the spatial coverage of the core sites across the estuary.

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Appendix 1: Monitored sites

Table A1. East Coast Estuary Ecology sites with sufficient data for trend analysis and the length of the time series.

	Site	Location	Time series
1	WNG1	Whangateau	2009–2023
2	WNG4	Whangateau	2009–2023
3	WNG7	Whangateau	2009–2023
4	PUH1	Pūhoi	2002–2023
5	PUH4	Pūhoi	2002–2023
6	PUH7	Pūhoi	2002–2023
7	WWR1	Waiwera	2002–2023
8	WWR3	Waiwera	2002–2023
9	WWR8	Waiwera	2002–2023
10	ORW1	Ōrewa	2002–2023
11	ORW4	Ōrewa	2002–2023
12	ORW8	Ōrewa	2002–2023
13	OKR3	Ōkura	2001–2023
14	OKR7	Ōkura	2001–2023
15	OKR9	Ōkura	2001–2023
16	MNG3	Mangemangeroa	2002–2023
17	MNG5	Mangemangeroa	2002–2023
18	MNG6	Mangemangeroa	2002–2023
19	TRN1	Tūranga	2004–2023
20	TRN4	Tūranga	2004–2023
21	TRN7	Tūranga	2004–2023
22	WKP1	Waikōpua	2004–2023
23	WKP3	Waikōpua	2004–2023
24	WKP6	Waikōpua	2004–2023

Appendix 2: Trend analysis method

Data

Due to changes in laboratory techniques and evolution of the East Coast Estuaries Ecology programme, data on sediment characteristics are available from the following dates:

- Very fine sand + mud content – August 2004
- Organic content – September 2009
- Chlorophyll *a* – September 2012

Macrofauna abundance data are available from the start of the monitoring period for all sites (see Appendix 1: Monitored sites).

Trends were only analysed for variables with five or more data points, as results based on fewer observations are likely to be unreliable. Climatic variables may also be important predictors of trends based on less than 10 years of data (Hewitt et al., 2016), so any such trends should be treated with caution unless supported by similar trends within the estuary.

Trend analysis

The statistical approaches largely follow those outlined by Drylie (2021) and Hewitt et al. (2015) and all trend analyses were performed in RStudio (v4.3.1). As a first step, visual assessment of scatterplots was used to determine whether step changes, multi-year cycles, linear or non-linear patterns could be seen. As the within-year sampling frequency for the East Coast Estuaries is equal to two, temporal autocorrelation did not need to be assessed and the following steps were taken:

- If a step change was indicated, analysis was conducted using a t-test with data grouped before and after the suspected step.
- Otherwise, an ordinary least squares (OLS) regression with time was run, using log transformations to include monotonic non-linear responses. Polynomial non-linear responses were not investigated to maintain a focus on continuous, long-term trends.
- If the OLS assumption of homoscedasticity was violated, then a generalised least squares (GLS) regression was run instead.
- Where a statistically significant trend was observed ($p < 0.15$), residuals were examined for indications of multi-year cycles; where these indicated significant bias, the trend was considered a multi-year cycle. Inspection of residual plots also indicated whether trends occurred over the entire monitoring period or shorter time frames and enabled detection of their start and end points.

Appendix 3: Sediment trends scatterplots

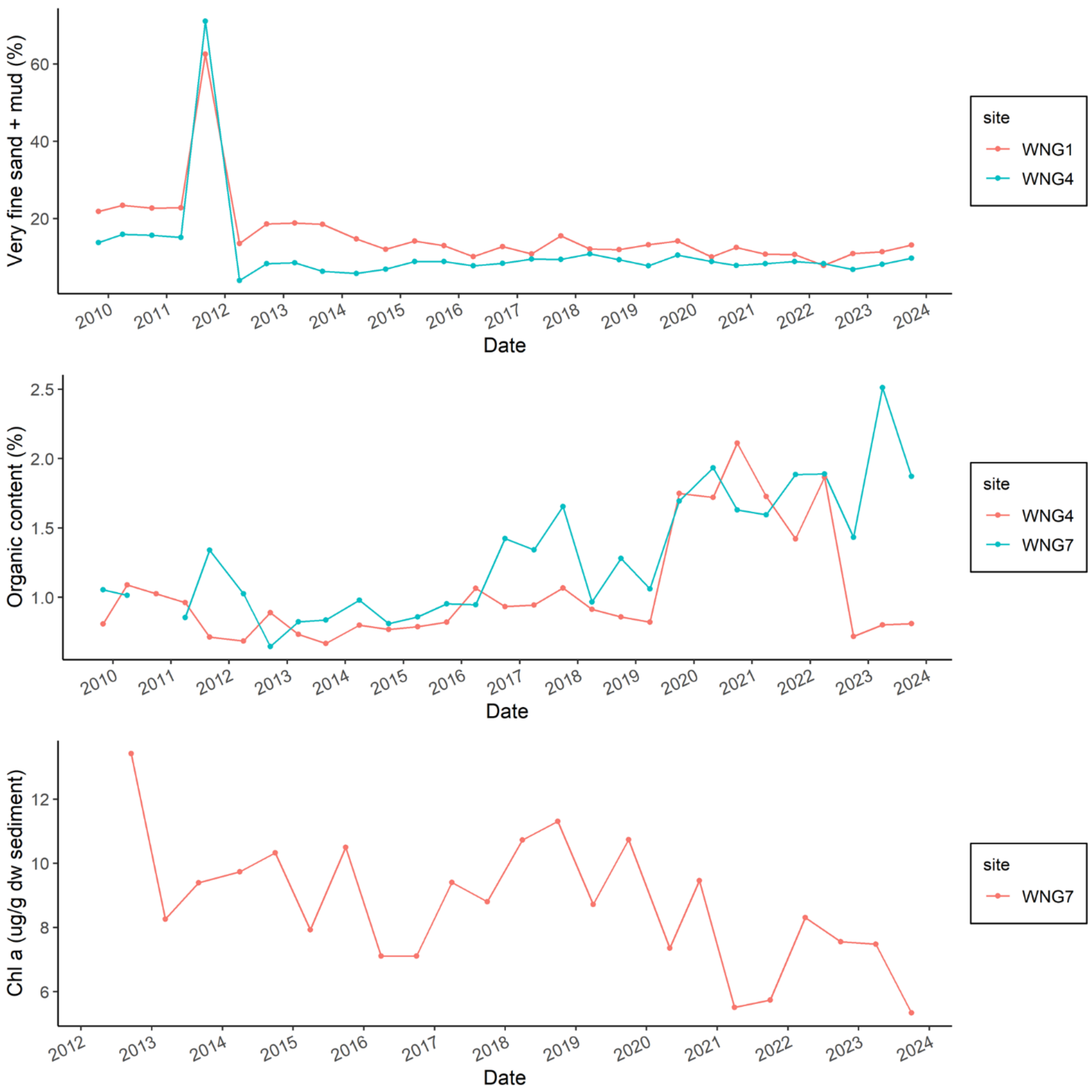

Figure A1. Surface sediment characteristics with significant trends (2009 to 2023) at core Whangateau sites.

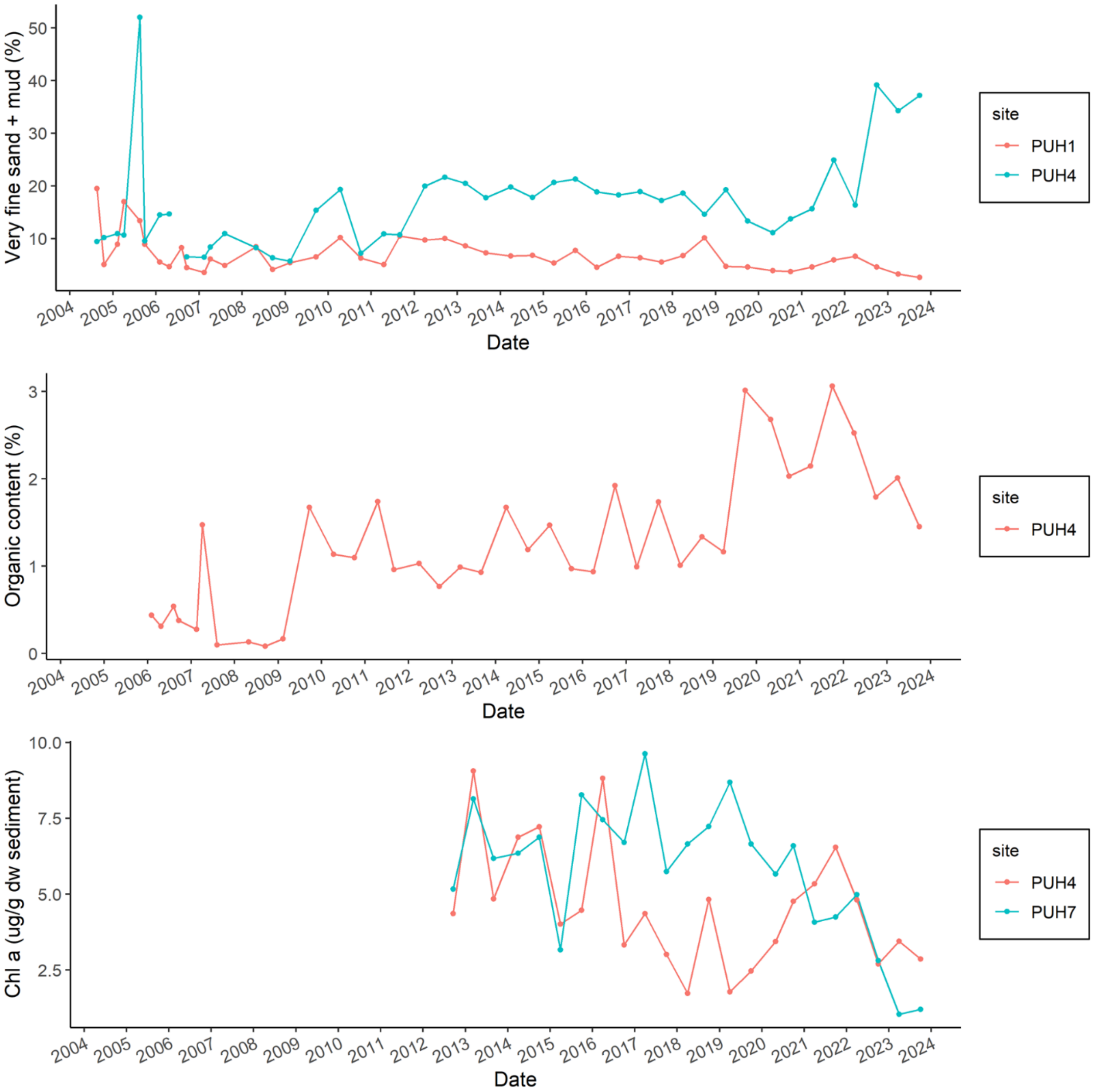

Figure A2. Surface sediment characteristics with significant trends (2004 to 2023) at core Pūhoi sites.

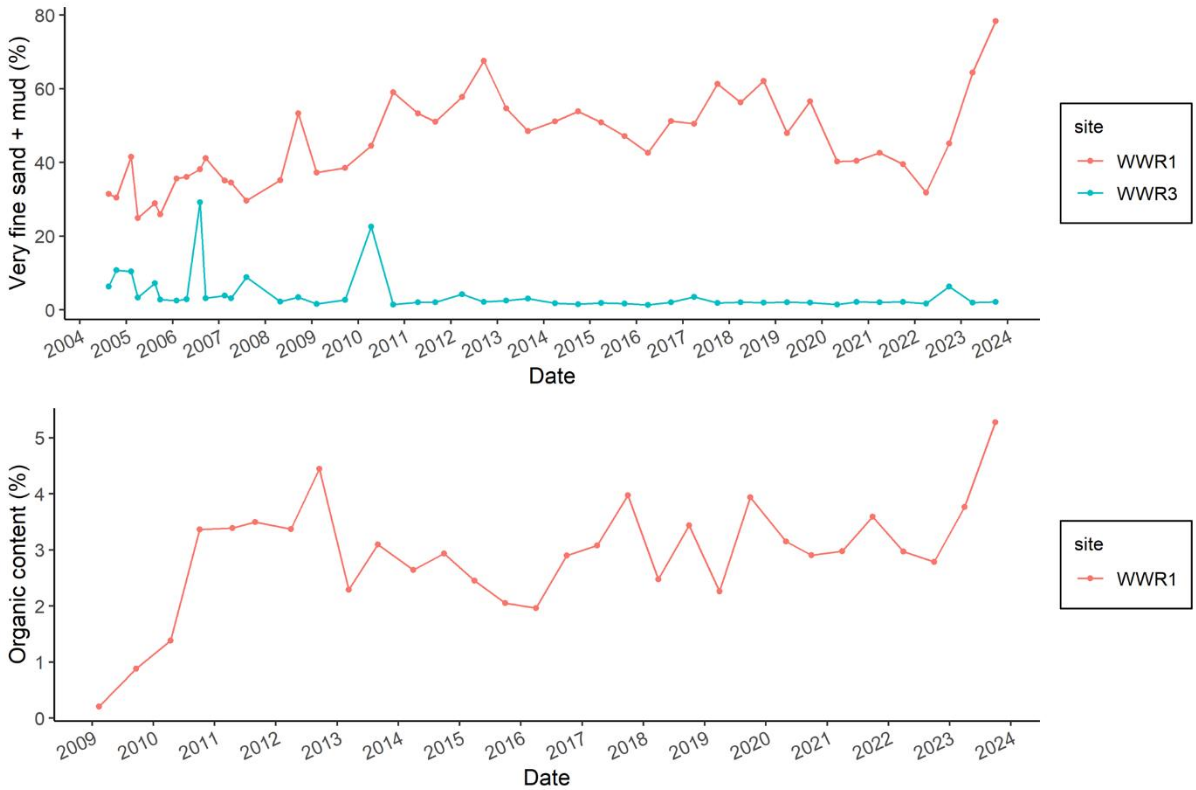

Figure A3. Surface sediment characteristics with significant trends (2004 to 2023) at core Waiwera sites.

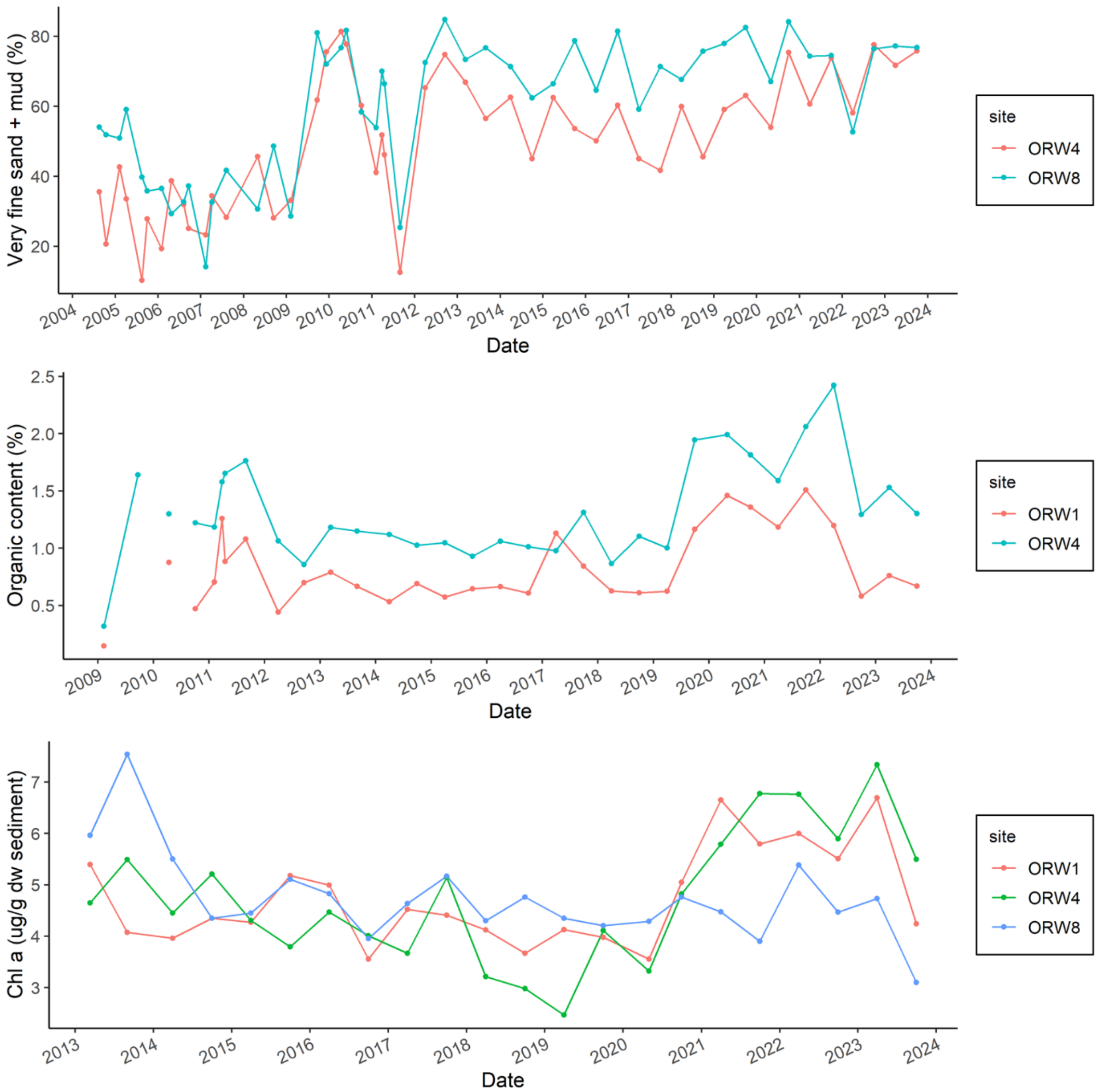

Figure A4. Surface sediment characteristics with significant trends (2004 to 2023) at core Ōrewa sites.

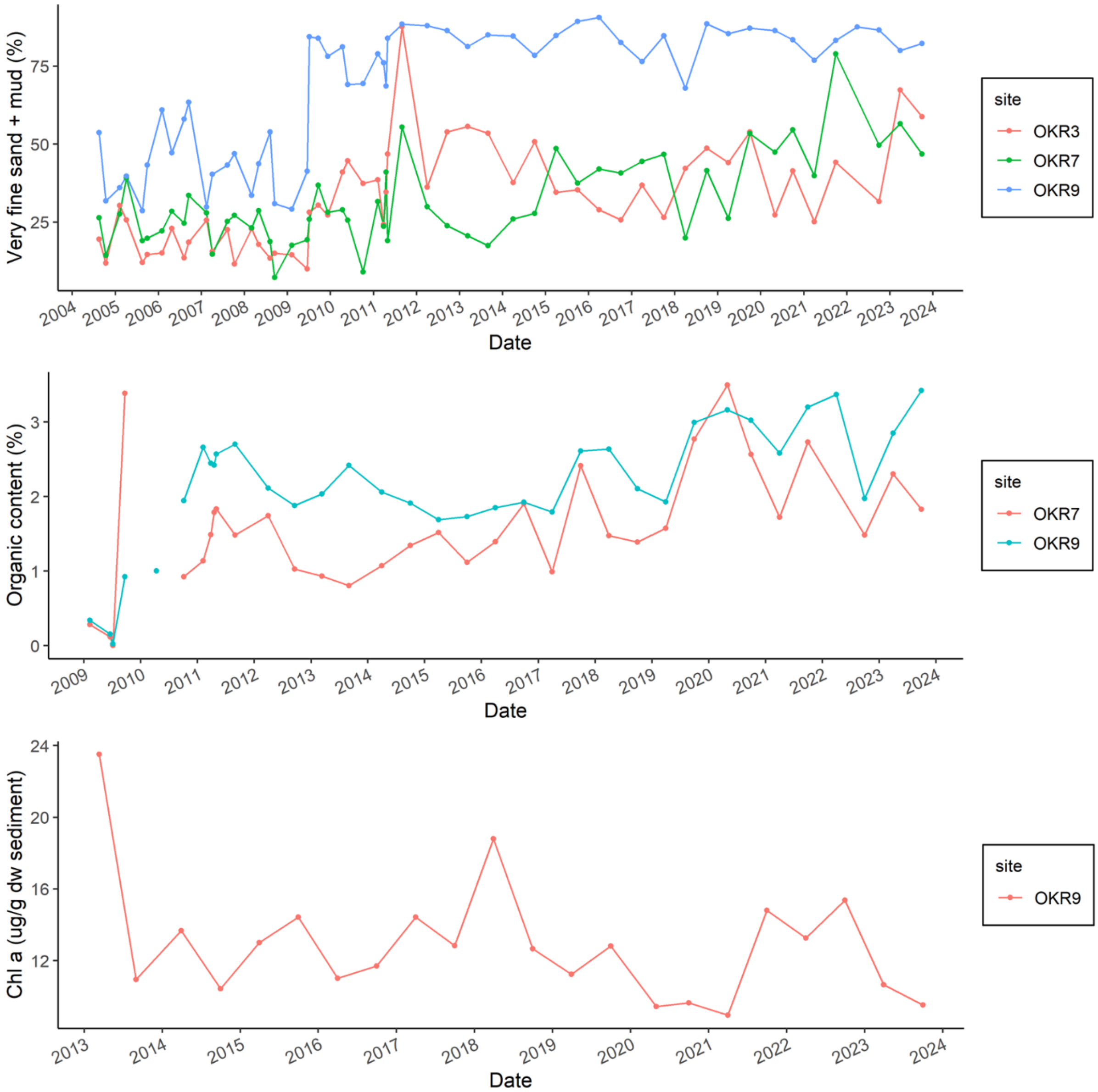

Figure A5. Surface sediment characteristics with significant trends (2004 to 2023) at core Ōkura sites.

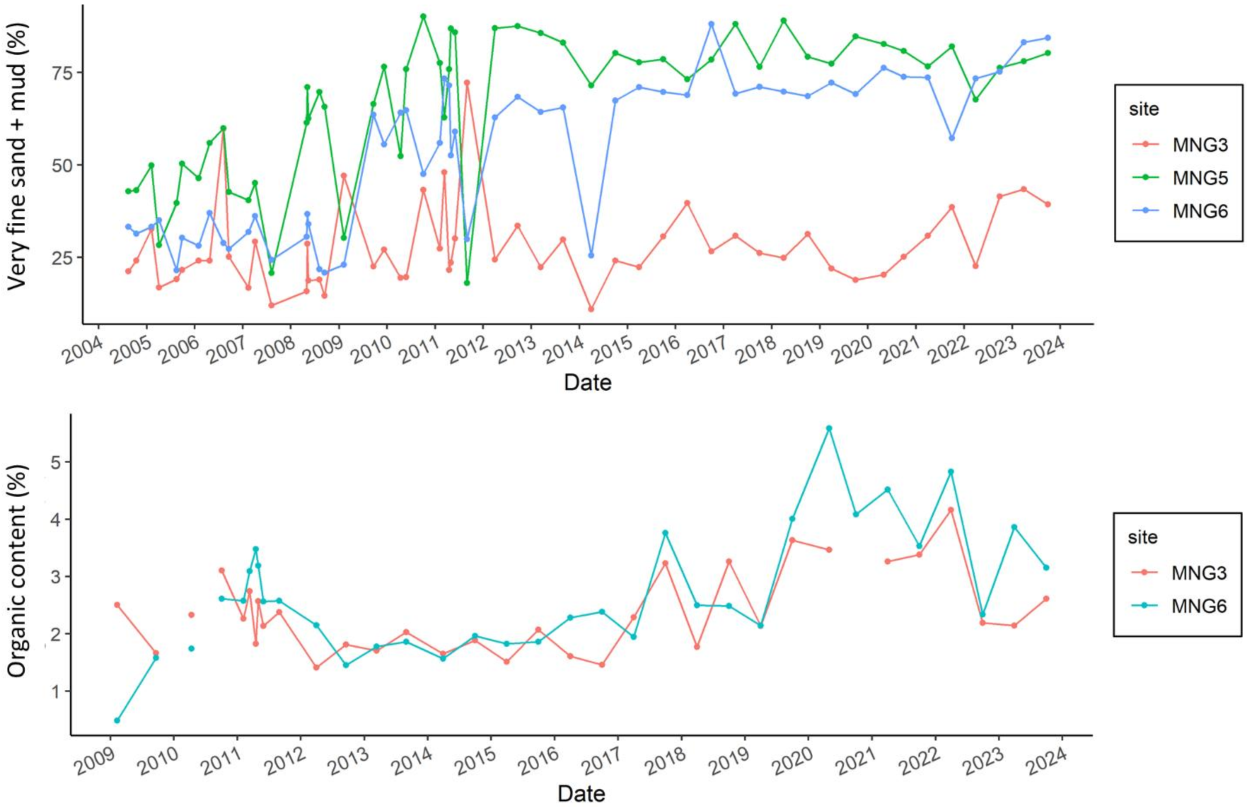

Figure A6. Surface sediment characteristics with significant trends (2004 to 2023) at core Mangemangeroa sites.

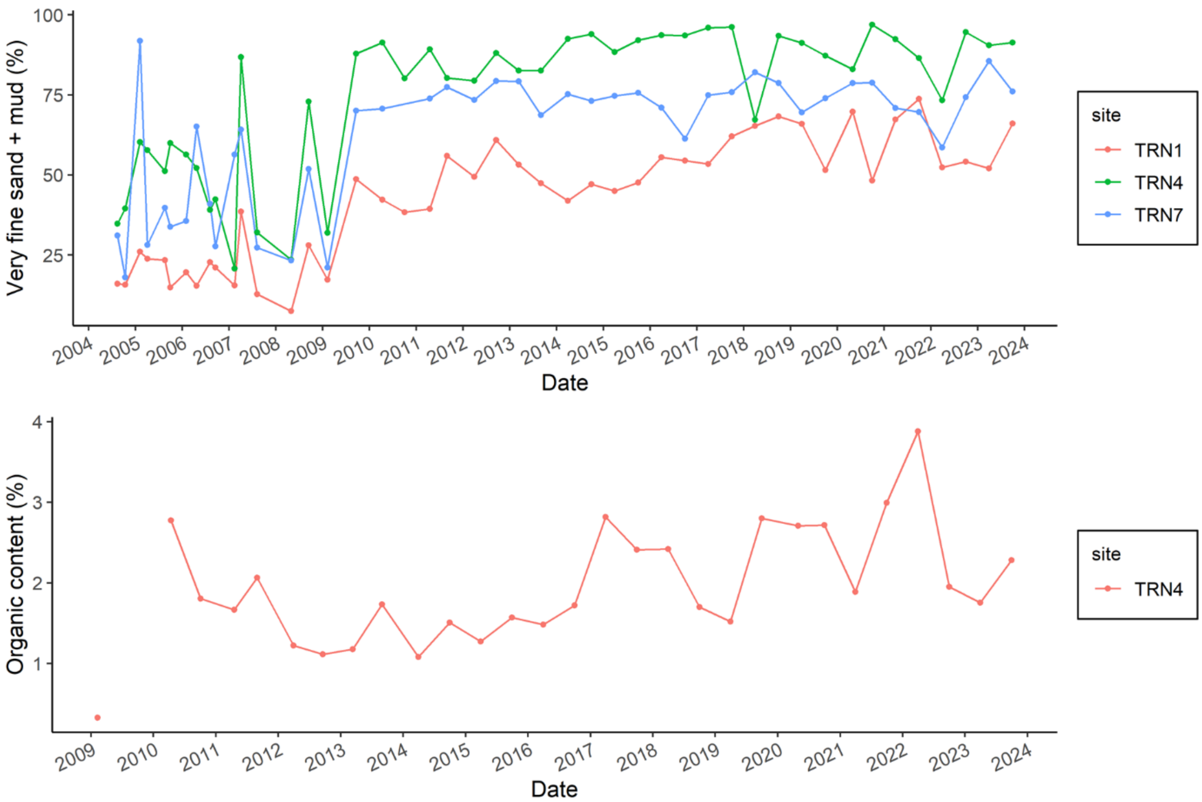

Figure A7. Surface sediment characteristics with significant trends (2004 to 2023) at core Tūranga sites.

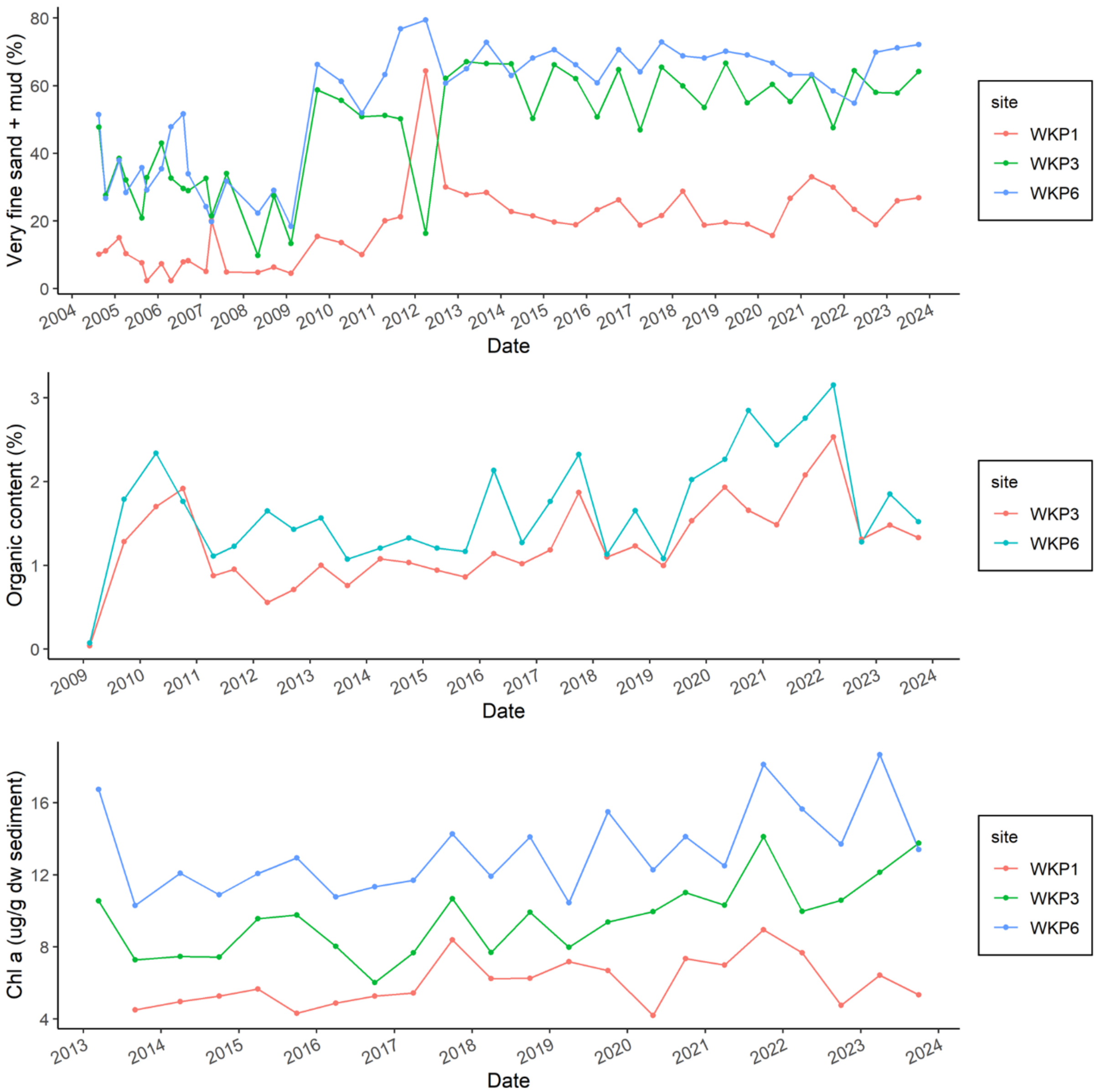

Figure A8. Surface sediment characteristics with significant trends (2004 to 2023) at core Waikōpua sites.

Appendix 4: Species richness trends scatterplots

Figure A9. Species richness time series for core Pūhoi sites with significant trends (2004 to 2023).

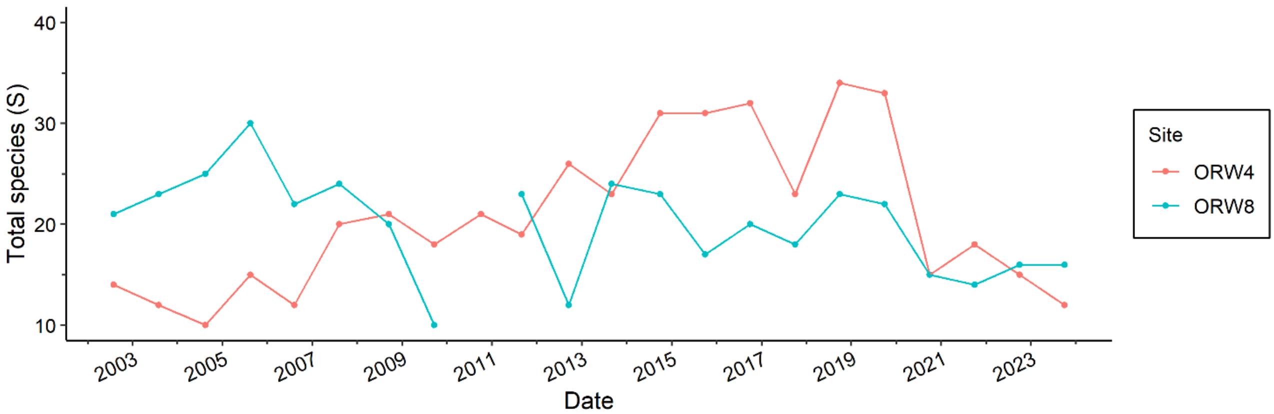

Figure A10. Species richness time series for core Ōrewa sites with significant trends (2002 to 2023).

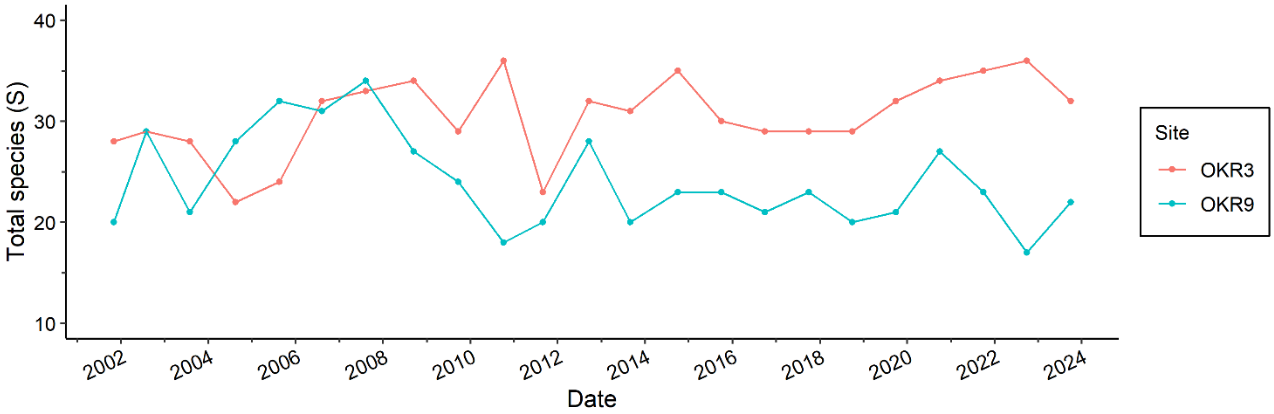

Figure A11. Species richness time series for core Ōkura sites with significant trends (2001 to 2023).

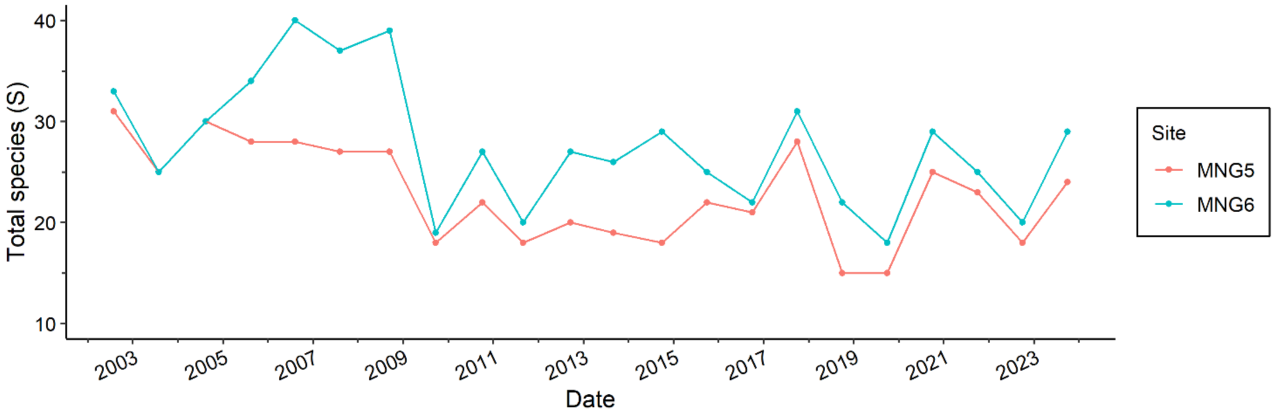

Figure A12. Species richness time series for core Mangemangeroa sites with significant trends (2002 to 2023).

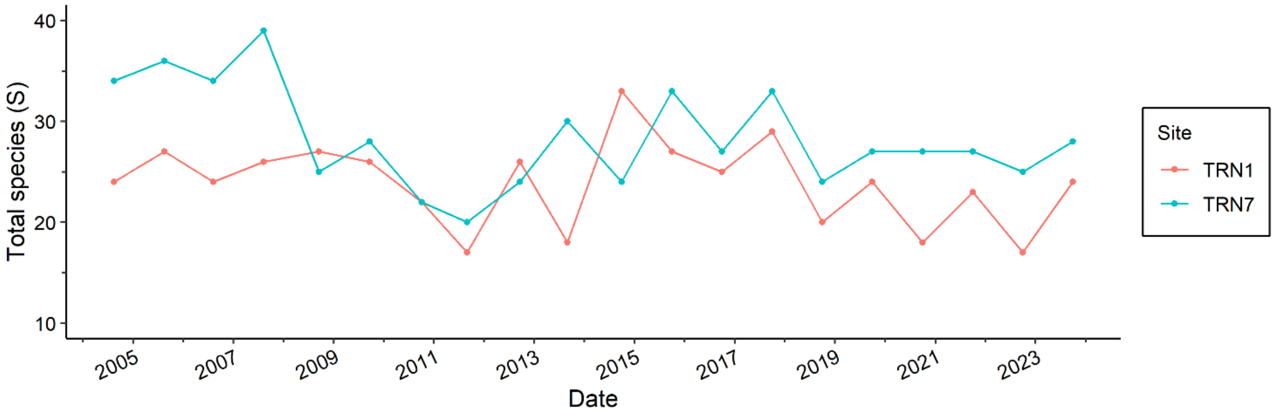

Figure A13. Species richness time series for core Tūranga sites with significant trends (2004 to 2023).

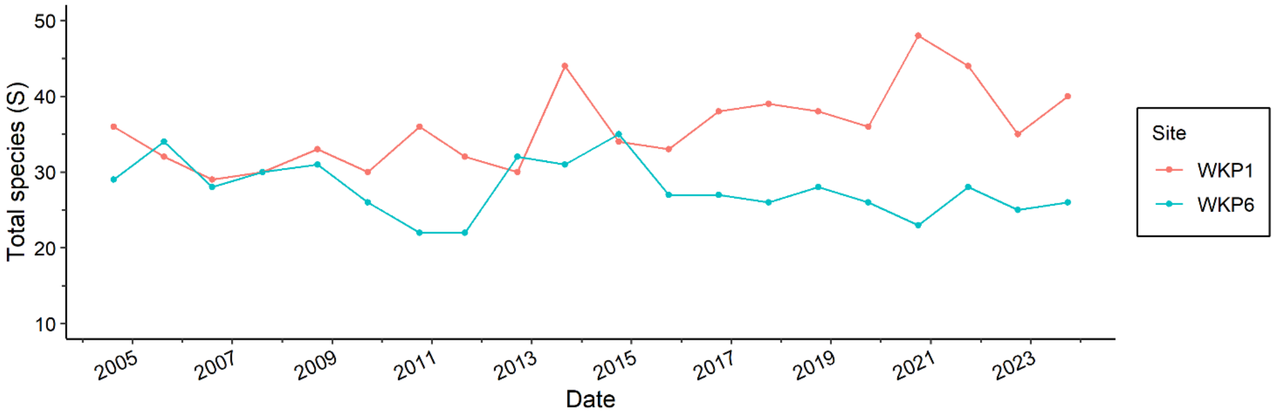

Figure A14. Species richness time series for core Waikōpua sites with significant trends (2004 to 2023).

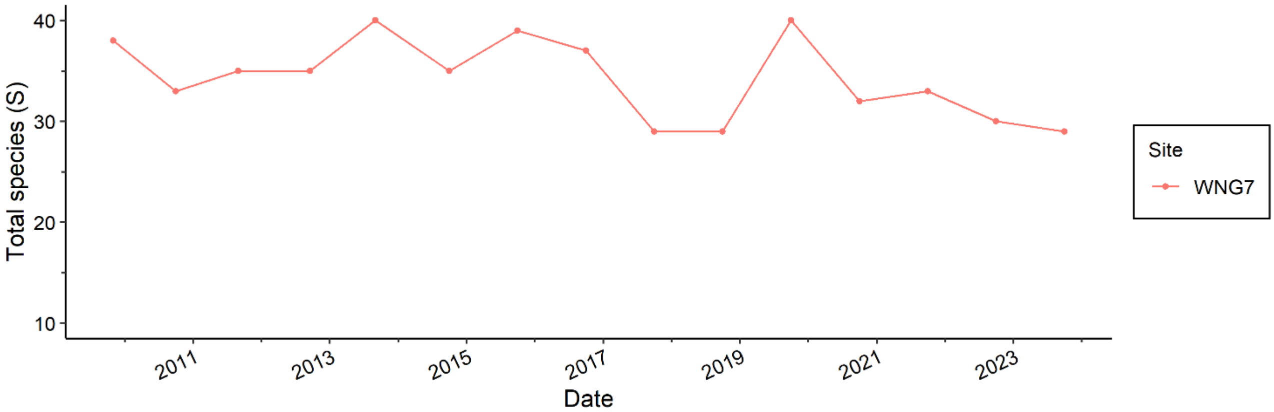

Figure A15. Species richness time series for core Whangateau sites with significant trends (2009 to 2023).

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