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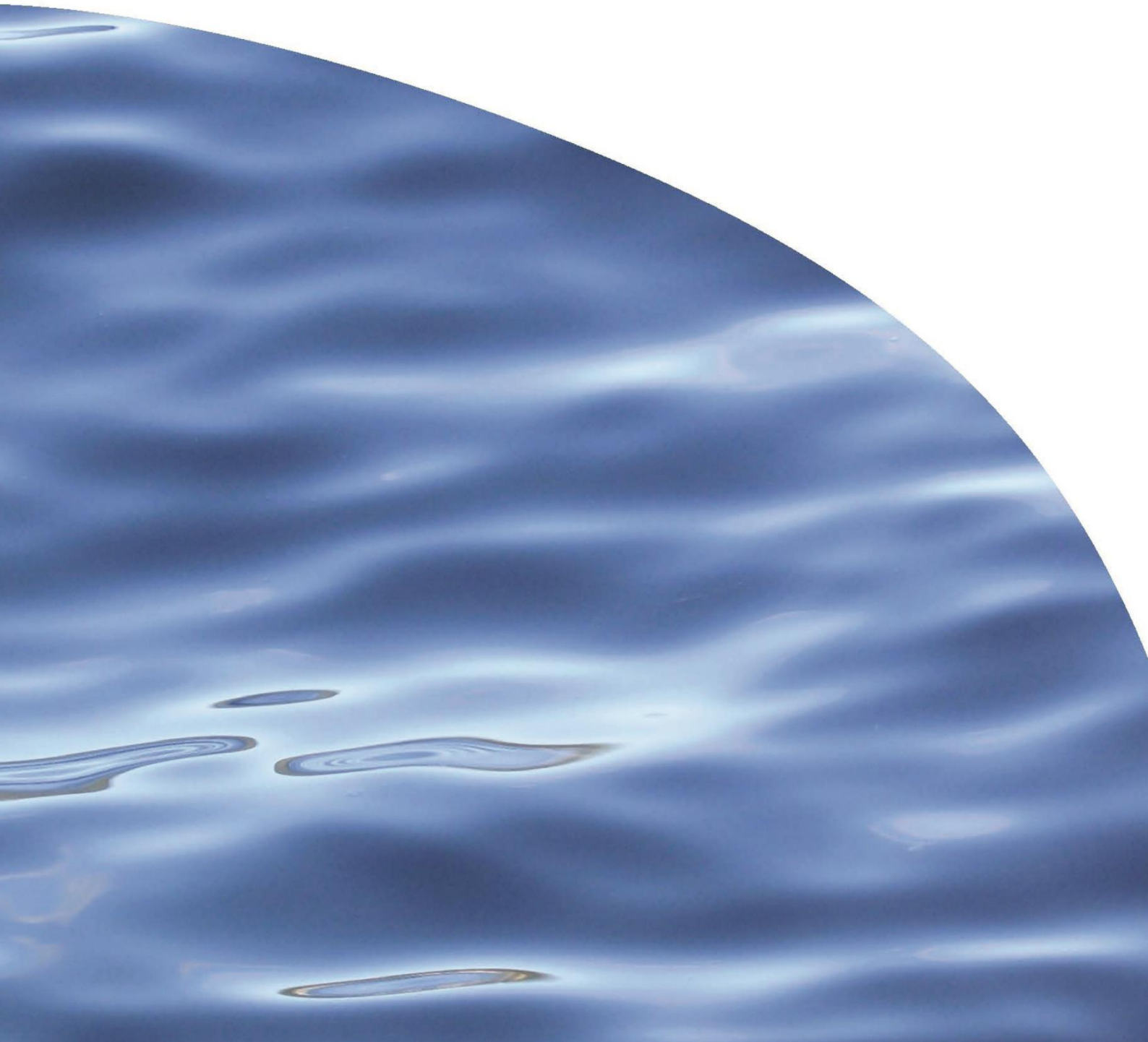
NATIONAL ESTUARY DATASET: INCONSISTENCIES IN SURVEY DATA



NATIONAL ESTUARY DATASET: INCONSISTENCIES IN SURVEY DATA

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Prepared for Northland Regional Council

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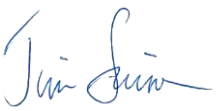

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EXECUTIVE SUMMARY

Northland Regional Council (NRC) carry out estuary monitoring as part of their commitments under the New Zealand Coastal Policy Statement (NZCPS) and the Resource Management Act 1991 as do other councils and unitary authorities. The degradation of coastal marine habitats and ecosystems is one of the top three issues for the marine environment (Ministry for the Environment & Statistics New Zealand 2016). Having estuary monitoring data that can be compared to data from other regions could help to identify environmental issues affecting estuary health. While some sampling protocols and methods are the same across council monitoring programmes, there are also many differences, which makes interregional comparison of data difficult.

Cawthron Institute (Cawthron) recently compiled and analysed a National Estuary Dataset containing ecological monitoring data from estuaries, for research within the Ministry of Business, Innovation and Employment-funded programme *Oranga Taiao, Oranga Tangāta* (OTOT). The dataset contains intertidal fine-scale benthic ecological data from 2001 to 2016. During this process we identified inconsistencies in sampling procedures and laboratory methods, which subsequently affected our ability to compile and analyse the data.

In 2017, NRC contracted Cawthron to outline the inconsistencies encountered during compilation and analysis of the National Estuary Dataset. For variables in the dataset, Cawthron identified inconsistencies in:

- monitoring frequency and/or timing
- sampling design
- sample collection and analysis.

These inconsistencies increased the compilation time and reduced the overall quantity and quality of the data available for analysis. Standardisation of estuary monitoring protocols in the future would reduce the amount of metadata required and increase the usefulness of the data for interregional comparisons and national-scale research.

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1. INTRODUCTION

The degradation of coastal marine habitats and ecosystems is one of the top three issues for the marine environment (Ministry for the Environment & Statistics New Zealand 2016). Estuaries are part of the coastal marine area (CMA) and their management is subject to the New Zealand Coastal Policy Statement (NZCPS) and Part IV (Section 35; 1 and 2a) of the Resource Management Act. Northland Regional Council (NRC), along with other councils and unitary authorities[1] (hereafter referred to as councils), carry out estuary monitoring programmes. Having estuary monitoring data that can be compared to data from other regions could help to identify environmental issues affecting estuary health both nationally and locally.

While some sampling protocols and methods are generally the same across council monitoring programmes (e.g. follow the Estuary Monitoring Protocol or EMP; Robertson et al. 2002), there are also many differences, which makes inter-regional comparison of data difficult. Previous work noting differences between estuary monitoring programmes in New Zealand includes the development of a marine environmental monitoring programme (MEMP) (Hewitt et al. 2014a), development of a protocol for processing, identification and quality assurance of marine benthic invertebrate samples (Hewitt et al. 2014b), exploration of variables to report for Land Air Water Aotearoa (LAWA) (Bolton-Ritchie & Lawton in draft), and development of attributes and state variables for the Ministry the Environment (MfE) project *Managing Upstream* (Zaiko et al. in draft).

Cawthron Institute (Cawthron) recently compiled a National Estuary Dataset containing ecological monitoring data from estuaries, to facilitate research within the Ministry of Business, Innovation and Employment-funded *Oranga Taiao, Oranga Tangāta* (OTOT) programme[2]. The dataset contains intertidal fine-scale benthic ecological data from 2001 to 2016, collected largely by councils. Cawthron subsequently analysed the dataset to test the performance of biotic indices of estuary health (Berthelsen et al. 2018). During this process we identified inconsistencies in sampling procedures and laboratory methods, which subsequently affected our ability to compile and analyse the data. Some of these inconsistencies were identified in previous work (e.g. Hewitt et al. 2014a; Bolton-Ritchie & Lawton in draft), while to our knowledge others have not previously been reported in this context—particularly those affecting the finer details of data compilation and analysis.

In 2017, NRC contracted Cawthron to outline the inconsistencies encountered during compilation and analysis of the National Estuary Dataset. This information could be used to help standardise procedures and laboratory methods with other regions. Ultimately, this could enable data to be more easily compared between regions in

[1] A unitary authority is a territorial authority (district or city) which also performs the functions of a regional council.
[2] *Oranga Taiao Oranga Tangata* is a large multi-year study aimed at providing knowledge and toolsets to support the co-management of estuaries.

order to provide a better understanding of the health status of the estuaries and the impacts of environmental stressors on a spatial scale larger than a council region. The goal was to identify:

- inconsistencies in monitoring frequency and timing, sampling design and sample collection and analysis for variables in the National Estuary Dataset.
- the issues these inconsistencies caused for data compilation and data analysis.
- metadata (data that describe other data and assist to interpret them) that could be included in future reports/data files to make data comparison and analysis easier.

Making recommendations regarding how to reduce inconsistencies was outside the scope of this work. Describing the specific inconsistencies associated with each council's monitoring programme was also outside the scope. However, we have provided figures and tables so that readers can see these.

2. OVERVIEW OF NATIONAL ESTUARY DATASET

We derived the National Estuary Dataset from fine-scale intertidal benthic ecological data collected using the EMP (Robertson et al. 2002), but also included data from similar survey methodologies. Although most of the data were collected by councils for the purpose of State of the Environment monitoring, the dataset also includes some consent monitoring data from Porirua Harbour (Boffa Miskell Limited 2014) in the Wellington region and research data from Tauranga Harbour in the Bay of Plenty region for the Manaaki Taha Moana programme (Ellis et al. 2013), and for development of the EMP (Robertson et al. 2002) from seven regions nationally (Northland, Bay of Plenty, Tasman, Marlborough, Canterbury, Otago and Southland). Although these additional data were not collected by councils, for simplicity throughout the report we have used council names to define regions from which data were acquired. For example, no data labelled as Bay of Plenty Regional Council (BOPRC) were collected by that council.

The raw data were acquired from the regions of fourteen councils (Table 1) and the dataset contains information from 70 estuaries, 409 sites and 815 sampling events (Figure 1, Figure 2, Appendix 1). Data were not able to be acquired from some councils, e.g. Gisborne District Council, Taranaki Regional Council, Horizons Regional Council, or from other sources for their regions. Although not discussed further in this report, a lack of, or limited amount of data from some regions restricted the scope for data analyses.

The dataset contains intertidal (but no subtidal) macrofaunal abundance data (sieved through 0.5 mm mesh and where all sieved taxa were included) and corresponding sediment physico-chemical data for at least one but ideally all of the following variables:

- grain size
- nutrients
- organic content
- metals

It also contained associated metadata.

The data were usually acquired as a Microsoft Excel spreadsheet (data file) with compilation involving merging the individual data files into a single dataset. Each row in the dataset represented a single sampling event (i.e. a sampling occasion where variables were measured concurrently at the same site). Until we got an idea of the variation in methodologies between all sampling events, it was difficult to anticipate all relevant metadata requirements. Therefore we initially chose to largely rely on obtaining metadata from the raw data files and reports, and only emailed key council contacts if we could not find the information in the files and reports.

Although we aimed to acquire and then include all available data that met our requirements, the dataset does not necessarily contain all data collected for ecological estuarine monitoring programmes during this period. Some data that met the criteria above were deliberately not included. For example Auckland Council (AC) data prior to 2010 were not included in the dataset as it was recognised that macrofaunal taxonomic identification was conducted at a lower resolution (Ebrahim Hussain, Auckland Council, pers. comm.). Some data met our criteria but has unintentionally not been included in the dataset at this stage. The example we know of is some of the more recent data from NRC sentinel sites. The inconsistencies highlighted in this report need to be interpreted in the context that not all data was included in the dataset. For example, this could influence inconsistencies such as the timing between sampling events within a site and the number of parameters measured per sampling event. We also chose to exclude all data for some variables e.g. macroalgal cover, epifauna abundance and sediment chlorophyll-*a*, phaeophytin, organic compounds and Redox Potential Discontinuity (RPD) depth, due to inconsistencies in sampling frequency, methodology sample collection and analysis and/or data availability.

Table 1. Councils supplying data for the National Estuary Dataset.

Abbreviation	Councils
AC	Auckland Council
BOPRC[3]	Bay of Plenty Regional Council
ECAN and CCC[4]	Environment Canterbury and Christchurch City Council
ES	Environment Southland
GWRC	Greater Wellington Regional Council
HBRC	Hawke's Bay Regional Council
MDC	Marlborough District Council
NCC	Nelson City Council
NRC	Northland Regional Council
ORC	Otago Regional Council
TDC	Tasman District Council
WCRC	West Coast Regional Council
WRC	Waikato Regional Council

[3] Research data only – not from the council's estuary monitoring programme.
[4] We have used the term ECAN throughout the report to represent data that was acquired from either ECAN or CCC.

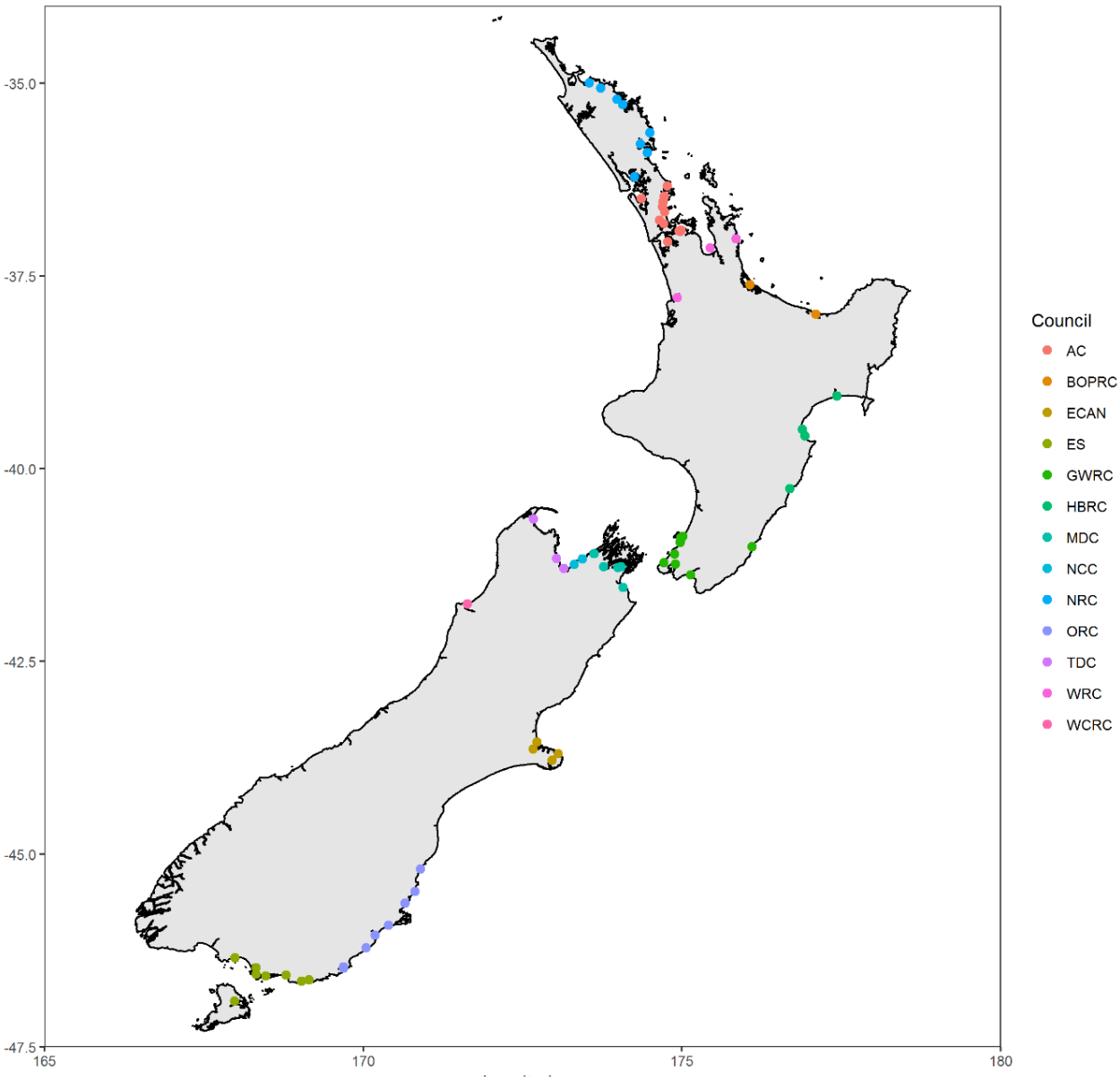

Figure 1. Locations of all estuaries (coloured dots) in the National Estuary Dataset, colour-coded to council.

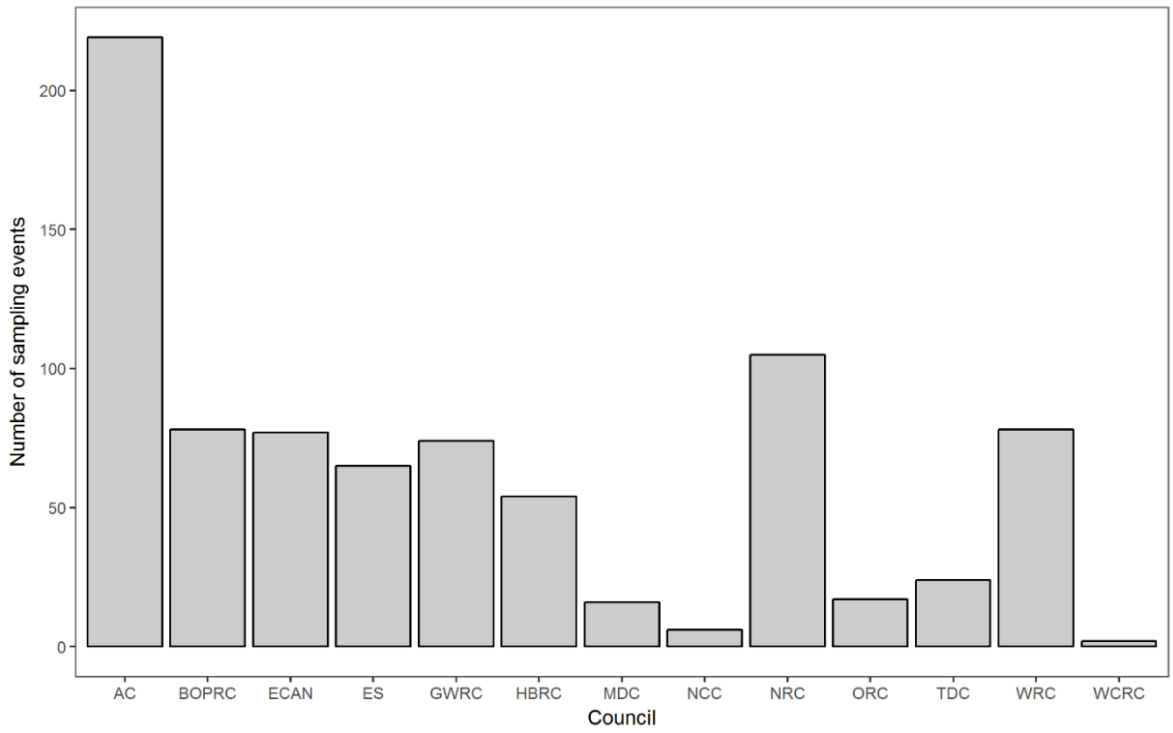

Figure 2. The total number of estuary monitoring sampling events from each region included in the National Estuary Dataset.

3. INCONSISTENCIES

We identified inconsistencies in methodology that affected compilation and analysis of the National Estuary Dataset for the following components of estuary monitoring programmes:

- monitoring frequency and timing
- sampling design
- sample collection
- sample analysis
- data file content and structure.

Most methods were applied consistently by a given council but these sometimes differed from methods used by other councils. In addition, some inconsistencies were present in monitoring programmes within a region and these were often associated with historical versus current monitoring methodologies. Other inconsistencies may have been introduced by service providers for circumstantial reasons, or by researchers following other protocols. Even though some of these inconsistencies are not necessarily relevant to current monitoring programmes, we still think it is important that councils are aware of them in case they want to make comparisons with earlier data. For each component of estuary monitoring, the following sections first describe

the various types of inconsistencies in more detail. The issues they caused for data compilation and data analysis are then listed.

3.1. Monitoring frequency and timing

3.1.1. Frequency per site, timing of sampling events

Monitoring frequency at sites[5] varied, ranging from the sampling of some sites only once during the 15-year period to multiple times a year (Figure 3). The timing (month of the year) during which sampling was conducted also varied considerably (Figure 4). However, with some exceptions, particularly when multiple sampling events were conducted per year, sampling at a site was often conducted at a similar time of the year (i.e. within a couple of months) to previous sampling at that site.

[5] A site is a specific area in an estuary within which all samples were collected during a sampling event.

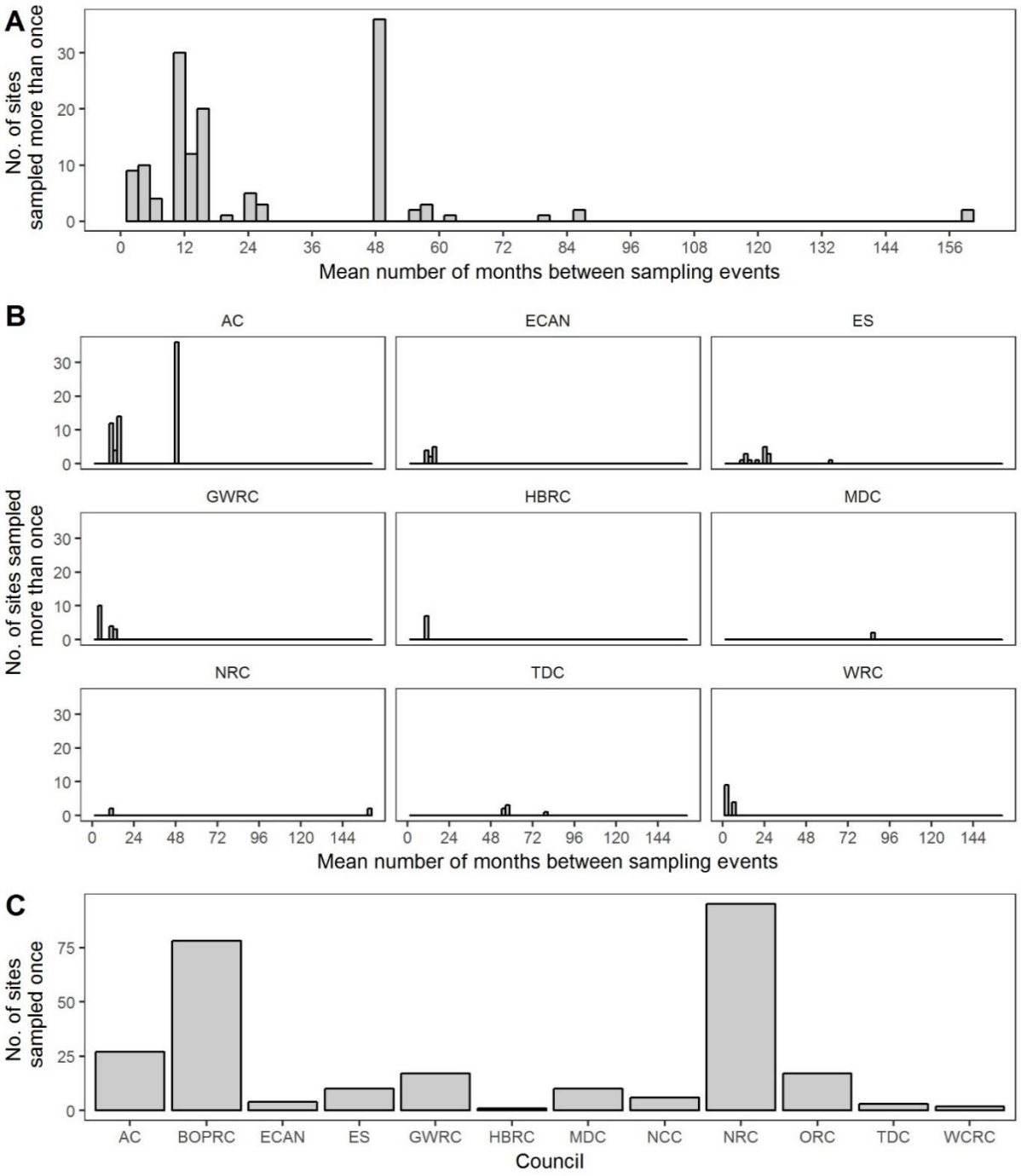

Figure 3. Mean time between sampling events per site for all sites sampled more than once in the National Estuary Dataset, A) overall and B) per council. As we did not have exact date information, for the purposes of creating this plot we assumed that sampling was conducted on the first day of the month. The mean number of months between each sampling event was calculated by taking the date of the first and last sampling events for each site and then dividing by the total number of sampling events (n) minus one (n - 1) conducted at this site within this period. C) Number of sites per council for which only one sampling event was conducted.

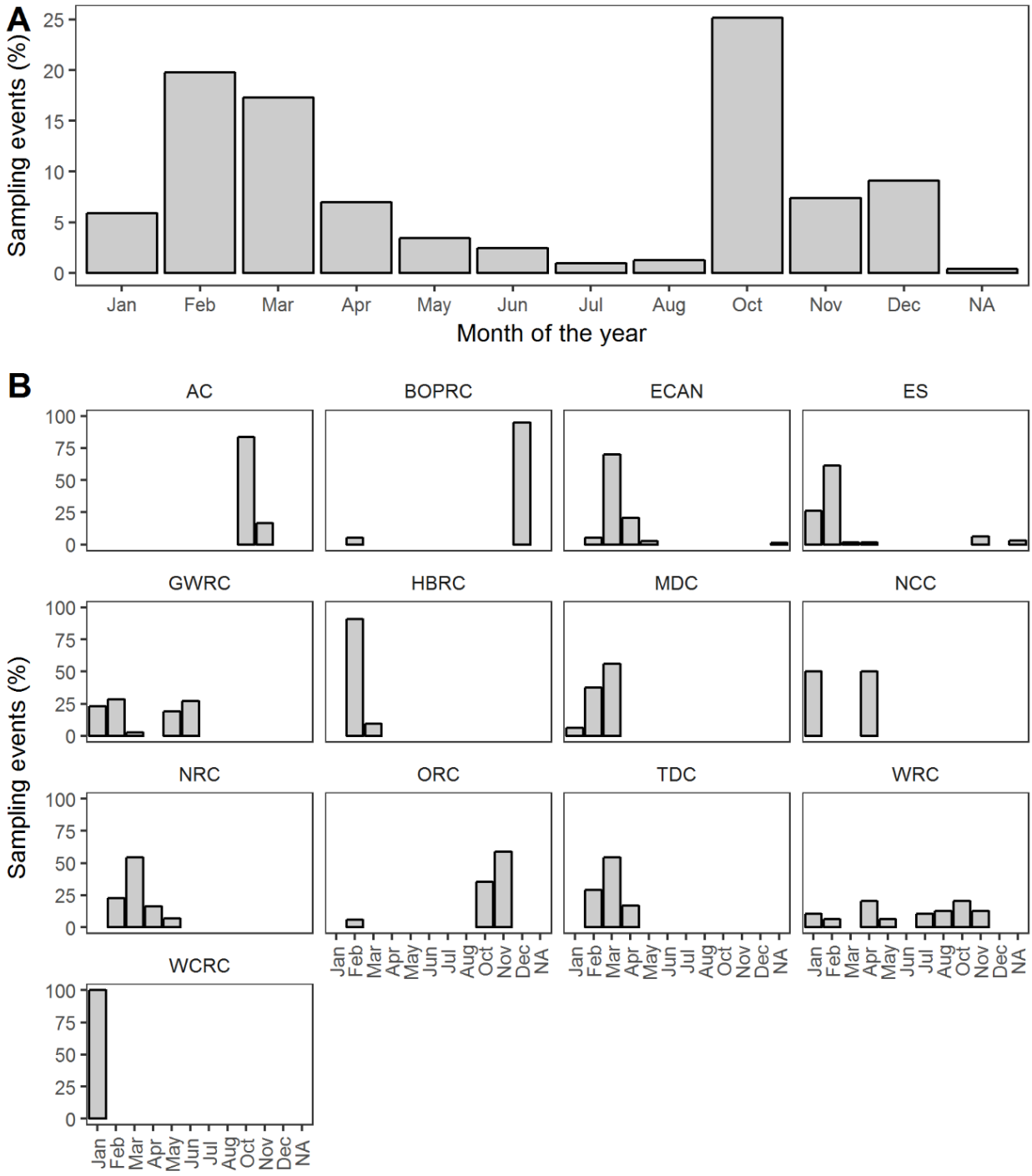

Figure 4. Percentage of sampling events in the National Estuary Dataset conducted in each month, A) overall and B) per council.

Compilation issues

The sampling date was often not included in the data file and therefore this information had to be gleaned by searching relevant reports (if these existed and

contained the information)—a time-inefficient process that also increased the risk of the metadata obtained being incorrect.

Analysis issues

Infrequent monitoring reduced the amount of data available for analysis, as well as limited the scope for analysis of temporal patterns (e.g. natural variability and changes in ecological health over time).

Prior to our analysis we needed to consider the month of sampling, particularly for macrofaunal data due to possible seasonal variation in macrofaunal communities (e.g. recruitment patterns) (Hewitt et al. 2014b). If data from different months or season were not considered comparable, the amount of data available for analysis is likely to be reduced.

Other—reporting frequency

Reports were not necessarily produced after every sampling event. Reports may be written after a series of sampling events (which may take place at a future date). For our dataset, the amount of metadata was limited when there was no report available, resulting in increased time required to collect this information.

3.1.2. Frequency that variables were monitored per sampling event

Along with the macrofaunal data, grain size was the only sediment physico-chemical variable measured during all sampling events (Figure 5). All other variables were either measured infrequently (i.e. during some but not all sampling events), or not at all, at each site.

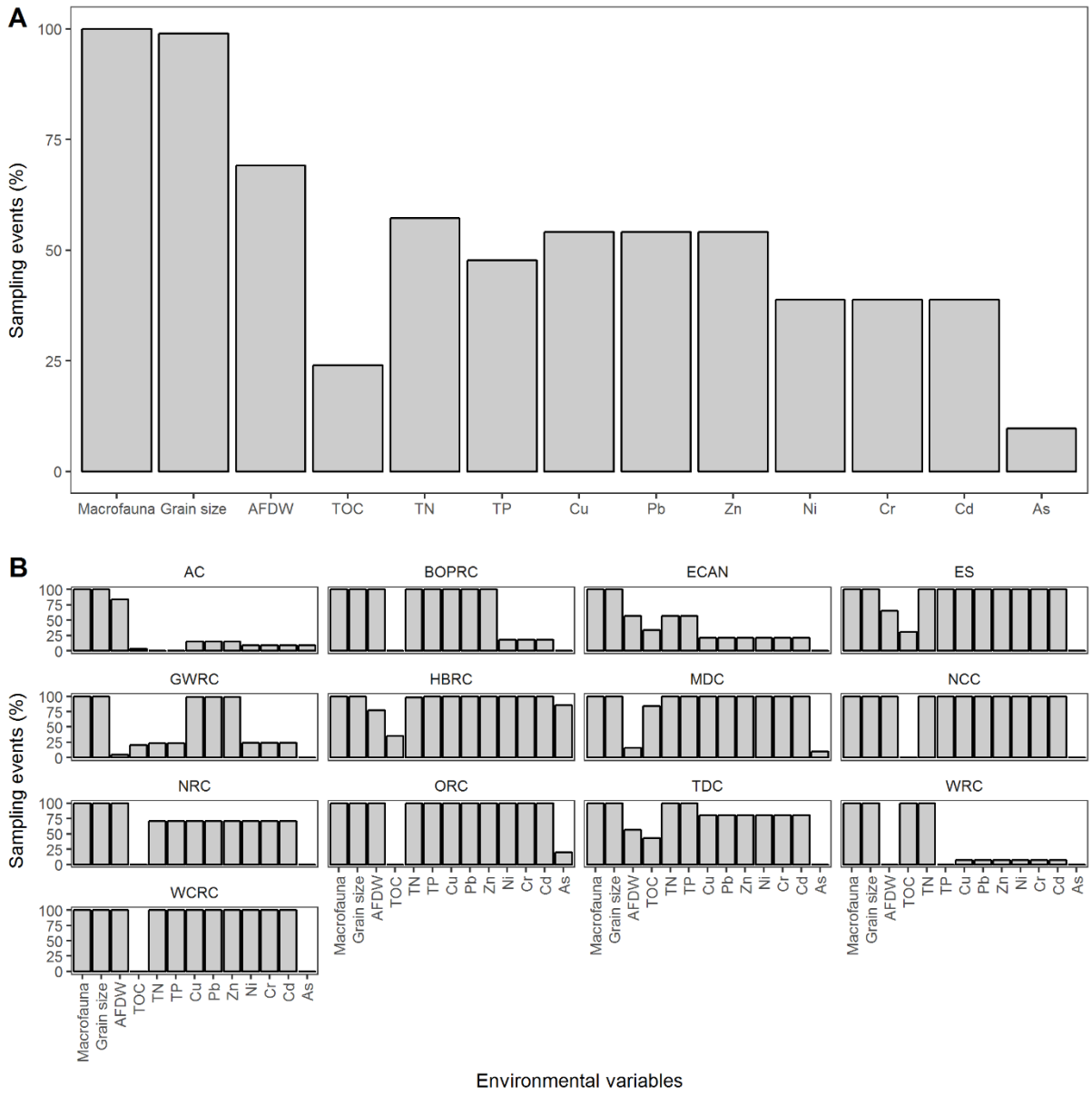

Figure 5. Percentage of sampling events in the National Estuary Dataset during which data for each environmental variable (macrofauna and physico-chemical) were collected A) overall and B) per council. Ash-free dry weight (AFDW), total organic carbon (TOC), total nitrogen and total Kjeldahl nitrogen (TN), total phosphorus (TP), copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr), cadmium (Cd), arsenic (As).

Compilation issues

We were able to fill in some gaps where metals had not been sampled by supplementing the dataset with data from other monitoring programmes undertaken at the same site. It required matching two sets of results, which took additional time. In some cases the date of sample collection of the two sets of data were not able to be exactly matched.

Analysis issues

As some councils did not measure some physico-chemical variables, or sampling of these was infrequent, the amount of data available for analysis was limited. Assuming a balanced design, the more variables used in an analysis, the more sampling events that have to be excluded from the analysis because they lack at least one of those variables (sometimes including all data from one or more councils).

Metals data supplemented from different monitoring programmes needed to be checked for comparability (methodology) prior to inclusion in analyses. A differing sample collection date can introduce some uncertainty regarding the relationship between the two sets of data.

3.2. Sampling design

Besides variation in sampling frequency and timing (Section 3.1), we encountered a number of inconsistencies in sampling design at the level of the site or below (Table 2, Figure 6, Figure 7, Figure 8). We did not explore higher level inconsistencies in survey design such as number of sites per estuary.

3.2.1. Compilation issues

The metadata summarised in Table 2 are important for determining whether data are comparable. Yet this information was often not included in the raw data files and had to be gleaned by searching relevant reports (if these existed and contained the information), as well as through communication with key council contacts. This was a time-inefficient process that also increased the risk of the obtained metadata being incorrect.

For composite estuaries (i.e. an estuary containing ‘sub’ estuaries representing different types, Hume et al. 2016), we needed to consider the scale at which the estuary name was assigned e.g. Pelorus Sound in Marlborough is a composite estuary that contains different-typed estuaries within it.

There was some replication in estuary and site names, and therefore we could not use these to uniquely identify a specific sampling event. For example, there are two Waikawa estuaries; one in Marlborough and the other in Southland. Many councils also used a simple numbering or lettering system to assign site names. Our solution was to assign a unique code to each sampling event (i.e. based on council_estuary_site_year_month).

Table 2. Inconsistencies in sampling design and data file content and structure encountered during compilation and analysis of the National Estuary Dataset. Examples of the general types/range of inconsistencies are provided. No inconsistencies in sample design were specifically identified for the macrofaunal data. * data not included in National Estuary Dataset.

Data type	Sites	Replicates	Data file content/structure
General i.e. common to both macrofauna and physico-chemical data	Size The maximum site size was 10,800 m^2 (Halliday et al. 2012) but in most cases the site size was considerably smaller e.g. EMP site size is 1800 m^2 (Robertson et al. 2002). Representativeness The location of survey sites differed in regards to what part of the estuary they represented e.g. the arm of an estuary versus close to the entrance. Tidal height[6] The tidal height of survey sites varied from subtidal* or from low to mid/high in the intertidal. Vegetation cover Sites were either unvegetated or covered in vegetation (e.g. mangroves, seagrass, macroalgae).	Sampling within a site Sampling procedures varied e.g. some replicates were collected from a site based on a gridded layout while others were sampled randomly from within a site. Replicate number The number of replicates varied between sampling events. For macrofaunal data the number of replicates collected/analysed during each sampling event ranged from 1 to 15. For physico-chemical variables they ranged from 1 to12.	Key metadata The inclusion of key metadata, e.g. month, tidal height, site size, site location, was inconsistent. Scale at which estuary name assigned Some estuaries are composite estuaries that contain different types of estuaries within them (Hume et al. 2016). Estuaries in the data files were assigned at different scales. Estuary and site names Some estuaries and many sites had identical names. In some cases the same site was given a slightly different name in different data files.
Physico-chemical sediment	None identified	Compositing of replicates Replicates were sometimes composited and sometimes not. Where composited the number of replicates varied. e.g. see Bolton-Ritchie & Lawton (in draft) for examples of the number of replicates composited.	None identified

[6] Tidal height information was obtained from site descriptions – we did not assess the methodology used to determine tidal height. In a small number of cases, tidal height was not noted in the data or report so we estimated tidal height based on site position.

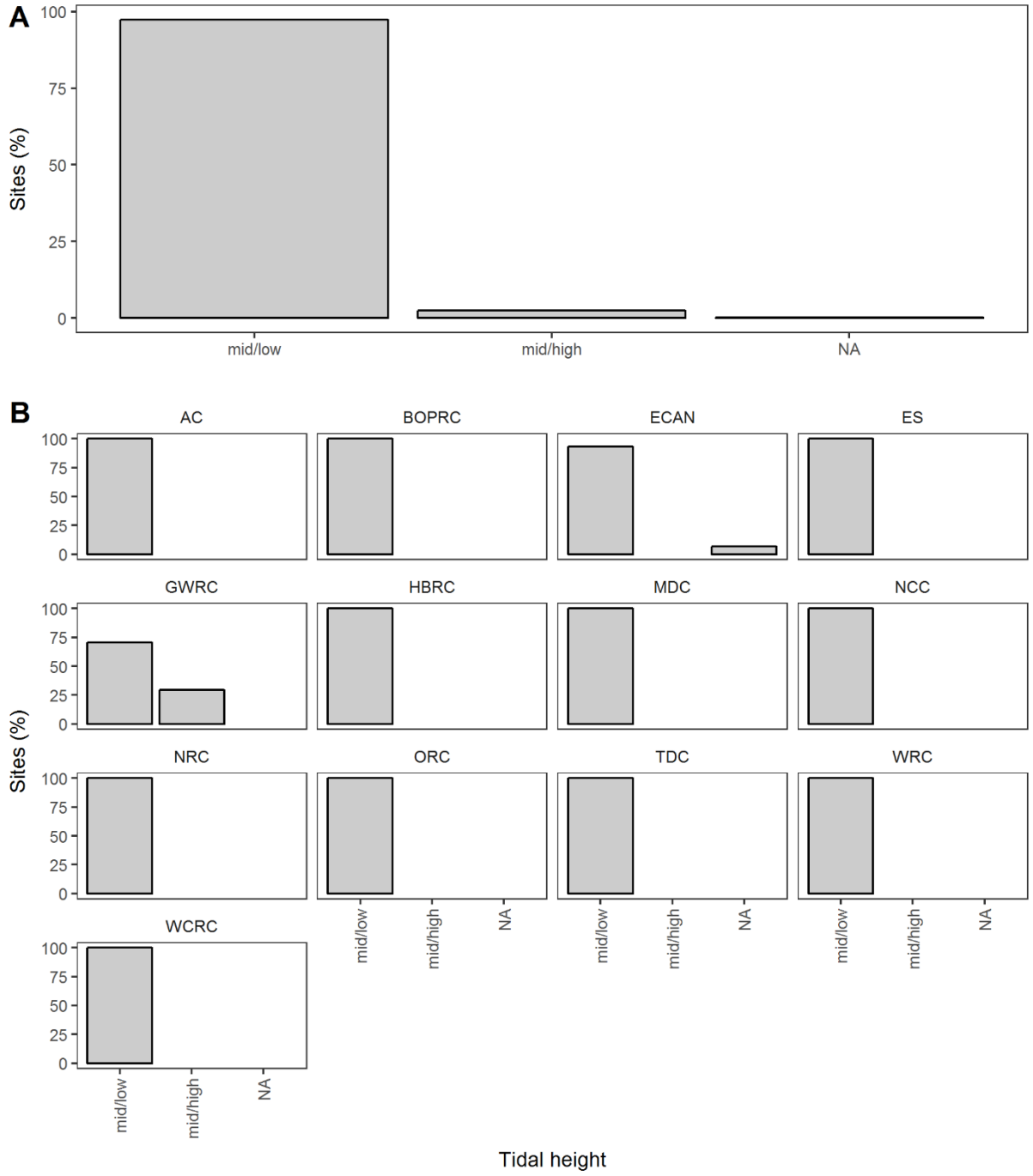

Figure 6. Percentage of sites in the National Estuary Dataset showing tidal height of the site A) overall and B) per council. The categories 'low' and 'mid' have been combined with the mid/low category. NA represents metadata that were not known at the time.

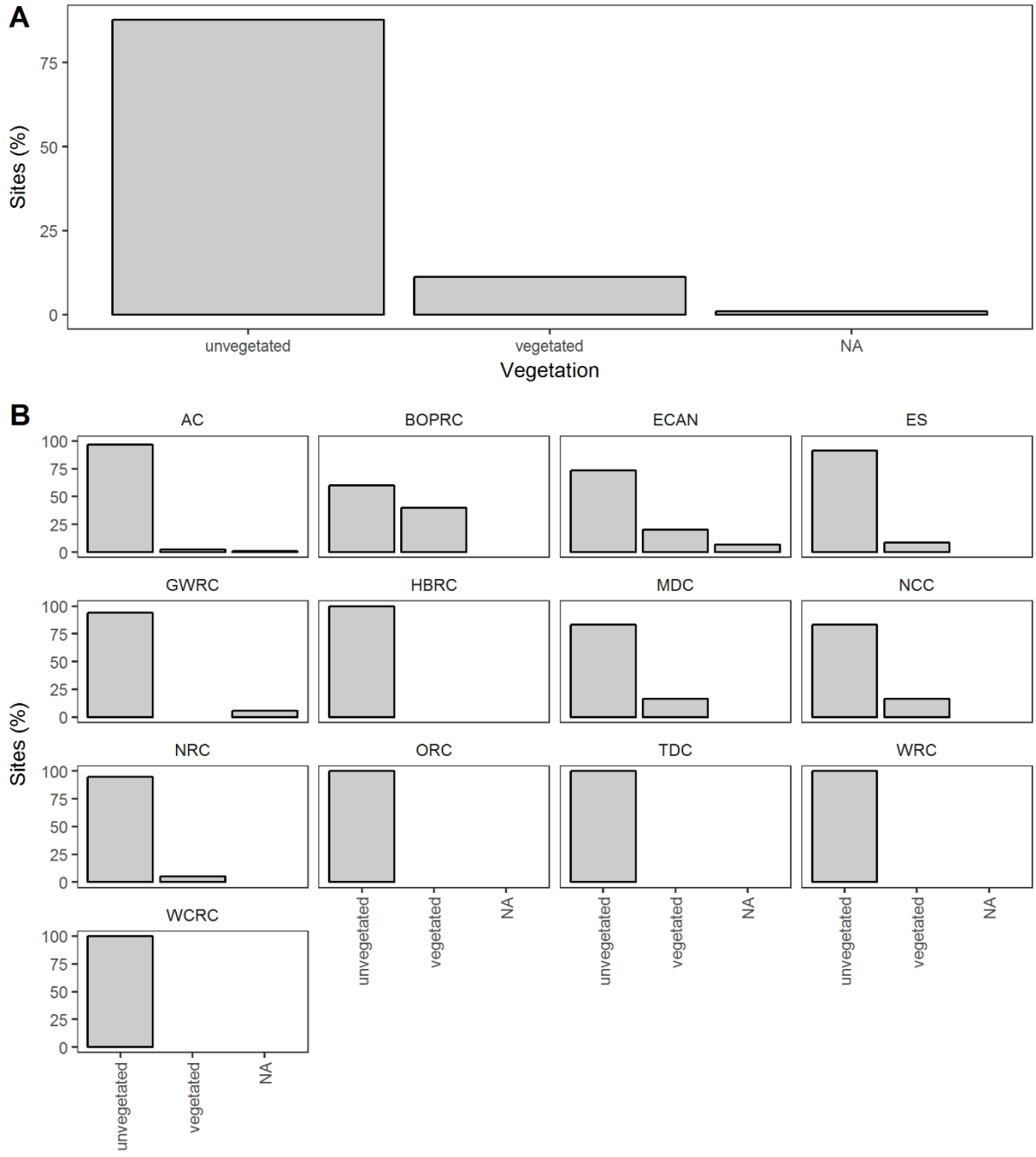

Figure 7. Percentage of sites in the National Estuary Dataset showing vegetation categories A) overall and B) per council. NA represents metadata that were not known at the time.

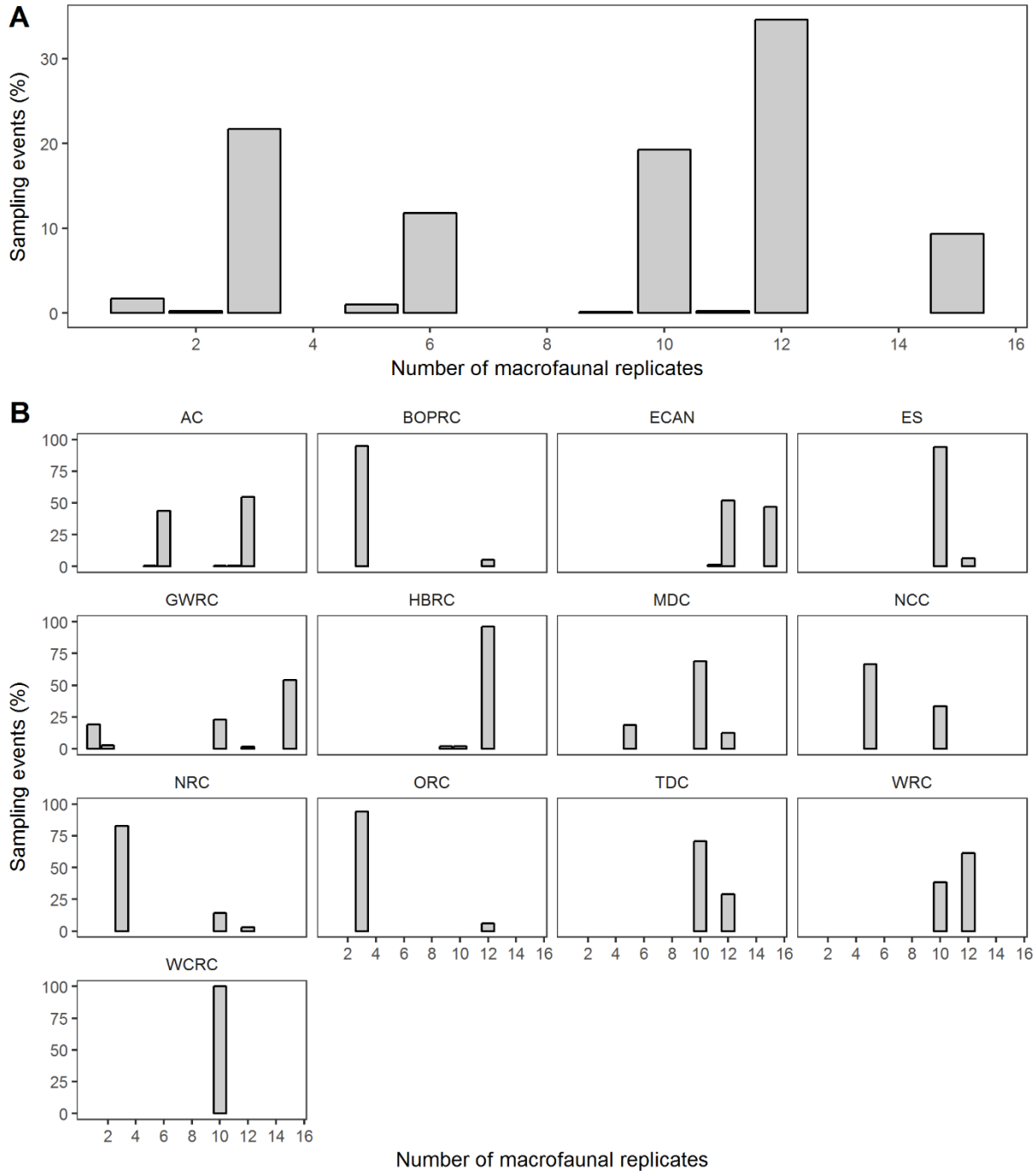

Figure 8. Percentage of sampling events in the National Estuary Dataset showing number of macrofaunal replicates A) overall and B) per council.

Corresponding macrofaunal and physico-chemical replicates (i.e. paired replicates sampled close to each other within a site) could not always be matched within the data. This was because the relationship between physico-chemical replicates and their composited sample was not always clear in the data file. To be able to match each macrofaunal replicate to a physico-chemical variable value, we had to average

physico-chemical data at the level of the site (i.e. we matched the average value of a physico-chemical variable from one sampling event to all macrofaunal replicates from that sampling event).

Sometimes the position of a site was slightly changed between sampling events, even though it kept the same site name, making it difficult for us to confirm site position. Conversely some sites had different names but were in a very similar position, although this was a discrepancy between the 2001 EMP data and council monitoring data. Sometimes site position information had to be estimated from report diagrams (i.e. there was no Global Positioning System location—usually for older surveys), or was occasionally not able to be acquired at all.

As we used a programme in the statistical package R to merge data files, inconsistencies in the name of the same site between data files (e.g. separate files for macrofaunal and physico-chemical data from the same sampling event) hampered this process. This also introduces some risk as we had to make assumptions that slightly differing site names were referring to the same site.

3.2.2. Analysis issues

Data analysis was hampered when aspects of the sampling design were not considered comparable. For example, differences in site representativeness, location in regards to tidal level and whether a site is covered in vegetation or not can influence the composition of macrofaunal communities, and/or magnitude of the sediment physico-chemical variables, present. Depending on analytical requirements, in some cases these differences could require the exclusion of some data from analyses, limiting the amount of data available. The tidal height of a site was sometimes described as mid/low, rather than distinguishing between mid or low. To avoid excluding data, we had to combine these three categories during analysis, therefore losing the ability to compare between them.

The environmental variability, e.g. macrofaunal community composition, observed within a site can change depending on site size, and/or the number of replicates (or composited samples) analysed. Where these factors differ, their effect on environmental variability may need to be considered prior to analysis to ensure comparability between sites—particularly if the analysis requires macrofaunal data to be averaged at the site level.

Averaging physico-chemical data to the level of the site limited the ability to analyse small scale (within-site) relationships between physico-chemical variables and macrofaunal abundance.

Estuary type can change depending on the scale at which this is assessed. Therefore whether the estuary name was assigned at the composite or sub-estuary scale was important if estuary typology was to be used as a factor in analyses.

3.3. Sample collection, analysis and data file content/structure

We found inconsistencies in sample collection and analysis, and data file content/structure.

3.3.1. Macrofaunal data

In all cases macrofaunal samples were collected in a standard way using a core, whose taxa were identified and counted. However, we found a number of inconsistencies in sample collection and analysis, and the content/structure of data files (Table 3, Figure 9, Figure 10). The taxonomists involved in macrofaunal identification were from: Boffa Miskell, Cawthron Institute, EOS Ecology, Coastal Marine Ecology Consultants (CMEC), Canterbury Regional Council, National Institute of Water and Atmosphere (NIWA), NRC, Ryder Consulting, Triplefin Environmental Consulting, Waikato Regional Council and Auckland War Memorial Museum.
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Table 3. Inconsistencies in sample collection and analysis, and data file content and structure for macrofaunal data encountered during compilation of the National Estuary Dataset. Examples of the general type/range of inconsistencies are provided. * data not included in National Estuary Dataset.

Data type	Sample collection	Sample analysis	Data file content/structure
Macrofaunal abundance	**Core depth** Cores of two different depths (150 mm and approximately[7] 100 mm) were used in different council programmes. **Core diameter** Cores of three different diameters (125 mm, 130 mm and 150 mm) were used in different council programmes. **Sieve size** Sieves of different mesh sizes (500 µm and 1000 µm*) were used by different councils.	**Taxa included** Survey data varied regarding whether they included all taxa or indicator taxa only*. In some cases taxa not considered macrofauna e.g. macroalgal species, or not traditionally considered macrofauna, e.g. vertebrates, were also included in the data. **Taxonomic resolution** The resolution at which some taxa were identified appeared to be variable between taxonomic experts e.g. some taxa were identified to species level by some taxonomists while other taxonomists appeared to identify the same taxa to a higher level such as genus, family, order etc. **Age and size classes** Survey data appeared to vary in terms of whether juveniles were reported separately or together with adults. This was also the case for taxa size classes, particularly larger bivalve taxa. In some cases, early life stages such as megalope, eggs and larvae were reported separately. **Taxonomic naming** Some taxa were named using their common name rather than their scientific name, while other taxa were named using taxa codes specific to that council (e.g. polychaete sp. A). The scientific names of some taxa were misspelt. The terms sp. (indicating one taxon), and spp. (indicating more than one taxa) for taxonomic levels higher than species were inconsistently applied throughout the data. **Synonyms** Due to scientific name changes for some taxa, multiple names were often applied to the same taxa i.e. older names (synonyms) or the currently accepted name. An example is the crab *Macrophthalmus hirtipes* (synonym) and *Hemiplax hirtipes* (current name). **Quality Assurance (QA) protocols** Whether or not standard (QA) protocols were used during analysis of macrofaunal samples was often not reported. However recently, QA procedures developed by Hewitt et al. (2014b) have been followed in some cases (Zaiko et al. in draft).	**Key metadata** Key metadata not often not provided. **Structure of data** Data were not displayed in a standardised way e.g. data were displayed in different orders and orientations.

[7] Note that the 100 mm core depth is approximate as the ability to push the core into the substrate can be reduced if the substrate is particularly hard or dense. Conversely, in soft sediments it may be possible to push the core to the desired 150 mm depth.

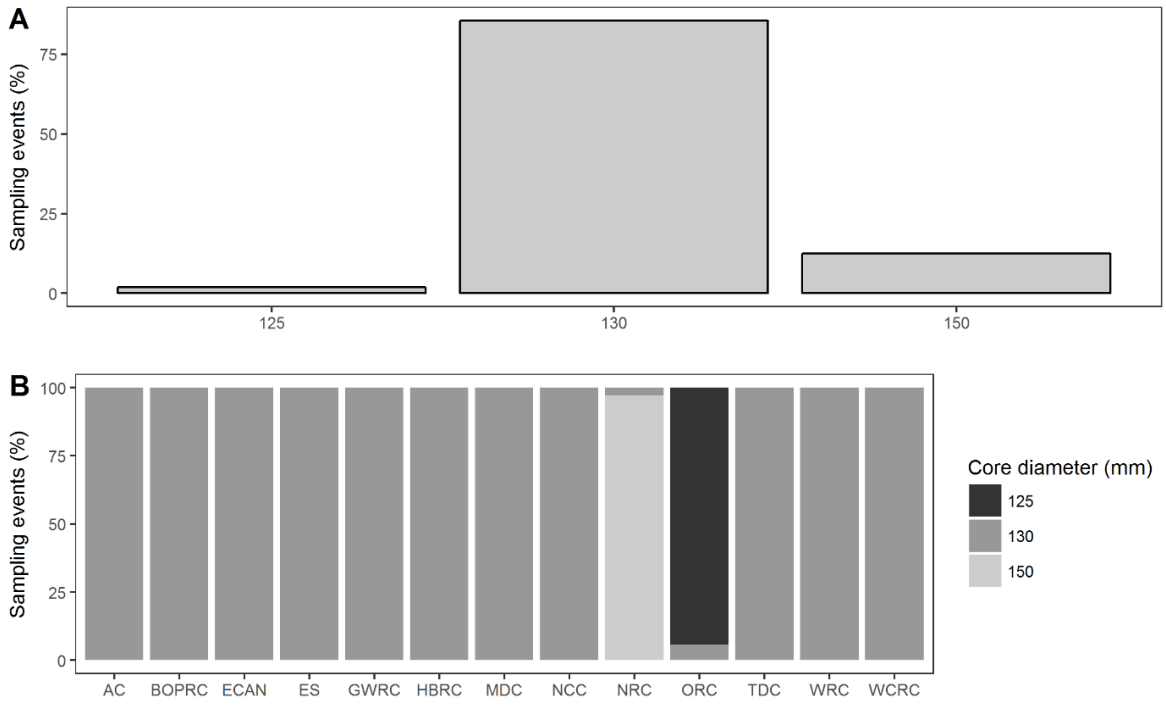

Figure 9. Percentage of sampling events in the National Estuary Dataset for which different core diameters were used to collect macrofaunal samples, A) overall and B) per council.

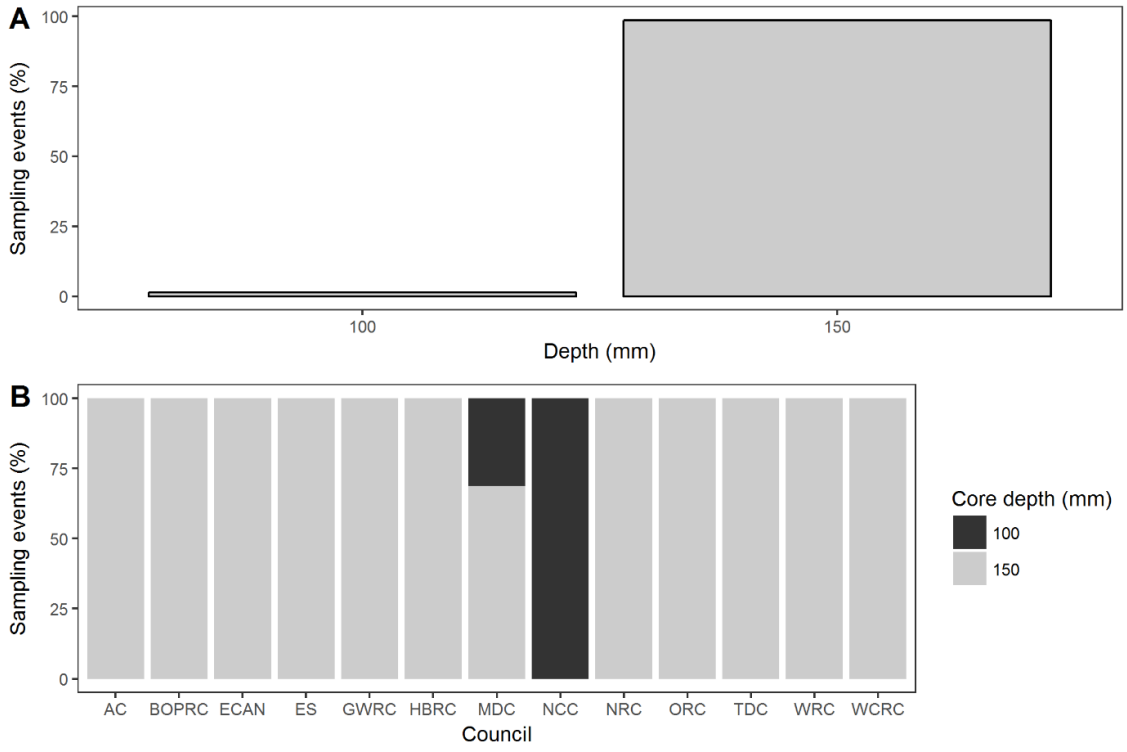

Figure 10. Percentage of sampling events in the National Estuary Dataset for which different core depths were used to collect macrofaunal samples, A) overall and B) per council. Note that the 100 mm core depth is approximate as the ability to push the core into the substrate can be reduced if the substrate is particularly hard/dense. Conversely, in soft sediments it may be possible to push the core to the desired 150 mm depth.

Compilation issues

As with other information on survey methodology, metadata required to ensure comparability (e.g. core diameter, depth and sieve mesh size) usually had to be gleaned from relevant reports (where these existed) as well as through communication with key council contacts – a time-inefficient process that also increases the risk of the obtained data being inaccurate.

Determining whether data contained all taxa or indicator taxa only also required consideration, and we only included data containing all taxa in the dataset.

Data derived from different sieve mesh sizes were considered not comparable and therefore all data from a sieve mesh size other than 0.5 mm (i.e. 1 mm—data from BOPRC monitoring programme) were excluded.

Misspelling of taxa names, use of taxon codes specific to taxonomist (e.g. polychaete sp. A) and common names, inconsistent use of the terms sp. and spp., and the presence of synonyms were all issues that we needed to resolve at the data compilation stage.

Resolving inconsistencies in taxonomic resolution, to increase comparability of data prior to our data analyses, was one of the most time-inefficient processes. During data exploration, we concluded that this required considerable lumping to higher taxonomic levels, as well as the exclusion of some data within which we considered some key taxa to be identified to a relatively poor resolution. Amphipods were an example of a taxon group identified at inconsistent resolutions. Some taxonomists identified at least some amphipods to species while others appeared to only identify amphipods to higher levels such as family or order. Hence for the resolution to be consistent across the entire dataset, we were required to lump all amphipod taxa to the level of order. Polychaetes provide another example where, in order to keep some polychaete taxa identified below the level of family, prior to analysis we were required to remove some sampling events for which polychaete taxa appeared to be identified at a relatively poor resolution.

Because of apparent inconsistencies in the reporting of juveniles separately, we combined these with their parent taxa. Juveniles are often more difficult to identify (Hewitt et al. 2014b), and therefore more likely to be identified at a taxonomic level higher than species. If not reported separately from their parent taxa, their presence could result in the combining of that taxa group to a higher level to match the resolution of the juveniles. This would result in a reduction of taxonomic resolution for that taxa group. Further details regarding taxonomic resolution of the dataset will be provided in Berthelsen et al. (in draft).

As the terms sp. and spp. associated with taxa names were inconsistently used, we did not include these in the dataset. Therefore the assumption was that any taxa identified at a level higher than species could include one or more taxa.

Inconsistent structure of information in data files also increased compilation time. For example, the data were often presented in a different order or orientation that was not always easily comparable with other data.

Analysis issues

The inclusion of indicator taxa only, as well as the use of a different sieve mesh size by one monitoring programme, limited the amount of data in the dataset and hence, the amount available for analysis.

The influence of the use of cores with different diameter or depth (which can vary depending on substrate type) on taxa abundance and richness needed to be considered and potentially resolved (e.g. adjusted for) prior to analysis. For example, this could require either adjustment of abundance values for standardisation purposes, or the exclusion of the data from analyses.

Differences in taxonomic resolution can influence both the number of taxa and the ability to assign tolerance and functional trait groups to taxa. This has consequences for calculating and comparing macrofaunal metrics such as taxonomic richness, and biotic indices e.g. Azti Marine Biotic Index (AZTI), Traits Based Index (TBI) and the Benthic Health Model (BHM). In our analyses, both the considerable lumping of taxa to higher taxonomic levels, and subsequent exclusion of data identified to a lower resolution, reduced the quality (e.g., patterns relating to specific taxa may have been obscured) and amount of data available for analysis.

The lumping of juveniles with their parent taxa limited our ability to analyse the effects of recruitment events on community structure and investigate seasonal patterns. This increased the chances of recruitment events obscuring longer-term patterns in abundance.

Another consideration was the definition of macrofauna and whether the removal of taxa outside this definition (e.g. macroalgae) or not traditionally considered macrofauna (e.g. vertebrates), as well as early life stages (e.g. eggs, megalope and larvae) and sessile taxa (e.g. ascidians, bryozoans, tunicates and sponges) was required depending on the analysis.

Unknown QA assurance meant that the quality of the macrofaunal data was uncertain. In some cases, this may be a reason for excluding data from the analysis.

Other biological data

Epifaunal abundance and macroalgal coverage data were also collected (using a quadrat) for some sampling events. However we did not include this data in the National Estuary Dataset because it was often not included in the data files, and would have needed to be extracted from the relevant reports prior to compilation requiring additional effort.

3.3.2. Sediment physico/chemical data

Besides differences in monitoring frequency for the sediment physico-chemical variables (Section 3.1), we also identified inconsistencies in sample analysis, and the content and structure of the data files (Table 4), particularly for the analysis of grain size (Figure 11), nitrogen (Figure 12) and organic content. Detailed examples of different analytical methods for the sediment physico-chemical variables are provided in Appendix 2. Laboratories that conducted the analyses included: Auckland Uniservices, Cawthron Institute, Hill Laboratories, NIWA, University of Waikato and Watercare Laboratory Services. We did not identify any inconsistencies in sample collection, although we did not assess this in detail. For example we did not determine whether there were any inconsistencies in the depth of sediment collected for analysis (see Bolton-Ritchie & Lawton (in draft) for discussion on this).

Table 4. Inconsistencies in sample analysis and data file content and structure for sediment physico-chemical data encountered during compilation of the National Estuary Dataset. Examples of the general type/range of inconsistencies are provided. * data not included in National Estuary Dataset.

Data type	Sample analysis	Data file content/structure
Physico-chemical sediment variables in general	None identified	Units Units for each physical/chemical variable were not always provided. Variable name All variables were represented by more than one name in the dataset. For example other names given for ash-free dry weight (AFDW) include LOI (loss on ignition), organic matter and organic content. Treatment of values below Analytical Detection Limits (ADLs) There were uncertainties regarding values below ADL including whether the values had previously been halved—a common convention, or whether they were accompanied by the < symbol. Key metadata Key metadata were often not provided. Number of data spreadsheets per sampling event Data from the same sampling event were often displayed in different tabs in a data file. Structure of data Data were not laid out in a standardised way, e.g. data were displayed in different orders or orientations.
Grain size	Main methods There were two main methods for grain size analysis - laser and wet sieve.	Name of sediment grain size fractions Sediment grain size fractions were sometimes given as a general name, e.g. granule, gravel, silt, clay, fine sand, rather than the actual size fraction.

Data type	Sample analysis	Data file content/structure
Grain size, cont.	Maximum grain size analysed The maximum grain size analysed differed between analysis methods e.g. Malvern Mastersizer (laser) only analyses grains < 2000 µm, while all grain sizes are generally analysed during wet sieving. Number of grain size classes Differing numbers of grain size classes were reported and this often depended on the main grain size method used e.g. 3, 6, 7 for wet sieve, many for laser. Methods within main methods The methods for wet sieving and laser analysis can vary within each of the two main methods, e.g. Appendix 2, Bolton-Ritchie & Lawton (in draft).	Sediment grain size fractions Sediment grain size fractions were not always consistent, e.g. > 500 µm versus 1000-2000 µm.
Metals (e.g. copper, zinc, lead, nickel, chromium, arsenic)	ADLs The ADLs from different laboratories sometimes varied e.g. the ADLs for copper ranged from 0.5–2 mg/kg. Trace versus screen analysis Some metals were analysed using trace methods and some were analysed using screen methods—this can influence the ADLs. Sediment size fractions Metals were analysed from different sediment size fractions e.g. < 63 µm*, < 500 µm, total or < 2000 µm. Methods Methods for metal analysis were sometimes variable e.g. different extraction methods were used for the < 63 µm grain size fraction in comparison to the > 500 µm or total size fractions (Hewitt et al. 2014a).	None identified

Data type	Sample analysis	Data file content/structure
Organic content	Organic content type Two main types of organic content were analysed, these were total organic carbon (TOC) and ash free dry weight (AFDW)[8].	None identified
Nutrients (nitrogen and phosphorus)	ADLs The ADLs from different laboratories sometimes varied e.g. ADLs for TN ranged from 50 to 500 mg/kg depending on laboratory. Nitrogen types Two main nitrogen types were analysed, these were total nitrogen (TN) and total Kjeldahl nitrogen (TKN[9]).	None identified

[8] Some councils currently monitor AFDW, while others have since switched to TOC.
[9] Note that the use of TKN appears to be historical and not part of current monitoring programmes.

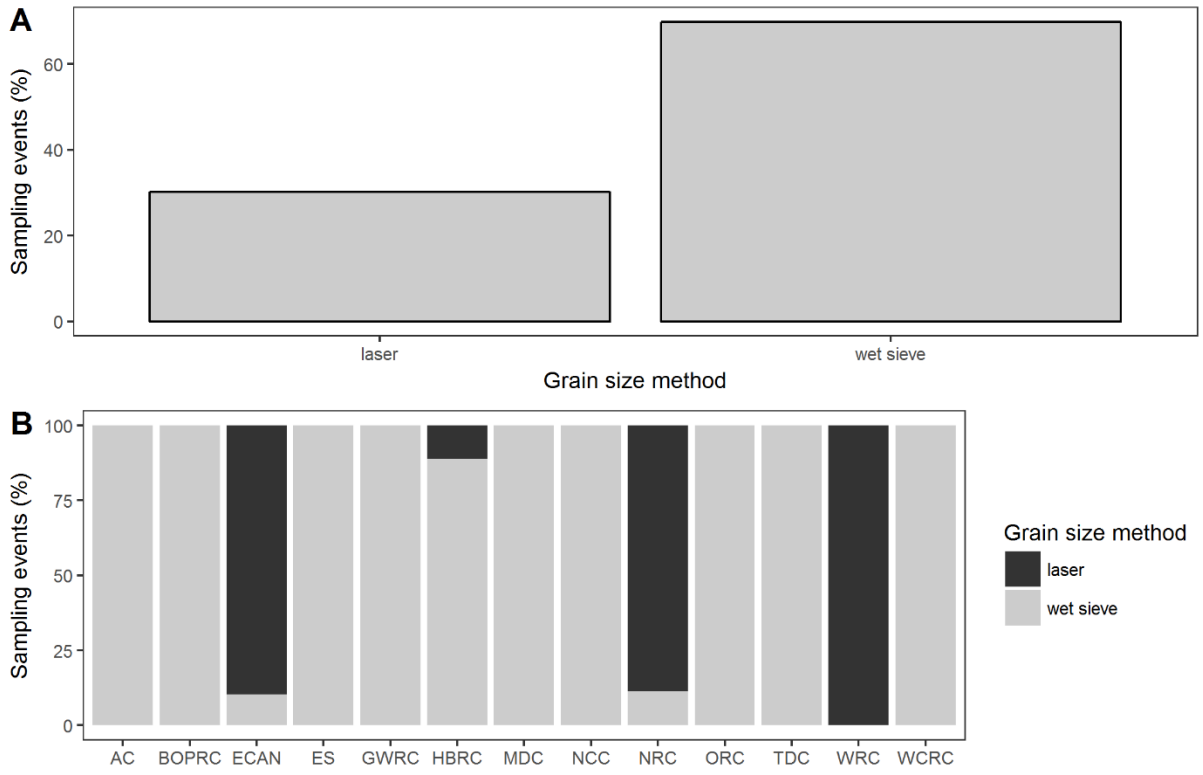

Figure 11. Percentage of sampling events in the National Estuary Dataset during which different grain size analysis methods (wet sieve or laser) were used A) overall and B) per council. Note that the grain size method for the Porirua (GWRC) consent monitoring data (Boffa Miskell Limited 2014) was assigned as wet sieve as grains > 2000 µm were analysed, even though it is described as a mixture of both wet sieving and laser analysis in the report.

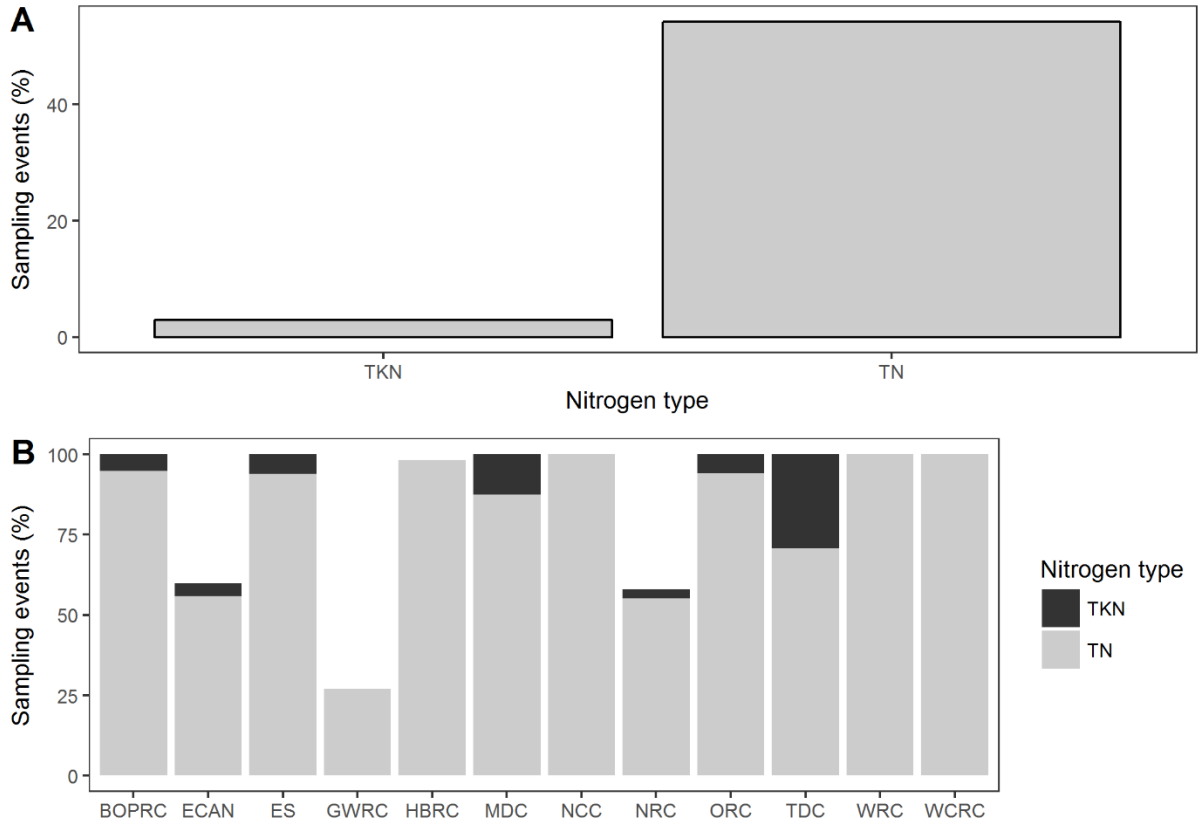

Figure 12. Percentage of sampling events in the National Estuary Dataset during which different nitrogen types (TN or TKN) were used A) overall and B) per council.

Compilation issues

Metadata required to identify the main inconsistencies in physico-chemical sample collection and analysis methods (e.g. grain size analysis and nitrogen type, Analytical Detection Limits—ADLs) had to be gleaned from relevant reports (where these existed) as well as through communication with key council contacts and laboratories; a time-inefficient process that also increases the risk of the data obtained being inaccurate.

Resolving issues associated with differing content in data files (e.g. lack of variable units, different names for same variables) was also inefficient.

Due to inconsistencies in grain size classes, we recalculated them into standardised classes (e.g. we standardised to < 63 µm, 1–2 mm, > 2 mm). Where possible, as part of this process we also standardised the results from wet sieving analysis to the percentage of 2 mm (as opposed to the percentage of total) to align them with those from laser analysis.

Having different tabs in a data file for the same sampling events sometimes made it difficult to match data from the same sampling event during compilation, particularly if site names were slightly different. Inconsistent layout of information in data files also increased compilation time. For example the data files often had different structures in terms of the order and orientation of information.

Analysis issues

Data collection or analytical methods not considered directly comparable (e.g. total organic carbon—TOC, and ash-free dry weight—AFDW for organic content) can limit data analysis by reducing the amount of data available due to exclusion of data, or require separate analysis of some data.

Analytical detection limits (ADLs) that were high in relation to thresholds for ecological impacts limited the ability to analyse the potential ecological effects of that variable. For example, the ADL of TN analysed by one laboratory was 500 mg/kg, however a TN concentration of 250–1000 mg/kg[10] can cause minor stress on sensitive organisms (see Robertson et al. 2016).

Other variables

Sediment chlorophyll-*a*, phaeophytin, organic compounds (those that can be toxic to animals, e.g. polycyclic aromatic hydrocarbons) and redox potential discontinuity (RPD) data were not included in the National Estuary Dataset. Inconsistencies in sample design, collection and analysis have been identified for sediment chlorophyll-*a* (Zaiko et al. in draft). RPD measurements can be subjective and do not always equate to the oxygen profile measured in a laboratory (Hewitt et al. 2014a), and as these data was recorded in the field it was not often included in the raw data. The data would therefore have had to be extracted from the relevant reports, a process that would have required additional work. Organic compounds were infrequently sampled in ecological programmes.

[10] Interim thresholds only.

4. USEFUL METADATA

4.1. Compilation

When we compile estuary monitoring data, useful metadata[11] highlights inconsistencies in the monitoring programmes. Data compilation would be much easier if these metadata were provided with the data file as well as in a technical report. Standardisation of all aspects of estuary monitoring would greatly reduce the amount of metadata required. For example, if it was known that the same grain size analysis was used in all programmes, the metadata for the grain size analysis method would not be required for each individual sampling event.

4.2. Analysis

Standardisation of all aspects of estuary monitoring would increase the amount of data available for analysis, particularly for making inter-regional or national comparisons, as well as the type of analyses that could be conducted and the hypotheses tested.

4.3. Additional metadata

We found relatively high amounts of unexplained variation in macrofaunal abundance during analysis of the dataset. Additional data not usually provided that may help to explain observed variation could include environmental parameters such as salinity of residual overlying water at low tide, and other water quality measures (e.g. temperature, turbidity, clarity and currents – although these can be highly variable), as well as fetch (wind and waves) and other climate-related (e.g. El Niño–Southern Oscillation, see Hewitt et al. 2016) variables. Additional stressor data such as those for emerging contaminants and fishery harvesting (e.g. shellfish gathering pressure) could also be useful in explaining observed variability. Consideration of region and estuary type may also improve interpretation of results.

[11] data that describe other data and assist to interpret them.

5. CONCLUSION

During compilation of the National Estuary Dataset, we encountered many inconsistencies associated with monitoring frequency and timing, sampling design, sample collection and analysis, and data file content/structure, in estuary monitoring data. These inconsistencies greatly increased the compilation time and reduced the overall quantity and quality of the data available for analysis.

These data are expensive to collect yet valuable, as they can be used to assess the current health, functioning and integrity of estuaries, as well as how these may change over time as a result of human activities. Standardisation of estuary monitoring protocols in the future would increase the scientific robustness of these data, allowing them to be more useful for interregional comparisons and national-scale research.

6. ACKNOWLEDGMENTS

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8. APPENDICES

Appendix 1. Number of estuaries, sampling events, sites and years included for each council in the National Estuary Dataset.

Council	No. of estuaries	No. of sampling events	No. of sites	Years	First year	Last year
Auckland Council	13	219	93	5	2010	2014
Bay of Plenty Regional Council	2	78	78	2	2001	2011
Environment Canterbury and Christchurch City Council	4	77	15	10	2001	2015
Environment Southland	8	65	23	12	2001	2013
Greater Wellington Regional Council	9	74	34	9	2004	2014
Hawke's Bay Regional Council	4	54	8	10	2006	2015
Marlborough District Council	5	16	12	4	2001	2016
Nelson City Council	2	6	6	2	2009	2012
Northland Regional Council	8	105	99	8	2001	2016
Otago Regional Council	8	17	17	6	2001	2012
Tasman District Council	3	24	9	5	2001	2015
West Coast Regional Council	3	78	13	2	2013	2014
Waikato Regional Council	1	2	2	1	2007	2007

Appendix 2. Detailed examples of the analysis methods for sediment physico-chemical variables in the National Estuary Dataset. Note that these methods are not necessarily exhaustive. Table taken from Berthelsen et al. (in draft).

Variable	**Laboratory analysis** **[information source]**
Sediment grain size - laser	Sediments were pre-treated with 10% hydrogen peroxide to remove organic material and 1M hydrochloric acid to remove carbonate material. Calgon™ was added as a dispersant and samples were placed in an ultrasonic bath for 10 minutes to aid disaggregation. Samples were analysed using a Malvern Mastersizer 2000. Grain size data were grouped into the following grain size categories: mud (< 63 µm); very fine sand (63-125 µm); fine sand (125-250 µm); medium sand (250-500 µm); coarse sand (500-1000 µm) and gravel (> 1000 µm) (following the Wentworth sediment classification). [Needham et al. 2014] (Report only until 2011 but assume the same analysis used from 2012 onwards.) Samples were analysed by Auckland University Services Ltd with a laser diffraction particle analyser (Malvern Mastersizer 2000). The following size fractions were determined: < 63 µm (mud); 63 -230 µm (fine sand); 250-500 µm (medium sand); and > 500 µm (coarse sand). [Griffiths 2011]
Sediment grain size – wet sieve	Fraction ≥ 2 mm, Wet sieving, 2.00 mm sieve, gravimetry, Fraction < 2 mm, ≥ 63 µm* Wet sieving, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference), Fraction < 63 µm Wet sieving, 63 µm sieve, gravimetry (calculation by difference). [Hill Laboratories Analysis Report Quote 31586 Porirua 2008]. Texture (2 mm, 63 µm sieves), Sieving, gravimetric. All drying 35 °C, overnight [Hill Laboratories Analysis Report Quote 439846 Waikouaiti 2006]. Gravel (> 2 mm), Very Coarse Sand (< 2 mm and > 1 mm), Coarse Sand (< 1mm & > 500 µm), Medium Sand (< 500 µm and > 250 µm), Fine Sand (< 250 µm and > 125 µm), Very Fine Sand (< 125 µm and > 63µm), Silt & Clay (< 63 µm). In-House Method. [Cawthron Laboratory Report number S84798 Tauranga 2011] Wet sieving and calculation of percentage fractions according to dry weight [Robertson et al. 2002, Gillespie & Clark 2007]

Variable	Laboratory analysis [information source]
Sediment grain size – wet sieve, cont.	Grain size analyses were performed by University of Waikato using wet sieving and laser particle analysis generate fractions; > 2 mm, < 2 mm to > 1 mm, < 1 mm to > 500 µm, < 500 µm to > 250 µm, < 250 µm to > 125 µm, < 125 µm to > 63 µm and < 63 µm. These fractions correspond to the following particle size classes: gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt and clay. [Boffa Miskell Limited 2014][12] The samples are homogenised and a subsample of approximately 5 g of sediment taken, and digested in ~ 9% hydrogen peroxide until frothing ceases. The sediment sample is then wet sieved through 2000 µm, 500 µm, 250 µm and 63 µm mesh sieves. Pipette analysis is used to separate the < 63 µm fraction into > 3.9 µm and < 3.9 µm. All fractions are then dried at 60°C until a constant weight is achieved (fractions are weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as percentage weight of gravel/shell hash (> 2000 µm), coarse sand (500–2000 µm), medium sand (250–500 µm), fine sand (62.5–250 µm), silt (3.9–62.5 µm) and clay (< 3.9 µm). [Halliday et al. 2012] Prior to analysis, the samples are homogenised and a subsample of approximately 5 g of sediment taken. They are then digested in 6% hydrogen peroxide until all organic matter is removed, and sampled by wet sieving and pipette analysis (Gatehouse 1971). Pipette analysis is used to separate the < 63 µm fraction into > 3.9 µm and < 3.9 µm. All fractions are then dried at 60°C until a constant weight is achieved (fractions are weighed at ~ 40 hr and then again at 48 hr). The results of the grain size analyses are presented as percentage composition of gravel/shell hash (> 2 mm), coarse sand (500–2000 µm), medium sand (250–500 µm), fine sand (62.5–500 µm), silt (3.9-62.5 µm) and clay (< 3.9 µm). Mud content is calculated as the sum of the silt and clay content. [Greenfield et al. 2016] Prior to grainsize analysis, organic matter was removed using 9% hydrogen peroxide until fizzing ceased. Samples were then dried and weighed to obtain a total dry weight. They were then deflocculated for at least 4 hours (using Calgon 5 g per litre) and wet-sieved on a stack of sieves (500, 250, 125 and 63 µm). Each fraction was dried, weighed and calculated as a percentage of the total weight. The fraction less than 63 µm was calculated by subtraction of all other dry weights from the initial dry weight. Sediment % weight was then expressed for coarse sand (> 500 µm), medium sand (250–499 µm), fine sand (125–249 µm), very fine sand (63–124 µm) and mud (< 63 µm). Sampling in Whangateau initially used the sampling protocol in the ecological monitoring programmes conducted in Manukau, Mahurangi and Central and Upper Waitemata Harbours. In these programmes, very fine sand and fine sand were not separated, but three additional fractions were calculated: % gravel (> 2 mm); and the mud component was separated by pipette analysis into % silt (4–63 µm) and % clay (< 3.9 µm). However, from 2011, samples have been analysed as above. [Hewitt & Simpson 2012]

[12] Consent monitoring data. This was assigned the wet sieving methodology in the dataset as grains > 2000 µm were analysed

Variable	Laboratory analysis [information source]
Metals	Dry weight by ICPMS – USEPA 200.8 (Modified) [Watercare Laboratory Sampling Number MON-005477 Keri Keri 2008] Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2. [Hill Laboratories Report Number 627385 Porirua 2008] Nitric / hydrochloric acid digestion, ICP-MS (Low level). US EPA 200.2 [Hill Laboratories Report Number 439846 Waikouaiti 2006, Madarasz 2006] Dried sample, < 2 mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2 [Hill Laboratories Report Number 618099 Kaikorai 2007] Dried sample, < 2 mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2 [Hill Laboratories Report Number 618099 Kaikorai 2007] Dry/sieve sample, Digestion US EPA 200.2. Air dry 35°C/2mm sieve Nitric/HCl acid digestion, ICP-MS [Smith 2009] Dried sample, < 2 mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level [Hill Laboratories Report Number 1248339 Waimea 2014] USEPA 200.2 Digestion / ICP-MS [Cawthron Laboratory Report Number S84798 Tauranga 2011] Perchloric/nitric acid digestion and flame atomic absorption spectrometry (ASTM 3974 Digestion Practice A; AOAC 1995 950.46 modified) [Robertson et al. 2002, Gillespie & Clark 2007] Chemical analysis was performed on total recoverable acid digested < 500 µm dry sieved fractions for all metals [Hewitt & Simpson 2012]

Variable	Laboratory analysis [information source]
Total organic carbon	Acid pretreatment to remove carbonates if present, neutralisation, Elementar Combustion Analyser. [Boffa Miskell Limited 2014] Acid pretreatment to remove carbonates if present, Elementar Combustion Analyser. [Hill Laboratories Report Number 1248339 Waimea 2014, Hill Laboratory Report Number 1401330 Havelock, 2015] Sediments were dried and finely ground, then analysed for total organic carbon content using an automated CHN analyser. Samples were pre-treated with acid to remove carbonate material prior to analysis [Needham et al. 2014] (Report only until 2011 but assume the same analysis used from 2012 onwards.)
Ash-free dry weight	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 21st ed. 2005. [Hill Laboratories Report Number 627385 Porirua 2008] Ignition in muffle furnace 550°C, 1hr, gravimetric. (Also called Volatile Matter or Ash Free Dry Weight) APHA 2540 G 20th ed. 1998 [Hill Laboratories Report Number 439846 Waikouaiti 2006, Madarasz 2006] APHA 21st Edn 2540 D+ E (Mod) [Cawthron Laboratory Report number S84798 Tauranga 2011, Smith 2009] APHA 20th Edn 2540D+ E (Mod) [Madarasz 2006] Weight loss from dry sediment after combustion at 550°C (APHA 1999, 20th Edn, modified 2540D + E) [Robertson et al. 2002] Approximately 5 g of sediment is placed in a dry, pre-weighed tray. The sample is then dried at 60°C until a constant weight is achieved (the sample is weighed after ~ 40 h and then again after 48 h). The sample is then ashed for 5.5 h at 400°C (Mook and Hoskin 1982) and then reweighed. [Halliday et al. 2012]
Total phosphorus	Dry Weight by ICP-MS – USEPA 200.8 (Modified) [Watercare Laboratory Sampling Number MON-005477 Keri Keri 2008]

Variable	Laboratory analysis [information source]
Total phosphorus, cont.	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. USEPA 200.2. [Hill Laboratories Report Number 627385 Porirua 2008] Nitric / hydrochloric acid digestion, ICP-MS. US EPA 200.2 [Hill Laboratories Report Number 439846 Waikouaiti 2006, Madarasz 2006] Dried sample, < 2 mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2 [Hill Laboratories Report Number 618099 Kaikorai 2007] ICP-MS Aqua Regia Digest [Gillespie & Clark 2007] USEPA 200.2 Digestion / ICP-MS [Cawthron Laboratory Report Number S84798 Tauranga 2011] Colourimetric (APHA, 20th Edn. 1999, Method 4500-P. A, B, E) [Robertson et al. 2002]
Total Kjeldahl nitrogen	Distillation, colourimetric (APHA, 19th Edn. 1995, Method 4500-N Org C) [Robertson et al. 2002]
Total nitrogen	IN HOUSE [Watercare Laboratory Sampling Number MON-005477 Keri Keri 2008] Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]. [Hill Laboratories Report Number 627385 Porirua 2008, Smith 2009, Madarasz 2006] Catalytic Combustion, separation, Thermal Conductivity Detector [Elementar Analyser]. [Hill Laboratories Report Number 1248339 Waimea 2014] APHA 21st Edn 4500N C [Cawthron Laboratory Report Number S84798 Tauranga 2011]

Variable	Laboratory analysis [information source]
Total nitrogen, cont	Sediments were dried and finely ground, then analysed for total nitrogen content using an automated CHN analyser [Needham et al. 2014] (Report only until 2011 but assume the same analysis used from 2012 onwards.) APHA 20th Edn 4500N C [Gillespie & Clark 2007]

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