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Drivers, patterns and relationships between estuary health metrics in the Waikato region

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SELECTING APPROPRIATE STATE OF THE ENVIRONMENT INDICATORS FOR ESTUARY MONITORING IN THE WAIKATO REGION

SELECTING APPROPRIATE STATE OF THE ENVIRONMENT INDICATORS FOR ESTUARY MONITORING IN THE WAIKATO REGION

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EXECUTIVE SUMMARY

In Aotearoa New Zealand, five macrofauna-based indicators are commonly used to assess estuary health. These include two Regional Benthic Health Models (BHMs), two National BHMs and the Traits Based Index (TBI). These indicators are underpinned by different formulations, use different taxa to calculate scores and examine different components of estuarine health. While they should not be expected to be highly correlated, there should be some degree of consistency when classifying the health of sites as low, moderate or highly impacted.

Waikato Regional Council (WRC) uses all five indicators to assess estuarine health in its region. The overarching objective of this report was to investigate the performance of different indicators of estuary health for Waikato estuarine sites compared to stressor gradients and to one another, and to explore drivers of any differences in health scores. This will help the council decide which indicators are best to use in future monitoring.

Overall, both the Regional and the National BHMs performed well in assessing the health of estuarine sites in Waikato in response to sedimentation and metal contamination impacts. However, the effect of these stressors on macrofaunal communities was best represented by the National BHMs. Additional findings are as follows:

- The National BHMs generally ranked sites in a similar way to the Regional BHMs. Differences in group scores often occurred where scores were close to the boundary between two groups. Where groups differed, the National Mud BHM tended to rank sites as being more impacted by sediment than the Regional Mud BHM, aside from at Thames Gun Club and Gumdigger Gully, where the opposite pattern was found. Where Metals BHM scores differed, the National Metals BHM tended to rank sites as being more impacted by metal contamination than did the Regional Metals BHM. There was no evidence that differences between Regional and National BHM scores were more pronounced in certain estuaries.
- Slight differences in Regional and National BHM scores could be driven by differences in the structure of the underlying models, differences in the dataset used to develop the models, differences in taxonomic assignment between the models, and the way in which the raw scores are assigned to BHM groups.

We recommend switching from the Regional BHMs to the National BHMs to assess the health of estuarine sites in Waikato in response to sedimentation and metal contamination impacts. Although the indicators provide similar information, the effect of these stressors on macrofaunal communities was better represented by the National BHMs. Furthermore, the National BHMs allow estuary health to be assessed relative to other sites across Aotearoa New Zealand, and this information can be uploaded onto the recently developed estuarine health module of the Land, Water, Air, Aotearoa (LAWA) website.

We also recommend the continued use of the TBI to assess the health of estuarine sites in Waikato. The BHMs and the TBI provide complementary information; the BHMs are more sensitive to changes in mud content and metal contamination, while the TBI provides additional information on the functional redundancy / resilience of a site and integrates the effects of mud and metal contamination on macrofaunal communities.

Finally, we recommend the development of a national working group that oversees the National BHM, manages version control and any updates, and supports a programme of ongoing validation.

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GLOSSARY

Term	Definition
Benthic	Pertaining to the seabed.
BHMmetals	The Benthic Health Model developed in the Auckland region to track changes in estuarine health in response to heavy metal contamination (referred to as the Regional Metals BHM in this report).
BHMmud	The Benthic Health Model developed in the Auckland region to track changes in estuarine health in response to sedimentation (referred to as the Regional Mud BHM in this report).
BHM scores	The outputs of the Benthic Health Models. For the Regional BHMs, these are equivalent to the canonical analysis of principal coordinates (CAP) scores. For the National BHMs, the CAP scores are standardised from 1 to 6 to produce the BHM scores.
CAP	Canonical analysis of principal coordinates, a multivariate statistical approach that underpins the Benthic Health Models.
CAP scores	The raw outputs of the Benthic Health Models.
LAWA	Land, Water, Air, Aotearoa. A website for sharing environmental information with the public (https://www.lawa.org.nz).
Macrofauna	Animals larger than 0.5 mm inhabiting soft sediments (e.g. polychaete worms, crabs, shellfish).
National Benthic Health Models (BHMs)	Indicators of estuarine health based on benthic macrofauna communities that track sedimentation and metal contamination impacts. They can be applied to estuaries across Aotearoa New Zealand. There are two models: Mud BHM and Metals BHM (referred to as the National Mud BHM and the National Metals BHM, respectively, in this report).
PCA	Principal component analysis, a multivariate statistical approach.
PC1 Metals	A single gradient that represents the combined concentrations of copper, lead and zinc. It is used in the Regional Metals BHM and National Metals BHM. The gradient is derived from the first axis of a principal component analysis (PCA) of sediment copper, lead and zinc concentrations.
Regional Benthic Health Models (BHMs)	Indicators of estuarine health based on benthic macrofauna communities that track sedimentation and metal contamination impacts. They were originally developed for use in the Auckland region. There are two models: BHMmud and BHMmetals (referred to as the Regional Mud BHM and the Regional Metals BHM, respectively, in this report).
Traits Based Index (TBI)	An indicator of estuarine health based on benthic macrofauna communities that indicates the functional redundancy / resilience of a site.
WRC	Waikato Regional Council.

1 Introduction

Several indicators of estuarine health are used by regional government agencies across Aotearoa New Zealand for state of the environment reporting (e.g. Berthelsen et al. 2018; Berthelsen et al. 2019). Many of these indicators are based on changes in the macrofaunal communities that inhabit the intertidal sediments of estuaries (e.g. shellfish, worms, small crustaceans). Indicators based on macrofaunal communities are informative about estuary health because these communities respond relatively rapidly to stressors, integrate the effects of multiple stressors over time, and are composed of a diverse range of species with differing functional roles, trophic levels and sensitivities (Borja et al. 2000; Dauer 1993; Pearson and Rosenberg 1978). Incorporating community information into ecosystem health assessments allows organisms to ‘tell the story’ with respect to classifying sites along a continuum from degraded to non-degraded (Diaz et al. 2004).

In Aotearoa New Zealand, five macrofauna-based indicators are commonly used to assess estuary health.[1] These include two Regional Benthic Health Models (BHMs), two National BHMs and the Traits Based Index (TBI). These five indicators are underpinned by different formulations, use different taxa to calculate scores and examine different components of estuarine health. While they should not be expected to be highly correlated, there should be some degree of consistency when classifying the health of sites as low, moderate or highly impacted.

Waikato Regional Council (WRC) uses all five indicators to assess estuarine health in its region. WRC contracted Cawthron Institute (Cawthron) to investigate the performance of different indicators of estuary health for Waikato estuarine sites compared to stressor gradients and to one another, and to explore drivers of any differences in health scores. This will help the council decide which indicators are best to use in future monitoring.

1.1 Regional Benthic Health Models

The BHM approach to estuary health assessment was originally developed by Auckland Council, the University of Auckland and the National Institute of Water and Atmospheric Research (NIWA) to provide a tool for classifying sites within the Auckland region according to categories of relative ecosystem health. The first model was based on multivariate analysis of community composition responses to stormwater contamination (BHMmetals; Anderson et al. 2002; Anderson et al. 2006). The model is now called the BHMmetals and is based on a multivariate analysis of the

[1] The New Zealand AMBI (Robertson et al. 2016) is another macrofauna index that is used to assess estuary health in Aotearoa New Zealand, but it is not currently used by Waikato Regional Council.

variation in macrofaunal community composition related to sediment copper, lead and zinc concentrations. These metals are generally the key metals of concern in Aotearoa New Zealand estuaries (ARC 2004). This multivariate approach incorporates information on almost all taxa and their relative abundances, meaning the BHMs have high sensitivity to detect small changes in estuary health before significant ecosystem damage occurs. A second BHM, now called the BHMmud, was developed in 2010 to determine estuary health relative to sediment mud content (a proxy for sedimentation) within the Auckland region (Hewitt and Ellis 2010). In this report, the BHMmetals and the BHMmud will be referred to as the Regional Metals BHM and the Regional Mud BHM.

During model development, the relationship between macrofaunal community changes and variations in the concentration of sediment mud or metals was established. However, mud and metal concentrations are not used to calculate BHM scores for new sites – the model relies completely on community composition to assess estuary health. The output from each model is a CAP score from the multivariate model that underpins the indicator. These CAP scores can be simplified into five health groups, ranging from ‘Extremely Good’ to ‘Unhealthy with Low Resilience’ (Hewitt et al. 2012), that provide a measure of the health of a site relative to other estuarine sites in the Auckland region (Table 1).

Both models were developed using data from intertidal sites in the Auckland region. Because the scores they produce represent a measure of health relative to the sites used to develop the models, their application is restricted to estuaries within the Auckland region (Hewitt et al. 2012). However, the Regional BHMs are now routinely applied to assess the health of Waikato’s estuaries and are occasionally used with caution in other regions (e.g. McCartain and Hewitt 2016; Parkes et al. 2016).

Further details of the development and validation of the Regional BHMs can be found in Anderson et al. (2002, 2006) and Hewitt and Ellis (2010).

1.2 National Benthic Health Models

The National BHMs were developed in 2020 by Cawthron, the University of Waikato and NIWA in response to the need for an estuarine indicator that could be applied to estuaries across Aotearoa New Zealand (Clark et al. 2020). Like the Regional BHMs, two separate models were developed: the Mud BHM and the Metals BHM. These provide a standardised measure of the relative impact of sedimentation and heavy metal contamination on macrofaunal communities in Aotearoa New Zealand’s estuaries. The National BHMs were developed following the same multivariate approach as the Regional BHMs. The Mud BHM assesses the impact of mud in surface sediments on macrofaunal communities. Mud content in surface sediments is used as a surrogate for sediment accumulation rates. The Metals BHM assesses the impact of copper, lead and zinc in surface sediments on macrofaunal communities.

The National BHMs have an extra step that differs from the Regional BHMs, in that the raw CAP scores produced by the multivariate model that underpins the indicator are standardised to produce a BHM score between 1 and 6. A score of 1 indicates the lowest impact of the stressor(s) on macrofaunal communities and 6 indicates the highest impact, relative to other estuarine sites across Aotearoa New Zealand (Table 1). 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 an Aotearoa New Zealand context (refer to Clark 2022 for further details), but these absolute health categories will not be used in this report.

The National BHMs were developed using data from intertidal sites across Aotearoa New Zealand, meaning they can be applied to estuaries across the country. Having a national-scale tool enables managers to evaluate the health of their estuary in a national context, reduces the substantial costs that would be required to develop separate estuary-scale or regional-scale models, and reduces the reliance on reference sites. For these reasons, the National Mud BHM has been selected as a national indicator of estuarine health within the recently developed estuarine health module of the Land, Water, Air, Aotearoa (LAWA) website.[2] The creation of this platform will hopefully encourage greater consistency in state of the environment reporting across Aotearoa New Zealand and will require the use of nationally applicable indicators.

Full details of the development and validation of the National BHMs are provided in Clark et al. (2020).

1.3 Traits Based Index

The Traits Based Index (TBI) was developed by NIWA for Auckland Council in 2011 as a scientifically defensible indicator of the ecological integrity of the estuarine and coastal areas of the Auckland region (Lohrer and Rodil 2011). Unlike the Regional and National BHMs, which provide a measure of health based on changes in the structure of the entire macrofaunal community, the TBI provides a measure of the functional redundancy or resilience of a site. Instead of looking at changes in the abundance of different macrofaunal species, it categorises each organism according to characteristics (traits) that are likely to reflect ecosystem function. Changes in the abundance of these traits, rather than the abundance of different species, are then used to assess health.

[2] https://www.lawa.org.nz/explore-data/estuaries

The TBI is based upon the richness of macrofaunal taxa in seven individual functional trait groups (living position, sediment topography feature created, direction of sediment particle movement, degree of mobility, feeding behaviour, body size, body shape and body hardness). These seven traits were initially selected because they were found to be sensitive to changes in sediment mud content and metal contamination.

Sites with high functional redundancy (i.e. with many species present in each functional trait group) will tend to have higher inherent resistance and resilience in the face of environmental changes, as the higher numbers of species per functional group provide 'insurance' for stochastic or stress-induced losses of particular species (Lohrer and Rodil 2011).

The index runs from 0 to 1, with values closer to 0 indicating low levels of functional redundancy and highly degraded sites (Table 2). Declines in TBI scores alongside increases in mud and heavy metals are interpreted as losses of functional redundancy. The TBI was developed using data from intertidal sites in the Auckland region, but because this indicator is based on the number of species in traits, rather than the identity of the species, it can be used in other regions of Aotearoa New Zealand where species pools may differ.

Full details of the development and validation of the TBI is provided in Lohrer and Rodil (2011), Rodil et al. (2013) and Hewitt et al. (2012).

1.4 Comparison of indicators

The Regional and National BHMs were developed following the same general approach, but the Regional BHMs used data from the Auckland region while the National BHMs used data from across Aotearoa New Zealand. Both indicators can be simplified into five categories corresponding to the level of impact or health at a given site (Table 1).

Slight differences exist in the models that underpin the BHMs:

- The taxonomic resolution of the macrofauna data differs between the Regional and National BHMs.
- The Regional Mud BHMs were developed using raw mud values while the National Mud BHMs were developed using log-transformed mud values.
- Slightly different data were used to develop the PC1 Metals gradient that characterises the copper, lead and zinc gradient in the Metals BHM. The Regional Metals BHM uses metals data (< 500 µm fraction) from sites in Auckland, and the

National Metals BHM uses metals data (< 500 µm fraction) from sites across Aotearoa New Zealand.

- The National BHM incorporates a standardisation step to convert the raw CAP scores into easier to understand values ranging from 1 to 6.

Table 1. Descriptive names and boundary cut-off values for National and Regional Benthic Health Model (BHMs) categories. 'Level of impact' and 'Health' are relative to other estuarine sites in Auckland or Aotearoa New Zealand rather than being an absolute measure of impact.

Group	Level of impact	Health	Regional		National	
			Mud BHM	Metals BHM	Mud BHM	Metals BHM
1	Very low	Extremely good	≤ −0.12	≤ −0.164	≥ 1.0 < 2.0	
2	Low	Good	> −0.12 ≤ −0.05	> −0.164 ≤ −0.0667	≥ 2.0 < 3.0	
3	Moderate	Moderate	> −0.05 ≤ 0.02	> −0.0667 ≤ 0.0234	≥ 3.0 < 4.0	
4	High	Poor	> 0.02 ≤ 0.10	> 0.0234 ≤ 0.10	≥ 4.0 < 5.0	
5	Very high	Unhealthy with low resilience	> 0.10	> 0.10	≥ 5.0	

The TBI is a measure of the functional redundancy / resilience of a site. It is quite a different measure of health from the BHMs, because it is calculated based on the richness of only seven individual functional trait groups, rather than the structure of the entire macrofaunal community. The TBI is not considered to have a linear response and is generally less sensitive to mud and heavy metal pollution than the relevant BHMs, but it provides information on whether functional redundancy is changing and whether specific functional traits are being affected (Hewitt et al. 2012). Due to its lower sensitivity, the TBI can be simplified into only three categories (Table 2).

Table 2. Descriptive names and boundary cut-off values for the Traits Based Index (TBI) categories.

Group	Functional redundancy / resilience	TBI
1	Good	> 0.4 ≤ 1.0
2	Intermediate	> 0.3 ≤ 0.4
3	Poor	> 0 ≤ 0.3

1.5 Report objectives

The overarching objective of this report was to investigate the performance of different indicators of estuary health for Waikato estuarine sites in comparison to one another and to stressor gradients, and to explore drivers of any differences in performance. The focus was on differences between the Regional and National BHMs, but comparison with the TBI was made where appropriate.

Specifically, Cawthron was asked to:

- explore and comment on the relationships (shape / strength) between different indicators of health across Waikato estuarine sites
- outline and summarise whether differences in relationships are in a specific direction
- comment on the Manaia Road, Pauanui, Thames Gun Club, Te Puru and Haroto Bay sites over time
- explore what is underpinning the differences in health scores at the sites listed above
- comment on scores in the context of the environmental data available for the sites listed above
- provide an account of the above that can be incorporated into state of environment monitoring reports
- include any relevant material on the comparison of indicator performance (i.e. if this has been undertaken in other regions)
- provide a summary suitable for a lay audience that can be incorporated into summaries of health on WRC's website
- make recommendations on the use and effectiveness of different indicators with respect to performance for Waikato estuarine sites.

2 Methods

2.1 Dataset

Indicator data, and the macrofauna data these indicators were derived from, were provided to Cawthron by WRC. These data were collected between 2012 and 2020 from 20 sites across four estuaries (Table 3). Two of the 125 sampling site / times were included in the development of the National BHMs (Oturu Stream and Pepe Inlet, November 2014). Sediment mud content (sediment grain size < 63 µm; %) and metals data (copper, lead and zinc; mg/kg) were available for at least one sampling time at each site, except for Kaitoke, which had no metals data. When metals data were not collected concurrently with the macrofauna data, metals data collected at an alternative time within the same year of macrofauna sampling were used instead.

Table 3. Estuary monitoring data used in this report. The 'Mud' and 'Metals' columns indicate whether sediment mud content (< 63 µm) and or metals (copper, lead and zinc) data were available for at least one sampling event (Y = yes, N = no), and for the metals, whether these data were collected at the same time as the macrofauna data (exact match) or at a different time in the same year (close match).

Estuary	Site	Code	No. times sampled	Years	Mud	Metals (match)
Coromandel	Awakane Stream	AS	2	2019–2020	Y	Y (close)
	Brickfield Bay	BB	2	2019–2020	Y	Y (close)
	Coromandel Town	CT	2	2019–2020	Y	Y (close)
	McGregor Bay	MG	2	2019–2020	Y	Y (close)
Firth of Thames	Kaiaua	KA	7	2012–2018	Y	Y (exact / close)
	Kuranui Bay	KB	9	2012–2020	Y	Y (exact / close)
	Miranda	MI	9	2012–2020	Y	Y (exact / close)
	Te Puru	TP	7	2012–2018	Y	Y (exact)
	Thames Gun Club	GC	7	2012–2018	Y	Y (exact / close)

Estuary	Site	Code	No. times sampled	Years	Mud	Metals (match)
Raglan Harbour	Haroto Bay	HB	7	2012–2020	Y	Y (close)
	Kaitoke Bay	KT	2	2019–2020	Y	N
	Okete Bay	OB	9	2012–2020	Y	Y (close)
	Ponganui Creek	X	3	2016–2018	Y	Y (close)
	Te Puna Point	TU	3	2016–2018	Y	Y (close)
	Whatitirinui Island	WI	9	2012–2020	Y	Y (close)
Tairua Harbour	Gumdigger Gully	GG	9	2012–2020	Y	Y (exact / close)
	Manaia Road	MR	9	2012–2020	Y	Y (exact / close)
	Oturu Stream	OS	9	2012–2020	Y	Y (exact / close)
	Pauanui	PA	9	2012–2020	Y	Y (exact / close)
	Pepe Inlet	PE	9	2012–2020	Y	Y (exact / close)

2.2 Data tidying

2.2.1 Indicator data

As mentioned in Section 1.2, the National BHM's produce a BHM score between 1 and 6, with 1 indicating the lowest impact of the stressor on macrofaunal communities and 6 indicating the highest impact, relative to other estuarine sites across Aotearoa New Zealand. To obtain these scores, the data produced from the underlying model (CAP scores) need to be standardised using the following equations (refer to Clark et al. 2020 for details):

Eq. 1: National Mud BHM = (1+(6–1)*((Mud CAP score * – 1) + 0.177114162796166) / 0.304912508295966)

Eq. 2: National Metals BHM = (1+(6–1)*(Metals CAP score + 0.18224921053598) / 0.326788414557379)

These equations simply rescale the CAP scores from 1 to 6 for ease of interpretation using the minimum and range of the original CAP model scores. The sign (+ or −) of the CAP scores is arbitrary, so for the National Mud BHM, the direction of the axis should be reversed by multiplying it by −1 so that it is deliberately oriented such that increasing BHM scores correspond to increasing sediment impact. This step is included in Equation 1 above. The CAP scores for the National Metals BHM are already oriented in an intuitive direction and so do not need to be reversed (although they do need to be standardised from 1 to 6). Our experience is that the CAP scores for a given model are not always oriented in the same direction[3]. Therefore, when calculating scores for new sites it is always good practice to check the CAP plots to make sure the axis is oriented as expected and adjust the scores if not. It is also important to note that some of the sites underlying the National models are not the same for Mud and Metals BHMs.

2.2.2 Sediment data

Metal data with values less than the analytical detection limit were replaced with values equivalent to half the analytical detection limit. Sediment data (mud, copper, lead and zinc) were then averaged by site / time.

For the Regional and National Metals BHMs, a single gradient is used that corresponds to increases in the combined concentrations of copper, lead and zinc (PC1 Metals). These PC1 Metals gradients were originally derived from the first axis of a principal component analysis (PCA) when each of the models was being developed (Anderson et al. 2006; Clark et al. 2020). Different metals data were used to develop the Regional and National BHMs; therefore, each model has a slightly different PC1 Metals gradient. This means that constraining factors in the CAP model (i.e. the gradient along which the model will try to separate the cloud of multivariate data points) may differ slightly between the Regional and National Metals BHMs, which could affect model scores.

The PC1 Metals score for a given site can be calculated from its sediment copper, lead and zinc concentrations using the eigenvector weights and the mean log concentrations of each metal across the sites used to develop the models (Equations 3 and 4[4]).

$$\text{Eq. 4: Regional PC1 Metals} = 0.615 * (\text{LogCu} - 2.472) + 0.586 * (\text{LogPb} - 2.925) + 0.528 * (\text{LogZn} - 4.418)$$

[3] The Regional BHM CAP scores sometimes come out in different orientations, but this has not yet been observed for the National BHMs.
[4] Log values are log(X + 1).

Eq. 5: National PC1 Metals = 0.653 * (LogCu - 1.80129868718257) + 0.536 * (LogPb - 2.280809502) + 0.535 * (LogZn - 3.832135075)

PC1 Metals values were calculated for each site / time using both the National PCA and the Regional PCA. These PC1 Metals values were used to assess the suitability of the BHMs for application in Waikato estuaries and the ability of these indicators to track changes in metal contamination (see Section 2.3 for details).

2.3 Data analyses

2.3.1 Assessing the suitability of the BHMs

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), if available, to determine whether any sites or times fall outside the model data points (i.e. are offset from the original regression). 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. Due to differences in the underlying model, the Regional BHMs were plotted against raw mud values and the Regional PC1 Metals values, and the National BHMs were plotted against log-transformed mud values and the National PC1 Metals values.

Ideally, BHM scores from new sites or times would fall within the range of the model data. 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 that site relative to other estuarine sites across Aotearoa New Zealand.

2.3.2 Assessing the ability of indicators to track stressor gradients

The ability of each indicator to track changes in relevant stressor gradients was assessed by plotting raw indicator scores for each site against either raw mud values, log mud values or the PC1 Metals values. Again, the PC1 Metals values used for plotting the Regional Metals BHM were from the Regional PCA, and the values used for plotting the National Metals BHM were from the National PCA. The TBI scores were plotted against both sets of PC1 Metals values. Spearman's rank correlations were also calculated to determine the strength of these relationships.

2.3.3 Assessing the relationship between different indicators

The shape and strength of the relationship between the Regional BHMs, the National BHMs and the TBI were assessed by producing scatterplots of indicator scores for each site and calculating Spearman's rank correlations. Comparisons were made only between indicators that tracked the same stressor (i.e. the Regional Mud BHM was not compared against the National Metals BHM). The TBI can be affected by both mud and metal stress, so was compared with all indicators.

For each of the sites, Regional and National BHM group scores were plotted through time to determine whether the different models ranked sites as being impacted in the same way by sediment and metal contamination. However, some nuances are lost when plotting group scores because it is not possible to determine visually whether the score was close to the group boundary. Therefore, plots of raw BHM and CAP scores are also provided in Appendices 2 and 3. TBI scores were not compared to BHM group scores because the TBI has only three groups and the BHMs have five.

2.3.4 Investigating drivers of differences between Regional and National BHM scores

To explore which taxa were driving discrepancies between Regional and National BHM scores, we compared the taxa categories used in each of the BHMs (Appendix 4). Scores for both models are calculated from the same macrofauna data, but these data are aggregated in different ways depending on which model is used. The results relating to differences in taxonomic assignment between the two models (Section 3.4.1) are not specific to WRC's data and are relevant to all councils.

We also examined more closely differences in taxonomic assignment between models using a sub-set of data from 2016 (Appendix 5). These results (Section 3.4.2) provide a case study of the effects of differences in taxonomic assignment on BHM scores, but they may have been different if data from other sites or years were used because different taxa may have been present. WRC supplied Cawthron with the aggregated macrofauna data underpinning the Regional BHM scores in 2016 and the aggregated macrofauna data underpinning the National BHM scores in all years. We first compared the Mud and Metal BHM group scores and taxonomic assignment between data in the two models at sites sampled in 2016. We then created a non-metric multi-dimensional scaling (MDS) plot using untransformed macrofauna abundance data to explore differences in community structure between the models in 2016. For sites that showed large discrepancies between BHM scores or differences in community structure on the MDS, we undertook a SIMPER analysis on untransformed macrofauna abundances data to compare similarities in community structure between the models and to understand which taxa were driving differences.

3 Results

3.1 Suitability of the BHMs for assessing the health of Waikato estuaries

All sites in Coromandel, Firth of Thames, Raglan Harbour (Whāingaroa Harbour; hereafter Raglan Harbour) and Tairua Harbour (for which data were available) had a good fit with the Regional and National BHM model data,[5] indicating that the BHMs can be reliably used to assess their health relative to other intertidal estuarine sites across Aotearoa New Zealand (Figure 1 and Figure 2). The National Mud BHM scores (but not the Regional BHM scores) for Kuranui Bay in 2016 and Te Puru in 2012 (both Firth of Thames) were higher than expected given the measured sediment mud content at these sites. However, scores from other sampling times at these sites fit the National BHM data; therefore, our recommendation is that the Mud BHM scores can be used to assess health at Kuranui Bay and Te Puru relative to other sites across Aotearoa New Zealand.

Similarly, the Regional Mud BHM scores for Gumdigger Gully (Tairua) were slightly higher than expected given the measured sediment mud content at this site but generally fit the Regional BHM data. Regional and National Metals BHM scores for Kuranui Bay and Te Puru (Firth of Thames) were slightly lower than expected given the level of metal contamination but generally fit the model data. The fit of the Metals BHM could not be assessed for Kaitoke, as no metals data were provided.

5 Sites or times generally fell within the model data points when plotted.

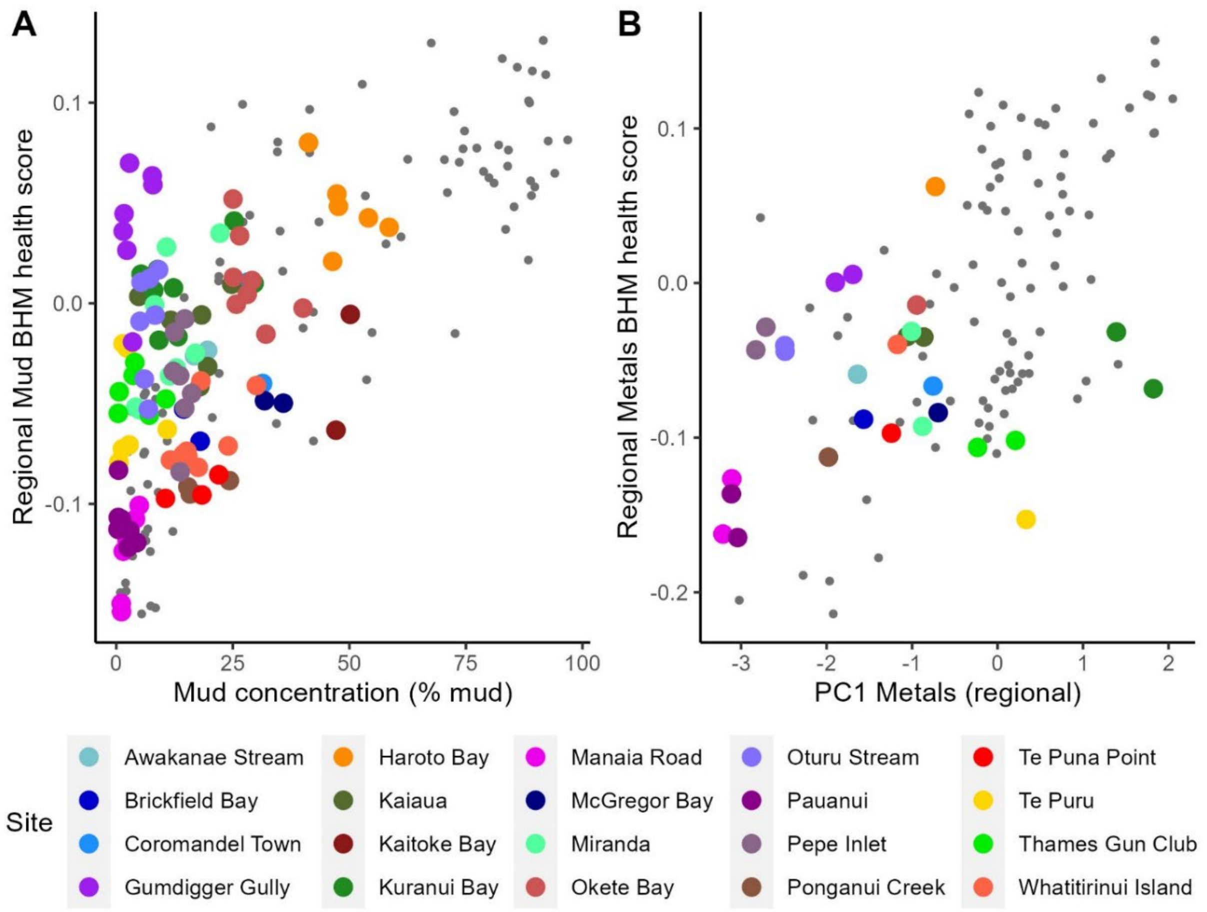


Figure 1. **Comparison of the Regional Mud Benthic Health Model (A) and the Regional Metals Benthic Health Model (B) scores from Waikato estuaries (coloured circles) with those from sites (across Auckland) used to develop the model (grey circles). Lower scores are less impacted and higher scores are more impacted relative to other estuarine sites across the Auckland region.**

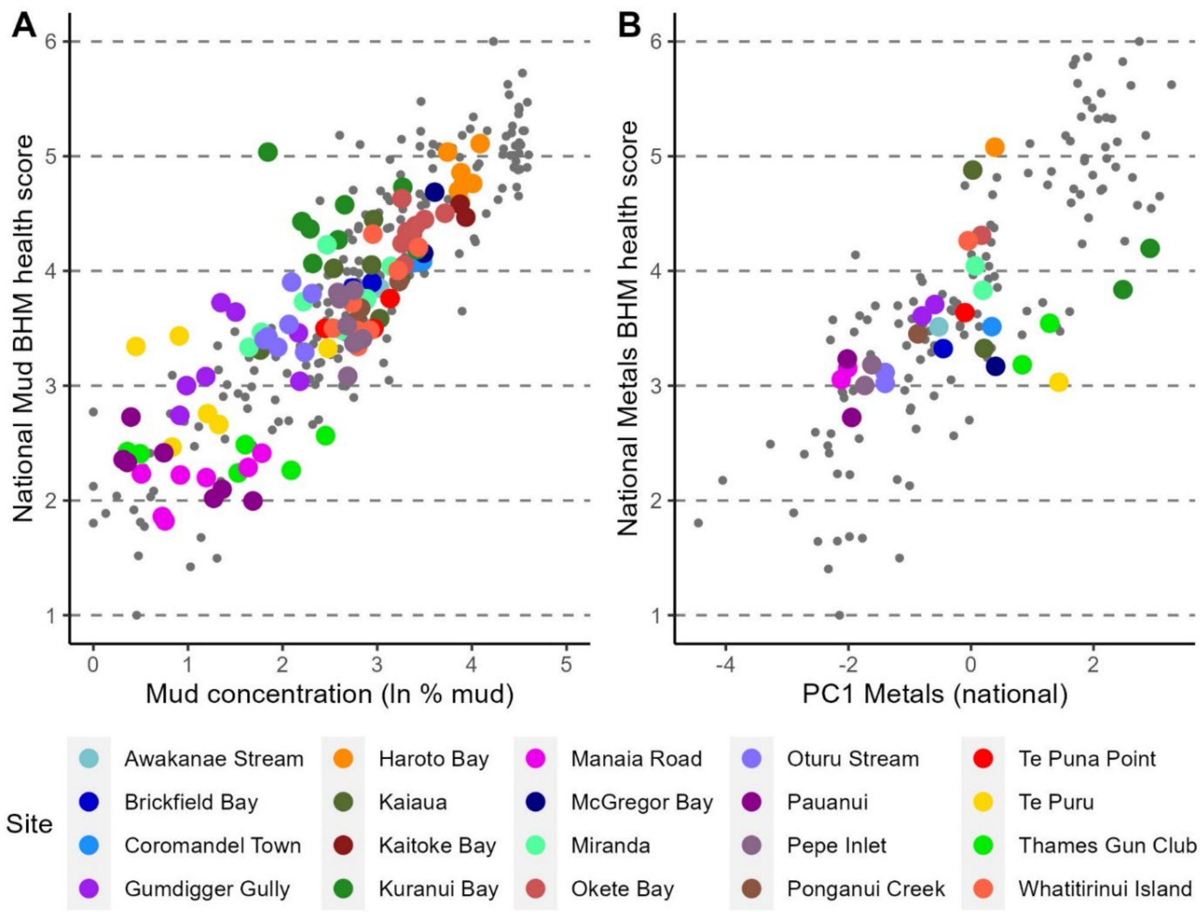


Figure 2. **Comparison of the National Mud Benthic Health Model (A) and the National Metals Benthic Health Model (B) scores from Waikato estuaries (coloured circles) with those from sites (across Aotearoa New Zealand) used to develop the model (grey circles). Scores range from 1 (least impacted) to 6 (most impacted) relative to other estuarine sites across Aotearoa New Zealand.**

3.2 Ability of indicators to track stressor gradients

For the WRC data, the National Mud BHMs scores had a strong correlation with mud (r = 0.82), while the Regional Mud BHMs scores had relatively weak correlation (r = 0.37) and the TBI showed almost no correlation (r = 0.03; Figure 3). The relationship between the log mud values and the National Mud BHM scores was more linear than the relationship with the raw mud scores, reflecting the use of log-transformed mud values in model development.

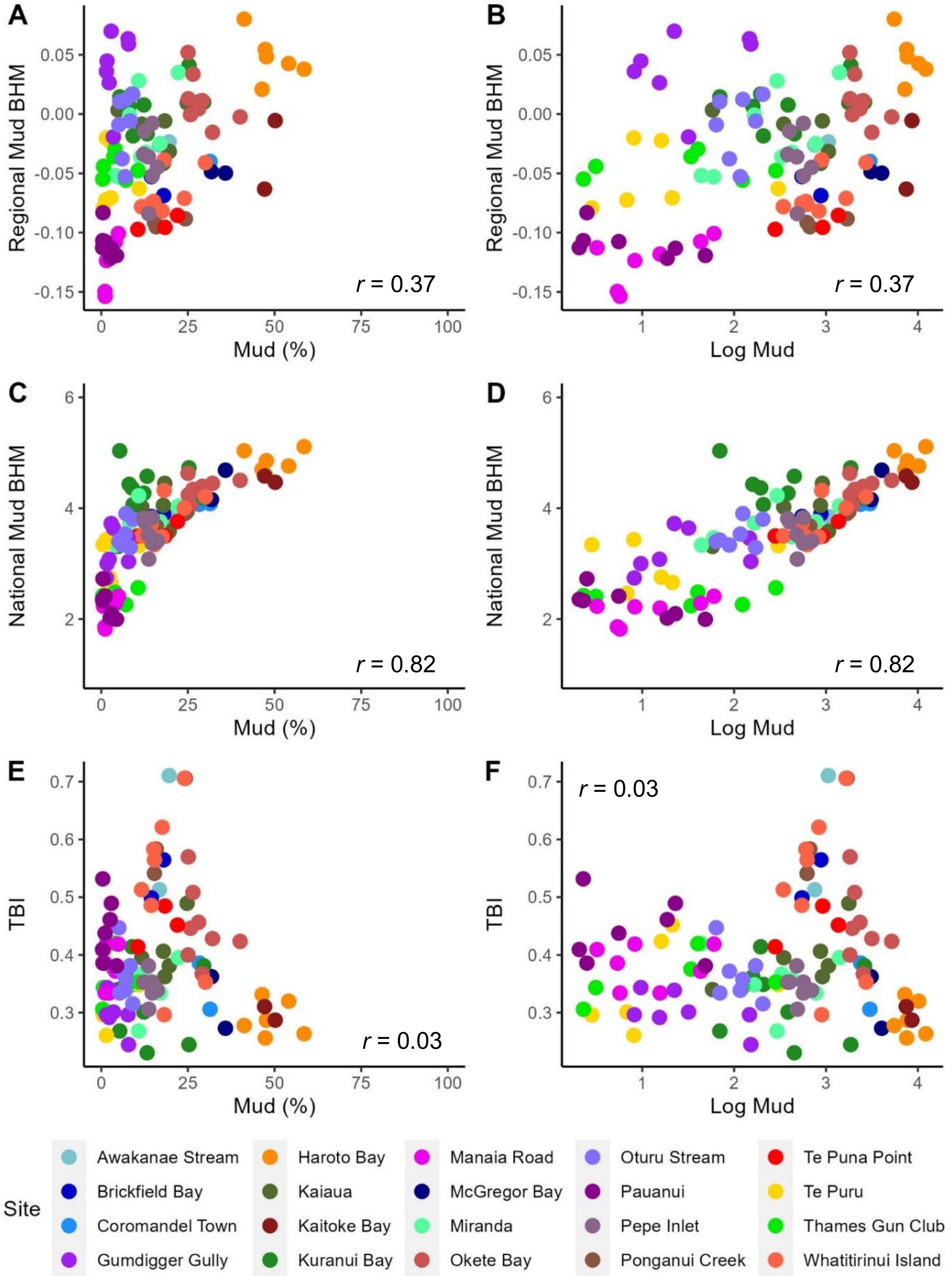


Figure 3. **Scatterplots showing the relationship between mud (%; left column) or log mud (right column) and three indicators of sedimentation stress: Regional Mud BHM (top panels), National Mud**

BHM (middle panels) and TBI (bottom panels). R values indicate the Spearman's rank correlation.

Similarly, for the WRC data, the National Metals BHM scores had the best correlation with metals (*r* = 0.50), followed closely by the TBI (*r* = -0.42; Figure 4). The correlation between the Regional Metals BHMs scores and metals was weak (*r* = 0.18). The two PC1 Metals gradients were very similar to each other, with a perfect correlation between the gradient calculated using the Regional PCA and gradient calculated using the National PCA (*r* = 1.0; Appendix 1).

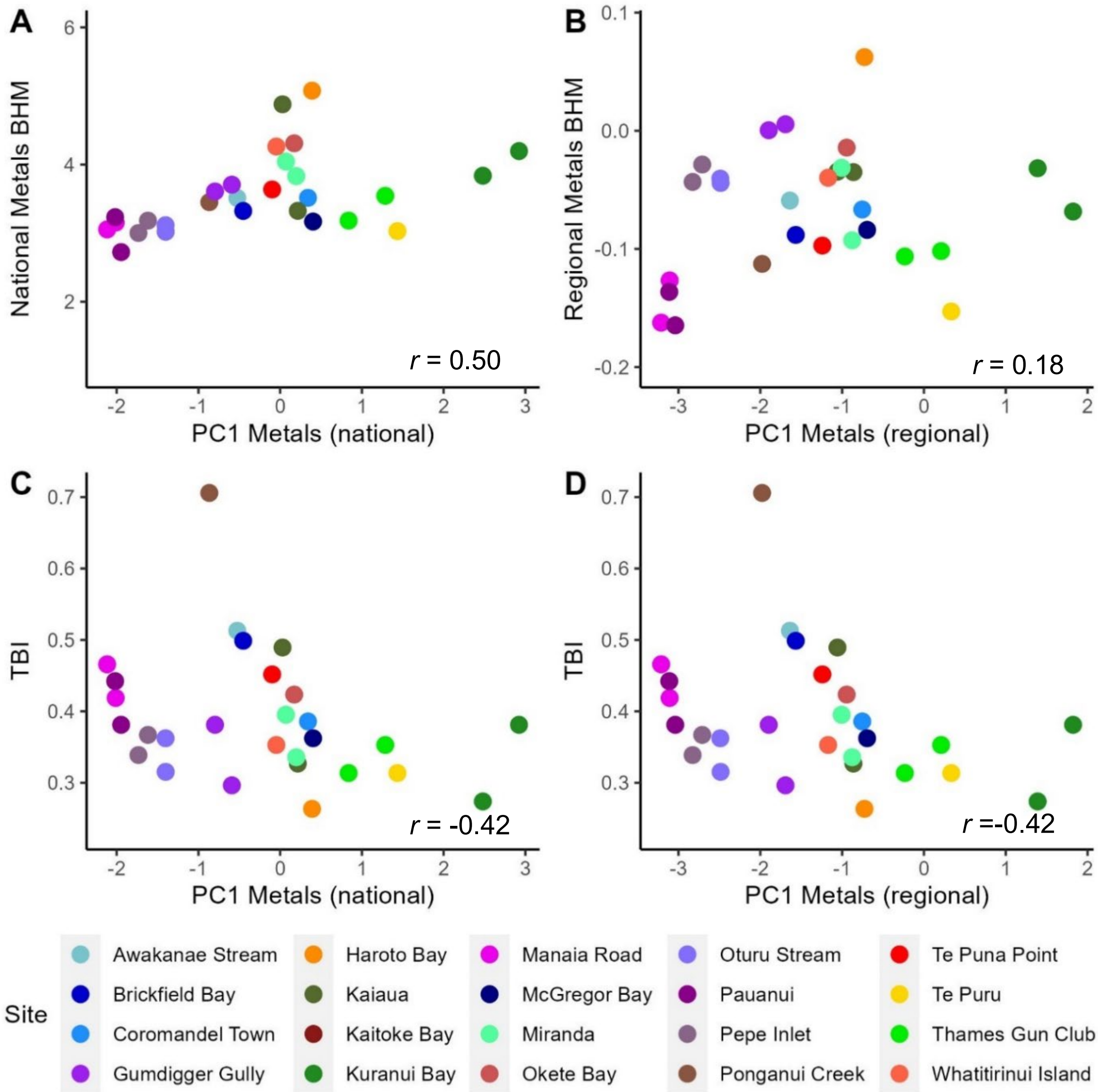


Figure 4. Scatterplots showing the relationship between metal contamination (represented by PC1 Metals, which is a combination of changes in copper, lead and zinc, calculated using the

national or regional formulae) and three indicators of metal contamination stress: National and Regional Metals BHM (top panels), and TBI (bottom panels). R values indicate the Spearman's rank correlation.

3.3 Relationships between indicators

3.3.1 Correlations between indicators

Scores from the Regional and National Mud BHMs had a moderate correlation (r = 0.60), indicating that the national models generally ranked sites in a similar way to the regional models (Figure 5). However, relatively consistent differences between rankings were observed at some sites. The Regional Mud BHMs tended to rank Gumdigger Gully as being more impacted by sediment than did the National BHMs, possibly reflecting the fact that the Regional Mud BHM scores for this site were slightly higher than expected given the measured sediment mud content (Figure 1). Conversely, the Regional BHMs ranked Te Puna Point and Ponganui Creek as less impacted by sediment than did the National Mud BHM, and the same pattern was observed at McGregor Bay and Kaitoke Bay in 2020. Of the five sites identified as being of particular interest to WRC, Manaia Road, Pauanui, Te Puru and Haroto Bay had Mud BHM scores that were generally very similar. There was more discrepancy between Regional and National Mud BHM scores at Thames Gun Club. The correlations between the Mud BHMs and TBI scores were not very strong (Figure 5; r = −0.42 with Regional Mud BHM, r = −0.19 with National Mud BHM). No major differences in Regional and National BHM scores were observed at the two sites that had higher than expected National BHM scores relative to their mud values (Kuranui Bay 2016 and Te Puru 2012).

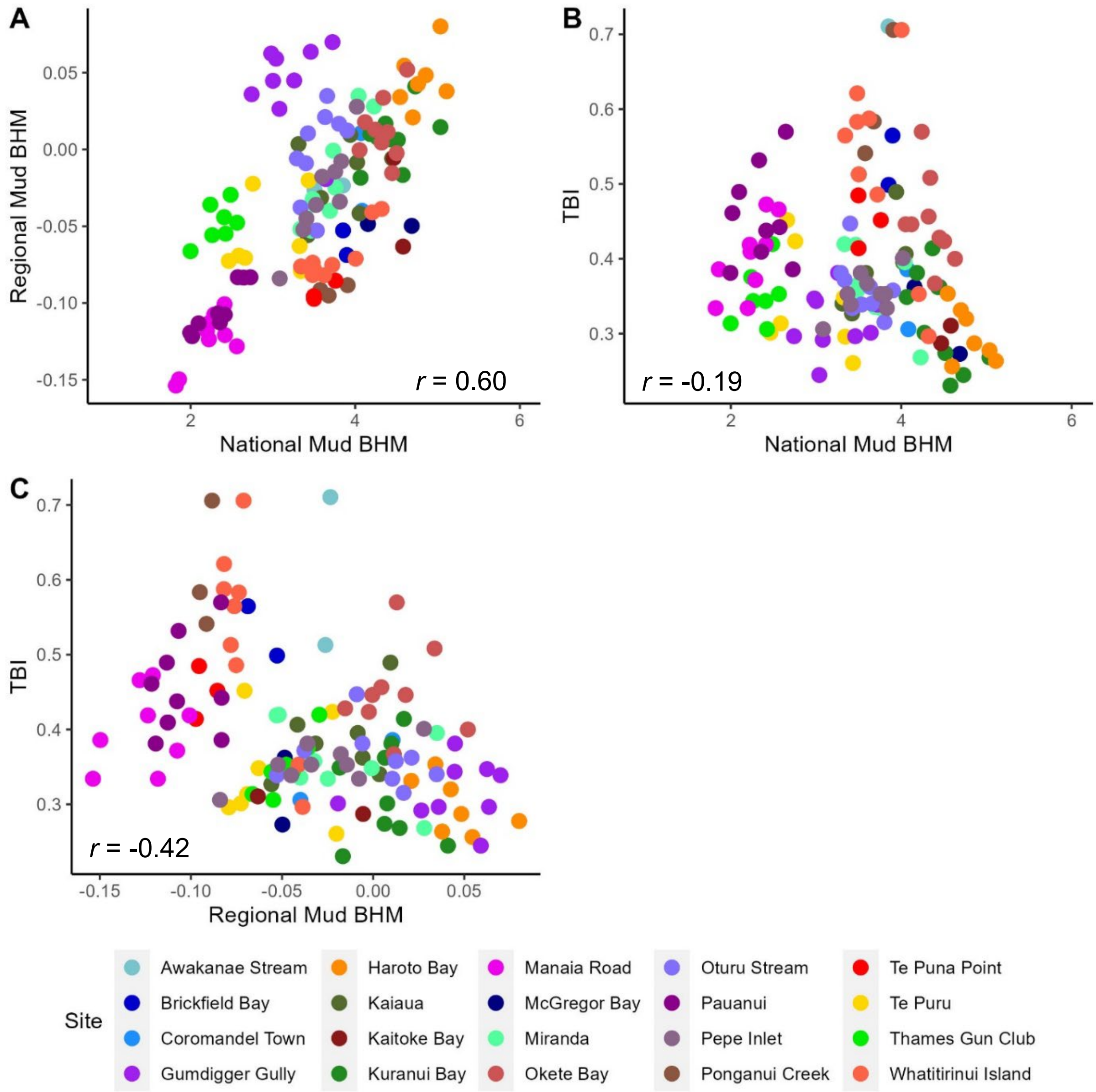


Figure 5. Relationships between different indicators of sedimentation stress. R values indicate the Spearman's rank correlation.

Scores from the Regional and National Metals BHMs had a moderate correlation (*r* = 0.60), indicating that the national models generally ranked sites in a similar way to the regional models (Figure 6). However, fairly consistent differences between rankings were observed at some sites. The Regional Metals BHMs tended to rank Gumdigger Gully, Pepe Inlet and Oturu Stream as being more impacted by metals than did the National BHMs. Of the five sites identified as being of particular interest to WRC, Manaia Road, Pauanui, Haroto Bay and Thames Gun Club had Metals BHM scores that were generally very similar. However, in 2018, Te Puru was ranked by the National Metals BHM as being much more contaminated by metals compared to the

Regional BHM. The correlations between the Metals BHMs and TBI scores were not very strong (Figure 6; *r* = −0.26 with Regional Metals BHM, *r* = −0.17 with National Metals BHM).

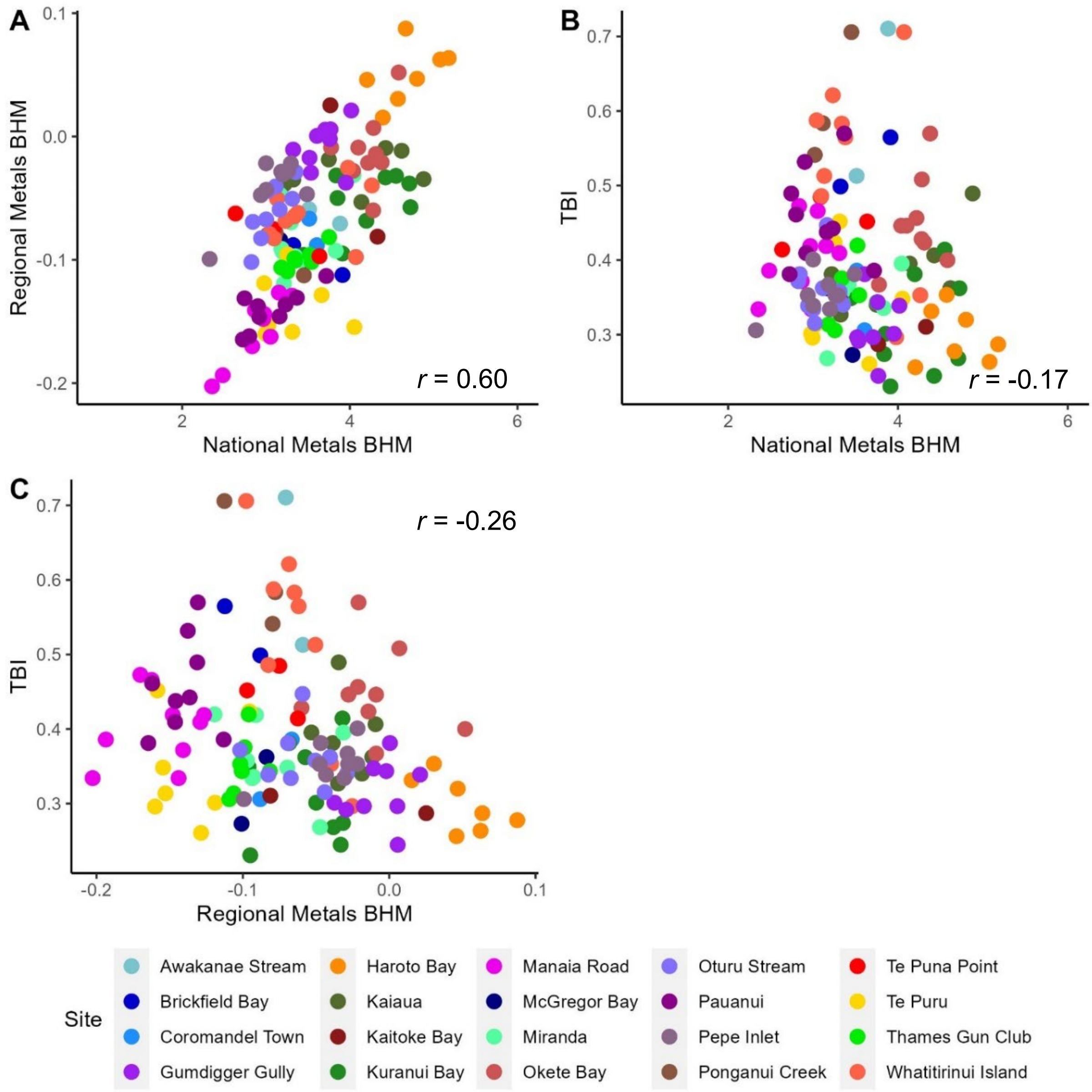


Figure 6. Relationships between different indicators of metal contamination stress. R values indicate the Spearman's rank correlation.

3.3.2 Comparison of Regional and National Mud BHM scores through time

In 96% of cases, the Regional and National Mud BHMs ranked sites in the same or adjacent group, apart from five sampling occasions, where scores differed by two groups. Where group scores differed, the National Mud BHM tended to rank sites as being more impacted by sediment, aside from at Thames Gun Club and Gumdigger Gully, where the opposite pattern was found. Differences in group scores often occurred where scores were close to the boundary between two groups.

The National BHM ranked sites in Coromandel estuaries as being more impacted by sediment than did the Regional BHM, apart from at Awakanae Stream, where group scores were the same (Figure 7). However, Regional BHM scores for Brickfield Bay and National BHM scores for Coromandel Town were close to the category boundaries, helping to explain some of these discrepancies (Appendix 2).

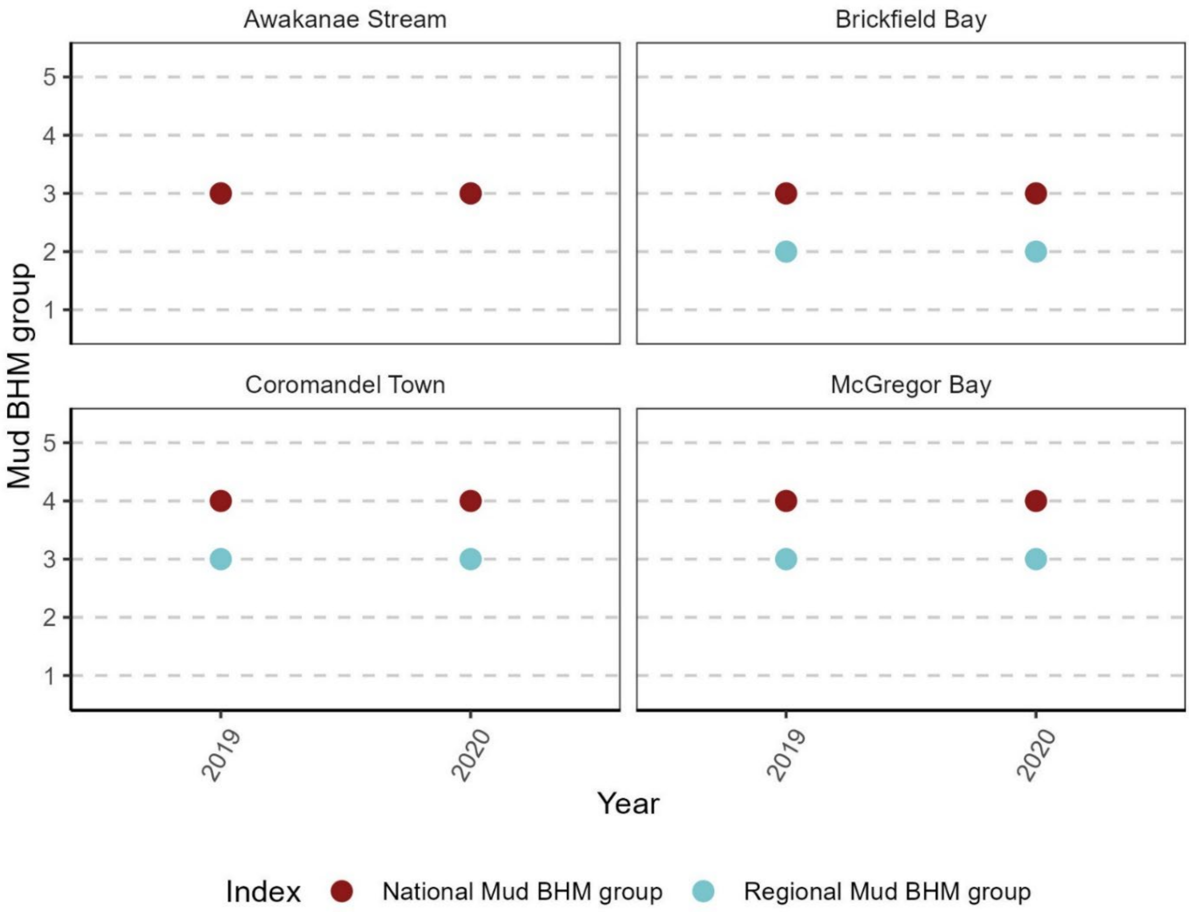


Figure 7. **National and Regional Mud Benthic Health Model (BHM) group scores for estuary sites in Coromandel. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.**

In the Firth of Thames, sites in Miranda were almost always assigned the same Mud BHM group score (Figure 8). Where differences arose, the Regional BHM scores were very close to the category boundary. Sites from Kuranui Bay, on the other hand, were consistently ranked by the Regional BHM as being more impacted by sediment, compared to the National BHM (aside from in 2019). The greatest discrepancy between Mud BHM group scores at Kuranui Bay occurred in 2016, when the Regional Mud BHM assigned a Moderate (Group 3) ranking and the National BHM assigned a Very High / Unhealthy (Group 5) ranking. In this year, the Regional BHM score was very close to the Group 3/4 boundary and the National BHM score was very close to the Group 4/5 boundary (Appendix 2), helping to explain this difference. Furthermore, the National Mud BHM score for this site / time was found to be higher than expected given the measured sediment mud content at this site (i.e. did not fit the model data as well as the Regional BHM, suggesting that the Regional BHM score may be more accurate; Figure 1). Mud BHM group scores from sites in Kaiaua, Te Puru and Thames Gun Club sometimes aligned, and where they did not the National BHM tended to rank sites as more impacted by sediment in Kaiaua and Te Puru compared to the Regional BHM and less impacted at Thames Gun Club. Often these differences arose when scores were close to the category boundaries.

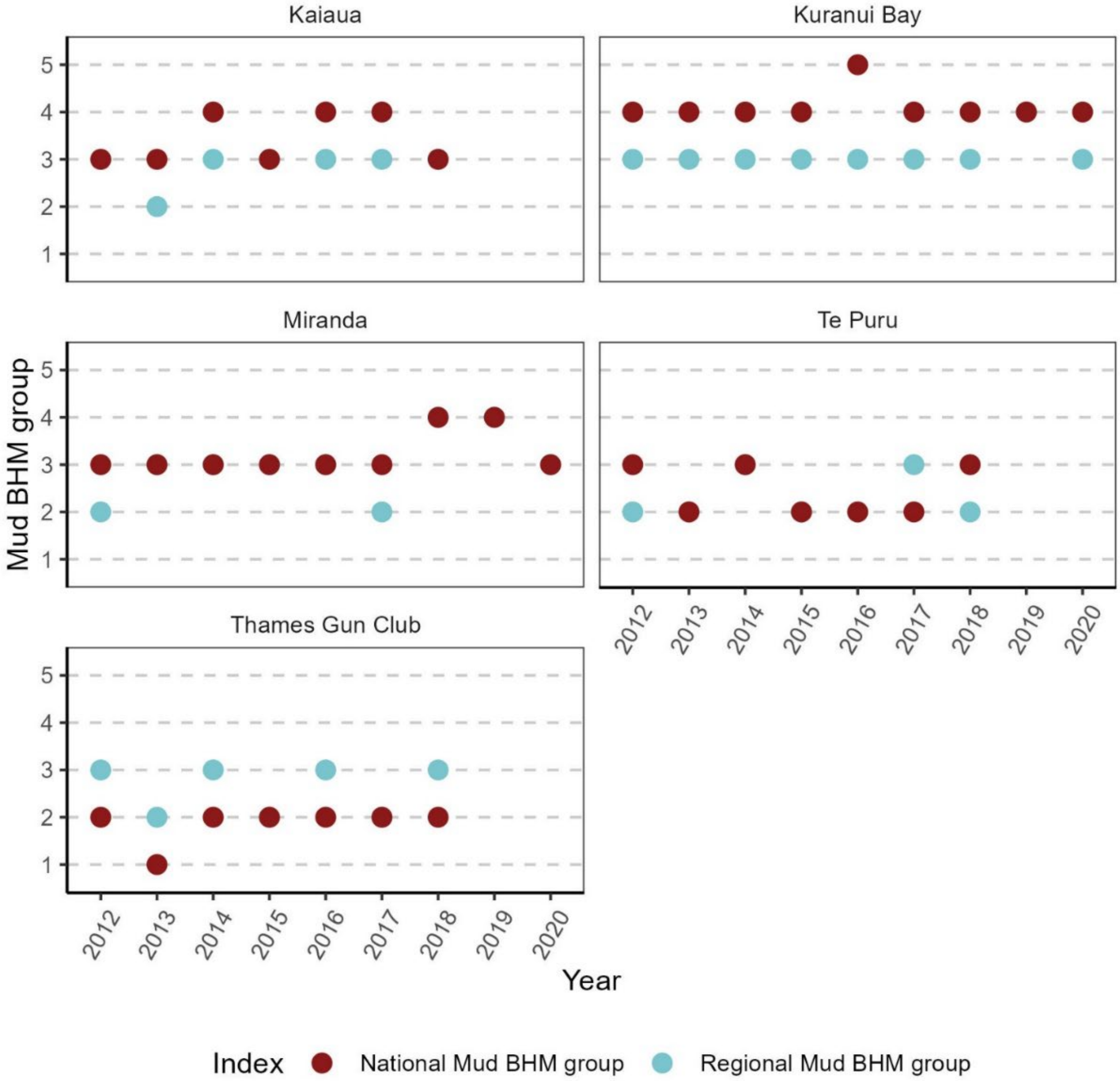


Figure 8. **National and Regional Mud Benthic Health Model (BHM) group scores for estuary sites in the Firth of Thames. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will only be visible where there is a difference.**

In Raglan Harbour, sites were almost always ranked as being more impacted by sediment by the National Mud BHM, compared to the Regional BHM, apart from Haroto Bay where group scores were often the same (Figure 9). In 2020, Mud BHM scores at Kaitoke Bay and Whatitirinui Island differed by more than one group; the Regional Mud BHM assigned a Low / Good (Group 2) ranking while the National BHM assigned a High / Poor (Group 4) ranking. At both sites, the Regional BHM scores were close to the Group 2/3 boundary, and at Whatitirinui Island the National BHM was also very close to the Group 3/4 boundary, helping to explain these differences (Appendix 2).

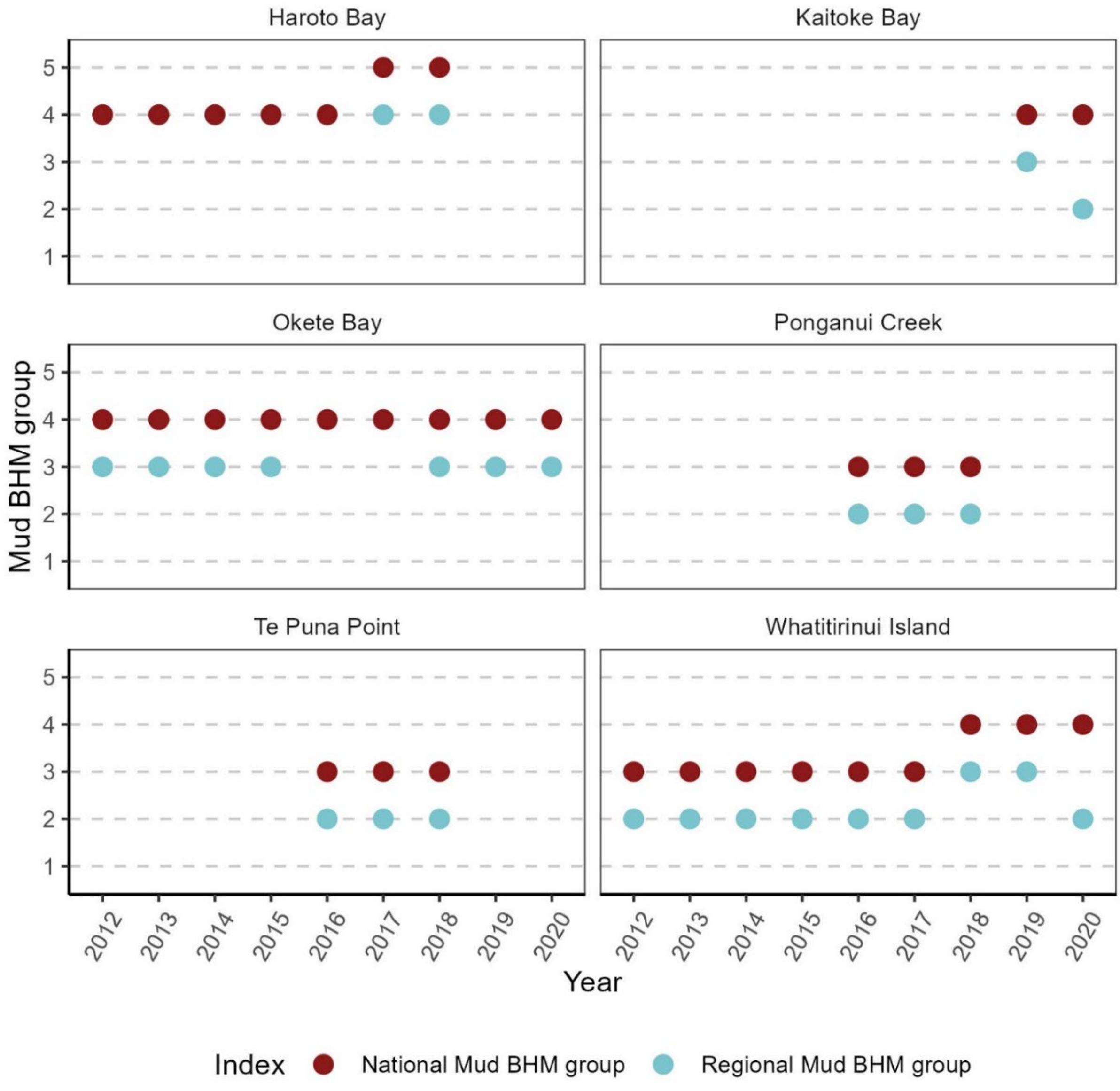


Figure 9. **National and Regional Mud Benthic Health Model (BHM) group scores for estuary sites in Raglan Harbour. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will only be visible where there is a difference.**

In Tairua Harbour, sites were often ranked the same (Figure 10). The exception was Gumdigger Gully, which was consistently ranked by the Regional BHM as being more impacted by sediment compared to the National BHM (except in 2020). This could reflect the fact that the Regional Mud BHM scores for Gumdigger Gully were found to be slightly higher than expected given the measured sediment mud content at this site (i.e. they did not fit the model data as well as the National BHM, suggesting that the National BHM score may be more accurate; Figure 1). In 2012 and 2016, Mud BHM scores at Gumdigger Gully differed by more than one group: the National Mud BHM assigned a Low / Good (Group 2) ranking, while the Regional BHM assigned a High /

Poor (Group 4) ranking. In both years, the National BHM score was close to the Group 2/3 boundary and in 2016 the Regional BHM score was also close to the Group 4/G3 boundary, helping to explain these differences (Appendix 2).

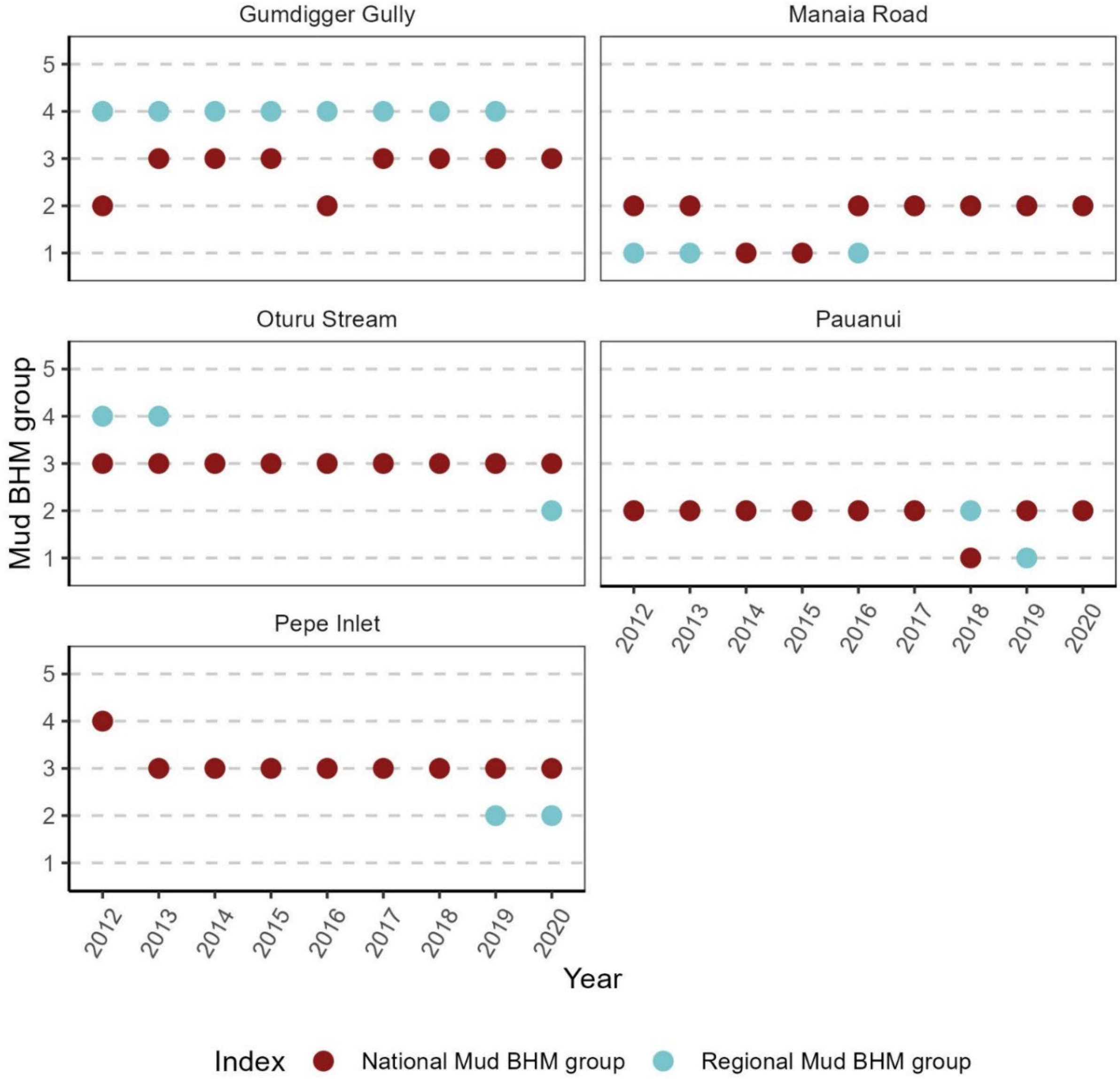


Figure 10. **National and Regional Mud Benthic Health Model (BHM) group scores for estuary sites in the Tairua Harbour. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.**

3.3.3 Comparison of Regional and National Metals BHM scores through time

In 97% of cases, the Regional and National Metals BHMs ranked sites in the same or adjacent group, apart from four sampling occasions, where scores differed by two groups. Where group scores differed, the National Metals BHM tended to rank sites as being more impacted by metal contamination. Differences in group scores often occurred where scores were close to the boundary between two groups.

The National BHM ranked sites in Coromandel estuaries as being more impacted by metal contamination than did the Regional BHM, apart from at Awakanae Stream in 2019, where group scores were the same (Figure 11). However, the Regional BHM scores were often close to the category Group 2/3 boundary, helping to explain some of these discrepancies (Appendix 3).

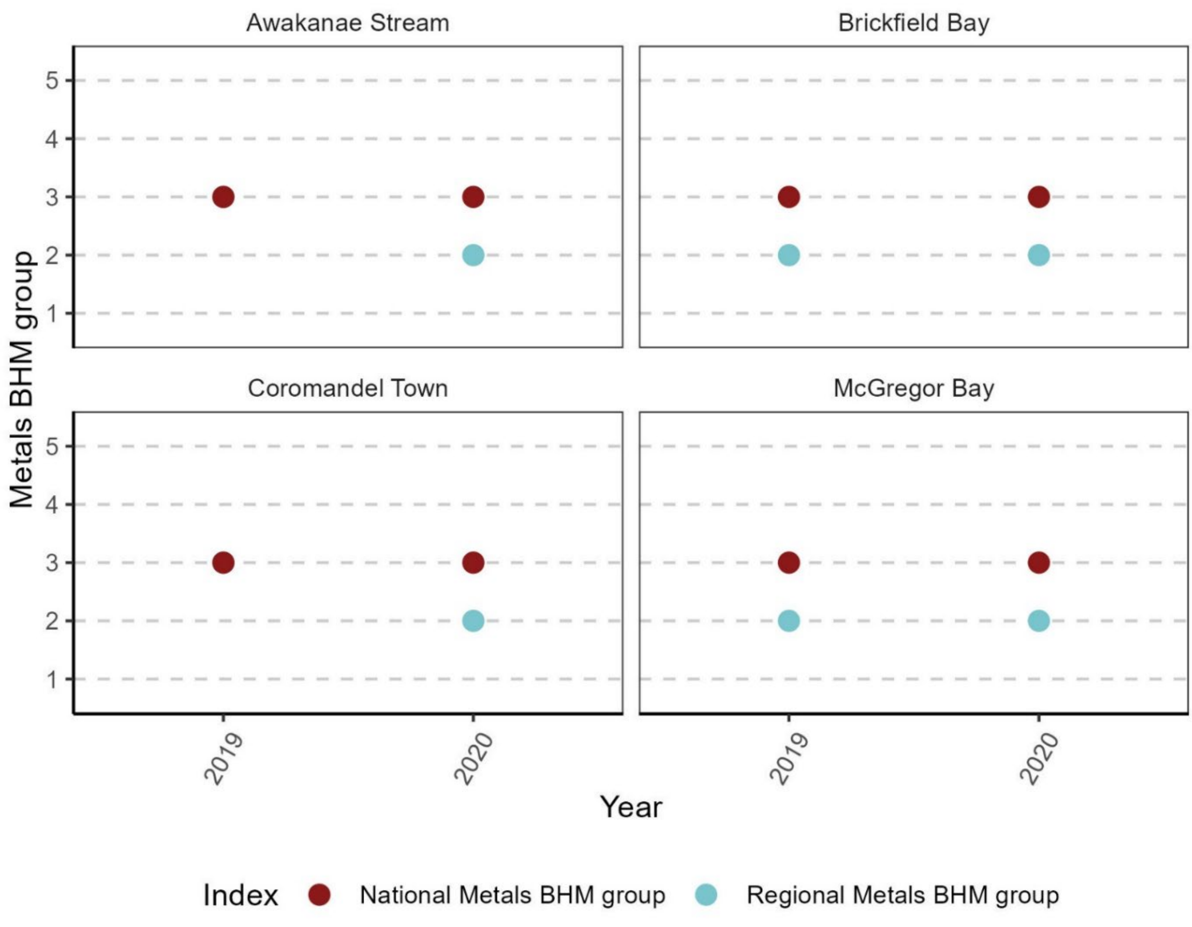


Figure 11. National and Regional Metals Benthic Health Model (BHM) group scores for estuary sites in Coromandel. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.

In the Firth of Thames, sites were almost always ranked as being more contaminated with metals when using the National BHM compared to the Regional BHM (Figure 12). There were two instances where the score differed by more than one group: Kuranui Bay and Te Puru in 2018. On these occasions, the Regional Metals BHM assigned a Low / Good (Group 2) ranking and the National BHM assigned a High / Poor (Group 4) ranking. At both sites, the National BHM scores were close to the Group 3/4 boundary, and at Kuranui Bay the Regional BHM score was also very close to the Group 2/3 boundary, helping to explain these differences (Appendix 3).

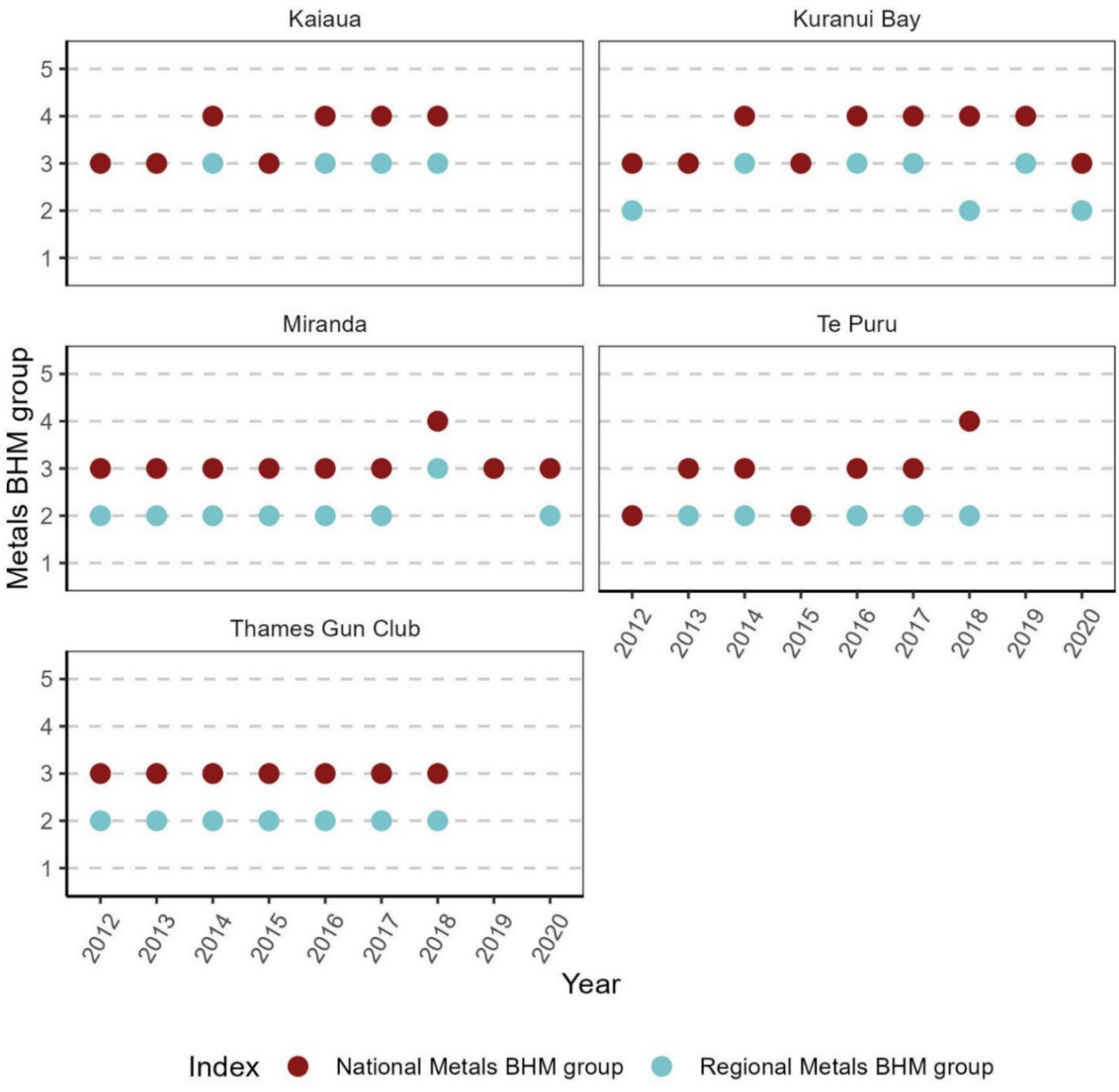


Figure 12. **National and Regional Metals Benthic Health Model (BHM) group scores for estuary sites in the Firth of Thames. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.**

In Raglan Harbour, sites were almost always ranked by the National Metals BHM as being more impacted by metals compared to the Regional BHM (Figure 13). In 2020, Metals BHM scores at Kaitoke Bay and Whatitirinui Island differed by more than one group: the Regional Metals BHM assigned a Low / Good (Group 2) ranking, while the National BHM assigned a High / Poor (Group 4) ranking. At both sites, the Regional BHM scores were close to the Group 2/3 boundary, and at Whatitirinui Island the National BHM was also very close to the Group 3/4 boundary, helping to explain these differences (Appendix 3). However, the trend at Kaitoke Bay differed between models, with the National Metals BHM suggesting an increase in impact between 2019 and 2020 and the Regional Metals BHM suggesting a decrease (Appendix 3). No metals data were available to validate the fit of this site with the Metals BHMs.

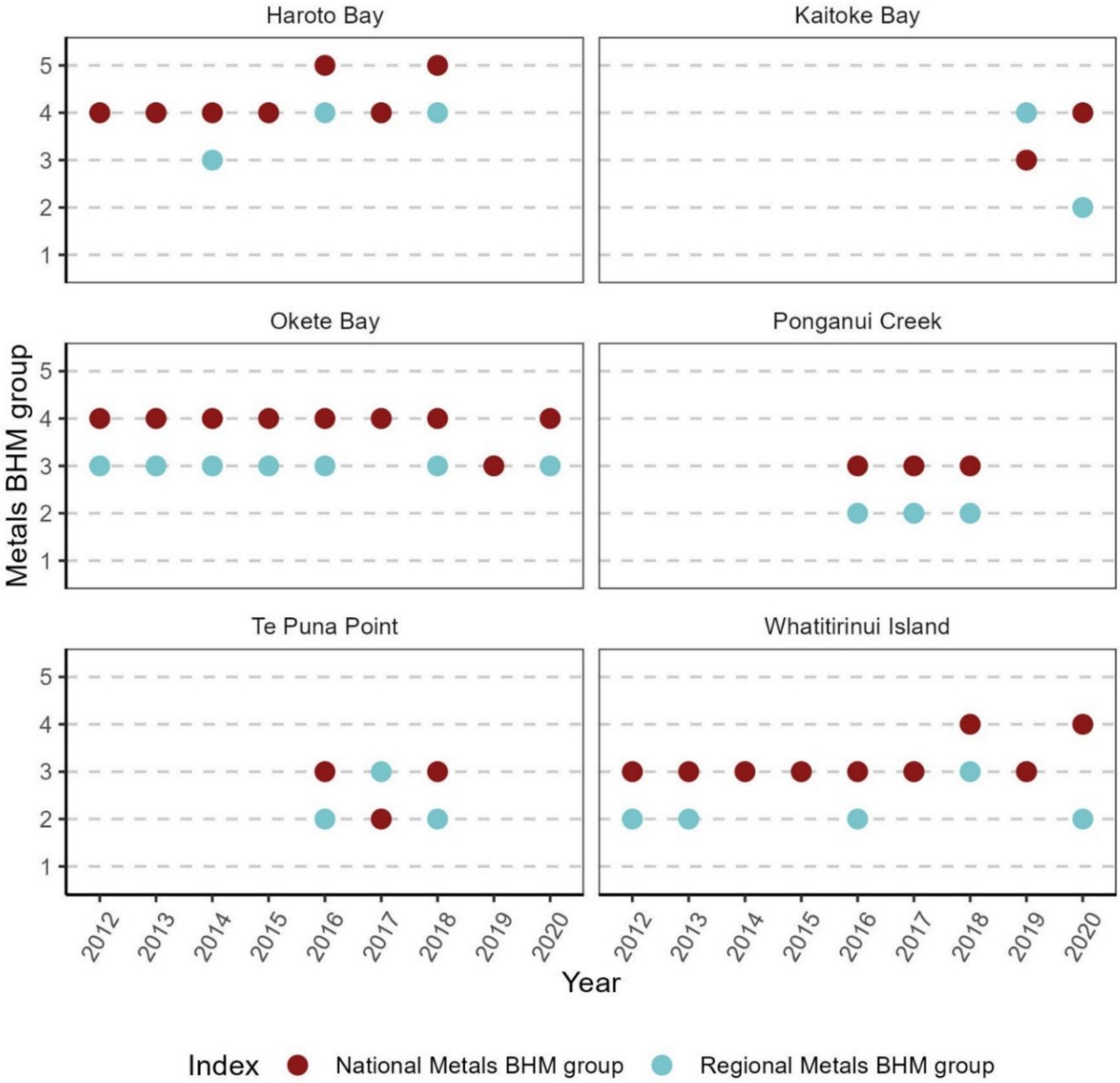


Figure 13. National and Regional Metals Benthic Health Model (BHM) group scores for estuary sites in Raglan Harbour. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.

In Tairua Harbour, sites were often ranked the same (Figure 14). The exception was Manaia Road, where National Metals BHM group scores were often higher than regional scores, and Pauanui, where scores aligned half the time. Where scores differed, the National BHM tended to rank sites as being more impacted by metals.

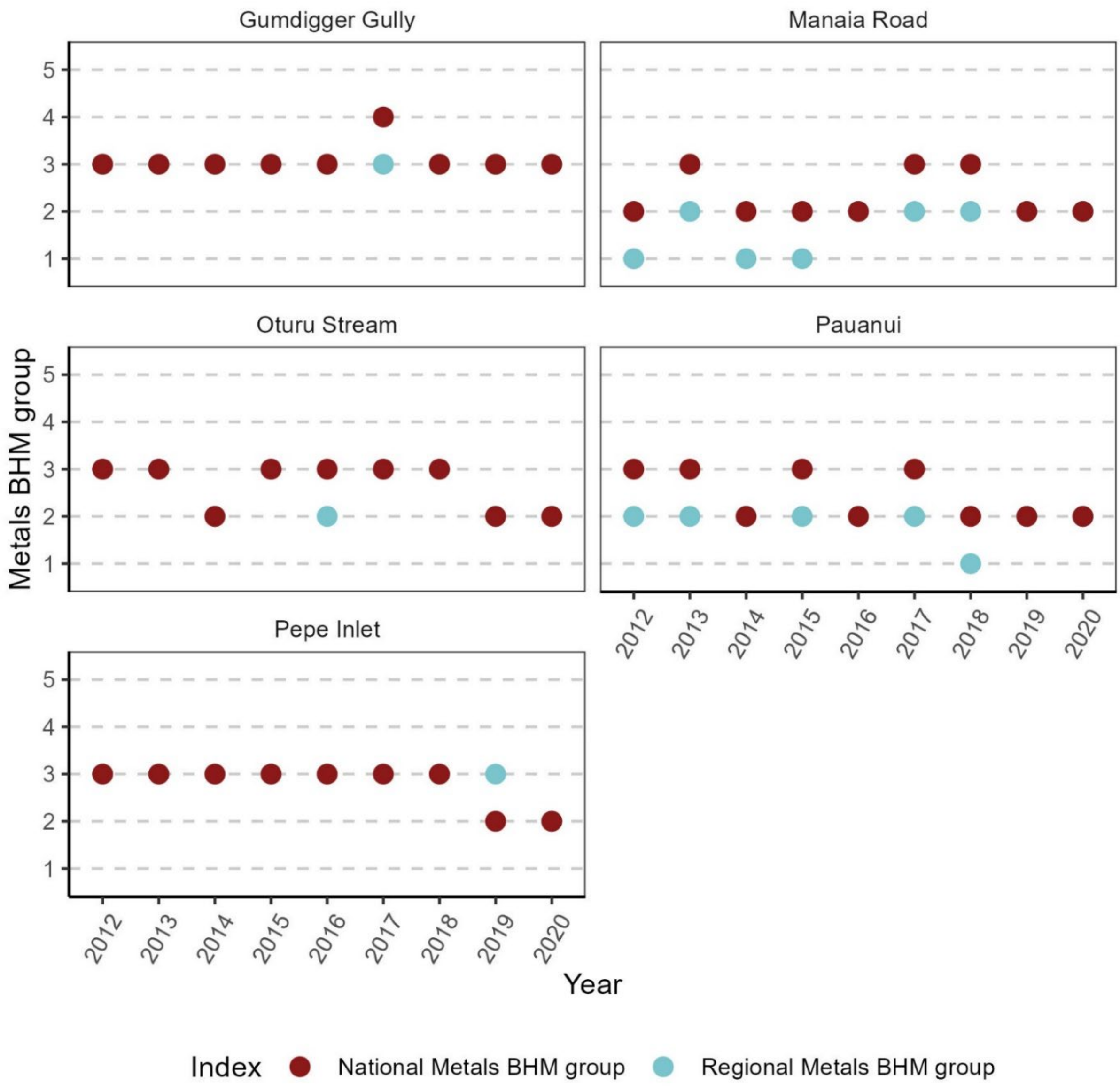


Figure 14. **National and Regional Metals Benthic Health Model (BHM) group scores for estuary sites in Tairua Harbour. National BHM group scores are overlaid on top of regional group scores; therefore, regional scores will be visible only where there is a difference.**

3.4 Drivers of differences between Regional and National BHM scores

3.4.1 Differences in taxonomic assignment

In general, the taxonomic assignments between the Regional and National BHMs are similar (see Appendix 4 for further details). Many categories are identical (e.g. *Paphies australis*, *Zeacumantus lutulentus*, *Taeniogyrus dendyi*, Nemertea, *Notomastus*). Both models separate Anthuroidea, Cirolanidae and *Exosphaeroma* species from other isopods. Both models aggregate nereid worms; the crabs *Austrohelice crassa*, *Hemigrapsus* sp. and *Hemiplax hirtipes*; polychaete worms belonging to the polydorid complex group; and *Capitella* with oligochaete worms.

Both models separate amphipods into corophids, paracalliopids, phoxocephalids and other amphipods. However, the Regional BHMs further distinguish *Waitangi brevirostris* from the rest of the phoxocephalids. *Waitangi brevirostris* was not separated out in the National BHMs because the taxonomic resolution of the data used to develop the model did not allow for this. Similarly, the Regional BHMs separate cumaceans into three species, but as this was not possible for the National BHMs, cumaceans are aggregated together in a single category. The Regional BHMs separate *Asychis amphiglyptus* and *Macroclymenella stewartensis* from other Maldanidae worms, and separate Polynoidae worms into five taxonomic categories. *Euchone* sp. are separated out from other Sabellidae worms in the Regional BHMs. Exogoninae and Syllinae worms are separated in the Regional BHMs but aggregated as Syllidae in the National BHMs. The National BHMs aggregate *Barantolla lepte* with *Heteromastus filiformis* due to the practical difficulties of making taxonomic distinctions between these two species.

Several taxa are included in the National BHMs but not the Regional BHMs, usually because they were not present at Auckland sites at the time the Regional BHMs were developed. These taxa include an anemone (*Anemonia*), arrow worms (Chaetognatha), several molluscs (*Lasaea*, Lasaeidae other, *Perrierina turneri*, Myochamidae, Mytilidae other, *Ostrea chilensis*, *Leptomya retiaria retiaria*, *Zemysina globus*, *Pisinna zosterophila*, *Zeacumantus subcarinatus*, *Cominella maculosa*, *Neoguraleus*, *Nassarius burchardi*, *Nucula*, Rissoidae, *Zalipais lissa*, *Halopyrgus pupoides*, *Potamopyrgus*, *Euterebra tristis*), some crabs (*Paguristes*, Paguridae, *Cyclograpsus lavauxi*), a range of polychaete worms (*Phyllochaetopterus socialis*, Dorvilleidae, Eunicidae, Onuphidae, *Owenia petersenae*, Paraonidae other, Scalibregmatidae, Serpulidae, Sphaerodoridae, *Paraprionospio*, *Prionospio* other, *Scolelepis*, Terebellidae, Trichobranchidae) a sea star (*Patiriella regularis*) and a shrimp (*Biffarius filholi*).

A few taxa are included in the Regional BHMs but not the National BHMs (*Scintillona zelandica*, *Amalda*, *Bulla quoyi*, gastropod unknown (later identified as *Eationella*), opistobranch, *Asychis amphiglyptus*). A key difference between the models is that the Regional BHMs include barnacles, while the Nationals BHMs exclude them on the basis that they are highly aggregative taxa. Given the potentially high number of barnacles that could be found at a site, this could have a significant effect on BHM scores, however the use of a square root transformation in the calculation of the scores decreases this effect.

There are other minor differences between categories. Often a species or genus category is used in the Regional BHMs, whereas the National BHMs use a genus or family instead (e.g. *Edwardsia* vs. Edwardsiidae or *Cossura consimilis* vs. *Cossura*). In practice, this often results in the same taxonomic assignment because there may be few other estuarine species at a site that fit the broader category.

3.4.2 Differences in taxonomic assignment at Waikato estuarine sites in 2016

To further examine the effects of the differences in taxonomic assignment described in the previous section, we compared Regional and National BHM scores at Waikato sites in 2016 (Figure 15) and differences in taxonomic assignments (Table 4). Mud BHM scores were in the same category for seven of the 15 sites. The rest of the sites were in adjacent categories, except for Gumdigger Gully (GG) and Kuranui Bay (KB), where scores differed by two categories. Gumdigger Gully had a Regional Mud BHM score of 0.04 and a National Mud BHM score of 2.7 (which is close to the Group 2/3 boundary). Kuranui Bay had a Regional Mud BHM score of 0.01 (which is close to the Group 3/4 boundary) and a National Mud BHM score of 5.0 (which is just over the Group 4/5 boundary). Metals BHM scores were in the same category for four of the 15 sites and the rest of the sites were in adjacent categories.

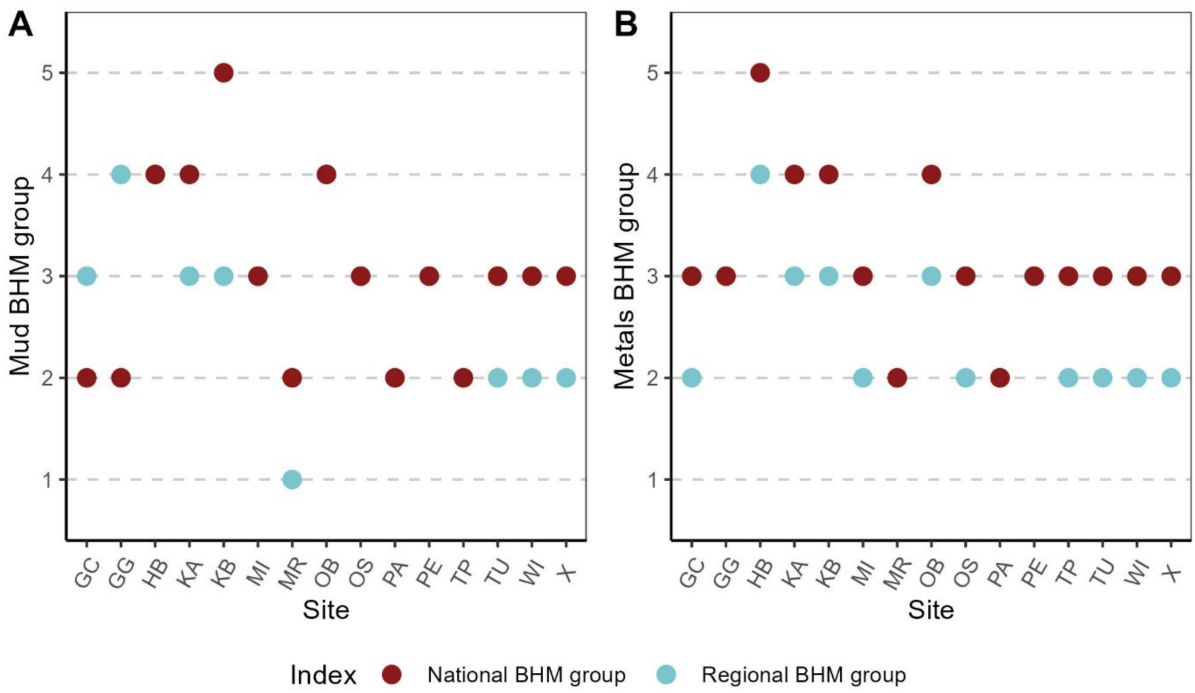


Figure 15. National and Regional Mud (A) and Metals (B) Benthic Health Model (BHM) scores for Waikato estuary sites in 2016 (see Table 3 for full site names). National BHM scores are overlaid on top of regional scores; therefore, regional scores will be visible only where there is a difference.

In general, the taxonomic assignments were very similar between the two models. Differences are outlined in Table 4, with full details provided in Appendix 5. Differences at the sites sampled in 2016 included:

- the exclusion of nine taxa from the Regional BHMs and three taxa from the National BHMs
- amphipod taxa that were included in the 'Amphipod other' category in each model
- isopod taxa that were included in the 'Isopod other' category in each model
- aggregation of *Asychis amphiglyptus* and *Macroclymenella stewartensis* as Maldanidae, aggregation of *Colurostylis* spp. and *Cyclaspis thomsoni* as Cumacea, aggregation of phoxocephalids and *Waitangi brevirostris* as Phoxocephalidae, and aggregation of Exogoninae and Syllinae as Syllidae in the National BHMs
- aggregation of *Cyclomactra* and *Mactra* as *Cyclomactra (Mactra) ovata* in the Regional BHMs
- unexplained minor differences in the total abundance of *Arcuatula senhousia*, *Exosphaeroma* and *Prionospio* in the Regional BHMs and Polyplacophora in the National BHMs.

These are just examples of taxonomic differences between the models; other differences would likely be found if the data from other years were examined.

Table 4. Differences in taxonomic assignment between the Regional and National Benthic Health Models (BHMs) at Waikato estuarine sites in 2016. Values refer to the sum of that taxon across the 15 sites sampled in 2016. Only taxa assigned differently between the two models are shown here and discrepancies are highlighted in grey. Full results can be found in Appendix 5.

Raw data		Regional BHMs		National BHMs		Notes
Amalda depressa	0.3	*Amalda*	0.3			No *Amalda* were found at sites in the National BHMs, so this taxon is excluded from those models
Ampelisca sp. Amphipod indet. *Gammaropsis* sp. *Lysianassidae* *Melita awa* *Melitidae* *Methalimedon* sp. *Paramoera chevreuxi* Talitridae Oedicerotidae	1.3 3.5 0.1 0.2 0.2 0.3 2.0 0.9 0.1 0.2	Amphipod other	8.8	Amphipod other	4.0	Some amphipods (*Ampelisca* sp., Amphipod indet.) were excluded from the National BHMs 'Amphipod other' category because they were not specifically listed in this category
Arcuatula senhousia	0.6	*Arcuatula (Musculista) senhousia*	0.4	*Arcuatula senhousia*	0.6	Unsure why Regional BHMs have 0.2 less *Arcuatula (Musculista) senhousia* than the National BHMs
Asychis amphiglyptus *Macroclymenella stewartensis*	0.4 0.1	*Asychis amphiglypta* *Macroclymenella stewartensis*	0.4 0.1	Maldanidae	0.5	*Asychis amphiglyptus* and *Macroclymenella stewartensis* aggregated as Maldanidae in National BHMs
Chaetognatha	0.6			Chaetognatha	0.6	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data as rarely found in the intertidal in the Auckland region so is excluded from the Regional BHMs

Raw data		Regional BHMs		National BHMs		Notes
Chiton glaucus *Sypharochiton pelliserpentis* *Notoplax rubiginosa*	2.3 0.1 0.1	Chiton	2.5	Polyplacophora	2.4	Presume National BHMs had 0.1 fewer chitons because *Sypharochiton pelliserpentis* is not a typical estuarine soft-sediment taxon and so was removed
Colurostylis lemurum *Cyclaspis thomsoni*	41.6 0.1	*Colurostylis* spp. *Cyclaspis thomsoni*	41.6 0.1	Cumacea	41.7	*Colurostylis* and *Cyclaspis thomsoni* aggregated as Cumacea in National BHMs
Cyclomactra ovata *Mactra*	1.7 0.5	*Cyclomactra (Mactra) ovata*	2.2	*Cyclomactra* *Mactra*	1.7 0.5	*Cyclomactra* and *Mactra* aggregated as *Cyclomactra (Mactra) ovata* in Regional BHMs. In the Regional BHMs, (mactra) means that in many of the original data sets *Mactra ovata* was identified but this then changed genus to *Cyclomactra ovata*
Exosphaeroma planulum *Exosphaeroma* spp. *Exosphaeroma waitemata*	2.0 1.2 84	*Exosphaeroma* spp.	87.0	*Exosphaeroma*	87.2	Unsure why Regional BHMs have 0.2 fewer *Exosphaeroma* than the National BHMs
Isocladus sp. *Isocladus spiculatus* *Paravireia* sp.	0.1 0.2 6.8	Isopod other	0.3	Isopod other	7.1	*Paravireia* sp. was not found in the original Regional BHM data so is excluded from the Regional BHMs
Lasaea parengaensis	14.8			*Lasaea*	14.8	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data as it only appeared in Auckland datasets later on so is excluded from the Regional BHMs
Neoguraleus murdochi	0.1			*Neoguraleus*	0.1	Not a taxon category in Regional BHMs – was not found in the original Regional BHM so is excluded from the Regional BHMs data
Opisthobranchia	0.1	Opistobranch (Philine type)	0.2			Excluded from National BHMs (not infauna)

Raw data		Regional BHMs		National BHMs		Notes
Philine spp.	0.1					
Phoxocephalidae *Torridoharpinia hurleyi* *Torridoharpinia* sp. *Waitangi brevirostris*	1.1 10.2 3.7 10.9	Phoxocephalids *Waitangi brevirostris*	15.0 10.9	Phoxocephalidae	25.9	*Waitangi brevirostris* is aggregated with the rest of the phoxocephalids in the National BHMs
Pissinia zosterophylla	0.1			*Pisinna zosterophila*	0.1	Not a taxon category in Regional BHMs – assume excluded
Potamopyrgus spp.	2.8			*Potamopyrgus*	2.8	Not a taxon category in Regional BHMs – assume excluded
Prionospio cirrifera *Prionospio ehlersi*	0.1 0.1	*Minuspio*	0.1	*Prionospio* other	0.2	*P. cirrifera* was identified as *Minuspio* in the original Regional BHM data
Serpulidae	0.2			Serpulidae	0.2	Not a taxon category in Regional BHMs – assume excluded
Sessilia	92.2	Barnacles	92.2			Barnacles excluded from National BHMs (aggregative taxa)
Sphaerosyllis sp. *Syllidae*	0.3 1.2	Exogoninae Syllinae	0.3 1.2	Syllidae	1.5	Exogoninae and Syllinae aggregated as Syllidae in National BHMs
Tritia burchardi	0.1			*Nassarius burchardi*	0.1	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data, this invasive species appeared later on so is excluded from the Regional BHMs
Xenostrobus pulex	1.1			Mytilidae other	1.1	Not a taxon category in Regional BHMs – assume excluded
Zeacumantus subcarinatus	28.1			*Zeacumantus subcarinatus*	28.1	Not a taxon category in Regional BHMs – assume excluded

An MDS plot showed that despite the taxonomic differences between models, community structure was very similar at each site (Figure 16). The site that showed the greatest difference between models was Pauanui (PA). Community structure did not differ much between models at Kuranui Bay or Gumdigger Gully, even though these sites showed the greatest difference in BHM groups. This either indicates that very small differences in how taxa are assigned between the models can affect group scores or that other factors (e.g. the structure of the underlying models, differences in the dataset used to develop the model and the way in which the raw scores are assigned to BHM groups) are influencing group scores.

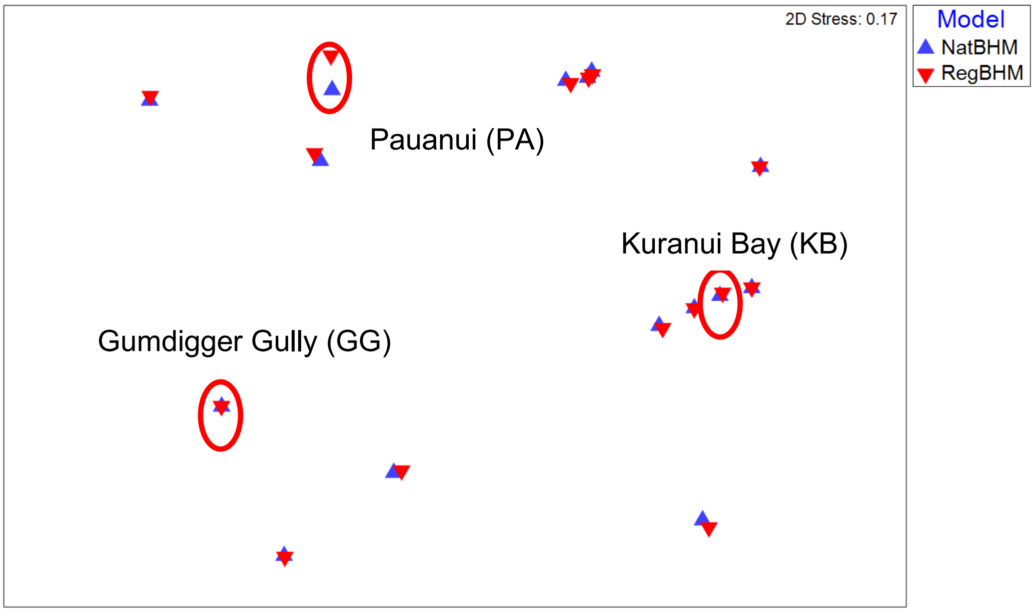


Figure 16. Non-metric multi-dimensional scaling (MDS) plot of Bray–Curtis similarities calculated from untransformed macrofauna abundance data comparing community structure between Waikato estuarine sites sampled in 2016, using data with taxonomic resolution aggregated for either the National Benthic Health Models (NatBHMs) or the Regional Benthic Health Models (RegBHM).

For the two sites with Mud BHM scores that differed by more than two groups (Kuranui Bay and Gumdigger Gully), only minor taxonomic differences were present between the two models (Table 5; average dissimilarities of 0.3–3.7%). At Kuranui Bay, the Regional BHMs included amphipods (likely *Ampelisca* sp. or 'Amphipod indeterminata') in the 'Amphipod other' category (*n* = 0.1) but these amphipods were (incorrectly) excluded from the National BHMs. *Cyclomactra* (*n* = 0.1) was also assigned to a different category.

At Gumdigger Gully, the gastropod *Potamopyrgus* (*n* = 2.8) was included in the National BHMs but not the Regional BHMs, and the cumacean *Colurostylis* (*n* = 1.5) was also assigned to a different category in the National BHMs. Furthermore, isopods (likely *Paravireia* sp.) were included as 'Isopod other' (*n* = 0.1) in the National BHMs, but no taxa were included in this category for the Regional BHMs.

Differences in taxonomy at Pauanui, the site showing the biggest difference between models in the MDS plot, were driven by several taxa (Table 5; average dissimilarity 29%). The main difference was the inclusion of barnacles (*n* = 67.6) in the Regional BHMs and the inclusion of *Zeacumantus subcarinatus* (*n* = 25.4) in the National BHMs. Furthermore, the National BHMs included several taxa that were not included in the Regional BHMs and did not separate *Waitangi brevirostris* (*n* = 6.6) from other phoxocephalids. As with Gumdigger Gully, isopods (likely *Paravireia* sp.) were included as 'Isopod other' (*n* = 5.5) in the National BHMs, but no taxa were included in this category for the Regional BHMs. As with Kuranui Bay, the Regional BHMs included amphipods in the 'Amphipod other' category (*n* = 0.5) that were not included in this category in the National BHMs, and the cumacean *Colurostylis* (*n* = 1.4) was also assigned to a different category.

Table 5. Differences in taxonomic assignment between the Regional (Reg) and National (Nat) Benthic Health Models (BHMs) at Kuranui Bay, Gumdigger Gully and Pauanui sites in 2016. Values refer to the sum of that taxon at each site. Only taxa assigned differently between the two models are shown here and discrepancies are highlighted in grey.

Taxon	Kuranui Bay		Gumdigger Gully		Pauanui	
	Reg	Nat	Reg	Nat	Reg	Nat
Amphipod other	0.1	0			0.5	0.3
Barnacles					67.6	0
Colurostylis spp.			1.5	0	1.4	0
Cumacea			0	1.5	0	1.4
Cyclomactra	0	0.1				
Cyclomactra (Mactra) ovata	0.1	0				
Isopod other			0	0.1	0	5.5
Lasaea					0	6.5
Mytilidae other					0	0.8
Phoxocephalidae					0.4	7.0
Waitangi brevirostris					6.6	0
Pisinna zosterophila					0	0.1
Potamopyrgus			0	2.8		
Syllinae					0	0.5
Zeacumantus subcarinatus					0	25.4

4 Discussion

Overall, both the Regional and the National BHMs performed well to assess the health of estuarine sites in Waikato in response to sedimentation and metal contamination impacts. However, correlations between indicator scores and changes in mud content (sedimentation) and metal contamination showed that the effect of these stressors on macrofaunal communities was best represented by the National BHMs compared to the Regional BHMs and TBI. Furthermore, the National BHMs have the advantage of allowing estuary health to be assessed relative to other sites across Aotearoa New Zealand. However, the TBI did track changes in metal contamination almost as well as the National BHMs and provides an important and complementary measure of the functional redundancy or resilience of a site. Additional report findings are detailed below.

- The National BHMs generally ranked sites in a similar way to the Regional BHMs. Differences between Regional and National BHM scores have previously been examined by Clark et al. (2020) for sites in the Auckland region. As expected, higher correlations between BHM scores were found at the Auckland sites (Mud BHM r = 0.98, Metals BHM r = 0.76) than for Waikato sites (Mud and Metals BHM both r = 0.60) driven by the Auckland sites covering a strong gradient in both mud and metals.
- In almost all cases, both models ranked sites in the same or adjacent group. Further investigation revealed that differences in group scores often occurred where scores were close to the boundary between two groups. Where scores differed, the National Mud BHM tended to rank sites as being more impacted by sediment than the Regional Mud BHM, aside from at Thames Gun Club and Gumdigger Gully, where the opposite pattern was found. Where Metals BHM scores differed, the National Metals BHM tended to rank sites as being more impacted by metal contamination than did the Regional Metals BHM. Correlations between BHM scores and stressors indicated that the National BHMs were a better measure of sedimentation and metal contamination impacts than the Regional BHMs. There was no evidence that differences between Regional and National BHM scores were more pronounced in certain estuaries. However, Regional and National BHMs group scores were often equal at sites in Tairua Harbour.
- Slight differences in Regional and National BHM scores could be driven by differences in the structure of the underlying models (i.e. raw mud vs. log mud and different PC1 Metals gradients), differences in the dataset used to develop the model (e.g. regional vs. national data and different gradients of impact), differences in taxonomic assignment between models, and the way in which the raw scores are assigned to BHM groups. Despite the use of different PC1 Metals gradients between models, the relationship between copper, lead and zinc in Auckland appears to be very similar to that found in other estuaries around

Aotearoa New Zealand, suggesting this factor is not responsible for differences in BHM scores. The extent of the mud and metals gradients was also similar between the two models (0% to ~98% mud; metals values ranging from 0 mg/kg to ~50 mg/kg for Cu, 0 mg/kg to ~70–90 mg/kg for Pb and 0 mg/kg to ~300 mg/kg for Zn).

- The Regional and National BHMs differ in how the macrofauna data are aggregated into different taxonomic groups before running the model. In general, the taxonomic assignments between the Regional and National BHMs are similar, but some differences are present. These differences occur because the taxonomic resolution of the National BHM dataset did not allow for greater discrimination between groups (e.g. Cumacea, Maldanidae Phoxocephalidae, Polynoidae), species were included in the National BHMs that were not present in the Auckland dataset, or different decisions were made about whether or not to include less common species (e.g. many mollusc species) or species that behaved in an unusual manner (e.g. barnacles). Some of these differences may affect the ability of the BHMs to separate sites along a gradient of impact. For example, cumaceans differ in their sensitivities to stress but are included as a single taxonomic group in the National BHMs.
- Analysis of data from 2016 showed that despite differences in taxonomic assignment between the Regional and National BHMs, community structure was broadly similar at most sites. Therefore, differences in taxonomic assignment between the two models are not expected to have a large effect on BHM scores in most cases. This aligns with the findings of other studies (e.g. examples in Clarke et al. 2014 and Olsgard et al. 1998) that have demonstrated that similar patterns in community structure can be found across different taxonomic levels. Lower levels of taxonomic resolution should not be seen as a weakness if the indicator is sensitive enough to measure status or trends that are relevant to policy decisions and reflect responses to management actions (Borja and Dauer 2008). In 2016, the largest difference was observed at Pauanui, with differences primarily driven by the inclusion of high abundances of barnacles in the Regional BHMs and the snail *Zeacumantus subcarinatus* in the National BHMs. This is just an example of taxonomic differences that could drive differences between BHM scores, and we would likely find other differences if we examined data from other years. It should be noted, however, that differences in group scores between the two models were observed at some sites that had very similar community structure. This could indicate that very small differences in how taxa are assigned between the models can affect group scores in some cases, or that other factors (see above) are influencing group scores.
- The Regional and National BHMs scores did not correlate very well with the TBI scores. This is to be expected as the TBI is a measure of the functional redundancy / resilience of a site, rather than a measure of health based on macrofauna community structure. The TBI is generally less sensitive to mud and heavy metal pollution than the BHMs, but it provides information on whether

functional redundancy is changing and whether specific functional traits are being affected. It also integrates the effects of mud and metal contamination and any other local stressors on macrofaunal communities (Hewitt et al. 2012). It is also not expected to have a linear response to stress. In this report, we did not investigate in detail how TBI scores varied relative to BHM scores at particular sites, however this could be done. Lack of correlation between the TBI and BHM scores could be used to suggest whether interactions between the effects of mud and metals were occurring at a site, or whether another stressor was also exerting an influence.

4.1 Conclusion and recommendations

Based on the report findings, our conclusions and recommendations are as follows:

- Switching from the Regional BHMs to the National BHMs to assess the health of estuarine sites in Waikato in response to sedimentation and metal contamination impacts. While these indicators provide similar information, the effect of these stressors on macrofaunal communities was better represented by the National BHMs. Furthermore, the National BHMs allow estuary health to be assessed relative to other sites across Aotearoa New Zealand, and this information can be uploaded onto the recently developed estuarine health module of the LAWA website.
- Continued use of the TBI to assess the health of estuarine sites in Waikato. The BHMs and the TBI provide complementary information: the BHMs are more sensitive to changes in mud content and metal contamination, while the TBI provides additional information on the functional redundancy / resilience of a site and integrates the effects of mud and metal contamination on macrofaunal communities.
- Further work to validate the combination of the National BHMs with the TBI scores to create an overall measure of health if this is desired.
- Creating a robust process for calculating BHM scores. Cawthron was investigating the use of an automated R script that could be used to calculate BHM scores. However, after talking to Marti Anderson from PRIMER-e software, it appears that there is no equivalent R package that carries out the underlying multivariate model (canonical analysis of principal coordinates, CAP) in the same manner as the routine in PRIMER. It may be possible to write a pipeline in PRIMER that can automatically carry out the correct series of steps, and Cawthron is investigating this option further. At this stage, calculation of National BHM scores is being carried out only by Cawthron and NIWA. BHM score calculation should remain restricted to these two organisations until a more robust process for score calculation is developed. If BHM score calculation becomes less restricted, it

would be prudent to run some training sessions and have a quality assurance process in place before uploading National BHM scores into the LAWA website.

- Development of a national working group that oversees the National BHM, manages version control and any updates, and supports a programme of ongoing validation.

A summary of the different indicators WRC uses for estuary health assessment that is suitable for a lay audience is provided in the box below.

SUMMARY OF INDICATORS

Waikato Regional Council uses three key indicators to assess estuary health: the Mud Benthic Health Model (BHM), the Metals BHM and the Traits Based Index (TBI). These indicators assess health based on changes in the animal communities living in the seafloor sediments (e.g. shellfish, worms, crabs). We expect to find certain animals in healthy parts of the estuary (e.g. pipi and tuangi), and different animals in parts of the estuary that are degraded (e.g. pollution-tolerant worms and few sensitive species). Indicators based on these animals are informative because ecological communities respond relatively rapidly to stressors, integrate the effects of multiple stressors over time, and are composed of a diverse range of species with differing functional roles, trophic levels and sensitivities. These indicators allow the animals to 'tell the story', with respect to classifying sites along a continuum from degraded to non-degraded.

Benthic Health Models (BHMs)

The BHMs use information about the diversity and abundance of animals to assign a score, which indicates the health of an estuarine site in response to two of Aotearoa New Zealand's key coastal stressors: sedimentation and heavy metal contamination, which are often caused by human activities. There are two separate indicators. The Mud BHM tracks estuarine health in response to sedimentation, and the Metals BHM tracks health in response to metal contamination. Both indicators run from 1 to 6, with values near 1 indicating the lowest impact of the stressor on ecological communities and values near 6 indicating the greatest impact, relative to other estuarine sites across Aotearoa New Zealand. Originally, the BHMs were developed to assess estuary health in Auckland, but a new national model has now been developed that can assess estuary health in estuaries across Aotearoa New Zealand.

Traits Based Index (TBI)

The TBI uses information about the number of species with certain traits (e.g. worm-shaped animals with limited mobility) to assign a score, which provides a measure of the resilience of a site (i.e. the ability of the ecological communities to cope with changes in environmental conditions). The index runs from 0 to 1, with values closer to 0 indicating low levels of functional redundancy and highly degraded sites. Declines in TBI scores with increases in mud and heavy metals are interpreted as losses of functional redundancy. A loss of functional redundancy means there are fewer species that can carry out ecological functions, so the estuary is less likely to be resilient to further changes in environmental conditions.

Differences between indicators

The BHMs and the TBI provide complementary information. The BHMs are more sensitive to changes in mud content and metal contamination, but the TBI provides additional information on the functional redundancy or resilience of a site and looks at the combined overall effect of stressors on the seafloor animal communities.

5 Acknowledgements

Thank you to Sarah Hailes and Drew Lohrer (NIWA) for providing the data underlying the calculation of the Benthic Health Models. Anna Berthelsen provided a helpful review of this report.

6 Appendices

Appendix 1. Correlation between PC1 Metals gradients

There was a perfect correlation (r = 1.0) between the PC1 Metals gradients calculated using the Regional and National PCAs.

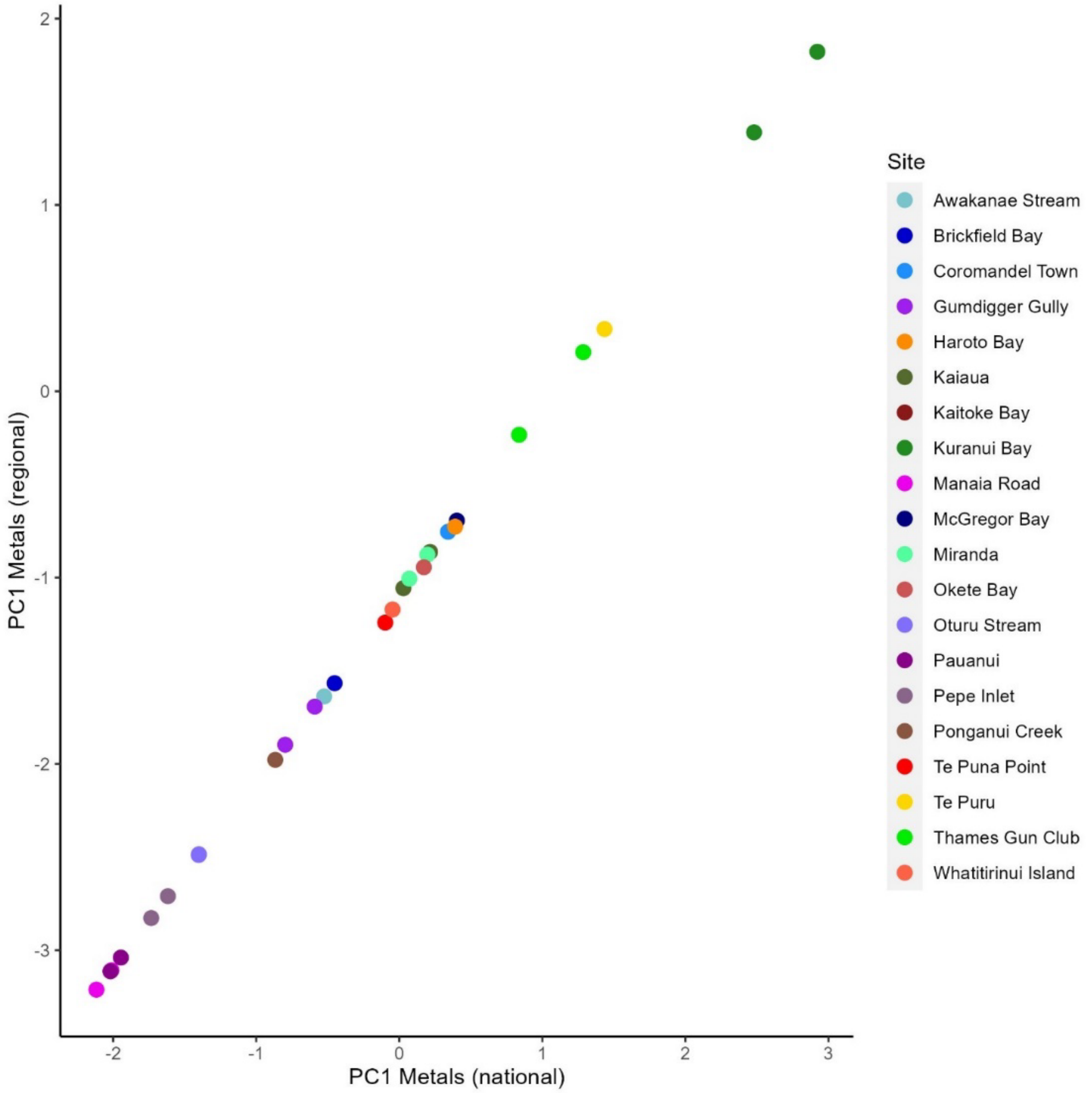
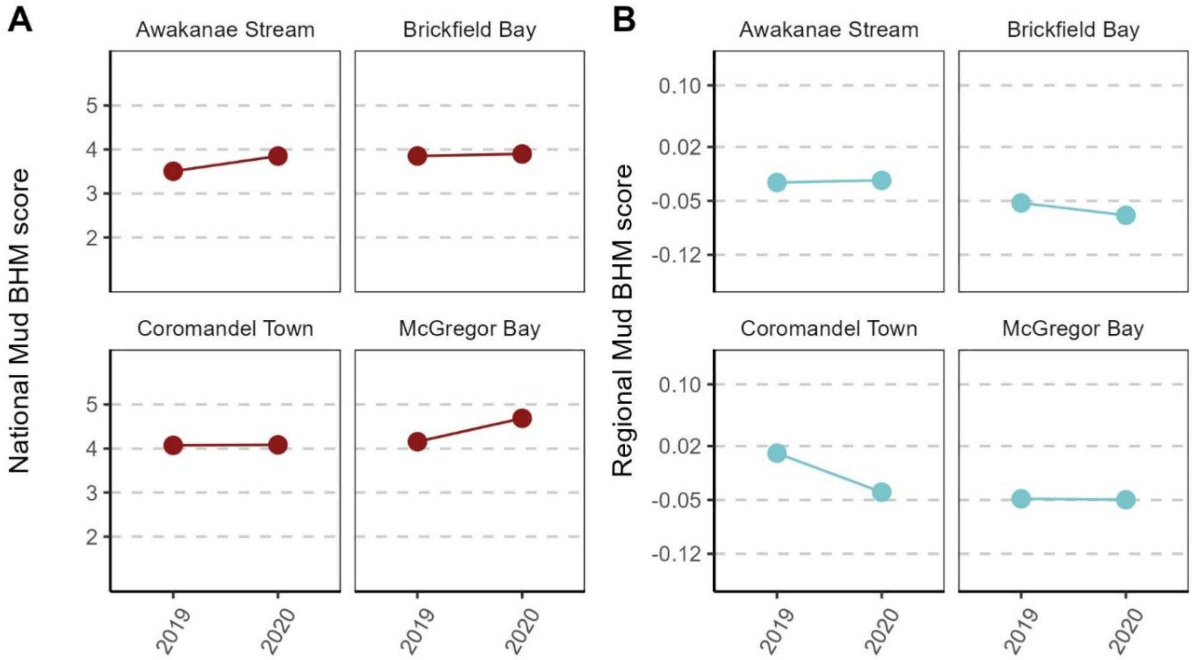


Figure A1.1. Scatterplot of PC1 Metals values calculated using either the National principal component analysis (PCA) or the Regional PCA.

Appendix 2. Mud Benthic Health Model scores in Waikato estuaries

Figure A2.1. National (A) and Regional (B) Mud Benthic Health Model (BHM) scores for estuary sites in



Coromandel. Group boundaries are indicated by dashed grey lines.

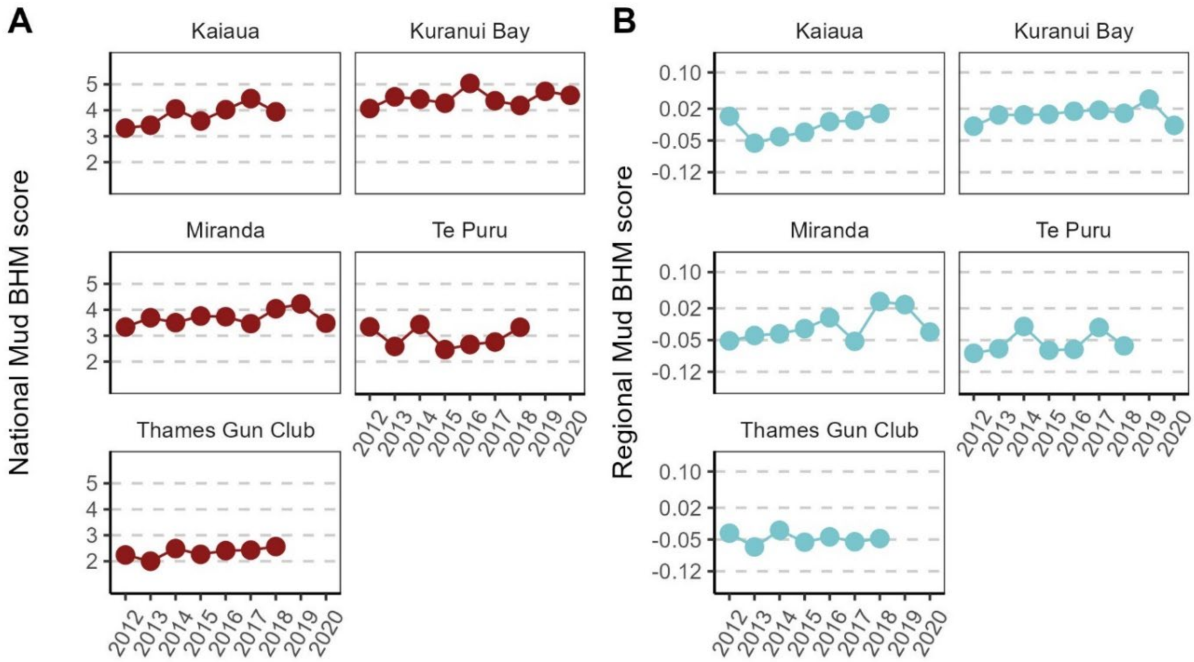


Figure A2.2. National (A) and Regional (B) Mud Benthic Health Model (BHM) scores for estuary sites in the Firth of Thames. Group boundaries are indicated by dashed grey lines.

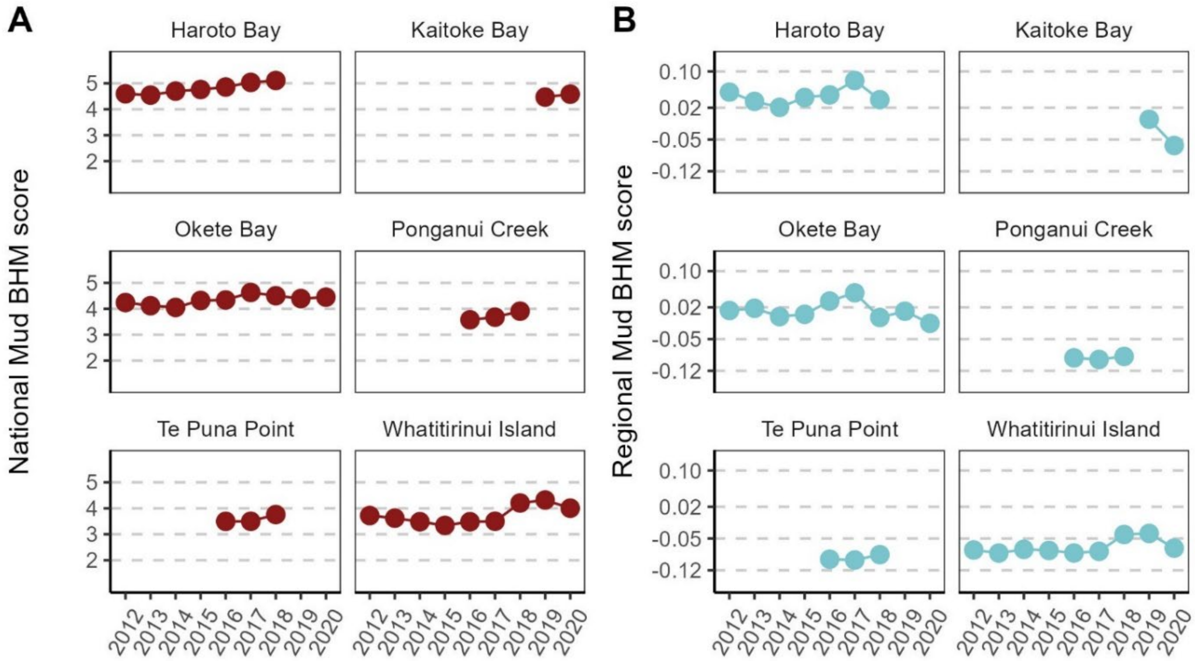


Figure A2.3. National (A) and Regional (B) Mud Benthic Health Model (BHM) scores for estuary sites in Raglan Harbour. Group boundaries are indicated by dashed grey lines.

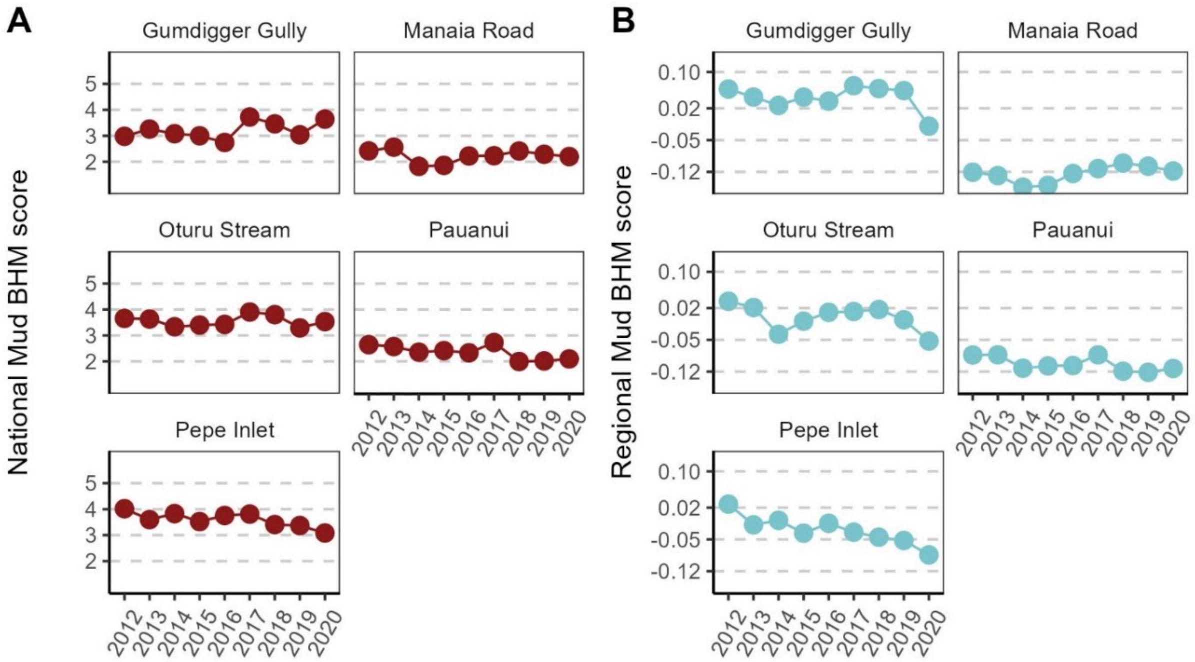


Figure A2.4. National (A) and Regional (B) Mud Benthic Health Model (BHM) scores for estuary sites in Tairua Harbour. Group boundaries are indicated by dashed grey lines.

Appendix 3. Metals Benthic Health Model scores in Waikato estuaries

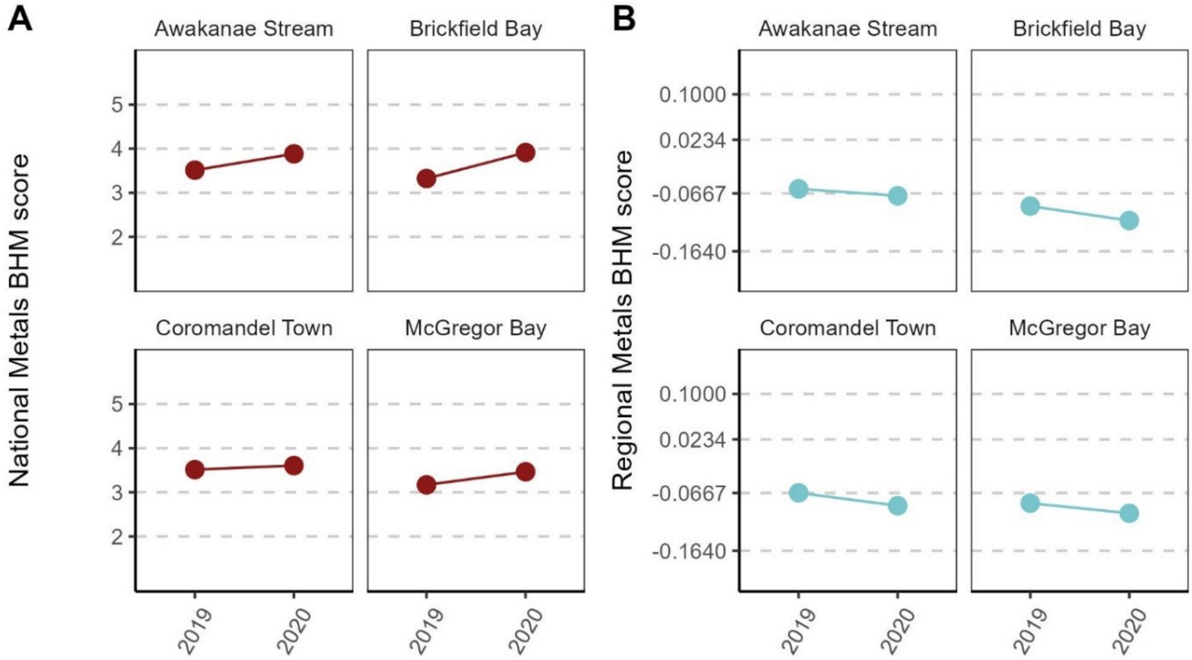


Figure A3.1. National (A) and Regional (B) Metals Benthic Health Model (BHM) scores for estuary sites in Coromandel. Group boundaries are indicated by dashed grey lines.

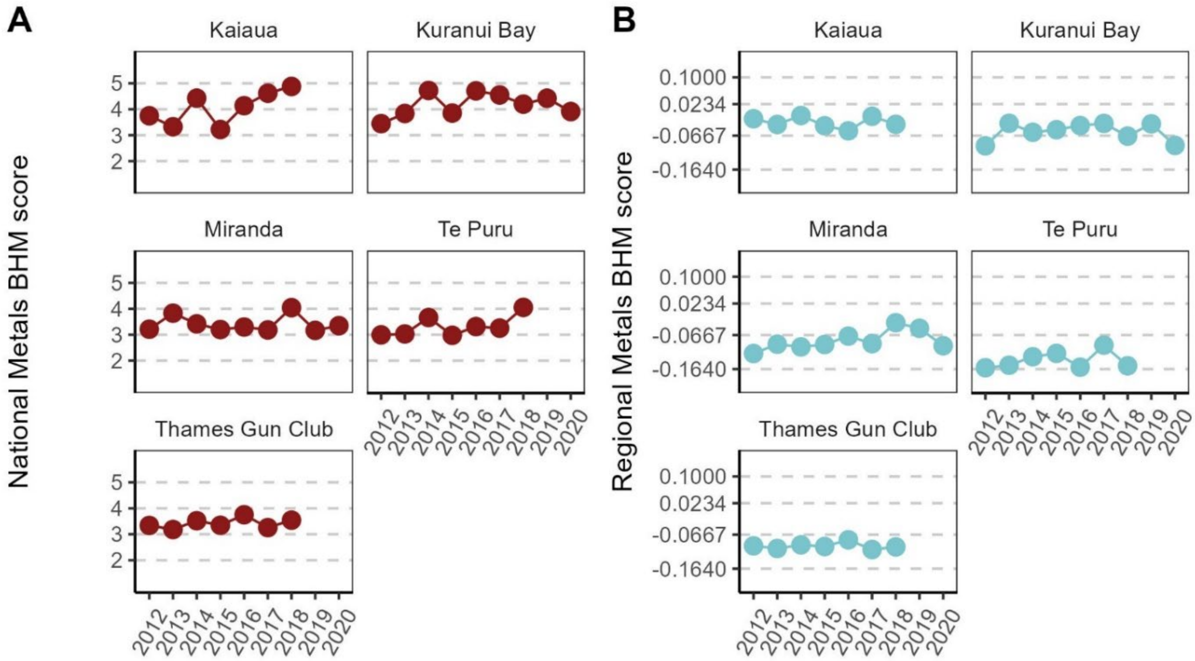


Figure A3.2. National (A) and Regional (B) Metals Benthic Health Model (BHM) scores for estuary sites in the Firth of Thames. Group boundaries are indicated by dashed grey lines.

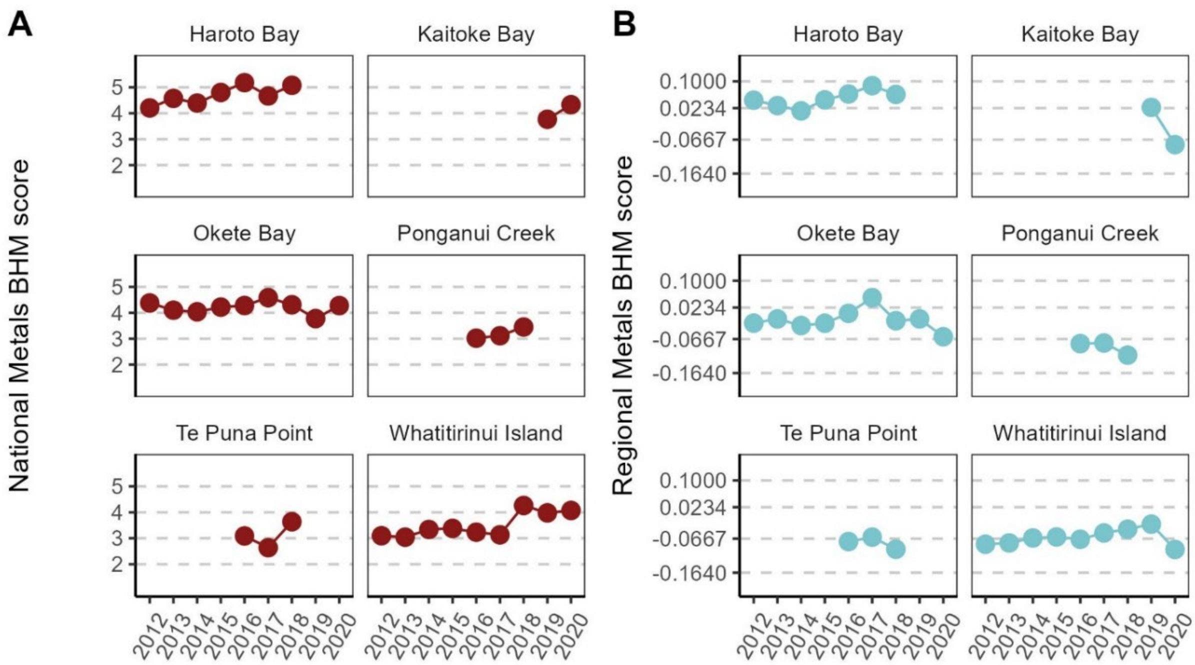


Figure A3.3. National (A) and Regional (B) Metals Benthic Health Model (BHM) scores for estuary sites in Raglan Harbour. Group boundaries are indicated by dashed grey lines.

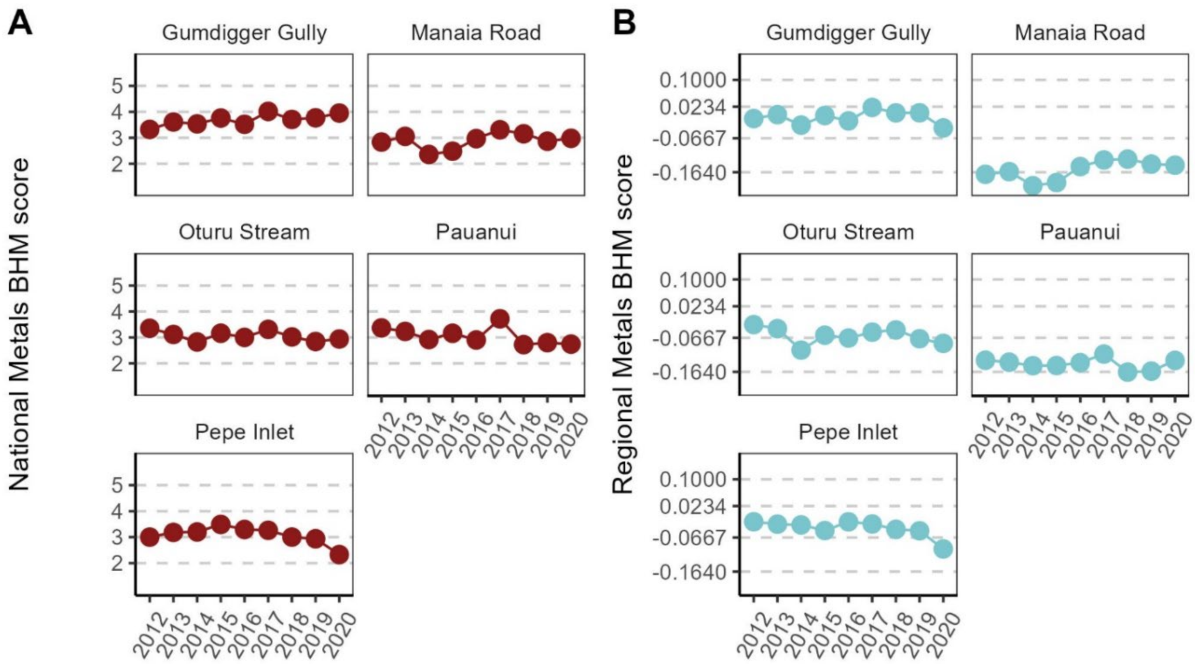


Figure A3.4. National (A) and Regional (B) Metals Benthic Health Model (BHM) scores for estuary sites in Tairua Harbour. Group boundaries are indicated by dashed grey lines.

Appendix 4. Differences in taxa categories between the Regional and National Benthic Health Models

Table A4.1 Differences in taxonomic assignment between the Regional and National Benthic Health Models (BHMs).

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Amphipod	Amphipod other	amphipod other	aora maculata caprellidae dexaminidae gammaridae liljeborgia liljeborgiidae lysianassidae melita awa methalimedon paramoera chevreuxi parawaldeckia talitridae urothoidae
Amphipod Corophiidae (Family)	Corophidae	corophiidae	corophiidae corophium monocorophium monocorophium sextonae paracorophium paracorophium excavatum paracorophium lucasi
Amphipod Paracalliopiidae (Family)	Paracalliope spp.	paracalliopiidae	paracalliope paracalliope novizealandiae paracalliopiidae
Amphipod Phoxocephalidae (Family)	Phoxocephalids Waitangi brevirostris	phoxocephalidae	phoxocephalidae torridoharpinia hurleyi waitangi brevirostris
Anthozoa		anemonia	anemone
Anthozoa	Anthopleura aureoradiata	anthopleura hermaphroditica	anthopleura aureoradiata
Anthozoa	Edwardsia	edwardsiidae	edwardsia edwardsia leucomelos edwardsia neozelanica edwardsiidae
Arrow worm		chaetognatha	chaetognatha
Bivalve	Bivalve unid	bivalve unid	bivalvia
Bivalve Carditidae (Family)	Carditidae Venericardiae	carditidae	
Bivalve Cyamiidae (Family)		perrierina turneri	perrierina turneri

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Bivalve Galeommatidae (Family)	Scintillona zelandica		
Bivalve Lasaeidae (Family)	Arthritica bifurcata	arthritica	arthritica arthritica bifurca
Bivalve Lasaeidae (Family)		lasaeidae other	mysella
Bivalve Lasaeidae (Family)		lasaea	lasaea parengaensis
Bivalve Mactridae (Family)	Cyclomactra (Mactra) ovata	cyclomactra	cyclomactra ovata
Bivalve Mesodesmatidae (Family)	Paphies australis	paphies australis	paphies australis
Bivalve Myochamidae (Family)		myochamidae	myadora
Bivalve Mytilidae (Family)	Arcuatula (Musculista) senhousia	arcuatula senhousia	arcuatula senhousia
Bivalve Mytilidae (Family)		mytilidae other	mytilidae mytilus edulis xenostrobus pulex
Bivalve Ostreidae (Family)	Crassostrea gigas	crassostrea gigas	crassostrea gigas
Bivalve Ostreidae (Family)		ostrea chilensis	ostrea chilensis
Bivavle Psammobiidae (Family)	Soletellina-Hiatula spp.	hiatula	hiatula hiatula nitida hiatula siliquens
Bivalve Semelidae (Family)		leptomya retiaria retiaria	leptomya retiaria retiaria
Bivalve Semelidae (Family)	Theora lubrica	theora lubrica	theora lubrica
Bivavle Solemyidae (Family)	Solemya parkinson	solemya parkinsonii	solemya parkinsonii
Bivalve Tellinidae (Family)	Tellina edgari	bartschicoma edgari	
Bivalve Tellinidae (Family)	Macomona liliana	macomona liliana	macomona liliana
Bivalve Ungulinidae (Family)		zemysina globus	diplodonta globus
Bivalve Ungulinidae (Family)	Felaniella zelandica	zemysia zelandica	diplodonta zelandica
Bivalve Veneridae (Family)	Austrovenus stutchburyi	austrovenus stutchburyi	austrovenus stutchburyi
Brittlestar	Ophiuroid	ophiuroidea	amphiura ophiuroidea
Cirripedia (Subclass)	Barnacles		

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Chiton	Chiton	polyplacophora	acanthochitona zelandica chiton glaucus
Crab Diogenidae (Family)		paguristes	paguristes
Crab Hymenosomatidae (Family)	Halicarcinus spp.	halicarcinus	halicarcinus halicarcinus cookii halicarcinus varius halicarcinus whitei
Crab Paguridae (Family)		paguridae	paguridae pagurus
Crab Varunidae (Family) and Macrophthalmidae (Family)	Helice, hemigrapsus, macropthalmus	austrohelice.hemigrapsus.hemiplax	austrohelice crassa hemigrapsus hemigrapsus crenulatus hemigrapsus sexdentatus hemiplax hirtipes
Crustacean		crustacea unid	brachyura crustacea decapoda
Cumacean	Colurostylis spp. Cyclaspis thomsoni Diastylopsis sp. (Cumacea)	cumacea	colurostylis colurostylis lemurum cumacea cyclaspis thomsoni diastylopsis elongata
Gastropod		gastropoda unid	gastropoda
Gastropod Amphibolidae (Family)	Amphibola crenata	amphibola crenata	amphibola crenata
Gastropod Anabathridae (Family)		pisinna zosterophila	pisinna zosterophila
Gastropod Ancillariidae (Family)	Amalda		
Gastropod Batillariidae (Family)	Zeacumantus lutulentus	zeacumantus lutulentus	zeacumantus lutulentus
Gastropod Batillariidae (Family)		zeacumantus subcarinatus	zeacumantus subcarinatus
Gastropod Buccinidae (Family)	Cominella adspersa	cominella adspersa	cominella adspersa
Gastropod Buccinidae (Family)	Cominella glandiformis	cominella glandiformis	cominella glandiformis
Gastropod Buccinidae (Family)		cominella maculosa	cominella maculosa
Gastropod Bullidae (Family)	Bulla quoyi		

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Gastropod Calyptraeidae (Family)	Sigapatella (Zegalureus) tenuis	sigapatella tenuis	zegalerus tenuis
Gastropod Eatoniellidae (Family)	Gastropod unknown Eationella		
Gastropod Haminoeidae (Family)	Haminoea zelandiae	haminoea zelandiae	haminoea zelandiae
Gastropod Lottiidae (Family)	Notoacmea spp.	notoacmea	notoacmea notoacmea elongata notoacmea scapha
Gastropod Mangeliidae (Family)		neoguraleus	neoguraleus neoguraleus sinclairi
Gastropod Muricidae (Family)	Xymene sp.	xymene	xymene xymene ambiguus xymene plebeius
Gastropod Nassariidae (Family)		nassarius burchardi	nassarius burchardi
Gastropod Nuculidae (Family)	Linucula (Nucula) hartvigiana	linucula hartvigiana	linucula hartvigiana
Gastropod Nuculidae (Family)		nucula	nucula nitidula
Gastropod Opisthobranchia (Infraclass)	Opistobranch (Philine type)		
Gastropod Pyramidellidae (Family)	Turbonilla sp.	turbonilla	turbonilla
Gastropod Retusidae (Family)		relichna aupouria	relichna aupouria
Gastropod Nassariidae (Family)		nassarius burchardi	nassarius burchardi
Gastropod Nuculidae (Family)	Linucula (Nucula) hartvigiana	linucula hartvigiana	linucula hartvigiana
Gastropod Nuculidae (Family)		nucula	nucula nitidula
Gastropod Opisthobranchia (Infraclass)	Opistobranch (Philine type)		
Gastropod Pyramidellidae (Family)	Turbonilla sp.	turbonilla	turbonilla
Gastropod Rissoidae (Family)		rissoidae	rissoidae
Gastropod Skeneidae (Family)		zalipais lissa	zalipais lissa

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Gastropod Tateidae (Family)		halopyrgus pupoides	halopyrgus pupoides
Gastropod Tateidae (Family)		potamopyrgus	potamopyrgus potamopyrgus antipodarum potamopyrgus estuarinus
Gastropod Terebridae (Family)		euterebra tristis	euterebra tristis
Gastropod Trochidae (Family)	Cantharidus-Micrelenchus sp	cantharidus.micrelenchus	micrelenchus huttonii micrelenchus tenebrosus
Gastropod Trochidae (Family)	Diloma (Zediloma) subrostrata	diloma	diloma subrostratum
Holothuroid	Taeniogyrus (Trochodota) dendyi	taeniogyrus dendyi	taeniogyrus dendyi
Isopod Anthuridae (Family)	Anthuridae	anthuroidea	anthuroidea
Isopod Cirolanidae (Family)	Cirolana sp.	cirolanidae	cirolanidae eurylana eurylana cookii natatolana
Isopod Sphaeromatidae (Family)	Exosphaeroma spp.	exosphaeroma	exosphaeroma exosphaeroma chilensis exosphaeroma falcatum exosphaeroma obtusum exosphaeroma planulum exosphaeroma waitemata
Isopod	Isopod other	isopod other	cassidina typa isocladus isocladus armatus paravireia
Mantis shrimp	Mantis shrimp	stomatopoda	heterosquilla stomatopoda
Nemertean Phoronid Platyhelminth	Nemertean Phoronid Platyhelminth	nemertea phoronida platyhelminthes	nemertea phoronida platyhelminthes stylochidae
Polychaete		polychaeta unid	polychaeta
Polychaete Capitellidae (Family)	Heteromastus filiformis	heteromastus filiformis.baranatolla lepte	heteromastus filiformis barantolla lepte
Polychaete Capitellidae	Capitella +oligo	capitella.oligochaete	capitella capitella capitata oligochaeta

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
(Family) and Oligochaete			
Polychaete Capitellidae (Family)	Notomastus	notomastus	notomastus zeylanicus
Polychaete Cirratulidae (Family)	Cirratulid	cirratulidae	cirratulidae aphelochaeta
Polychaete Cossuridae (Family)	Cossura consimilis	cossura	cossura consimilis cossura
Polychaete Dorvilleidae (Family)		dorvilleidae	dorvilleidae
Polychaeta Eunicidae (Family)		eunicidae	lysidice
Polychaete Glyceridae (Family)	Glycera spp.	glyceridae	glycera americana glycera lamelliformis glycera ovigera glyceridae hemipodia simplex
Polychaete Goniadidae (Family)	Goniadidae	goniadidae	glycinde glycinde trifida goniada grahami goniadidae
Polychaete Hesionidae (Family)	Hessionid	hesionidae	Hesionidae oxydromus angustifrons
Polychaete Lumbrineridae (Family)	Lumbrinereidae	lumbrineridae	lumbrineridae scoletoma brevicirra
Polychaete Magelonidae (Family)	Magelona ident	magelona	magelona magelona dakini magelona papillicornis
Polychaete Maldanidae (Family)	Asychis amphiglypta Macroclymenella stewartensis Maldanidae	maldanidae	asychis axiothella serrata macroclymenella stewartensis maldanidae
Polychaete Nephtyidae (Family)	Aglaophamus macroura	aglaophamus	aglaophamus aglaophamus macroura
Polychaete Nereididae (Family)	Nereididae	nereididae	ceratonereis nereididae nicon aestuariensis perinereis perinereis nuntia brevicirris perinereis vallata platynereis australis
Polychaete Opheliidae (Family)	Armandia maculata	armandia maculata	armandia maculata

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Polychaete Onuphidae (Family)		onuphidae	onuphidae
Polychaete Orbiniidae (Family)	Orbinids	orbiniidae	naineris orbinia papillosa orbiniidae scoloplos cylindrifer
Polychaete Oweniidae (Family)	Owenia fusiformis	owenia fusiformis	owenia fusiformis
Polychaete Oweniidae (Family)		owenia petersenae	owenia petersenae
Polychaete Paraonidae (Family)	Aricidea sp.	aricidea	aricidea
Polychaete Paraonidae (Family)		paraonidae other	levinsenia gracilis paradoneis paradoneis lyra paraonidae (if identified in conjunction with aricidea)
Polychaete Pectinariidae (Family)	Pectinaria australis	pectinariidae	pectinaria
Polychaete Polynoidae (Family)	Disconatus accolus Harmothoe sp. Lepidonotinae Paralepidonotus ampulliferus Polynoid	polynoidae	disconatis accolus frennia lepidonotinae lepidonotus paralepidonotus ampulliferus polynoidae
Polychaete Phyllodocidae (Family)	Phyllodocid spp.	phyllodocidae	phyllodocidae eteone
Polychaete Sabellidae (Family)	Euchone sp. Sabellidae	sabellidae	euchone neosabellaria kaiparaensis pseudopotamilla sabellidae
Polychaete Scalibregmatidae (Family)		scalibregmatidae	hyboscolex longiseta
Polychaete Serpulidae (Family)		serpulidae	serpulidae spirobranchus cariniferus
Polychaete Sphaerodoridae (Family)		sphaerodoridae	sphaerodoridae sphaerodoropsis
Polychaete Spionidae (Family)	Polydorid complex	polydorid complex	boccardia boccardia acus

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
			boccardia polybranchia boccardia syrtis polydora cornuta pseudopolydora pseudopolydora paucibranchiata
Polychaete Spionidae (Family)	Aonides trifida	aonides	aonides aonides oxycephala aonides trifida
Polychaete Spionidae (Family)	Microspio (Scolelepeis) maori	microspio	microspio maori
Polychaete Spionidae (Family)		paraprionospio	paraprionospio paraprionospio coora
Polychaete Spionidae (Family)	Prionospio (Aquilaspio) aucklandica	prionospio aucklandica	prionospio aucklandica
Polychaete Spionidae (Family)		prionospio other	prionospio cirrifera prionospio yuriel prionospio (if identifed in conjunction with P. aucklandica)
Polychaete Spionidae (Family)	Scolecolepides benhami	scolecolepides	scolecolepides scolecolepides benhami
Polychaete Spionidae (Family)		scolelepis	scolelepis
Polychaete Syllidae (Family)	Exogoninae Syllinae	syllidae	exogoninae sphaerosyllis sphaerosyllis semiverrucosa syllidae syllinae syllis
Polychaete Terebellidae (Family)		terebellidae	terebellidae
Polychaete Travisiidae (Family)	Travisa olens	travisia olens	travisia olens travisia olens novaezealandiae
Polychaete Trichobranchidae (Family)		trichobranchidae	trichobranchidae
Seastar Asterinidae (Family)		patiriella regularis	patiriella regularis
Shrimp Alpheidae (Family)	Alpheus	alpheus	alpheus
Shrimp Callianassidae (Family)		biffarius filholi	biffarius filholi

Group	Regional BHMs	National BHMs	Taxa contained within National BHM category
Shrimp Crangonidae (Family)	Philocheras (Pontophilus) australis	philocheras australis	philocheras australis
Shrimp Mysida (Order)	Mysidacea	mysida	mysida mysidae
Shrimp Palaemonidae (Family)	Palaemon affinis	palaemon	palaemon palaemon affinis
Shrimp-like Leptostraca (Order)	Nebalace	nebaliacea	nebaliacea
Spinunculid	Sipunculid	sipuncula	sipuncula sipunculidae
Tanaids	Tanaidacea	tanaidacea	tanaidacea

Appendix 5. Differences in taxonomic assignment between the Regional and National Benthic Health Models at Waikato estuarine sites in 2016

Table A5.1 Differences in taxonomic assignment between the Regional and National Benthic Health Models (BHMs) at Waikato estuarine sites in 2016. Total values refer to the sum of that taxon across the 15 sites sampled in 2016.

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
Aglaophamus sp.	0.7	Aglaophamus macroura	0.7	aglaophamus	0.7	
Amalda depressa	0.3	Amalda	0.3			No Amalda were found at sites in the National BHMs, so this taxon is excluded from those models
Ampelisca sp. Amphipod indet. Gammaropsis sp. Lysianassidae Melita awa Melitidae Methalimedon sp. Paramoera chevreuxi Talitridae Oedicerotidae	1.3 3.5 0.1 0.2 0.2 0.3 2.0 0.9 0.1 0.2	Amphipod other	8.8	amphipod.other	4	Some amphipods (Ampelisca sp., Amphipod indet.) were (incorrectly) excluded from the National BHMs amphipod.other category because they were not specifically listed in this category
Anthopleura aureoradiata	12	Anthopleura aureoradiata	12	anthopleura.hermaphroditica	12	
Aonides trifida	222.9	Aonides trifida	222.9	aonides	222.9	
Arcuatula senhousia	0.6	Arcuatula (Musculista) senhousia	0.4	arcuatula.senhousia	0.6	Unsure why Regional BHMs have 0.2 less Arcuatula (Musculista) senhousia than the National BHMs
Aricidea sp.	7.1	Aricidea sp.	7.1	aricidea	7.1	

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
Armandia maculata	6.3	Armandia maculata	6.3	armandia.maculata	6.3	
Arthritica bifurca (total)	56.6	Arthritica bifurcata	56.6	arthritica	56.6	
Asychis amphiglyptus Macroclymenella stewartensis	0.4 0.1	Asychis amphiglypta Macroclymenella stewartensis	0.4 0.1	maldanidae	0.5	Asychis amphiglyptus and Macroclymenella stewartensis aggregrated as Maldanidae in National BHMs
Austrohelice crassa Hemigrapsus sexdentatus Hemiplax hirtipes	1.1 0.3 9.7	Helice, hemigrapsus, macropthalmus	11.1	austrohelice.hemigrapsus.hemiplax	11.1	
Austrovenus stutchburyi (total)	290.6	Austrovenus stutchburyi	290.6	austrovenus.stutchburyi	290.6	
Bivalve indet.	0.3					Excluded from Regional BHMs and National BHMs (broad category)
Boccardia acus Boccardia syrtis	1.9 11.3	Polydorid complex	13.2	polydorid.complex	13.2	
Capitella spp. Oligochaetes	12.7 79.4	Capitella +oligo	92.1	capitella.oligochaete	92.1	
Cardiida	2.3					Excluded from Regional BHMs and National BHMs (broad category)
Ceratonereis sp. Nereididae indet. Nereididae Nicon aestuariensis Perinereis vallata Platynereis australis	33.3 6.9 27.6 7.1 0.6	Nereididae	75.5	nereididae	75.5	

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
Chaetognatha	0.6			chaetognatha	0.6	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data as rarely found in the intertidal in the Auckland region so is excluded from the Regional BHMs
Chiton glaucus Sypharochiton pelliserpentis Notoplax rubiginosa	2.3 0.1 0.1	Chiton	2.5	polyplacophora	2.4	Presume National BHMs had 0.1 less chitons because Sypharochiton pelliserpentis is not a typical estuarine soft-sediment taxon so was removed
Cirratulidae	0.3	Cirratulid	0.3	cirratulidae	0.3	
Colurostylis lemurum Cyclaspis thomsoni	41.6 0.1	Colurostylis spp. Cyclaspis thomsoni	41.6 0.1	cumacea	41.7	Colurostylis and Cyclaspis thomsoni aggregated as Cumacea in National BHMs
Cominella adspersa	0.1	Cominella adspersa	0.1	cominella.adspersa	0.1	
Cominella glandiformis	4.6	Cominella glandiformis	4.6	cominella.glandiformis	4.6	
Copepoda	5.9					Excluded from Regional BHMs and National BHMs (meiofauna)
Corophiidae Paracorophium lucasi	1.9 141.5	Corophidae	143.4	corophiidae	143.4	
Cossura consimilis	20.6	Cossura consimilis	20.6	cossura	20.6	

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
Crab indet.	1.6					Excluded from Regional BHMs and National BHMs (broad category)
Crustacean indet.	0.2					Excluded from Regional BHMs and National BHMs (broad category)
Cyclomactra ovata Mactra	1.7 0.5	Cyclomactra (Mactra) ovata	2.2	cyclomactra mactra	1.7 0.5	Cyclomactra and Mactra aggregated as Cyclomactra (Mactra) ovata in Regional BHMs. In the Regional BHMs, (mactra) means that in many of the original data sets *Mactra ovata* was identified but this then changed genus to *Cyclomactra ovata*
Diloma sp. Diloma subrostrata	0.8 8.1	Diloma (Zediloma) subrostrata	8.9	diloma	8.9	
Edwardsia	0.7	Edwardsia	0.7	edwardsiidae	0.7	Edwardsia
Euchone sp.	0.2	Euchone sp.	0.2	sabellidae	0.2	Euchone sp.
Eurylana arcuata	0.4	Cirolana sp.	0.4	cirolanidae	0.4	Eurylana arcuata
Exosphaeroma planulum Exosphaeroma spp. Exosphaeroma waitemata	2 1.2 84	Exosphaeroma spp.	87	exosphaeroma	87.2	Unsure why Regional BHMs have 0.2 fewer Exosphaermoa than the National BHMs
flatfish juvenile	0.4					Excluded from Regional BHMs and National BHMs (not infauna)

Raw data		Regional BHMs		National BHMs		Notes
Taxa	Total	Taxa	Total	Taxa	Total	
Flatworms	0.6	Platyhelminth	0.6	platyhelminthes	0.6	
Gastropod indet.	0.1					Excluded from Regional BHMs and National BHMs (broad category)
Glycera ovigera Glycera sp.	2.7 0.1	Glycera spp.	2.8	glyceridae	2.8	
Glycinde trifida Goniadidae	0.1 3.2	Goniadidae	3.3	goniadidae	3.3	
Gonimyrtea concinna	0.2					Excluded from Regional BHMs and National BHMs (not in original models)
Halicarcinus sp. Halicarcinus whitei	0.2 5.8	Halicarcinus spp.	6	halicarcinus	6	
Haminoea zelandiae	0.1	Haminoea zelandiae	0.1	haminoea.zelandiae	0.1	
Hesionidae	4.4	Hessionid	4.4	hesionidae	4.4	
Heteromastus filiformis	164.1	Heteromastus filiformis	164.1	heteromastus.filiformis.baranatolla.lepte	164.1	
Isocladus sp. Isocladus spiculatus Paravireia sp.	0.1 0.2 6.8	Isopod other	0.3	isopod.other	7.1	Paravireia sp. was not found in the original Regional BHM data so is excluded from the Regional BHMs
Lagis australis	1.8	Pectinaria australis	1.8	pectinariidae	1.8	
Lasaea parengaensis	14.8			lasaea	14.8	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data as it only appeared in Auckland datasets later on so is

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
						excluded from the Regional BHMs
Leodamas cylindrifer Orbinia papillosa	9.7 7.1	Orbinids	16.8	orbiniidae	16.8	
Linucula hartvigiana (total)	162.7	Linucula (Nucula) hartvigiana	162.7	linucula.hartvigiana	162.7	
Macomona liliana (total)	31.9	Macomona liliana	31.9	macomona.liliana	31.9	
Magallana gigas	0.9	Crassostrea gigas	0.9	crassostrea.gigas	0.9	
Magelona dakini	12.3	Magelona ident	12.3	magelona	12.3	
Micrelenchus huttonii	2.8	Cantharidus-Micrelenchus sp	2.8	cantharidus.micrelenchus	2.8	
Microspio maori	36.4	Microspio (Scolelepeis) maori	36.4	microspio	36.4	
Mysidacea Mysida	2.1	Mysidacea	2.1	mysida	2.1	
Nebalia sp.	0.6	Nebalace	0.6	nebaliacea	0.6	
Nematoda	5.2					Excluded from Regional BHMs and National BHMs (meiofauna)
Nemerteans Nemertea	17.5	Nemertean	17.5	nemertea	17.5	
Neoguraleus murdochi	0.1			neoguraleus	0.1	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data so is excluded from the Regional BHMs
Nepinnotheres novaezelandiae	0.1	Pinnotheres	0.1	pinnotheridae	0.1	
Notoacmea spp.	39.6	Notoacmea spp.	39.6	notoacmea	39.6	

Raw data		Regional BHMs		National BHMs		Notes
Taxa	Total	Taxa	Total	Taxa	Total	
Nozeba emarginata	0.2					Excluded from Regional BHMs and National BHMs (not in original models)
Opisthobranchia Philine spp.	0.1 0.1	Opistobranch (Philine type)	0.2			Excluded from National BHMs (not infauna)
Ostracods	1.3					Excluded from Regional BHMs and National BHMs (meiofauna)
Owenia petersenae Owenia sp.	0.1 0.2	Owenia fusiformis	0.3	owenia.petersenae	0.3	There is an O. fusiformis category in National BHMs but assigned to O. petersenae presumably due misnaming in original dataset
Paphies australis (total)	75.5	Paphies australis	75.5	paphies.australis	75.5	Paphies australis (total)
Paracalliopiidae	16.1	Paracalliope spp.	16.1	paracalliopiidae	16.1	Paracalliopiidae
Paradoneis lyra Paraonidae	6.4 0.6	Paraonid other	7	paradonidae.other	7	
Philocheras australis	1.4	Philocheras (Pontophilus) australis	1.4	philocheras.australis	1.4	
Phoronida	1.4	Phoronid	1.4	phoronida	1.4	
Phoxocephalidae Torridoharpinia hurleyi Torridoharpinia sp Waitangi brevirostris	1.1 10.2 3.7 10.9	Phoxocephalids Waitangi brevirostris	15 10.9	phoxocephalidae	25.9	Waitangi brevirostris is aggregated with the rest of the phoxocephalids in the National BHMs

Raw data		Regional BHMs		National BHMs		Notes
Taxa	**Total**	**Taxa**	**Total**	**Taxa**	**Total**	
Pissinia zosterophylla	0.1			pisinna.zosterophila	0.1	Not a taxon category in Regional BHMs – assume excluded
Potamopyrgus spp.	2.8			potamopyrgus	2.8	Not a taxon category in Regional BHMs – assume excluded
Prionospio aucklandica	59.5	Prionospio (Aquilaspio) aucklandica	59.5	prionospio.aucklandica	59.5	
Prionospio cirrifera Prionospio ehlersi	0.1 0.1	Minuspio	0.1	prionospio.other	0.2	*P. cirrifera* was identified as *Minuspio* in the original Regional BHM data
Pseudarcopagia disculus	0.5					Excluded from Regional BHM and National BHMs (not in original models)
Saccostrea cucullata glomerata	0.1					Excluded from Regional BHM and National BHMs (not in original models)
Scolecolepides benhami	8.1	Scolecolepides benhami	8.1	scolecolepides	8.1	
Scoletoma brevicirra	0.1	Lumbrinereidae	0.1	Lumbrinereidae	0.1	
Serpulidae	0.2			serpulidae	0.2	Not a taxon category in Regional BHMs – assume excluded
Sessilia	92.2	Barnacles	92.2			Barnacles excluded from National BHMs (aggregative taxa)

Raw data		Regional BHMs		National BHMs		Notes
Taxa	Total	Taxa	Total	Taxa	Total	
Shrimp indet.	0.2					Excluded from Regional BHMs and National BHMs (broad category)
Sphaerosyllis sp Syllidae	0.3 1.2	Exogoninae Syllinae	0.3 1.2	syllidae	1.5	Exogoninae and Syllinae aggregated as Syllidae in National BHMs
Stomatopoda	0.1	Mantis shrimp	0.1	stomatopoda	0.1	
Tanaidacea	1	Tanaidacea	1	tanaidacea	1	
Theora lubrica (total)	0.1	Theora lubrica	0.1	theora.lubrica	0.1	
Tritia burchardi	0.1			nassarius.burchardi	0.1	Not a taxon category in Regional BHMs – was not found in the original Regional BHM data, this invasive species appeared later on so is excluded from the Regional BHMs
Turbonilla sp.	4.3	Turbonilla sp.	4.3	turbonilla	4.3	
Xenostrobus pulex	1.1			mytilidae.other	1.1	Not a taxon category in Regional BHMs – assume excluded
Xymene plebeius	0.6	Xymene sp.	0.6	xymene	0.6	
Zeacumantus lutulentus	2.5	Zeacumantus lutulentis	2.5	zeacumantus.lutulentus	2.5	
Zeacumantus subcarinatus	28.1			zeacumantus.subcarinatus	28.1	Not a taxon category in Regional BHMs – assume excluded

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