CAWTHRON

REPORT NO. 3825

THE SEDIMENTS AND BIOTA WITHIN TE IHUTAI/ AVON HEATHCOTE ESTUARY 2007–2021

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Prepared for Environment Canterbury

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ISSUE DATE: 1 December 2022

RECOMMENDED CITATION: Berthelsen A, Clark D, Pavanato H 2022. The sediments and biota within Te Ihutai/Avon Heathcote Estuary 2007-2021. Prepared for Environment Canterbury. Cawthron Report No. 3825. 89 p. plus appendices.

EXECUTIVE SUMMARY

Te Ihutai/Avon-Heathcote Estuary is a large tidal lagoon south-east of the city of Ōtautahi Christchurch. It is fed by the Ōpāwaho/Heathcote and Ōtākaro/Avon rivers. The Healthy Estuary and Rivers of the City monitoring programme aims to identify long-term changes in water quality and ecosystem health of Ihutai. Intertidal ecological monitoring data (sediments and biota) are collected annually by Christchurch City Council from sites within the estuary and tidal reaches of Ihutai's rivers. These data are reported annually. An additional report is to be produced every five years that reviews current data and makes comparisons to historical data. Environment Canterbury (ECan) contracted Cawthron Institute (Cawthron) to carry out such an assessment for data collected between 2007 to 2021. Here we assess the ecological health of the estuary and environmental drivers based on monitoring data state and trends. We also make future recommendations for the monitoring programme.

Estuary health and environmental drivers

Enrichment:

- The most recent trophic indicator results suggest that nutrient enrichment in Ihutai is greatest at the Avon River Mouth site, which had levels of nitrogen and organic carbon in the poor health range, and phosphorus levels in the fair health range, in the sediment. This enrichment has not triggered blooms of macroalgae or high numbers of capitellid worms, although capitellid worm abundance may have been limited by low salinity. Enrichment levels were lower than Avon at the Heathcote River Mouth site, but sediment organic carbon was still in the poor health range.
- Enrichment has increased over the duration of the monitoring period at the Pleasant Point and Plover Street sites. Sediment organic carbon at these sites is in the poor health category, and has increased since monitoring began. Capitellid worms were generally present in higher numbers since 2013, although most recent abundances were low. Ongoing enrichment at these sites is indicated by: increasing chl-*a* (representing microalgae) at Pleasant Point, and often moderate to high sea lettuce cover from 2013 and an overall increase in sediment nitrogen concentrations (currently reflecting fair health) at Plover Street. Monitoring has not been carried out at Sandy Point since 2007 when large sea lettuce blooms were observed at this site.
- Enrichment appears to have decreased to some extent at Discharge Point and Humphreys Drive since the wastewater discharge was diverted from the estuary. This conclusion is supported by a drop in sediment nitrogen concentrations at Discharge Point and low macroalgal cover since 2012 at Humphreys Drive. However, these sites are still enriched as their sediment organic carbon concentrations reflect poor health. Also, high numbers of capitellid worms were recorded in a recent survey, and sediment chl-*a* concentrations increased over time, at Humphreys Drive.

- At Causeway, enrichment appears to be decreasing based on macroalgal abundance trends, but sediment organic carbon and nitrogen are both in poor and fair health, respectively.

Sedimentation:

- Overall, Ihutai was muddy, particularly at the river sites. This was reflected by the infauna communities and Mud BHM scores at these two sites.
- Mud content and Mud BHM scores reflecting poor health were also present for Humphreys Drive and Pleasant Point Jetty, with worsening Mud BHM scores and mud content, respectively.
- Mud BHM scores and increasing mud content at Plover Street indicated that sedimentation impacts are getting worse at this site. However, seagrass cover and cockle/tuaki abundance also increased over time at this site, suggesting that sedimentation to date has not limited these species.
- Mud content at Discharge Point was in fair health and has improved over time, but Mud BHM scores still indicated poor health. Sedimentation effects were lowest at the Causeway site, which had sediment mud content in the fair health range, high abundances of mud sensitive taxa and Mud BHM scores that indicated moderate sedimentation impact relative to other estuarine sites across New Zealand.

Metals contamination:

- Overall, metal contamination within Ihutai sediments was generally low in relation to most guidelines for contaminants.
- The exception was the most recent sampling at the Avon River Mouth site (2016), where levels of copper and lead were above some of the lower thresholds, indicating at least some possible detrimental impacts on infauna.
- Sediment metal levels in general were higher at the Avon River Mouth site compared to the other estuary sites.
- Indicators suggested that metal contamination increased slightly at Plover Street but was declining at Discharge Point. Metals values also declined at Humphreys Drive. Metals BHM scores did not align with metal contamination results at the Heathcote River Mouth site.

It was outside of the report scope to identify the specific activities causing, or sources of, the stressors for Ihutai; however, key general causes of the above stressors (eutrophication, sedimentation and metal contamination) are outlined in the report (Sections 1.3 and 4). Further site-specific investigation may be required to confirm stressor causes for any given site.

Recommendations for future monitoring

Overall, the Ihutai ecological (sediments and biota) monitoring programme has provided a robust set of data for assessing the ecological health of the estuary, including trends over time and environmental drivers. A summary of our recommendations for future monitoring are as follows:

- Using the National Estuary Monitoring Protocol (NEMP) for fine-scale sampling means that the methods are robust, and generally comparable to national data. We commend the annual monitoring of many parameters, as this enables robust analysis of temporal trends. We recommended continuing with this sampling approach, with additional recommendations for collection of cockle/tuaki (*Austrovenus stutchburyi*) population size-structure data.
- For future sampling, we recommend considering guidance for the design of long-term monitoring programmes for estuaries. This would need to be considered with reference to the specific objectives of the Ihutai monitoring (biota and sediments) programme.
- Additional parameters could be included in the data analyses to account for important covariables that may drive natural cycles (e.g., climatic indices, temperature), as this information can be used to partition out variation that is not of interest, increasing the power to detect stressor effects and approaching tipping points.
- Annual (or at least more frequent than every five years) collection of sediment quality data (metals, nutrients, chl-*a* and TOC) could be undertaken at all sites to allow for more frequent/robust trend analyses.
- Unless already encompassed in another programme, additional monitoring could include fine-scale seagrass surveys, for the purpose of measuring changes in seagrass ecological health. Additionally, we recommend more frequent broad-scale mapping of macroalgae and other important habitats such as salt marsh within Ihutai.
- The National BHMs are suitable for assessing the health of the monitored sites in Ihutai and their continued use is recommended for this estuary.

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1. INTRODUCTION

1.1. Monitoring overview

Te Ihutai/Avon Heathcote estuary (hereafter Ihutai) is a large tidal lagoon (Hume et al. 2016) south-east of Ōtautahi Christchurch City. It is fed by the Ōpāwaho/Heathcote and Ōtākaro/Avon rivers. The Healthy Estuary and Rivers of the City monitoring programme aims (among other things) to identify long-term changes in the water quality and ecosystem health of Ihutai (Batchelor et al. 2009). As part of this work, intertidal ecological monitoring data (sediments and biota) are collected annually by Christchurch City Council from the estuary and tidal reaches of Ihutai's rivers. These data are reported annually[1], with an additional report to be produced every five years that reviews the previous five years of data and makes comparisons to historical data. The scientific report by Bolton-Ritchie (2015) encompassed monitoring data for the years 2007 to 2013[2]. Following on, our report assesses sediment and biota data from 2007 to 2021. Our scope did not include assessment of Ihutai water quality; other reports can be referred to for this, for example Gadd et al. (2020). Nor did it include a cultural health assessment; for an example, see Lang et al. (2012).

1.2. Major events

Since 2007, several major events have affected the Ihutai estuary. The Christchurch City wastewater discharge was diverted from the estuary in March 2010, and a series of large earthquakes occurred in 2010 and 2011. The wastewater diversion led to a reduction of nutrients entering the estuary (Bolton-Ritchie 2011). Effects from the earthquakes included the temporary discharge of raw sewage, a likely increase in sediment loads entering the estuary, and subsidence, uplift and liquefaction of the estuary bed (Measures et al. 2011; Zeldis et al. 2011). In terms of ecological impacts, Zeldis et al. (2020) found that despite decades of nitrogen loading and eutrophic growths (i.e., macro- and microalgae), Ihutai did not store a eutrophic legacy in its sediments and was, therefore, relatively resilient to eutrophication. Additionally, Skilton (2013) found that the wastewater diversion had a major impact on food web dynamics and that the large amounts of clean and unpolluted sediments introduced during the earthquakes accelerated the recovery of the estuary. Bolton-Ritchie (2015), Skilton (2013) and Zeldis et al. (2020) provide further information on how these major events have affected the ecology of the estuary.

In our report, data collected from 2007–2010 can be considered as pre-wastewater diversion and pre-earthquakes and all data collected from 2011 onwards as post-wastewater diversion and post-earthquakes (as per Bolton-Ritchie 2015).

[1] Previous annual monitoring reports can be found at https://www.ecan.govt.nz/technical-reports/.
[2] Sediment data 2007–2013, biota data 2008–2013.

1.3. Sediments, biota and impacts

Healthy intertidal estuary flats and tidal river reaches support a diverse range of small benthic invertebrates including shellfish, snails, worms and crustaceans. These animals in turn provide food for fish and birds, while shellfish, such as cockles/tuaki, are also a valued food item for many people. Animals oxygenate sediments through feeding and burrowing. Seaweed and plants such as seagrass can also be present in healthy estuarine ecosystems and provide food and habitat for many animals among other environmental benefits. The sediment quality of estuarine ecosystems affects the presence and abundance of the sediment-dwelling biota (animals and plants). In Ihutai, sediment quality has been impacted by:

- fine sediment (mud) running off the land and entering the rivers and estuary
- the presence of liquefaction sediment, including sediments that have been transported down the rivers as well as that which erupted from within the estuary during the earthquakes
- estuarine and river hydrodynamics (and resulting transport or deposition of sediment) and changes in hydrodynamics
- inputs of organic matter (e.g., plant debris such as leaves, twigs, rotting seaweed and dead phytoplankton, sewage and dead animals)
- the quality of the water, in particular nutrient concentrations
- contaminants such as metals, pesticides and herbicides entering the rivers and estuary in stormwater and other legal and illegal discharges, and from diffuse sources.

Climate change may also be changing Ihutai ecology. For example, estuaries can be affected by changes in air and water temperature, increasing sea level and ocean acidification, and increases in the frequency and intensity of rainfall and storms (potentially resulting in increased sediment and nutrient loading, erosion and disturbance).

1.4. Specific report objectives

Our report analyses and discusses state and trends in the ecology of Ihutai from 2007–2021. We consider sediment quality (grain size, nutrients, organic carbon, chlorophyll-*a* and contaminants) and biota (infauna, epifauna and epiflora) from sites within the estuary. The key report objective was to assess estuary ecological health, including environmental drivers. An additional topic that we addressed was whether the sediment grain size data align with broad scale mapping results. We also make future recommendations for the monitoring programme.

2. METHODS

2.1. Monitoring sites

Ecological data (sediments and biota) were collected from eight monitoring sites in and around Ihutai (Figure 1). Six of the sites were located within the estuary: Plover Point, Pleasant Point Jetty, Discharge Point, Humphreys Drive, Causeway and Sandy Point. The additional two sites were situated in the tidal reaches of the Ōtākaro/Avon and Ōpāwaho/Heathcote river mouths. Site co-ordinates and additional location details are presented in Appendix 1.

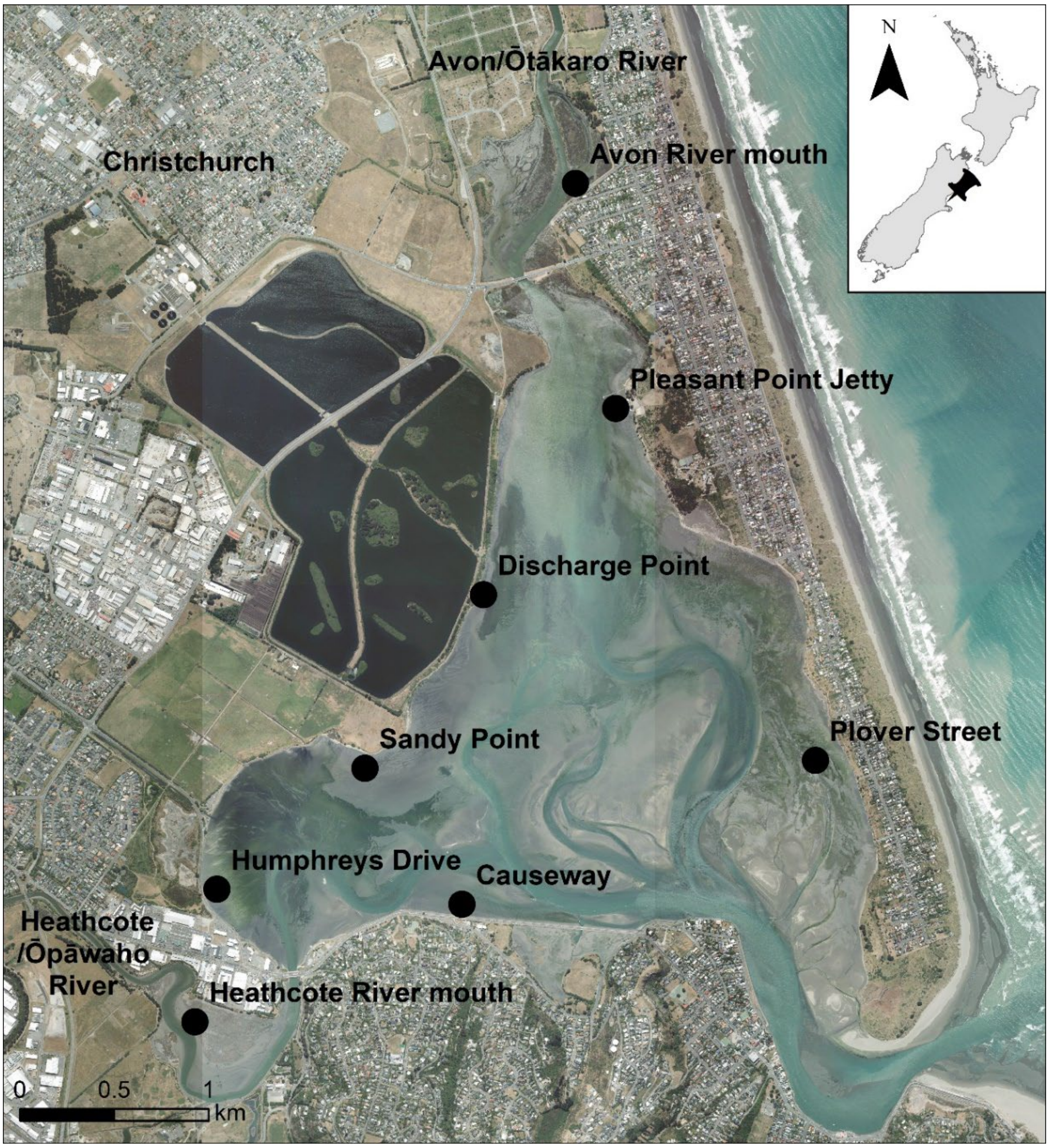

Figure 1. Monitoring sites within Te Ihutai/Avon Heathcote Estuary and the tidal reaches of its rivers.

2.2. Sampling overview

Monitoring sites were located at the mid-low tide shore as per the National Estuarine Environmental Assessment and Monitoring Protocol (NEMP, Robertson et al. 2002). The sampling area was divided into plots (15 m x 10 m or 5 x 5 m; refer to Appendix 1 for individual site layout details). The following sampling took place in each plot:

- one surface (top 20 mm) sediment sample collected
- one 130 mm diameter x 150 mm deep sediment core (i.e., infauna core) collected
- one 50 cm x 50 cm (0.25 m^2) quadrat surveyed.

From 2007 to 2014, the number of individual samples, cores and quadrats collected or surveyed each year at each site was fifteen; from 2015 onwards this number was reduced to twelve. Sampling of biota and sediments occurred annually (during March or April). Monitoring at Sandy Point ceased after 2007 and monitoring at the Causeway site only began in 2015. There were no 2019 data for any parameters for any of the sites. Sediment grain size and infauna data were not collected at the Avon and Heathcote river mouth sites in 2007 and 2021, and infauna data were also not collected at Avon River Mouth in 2010. Sediment parameters besides grain size were analysed infrequently.

Additionally, to determine cockles/tuaki (*Austrovenus stutchburyi*) size, the sediment in each quadrat was dug out and all cockles found in or on top of the sediment were measured. Cockle/tuaki sizes were also determined from the cores. The quadrat and core cockle/tuaki size measurements in our report relate to certain timeframes and/or sites only. See methods sections below for further details.

2.3. Sediment quality

2.3.1. Sampling details and laboratory analyses

The surface sediment samples collected from each site were usually combined into groups of composite samples. There were five composites when fifteen samples were collected overall (2007–2014) and three composites when twelve samples were collected overall (2015–2021) from each site for analysis. The exception was 2007 when there were 10 samples analysed. Each sample or composited sample was analysed for grain size distribution. Less frequently, these samples were also analysed for total organic carbon (TOC)[3], chlorophyll-*a* (chl-*a*), total recoverable phosphorus (TRP), total nitrogen (TN), ammonium-nitrogen[4] and metals concentrations (arsenic[5], cadmium, chromium, copper, lead, nickel and zinc). The less-frequent analyses were done in 2007, 2011, 2016 and 2021 for all sites

[3] Note that for 2011 the parameter labelled as organic matter was plotted with the TOC value for other years.
[4] Data for this parameter were not included in our report as they have not been collected since 2011.
[5] This is technically a metalloid but referred to as a metal in our report for simplicity.

monitored during these years, except for the two river mouth sites for which the analyses were conducted in 2011 and 2016 only. Analytical method details are outlined in Table 1.

Table 1. Analytical methods used to analyse sediment for Ihutai ecological monitoring as per Bolton & Richie (2015). Methods for Total Recoverable Arsenic and Total Organic Carbon are also included based on details in Environment Canterbury's 'Field and Laboratory Procedures for Marine Ecology Monitoring'. Methods for Total Recoverable Phosphorus obtained from Hill Laboratory.

Analysis	Method	Analytical detection limit	Laboratory
Total Recoverable Arsenic Total Recoverable Cadmium Total Recoverable Chromium Total Recoverable Copper Total Recoverable Lead Total Recoverable Nickel Total Recoverable Zinc	Dried sample, sieved (500µm). Nitric/Hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2.	0.2 mg/kg dry wt 0.010 mg/kg dry w 0.2 mg/kg dry wt 0.2 mg/kg dry wt 0.04 mg/kg dry wt 0.2 mg/kg dry wt 0.4 mg/kg dry wt	Hill Laboratories Hill Laboratories Hill Laboratories Hill Laboratories Hill Laboratories Hill Laboratories Hill Laboratories
Ash	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 21st ed. 2005.	0.04 g/100g dry wt	Hill Laboratories
Organic matter	Calculation: 100 – Ash (dry wt).		Hill Laboratories
Total Organic Carbon	Acid pre-treatment to remove carbonates if present, Elementar Combustion Analyser.	0.05 g/100g dry weight	Hill Laboratories
Chlorophyll-*a*	From NIWA periphyton monitoring manual		Hill Laboratories/ Cawthron
Total recoverable phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	Hill Laboratories
Total nitrogen	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]	500 mg/kg dry weight	Hill Laboratories
Sediment grain size	Malvern Laser Sizer particle size analysis.		University of Waikato

2.3.2. Data analyses

We investigated similarities and differences in grain size composition between sites over time using non-metric Multi-Dimensional Scaling ordination (nMDS, Kruskal & Wish 1978). Euclidean distances were used to generate the similarity matrix from which the MDS ordination was produced (Clark et al. 2001). In this MDS ordination, the more similar the grain size, the closer together the points on the plot. Each plot has a stress value. Stress (goodness-of-fit) is a measure of how well the 2-dimensional ordination of points on the plot represents the actual values in the similarity matrix (Clarke & Warwick, 2001). Low stress values (< 0.1) indicate that the plot represents the differences between data points well. However, plots with stress values < 0.2 still give a potentially useful 2-dimentional picture. Vector overlays on the nMDS plot were used to display grain size categories with > 0.6 Pearson correlation coefficient across samples. All multivariate analyses were performed using PRIMER v7 software (Clark et al. 2001).

2.3.3. Guidelines for assessing sediment quality

We used a range of existing guidelines to assess sediment quality. For mud content, we used the Land, Air, Water, Aotearoa (LAWA)[6] guidelines (Table 2). For total nitrogen (TN) and total organic carbon (TOC) we used interim Estuary Trophic index (ETI) guidelines (Table 3; Robertson et al. 2016a) and for total recoverable phosphorus (TRP) we used interim guidelines from Robertson and Stevens (2010; Table 4). We also assigned general health categories to these guideline values that are suggestive of good, fair or poor health.

[6] https://www.lawa.org.nz/learn/factsheets/estuaries/mud-content-in-estuaries/

Table 2. Guidelines for mud content in estuarine sediments from Land, Air, Water, Aotearoa (LAWA). Colours are used to indicate values that are suggestive of good (green), fair (yellow) or poor (red) health.

Rating	Mud (%)	Rationale
Good	≤ 3–10%	A small amount of mud is beneficial because the fine particles contain organic matter, which some macrofauna feed on. This means that the most diverse macrofauna communities are often found when there is around 3% mud content, but diversity starts to decline beyond this (Douglas 2019).
	> 3–10%	Macrofaunal communities are most resilient when mud content is < 10% (Rodil et al. 2013).
Fair	> 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%.
Poor	> 30–60%	Macrofaunal communities are unbalanced when mud content is > 30% (Robertson et al. 2016a).
	> 60%	Macrofaunal communities are degraded beyond 60% mud content (Rodil et al. 2013).

Table 3. Guidelines (interim) for total nitrogen (TN) and total organic carbon (TOC) from the Estuary Trophic Index (Robertson et al. 2016a). Colours are used to indicate values that are suggestive of good (green), fair (yellow) or poor (red) health.

Rating	TN (mg/kg)	TOC (%)
Minimal eutrophication	< 250	< 0.5
Moderate eutrophication	250–1000	0.5–1
High eutrophication	> 1000–2000	> 1–2
Very high eutrophication	> 2000	> 2

Table 4. Guidelines (interim) for total recoverable phosphorus (TRP) from Robertson & Stevens (2010b). Colours are used to indicate values that are suggestive of good (green), fair (yellow) or poor (red) health.

Rating	TRP (mg/kg)
Very good	< 200
Good	200–500
Fair	> 500–1000
Poor	> 1000

To assess sediment metal contamination, we compared metal (arsenic, cadmium, chromium, copper, lead, nickel and zinc) concentrations against several sediment quality guidelines (Table 5). National sediment quality criteria guidelines predict ‘acceptable’ levels of contaminants in sediment, above which adverse ecological effects may occur (ANZG 2018). The default guideline value (DGV) indicates the concentration below which there is a low risk of unacceptable effects occurring and metal concentrations should remain below these values to help ensure the protection of aquatic ecosystems. In contrast, the ‘upper’ guideline values (GV-high) provide an indication of the concentration at which observation of toxicity-related adverse effect might be expected. DGVs and GV-High values are conceptually equivalent to (and in many cases the same as) the ISQG-Low and -High criteria, respectively, used by ANZECC (2000). Note that the guidelines are limited to certain individual analytes, and do not take into account the synergistic effects of contaminants within sediments.

More conservative metal guidelines are available, such as the sediment quality environmental response criteria (ERC) used by Auckland Council (ARC 2004). The use of more conservative guidelines provides early warning signals and allows action to be taken before substantial impacts occur. The ERC are derived from ANZECC (2000) Sediment Quality Guideline ISQG-Low values and other internationally recognised guidelines presented in ANZECC (2000) (ARC 2004). Metal concentrations are ranked as either green, amber or red. Concentrations in the green zone present a low risk of effects on organisms, so the site is unlikely to be impacted. Concentrations in the amber zone indicate contaminant levels are elevated and the biology of the site is possibly impacted, while concentrations in the red zone indicate that contaminant levels are high and the biology of the site is probably impacted (ARC 2004). These values were used to assess the impacts of contamination from copper, lead and zinc.

Significant changes in community structure can still occur below the guideline values (Hewitt et al. 2009; Tremblay et al. 2017), therefore, it can also be useful to compare metal concentrations to guidelines derived from field-based studies of species sensitivity distributions. We used effect concentration values (FEC) guidelines for copper, lead and zinc that represent the point at which we would expect to see a 50% decrease in the abundance of 5% of the taxa (Hewitt et al. 2009). We also compared copper concentration to the *Austrovenus* EC50 threshold for copper, over which 50% of cockles are expected to decline (Hewitt et al. 2009).

Table 5. Guidelines for metal contamination. As = Arsenic, Cd = cadmium, Cr = chromium, Cu = copper, Pb = lead, Ni = nickel, Zn = zinc. Colours are used to indicate values that are suggestive of good (green), fair (yellow) or poor (health).

Rating	As	Cd	Cr	Cu	Pb	Ni	Zn	Source
FEC lower (adjusted)				5.3	10.4		113	Hewitt et al. (2009)
Austrovenus EC50				11.2				Hewitt et al. (2009)
FEC upper				9.3	19.4		118	Hewitt et al. (2009)
ERC-Green/Amber boundary				19	30		124	ARC (2004)
ERC-Amber/Red boundary				34	50		150	ARC (2004)
DGV	20	1.5	80	65	50	21	200	ANZG (2018)
GV-High	70	10	370	270	220	52	410	ANZG (2018)

EC50, concentration effective in producing 50% decline in abundance; FEC, effect concentrations; ERC, Environmental Response Criteria; DGV, Default Guideline Value; GV, Guideline Value.

2.3.4. Comparing grain size composition against broad scale mapping

Grain size data were compared to non-vegetated substrate classes from a broad-scale mapping study of Ihutai by Hollever and Bolton-Ritchie (2016). We could only make general comparisons between the grain size data at each site and the mapped substrate classes because it was not clear from Hollever and Bolton-Ritchie (or from Robertson et al. [2002] on which their methods were based) how these substrate classes correspond to grain size composition. Other studies have made efforts to relate grain size composition to broad scale structural classes (e.g., soft mud). However, the method of determining these classes can be subjective, given many of them are defined by their 'softness' in relation to how deep someone's feet sink into the substrate when it is walked on (as per structural class definitions in Robertson et al. 2002). Softness depends on several factors, such as the foot size and weight of the person doing the ground-truthing fieldwork, the amount of interstitial water present at the time of sampling or how 'sun-baked' the substrate is (Berthelsen et al. 2015; Stevens et al. 2020). Stevens et al. (2020) have since revised these classes to provide a more meaningful classification of sediment based on mud content using sediment firmness as an independent descriptor.

2.4. Biota

2.4.1. Sampling details

Infauna

Each infauna core sample was passed through a sieve with mesh size of 0.5 mm and the material retained on the sieve stored in alcohol. The animals present in each sample were sorted from the debris using a binocular microscope. They were then identified, to species level where possible, and counted. Additionally, from 2015 to 2021, the length of cockles/tuaki from the infauna cores from all sites was measured.

Epifauna and epiflora

Observations were made from the quadrats (0.25 m^2), recording the number of individuals for each animal taxon on the surface of the mud (the epifauna) and the number of crab burrows. Where there was high sea lettuce (*Ulva* sp.) cover within a quadrat, epifauna samples were collected and returned to the laboratory for processing. The percentage of the surface covered by epiflora (e.g., macroalgae, seagrass, biofilm) was also determined using a grid overlying the quadrat. The size of mud snails (*Amphibola crenata*) on the sediment surface in the quadrats was also measured. Additionally, cockles/tuaki from the quadrats were measured for size. This included both those collected on the sediment surface combined with those dug out of the sediment to a depth of either 150 mm (2007 to 2014) or 120 mm (2015 to 2021). The cockle/tuaki quadrat measurement data in our report relates only to the Plover Street and Causeway sites (from 2007 to 2021).

2.4.2. Data analyses

Taxa naming and selection for analysis

Prior to analysis of biota (infauna, epifauna and epiflora) data, we checked all taxa for naming updates and consistency in order to standardise the data over time. We used the World Register of Marine Species (WoRMS[7]) in the first instance to confirm (and update if required) accepted names for each taxon. Prior to undertaking macroinvertebrate community analyses (multivariate and community indices), we removed the following taxa recorded in the raw data: vertebrates (i.e., flounder), various juvenile forms of invertebrates that were planktonic or identified to a very coarse resolution (i.e., megalope, unidentified juvenile crab, unidentified juvenile mussel) and unnamed taxa (e.g., 'Unidentified'). We also combined the taxa names 'Nereididae' and 'Nereididae juveniles'. For the Benthic Health Models (BHMs), additional standardisation of the taxonomic resolution was undertaken (refer Section 2.4.3). For epiflora, *Enteromorpha* and *Ulva* sp. were combined (under *Ulva* sp.) based on the accepted name in WoRMS.

Community composition and links to sediment characteristics

Community assemblages of infauna and epifauna for each site/year were contrasted using nMDS based on Bray-Curtis similarity matrices (Clarke et al. 2001; Clark & Warwick 1994). This was conducted on count data that were square-root transformed to de-emphasise the influence of the numerically dominant taxa. Taxa similarities within sites were identified using analysis of similarities (SIMPER; Clarke & Warwick 1994). All multivariate analyses were performed using PRIMER v7 software (Clark et al. 2001).

[7] World Register of Marine Species https://www.marinespecies.org/

Plotting indicator taxa and community metrics

The overall abundance or percent cover (depending on taxon) for the key indicator taxa, as well as for community metrics and Benthic Health Models (see following sections) was analysed (average ± standard deviation) for each survey (site and year). This included the following size classes of cockles/tuaki: recruits (0-5 mm), juveniles (5–20 mm), adults (20-35 mm) and edibles (≥ 35 mm). For mud snails the following size classes were included: 0–5 mm, 5–10 mm, 10–15 mm, 15–20 mm, 20–25 mm, 25–30 mm and 30–35 mm. All results were then plotted.

2.4.3. Community indices and benthic health models

Community metrics

From the infauna count data in each core, abundance (i.e., number of individuals) and number of species were obtained. We then calculated Pielou's evenness and Shannon Weiner diversity (Table 6). The indices were calculated using the PRIMER 7 DIVERSE function (Clark et al. 2001). These indices are useful for making comparisons between sites and years, and any significant differences may then be interpreted with respect to key environmental parameters. More specifically, infaunal community metrics can, to some extent, indicate the level of impact of stressors such as organic enrichment and sedimentation. For example, infaunal community abundance and number of species often increase with increasing enrichment and then decrease if enrichment goes beyond a certain level (Pearson & Rosenberg 1978). Communities also tend to become impoverished at higher mud levels (Robertson et al. 2016b). However, metric results must be interpreted with caution given that their responses to a given stressor is not necessarily linear (e.g., as per Pearson & Rosenberg 1978) and that they can be impacted by more than one stressor.

Table 6. Descriptions of infauna community indices.

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

Benthic Health Models

The infauna-based National BHMs were developed in 2020 as a standardised measure of the relative impact of sedimentation and heavy metal contamination on benthic (seafloor) infaunal communities in New Zealand's estuaries (Clark et al. 2020). There are two separate models: the Mud BHM and the Metals BHM. The Mud BHM assesses the impact of mud in surface sediments on infaunal communities, which can be used as a surrogate for sediment accumulation rates. The Metals BHM assesses the impact of copper, lead and zinc in surface sediments (measured on an *Elementar* Analyser) on faunal communities. These metals are generally the key metals of concern in New Zealand estuaries (ARC 2004).

The output from each model is a BHM score between 1 and 6, with 1 indicating the lowest impact of the stressor(s) on infaunal communities, and 6 indicating the highest impact, relative to other estuarine sites across New Zealand. The BHM scores can be expressed in five categories (Table 7). For the Metals BHM, additional guidance based on existing sediment quality guidelines has been developed to indicate the absolute health (poor, fair, good) of estuarine communities in a New Zealand context (Table 8). Further details about the BHMs can be found in Appendix 5 and in Clark (2022) and Clark et al. (2020).

BHM scores were calculated using the infauna count data. The taxonomic resolution of the infauna data were standardised following the protocol outlined in Clark (2022) and replicates averaged by site for each year of sampling. BHM health scores were calculated following the methods of Clark et al. (2020) using PRIMER 7 (v 7.0.13) with the PERMANOVA+ add-on (Anderson et al. 2008; Clarke & Gorley 2015). Six of the sampling events were included in the original BHMs (Appendix 5, Table A5.4).

Before using the BHMs to assess estuary health at a new site, the fit of the calculated BHM scores should be assessed against the national dataset used to develop the models (Clark 2022). The fit was checked for the Ihutai monitoring sites and details of how this was done can be found in Appendix 5.

Table 7. Descriptive names and boundaries for Benthic Health Model (BHM) score categories.

BHM Group	Level of impact relative to other estuarine sites in New Zealand*	BHM score
1	Very low	1.0 to < 2.0
2	Low	2.0 to < 3.0
3	Moderate	3.0 to < 4.0
4	High	4.0 to < 5.0
5	Very high	≥ 5.0

* This is a relative measure of impact rather than an absolute measure of health.

Table 8. Absolute health boundaries for the National Metals Benthic Health Model (BHM).

Absolute health	Metals BHM score
Good	< 3.6
Fair	3.6 to < 4.8
Poor	4.8 or greater

2.4.4. Indicator taxa

Key indicator taxa abundances were used to indicate the level of certain human-caused stressors.

Nutrient/organic enrichment

Indicator taxa for nutrient or organic enrichment include capitellid polychaetes (i.e., Capitellidae spp.[8] in our infauna data). Overseas, the family Capitellidae generally is considered tolerant of organic enrichment (AZTI 2018). Both *Heteromastus filiformis* and the genus *Capitella* are members of this family. However, taxa tolerances can vary in different locations. For example, *Capitella capitata* was tolerant of organic enrichment at subtidal sites in the Marlborough Sounds (Keeley et al. 2012) but *Capitella* species are also found at undisturbed estuarine sites in New Zealand (Hewitt et al. 2005). Similarly, Hewitt et al. (2005) found that *H. filiformis* was sensitive to

[8] Capitellidae spp. was a combination of the taxa Capitellidae spp., *Capitella* sp. and *Heteromastus filiformis*.

pollution compared to other *Capitella* species, but Keeley et al. (2012) reported that this species was indifferent to organic enrichment. For our purposes, we considered high capitellid worm abundance (sum of Capitellidae spp., *Capitella* sp. and *H. filiformis*) to be a likely indicator of nutrient enrichment, noting that plotted abundances were similar regardless of whether *H. filiformis* was included. Additional infauna or epifauna taxa identified from our community analyses were also used as indicators of enrichment but were not plotted individually. Note that there is also some evidence to suggest that population density of mud snails can be relatively high at sites with elevated nutrients and organic matter (De Silva et al. 2022).

Algal growth, another indicator of nutrient enrichment, is often caused by excessive nutrients (Sutula et al. 2014). Nuisance macroalgae, such as *Ulva*/sea lettuce and *Agarophyton chilense*, form blooms under enriched conditions. The amount of chlorophyll-*a* within sediments can also be a proxy for microalgal biomass (Robertson et al. 2002). Microalgae are an important food source for many animals, but blooms or mats can indicate highly enriched conditions (Robertson et al. 2002).

Seagrass meadows can also be negatively impacted by nutrient enrichment (Turner & Schwarz 2006); for example, they can be smothered by macroalgal blooms and high epiphyte cover.

Sedimentation

Key indicator taxa for sedimentation included the polychaete *Aonides* sp. and shellfish wedge shells (*Macomona liliana*) and cockles/tuaki. *Aonides* is highly sensitive, and wedge shells and cockles/tuaki are sensitive, to sediment mud content and therefore their absence or low abundance can indicate impacts of sedimentation (Robertson et al. 2015). Conversely, mud snails are widely tolerant of sediment mud content (Robertson et al. 2015). Additional infauna or epifauna taxa identified from our community analyses were also used as indicators of sedimentation but were not plotted individually.

Seagrass meadows are also negatively impacted by the effects of sedimentation (Turner & Schwarz 2006), for example. low light levels in water column or sediment settling on seagrass leaves can reduce photosynthesis.

Metal contamination

Mud snail shell length has been positively correlated with sediment cadmium and zinc concentration (De Silva et al. 2022).

2.5. Trends over time for sediment and biota

We used generalised linear models (GLM; Dobson & Barnett 2002) to evaluate the statistical significance of trends over the monitoring period.

The trends were assessed for the following parameters:

- sediment grain size categories
- sediment quality parameters (metals [copper, lead, zinc], TOC, TN, TRP and chl-*a*)
- abundance of infauna indicator taxa (cockles/tuaki overall, cockle/tuaki size classes [for 2015-2021 only], wedge shells, *Aonides* sp. and Capitellidae spp.), community indices and BHMs
- Abundance of epifauna indicator taxa (mud snails overall, mud snail size classes). Also cockles/tuaki from quadrats (for Plover Street and Causeway Sites only[9])
- epiflora taxa percent cover (sea lettuce, *Agarophyton chilense* and seagrass).

The software R (R Core Team 2019) was used to carry out the GLMs. Further details on the GLMs and results are presented in Appendix 3. Given the very large number of models we were fitting, it was unfeasible to interpret results based on non-linear trends. We therefore used linear models to provide a simple, yet powerful, technique to assess trends over time. However, these models are not able to reflect any non-linear trends present and in these cases we took care to note this in the results.

Due to limited data, trends over time could not be assessed using GLMs for some parameters at some sites, including all parameters for the Sandy Point site (which was only sampled once). Visual inspection of plots (based on average values plus standard deviation) was used in some cases to assess whether there was a general trend over time. This approach was used to assess timeframes shorter than the overall monitoring period, for example to determine changes in relation to a specific event (e.g., earthquakes and wastewater diversion).

[9] We did not analyse trends for cockles/tuaki measured in the quadrats for all other sites as there were only data available from 2007 to 2014 and the previous trend report (Bolton-Ritchie 2015) already largely covered this timeframe.

3. RESULTS: PATTERNS AND TRENDS

In this section we discuss the monitoring results in relation to patterns and trends. Ecological state thresholds are indicated on many of the plots; however, these are discussed primarily in Section 4 (Ecological Health of the Estuary and Drivers).

3.1. Sediment quality

3.1.1. Sediment grain size

Sediment composition

Sediment composition at the two river mouth sites (Avon and Heathcote) was similar and was characterised by relatively large proportions of mud (Figure 2). At all other sites, sediment composition was correlated with different size classes of sand. Sediment composition from each site over time tended to cluster together on the similarity plot, indicating a degree of within-site consistency although variation was still relatively high for some sites. There was a degree of overlap between sites, indicating some sites shared sediment characteristics.

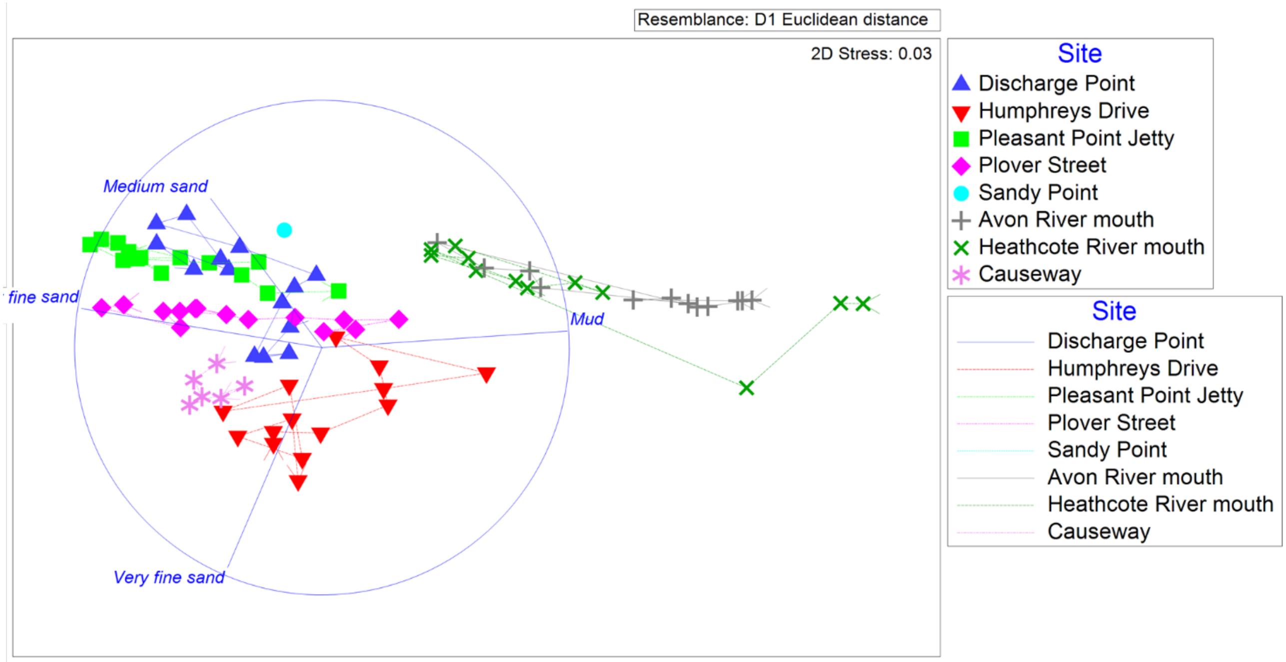

Figure 2. Differences in sediment grain size composition (based on Euclidean distance) among the seven monitored sites in Ihutai and associated tidal river mouths from 2007 to 2021 illustrated using non-metric multi-dimensional scaling (nMDS). Each symbol on the plot represents averaged data from one sampling year at one site. The vector overlay shows grain size categories with > 0.6 Pearson correlation coefficient across samples. A time trajectory is also displayed for each site.

Mud and fine sand were the dominant grain size fractions at most of the sites, followed by very fine and medium sand (Figure 3). Mud content was highest at the two river mouth sites (Avon and Heathcote) (Figure 4). Average mud content was generally lowest overall at the Causeway and Discharge Point sites in more recent years and at Plover Street and Pleasant Point Jetty in earlier years.

Mud content has significantly increased at over time at the Pleasant Point Jetty and Plover Street sites, with associated changes in other grain size categories (Table 9). Conversely, mud content significantly declined at Discharge Point and Heathcote River Mouth. Grain size has been relatively stable at the Humphreys Drive and Causeway sites, with no significant trends for mud observed. The grain size distribution at the Avon River Mouth is similar to when monitoring began, despite changes occurring between 2011–2017. Based on visual inspection of the plots, there was a sharp decline in mud in 2011 at both Avon and Heathcote sites. This lower level of mud content persisted at Heathcote River Mouth but mud content at Avon River Mouth is now back to levels recorded during the earlier years (2007 to 2009).

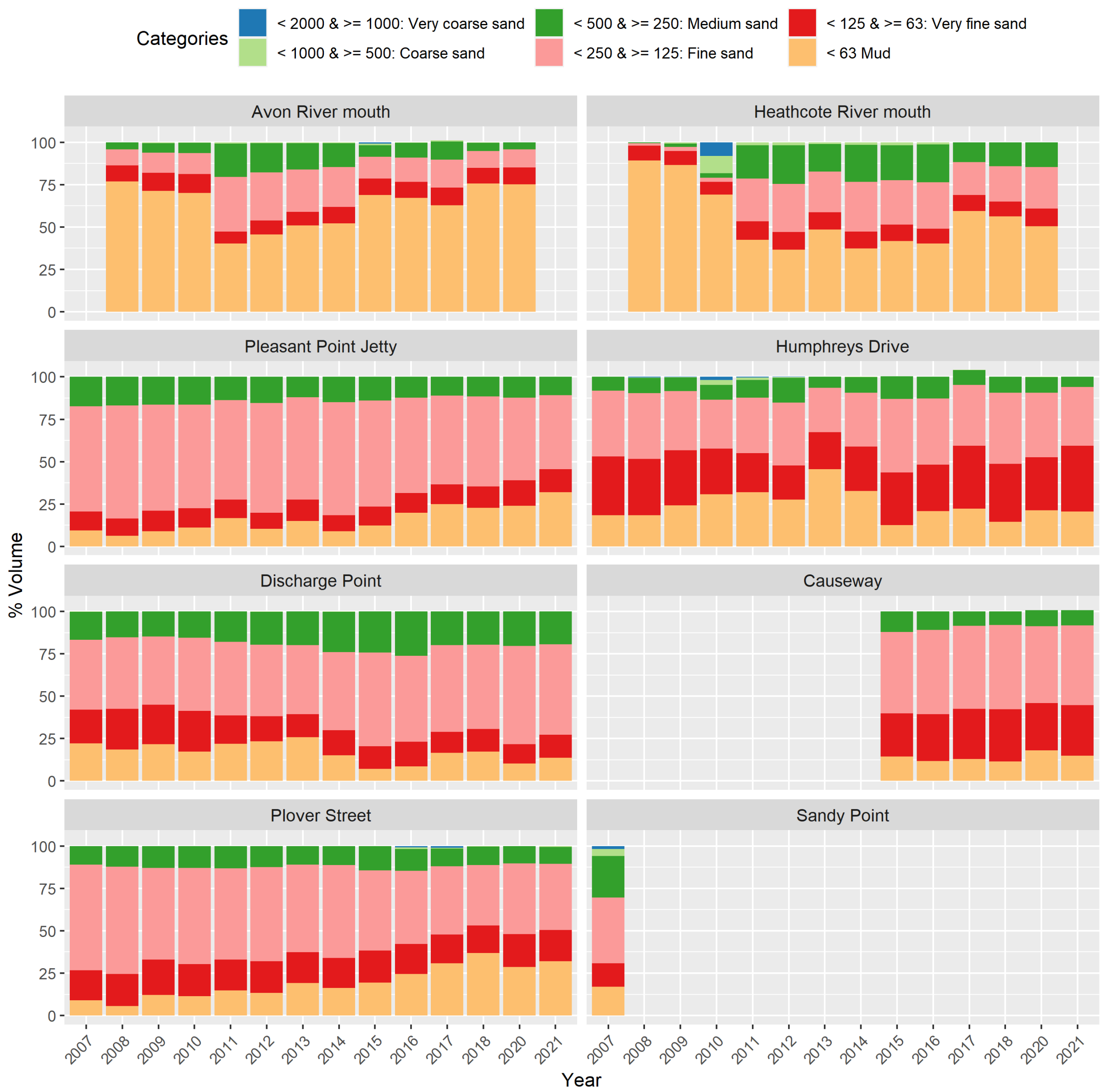

Figure 3. Sediment grain size categories (mean % volume) at monitoring sites in Ihutai from 2007 to 2021. 2019 is not included on the x-axis as no data were available for any of the sites.

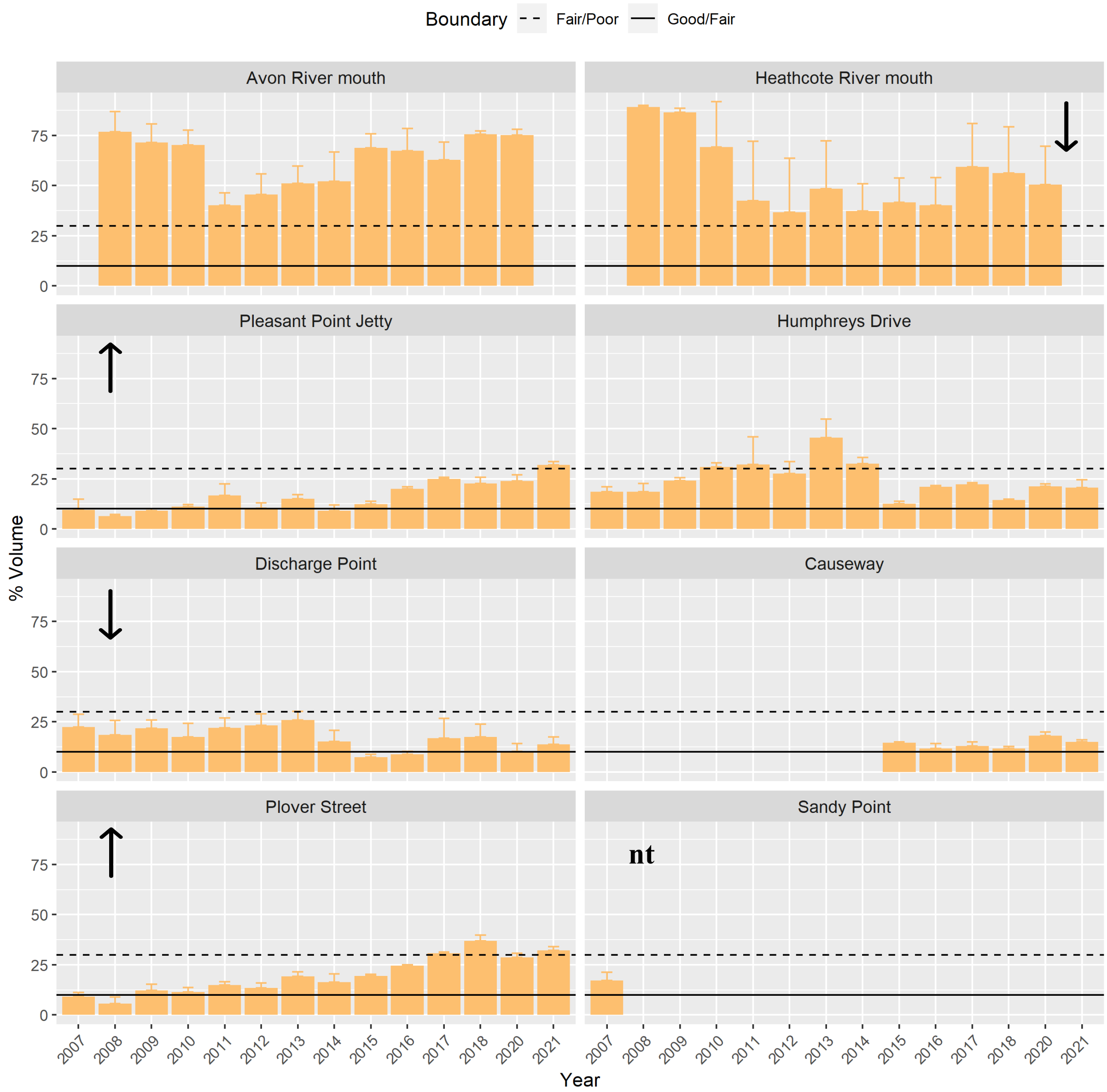

Figure 4. Sediment mud (< 63 µm) content of sediment (mean % volume) at monitoring sites in Ihutai from 2007 to 2021. Horizontal lines indicate mud levels indicative of good, fair and poor health (refer Table 2 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in mud values over time. Trends were not able to be assessed at Sandy Point due to insufficient data (nt = not tested).

Table 9. Trends in sediment grain size categories at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in mud values over time, a dash indicates no statistically significant ($p < 0.05$) trend and nt (not tested) indicates insufficient data were available for trend analysis. Mud (< 63 µm), VFS (very fine sand, ≥ 63 and <125 µm), FS (fine sand, ≥ 125 and < 250 µm), MS (medium sand, ≥ 250 and < 500 µm), CS (coarse sand, ≥ 500 and < 1000 µm), VCS (very coarse sand, ≥ 1000 and < 2000 µm).

Site	Mud	VFS	FS	MS	CS	VCS
Avon River mouth	-	-	-	-	-	**nt**
Pleasant Point Jetty	↑	↑	↓	↓	**nt**	**nt**
Discharge Point	↓	↓	↑	↑	-	**nt**
Plover Street	↑	↓	↓	-	↑	**nt**
Heathcote River mouth	↓	↑	↑	↑	↓	**nt**
Humphreys Drive	-	↑	-	-	↓	**nt**
Causeway	-	↑	-	-	**nt**	**nt**
Sandy Point	**nt**	**nt**	**nt**	**nt**	**nt**	**nt**

Comparisons to broad-scale habitat mapping

Broad-scale substrate mapping of Ihutai in 2016 (Hollever & Bolton-Ritchie 2016) aligned overall with the estuary-scale sediment grain size patterns observed in the monitoring results (Figure 5). Mapping indicated that sediments were generally 'softer' in the inner estuary and 'firmer' closer to the estuary entrance. Areas of 'soft mud/sand' and 'very soft mud/sand' were recorded around the Avon River Mouth site, which aligns with the high percentage of mud at this site (Figure 4). 'Firm mud/sand' was mapped near the Humphreys Drive site, which generally reflects sediment grain size here (i.e., lower mud content than at Avon River Mouth). Mapped substrates at Discharge Point were 'mobile mud/sand' and at Pleasant Point Jetty these were 'firm mud/sand'. This aligns with the grain size results indicating sediments dominated by sand with a component of mud at these two sites (Figure 3), although the percentage of mud has increased and decreased over time at Pleasant Point Jetty and Discharge Point, respectively. Broad-scale mapping also supported the grain size results for the sites closer to the estuary entrance (i.e., Plover Street and Causeway) for which sand was the dominant sediment type but mud was also present. Substrates in these areas comprised 'firm mud/sand' (Causeway) and 'firm sand' (nearby Plover Street alongside the seagrass meadow). The Heathcote River Mouth site was beyond the extent of the mapped area.

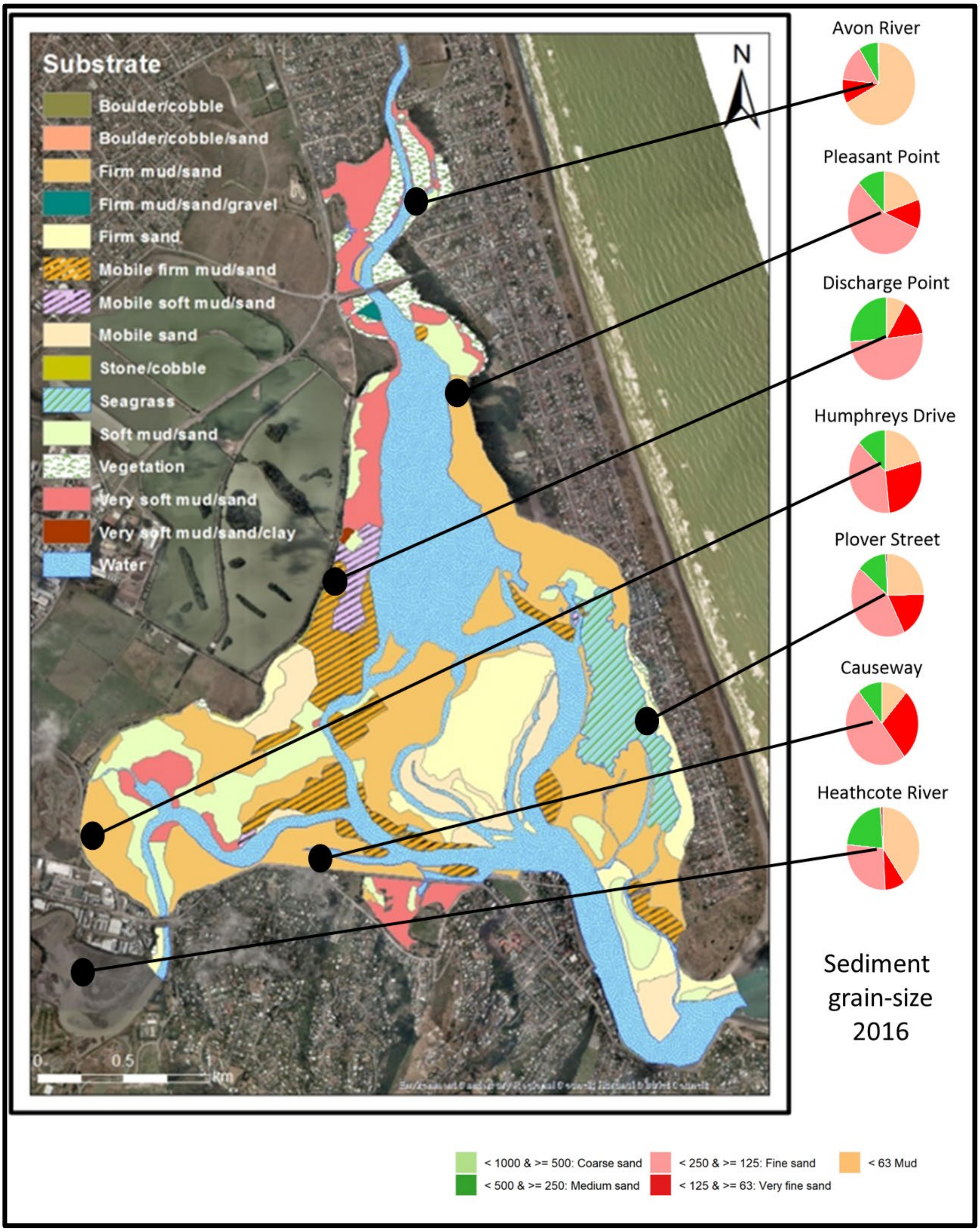

Figure 5. The intertidal substrates of Ihutai, the Estuary of the Heathcote/ Ōpāwaho and Avon/Ōtākaro. Map from Hollever and Bolton-Ritchie (2016). Average sediment grain size at monitoring sites in Ihutai in 2016 is displayed in the pie graphs for comparison.

3.1.2. Organic carbon, nutrients and chlorophyll-a

Total organic carbon

The highest average sediment TOC value was recorded at the Avon River Mouth site in 2016, followed by Humphreys Drive in 2011 (Figure 6). Lowest TOC values were recorded in 2007 for all sites at which monitoring took place during this year (all except the two river mouth sites and Causeway).

There was a statistically significant increase in TOC over time (2007–2021) at all sites for which enough data existed to conduct trend analyses (Discharge Point, Humphreys Drive, Pleasant Point Jetty and Plover Street). The largest significant trend occurred at Plover Street, where average values increased more than four-fold (Figure 6). At Humphreys Drive, a non-linear trend was observed where the highest values occurred during 2011, with average values dropping down after this although still remaining higher than those in 2007. Insufficient data were available to statistically test for trends at the Avon River Mouth, Causeway and Heathcote River Mouth sites. The exception to this was at the Avon River Mouth site, where values in 2016 increased by over half of those from 2011 (no data were available for 2021).

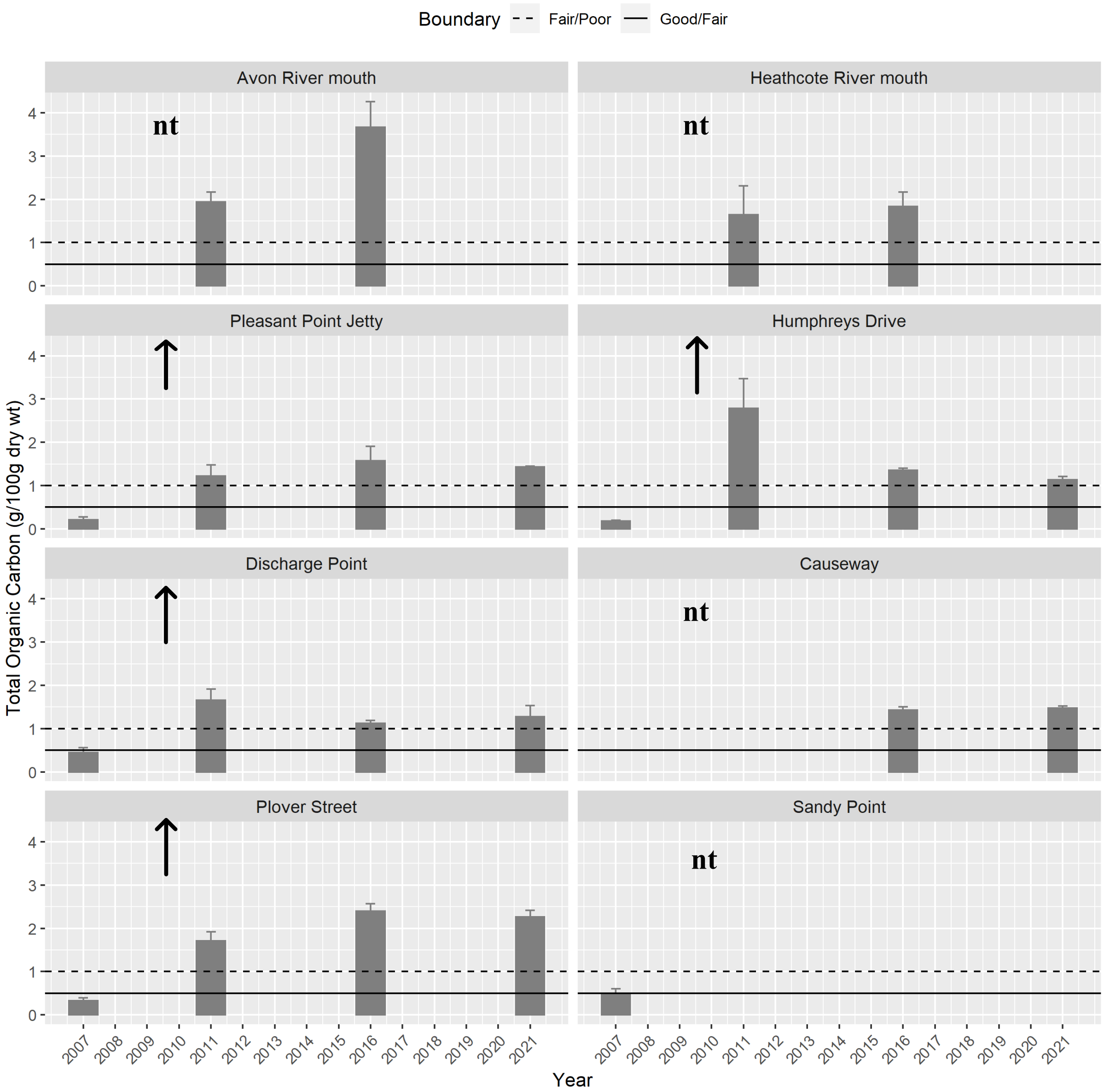

Figure 6. Sediment total organic carbon (TOC, g/100g dry weight) at monitoring sites in Ihutai from 2007 to 2021. In 2011, this parameter was recorded as 'organic matter' in the raw results rather than 'total organic carbon'. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate TOC levels indicative of good, fair and poor health (refer Table 3 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in TOC values over time and nt (not tested) indicates insufficient data were available for trend analysis.

Total nitrogen

The highest average sediment TN value recorded was at Humphreys Drive in 2011 followed by Avon River Mouth in 2016 (Figure 7). The next highest values occurred at Avon Heathcote in 2011 and Sandy Point in 2007. The lowest TN values overall were from Discharge Point, Humphreys Drive and Causeway in 2016 and 2021, and at Pleasant Point Jetty in 2007 and 2021.

There was a statistically significant decrease in TN over time (2007–2021) for Discharge Point, while for Plover Street there was an increase. At Discharge Point, the average TN value in 2021 was less than half that in 2007, while for Plover Street the overall increase was non-linear and on a smaller scale. There was no significant trend detected for the Humphreys Drive and Pleasant Point Jetty sites. The relatively high average TN value recorded for Humphreys Drive in 2011 was preceded and followed by much lower values. Trends could not be assessed for any other site due to limited data. Based on visual inspection of our plots, TN values for Avon River Mouth and Plover Street exhibited a slight increase and decrease, respectively, over time.

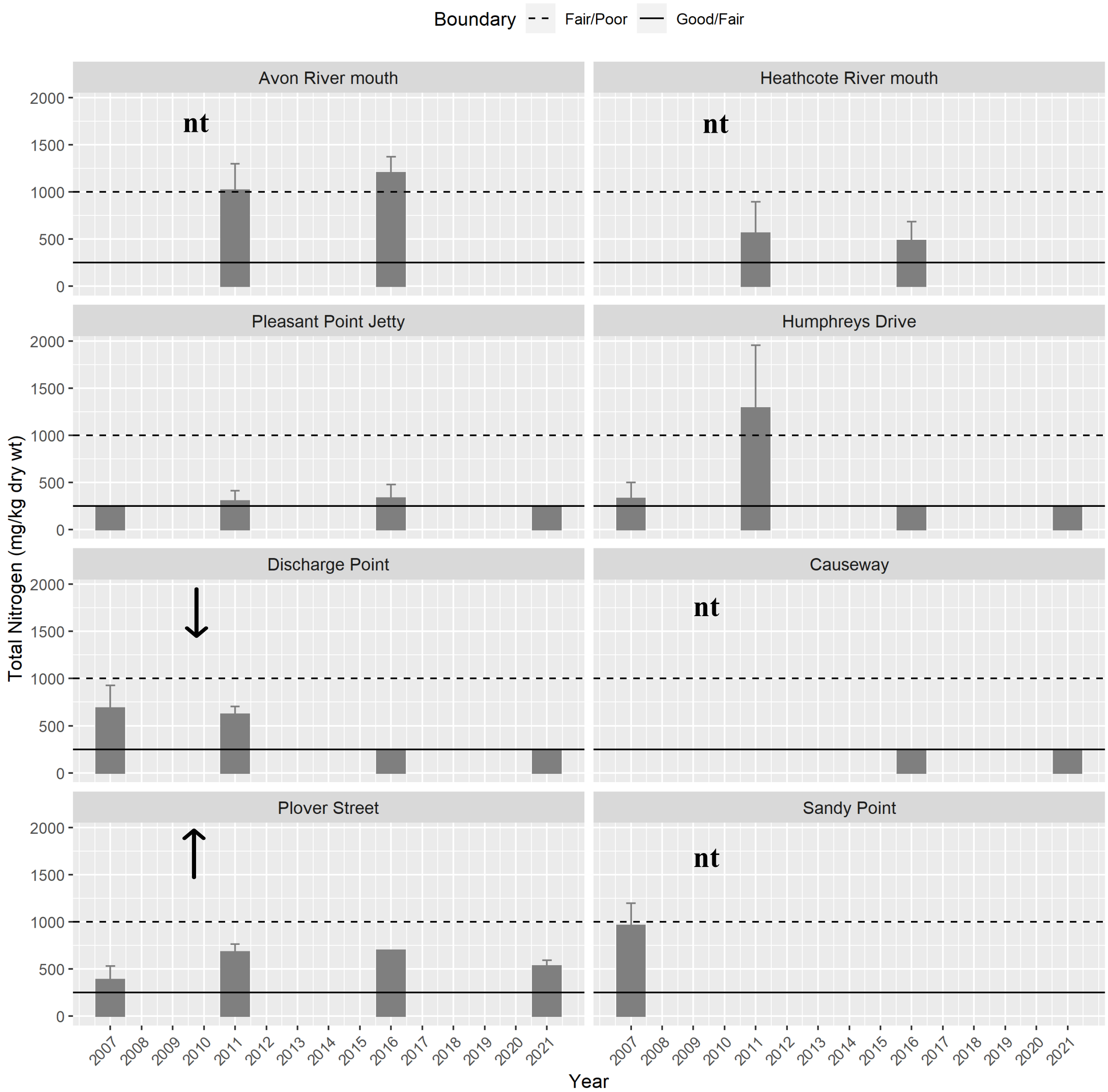

Figure 7. Sediment total nitrogen (TN, mg/kg dry weight) at monitoring sites in Ihutai from 2007 to 2021. Note that sampling only occurred during some years. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate TN levels indicative of good, fair and poor health (refer Table 3 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in TN values over time and nt (not tested) indicates insufficient data were available for trend analysis.

Total recoverable phosphorus

The highest average sediment TRP values in the monitoring data were recorded at the Avon River Mouth site, particularly in 2016, the most recent value available (Figure 8). The next highest values were present at the Heathcote River Mouth (2016) and Discharge Point (2007) sites. All other TRP values at the sites were lower and relatively similar to each other.

There was a statistically significant decrease in TRP over time (2007 to 2021) for Discharge Point (Figure 8). No significant trend was detected for the Humphreys Drive, Pleasant Point Jetty and Plover Street sites. Trends over time were not able to be assessed for the other monitoring sites due to limited data. Based on visual inspection of our plots, average TRP increased by around one third at the Avon River Mouth site from 2011 to 2016 while those at Heathcote and Causeway stayed roughly the same.

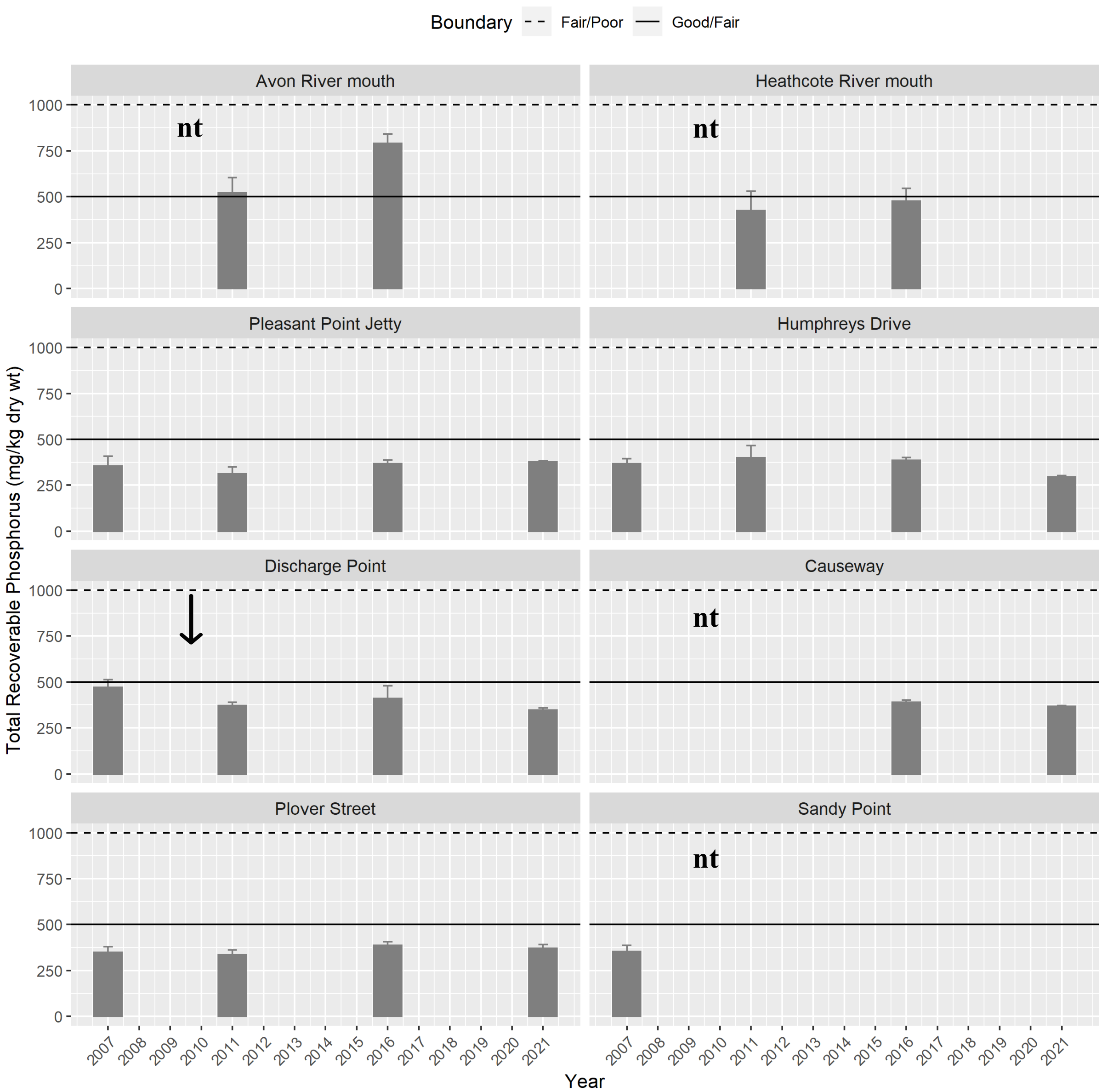

Figure 8. Sediment total recoverable phosphorus (TRP, mg/kg dry weight) at monitoring sites in Ihutai from 2007 to 2021. Note that sampling only occurred during some years. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate TRP levels indicative of good, fair and poor health (refer Table 4 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in TRP values over time and nt (not tested) indicates insufficient data were available for trend analysis.

Chlorophyll-*a*

The highest average benthic chl-*a* values recorded were at the Causeway site in 2016 and 2021 (Figure 9). Values recorded at all other sites were lower than this, especially for 2011 during which the lowest values overall were recorded for all sites except Humphreys Drive.

There was a statistically significant increase in chl-*a* over time at the Humphreys Drive and Pleasant Point Jetty sites. This trend was largest at Humphreys Drive, with around a one-third increase in average value from 2007 to 2021. For Pleasant Point Jetty, the lowest value recorded was recorded in 2011. No significant trend over time was detected for the Discharge Point and Plover Street sites. Trends over time could not be assessed for the other monitoring sites due to limited data. Based on visual observation of our plots, average chl-*a* at the Avon and Heathcote river mouth sites more than doubled in value from 2008 to 2016.

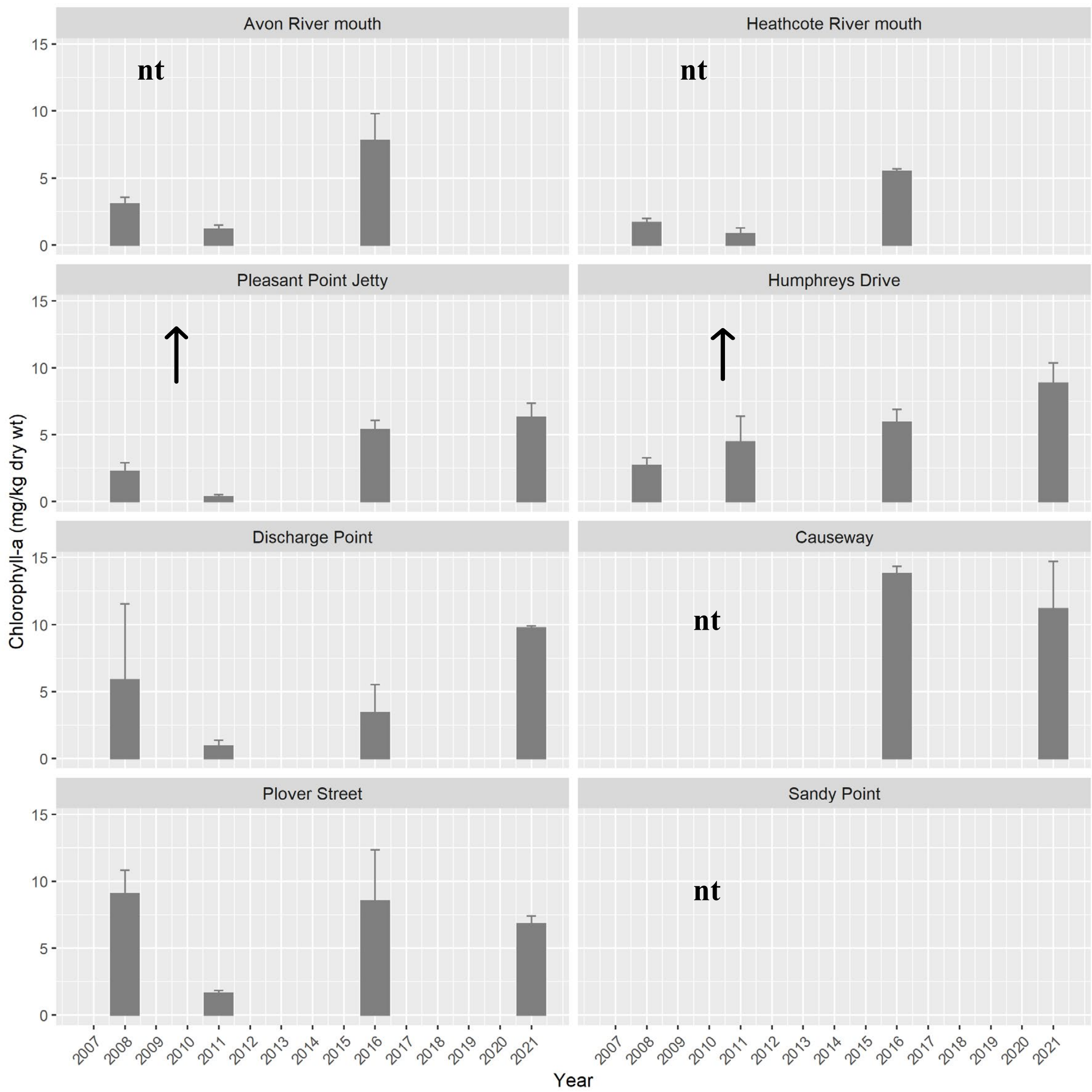

Figure 9. Benthic chlorophyll-*a* (chl-*a*, mg/kg dry weight) at monitoring sites in Ihutai from 2007 to 2021. Note that sampling only occurred during some years. Any values below the analytical detection limit were assigned a value half of the detection limit. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in chl-*a* values over time and nt (not tested) indicates insufficient data were available for trend analysis.

Metal contamination

There was a general pattern of higher sediment metals values at the Avon River mouth site compared to at all other sites. At all sites, average concentrations for all metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc) were below the DGV (Figure 10 to Figure 16). On most sampling occasions, copper, lead and zinc levels were also below the FEC-upper threshold that we used as the boundary between good and fair health. The exception was the most recent sampling at the Avon River Mouth in 2016. Here, copper and lead levels were greater than the FEC-upper limit and copper levels were also above a threshold where cockle numbers may be reduced by 50% (*Austrovenus* EC50). On at least one sampling occasion, copper and lead levels at the Avon River Mouth, Discharge Point, Heathcote River Mouth, Humphreys Drive and Sandy Point sites were above a more conservative threshold that represents the point at which we would expect to see a 50% decrease in the abundance of 5% of the taxa (FEC lower – adjusted).

Trends over time could be assessed only for copper, lead and zinc and only for the Discharge Point, Humphreys Drive, Pleasant Point Jetty and Plover Street sites. There was a slight but statistically significant increase in copper and lead at Plover Street (Figure 13, Figure 14). All three metals significantly decreased at Discharge Point, while lead and zinc both decreased at Humphreys Drive. Based on visual inspection of our plots, concentrations of copper, lead, nickel and zinc at Avon River Mouth increased over time from 2011 to 2016 (not able to be assessed for arsenic). Concentrations of copper and lead at Heathcote River Mouth appeared to stay roughly the same, with a slight increase in zinc.

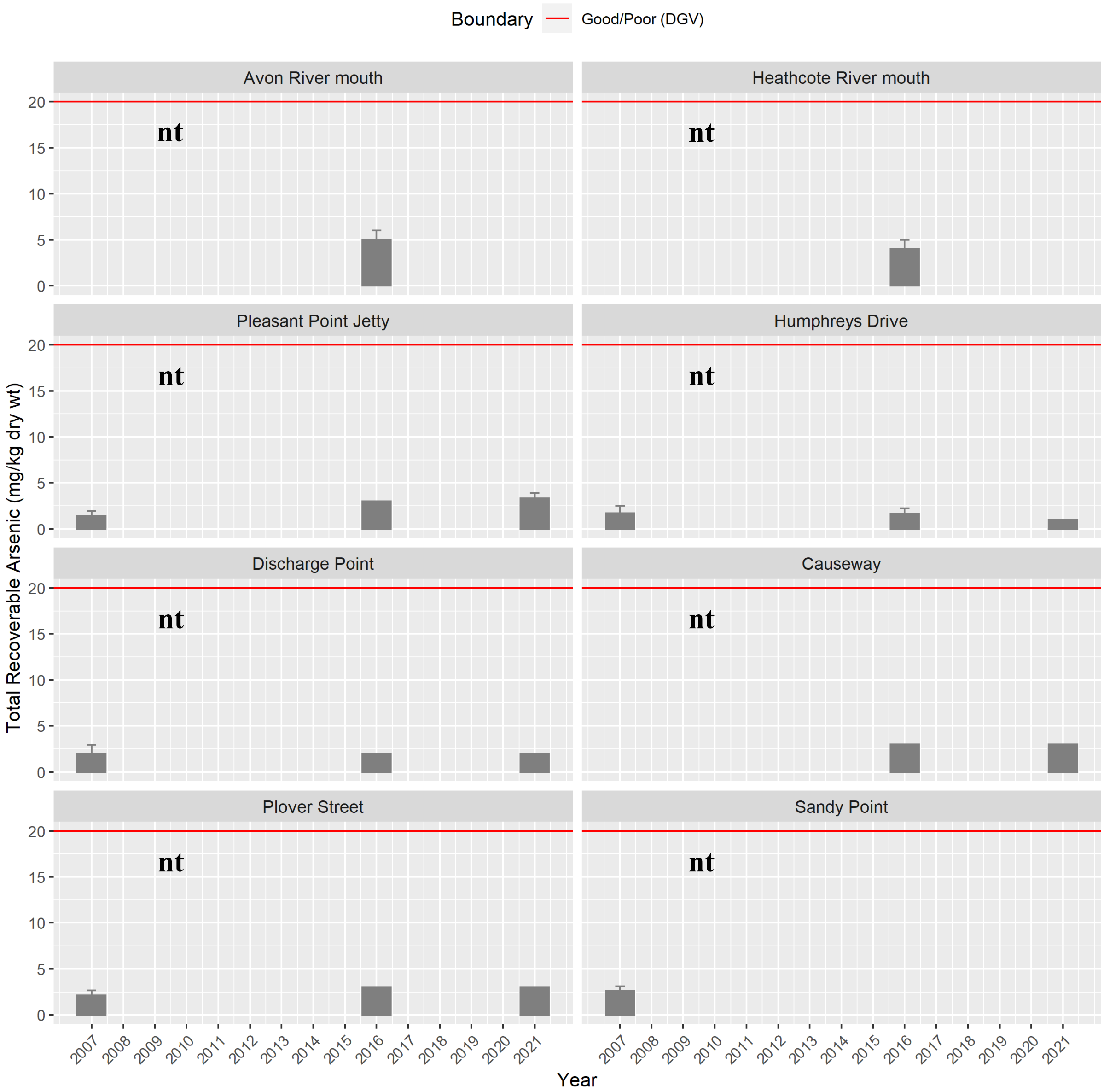

Figure 10. Sediment total recoverable arsenic (As, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate As levels indicative of good and poor health (refer Table 5 for details). Insufficient data were available for trend analysis (nt = not tested).

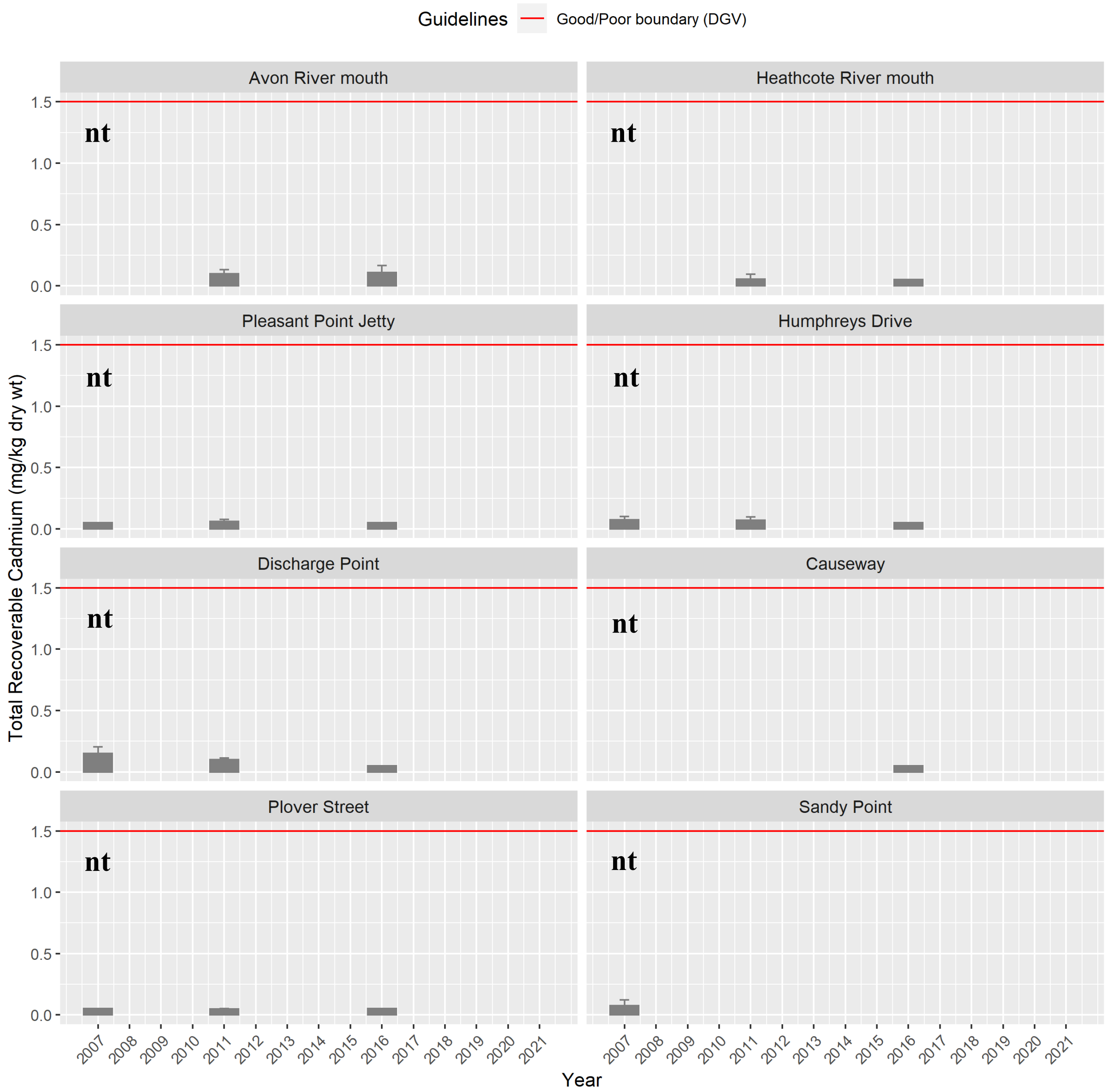

Figure 11. Sediment total recoverable cadmium (Cd, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Cd levels indicative of good and poor health (refer Table 5 for details). Insufficient data were available for trend analysis (nt = not tested).

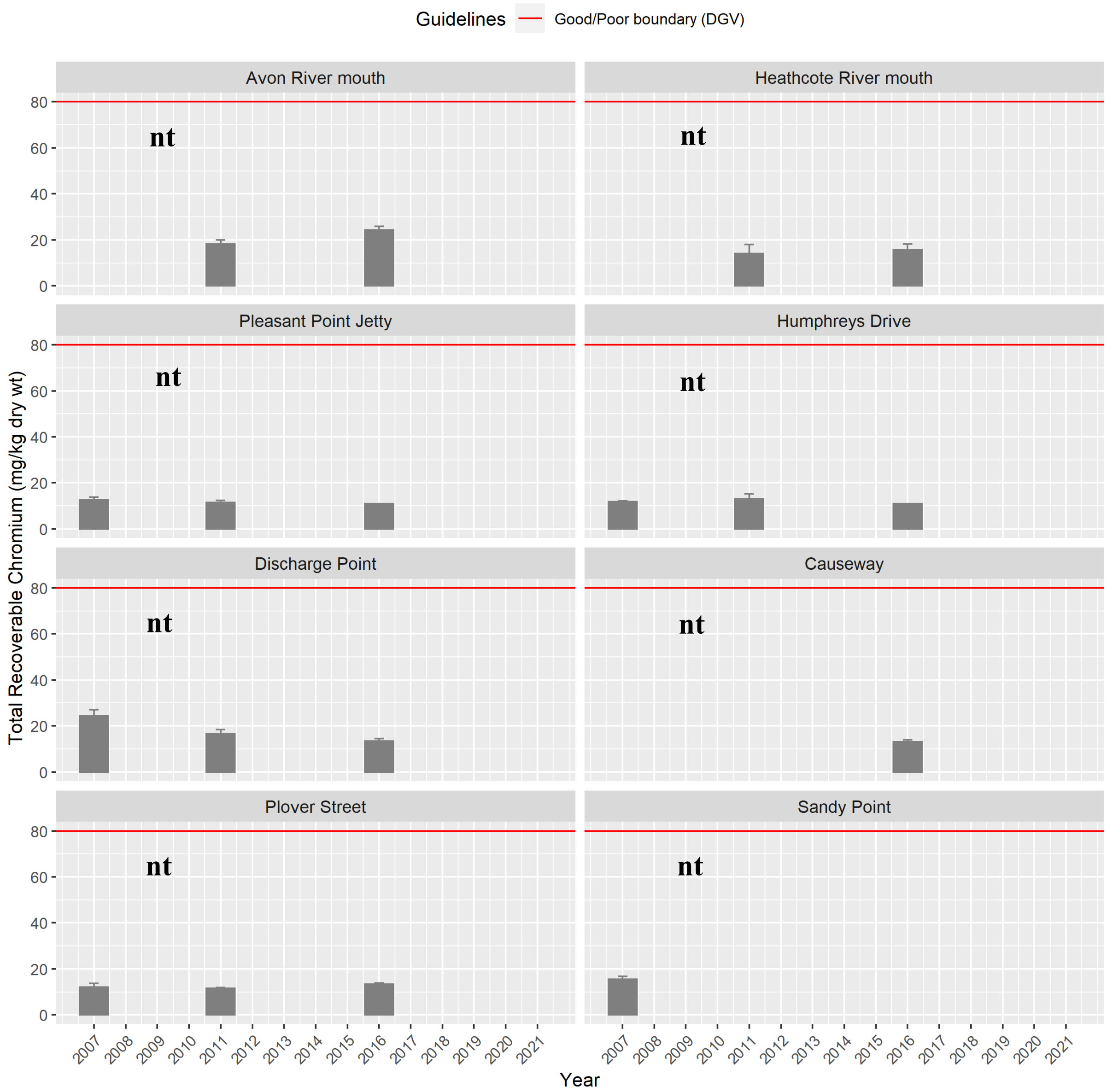

Figure 12. Sediment total recoverable chromium (Cr, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Cr levels indicative of good and poor health (refer Table 5 for details). Insufficient data were available for trend analysis (nt = not tested).

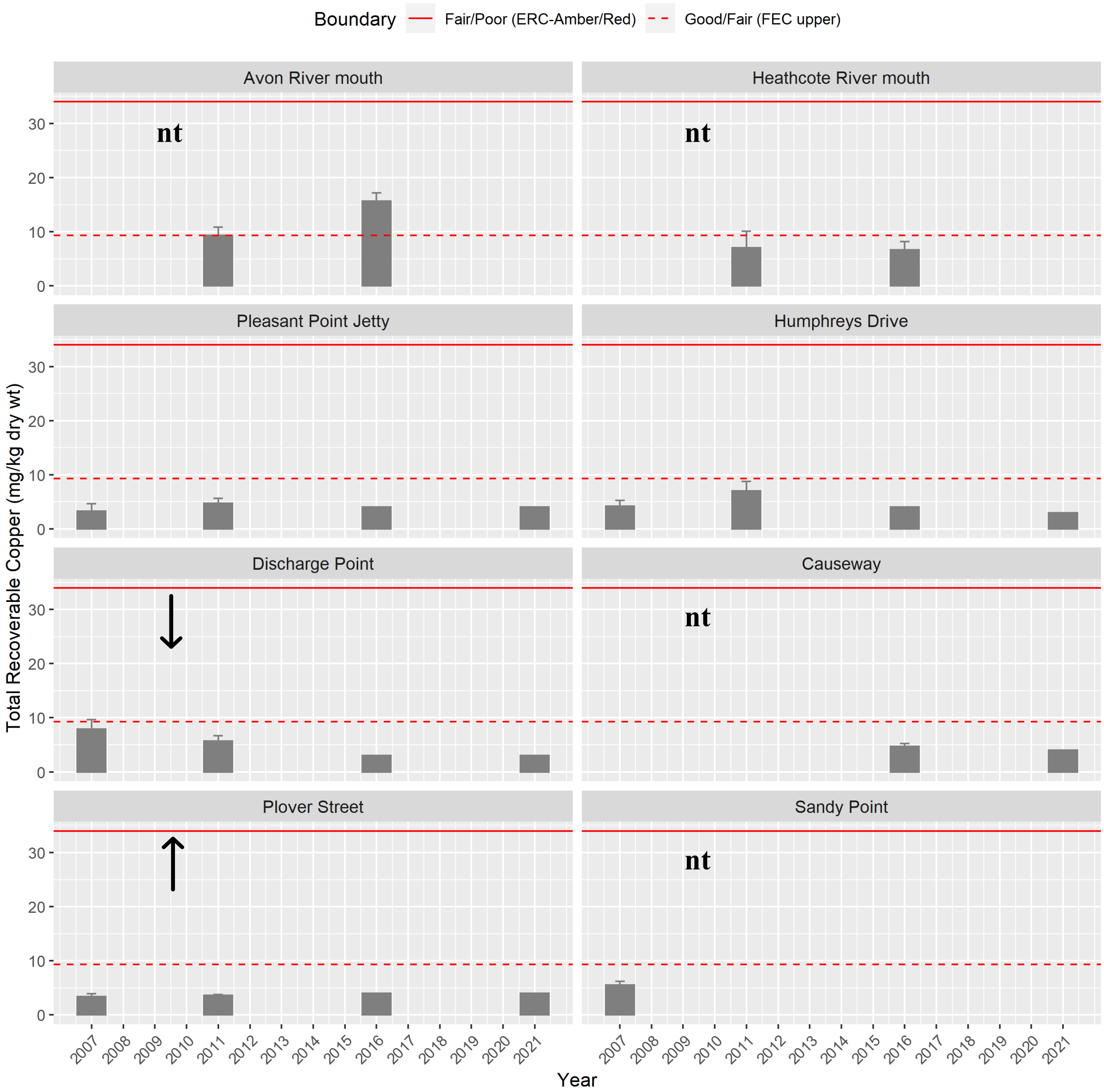

Figure 13. Sediment total recoverable copper (Cu, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Cu levels indicative of good, fair and poor health (refer Table 5 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in Cu values over time and nt (not tested) indicates insufficient data were available for trend analysis.

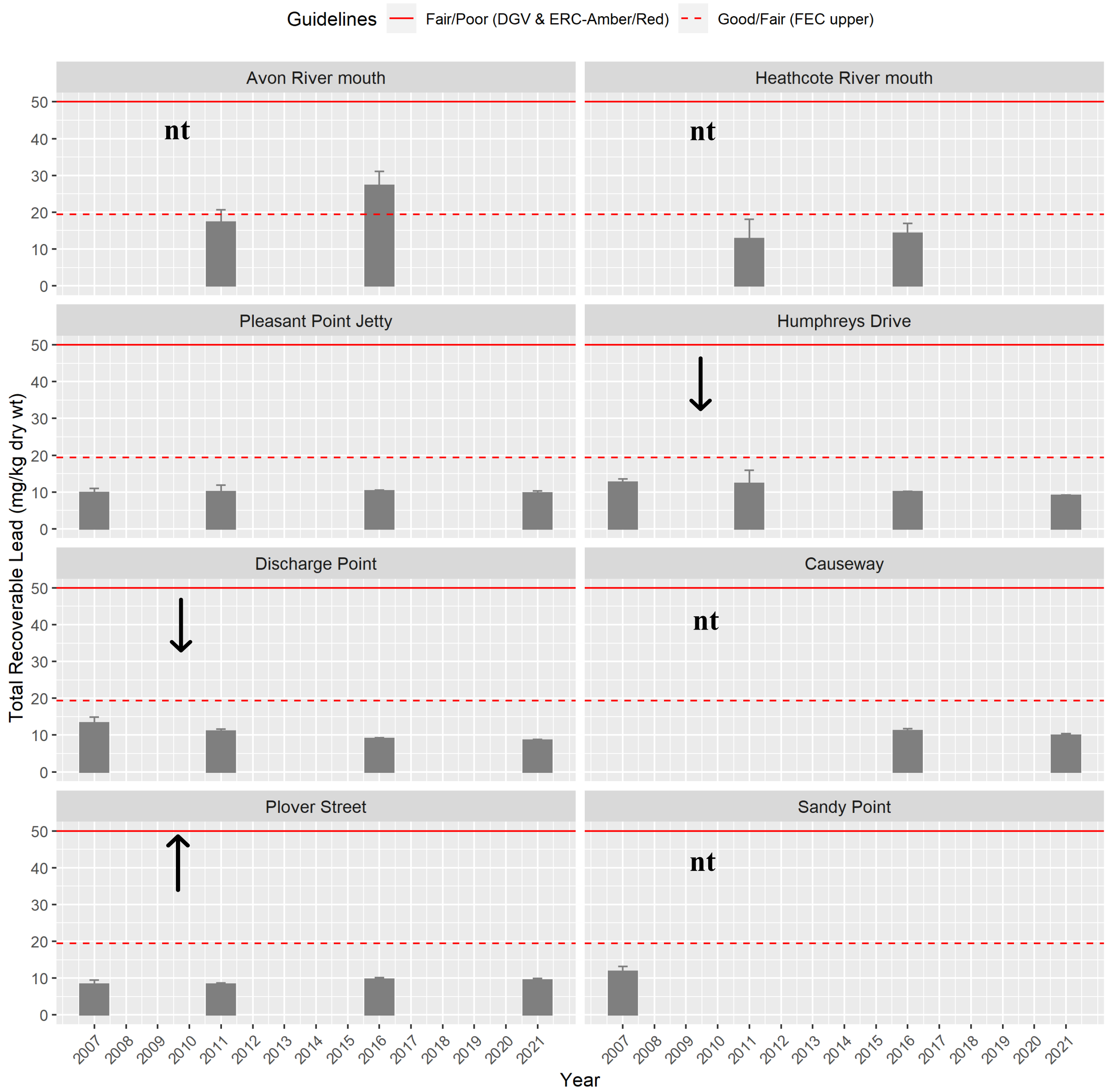

Figure 14. Sediment total recoverable lead (Pb, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Pb levels indicative of good, fair and poor health (refer Table 5 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in Pb values over time and nt (not tested) indicates insufficient data were available for trend analysis.

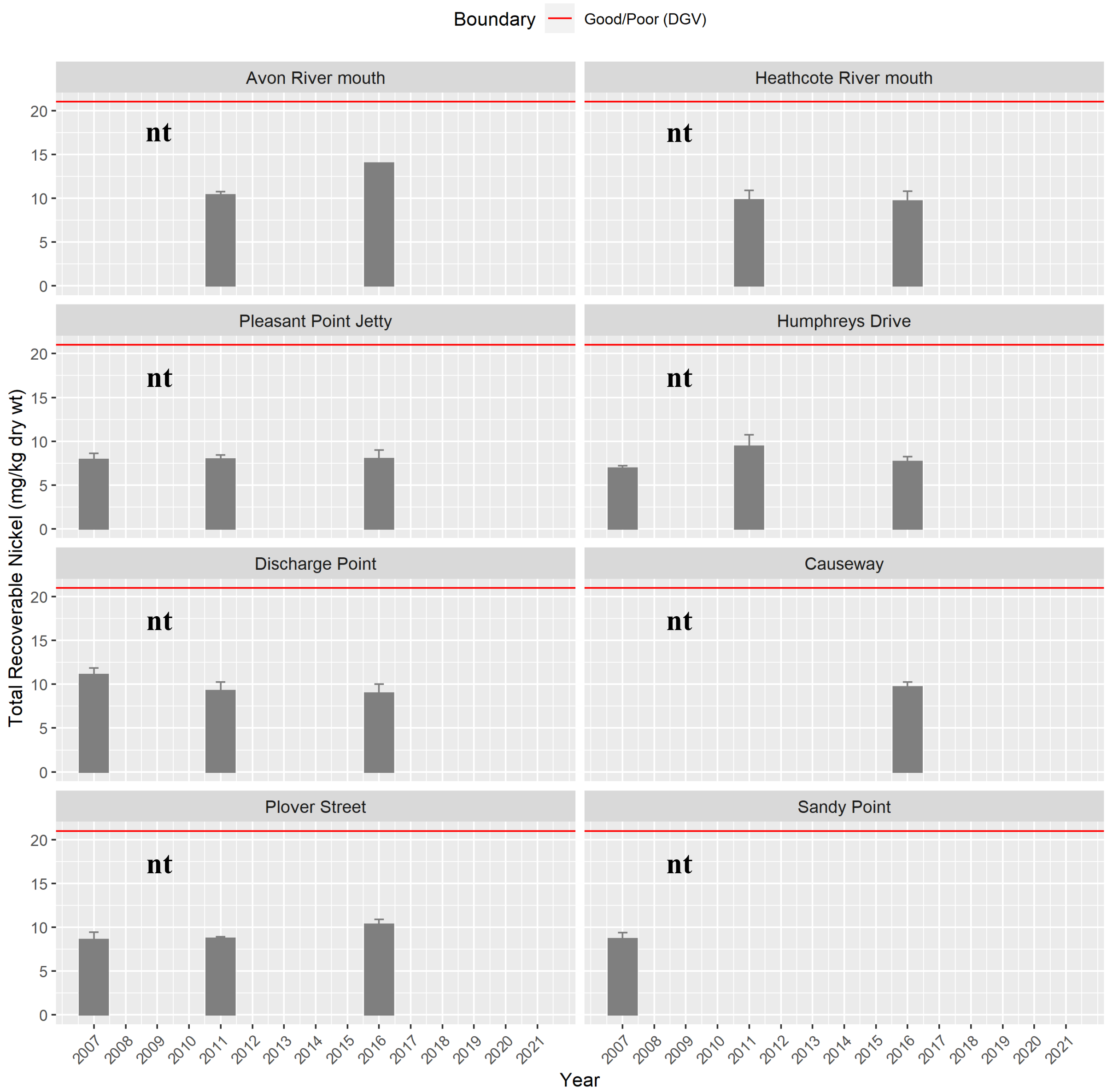

Figure 15. Sediment total recoverable nickel (Ni, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021. Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Ni levels indicative of good and poor health (refer Table 5 for details). Insufficient data were available for trend analysis (nt = not tested).

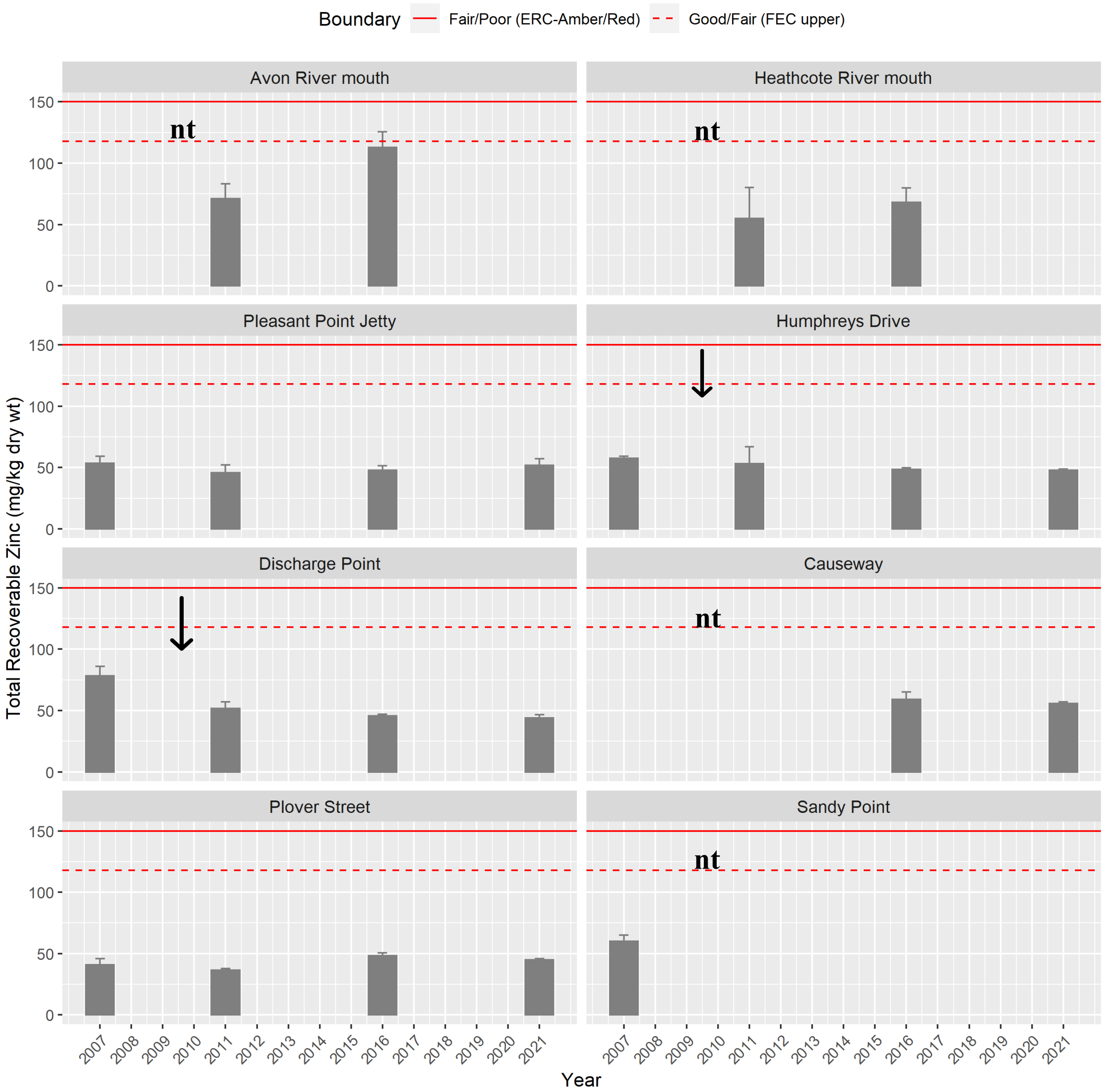

Figure 16. Sediment total recoverable zinc (Zn, mg/kg dry weight, average ± standard deviation) at monitoring sites in Ihutai from 2007 to 2021 . Any values below the analytical detection limit were assigned a value half of the detection limit. Horizontal lines indicate Ni levels indicative of good, fair and poor health (refer Table 5 for details). Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in Ni values over time and nt (not tested) indicates insufficient data were available for trend analysis.

3.2. Biota

3.2.1. Infauna communities

Community composition

The composition of infauna communities at the two sites closest to the estuary entrance (Causeway and Plover Street) was relatively similar and distinct from all other sites over the duration of the monitoring period (Figure 17). Based on highest average similarity (Appendix 2), these communities were characterised by species such as cockles/tuaki and the polychaete worm *Aonides* sp., which are sensitive to mud (Robertson et al. 2015). The communities also had a relatively high within-site similarity of 65% for Plover Street and 75% for Causeway (Appendix 2).

At the two river mouth sites (Avon and Heathcote), communities were relatively distinct from the other sites and from each other. These communities were characterised by the molluscs *Potamopyrgus* sp. (Avon) and *Arthritica* sp. (Avon and Heathcote) and the tunnelling mud crab *Austrohelice crassa* (Heathcote). *A. crassa* has a strong affinity for elevated mud concentrations, *Arthritica* sp. is tolerant of mud, and *Potamopyrgus* can be present at various mud concentrations (Robertson et al. 2015). *Arthritica* sp. can also indicate ‘moderately enriched conditions’ (Keeley et al. 2012). Within-site community similarity was 54% for Heathcote and 59% for Avon.

There was some overlap in community composition between the Discharge Point, Humphreys Drive and Pleasant Point Jetty sites. *Arthritica* sp. and the polychaete *Scolecolepides*[10] *benhami* were the two taxa with the highest contribution to similarity for all three of these sites. Within-site similarity for Humphreys Drive was relatively low (43%), but higher for Pleasant Point Jetty (58%) and Discharge Point (60%).

[10] According to Robertson et al. (2015), *Scolecolepides* spp. has a relatively positive response to higher sediment mud contents in New Zealand estuaries.

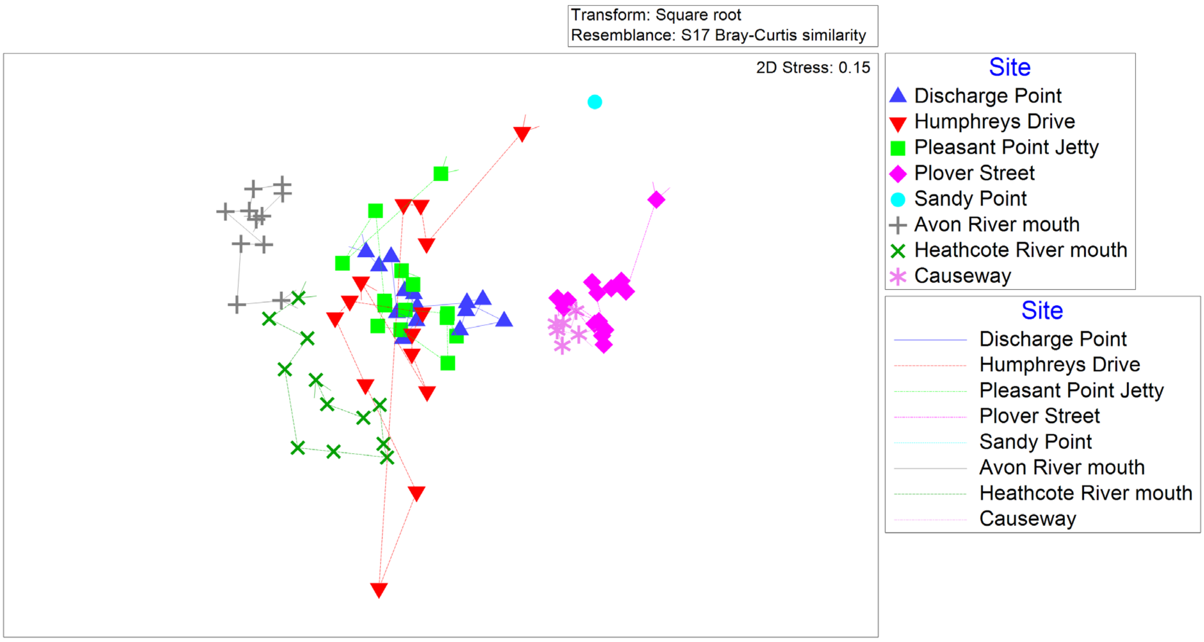

Figure 17. Differences in infauna community composition (based on Bray-Curtis similarity) among the seven monitored sites in Ihutai and associated tidal river mouths from 2007 to 2021 monitoring data illustrated using multi-dimensional scaling. Each symbol on the plot represents averaged data from one sampling year at any given site. Survey years not shown. A time trajectory is also displayed for each site.

Benthic Health Models

All the sites in Ihutai had a good fit with the BHMs, indicating that they can reliably be used to assess the health of these estuaries (refer Appendix 4 for details). Mud BHM scores at most of the monitored sites in Ihutai indicate moderate to very high impact from sedimentation compared to other estuarine sites across New Zealand (Figure 18). Highest impact from sedimentation was observed at the two river mouth sites (Avon and Heathcote) and Humphreys Drive. Lowest impact from sedimentation was observed at Plover Street and Sandy Point in 2007. However, there has been a statistically significant increase in Mud BHM scores at Plover Street since 2007, with the most recent sampling in 2021 indicating high impact from sedimentation. Mud BHM scores have also significantly increased at Humphreys Drive, from moderate impact in 2007 to very high impact in 2021. Several of the sites (Avon River Mouth, Pleasant Point Jetty and Humphreys Drive) showed an increase in Mud BHM scores following the earthquakes in 2010 and 2011.

Metals BHM scores at most of the monitored sites in Ihutai indicate that the impact from metals is moderate to high compared to other estuarine sites across New Zealand but indicative of fair health (Figure 19). The impact from metal contamination appears to be getting worse at Plover Street and Humphreys Drive, increasing from low impact (good health) in 2007 to high impact (fair health) in 2021. This increasing trend in Metals BHM scores was statistically significant at Plover Street. At

Humphreys Drive, a big increase in Metals BHM scores occurred after the 2011 earthquake. Conversely, Metals BHM scores at the Avon River Mouth site have decreased from very high impact (poor health) in 2008 to high impact (fair health) in 2020 ($p = 0.051$). This improvement coincided with the removal of the Christchurch City wastewater discharge into the estuary in 2010. The most recent BHM scores for each site are shown in Figure 20.

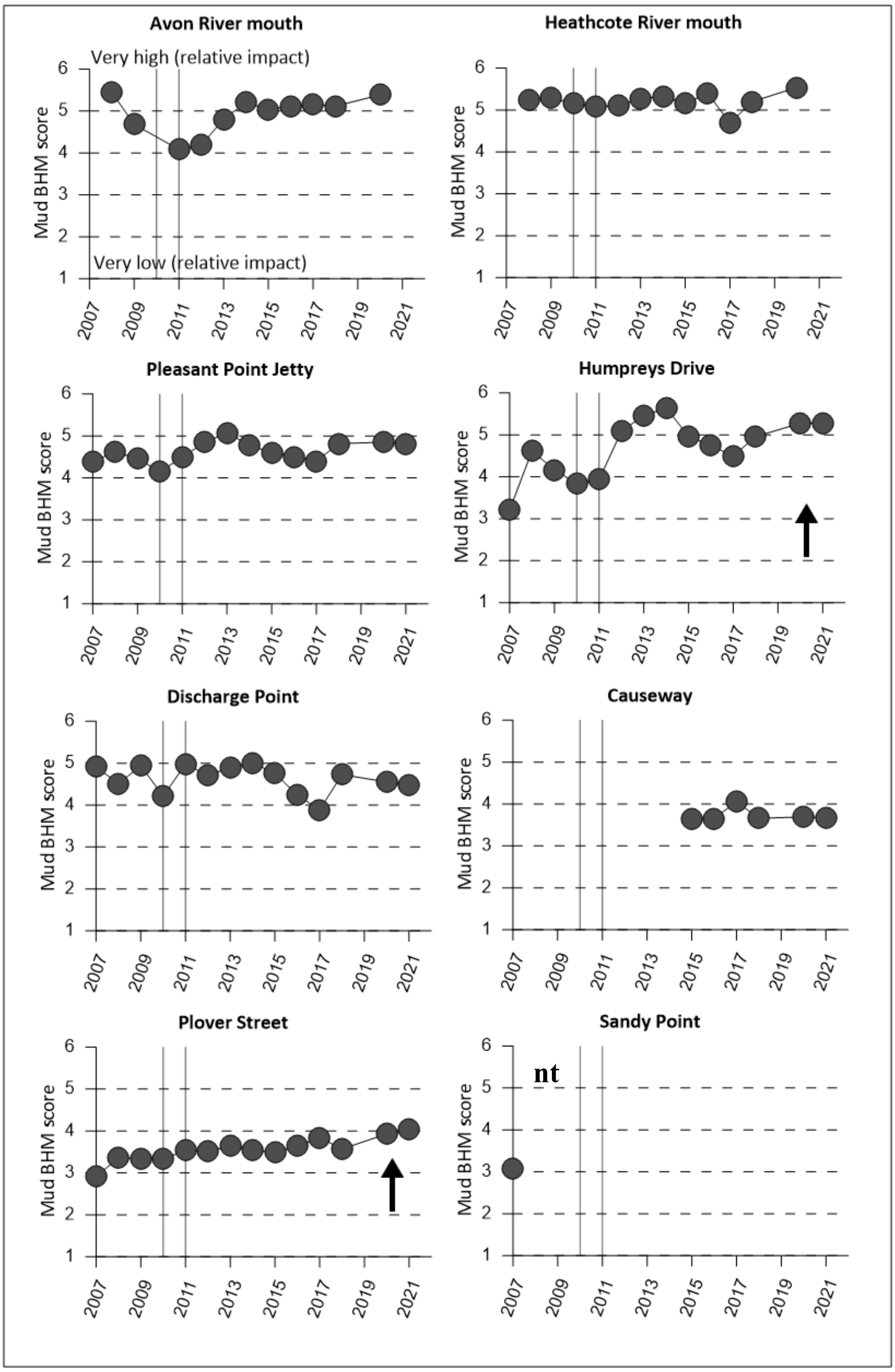

Figure 18. Mud Benthic Health Model (BHM) scores between 2007 and 2021 at eight sites in Ihutai. Vertical lines indicate the removal of the Christchurch City wastewater into the estuary (2010) and the earthquake sequence occurring in 2010 and 2011. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in Mud BHM scores over time. A trend was not able to be assessed at Sandy Point due to insufficient data (nt = not tested).

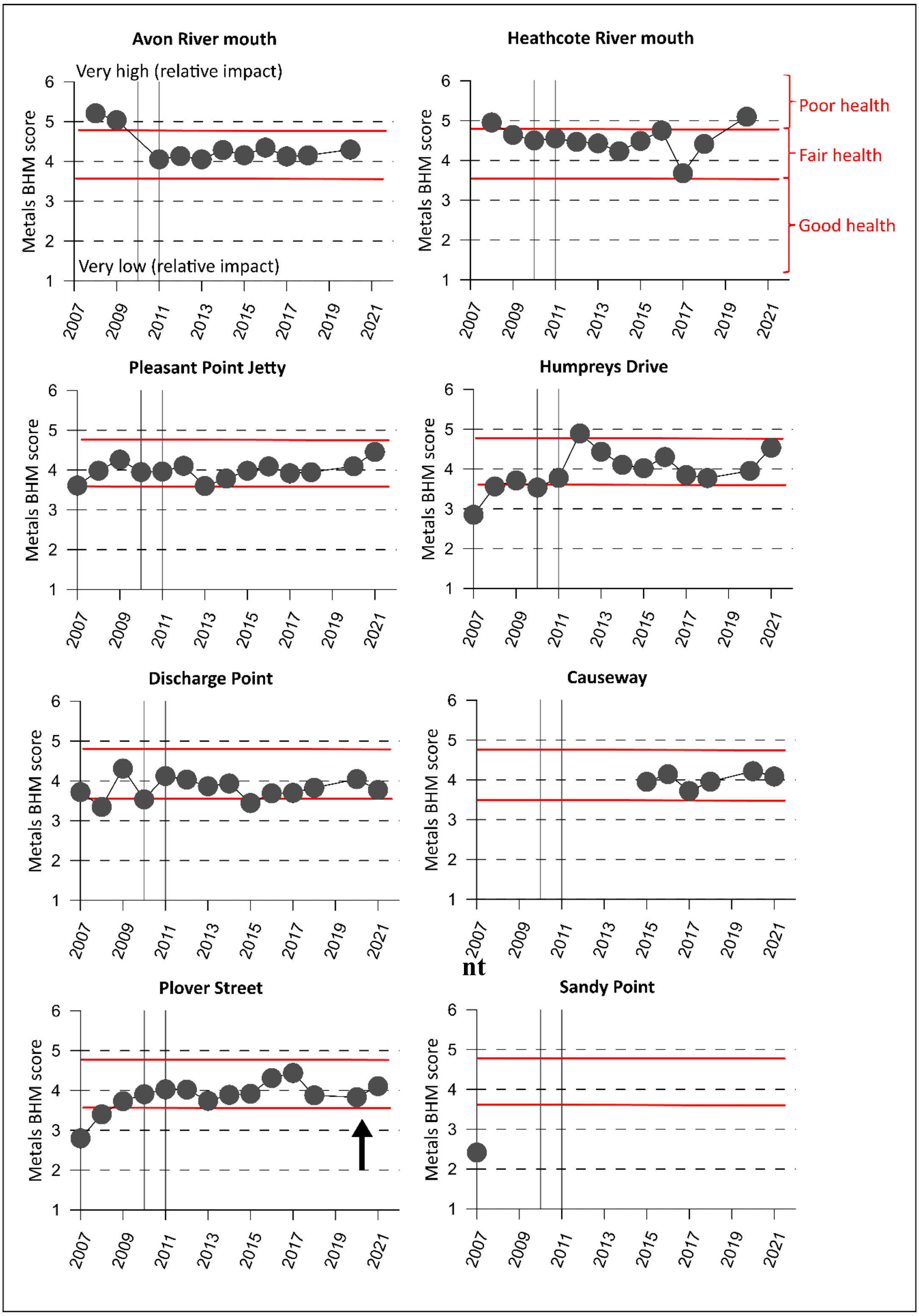

Figure 19. Metals Benthic Health Model (BHM) scores between 2007 and 2021 at eight sites in Ihutai. Indications of absolute health in a New Zealand context are provided in red (y-axis on the plot) for the Metals BHM. Vertical lines indicate the removal of the Christchurch City wastewater into the estuary (2010) and the earthquake sequence occurring in 2010 and 2011. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in Metals BHM scores over time. A trend was not able to be assessed at Sandy Point due to insufficient data (nt = not tested).

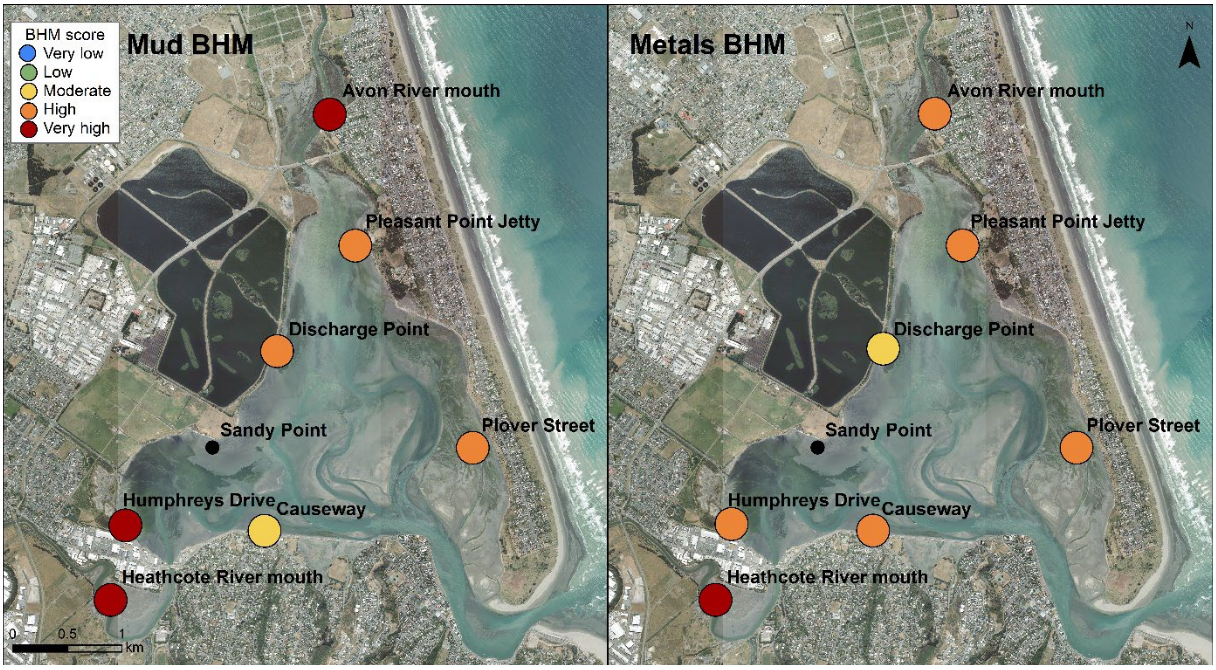

Figure 20. Recent Benthic Health Model (BHM) scores for mud (left) and metals (right) at seven sites in Ihutai. Circle colours indicate the BHM score category in 2020-2021. BHM scores for Sandy Point are not shown because it was last sampled in 2007.

Community indices

The average abundance of infauna was generally highest at the Avon River Mouth site (Figure 21), while the lowest abundances for most years occurred at the Heathcote River Mouth site. Abundance values at the other sites were not too dissimilar from each other overall, although differences in patterns over time were observed (see below). There was a statistically significant increase overall in infauna abundance over time at the Avon River Mouth, Humphreys Drive and Plover Street sites. The trends over time for these sites were not linear, with both Avon and Plover Street values peaking around the middle of the monitoring period (2013 and 2012, respectively) and those for Humphreys peaking closer to either end of the monitoring period (2010 and 2020). A significant decrease in abundance over time was detected at Heathcote River Mouth and Discharge Point. The trend for Discharge Point was also not linear, with highest values recorded during 2012 and 2013. No significant trend in abundance over time was detected for the Causeway and Pleasant Point Jetty sites.

The number of taxa overall was not too dissimilar between the sites, although the highest values were often observed at Plover Street from 2014 onwards and lower values were observed at the Heathcote River Mouth (Figure 22). There was a statistically significant increase in the number of infauna taxa over time at all sites except for Avon River Mouth and Causeway, for which no significant trend was detected. The largest increase was seen for Plover Street at which values more than doubled from 2007 to 2021. Conversely, the increase for some sites (especially Heathcote River Mouth) was very small and unlikely to be ecologically important. Trends at many of the sites were not linear, such as at Pleasant Point Jetty where peak values occurred 2016 and 2017 rather than in most recent years and at Humphreys Drive where the highest value occurred in 2016.

The average Shannon Weiner diversity index was not too dissimilar across and between sites over time (Figure 23). The highest values were recorded at the Pleasant Point Jetty (2016), Discharge Point (2018, 2021) and Plover Street (2020, 2021) sites. The lowest diversity was recorded for Sandy Point (2007) and Humphreys Drive (2010, 2011). There was a statistically significant increase in infauna diversity over time at the Heathcote River Mouth, Pleasant Point Jetty, Humphreys Drive, Discharge Point and Plover Street sites, while there was a significant decrease over time at the Avon River Mouth site. Again, many of these trends were not linear, for example at Plover Street values dropped until 2012 and then rose after that and at Pleasant Point Jetty values peaked in 2016. No significant trend in diversity was detected for the Causeway sites.

Taxa evenness was not too dissimilar between and within sites. The highest values recorded overall were at Pleasant Point Jetty and Humphreys Drive in 2007 as well as at Plover Street and Discharge Point in 2021 (Figure 24). Lowest values occurred at Humphreys Drive (2010) and Plover Street (2012). There was a statistically significant increase in evenness over time at the Heathcote River Mouth and Discharge Point sites. No significant trend was detected for any of the other sites (excluding Sandy Point, for which a trend was not tested).

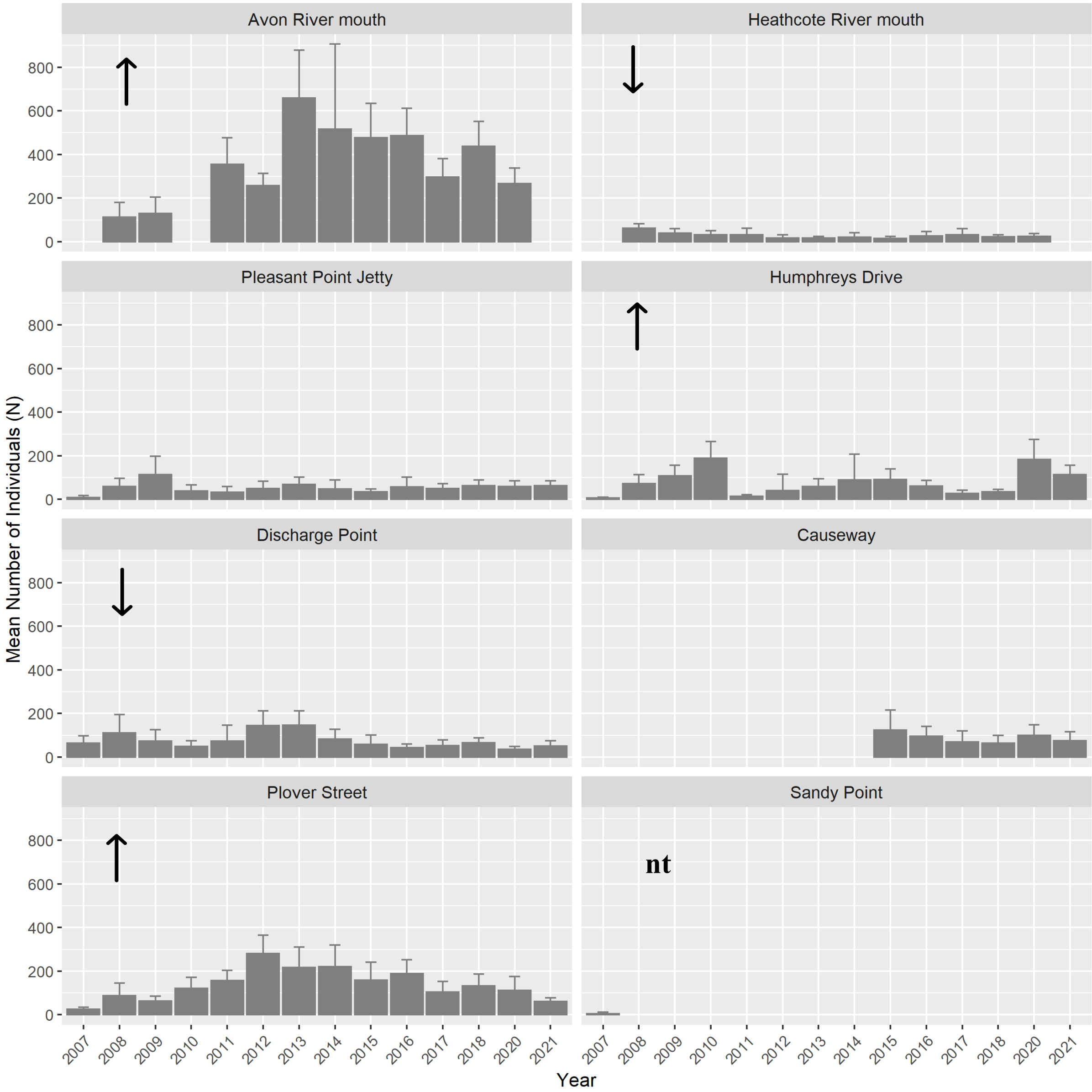

Figure 21. Total infauna abundance per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

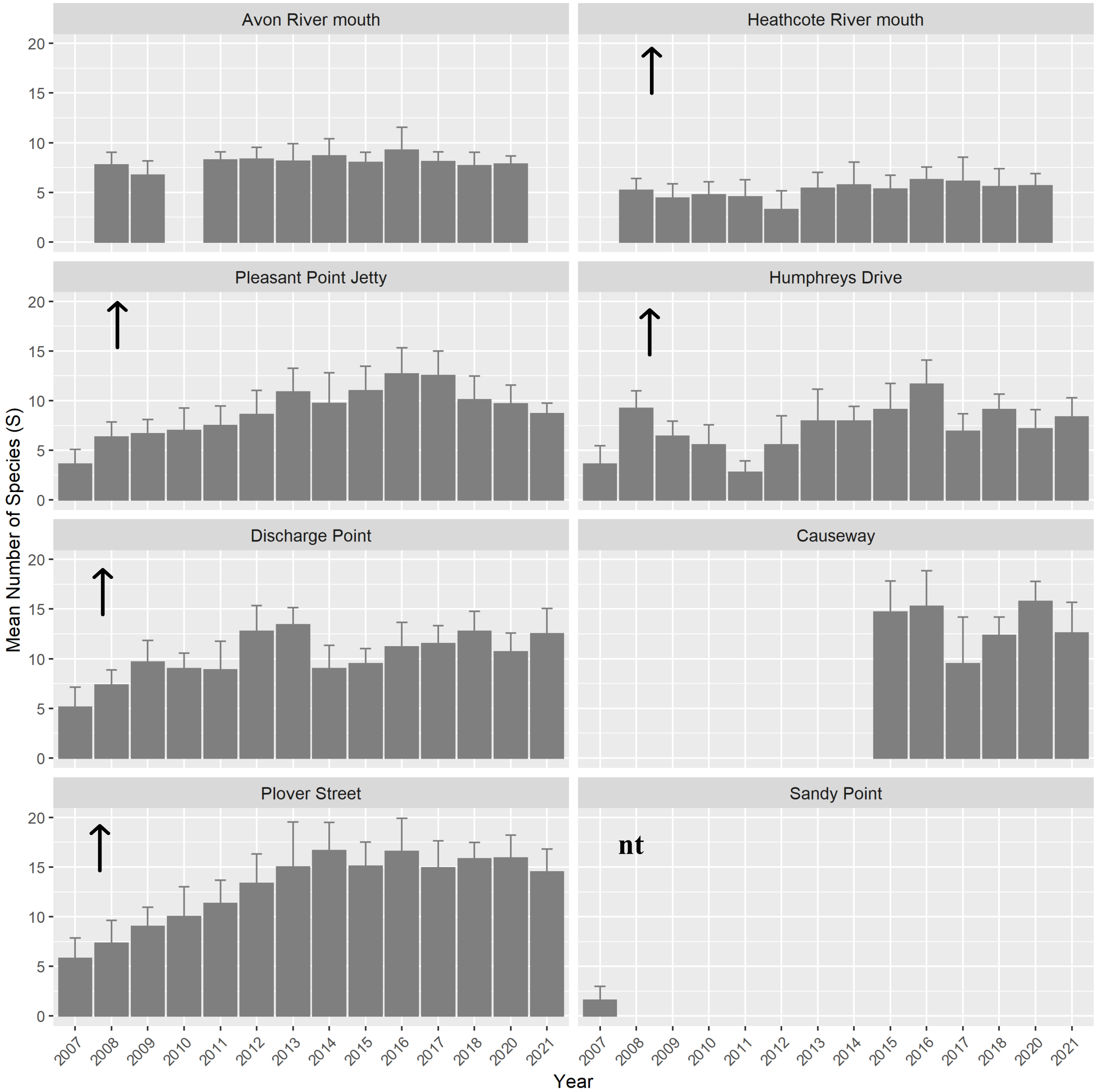

Figure 22. Total number of infauna taxa per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the number of taxa over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

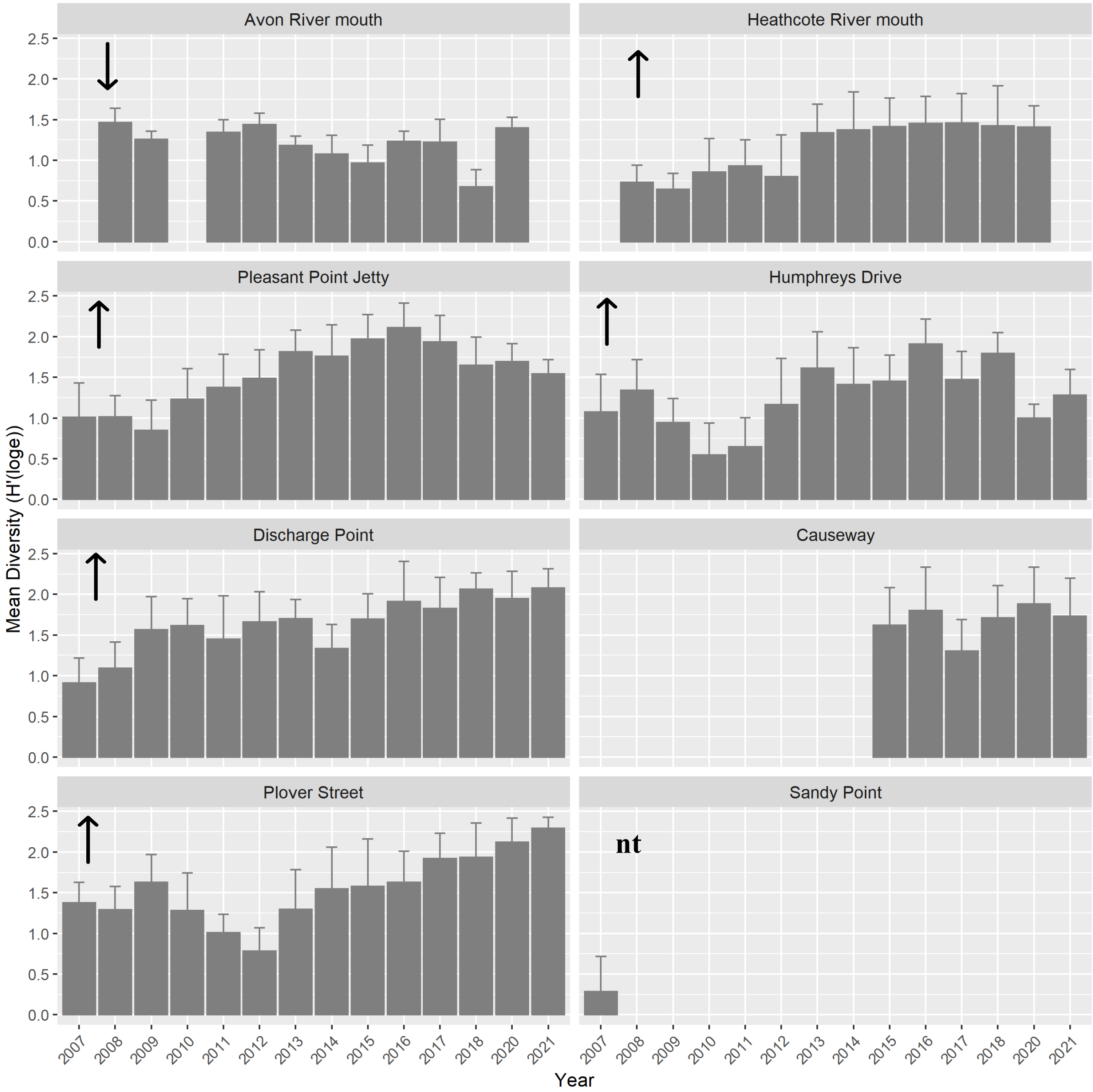

Figure 23. Total infauna diversity per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in diversity over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

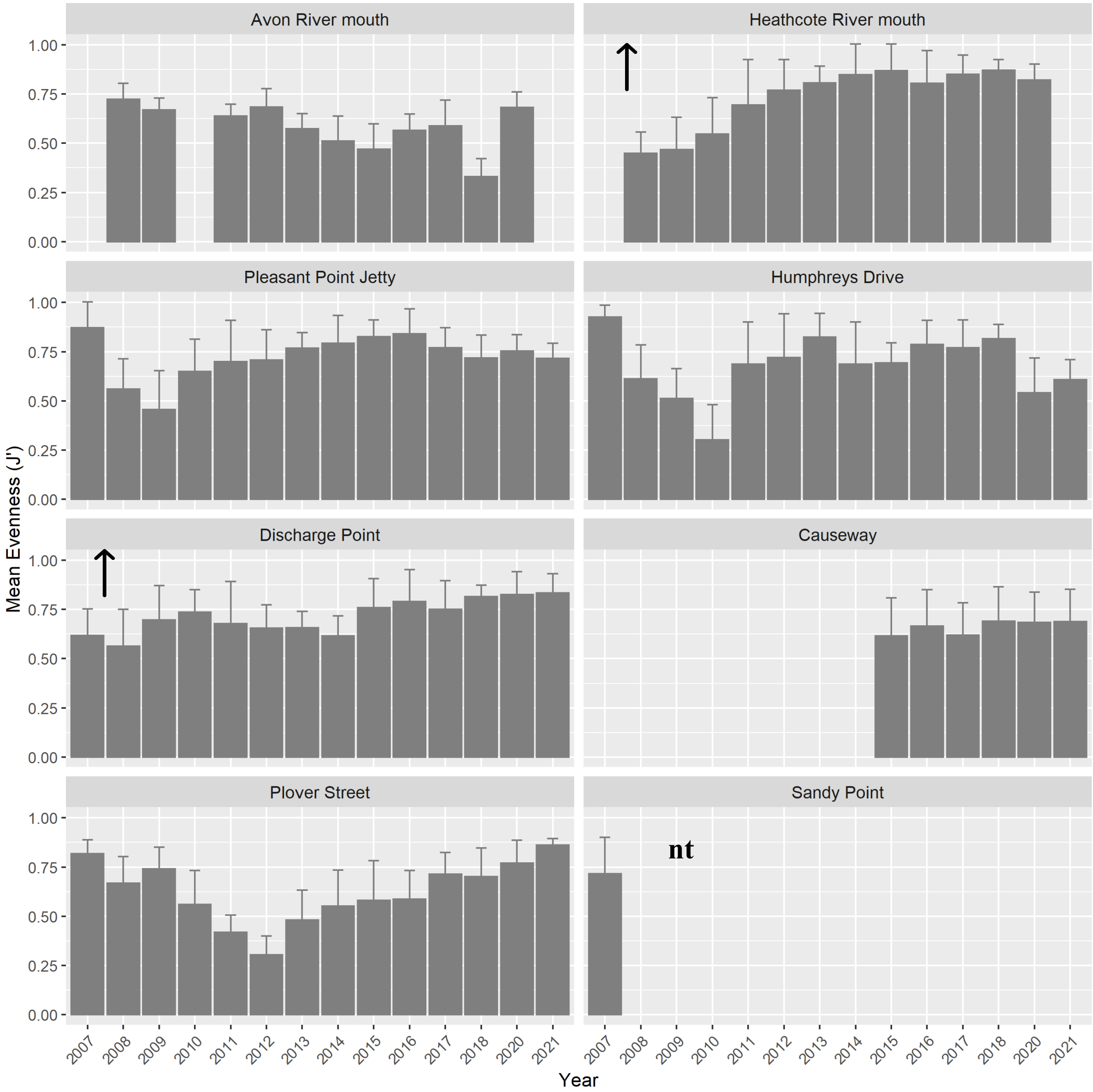

Figure 24. Total infauna evenness per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in evenness over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

3.2.2. Indicator infauna taxa

Capitellid worms

The average abundance of capitellid worms was highly variable within sites and on many sampling occasions. They were most abundant at Humphreys Drive and Discharge Point during certain years, followed by Plover Street (Figure 25). The highest abundances overall occurred at Humphreys Drive in 2010 and 2020. At other sites, capitellid abundance was much lower (usually more than around ten times lower). There was a statistically significant increase in capitellid abundance at the Heathcote River Mouth, Pleasant Point Jetty and Plover Street sites. These increases were small in context of the highest values recorded but were increases none the less. They were also not linear, with highest values generally recorded between the years of 2013 to 2018/2020 and with relatively low numbers in 2021. No significant trend in Capitellidae spp. was detected for the Avon River Mouth, Discharge Point, Humphreys Drive and Causeway sites.

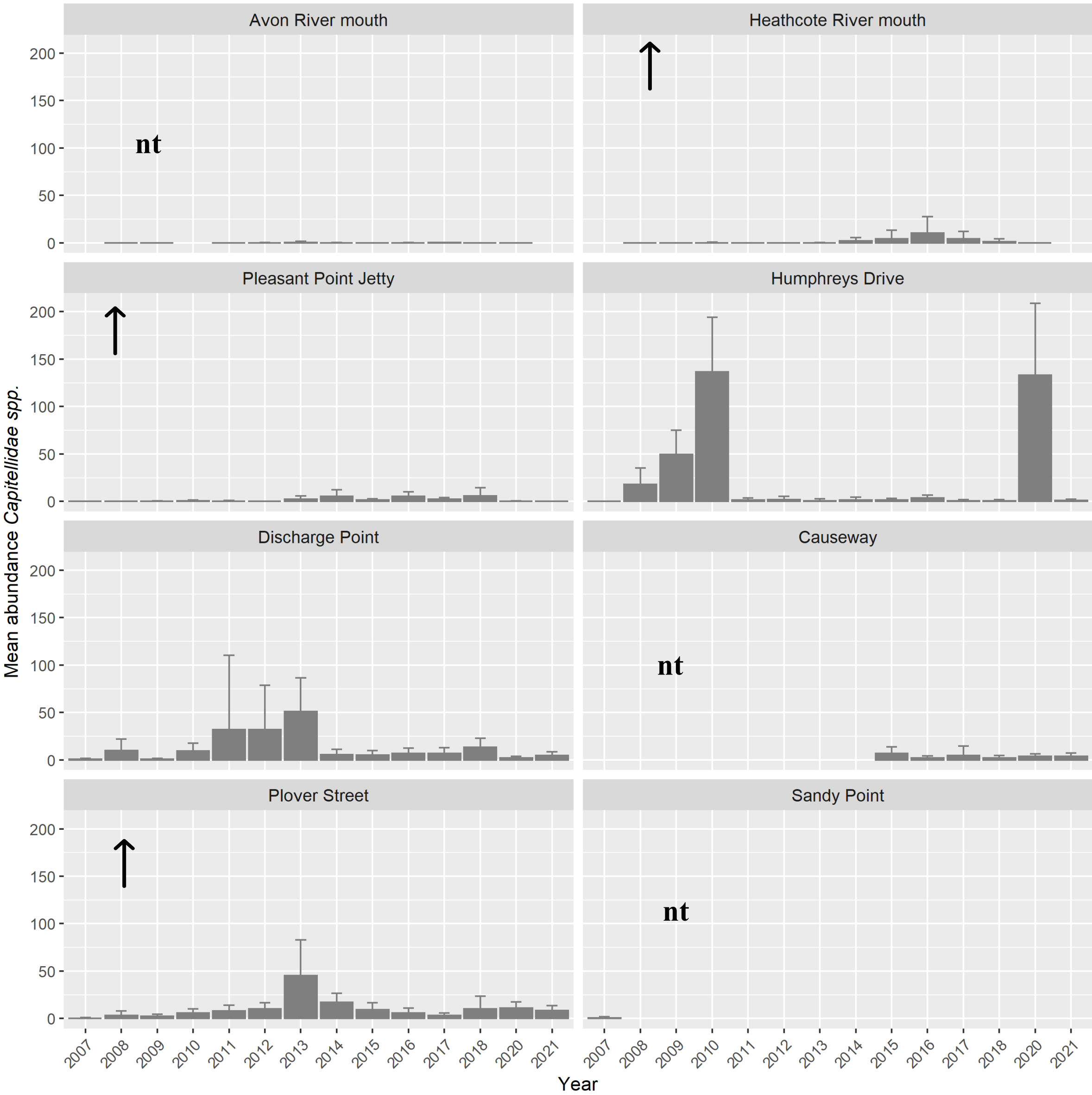

Figure 25. Total Capitellidae spp. (sum of Capitellidae spp., *Capitella* sp. and *H. filiformis*) abundance per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Aonides sp.

The average abundance of *Aonides* sp. worms was generally highest at the Plover Street (values peaked in 2012), although since 2017 comparable or higher values were recorded at Causeway (Figure 26). The abundance of *Aonides* sp. was next highest at Discharge Point, while for all other sites *Aonides* sp. abundance was zero or very low.

There was a statistically significant increase in *Aonides* sp. abundance at two sites. One of these was Discharge Point, at which there was a more than five-fold increase from 2007 to 2021 (although the absolute value was relatively small). The other was Pleasant Point Jetty, at which there was a very small increase. Conversely, there was a significant decrease in these worms at the Avon River Mouth site, but again this was very small. At all other sites a significant trend was not detected. Based on visual inspection of the data, at Plover Street there appeared to be quite a large increase in *Aonides* sp. between 2007 to 2012, after which values decreased to relatively low numbers again in 2021.

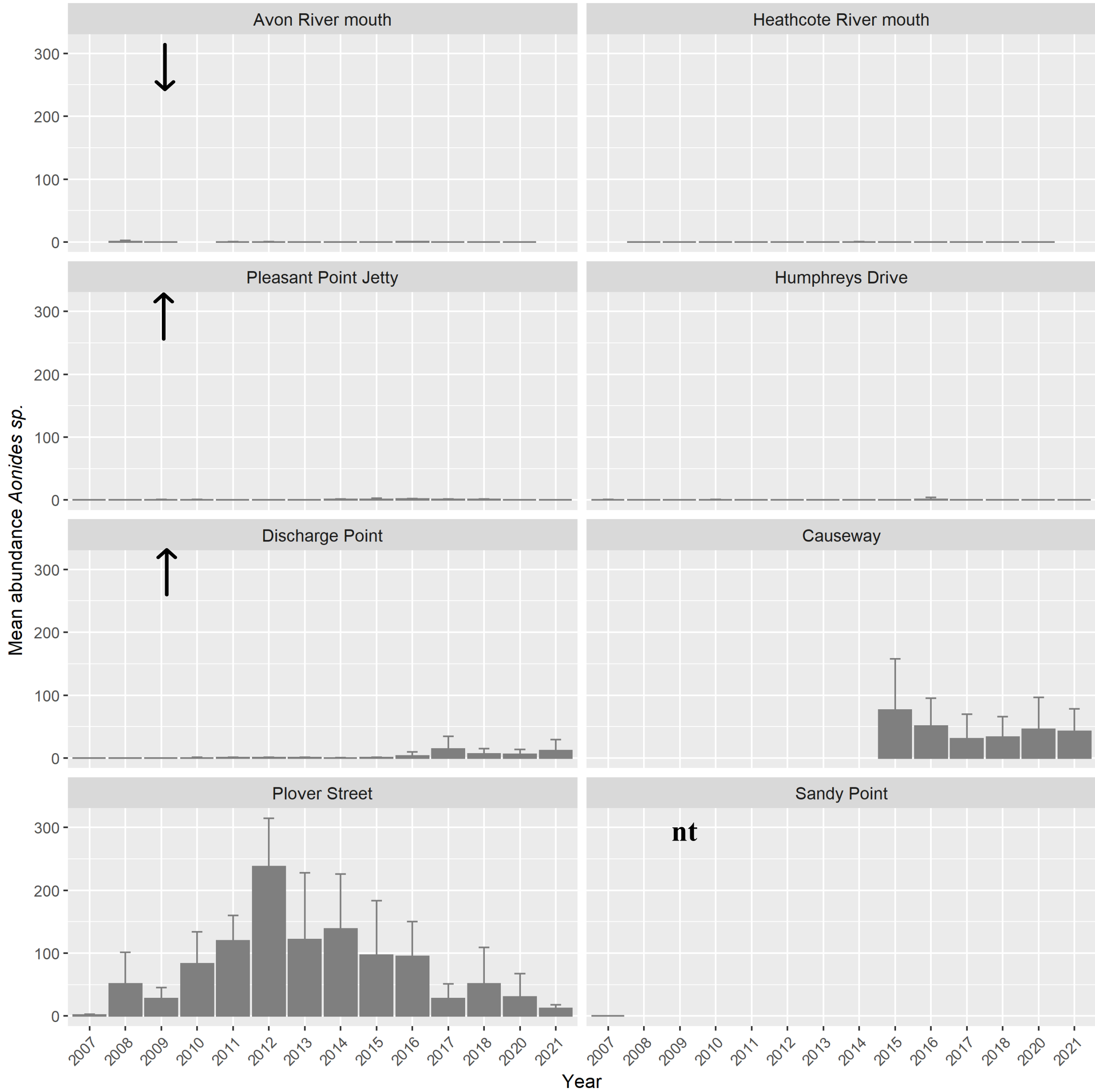

Figure 26. Total *Aonides* sp. abundance per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Wedge shell

Wedge shell (*Macomona liliana*) average abundances were generally highest at the Plover Street and Causeway sites, especially during the first half of the monitoring period at Plover Street (Figure 27). They were next highest at Discharge Point (in 2021), with lower values for all other sites and years especially at the Heathcote River Mouth where they were zero for all years.

There was a statistically significant increase in wedge shell abundance over time at the Causeway, Pleasant Point Jetty and Discharge Point sites, with the largest proportional increase observed for Discharge Point. A significant decrease was detected at Humphreys Drive and Plover Street. At Humphreys Drive, the trend was not linear with values increasing again in 2017 and 2018. At Plover Point, wedge shells decreased by more than half (in a generally linear fashion) from between 2007 and 2011 to 2015 and onwards. No significant trend in wedge shell abundance was detected for the Avon River Mouth site. No wedge shells were recorded at Heathcote River Mouth.

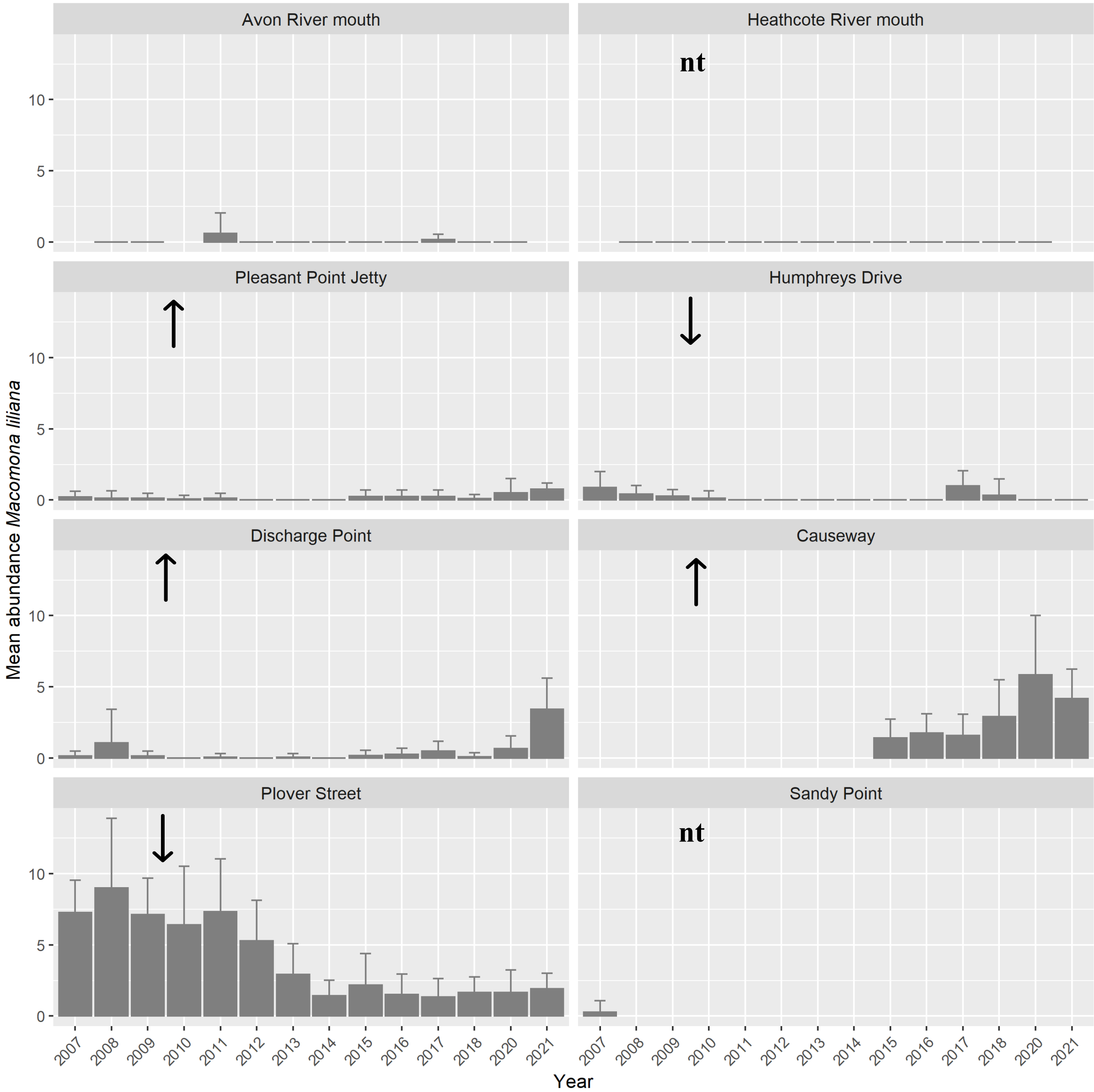

Figure 27. Total wedge shell (*Macomona liliana*) abundance per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Cockles/Tuaki

*Overall cockle/tuaki abundance from **cores** (2007 to 2021 – all sites):*

Similar to wedge shells, average overall cockle/tuaki abundances per core were highest at the sites closest to the estuary entrance (Plover Street and Causeway) (Figure 28). Cockle/tuaki abundances at all other sites were much lower, especially at the two river mouth sites (Avon and Heathcote).

There was a statistically significant increase in overall cockles/tuaki abundance over time at the Plover Street, Pleasant Point Jetty and Humphreys Drive sites (Appendix 3). For Plover Street and Humphreys Drive, the trend was not linear, with average values peaking in 2018 and then decreasing in more recent years. A significant decrease in cockle/tuaki abundance was observed for the Causeway site, although note that the opposite trend was observed based on quadrat data (see sections below for discussion on use of core vs quadrat sampling units and for quadrat results). No significant trend was observed for Discharge Point or the Avon and Heathcote river mouth sites.

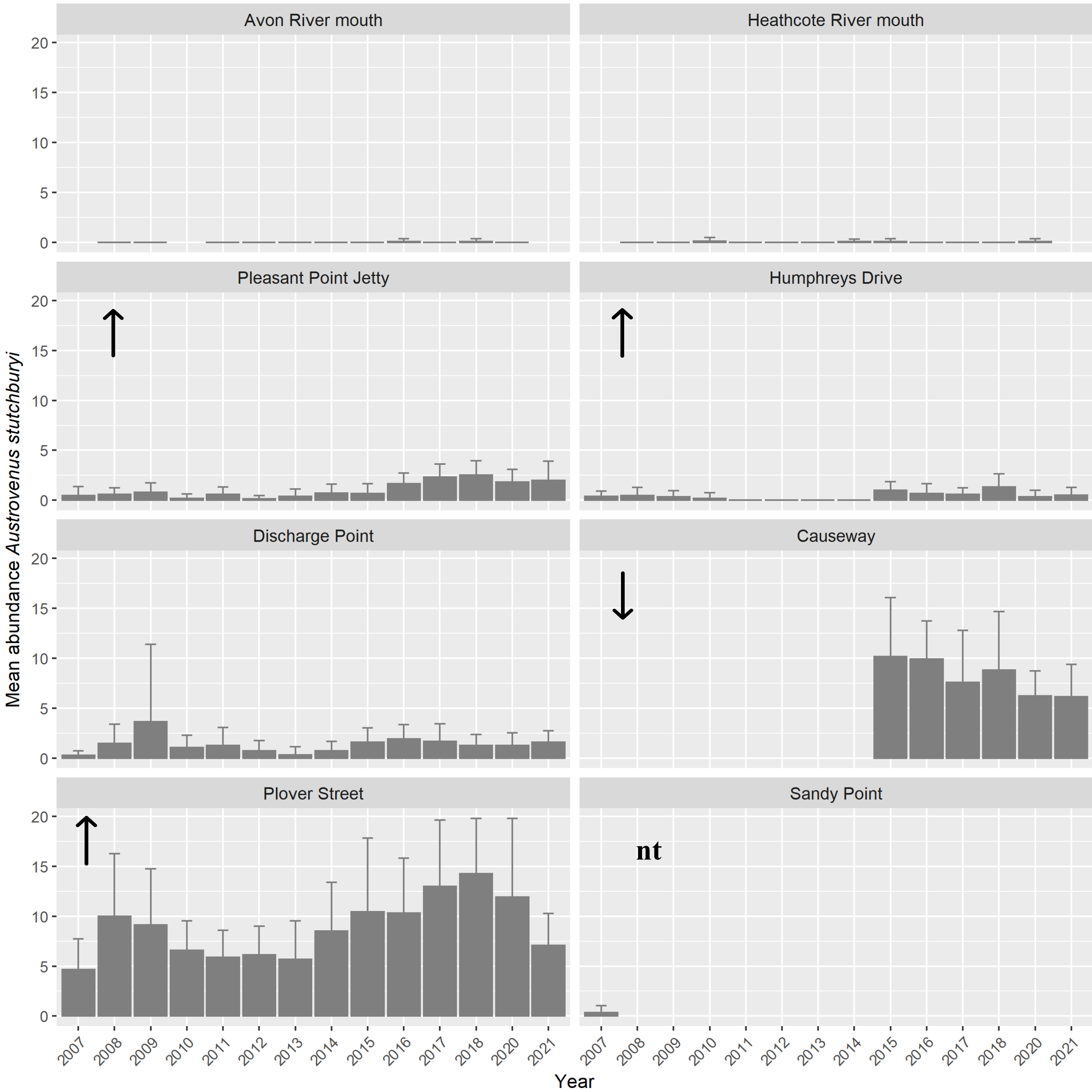

Figure 28. Total cockle/tuaki (*Austrovenus stutchburyi*) abundance per core (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

*Size class cockle/tuaki abundance from **cores** (2015 to 2021 – all sites):*

The proportion of cockle size classes from cores at the sites from 2015 to 2021 varied between sites, with the largest size class proportion being either adults, juveniles or recruits depending on the site and year (Figure 29). Edible cockles were present in all years at the Causeway site only. They were also present at Plover Street from 2015 to 2017, Pleasant Point Jetty in 2018 and 2021, and Discharge Point in 2015. Adult cockles were present during all years at Causeway, Plover Street, Pleasant Point.

Juveniles and recruits were recorded at most sites (Discharge Point, Pleasant Point Jetty, Causeway and Plover Point) in all years. Note that recruitment patterns may be changeable over time (due, for example, to changes in the intensity of settlement or survival of recruits) and therefore patterns may not necessarily be captured by 'point in time' annual surveys. Size classes recorded at Humphreys Drive varied over time, and for Avon and Heathcote River Mouth sites cockles were often not recorded and when they were in low numbers.

As stated in Bolton-Ritchie (2015), only individuals visible to the naked eye were measured, which means the smaller recruits may not have been detected and hence not measured. Also, different size-class abundance patterns in the core data were observed in comparison to the quadrat cockle/tuaki data (see following section). The core sampling unit is relatively small, especially for the larger cockles/tuaki, and therefore data collected in this manner may not be representative of the actual population size structure. For example, for Plover Street, no cockles/tuaki from the edible size class were recorded in the core data from 2018 to 2021, but they were in the quadrat data and the proportion of adults was also higher in the quadrat data.

No statistically significant trends were detected for any of the size classes and sites for which trends were assessed (Table 10). Trends were not assessed at the Avon and Heathcote Rive Mouth and Sandy Point sites due to limited data. Trends were also not assessed for the edible size class at any of the sites, or for adults at Humphreys Drive, for the same reason.

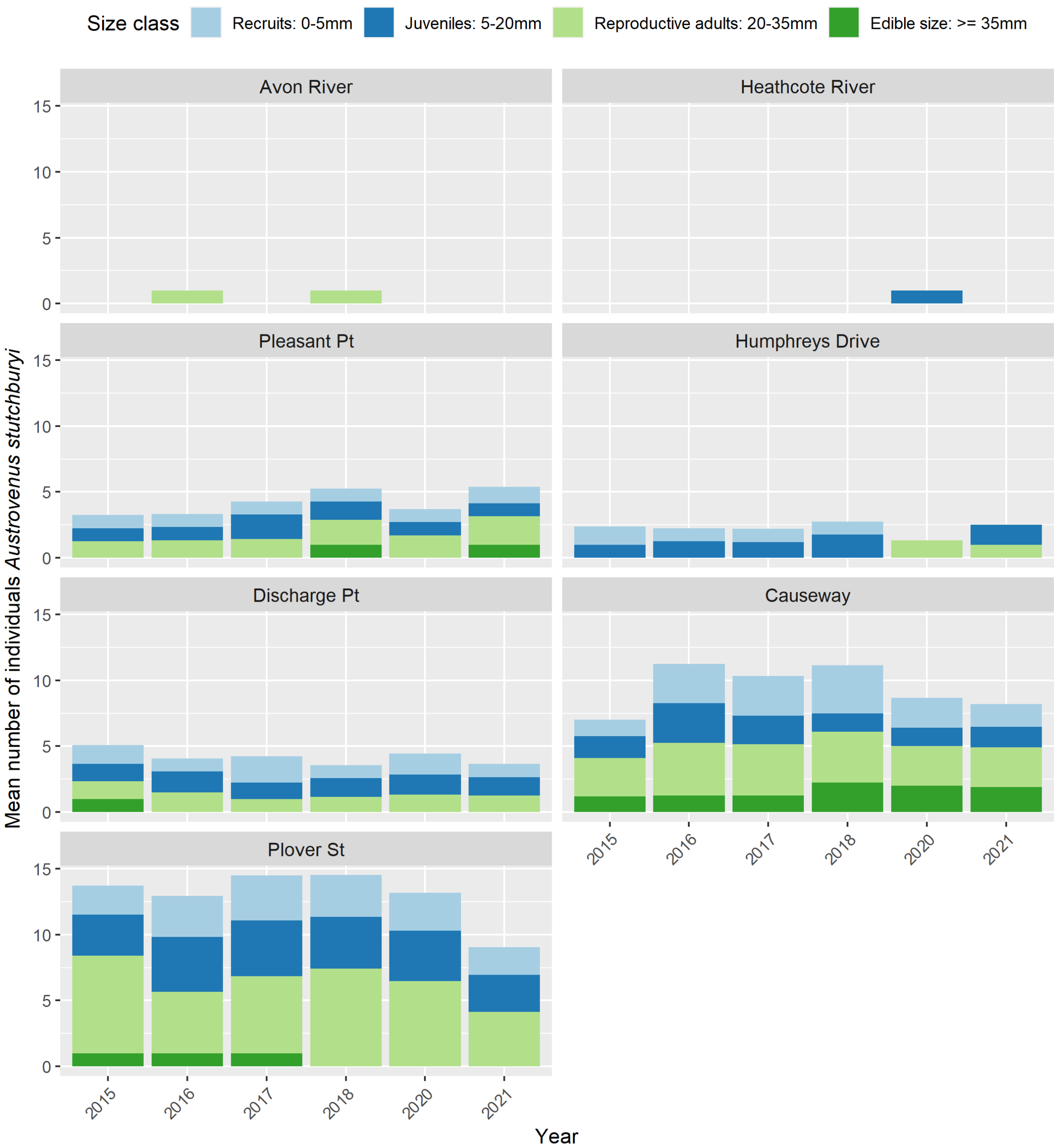

Figure 29. Average number of individuals per size class for cockles/tuaki (*Austrovenus stutchburyi*) per core at monitoring sites in Ihutai and associated tidal river mouths from 2015 to 2021.

Table 10. Trends from 2015 to 2021 in the abundance of cockles/tuaki (*Austrovenus stutchburyi*), across different size classes from cores at monitoring sites in Ihutai and associated tidal river mouths. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in mud values over time, a dash indicates no statistically significant ($p < 0.05$) trend and nt (not tested) indicates insufficient data were available for trend analysis.

	Size class (mm) Years 2015 to 2021			
Site	**Recruit (0–5)**	**Juvenile (5–20)**	**Adult (20–35)**	**Edible (35 plus)**
Avon River Mouth	nt	nt	nt	nt
Pleasant Point Jetty	-	-	-	nt
Discharge Point	-	-	-	nt
Plover Street	-	-	-	nt
Heathcote River Mouth	nt	nt	nt	nt
Humphreys Drive	-	-	nt	nt
Causeway	-	-	-	-
Sandy Point	nt	nt	nt	nt

Overall cockle/tuaki abundance from ***quadrats*** *(2007 to 2021 – Plover Street and Causeway sites):*

Based on the quadrat data, overall cockle/tuaki abundance was generally comparable between the Plover Street and Causeway sites from 2015 onwards (Figure 30). Abundances were slightly higher at Plover Street, although variability was high. There was a statistically significant increase in overall abundance at both sites (Appendix 3). It is possible that increases in abundance from 2015 onwards reflected sampling method differences, for example, cockles/tuaki were excavated to a sediment depth of 150 mm prior to 2015 and 120 mm after this although we would have predicted fewer cockles to have been recorded from 2015 onwards, rather than the increase in numbers observed.

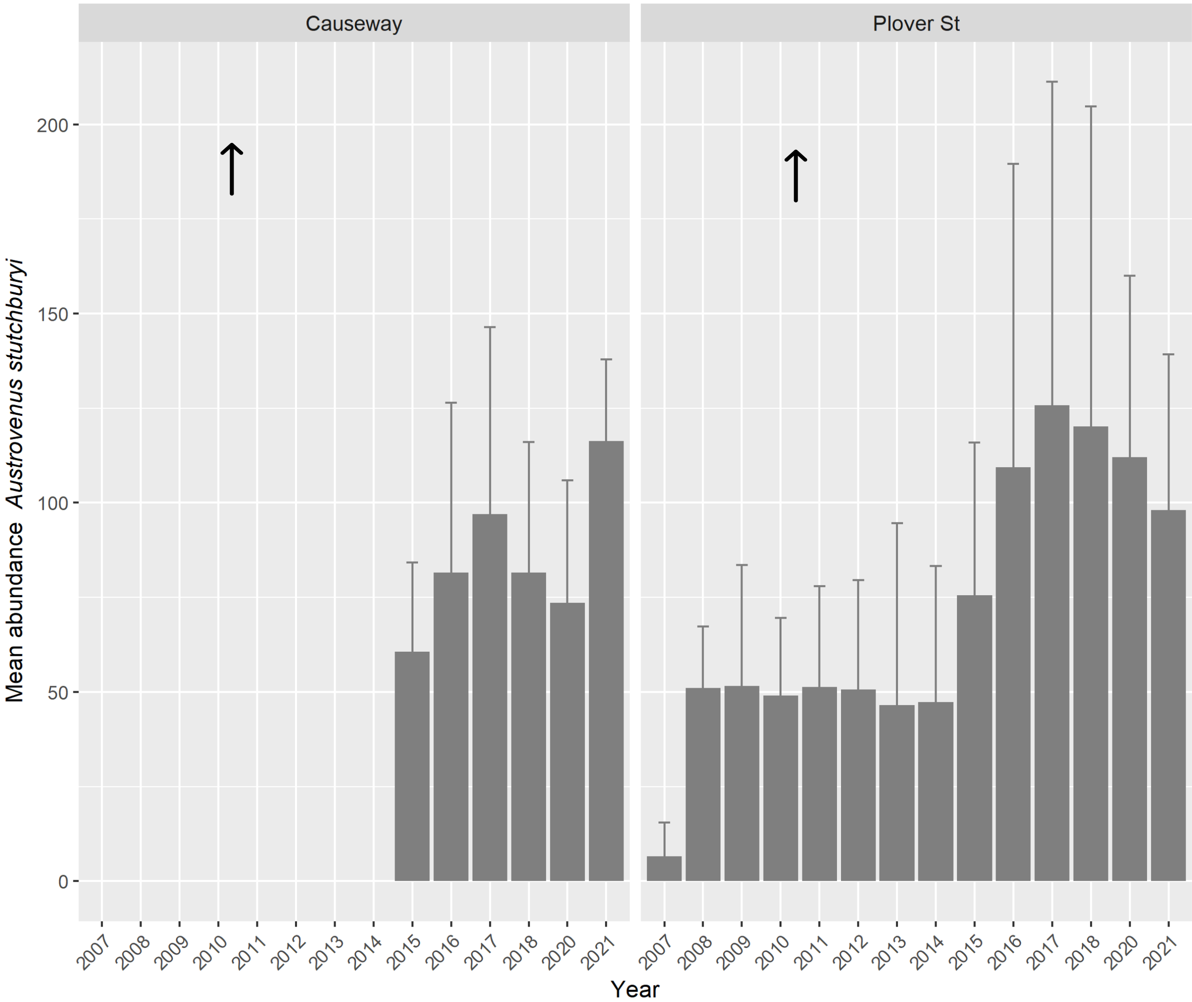

Figure 30. Total cockle/tuaki (*Austrovenus stutchburyi*) abundance per quadrat (average ± standard deviation) at the Plover Street and Causeway monitoring sites in Ihutai from 2007 to 2021. Note that data collection at the Causeway site began in 2015. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. For 2007 to 2014, cockles were excavated to a depth of 150 mm, and from 2015 to 2021 the depth was 120 mm. Also, 2019 is excluded from the x-axis as no data were available for this year.

Size class cockle/tuaki abundance from ***quadrats*** *(2007 to 2021 – Plover Street and Causeway):*

Based on the size class data from quadrats, cockle/tuaki populations at both Plover Street and Causeway were largely comprised of adults (Figure 31), followed by edibles and juveniles at Causeway and juveniles at Plover Street. No recruits were recorded at Causeway, while recruits and edibles were relatively low in abundance (compared to other size classes) at Plover Street. Note that recruitment patterns may be naturally changeable over time and therefore patterns are not necessarily captured by ‘point in time’ annual surveys.

There was a statistically significant increase in the number of juvenile and adult cockles at the Plover Street and Causeway sites (Table 11). The number of edible cockles also significantly increased at the Causeway site, with no significant trend detected for these at Plover Street. As for overall cockle abundance from the quadrats, these results need to be treated with caution as differences in sampling methods may have influenced abundance records (and therefore trend) results. A trend was not assessed for recruits at either site due to zero or low abundances.

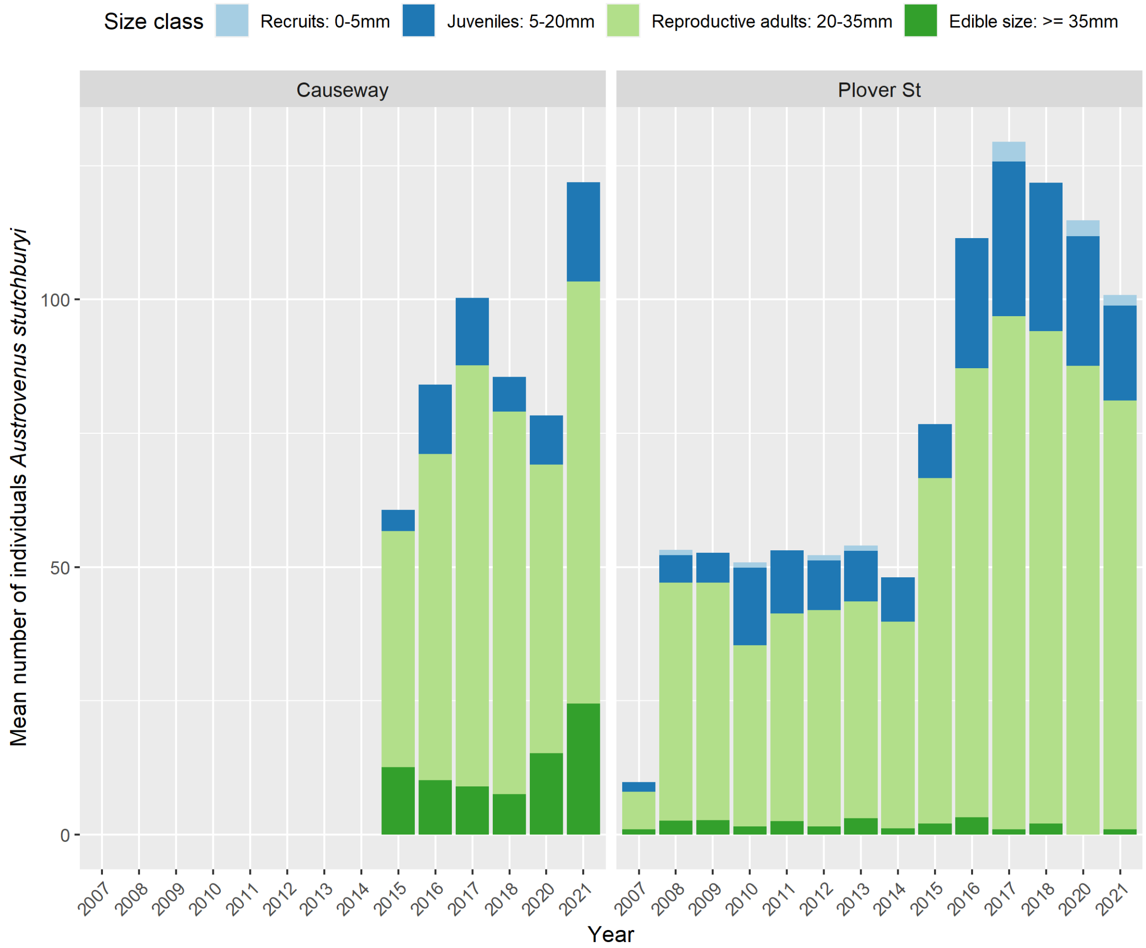

Figure 31. Average number of individuals per size class for cockles/tuaki (*Austrovenus stutchburyi*) per quadrat at the Plover Street and Causeway monitoring sites in Ihutai from 2007 to 2021. Note that data collection at the Causeway site began in 2015. For 2007 to 2014 the cockles were excavated to a depth of 150 mm, and from 2015 to 2021 the depth was 120 mm. There may also have been other unknown changes in methodology between 2014 and 2015. 2019 is excluded from the x-axis as no data were available for this year.

Table 11. Trends in the abundance of cockles/tuaki (*Austrovenus stutchburyi*) across different size classes from quadrats at the Plover Street and Causeway monitoring sites in Ihutai from 2007 to 2021. Note that data collection at the Causeway site began in 2015. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in mud values over time, a dash indicates no statistically significant ($p < 0.05$) trend and nt (not tested) indicates insufficient data were available for trend analysis. For 2007 to 2014 cockles were excavated to a depth of 150 mm, and from 2015 to 2021 the depth was 120 mm. There may also have been other unknown changes in methodology between 2014 and 2015.

	Size class (mm)			
Site	**Recruit (0-5)**	**Juvenile (5-20)**	**Adult (20-35)**	**Edible (35 plus)**
Plover Street	**nt**	↑	↑	**-**
Causeway	**nt**	↑	↑	↑

3.2.3. Epifauna

Community composition

Community composition at the two sites closest to the estuary entrance (Causeway and Plover Street) were relatively distinct from all other sites and also from each other (Figure 32). Taxa characterising the Plover Street and Causeway communities were sensitive to mud. For example, the gastropods *Diloma subrostratum*.[11] and *Micrelenchus tenebrosus* are potentially sensitive and highly sensitive, respectively, to mud (Robertson et al. 2015). For Plover Street and Causeway the within-site similarities in community composition were 55% and 75%, respectively (Appendix 2, Table A2.2).

There was a general level of overlap in community composition between most other sites (Discharge Point, Humphreys Drive, Pleasant Point Jetty and the two river mouth sites). Taxa characterising communities at all these sites were tolerant of mud, for example, the mud snail (*A. crenata*: Robertson et al. 2015). Burrows were likely made by the crabs *A. crassa* or *M. hirtipes*, which have a highly positive response to increasing mud (Robertson et al. 2015). For these three sites, within-site similarities in community composition ranged from 35% (Humphreys Drive) to 63% (Pleasant Point Jetty) and variation over time at an individual site was often greater than differences among sites.

[11] Presumably the same taxa as *Diloma subrostratum*, given WORMs does not recognise *Diloma subrostrata*.

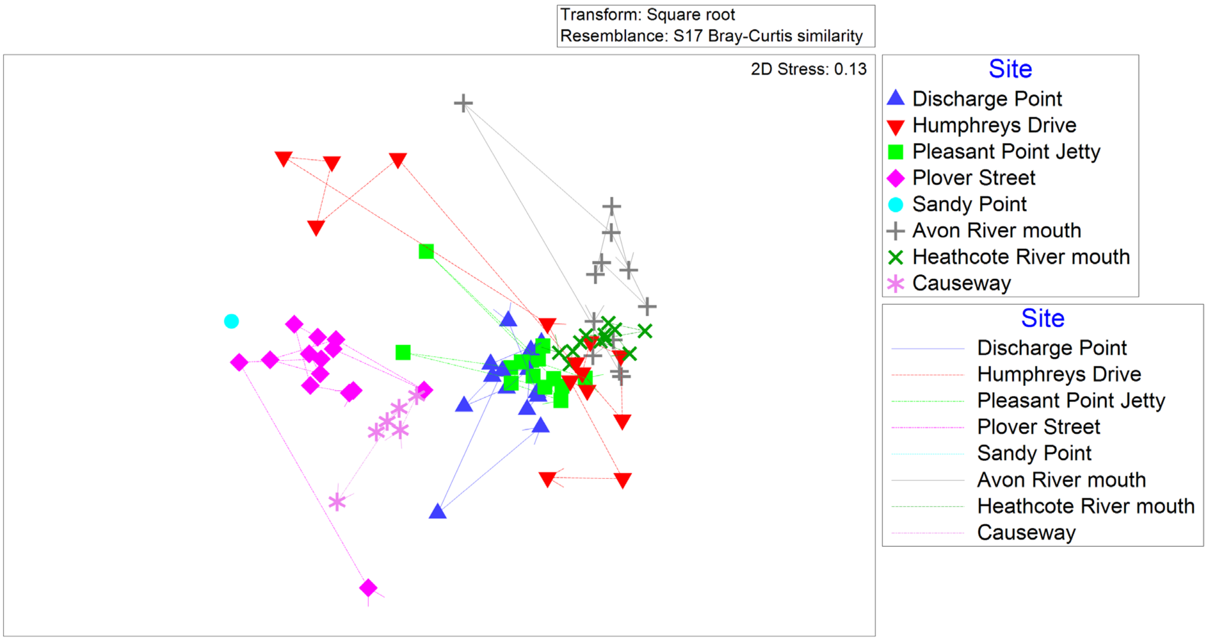

Figure 32. Differences in epifauna community composition (based on Bray-Curtis similarity) amongst the seven monitored sites in Ihutai and associated tidal river mouths from 2007 to 2021 illustrated using multi-dimensional scaling. Each symbol on the plot represents averaged data from one sampling year at any given site. A time trajectory is also displayed for each site.

Mud snails

Overall abundance:

The overall abundance of mud snails on the sediment surface was often highest at the Humphreys Drive (from 2012 onwards), followed by at Pleasant Point Jetty, Discharge Point and Avon River Mouth (Figure 33). Lower overall abundances occurred at the Plover Street and Heathcote River Mouth and Causeway sites. A significant increase in overall mud snail abundance was detected for Humphreys Drive, although the trend was not linear with variable average values from 2012 onwards (Figure 33). Abundance has remained stable at all other sites, although a trend was not tested for at Sandy Point due to limited data.

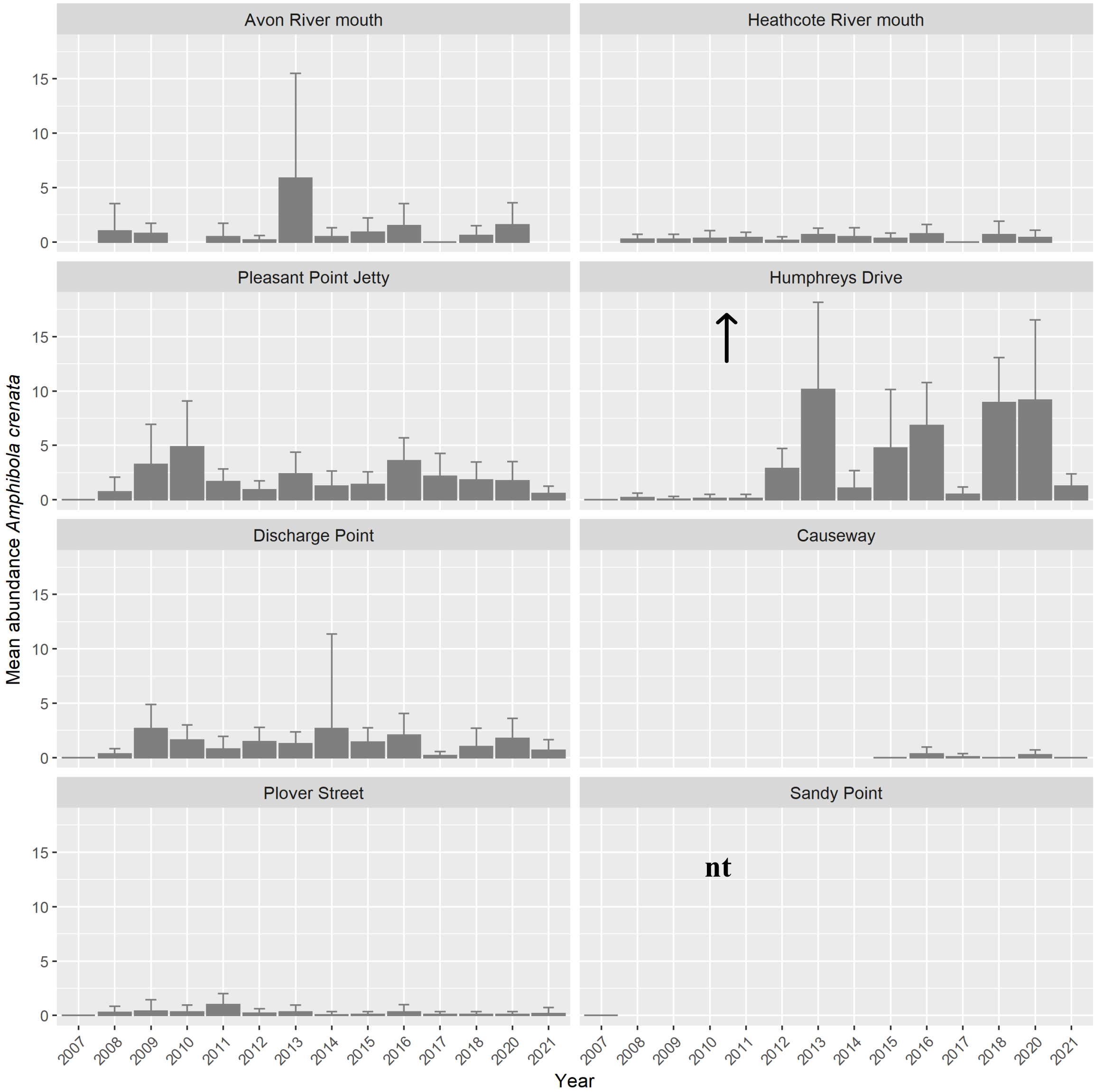

Figure 33. Number (average ± standard deviation) of mud snails (*Amphibola crenata*) across all size classes on the sediment surface per quadrat at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021.Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in the abundance over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Size class:

For most sites and years, the mud snail size class with the highest proportion based on abundance was the 20-25 mm class (Figure 34). Except for the largest size class (30-35 mm), all classes were present for all or most survey years at all sites.

For the largest snail size class present (25–30 mm), there were significant changes over time at the Pleasant Point Jetty and Discharge Point sites and a decrease at Heathcote River Mouth (Table 12). There was a significant decrease in abundance of the 20–25 mm snails at all sites assessed except for Heathcote River Mouth at which there was an increase. For the 15–20 mm snails increases occurred at Discharge Point and Humphreys Drive, and for the 10–15 mm snails there was an increase at Discharge Point. However, many of these trends were not linear. No statistically significant trends in mud snail abundance over time were detected for the 0–5 mm and 5–10 mm size classes at any of the sites. There were also no significant trends for any size class at the Avon River Mouth site.

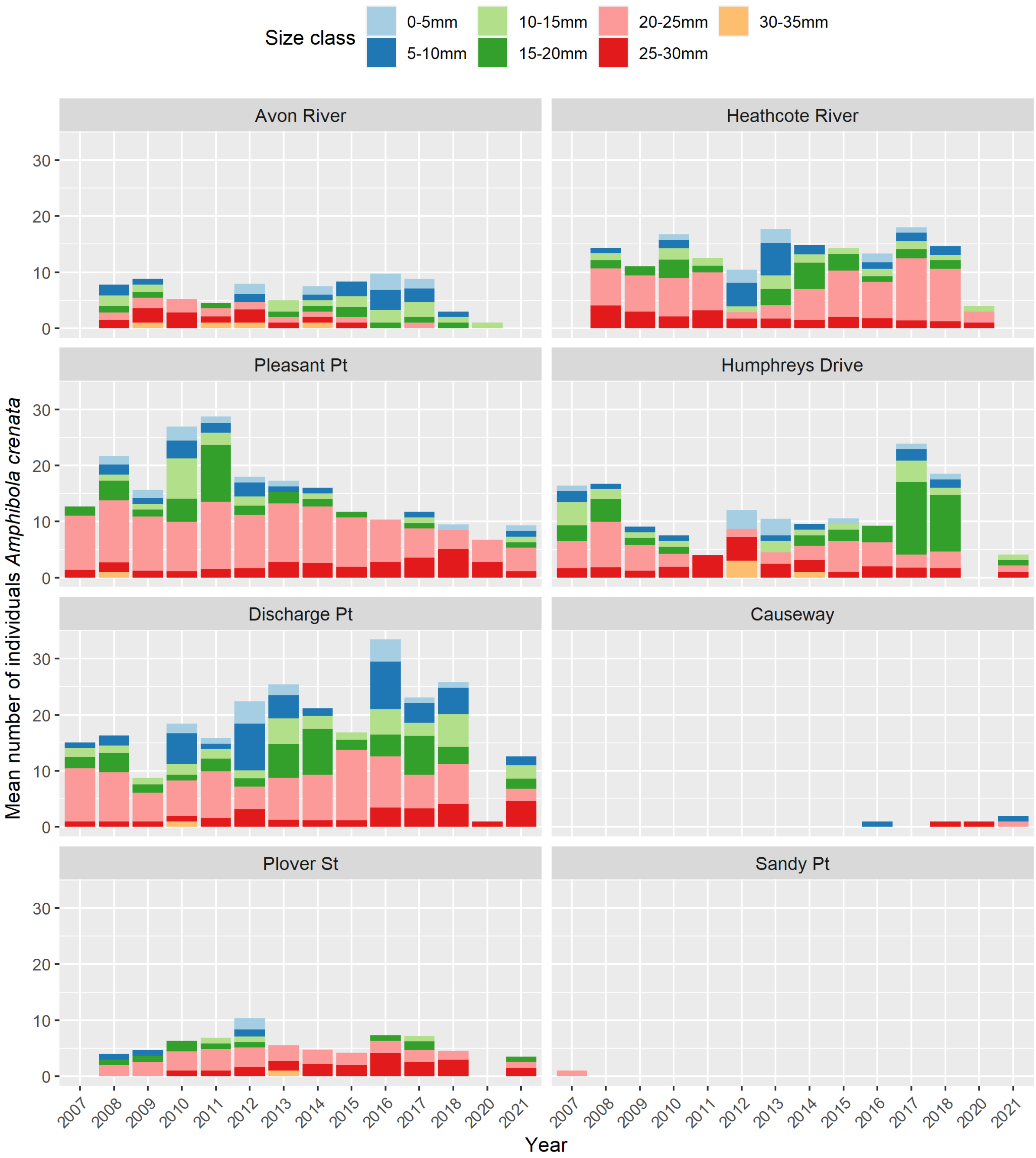

Figure 34. Average number of individuals per quadrat by size class for mud snails (*Amphibola crenata*) on the sediment at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021.

Table 12. Trends in the abundance of mud snails (*Amphibola crenata*) across different size classes from quadrats at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in mud values over time, a dash indicates no statistically significant trend ($p < 0.05$) and nt (not tested) indicates insufficient data were available for trend analysis.

	Mud snail size class (mm)					
Site	**0–5**	**5–10**	**10–15**	**15–20**	**20–25**	**25–30**
Avon River mouth	-	-	-	-	-	-
Pleasant Point Jetty	-	-	-	-	↓	↑
Discharge Point	-	-	↑	↑	↓	↑
Plover Street	nt	nt	nt	-	↓	-
Heathcote River mouth	-	-	-	-	↑	↓
Humphreys Drive	nt	-	-	↑	↓	-
Causeway	nt	nt	nt	nt	nt	nt
Sandy Point	nt	nt	nt	nt	nt	nt

3.2.4. Epiflora

Sea lettuce

Sea lettuce cover was low (less than 5%) near river mouths and at Pleasant Point Jetty, and variable at other sites (Figure 35). Humphreys Drive and Discharge Point had some high cover years prior to 2011, but low cover since then. Plover Street had often high, but highly variable cover, that has persisted over time. Cover at Sandy Point was very high on the single occasion it was surveyed.

Sea lettuce cover decreased significantly over time at the Discharge Point, Humphreys Drive, Avon River Mouth and Causeway sites. At Discharge Point and Humphreys Drive, cover was relatively high (> 50%) during the early monitoring years after which it dropped to much lower levels (less than 5%). At Avon River Mouth the decrease detected was very small. Sea lettuce cover has significantly increased over time at Plover Street, although the trend was not linear, with the highest average values occurring between 2013 and 2018.

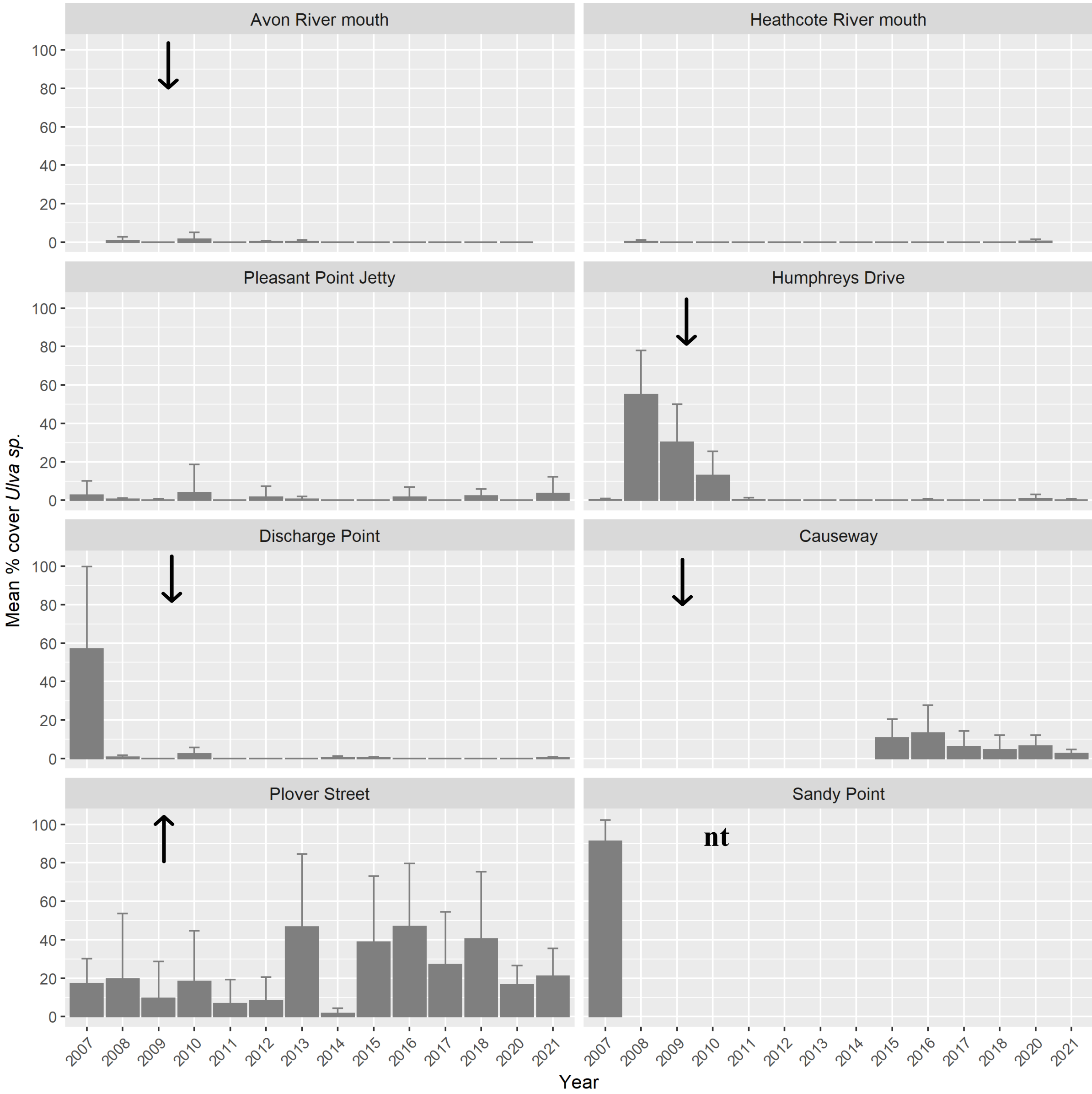

Figure 35. Percent cover of sea lettuce (*Ulva* sp.) per quadrat (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in cover over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Agarophyton chilense

At most sites, the average percentage cover of *A. chilense* was relatively low (i.e., not more than 5%, Figure 36). Higher cover was recorded at Humphreys Drive from 2008 to 2011) and, to a lesser extent, at Avon River Mouth in 2013 and Heathcote River Mouth in 2020. *Agarophyton chilense* cover has decreased significantly at most sites over time, although trends were often not linear and, except for at Humphreys Drive, values were generally low overall. However, at Plover Street and Heathcote River Mouth cover has remained stable and Sandy Point insufficient data were available to assess trends.

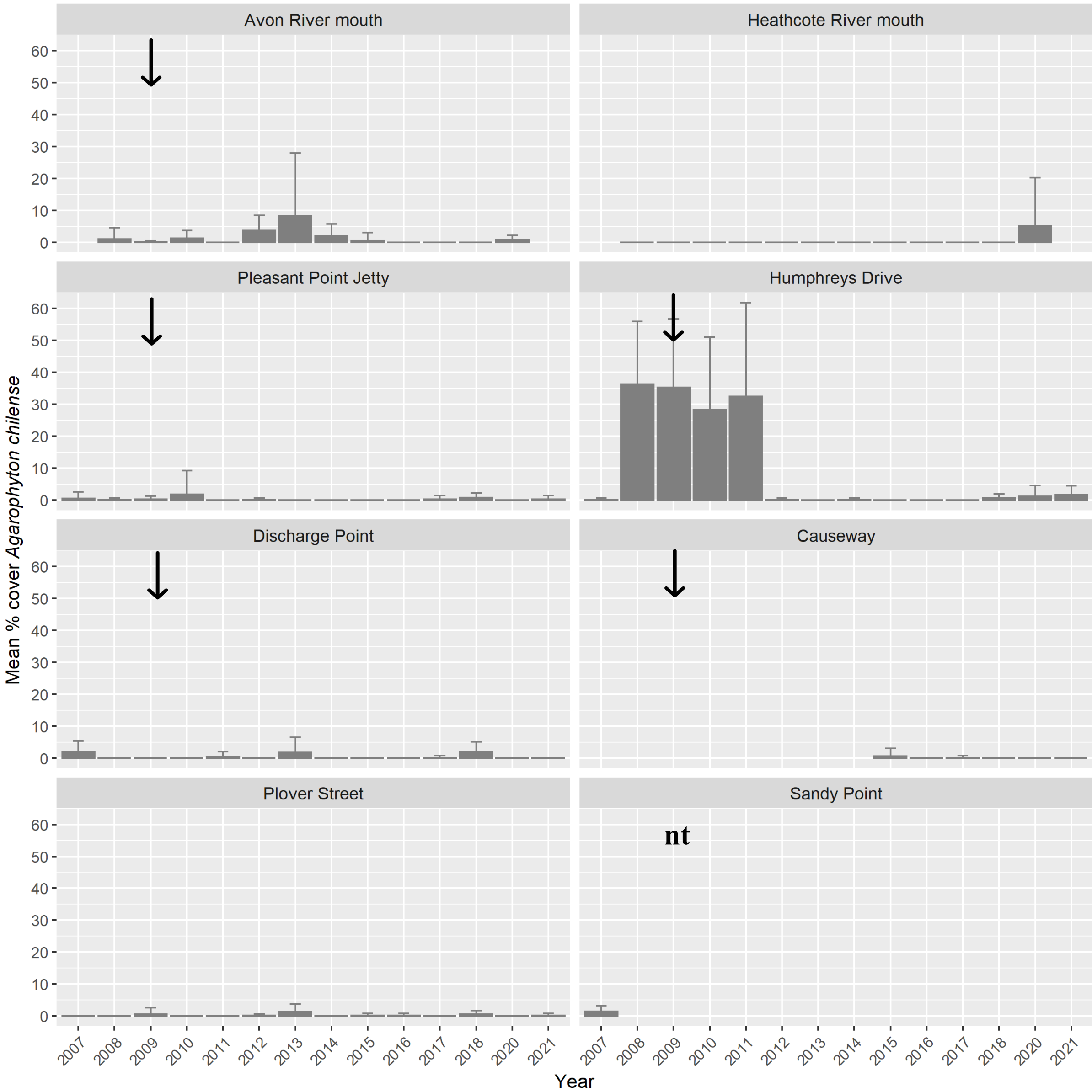

Figure 36. Percent cover of *Agarophyton chilense* per quadrat (average ± standard deviation) at monitoring sites in Ihutai and associated tidal river mouths from 2007 to 2021. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in cover over time and nt (not tested) indicates insufficient data were available for trend analysis. Note that 2019 is excluded from the x-axis as no data were available for this year.

Seagrass and biofilm

Seagrass (*Zostera muelleri*) was only recorded at the Plover Street site (Figure 37). There was a statistically significant increase in seagrass over time. The increase was large, from less than 5% in 2007 to around 50% in 2021, although there was high variability during all years. The upward trend in average cover was relatively steady over the years.

The average percent cover of biofilm was zero at all sites for the years monitored, except for at Discharge Point and Plover Street in 2008 where it was around 10% and 2.5%, respectively (data not shown).

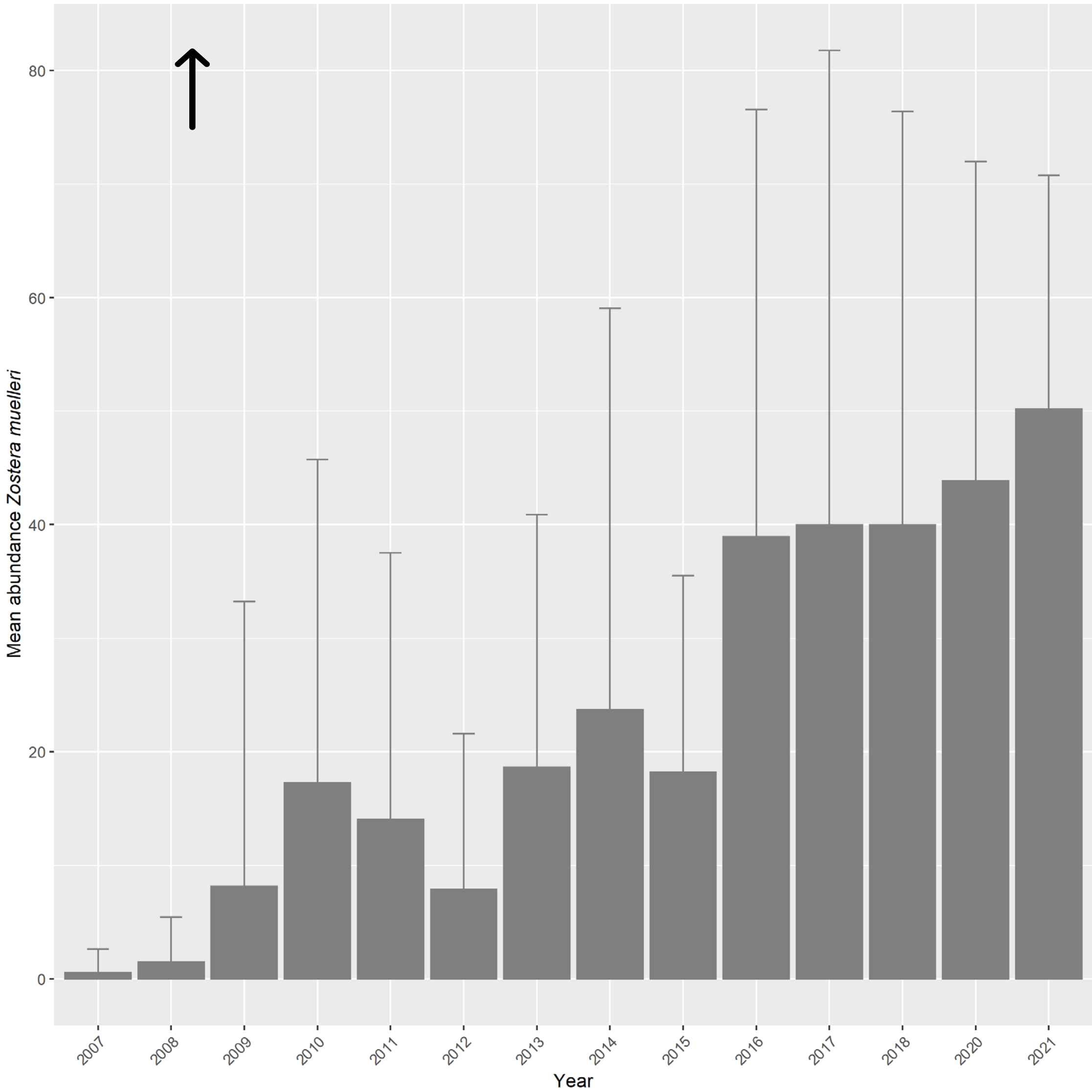

Figure 37. Percent cover of seagrass (*Zostera muelleri*) per quadrat (average ± standard deviation) at the Plover Street monitoring site in Ihutai and associated tidal river mouths from 2007 to 2021. The arrow indicates a statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in cover over time. 2019 is excluded from the x-axis as no data were available for this year.

4. ECOLOGICAL HEALTH OF THE ESTUARY AND ENVIRONMENTAL DRIVERS

4.1. Nutrient enrichment

A summary of trophic indicators across each site is presented in Table 13 and discussed in further detail in the sections below (with additional detail provided in Section 3 above). The most recent trophic indicator results suggest that nutrient enrichment in Ihutai is greatest at the Avon River Mouth site, which had levels of nitrogen and organic carbon in the poor health range, and levels of phosphorus in the fair health range, in the sediment. This enrichment has not triggered blooms of macroalgae or high numbers of capitellid worms, although capitellid worm abundance may have been limited by low salinity. Enrichment levels were lower than Avon at the Heathcote River Mouth site, but sediment organic carbon was still in the poor health range.

Enrichment has increased over the duration of the monitoring period at the Pleasant Point and Plover Street sites. Sediment organic carbon at these sites is in the poor health category and has increased since monitoring began. Capitellid worms were generally present in higher numbers since 2013, although most recent abundances were low. Ongoing enrichment at these sites is indicated by: increasing chl-*a* (representing microalgae) at Pleasant Point, and often moderate to high sea lettuce cover from 2013 and an overall increase in sediment nitrogen concentrations (currently reflecting fair health) at Plover Street. Monitoring has not been carried out at Sandy Point since 2007 when large sea lettuce blooms were observed at this site.

Enrichment appears to have decreased to some extent at Discharge Point and Humphreys Drive since the wastewater discharge was diverted from the estuary. This conclusion is supported by a drop in sediment nitrogen concentrations at Discharge Point and low macroalgal cover since 2012 at Humphreys Drive. However, these sites are still enriched as their sediment organic carbon concentrations reflect poor health. Also, high numbers of capitellid worms were recorded in a recent survey, and sediment chl-*a* concentrations increased over time, at Humphreys Drive.

At Causeway, enrichment appears to be decreasing based on macroalgal cover trends, but sediment organic carbon and nitrogen are both in poor and fair health, respectively.

Zeldis et al. (2020), Bolton-Ritchie (2015) and Skilton (2013) can be referred to for further detail on previous impacts of nutrient enrichment on the ecology of Ihutai relating to the wastewater diversion and earthquake events.

Key general causes of nutrient enrichment include inputs of organic matter (e.g. plant debris such as leaves, twigs, rotting seaweed and dead phytoplankton; sewage; and dead animals) and inputs of water containing dissolved nutrients. Although outside the scope of this report, in the following sections we include some commentary on potential causes or sources of nutrient enrichment for the Ihutai sites. Further investigation would be required to confirm the cause/s of any changes in nutrient enrichment for any given site.

Table 13. Indicators of nutrient enrichment at the Ihutai monitoring sites. Colours indicate whether the state of the site was good (green), fair (yellow) or poor (red) based on the most recent sampling for that indicator. Refer to Tables 3 and 4 for details on indicator thresholds for sediment organic carbon, nitrogen and phosphorus. The state for other parameters was assigned based on indicator values (e.g., low, moderate or high) using best professional judgement of the authors. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in indicator values over the full duration of the monitoring period time based on linear trends and nt (not tested) indicates insufficient data were available for trend analysis. Indicator values for Sandy Point are not shown because this site was last sampled in 2007.

Indicator	Avon River Mouth	Heathcote River Mouth	Humphreys Drive	Pleasant Point Jetty	Discharge Point	Plover Street	Causeway
Capitellidae	Low	Low ↑	Low (high in 2020)	Low ↑	Low	Low ↑	Low
Sea lettuce	Low ↓	Low	Low ↓	Low	Low ↓	Moderate ↑	Low ↓
Agarophyton chilense	Low ↓	Low	Low ↓	Low ↓	Low ↓	Low	Low ↓
Chl-*a*	nt	nt	↑	↑			nt
Seagrass	Not present	Not present	Not present	Not present	Not present	↑	Not present
Organic carbon	**nt**	**nt**	↑	↑	↑	↑	**nt**
Nitrogen	**nt**	nt			↓	↑	nt
Phosphorus	nt	nt			↓		nt

4.1.1. Sediment organic content

Organic enrichment can have various ecological impacts including eutrophication (Hyland et al. 2005). Based on interim guidelines for estuaries in Aotearoa New Zealand, sediment TOC values at all Ihutai sites from 2011 onwards were in the 'poor health' category, with high or very high eutrophication present. These results suggest that there is a risk to macroinvertebrate communities from enrichment. Average TOC was assessed as 'good' or 'fair' health for all sites in 2007 for which data were available. Based on linear trends over the duration of the monitoring period, TOC values significantly increased at all sites for which trends were able to be assessed (Figure 6). For example, Plover Street experienced over a four-fold increase since 2007. A large increase in TOC also appeared to have occurred at the Avon River Mouth site, although there was not enough data available to statistically test this for a trend. Given TOC at this river site was not monitored in 2021, it would be worth measuring the current values to establish whether values are still increasing. The trends and patterns in TOC we observed appear to contradict Zeldis et al. (2020), who found that sediment organic matter changed little either with the wastewater diversion or earthquakes, however this may be because their study was conducted over a shorter timeframe (of 6 years) than the data assessed in our report. TOC values appear to have been relatively stable since 2016 for all sites for which data were available, indicating that the drivers causing the past increases are potentially not as strong now. Overall, sediment TOC values in Ihutai were nearly all higher than the average seen for estuaries across Aotearoa New Zealand (0.6% mean, 0–3.4% range, Berthelsen et al. 2019).

4.1.2. Sediment nutrients

Nitrogen (rather than phosphorus) is generally considered to be the limiting nutrient for estuarine primary production (Howarth & Marino 2006). Nitrogen levels higher than the assimilation capacity of an estuary can stimulate plant growth resulting in severe adverse ecological effects (Cloern 2001; McGlathery et al. 2007). It is important to note that nutrient concentrations present in estuaries do not necessarily reflect nutrient loads or ecological state because nutrients can be rapidly taken up by algae such as macro- or micro- algae or phytoplankton (Gadd et al. 2020). Sediment nitrogen values in Ihutai suggestive of high eutrophication risk (i.e., poor health) were observed at Avon River Mouth (2011 and 2016) and at Humphreys Drive (2011 only) (Figure 7). All other nitrogen values across sites and years were either in the fair or good health categories. Sediment phosphorus was higher at the two river mouth sites (including in poor health at Avon) than other sites in Ihutai which were all in good health (Figure 8). These results indicate that nutrients are likely to be coming from an upstream source. Many, but not all, of the sediment TN values observed in Ihutai were lower than those seen on average in other estuaries across Aotearoa New Zealand (603 mg/kg mean, 250–3700 mg/kg range; Berthelsen et al. 2019). The relatively large decrease in TN at Discharge Point after 2011 aligns with the timing of the diversion of wastewater from the estuary. Although there was an overall increase in TN at Plover Street since 2007, concentrations in 2021 were slightly lower than the previous two surveys.

In terms of water quality, Gadd et al. (2020) found that water quality of the estuary has improved since 2007, with major improvements for nutrients (including DRP) occurring almost immediately after the diversion of the wastewater treatment plant discharge. Note that, based on nutrient loads and using Estuarine Trophic Index classifications, a recent assessment of eutrophic susceptibility identified Ihutai as having 'very high' susceptibility to macroalgal eutrophication (Gadd et al. 2020).

Considering sources of TN in the water column, modelled estimates by Tait et al. (2022) showed that oceanic nitrogen sources dominate throughout much of the Ihutai estuary, but the Ōtākaro/Avon and Ōpāwaho/Heathcote rivers introduced dissolved nitrogen at much higher concentrations. Several drainage systems were also identified as sources of water containing a high nitrogen concentration. Margetts et al. (2022) observed decreasing trends for nutrients (DRP, total ammonia and dissolved inorganic nitrogen) in waters at most sites within the Ōtākaro-Avon and Ōpāwaho-Heathcote rivers.

4.1.3. Infauna communities

Infauna communities can indicate where conditions are enriched by nutrients by the abundance and types of taxa they contain (refer to the methods in Section 2.4.4 for further details). Worms belonging to the family Capitellidae provide one such example. Within Ihutai, the relatively high abundances of capitellid worms at Humphreys Drive and Discharge Point in some years, and to a lesser extent at Plover Street, could be due to nutrient enrichment. Zeldis et al. (2020) found capitellid abundance to decrease one to two years after wastewater diversion in Ihutai, in the vicinity of Discharge Point and the eastern side of the estuary. The pattern shown in our data (Figure 25) was for average capitellid abundance to increase at Discharge Point and Plover Street until 2013 after which it reduced. At Humphreys Drive there was a drop in numbers from 2011 onwards until 2020. Capitellid abundance was low at both the Avon and Heathcote river mouth sites despite high organic enrichment. However, it is possible that lower salinity water may have limited the abundance of these worms. Key capitellid species (*C. capitata* and *H. filiformis* at least) were found to be intolerant of freshwater in Ihutai although *C. capitata* does inhabit areas with relatively low salinity (Estcourt 1967). The bivalve *Arthritica* sp., which is tolerant of moderate enrichment (Keeley et al. 2012[12]), also characterised communities at the Discharge Point, Humphreys Drive, Pleasant Point Jetty and both river mouth sites (Avon and Heathcote). High population densities of mud snails can also indicate nutrient/organic content (De Silva et al. 2022). In recent years (although not 2020), the highest abundances of mud snails were present at Humphreys Drive, potentially reflecting the high organic carbon present at this site (among other environmental drivers). However, mud snail abundance has been very variable at this site.

[12] Reported tolerance is for *Arthritica bifurcata*.

Infauna abundance was highest at Avon (Figure 21), potentially reflecting high enrichment. However, other sites with high enrichment (Heathcote and Discharge Point) were found to have the lowest abundance. Abundance decreased from 2013 at Discharge Point, with a drop overall after 2011. There was also a downward trend in abundance at Heathcote River Mouth over time, with upward trends shown for Humphreys Drive, Avon and Plover Street. The number of species was highest overall at Plover Street from 2014 onwards, and lowest overall at Heathcote River Mouth. There was an increase in the number of species over time at all sites except for Avon and Causeway. Given the potential for multiple stressors (e.g., enrichment and sedimentation) to be present at many sites over time, it was not possible to pinpoint environmental drivers of these community index patterns.

4.1.4. Macroalgae and benthic chlorophyll-a

Algal growth is often caused by excessive nutrients (Sutula et al. 2014), with nuisance macroalgae, such as sea lettuce (*Ulva*) and *Agarophyton chilense,* known to form blooms under enriched conditions. Ihutai has historically suffered from macroalgal blooms, largely due to the excessive nitrogen loading from wastewater entering the estuary, which was responsible for more than 90% of the estuary's nitrogen loading (Barr et al. 2020). The very high cover of sea lettuce at three sites (Sandy Point, Discharge Point and Humphreys Drive) during the initial monitoring years (Figure 35), and high *A. chilense* cover at Humphreys Drive from 2008 to 2011 (Figure 36), likely reflect the wastewater nutrient inputs into the estuary during this time (Barr et al. 2020). Accordingly, the drop in macroalgal cover to low levels at Humphreys Drive was likely driven by reduced levels of nutrient loading given the timing of this coincided with the diversion. However, there may be other drivers of these changes. For example, Bolton-Ritchie (2015) noted that it is possible that, in 2011, sediment liquified by the earthquakes covered the sea lettuce at Humphreys Drive and since then the area has been unsuitable for growth because the now higher seabed is inundated for shorter periods. At Discharge Point, the site closest to the wastewater outfall, it was not as easy to attribute the decrease in macroalgal cover over time to the wastewater diversion given that cover appears to have dropped dramatically a few years before the diversion took place.

The moderate to high sea lettuce cover at Plover Street, occurring consistently across years, indicates an ongoing presence of nutrient enrichment at this site. Continuing nutrient loading from rivers, discharges and oceanic inputs is thought to have an ongoing effect on trends in macroalgal coverage in Ihutai (Tait et al. 2022)—see additional details in Section 4.1.2 above. Temperature has also been found to drive macroalgal blooms in Ihutai, with a strong relationship observed between estuary-wide coverage of sea lettuce (but not *Agarophyton*) and warm temperature anomalies as well as an influence of water nitrogen concentrations on these trends. Tait et al. (2022) also concluded that water nitrogen concentrations throughout much of Ihutai were well above those that could limit growth of macroalgae.

The amount of chlorophyll-*a* within sediments can be a proxy for microalgal biomass. Microalgae are an important food source for many animals, but blooms or mats can indicate highly enriched conditions (Robertson et al. 2002). Dense microalgal mats have previously been prevalent in Ihutai due to hypertrophic nutrient loading (Zeldis et al. 2020). Based on data in our report (Figure 9), significant increases in benthic chl-*a* were observed at Humphreys Drive and Pleasant Point Jetty over time and could indicate increased nutrient enrichment at these sites. Benthic chl-*a* at the Avon and Heathcote river mouth sites also appeared to increase in recent years but there was insufficient data to test this trend. Aligning with many of our results for sediment chl-*a*, Gadd et al. (2020) reported significant increases of water column chl-*a*, an indicator of phytoplankton abundance, since 2014 at various sites within Ihutai including Humphreys Drive and Sandy Point. Note that Zeldis et al. (2020) found benthic microalgae to have reduced by 58% at sites within Ihutai following wastewater diversion.

4.1.5. Seagrass

Seagrass was only present at the Plover Street site in the monitoring data analysed in our report. In Ihutai, seagrass was historically abundant but suffered extensive loss prior to 1929 with almost no seagrass remaining by 1952 (Inglis 2003). Impacts on seagrass in more recent years include smothering by macroalgae and sediment following the 2011 earthquake (for more detailed history of this see Gibson and Marsden 2016). Based on our report, the substantial increase in seagrass cover at the Plover Street site over time (from < 5% in the first couple of years ~ 50% in 2021) suggests improving ecosystem health. This increase in seagrass cover is interesting given that trophic indicators at this site suggest enrichment increased over the duration of the monitoring period. Organic content within sediments was also in the poor health range, however, this could be due to the trapping properties of seagrass. In other Aotearoa New Zealand estuaries, higher levels of organic carbon or content (and nitrogen) have also been reported within sediments associated with seagrass compared to those that are unvegetated (e.g., Berthelsen et al. 2016; Gillespie et al. 2012).

In terms of other possible drivers, Tait et al. (2022) found that estuary-wide *Zostera* coverage in Ihutai was not influenced by temperature anomalies.

4.2. Sedimentation

A summary of sedimentation indicators (trends and recent state) across each site is presented in Table 14 and discussed in further detail in the sections below (also refer to results section above). Overall, Ihutai was muddy, particularly at the river sites. This was reflected by the infauna communities and Mud BHM scores at these two sites. Mud content and Mud BHM scores reflecting poor health were also found for

Humphreys Drive and Pleasant Point Jetty, with worsening Mud BHM scores and mud content, respectively. Mud BHM scores and worsening mud content at Plover Street indicated that sedimentation impacts are getting worse at this site. However, seagrass cover and cockle/tuaki abundance also increased over time at this site, suggesting that sedimentation to date has not limited these species. Mud content at Discharge Point was in the fair health category and has improved over time, but Mud BHM scores still indicated poor health. Sedimentation effects were lowest at the Causeway site, which had sediment mud content in fair health, high abundances of mud sensitive taxa and Mud BHM scores that indicated moderate sedimentation impact relative to other estuarine sites across New Zealand. Previous reports such as Zeldis et al. (2011), Bolton-Ritchie (2015) and Skilton (2013) can be referred to for further detail on previous impacts of sedimentation on the ecology of Ihutai relating to the earthquake events.

Key general causes of sedimentation include fine sediment (mud) running off the land and entering rivers and estuaries, the presence of liquefaction sediment, and estuarine and river hydrodynamics (and resulting transport or deposition of sediment). Although outside the scope of this report, in the following sections we include some commentary on potential causes or sources of sedimentation for the Ihutai sites. Further investigation would be required to confirm the cause/s of any changes in sedimentation for any given site.

Table 14. Indicators of sedimentation at the Ihutai monitoring sites. Colours indicate whether the state of the site was good (green), fair (yellow) or poor (red) based on the most recent sampling for that indicator. Refer to Table 2 for details on indicator thresholds for mud. The state for other parameters was assigned based on indicator values (e.g., low, moderate or high) using best professional judgement of the authors. The two upper and two lower categories for the Mud Benthic Health Model (BHM) have been merged to create three categories. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in indicator values over the full duration of the monitoring period based on linear trends and nt (not tested) indicates insufficient data were available for trend analysis. Indicator values for Sandy Point are not shown because this site was last sampled in 2007.

Indicator	Avon River Mouth	Heathcote River Mouth	Humphreys Drive	Pleasant Point Jetty	Discharge Point	Plover Street	Causeway
Mud content		↓		↑	↓	↑	
Infauna communities	Highly mud-tolerant	Highly mud-tolerant	Mud-tolerant	Mud-tolerant	Mud-tolerant	Mud-sensitive	Mud-sensitive
Cockles/tuaki*			↑	↑		High ↑	High ↑
Wedge shells		nt	↓	↑	High ↑	High ↓	High ↑
Aonides sp.	↓			↑	↑	High	High
Mud snails			Moderate (2021), High (2020) ↑				
Mud BHM			↑			↑	
Seagrass	Not present	Not present	Not present	Not present	Not present	↑	Not present

*Based on quadrat data for Plover Street and Causeway and core data for the other sites.

4.2.1. Sediment mud content

Fine sediment entering streams from land run-off, associated with deforestation and agricultural and urban development, is a well-known stressor in Aotearoa New Zealand's coastal environments (Robertson et al. 2016b; Thrush et al. 2004; Clark et al. 2021). However, these changes must be interpreted within the context of natural variability across an estuary. Sediment mud content at the two Ihutai river sites (Avon and Heathcote) showed 'poor health' across all years monitored and was generally much higher than commonly observed in other estuaries across Aotearoa New Zealand (21.6% mean; Berthelsen et al. 2019). This was despite a sharp decrease around the time of the earthquakes. Following the earthquakes, mud content at the Heathcote River mouth site (Figure 4) stayed relatively stable, although there has been an upward trend in recent years. At the Avon River mouth site, mud content eventually increased back to its pre-earthquake levels (Figure 4). It is likely that sediments are being deposited at these sites from upstream sources. Note that Zeldis et al. (2020) found the earthquake to not have had persistent effects on sediment percent mud.

Recently, mud content at the monitoring sites away from the river mouths was either also in 'poor' health (Humphrey Drive, Pleasant Point Jetty and Plover) or in 'fair health' (Causeway and Discharge Point). These values were also lower than or comparable to that observed elsewhere in Aotearoa New Zealand (Berthelsen et al. 2019). In addition to an overall decrease in mud content over time at the Heathcote River Mouth site, mud has also declined at Discharge Point but has increased on the eastern side of the estuary at Pleasant Point Jetty and Plover Street (Figure 4).

4.2.2. Infauna communities including cockles/tuaki

At lower levels, mud in estuarine sediments can be beneficial because some species feed on the organic matter it contains (Douglas et al. 2019) and macrofaunal communities are resilient (Rodil et al. 2013). However, higher levels can cause major declines in the resilience of macroinvertebrate communities (Rodil et al. 2013) and lead to communities that are impoverished, unbalanced and degraded (Robertson et al. 2016b). The composition of infauna communities recorded in the Ihutai monitoring data reflected the general patterns in sediment mud content at the sites (see previous section). For example, at the very muddy river mouth sites (Avon and Heathcote) infaunal communities were characterised by taxa tolerant of, or with a high affinity for, elevated mud concentrations such as the crab *A. crassa,* the bivalve *Arthritica* sp. and the snails *Potamopyrgus* and *A. crenata* (Robertson et al. 2015). These taxa were also likely tolerant to lower salinities. Conversely, the sandier sites closer to the estuary entrance (Plover Street and Causeway), had high abundances of mud-sensitive (Robertson et al. 2015) cockle/tuaki, wedge shells and the polychaete worm *Aonides* sp. and were characterised by mud-sensitive gastropods (*Diloma subrostratum* and *Micrelenchus tenebrosus*).

The Mud BHM scores (based on infaunal communities) indicated that most of the sites are experiencing moderate to very high impact from sedimentation compared to other estuarine sites across New Zealand. Mud BHM scores at the river mouth sites reflected their very high mud content. Mud BHM scores also indicated that sedimentation was increasing at Plover Street and Humphreys Drive.

The increase in the abundance of mud-sensitive cockles/tuaki over time at various sites (especially Pleasant Point Jetty, Plover Street and Causeway[13]: Figure 28 and Figure 30) was also a positive sign for ecological health, as was the increase in the abundance of wedge shells at the Causeway site and the relatively large increase in *Aonides* at Discharge Point (Figure 26). However, decreases in wedge shells at Humphreys Drive and Plover Street suggest that sedimentation impacts could be occurring. There were low or zero abundances of cockles/tuaki at the two river mouth sites, but this is not unexpected given that these shellfish can suffer mortality (and lower growth) when exposed to low salinities over time (Marsden 2004; Marsden & Adkins 2009). Note that there was no evidence of harvesting pressure by humans on cockles/tuaki, given that abundances of the larger cockle/tuaki size classes (edibles and adults) either increased or stayed stable over time at both Causeway and Plover Street (based on quadrat data).

Infauna abundance was highest at Avon River Mouth and lowest at Heathcote River Mouth and Discharge Point (Figure 21). Abundance decreased over time from 2013 at Discharge Point with a drop overall after 2011. There was also a downward trend in abundance at Heathcote River Mouth over time, with upward trends shown for Humphreys Drive, Avon and Plover Street. The number of species was highest at Plover Street from around 2014 onwards and lowest at Heathcote River Mouth. There was an increase in the number of species over time at all sites except for Avon and Causeway. Given the potential for multiple stressors (e.g., enrichment and sedimentation) present at many sites over time, it was not possible to pinpoint environmental drivers of these community metric patterns.

4.2.3. Seagrass

In Ihutai, seagrass was historically abundant but reduced over time due to various impacts (see summary in Seagrass Nutrients, Section 4.1.5). Based on the results in our report, the significant increase in seagrass cover at Plover Street over time (Figure 37) likely represents improving ecosystem health at this site, despite increasing sediment mud content and Mud BHM scores suggesting otherwise. The increase in sediment mud content over time indicated that fine sediment reduction wasn't a key driver in facilitating the increase in seagrass cover. During most monitoring years, sediment mud content at Plover Street was below 25% (Figure 4)

[13] There was a positive trend in cockle/tuaki abundance at the Causeway site based on the quadrat data but a negative trend based on the core data. Note that the quadrat is a bigger sampling unit than the core and is therefore likely to produce results that are more reflective of the actual cockle/tuaki population.

and therefore within the optimum range for seagrass (5–23% mud; Zabarte-Maeztu 2021). However, since 2016 the mud content has been beyond this optimum (≥ 25%) and therefore could negatively affect seagrass meadows in the future if this trend continues. *Z. muelleri* inhabiting muddy substrates may also require more light than usual to deal with adverse rhizosphere conditions (Zabarte-Maeztu 2021). Also see the discussion in Section 4.1.5 in relation to trophic indicators and other possible drivers.

4.3. Metal contamination

Overall, metal contamination within Ihutai sediments was generally low in relation to most guidelines for contaminants (Table 15). The exception was the most recent sampling at the Avon River Mouth site (2016), where levels of copper and lead were above some of the lower thresholds (Figure 13 and Figure 14), indicating at least some possible detrimental impacts on infauna. Sediment metal levels in general were higher at the Avon River Mouth site compared to the other estuary sites (Figure 10 to Figure 16). Indicators suggested that metal contamination was increasing at Plover Street but declining at Discharge Point. Metals values also declined at Humphreys Drive. Metals BHM scores did not align with metal contamination results at the Heathcote River Mouth site, where poor health was shown for the Metals BHM but good health for metals values. The results for metals contamination based on the monitoring data in our report are discussed further below. Skilton (2013) and Bolton-Ritchie (2015) can be referred to for further detail on impacts of metal contamination on the ecology of Ihutai in relation to the earthquakes and wastewater diversion.

Metal contaminants can enter estuaries through rivers, stormwater and other legal and illegal discharges, and from diffuse sources. Although outside the scope of this report, below we have included some commentary on potential sources of metal contamination at the Ihutai sites. Further investigation would be required to confirm the cause/s of any changes in metal contamination for any given site.

Table 15. Indicators of metal contamination at the Ihutai monitoring sites. Colours indicate whether the state of the site was good (green), fair (yellow) or poor (red) based on the most recent sampling for that indicator. Refer to Table 5 for details on indicator thresholds for metals. Metals BHM colours reflect absolute (good, fair, poor), rather than relative, health. Arrows indicate statistically significant ($p < 0.05$) increases (upward arrow) or decreases (downward arrow) in indicator values over the full duration of the monitoring period based on linear trends and nt (not tested) indicates insufficient data were available for trend analysis. Indicator values for Sandy Point are not shown because it was last sampled in 2007.

Indicator	**Avon River Mouth**	**Pleasant Point Jetty**	**Discharge Point**	**Plover Street**	**Causeway**	**Humphreys Drive**	**Heathcote River Mouth**
Arsenic	nt	nt	nt	nt	nt	nt	nt
Cadmium	nt	nt	nt	nt	nt	nt	nt
Chromium	nt	nt	nt	nt	nt	nt	nt
Copper	nt		↓	↑	nt		nt
Lead	nt		↓	↑	nt	↓	nt
Nickel	nt	nt	nt	nt	nt	nt	nt
Zinc	nt		↓		nt	↓	nt
Metals BHM				↑			

Metal contamination is considered a key threat to coastal marine environments in New Zealand (MacDiarmid et al. 2012). Arsenic, mercury, cadmium, chromium and nickel contamination is usually associated with rural land practices. The effects of these metals on ecological communities at the Ihutai monitoring sites were assessed using the DVG guidelines (ANZG) and found to pose a low risk. However, it is possible for negative effects on benthic communities to occur below these thresholds (Hewitt et al. 2009).

Copper, lead, and zinc are generally the key metals of concern in New Zealand's coastal environmental (ARC 2004) and are usually associated with urban stormwater sources and for example can originate from roofing material, car tyres and industrial practices. Additional guidance on the effects of these metals is available (refer Section 2.3.3, Table 5). Copper, lead and zinc values were highest at the Avon River Mouth site. On at least one sampling occasion, copper and lead levels at the Avon River Mouth, Discharge Point, Heathcote River Mouth, Humphreys Drive and Sandy Point sites were above a conservative threshold that represents the point at which we would expect to see a 50% decrease in the abundance of 5% of the taxa (FEC lower – adjusted; Hewitt et al. 2009). During the most recent sampling at the Avon River Mouth, copper levels were above a threshold over which cockle numbers may be reduced by 50% (*Austrovenus* EC50, Hewitt et al. 2009). Margetts et al. (2022) also found elevated levels of dissolved copper in water at many sites within the Avon and Heathcote rivers, and elevated dissolved lead in water at some sites within the Heathcote River, indicating an upstream source for these contaminants. Margetts et al. (2022) also found higher levels of dissolved zinc in water at Avon River Mouth compared to other estuary sites.

Metals BHM scores indicated that most sites were in fair health with respect to metal contamination (Figure 19). Despite low metal concentrations at Plover Street, increases in copper and lead at this site could be considered cause for concern. Metals BHM scores at this site have also significantly increased (Figure 19), indicating that communities have shifted from being in good health to being in fair health. Copper, lead and zinc have also substantially increased at the Avon River Mouth site, although insufficient data were available to test this trend. Although the trend in Metals BHM scores at this site appears to indicate improvements in ecological health, most of this improvement occurred between 2009 and 2011 and no sediment metals data were available for this time period. Metals BHM scores since 2011 have been relatively stable and indicative of fair health. Skilton (2013) found new sediments produced by the earthquake had lower concentrations of heavy metals. It would be useful to see what the current copper and lead concentrations are at the Avon River Mouth site to establish whether there is still an increasing trend in these metals.

The decrease in copper, lead and zinc at Discharge Point, and decrease in lead and zinc at Humphreys Drive could be considered an encouraging sign. However, Metals BHM scores at Humphreys Drive (Figure 19) do not reflect this decrease, with an apparent increase between 2011-2012, possibly reflecting the increase in copper that occurred around that time (Figure 13). The concentrations of these metals have been stable at these sites over the past two surveys.

Mud snail shell length has been observed to be positively correlated with sediment cadmium and zinc concentrations (De Silva et al. 2022). However, in our study we did not notice any obvious positive relationships between these two metals and larger sized mud snails.

5. MONITORING RECOMMENDATIONS

Our recommendations for future monitoring are as follows:

- Overall, the Ihutai ecological (sediments and biota) monitoring programme has provided a robust set of data for assessing the ecological health of the estuary, including trends over time and environmental drivers. Using the National Estuary Monitoring Protocol (NEMP) for fine-scale sampling means that the methods are robust, and generally comparable to national data. We commend the annual monitoring of many parameters, as this enables robust analysis of temporal trends. We recommended continuing with this sampling approach, apart from the methods used to collect data on cockle/tuaki (*Austrovenus stutchburyi*) population size-structure (see below).
- For future estuary monitoring, we recommend that cockle/tuaki population size-structure information is collected from sites of interest by counting and measuring the number of cockles/tuaki using quadrats, similar to how it has been carried out at Plover Street and Causeway for all years (and at all other sites prior to 2015). At each site, sediment from the quadrats (0.25 m^2), collected to a depth of 120 mm (to align with previous recent years) should be sieved and the abundance and size of the cockles/tuaki in each quadrat recorded. These data should be used to assess changes in cockle/tuaki population size-structure over time.
- There is no need to assess and report changes in cockle/tuaki population size-structure using two sampling methods (quadrats and cores). Given the larger size of these animals, we believe that quadrats are the most appropriate method. Therefore, we recommend using this approach to assess changes in cockle/tuaki population size-structure over time.
- We recommended continuing to follow the sampling approach used to date for counting and measuring mud snails (*Amphibola*) on the sediment surface.
- For future sampling, we recommend considering guidance[14] for the design of long-term monitoring programmes for estuaries. This would need to be considered with reference to the specific objectives of the Ihutai monitoring (biota and sediments) programme. For example, if monitoring for tipping points is of interest, then more frequent sampling (e.g., twice yearly) may be worthwhile at some sites.
- Additional parameters could be included in the data analyses to account for important covariates that may drive natural cycles (e.g., climatic indices, temperature), as this information can be used to partition out variation that is not of interest, increasing the power to detect stressor effects and approaching tipping points (Hewitt & Thrush 2019).
- Annual (or at least more frequent than every five years) collection of sediment quality data (metals, nutrients, chl-*a* and TOC) could be undertaken at all sites to

[14] https://www.sustainableseaschallenge.co.nz/tools-and-resources/lessons-for-designing-long-term-monitoring-programmes/

allow for more frequent/robust trend analyses. For some sediment quality parameters, we observed relatively large changes over time in recent surveys but could not statistically assess this trend due to insufficient data. Therefore, it would be precautionary to collect these data more frequently, so that any issues could be identified earlier to allow for a timely management response. We envision that more frequent collection of sediment quality data would require little additional sampling effort as the samples could be collected during annual sampling for biota and sediment grain size (although laboratory analyses would be an additional cost). This approach would also make it easier from a statistical perspective to assess environmental drivers of biotic composition.

- Unless already encompassed in another programme, additional monitoring could include fine-scale seagrass surveys, for the purpose of measuring changes in seagrass ecological health. This could be conducted at the same time as the annual monitoring. Additionally, more frequent broad-scale mapping of seagrass meadows (for example, as per Gibson & Marsden 2016; Hollever & Bolton-Ritchie 2015) would also provide valuable information on seagrass health over a larger spatial scale. A Coastal Special Interest Group seagrass working group has recently been set up, with one purpose being to develop a guidance for the development of seagrass monitoring programmes. We recommend making sure that any new seagrass monitoring programmes are aligned with this guidance. We also recommend regular broad-scale mapping of macroalgae and other important habitats such as salt marsh within Ihutai.
- The National BHMs are suitable for assessing the health of the monitored sites in Ihutai and their continued use is recommended for this estuary. The fit of new sampling sites should be checked before applying the National BHMs in future. Periodic future checks of fit are also recommended to ensure potential environmental changes (e.g., climate change or changes in the ratio of metals) are not affecting BHM scores. Several changes could be made to improve the taxonomic resolution for application of the BHMs in the future (refer Appendix 5).

6. ACKNOWLEDGEMENTS

Melanie Burns (ECan) provided the monitoring data collected for Christchurch City Council by EOS Ecology. Lesley Bolton-Ritchie and EOS Ecology (Nick Hempston) provided additional information relating to these data. Cawthron Institute marine taxonomy experts Fiona Gower and Paul Wolf provided taxonomic advice. Don Morrisey and Emma Newcombe (Cawthron) reviewed the report.

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8. APPENDICES

Appendix 1. Monitoring site details.

Table A1.1 Monitoring site co-ordinates, location and sampling layout details are taken from Bolton-Ritchie (2015). Note that the number of core and quadrat replicates collected from the individual site plots has changed over time, from fifteen prior to 2015 to twelve from 2015 onwards.

Site	Coordinates	Location and sampling layout
Plover Street	The co-ordinates of the shoreward NE corner of this area are E2489218 N5739927	On the eastern side of the estuary. Sampling is undertaken in a 60 m (alongshore) by 40 m (down shore) area. The sampling area is subdivided into 15 m by 10 m plots. In 2011 no sampling locations were on liquefaction mounds.
Pleasant Point Jetty	The co-ordinates of the landward NE corner of this area are E2488184 N5741804.	On the eastern side of the estuary. Sampling is undertaken in a 60 m (alongshore) by 40 m (down shore) area. The sampling area is subdivided into 15 m by 10 m plots. In 2011 one sample location was on a liquefaction mound.
Avon River Mouth	The co-ordinates of the landward NE corner of this area are E2487945 N5742910.	In the tidal reach on the eastern side of the lower Avon River/Ōtākaro. The area sampled is constrained by the width and length of intertidal mudflat in the area. Sampling is undertaken in a 55 m (alongshore) by 5 or 10 m (down shore) (5 m for 35 m and 10 m for 20 m of the alongshore length) area. The sampling area is subdivided into 5 m by 5 m plots. In 2011 one sample location was on a liquefaction mound.
Discharge Point	The co-ordinates of the landward SW corner of this area are E2487486 N5740698.	On the western side of the estuary. Sampling is undertaken in a 60 m (alongshore) by 40 m (down shore) area. The sampling area is subdivided into 15 m by 10 m plots. In 2011 three sample locations were in liquefaction mounds.
Humphreys Drive	The co-ordinates of the landward SW corner of this area are E22486095 N5739139.	On the western side of the estuary. Sampling is undertaken in a 60 m (alongshore) by 40 m (down shore) area. The sampling area is subdivided into 15 m by 10 m plots. In 2011 three sample locations were in liquefaction mounds.
Heathcote River Mouth	The co-ordinates of the landward NW corner of this area are E2485947 N5738483.	On the tidal reach on the western side of the lower Heathcote River/Ōpāwaho. The area sampled is constrained by the width and length of intertidal mudflat in the area. Sampling is undertaken in a 25 m (alongshore) by 15 m (down shore) area. The sampling area is subdivided into 5 m by 5 m plots. In 2011 seven sample locations were on a liquefaction mounds.
Causeway	E1577380 N5177502	No detailed description provided in report. In raw data, site is described as being 40 m (out into the estuary) by 60 m (parallel to estuary edge) into 15 m by 10 m plots.
Sandy Point	E2486866 N5739838	No detailed description provided in report. In the raw data, site outline is 40 m (out into the estuary) by 60 m (parallel to the estuary) into 15 m by 10 m plots.

Appendix 2. SIMPER analysis of biota composition showing similarities within sites.

Table A2.1 Infauna communities: SIMPER analysis.

Group Discharge Point
Average similarity: 59.82

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica sp.	4.54	12.20	2.94	20.40	20.40
Scolecolepides benhami	3.47	9.37	2.81	15.67	36.07
Capitella spp.	3.02	6.53	2.01	10.92	46.99
Nicon aestuariensis	1.51	4.19	2.18	7.01	53.99
Hemiplax hirtipes	1.20	3.42	4.83	5.72	59.71
Austrovenus stutchburyi	1.11	3.26	3.03	5.45	65.16
Amphibola crenata	1.04	2.64	1.72	4.42	69.58
Scolelepis sp.	1.57	2.41	0.79	4.03	73.62

Group Humphreys Drive
Average similarity: 42.56

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica sp.	3.94	10.27	1.55	24.14	24.14
Scolecolepides benhami	2.41	5.69	1.29	13.36	37.50
Capitella spp.	3.20	5.18	0.92	12.17	49.67
Amphibola crenata	1.43	3.11	1.04	7.31	56.99
Hemiplax hirtipes	1.07	3.04	1.77	7.15	64.13
Nicon aestuariensis	1.04	2.70	1.71	6.35	70.48

Group Pleasant Point Jetty
Average similarity: 58.25

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica sp.	3.87	13.97	2.49	23.98	23.98
Scolecolepides benhami	2.31	7.21	2.88	12.37	36.35
Nicon aestuariensis	1.39	5.07	3.58	8.71	45.06
Nereididae	1.72	4.32	1.39	7.41	52.47
Hemiplax hirtipes	1.18	4.06	4.57	6.97	59.44
Amphibola crenata	1.27	3.98	2.07	6.83	66.27
Austrovenus stutchburyi	0.96	3.17	2.82	5.44	71.70

Group Plover Street
Average similarity: 65.21

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Anoides sp.	8.05	14.53	2.27	22.28	22.28
Austrovenus stutchburyi	2.93	6.95	5.17	10.66	32.94
Scoloplos cylindrifer	2.55	6.19	3.75	9.49	42.43
Heteromastus filiformis	2.14	4.25	3.00	6.52	48.95
Macomona liliana	1.90	4.18	1.82	6.42	55.37
Micrelenchus tenebrosus	2.51	3.62	1.39	5.55	60.93
Hemiplax hirtipes	1.60	3.06	2.65	4.70	65.62
Arthritica sp.	1.19	2.10	1.96	3.23	68.85
Notoacmea elongata	1.35	2.09	1.62	3.21	72.05

Group Sandy Point
Fewer than 2 samples in group

Group Avon River mouth
Average similarity: 58.57

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Potamopyrgus sp.	11.50	15.82	1.25	27.00	27.00
Arthritica sp.	7.53	15.32	7.30	26.16	53.16
Nicon aestuariensis	3.00	6.47	4.87	11.05	64.21
Scolecolepides benhami	3.63	6.29	2.09	10.74	74.96

Group Heathcote River mouth
Average similarity: 53.79

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Arthritica sp.	3.26	15.60	1.96	29.01	29.01
Austrohelice crassa	1.44	7.81	2.12	14.53	43.54
Nicon aestuariensis	1.33	7.24	2.76	13.46	57.00
Nereididae	1.11	5.33	1.33	9.91	66.91
Scolecolepides benhami	0.97	3.95	1.17	7.34	74.25

Group Causeway
Average similarity: 75.37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Anoides sp.	6.74	17.30	16.91	22.95	22.95
Austrovenus stutchburyi	2.84	7.61	8.27	10.10	33.05
Macomona liliana	1.66	3.91	4.66	5.19	38.25
Scolelepis sp.	1.91	3.52	2.16	4.67	42.91
Capitella spp.	1.40	3.06	3.99	4.06	46.97
Nereididae	1.31	3.01	4.68	3.99	50.96
Heteromastus filiformis	1.23	2.71	2.70	3.59	54.55
Hemiplax hirtipes	1.18	2.66	8.18	3.54	58.08
Orbinia papillosa	1.16	2.63	3.42	3.49	61.58
Paracalliope spp.	1.33	2.54	2.65	3.38	64.95
Diloma subrostratum	1.12	2.42	2.70	3.21	68.16
Arthritica sp.	0.97	2.20	2.43	2.92	71.08

Table A2.2 Epifauna communities: SIMPER Analysis.

Group Discharge Point
Average similarity: 61.22

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Amphibola crenata	3.58	29.74	2.91	48.58	48.58
Crab burrows	1.98	13.72	2.41	22.41	70.99

Group Humphreys Drive
Average similarity: 34.71

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Crab burrows	2.07	16.26	0.99	46.84	46.84
Amphibola crenata	2.34	15.14	1.03	43.62	90.46

Group Pleasant Point Jetty
Average similarity: 63.07

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Amphibola crenata	3.39	30.68	2.95	48.65	48.65
Crab burrows	2.44	20.82	2.71	33.01	81.66

Group Plover Street
Average similarity: 55.26

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Micrelenchus tenebrosus	7.64	15.28	2.14	27.64	27.64
Diloma subrostratum	4.24	8.92	2.12	16.14	43.78
Notoacmea elongata	3.43	6.96	1.97	12.59	56.38
Austrovenus stutchburyi	1.83	3.45	2.69	6.23	62.61
Crab burrows	1.48	2.99	1.82	5.41	68.02
Cominella glandiformis	1.27	2.70	2.57	4.88	72.91

Group Sandy Point
Less than 2 samples in group

Group Avon River mouth
Average similarity: 51.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Crab burrows	3.61	30.17	2.08	59.12	59.12
Amphibola crenata	1.57	11.17	1.68	21.89	81.01

Group Heathcote River mouth
Average similarity: 76.15

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Crab burrows	6.11	48.86	3.87	64.17	64.17
Amphibola crenata	2.95	26.49	3.00	34.79	98.96

Group Causeway
Average similarity: 74.78

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diloma subrostratum	4.57	29.12	10.76	38.94	38.94
Micrelenchus tenebrosus	2.83	16.12	3.69	21.55	60.49
Crab burrows	2.08	10.59	2.25	14.17	74.66

Appendix 3. Trends over time in Ihutai biota and sediment quality—GLM results.

We used generalised linear models (GLMs) to evaluate the statistical significance of trends over the monitoring period. GLMs are an extension of linear models as they allow the response variable to come from different distributions besides the normal distribution. Table A3.1 overviews the distributions used for each of the models. For all the continuous response variables, a Gamma distribution was used. This distribution from the exponential family is suitable for continuous and strictly positive data. For the discrete and proportional response variables, Poisson, negative binomial or binomial distributions were used. These distributions are appropriate for count data.

For both the continuous and discrete/proportional outcomes models, the only explanatory variable included was 'year' as a numeric variable and models were fitted separately for each site. This means that the model will yield a single and general coefficient for year, which can indicate an annual trend of increase, decrease or lack of evidence for both (stability) at each site.

It is important to note some caveats of this approach. First, linear models are not able to capture data variability that is not linear on the link function scale. Second, models were fitted separately per site as interest lay in the understanding of fine-scale annual variation. However, this approach can be problematic if there is covariance among sites, which may cause an inflation of Type I error (α was defined as 0.05 for all analyses). If $\alpha > 0.05$, then the chance of wrongly rejecting the null hypothesis when it is indeed true is increased. A possible solution to this would be exploring covariance among sites and considering fitting models with all sites together and adding sites as a random effect. This, however, would increase the complexity of the analyses and further interpretation. The GLM results presented in this report are useful and enough to provide general indicators of trends over time.

Table A3.1 Response variables analysed showing the outcome type (continuous/discrete/ proportions) and the distribution used in the models. TN is total nitrogen, TRP is total recoverable phosphorus, TOC is total organic carbon, chl-*a* is chlorophyll-*a*, Cu is copper, Pb is lead and Zn is zinc.

Variable	Type	Distribution
Sediment grain size (per category)	Continuous, positive	Gamma
Nutrient indicators (TN, TRP, TOC, chl-*a*)	Continuous, positive	Gamma
Sediment contaminants (Cu, Pb, Zn)	Continuous, positive	Gamma
Infauna and epifauna abundance		
Cockle/tuaki	Discrete, count	Negative binomial or Poisson
Wedge shell	Discrete, count	Poisson
Capitellidae spp.	Discrete, count	Negative binomial
Aonides sp.	Discrete, count	Negative binomial or Poisson
Mud snail	Discrete, count	Negative binomial or Poisson
Infauna community indices		
Number of species	Discrete, count	Poisson
Number of individuals	Discrete, count	Negative binomial or Poisson
Evenness	Proportion, bounded between 0 and 1	Binomial
Diversity	Continuous, positive	Gamma
Mud BHM	Continuous, positive	Gamma
Metals BHM	Continuous, positive	Gamma
Epiflora		
Sea lettuce	Percentage (proportion)	Binomial
Agarophyton	Percentage (proportion)	Binomial
Seagrass	Percentage (proportion)	Binomial

Table A3.2 Generalised Linear Model (GLM) model results for Ihutai estuary monitoring parameters from 2007 to 2021. For the specific years that each model (site and parameter) represents, refer to report methods and results.

Parameter	Site	Estimate	SD	z- or t-value	p-value	Effect
Sediment grain size mud (< 63 µm)	Avon River mouth	0.011	0.009	1.248	0.212	nil
	Discharge Point	-0.052	0.008	-6.399	< 0.001	negative
	Humphreys Drive	-0.002	0.007	-0.296	0.768	nil
	Plover Street	0.132	0.008	16.534	< 0.001	positive
	Pleasant Point Jetty	0.109	0.008	12.874	< 0.001	positive
	Heathcote River mouth	-0.127	0.009	-14.703	< 0.001	negative
	Causeway	0.047	0.032	1.459	0.144	nil
Sediment grain size very fine sand (63-125 µm)	Avon River mouth	0.001	0.001	0.754	0.451	nil
	Discharge Point	-0.06	0.001	-71.31	< 0.001	negative
	Humphreys Drive	0.004	0.001	5.774	< 0.001	positive
	Plover Street	-0.004	0.001	-5.188	< 0.001	negative
	Pleasant Point Jetty	0.017	0.001	18.038	< 0.001	positive
	Heathcote River mouth	0.012	0.001	8.343	< 0.001	positive
	Causeway	0.023	0.002	9.234	< 0.001	positive
Sediment grain size fine sand (125-250 µm)	Avon River mouth	-0.012	0.011	-1.11	0.267	nil
	Discharge Point	0.043	0.006	7.147	< 0.001	positive
	Humphreys Drive	0.003	0.006	0.409	0.683	nil
	Plover Street	-0.074	0.006	-12.041	< 0.001	negative
	Pleasant Point Jetty	-0.044	0.006	-7.227	< 0.001	negative
	Heathcote River mouth	0.136	0.011	12.796	< 0.001	positive
	Causeway	-0.018	0.022	-0.825	0.409	nil
Sediment grain size medium sand (250-500 µm)	Avon River mouth	-0.007	0.014	-0.495	0.621	nil
	Discharge Point	0.032	0.008	4.224	< 0.001	positive
	Humphreys Drive	0.003	0.01	0.335	0.737	nil
	Plover Street	-0.009	0.009	-0.949	0.343	nil
	Pleasant Point Jetty	-0.04	0.009	-4.49	< 0.001	negative
	Heathcote River mouth	0.11	0.012	9.305	< 0.001	positive
	Causeway	-0.049	0.038	-1.274	0.203	nil
Sediment grain size coarse sand (500-1000 µm)	Avon River mouth	0.004	0.059	0.075	0.94	nil
	Discharge Point	-0.024	0.113	-0.215	0.83	nil
	Humphreys Drive	-0.115	0.054	-2.136	0.033	negative
	Plover Street	0.305	0.107	2.851	0.004	positive
	Heathcote River mouth	-0.158	0.036	-4.432	< 0.001	negative
Chlorophyll-*a*	Discharge Point	0.047	0.058	0.813	0.43	nil
	Humphreys Drive	0.087	0.016	5.29	< 0.001	positive
	Pleasant Point Jetty	0.11	0.035	3.126	0.007	positive
	Plover Street	0.004	0.032	0.122	0.905	nil
Total nitrogen	Discharge Point	-0.081	0.013	-6.412	< 0.001	negative
	Humphreys Drive	-0.029	0.044	-0.666	0.513	nil

Parameter	Site	Estimate	SD	z- or t-value	p-value	Effect
	Pleasant Point Jetty	0.008	0.012	0.698	0.494	nil
	Plover Street	0.034	0.014	2.386	0.028	positive
Total organic carbon	Discharge Point	0.079	0.024	3.247	0.004	positive
	Humphreys Drive	0.144	0.051	2.808	0.011	positive
	Pleasant Point Jetty	0.16	0.028	5.725	< 0.001	positive
	Plover Street	0.161	0.024	6.663	< 0.001	positive
Copper	Discharge Point	-0.077	0.009	-8.532	< 0.001	negative
	Humphreys Drive	-0.021	0.016	-1.312	0.205	nil
	Pleasant Point Jetty	0.015	0.013	1.102	0.284	nil
	Plover Street	0.013	0.005	2.829	0.011	positive
Lead	Discharge Point	-0.034	0.004	-8.37	< 0.001	negative
	Humphreys Drive	-0.024	0.007	-3.718	0.001	negative
	Pleasant Point Jetty	0.001	0.005	0.162	0.873	nil
	Plover Street	0.011	0.004	2.584	0.018	positive
Zinc	Discharge Point	-0.045	0.006	-7.487	< 0.001	negative
	Humphreys Drive	-0.015	0.005	-2.793	0.012	negative
	Pleasant Point Jetty	-0.004	0.005	-0.817	0.424	nil
	Plover Street	0.01	0.005	1.958	0.065	nil
Total recoverable phosphorus	Discharge Point	-0.02	0.005	-3.967	0.001	negative
	Humphreys Drive	-0.01	0.005	-1.927	0.069	nil
	Pleasant Point Jetty	0.004	0.006	0.765	0.454	nil
	Plover Street	0.006	0.004	1.672	0.111	nil
Aonides sp. abundance	Avon River mouth	-0.336	0.104	-3.212	0.001	negative
	Causeway	-0.067	0.066	-1.01	0.313	nil
	Discharge Point	0.51	0.049	10.421	< 0.001	positive
	Heathcote River mouth	0.058	0.197	0.297	0.767	nil
	Humphreys Drive	0.009	0.048	0.179	0.858	nil
	Pleasant Point Jetty	0.09	0.029	3.059	0.002	positive
	Plover Street	-0.039	0.022	-1.782	0.075	nil
Capitellidae spp. abundance	Avon River mouth	0.071	0.128	0.556	0.578	nil
	Heathcote River mouth	0.659	0.094	7.032	< 0.001	positive
	Pleasant Point Jetty	0.286	0.042	6.857	< 0.001	positive
	Humphreys Drive	-0.002	0.042	-0.046	0.964	nil
	Discharge Point	-0.052	0.027	-1.921	0.055	nil
	Causeway	-0.059	0.07	-0.836	0.403	nil
	Plover Street	0.091	0.021	4.325	< 0.001	positive
Macomona liliana (wedge shell) abundance	Avon River mouth	-0.124	0.09	-1.37	0.171	nil
	Pleasant Point Jetty	0.152	0.041	3.659	< 0.001	positive
	Humphreys Drive	-0.11	0.042	-2.645	0.008	negative
	Discharge Point	0.213	0.029	7.378	< 0.001	positive
	Causeway	0.225	0.033	6.741	< 0.001	positive
	Plover Street	-0.154	0.01	-15.503	< 0.001	negative
	Avon River mouth	0.307	0.244	1.257	0.209	nil

Parameter	Site	Estimate	SD	z- or t-value	p-value	Effect
Cockle/tuaki abundance (overall)	Causeway	-0.088	0.03	-2.913	0.004	negative
	Discharge Point	0.003	0.015	0.232	0.816	nil
	Heathcote River mouth	0.043	0.125	0.344	0.731	nil
	Humphreys Drive	0.085	0.027	3.111	0.002	positive
	Pleasant Point Jetty	0.142	0.018	8.069	< 0.001	positive
	Plover Street	0.042	0.011	3.89	< 0.001	positive
Cockle/tuaki abundance (per size class - core)	Causeway - Edible	0.079	0.061	1.298	0.194	nil
	Pleasant Point Jetty - Adults	0.076	0.06	1.265	0.206	nil
	Discharge Point - Adults	-0.015	0.08	-0.189	0.85	nil
	Causeway - Adults	-0.023	0.032	-0.711	0.477	nil
	Plover Street - Adults	-0.033	0.026	-1.261	0.207	nil
	Pleasant Point - Juveniles	-0.016	0.098	-0.16	0.873	nil
	Humphreys Drive - Juveniles	0.069	0.121	0.57	0.569	nil
	Discharge Point - Juveniles	-0.004	0.08	-0.049	0.961	nil
	Causeway - Juveniles	-0.076	0.05	-1.531	0.126	nil
	Plover Street - Juveniles	-0.026	0.031	-0.846	0.398	nil
	Pleasant Point - Recruits	0.034	0.107	0.323	0.747	nil
	Humphreys Drive - Recruits	-0.129	0.244	-0.527	0.598	nil
	Discharge Point - Recruits	0.007	0.078	0.089	0.929	nil
	Causeway - Recruits	-0.013	0.04	-0.32	0.749	nil
	Plover Street - Recruits	-0.018	0.037	-0.484	0.628	nil
Cockle/tuaki abundance (overall - quadrat)	Plover Street	0.105	0.013	8.055	< 0.001	positive
	Causeway	0.061	0.028	2.201	0.028	positive
Cockle/tuaki abundance (per size class - quadrat)	Plover St - Edibles	-0.029	0.028	-1.043	0.297	nil
	Causeway - Edibles	0.112	0.046	2.435	0.015	positive
	Plover Street - Adults	0.095	0.013	7.368	< 0.001	positive
	Causeway - Adults	0.095	0.013	7.368	< 0.001	positive
	Plover Street - Juveniles	0.117	0.015	7.768	< 0.001	positive
	Causeway - Juveniles	0.125	0.04	3.094	0.002	positive
Mud snail abundance (overall)	Avon River mouth	0.001	0.05	0.026	0.979	nil
	Heathcote River mouth	0.044	0.035	1.259	0.208	nil
	Pleasant Point Jetty	-0.005	0.021	-0.234	0.815	nil
	Humphreys Drive	0.271	0.029	9.402	< 0.001	positive
	Discharge Point	0.018	0.026	0.683	0.495	nil
	Causeway	-0.047	0.17	-0.278	0.781	nil
	Plover Street	-0.07	0.036	-1.926	0.054	nil
Mud snail abundance - per size class (0-5 mm)	Avon River mouth	0.042	0.077	0.546	0.585	nil
	Heathcote River mouth	-0.052	0.071	-0.727	0.467	nil
	Pleasant Point Jetty	-0.057	0.074	-0.778	0.437	nil
	Discharge Point	-0.024	0.039	-0.607	0.544	nil
Mud snail abundance - per size class (5-10 mm)	Avon River mouth	0.053	0.032	1.69	0.091	nil
	Heathcote River mouth	-0.041	0.032	-1.295	0.195	nil
	Pleasant Point Jetty	-0.069	0.048	-1.415	0.157	nil

Parameter	Site	Estimate	SD	z- or t-value	p-value	Effect
	Humphreys Drive	0.012	0.05	0.237	0.813	nil
	Discharge Point	-0.012	0.015	-0.788	0.431	nil
Mud snail abundance - per size class (10-15 mm)						
	Avon River mouth	0.018	0.037	0.494	0.622	nil
	Heathcote River mouth	-0.026	0.035	-0.725	0.468	nil
	Pleasant Point Jetty	-0.054	0.039	-1.393	0.164	nil
	Humphreys Drive	-0.014	0.022	-0.645	0.519	nil
	Discharge Point	0.089	0.017	5.09	< 0.001	positive
Mud snail abundance - per size class (15-20 mm)	Avon River mouth	0.004	0.055	0.077	0.939	nil
	Heathcote River mouth	-0.011	0.023	-0.483	0.629	nil
	Pleasant Point Jetty	0.001	0.024	0.029	0.977	nil
	Plover Street	-0.017	0.058	-0.296	0.767	nil
	Humphreys Drive	0.097	0.02	4.883	< 0.001	positive
	Discharge Point	0.043	0.019	2.223	0.026	positive
Mud snail abundance - per size class (20-25 mm)	Avon River mouth	-0.07	0.064	-1.097	0.273	nil
	Heathcote River mouth	0.022	0.009	2.352	0.019	positive
	Pleasant Point Jetty	-0.064	0.006	-9.947	< 0.001	negative
	Humphreys Drive	-0.066	0.011	-5.889	< 0.001	negative
	Discharge Point	-0.018	0.007	-2.378	0.017	negative
	Plover Street	-0.076	0.027	-2.837	0.005	negative
Mud snail abundance - per size class (25-30 mm)	Avon River mouth	-0.088	0.057	-1.552	0.121	nil
	Heathcote River mouth	-0.116	0.023	-5.134	< 0.001	negative
	Pleasant Point Jetty	0.066	0.014	4.74	< 0.001	positive
	Humphreys Drive	-0.014	0.022	-0.645	0.519	nil
	Discharge Point	0.091	0.017	5.232	< 0.001	positive
	Plover Street	0.072	0.04	1.792	0.073	nil
Sea lettuce (Ulva) - %cover	Discharge Point	-2.217	0.078	-28.379	< 0.001	negative
	Humphreys Drive	-0.522	0.014	-36.12	< 0.001	negative
	Plover Street	0.069	0.004	16.497	< 0.001	positive
	Pleasant Point Jetty	-0.007	0.016	-0.409	0.683	nil
	Avon River mouth	-0.371	0.074	-5.01	< 0.001	negative
	Heathcote River mouth	0.058	0.097	0.6	0.549	nil
	Causeway	-0.226	0.024	-9.404	< 0.001	negative
Seagrass - %cover	Plover Street	0.226	0.005	46.84	< 0.001	positive
Biofilm - %cover	Discharge Point	-0.7	0.061	-11.538	< 0.001	negative
	Plover Street	-0.692	0.115	-6.003	< 0.001	negative
Infauna – abundance	Avon River mouth	0.086	0.014	6.233	< 0.001	positive
	Heathcote River mouth	-0.061	0.016	-3.755	< 0.001	negative
	Pleasant Point Jetty	0.016	0.013	1.207	0.228	nil
	Humphreys Drive	0.034	0.017	2.01	0.044	positive
	Discharge Point	-0.049	0.012	-4.176	< 0.001	negative
	Causeway	-0.047	0.033	-1.402	0.161	nil

Parameter	Site	Estimate	SD	z- or t-value	p-value	Effect
	Plover Street	0.03	0.012	2.497	0.013	positive
Infauna – number of species	Avon River mouth	0.007	0.008	0.838	0.402	nil
	Heathcote River mouth	0.026	0.01	2.667	0.008	positive
	Pleasant Point Jetty	0.047	0.006	8.286	< 0.001	positive
	Humphreys Drive	0.038	0.006	5.691	< 0.001	positive
	Discharge Point	0.036	0.005	6.686	< 0.001	positive
	Causeway	-0.004	0.015	-0.257	0.797	nil
	Plover Street	0.055	0.005	11.489	< 0.001	positive
Infauna - diversity	Avon River mouth	-0.022	0.005	-4.264	< 0.001	negative
	Heathcote River mouth	0.075	0.008	9.386	< 0.001	positive
	Pleasant Point Jetty	0.05	0.005	9.814	< 0.001	positive
	Humphreys Drive	0.034	0.007	4.668	< 0.001	positive
	Discharge Point	0.044	0.005	9.685	< 0.001	positive
	Causeway	0.019	0.016	1.204	0.233	nil
	Plover Street	0.041	0.005	7.692	<0.001	positive
Infauna- evenness	Avon River mouth	-0.067	0.047	-1.423	0.155	nil
	Heathcote River mouth	0.205	0.058	3.551	< 0.001	positive
	Pleasant Point Jetty	0.048	0.039	1.225	0.221	nil
	Humphreys Drive	0.012	0.037	0.334	0.738	nil
	Discharge Point	0.079	0.04	1.989	0.047	positive
	Causeway	0.05	0.118	0.418	0.676	nil
	Plover Street	0.034	0.036	0.951	0.342	nil
Mud Benthic Health Model (BHM)	Avon River mouth	0.01	0.008	1.258	0.24	nil
	Heathcote River mouth	0.001	0.003	0.319	0.756	nil
	Pleasant Point Jetty	0.005	0.003	1.755	0.105	nil
	Humphreys Drive	0.023	0.008	2.92	0.013	positive
	Discharge Point	-0.006	0.004	-1.29	0.221	nil
	Causeway	-0.002	0.009	-0.222	0.835	nil
	Plover Street	0.016	0.002	6.493	< 0.001	positive
Metals Benthic Health Model (BHM)	Avon River mouth	-0.014	0.006	-2.246	0.051	nil
	Heathcote River mouth	-0.003	0.007	-0.433	0.674	nil
	Pleasant Point Jetty	0.005	0.003	1.546	0.148	nil
	Humphreys Drive	0.016	0.007	2.124	0.055	nil
	Discharge Point	0.001	0.005	0.188	0.854	nil
	Causeway	0.008	0.009	0.89	0.424	nil
	Plover Street	0.015	0.005	2.809	0.016	positive

Appendix 4. Additional information on the Benthic Health Models.

Table A4.1 Taxa removed before modelling following Clark (2022). Taxa names are those from the standardised 2007-2021 Ihutai infauna dataset rather than the raw data.

Taxon	Reason removed
Austrominius modestus	Aggregative species
Chironomus sp.	Insect
Dolichopodidae	
Ephydridae	
Ephydridae (pupa)	
Megalope	Juvenile
Nereididae juveniles	
Spionidae juvenile	
Unidentified Decapoda megalops	
Unidentified juv crab	
Unidentified juvenile mussel	
Calanoida	Meiofauna
Copepoda	
Nematoda	
Ostracoda	
Pantopoda	Not infauna
Anthozoa	Not in the original models
Capitellidae	
Cephalocarida	
Flabellifera	
Haustrum scobina	
Mytilidae	

Table A4.2 Model taxa categories used for taxa that could not be assigned following Clark (2022). Taxa names are those from the standardised 2007-2021 Ihutai infauna dataset rather than the raw data.

Taxon	**Category assigned**	**Sum of average abundances at each site**
Amphipoda	Corophiidae	393
Phreatogammarus sp.	Amphipod other	0.1
Prionospio spp.	*Prionospio* spp.	17.6

Table A4.3 Absolute health boundaries for the National Metals Benthic Health Model (BHM). Refer to Clark (2022) for full references.

Absolute health	**Metals BHM score**	**Justification**
Good	< 3.6	Upper value represents the point at which the abundance of *Austrovenus stutchburyi* will have declined by 50% (EC50; Hewitt et al. 2009) and is also equivalent to the boundary between Category 1 and 2 in the Auckland-specific Metals BHM. This value also represents the sediment quality guideline for sandy sediments in less than 100 m water depth derived by Bjørgesæter and Gray (2008) using field data from the Norwegian continental shelf.
Fair	3.6 to < 4.8	Encompasses the effect concentrations (FEC) guidelines derived by Hewitt et al. (2009) using field data from Auckland estuaries (BHM scores = 4.1-4.5). These values represent the point at which 5% of all taxa would have suffered a ≥ 50% decrease in abundance. This category also includes the adjusted community hazardous concentration 5% value (cHC5) derived by Kwok et al. (2008) using field data from Hong Kong (BHM score = 4.7). This value represents the highest concentration of a metal at which no benthic organisms are expected to be affected adversely.
Poor	4.8 or greater	Lower value represents Auckland Council's Green guideline for sediment metals (ARC 2004). This category also includes the value equivalent to Auckland Council's Red guideline for sediment metals (BHM score 5.3) and the ANZG (2018) Default Guideline Value for metals (BHM score 5.6).

Table A4.4 Sites included in the original Benthic Health Models.

Site	Year	Mud BHM	Metals BHM
Avon River mouth	2007	Yes	Yes
Heathcote River mouth	2007	Yes	Yes
Discharge Point	2011	Yes	Yes
Humphreys Drive	2011	Yes	Yes
Pleasant Point Jetty	2011	Yes	Yes
Plover Street	2012	Yes	No

Before using the BHMs to assess estuary health at a new site, the fit of the calculated BHM scores should be assessed by plotting the BHM scores for each site/time against either sediment mud content (for the Mud BHM) or PC1 Metals values (for the Metals BHM) to determine whether any sites or times fall outside of the model data points (i.e., are offset). The PC1 Metals value represents the combination of copper, lead and zinc concentrations at each site and/or time based on a Principal Components Analysis (refer to Clark et al. 2020 for details). Periodic checks of fit are also recommended to ensure potential environmental changes (e.g., climate change or changes in the ratio of metals) are not affecting BHM scores.

Ideally, BHM scores from new sites or times would fall within the range of the model data (pink circles in Figure A4.1). If BHM scores consistently fall outside of the range of the model data then the BHMs may not be a reliable indicator of health for this site relative to other estuarine sites across New Zealand. Possible drivers of offsets include differences in grain size measurement protocols (e.g., whether shell hash was excluded), a high proportion of coarse sands (> 0.5 mm), gravel (> 2 mm) or shell hash at the study site, scouring at the study site, strong freshwater influence, or the influence of an unmeasured stressor (i.e., one not being assessed using the BHM). Offsets are unlikely to alter the trajectory of the scores, therefore, trends in BHM scores through time (e.g., indicating increasing or decreasing impact) are likely to be valid, even if impact relative to other sites cannot be relied upon.

All of the sites in Ihutai had a good fit with the BHMs, indicating that they can reliably be used to assess the health of these estuaries. No consistent pattern was observed between model fit and site/times where taxa were only identified to Amphipoda or *Prionospio aucklandica* was not separated out from the other *Prionospio* spp.

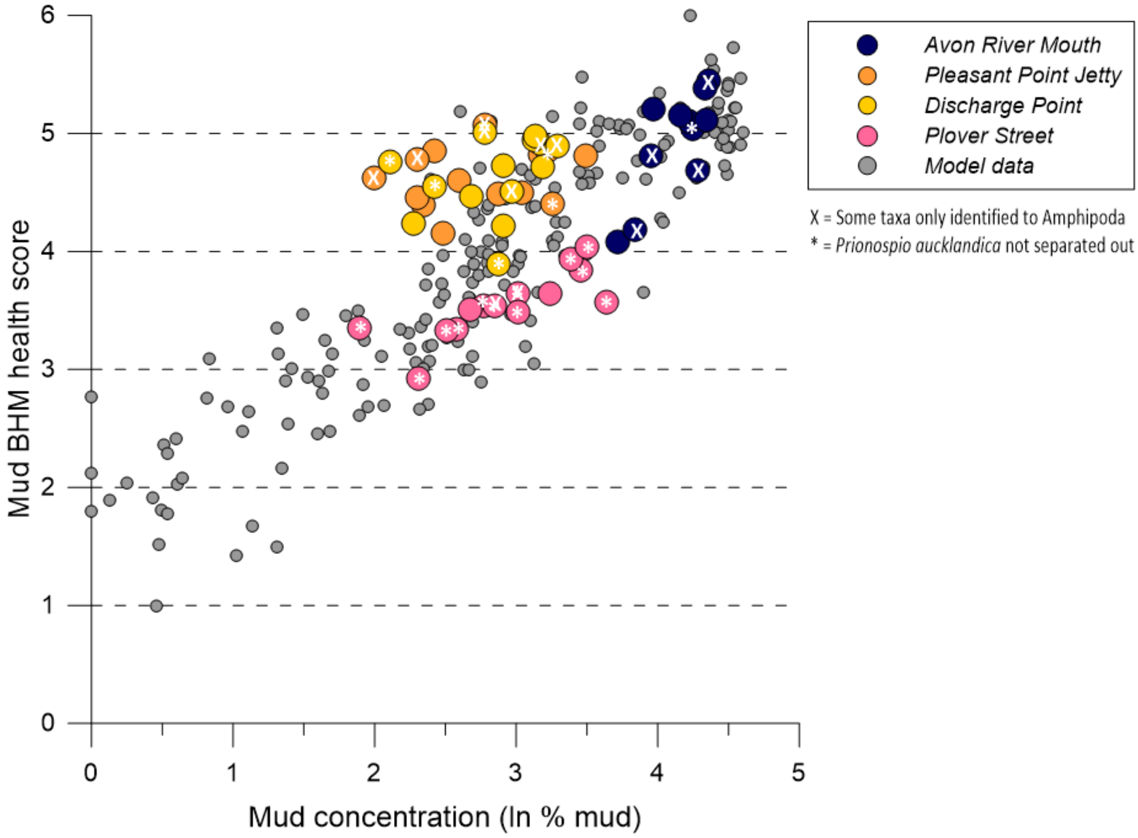

Figure A4.1 Comparison of Mud Benthic Health Model (BHM) scores at four Ihutai monitoring sites (coloured circles) with those from sites used to develop the model (grey circles).

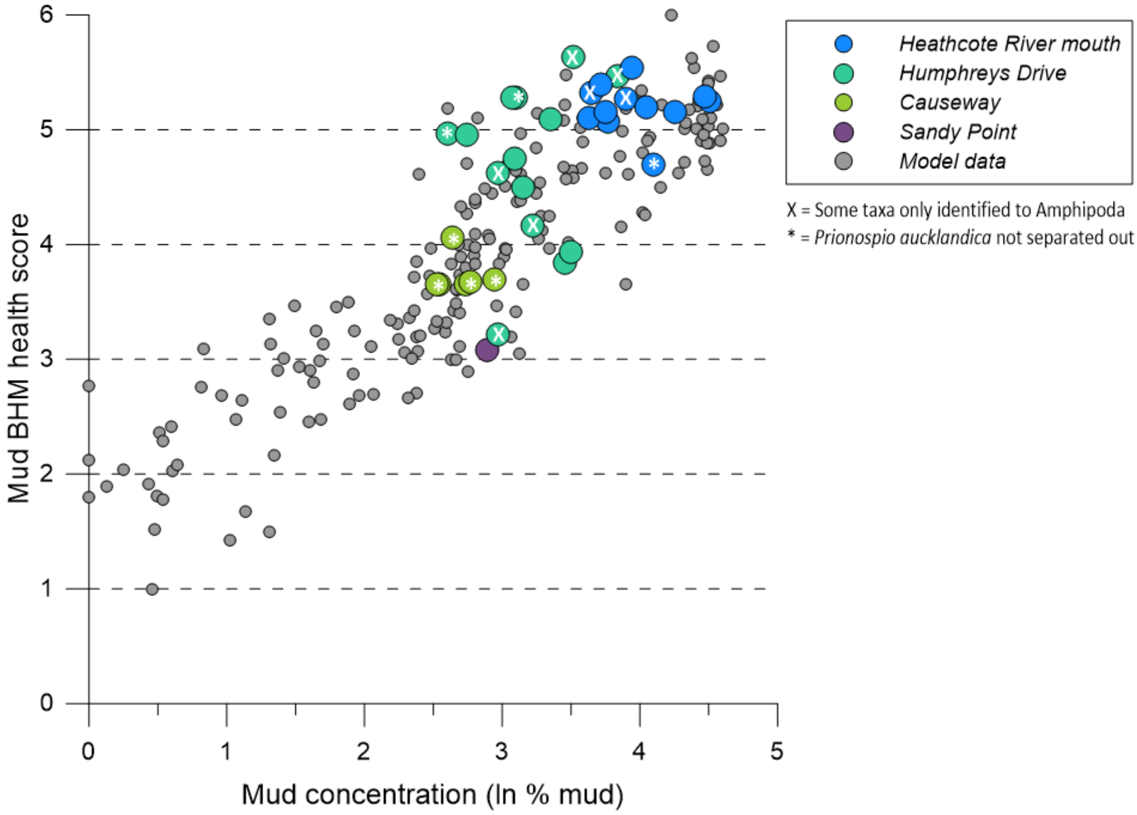

Figure A4.2 Comparison of Mud Benthic Health Model (BHM) scores at four Ihutai monitoring sites (coloured circles) with those from sites used to develop the model (grey circles).

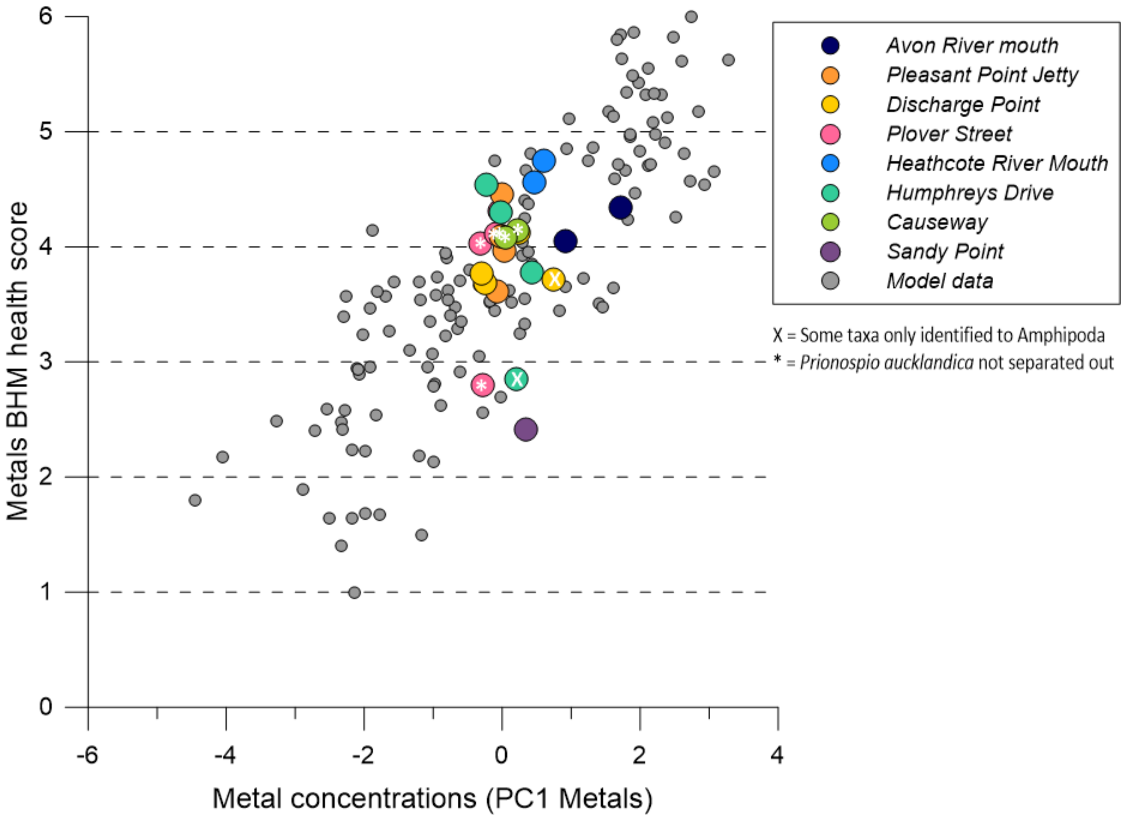

Figure A4.3 Comparison of Metals Benthic Health Model (BHM) scores at Ihutai monitoring sites (coloured circles) with those from sites used to develop the model (grey circles).

Appendix 5. Changes that could be made to improve the taxonomic resolution for application of the BHMs in the future.

Several changes could be made to improve the taxonomic resolution for application of the BHMs in the future:

- *Prionospio aucklandica* should be separated out from other *Prionospio* sp. – it was not clear if this was always the case.
- Anemone should not be used and instead taxa should be identified as either *Anthopleura hermaphroditica*, Edwardsiidae or Anemonia.
- Capitellidae should not be used and instead taxa should be identified as either *Heteromastus filiformis*/*Barantolla lepte*, *Capitella*/Oligochaete or *Notomastus* sp.
- Cephalocarida should not be used and instead taxa should be identified to a better level of taxonomic resolution.
- Flabellifera should not be used and instead taxa should be identified to either Anthuroidea, Cirolanidae, Exosphaeroma or Isopod other.
- *Arcuatula senhousia* should be separated out from other Mytilidae.
- Amphipoda should not be used and instead taxa should be identified as either Corophiidae, Paracalliopiidae, Phoxocephalidae or Amphipod other.