State of the Hawke's Bay Coastal Marine Environment:

2013 to 2018

April 2020
Hawkes Bay Regional Council Publication No. 5425

HAWKES BAY REGIONAL COUNCIL
TE KAUNIHERA Ā-ROHE O TE MATAU-A-MĀUI

ISSN 2703-2051 (Online)
ISSN 2703-2043 (Print)

Version

(06) 835 9200
0800 108 838
Private Bag 6006 Napier 4142
159 Dalton Street . Napier 4110

Environmental Science

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Prepared By:

Anna Madarasz-Smith, Principal Scientist/Team Lead, Marine and Coast
Becky Shanahan, Scientist, Marine and Coast

Reviewed By:

Anna Berthelsen – Marine Scientist – Cawthron Institute

Jeff Smith – Manager – Environmental Science

Signed:

Approved By:

Iain Maxwell – Group Manager – Integrated Catchment Management

HBRC Environmental Science Section is ISO 9001:2015 certified

ISSN 2703-2051 (Online)
ISSN 2703-2043 (Print)

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Executive summary

Hawke's Bay's coastal environments are subject to the combined pressures of activities occurring both on land and in the ocean, and are the cumulative receiving environment for the land and freshwater drainage network. This report provides analysis of the state of the environment monitoring undertaken by Hawke's Bay Regional Council (HBRC) within the Coastal Marine Environment. The aim of this report is to describe how the coastal environment is responding to these pressures. This is the second comprehensive report of the coastal monitoring network, and builds on the information obtained in the 2016 document (Wade et al., 2016).

The following report provides an analysis and summary of water quality, estuarine, sandy beach and intertidal reef ecology data up to, and including, 2018.

The objectives of the report are to:

- Describe the current state (5 years 2013-2018) of indicators of environmental health in our coastal marine environment;
- Describe what this information is telling us about the state and health of the coast using appropriate guidelines and contextual information;
- Describe whether these indicators are showing improvement or declines in environmental health; and
- Provide recommendations for further work needed to gain better understanding about land-based impacts on the coastal environment.

The report outlines the state and trends of Hawke's Bay.

Coastal Waters (section 2)

Many of the attributes that can describe the quality of coastal waters in Hawke's Bay are within levels observed elsewhere in New Zealand. Exceptions to this include sediment in estuarine waters, and water quality adjacent to Awatoto. Hawke's Bay estuaries appear to have high median turbidity levels compared to other national sites, likely due to the highly erodible nature of Hawke's Bay landscapes, the current land use, and flood events which can transport large quantities of sediments to regional estuaries and nearshore.

The waters offshore of Awatoto have the highest median levels of total nitrogen in the region, which exceed ANZECC guidelines for marine waters. This data does however fall below the levels observed at other New Zealand coastal sites. The accompanying high levels of chlorophyll *a* at this site, indicates that these nutrients are contributing to higher localised primary production. Levels of chlorophyll *a* at this site exceed the ANZECC guidelines, and fall on the national median for open coast waters.

Dissolved oxygen levels from HAWQi monitoring instruments show that dissolved oxygen levels can drop to <6 mg/L. These levels are consistent with those observed in the 'oxygen depleted' Firth of Thames, and is an area for further investigation. This finding demonstrates the value of high frequency monitoring as these dissolved oxygen levels were not observed in discrete water quality sampling. HAWQi instrumentation also detected the marine heatwave in the summer of 2017/2018.

Estuaries (section 3) and Estuarine Fish (section 4)

Sediment stress is one of the key issues observed through estuarine state of the environment monitoring. Moderate sediment stress was observed at sites in mid Ahuriri Estuary, with higher levels of sediment stress observed at other regional estuarine sites. Median levels of 'mud' in the lower and upper Ahuriri, the

Pōrangahau, Waitangi, Tukituki and Wairoa Estuaries exceed published literature for mud content thresholds (<25% mud content) that support healthy, diverse communities. Median mud content for the Waitangi and upper Ahuriri exceed 60%. At these sites, sensitive species are largely absent, and this can compromise the integrity and resilience of the estuary, as well as reducing its value for other species such as birds and fish.

Sediments at Ahuriri, Waitangi and Tukituki Estuary may be enriched with Phosphorus, and further work is required to understand potential impacts.

Sandy Beaches (section 5)

Macrofauna inhabiting beach systems is largely depauperate, which limits the potential use of this data for determining trends in health. These areas contain significant resources that contribute to the diet of many fish species, and so documenting our soft sediment biodiversity is critical to sustainable management and contributes to our understanding of regional indigenous fauna.

Sensitive areas such as sand dunes appear to be under pressure from animal pests, and improvements in the state and health of these habitats may be possible with improvements in pest management.

Intertidal Reefs (section 6)

Intertidal reef systems throughout Hawke's Bay are highly diverse, and spatially explicit. Within each site and tidal level however, a high level of stability is apparent. Similarity in the community structure appears to have reduced in the summer period of 2018. A corresponding marine heatwave is likely to have resulted in significant temperature stress for intertidal communities which may help to explain the changes in community structure observed at this time.

Seagrass beds are increasing in the southern Hawke's Bay coast, and although the cause of the increase is largely unknown, continued monitoring will enable tracking of these important habitats.

Going Forward:

Several areas of investigation are recommended including increasing our understanding of:

- The anthropogenic and natural sources of high phosphorus in the Ahuriri Estuary.
- Source apportionment for coastal waters of Awatoto.
- The spatial extent and magnitude of dissolved oxygen depletion in coastal waters.
- The spatial extent of mud and nutrients in regional estuaries.
- The potential impacts of phosphorus enrichment in regional estuaries.
- Biotic indices for estuaries (e.g. Benthic Health Model, Traits Based Index etc).
- Vehicular traffic and plastics in sandy beach systems.
- The full extent and health of seagrass (*Zostera muelleri*) beds in Hawke's Bay, including in the Pōrangahau Estuary.
- Subtidal habitats, including description of structure, and moving towards assessments of their current health.

1 The Hawke's Bay Marine and Coastal Area

The Hawke's Bay coastline stretches 353km from Mahanga on the Mahia Peninsula in the north, to Whangaehu beach in the south. The coastline supports a diverse range of habitats underpinned by the geology of the region. In the south, coastal cliffs, sandy beaches, extensive dune systems and rock platforms characterise the coastline between Cape Turnagain and Cape Kidnappers. River mouths, estuaries, gravel beaches and herb fields typify coastal habitats between Te Awanga and Tangoio. To the north of Tangoio steep cliffs and associated rocky reefs extend up to the Waikari River mouth. Between the Waikari River and Nuhaka River mouths the coastline is typified by low-lying dunes and sand and gravel beaches. In the far north of the region the Mahia Peninsula has large sandy beaches, extensive dune systems and expansive rock platforms.

Intertidal areas of the Hawke's Bay are dominated by firm sandy beaches (48%), rock/boulder field and rocky reef (42%) and gravel fields (8%; Stevens and Robertson, 2005). These intertidal habitats give rise to vast coastal cliffs (35%) and dune land (22%). The majority of land beyond the mean high water spring (MHWS) has been modified from its original state over the past few hundred years.

The land and river network of Hawke's Bay drains into the numerous large estuaries of Pōrangahau, Waitangi, Ahuriri, Wairoa and Maungawhio. Many smaller systems wind through catchments to make their way to the coast delivering sediments and nutrients to the coastal area. Although these systems comprise a small percentage of the overall coastal area, they make an important ecological contribution.

The subtidal area of the Coastal Marine Environment (CME) covers an area of 701,372 hectares. This includes a variety of habitats including the 'foul ground' of the Wairoa and Clive Hard's, the large rocky reef areas including Bull Rock, Portland Island and Long Point of Mahia Peninsula, the extensive hard substrate of Pania Reef, Black Reef, the Hinemahanga Rocks and the inshore reef systems between Aramoana and Paoanio Point (Figure 1-1). Further offshore deeper reef and sandbank habitats lie within the Lachlan Ridge, southwest of Mahia.

Many areas of significant conservation value are identified within the Hawke's Bay Regional Coastal Environment Plan (see Figure A-1).

1.1 Biogeography

The waters of Hawke's Bay are influenced by two major oceanic currents. The Wairarapa Coastal Current (WCC) transports relatively cool and fresh water northwards along the coast inshore of the relatively warmer and more saline southward flowing East Cape Current (ECC). Water temperatures on the northern side of the Mahia Peninsula in northern Hawke's Bay, outside the sphere of influence of the WCC, can be several degrees higher than those in the south of the region, influencing the marine species found in these areas. Water temperatures can vary widely, between approximately 10°C in winter and 24°C in summer (Section 2.4.1).

The highly erodible landscapes of Hawke's Bay have defined, and continue to influence, the Hawke's Bay marine environment. With land clearance over the last 200 years, sediments have become a major stressor on the coastal and marine habitats of Hawke's Bay. The water within Hawke Bay itself is heavily influenced by riverine inputs and is often stratified and turbid. This high degree of turbidity is caused by a combination of silt-laden riverine inputs and sediment re-suspension.

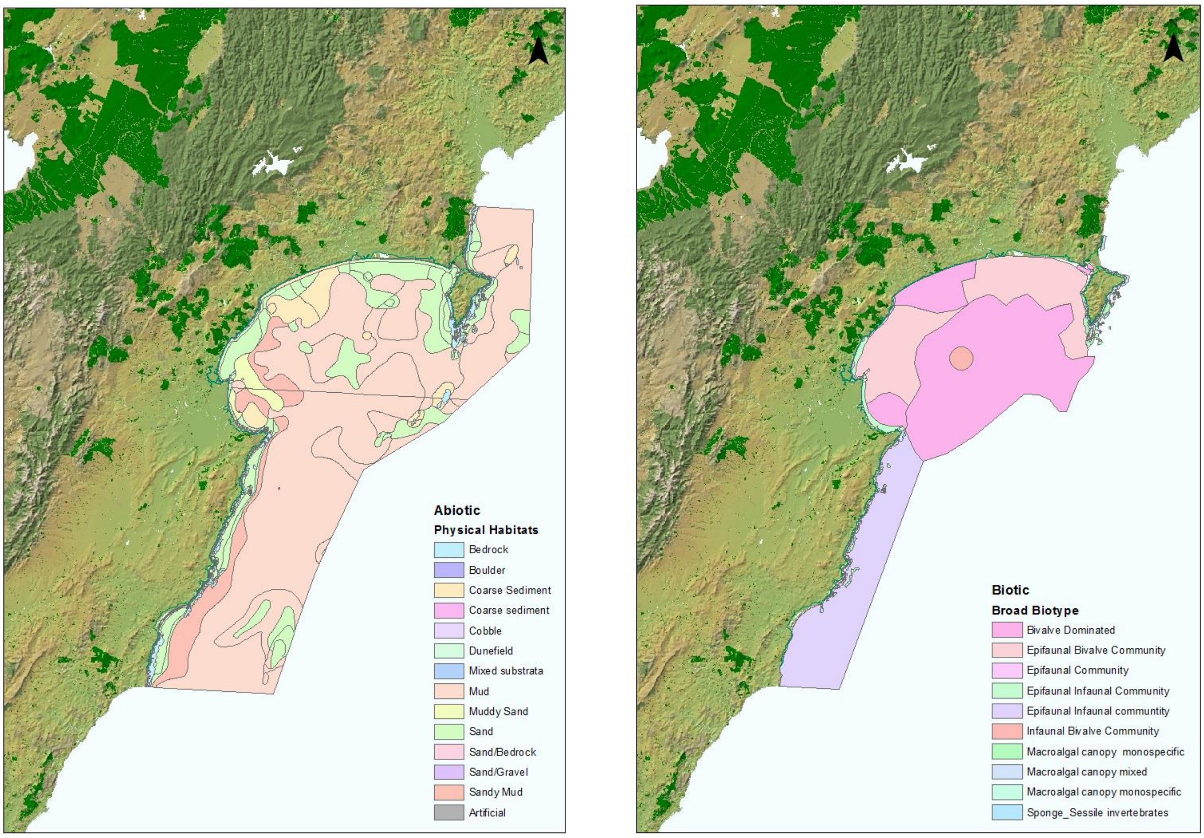


Figure 1-1: The major abiotic and biotic features of the Hawke's Bay Coastal Marine Area. Maps sourced from(Haggit and Wade, 2016).

1.2 Threats and Pressures

The coastal environment is the receiving environment for any land-based activities that may affect the water quality of rivers. Of the approximately 19.7 billion m^3 of rainfall that Hawke's Bay receives each year, it is estimated that 11 billion m^3 makes it way to the Hawke's Bay coastal waters (lawa.org.nz). This has the potential to deliver sediment, nutrients and other contaminants to the nearshore waters. Different areas within the CME have different levels of risk involved with these threats. Estuaries with long residence times are likely to be more at risk from the threats associated with increased nutrient loadings than the near-shore marine environment, where dilution mitigates many of the potential impacts.

One of the largest threats to the marine habitat is sedimentation. Hawke's Bay is particularly susceptible to high levels of sedimentation with highly erodible landscapes, loss of land cover, and typically localised and heavy rainfall. Many of Hawke's Bay's rivers are channelized, and the natural barriers to sediment have been removed. It has been estimated that the main Hawke's Bay rivers contribute 11 million tonnes of sediment per year to the CME (Hicks et al., 2011). High degrees of sedimentation can result in smothering of habitats, mortality of fauna through gill abrasion, and less abundant flora through reduced light levels.

Hawke's Bay's rivers also transport large volumes of nutrients to the CME. At certain times of the year these nutrient loads can augment nutrients naturally available in the coastal waters and promote blooms of phytoplankton and diatoms. While these algal blooms are natural processes that produce oxygen and sequester carbon, changes to the spatial and temporal extent may be due to land based inputs of fuel (nutrients). If the blooms occur on a large scale, they can smother organisms and cause oxygen depletion in the water column as they die off and decompose.

The focal points of coastal urban development occur within the city of Napier, although coastal towns such as Wairoa, and communities such as Mahia and Pōrangahau can also contribute discharges related to infrastructure into the coastal marine area (CMA)[1]. Two municipal ocean outfalls occur in the CMA adjacent to Napier and Clive, and into the lower Wairoa and Pōrangahau Rivers. Other diffuse inputs can occur from overwhelmed or under maintained septic tank systems which may impact water quality within the local area.

From the marine area itself, the arrival and growth of exotic species can fundamentally alter a system's community structure and function. Over 150 exotic species are already in New Zealand coastal waters (NIWA, 2002), often introduced as biofouling, or in the ballast water of marine vessels. The invasive kelp *Undaria pinnatifida,* is now widespread in the Hardinge Road/Napier Port area.

At a global scale, the Hawke's Bay coastal area is also threatened by changes associated with climate change. Ocean acidification and warming, sea level rise and increased storminess can all have deleterious effects on the marine environment.

Hawke's Bay Regional Council is responsible for promoting the sustainable management of the CMA. The framework for the protection, management and use of coastal resources is set in the Regional Coastal Environment Plan (RCEP, Hawke's Bay Regional Council, 2014). This plan gives effect to the RMA and the NZCPS at a regional level. A key requirement of the RCEP is for the Council to monitor specific aspects of the CMA in order to provide the information required to assess Council's effectiveness in managing resource use to achieve sustainability, as well as contributing to the information required as the basis for sound environmental management.

In order to provide information to support decision making, and to monitor the effects of activities on the coastal marine area, HBRC operates marine and coast state of the environment monitoring programmes. The following report is a synthesis of the programmes, their analyses and findings.

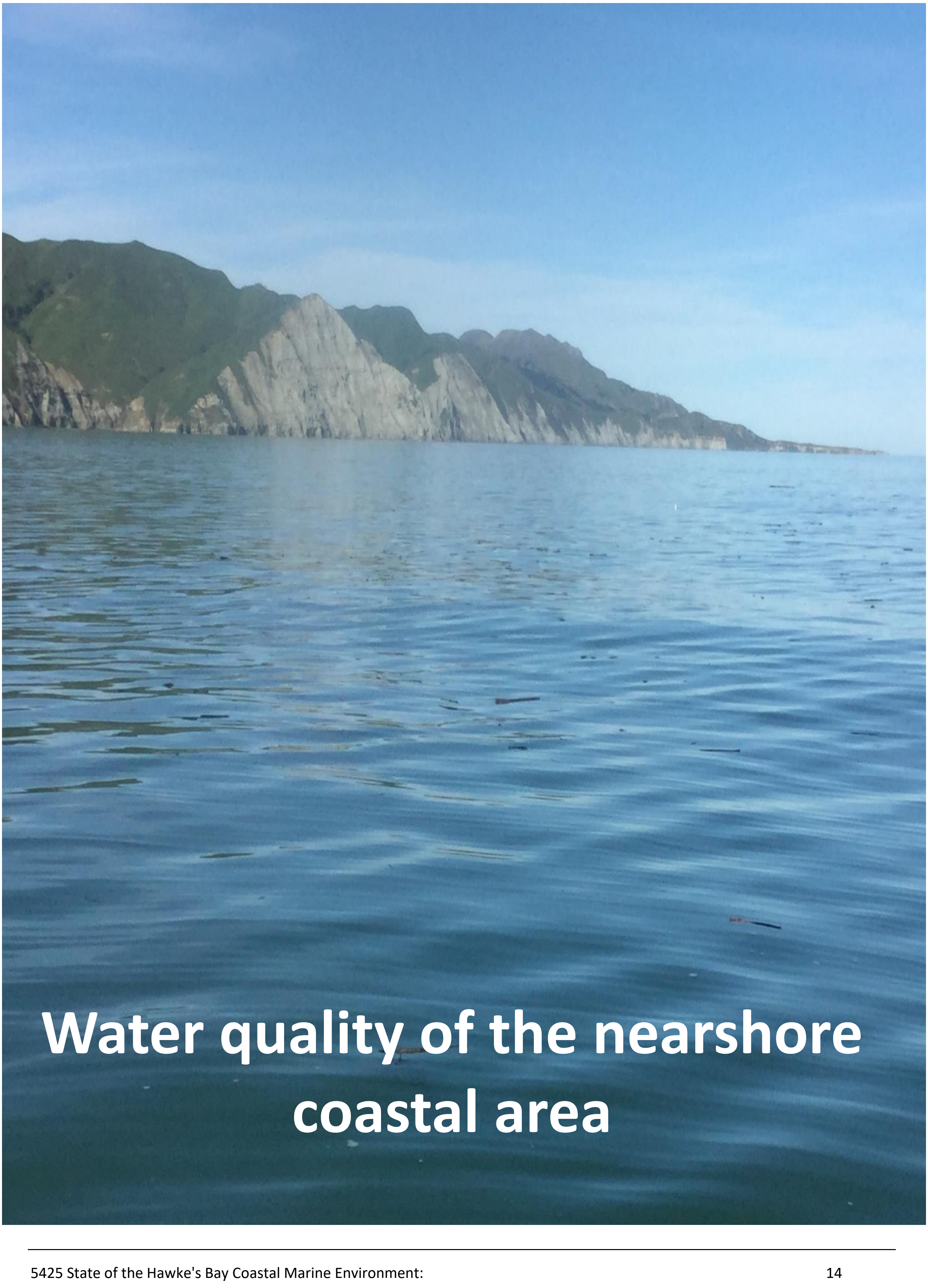
1.3 Objectives

The following report provides detailed technical information of the marine and coastal data collected by Hawke's Bay Regional Council. The report provides an analysis and summary of water quality, estuarine, sandy beach and intertidal reef ecology data up to, and including, 2018.

The objectives of the report are to:

- Describe the current state (5 years 2013-2018) of indicators of environmental health in our coastal marine environment;
- Describe what this information is telling us about the state and health of the coast using appropriate guidelines and contextual information;
- Describe whether these indicators are showing improvement or declines in environmental health; and
- Provide recommendations for further work needed to gain better understanding about land-based impacts on the coastal environment.

[1] The Coastal Marine Area (CMA) refers to the area between the Mean High Water Spring (the average point at which a spring high tide reaches) and the 12 nautical mile limit of the territorial sea. The Coastal Marine Environment (CME) refers to the area that can influence, or be influenced by the sea and includes the coastal margin area.



Water quality of the nearshore coastal area

2 Water Quality of the Nearshore Coastal Area

The coastal inshore waters of Hawke's Bay provide for a range of biological, social, economic and recreational activities. However, these areas are also the receiving environment for almost all land-based activities via the freshwater drainage network, and are therefore susceptible to water quality issues. In Hawke's Bay, large river systems contribute to the direct transport of pollutants to the nearshore coastal environment, and therefore monitoring coastal water quality is vital to ensuring that key functions and services remain intact.

2.1 Methods

Estuaries

Estuarine water quality monitoring has been undertaken since 2013 for the Mohaka, Waitangi, Ahuriri, and Tukituki Estuaries. More recently all estuaries have been brought into the Rivers State of the Environment Monitoring network to enable 'source to sink' assessment of water quality. Due to the different timeframes of data available for different estuaries, state assessments in this section have been made on standardised data length from November 2016 to June 2018. No trend analyses have been undertaken due to the short period of data collection even for some of the earlier sites.

Monthly samples were collected using the methods described for freshwater state of the environment river quality monitoring (*see* Hicks, 2019). Laboratory detection limits are detailed in Table B-1.

Nearshore

Water quality monitoring in the nearshore coastal area has been carried out by Hawke's Bay Regional Council since 2006 as part of the State of the Environment (SOE) programme. This SOE monitoring programme is undertaken on a six weekly basis (two samples per season). Six weekly sampling has occurred at seven sites between Ocean Beach and Mohaka since 2006, and was extended into north Hawke Bay in 2012 (Figure 2-1).

Hawke's Bay Regional Council also operates a coastal monitoring platform (HAWQi – **HA**wke's Bay **W**ater **Q**uality **i**nformation) which provides continuous measurements of water quality parameters including conductivity, temperature, dissolved oxygen, turbidity, chlorophyll *a* and current speed and direction. This platform is located approximately 5km east of Tangoio Bluff (Figure 2-1), and runs a series of Seabird™ and Wetlab™ instruments throughout the water column. These provide telemetered results through to the Hawke's Bay Regional Council servers at hourly intervals.

HAWQi Instruments and data recovery

Hawke's Bay Regional Council also operates a coastal monitoring platform (HAWQi – **HA**wke's Bay **W**ater **Q**uality **i**nformation) which provides continuous measurements of water quality parameters including conductivity, temperature, dissolved oxygen, turbidity, chlorophyll *a* and current speed and direction. This platform is located approximately 5km east of Tangoio Bluff (Figure 2-1), and runs a series of Seabird™ and Wetlab™ instruments throughout the water column. These provide telemetered results through to the Hawke's Bay Regional Council servers at hourly intervals.

Data is transmitted from deeper instruments via an inductive cable, which eliminates the requirement for easily damaged cables. These data are transmitted to the controller, developed by Monterey Bay Aquarium Research Institute (MBARI), and provided to HBRC from MBARI for this project. Data is transmitted back to HBRC via UHF radio telemetry, and is integrated with the HBRC time-series data management system (HydroTel and Hilltop). When there was sufficient data to test for trends over time, the method in section 2.1.3 was used.

All data collection and analyses were undertaken in accordance with internal quality assurance and quality control processes and procedures.

Figure 2-1: Estuarine, nearshore and HAWQi water quality monitoring sites in Hawke's Bay

2.1.1 Water quality guidelines relevant to the Nearshore Coastal Area

Environmental guidelines are often used to describe the general state of a natural resource, and typically how modified waters may have become. In New Zealand water quality guidelines for estuarine and nearshore coastal waters are lacking, likely due to a paucity of data in this area until approximately 10 years ago. During the development of the ANZECC guidelines (ANZECC, 2000), the NZ river network was used to define guidelines for upland and lowland rivers and streams in NZ. The guidelines recognised at this time that the equivalent data was not available for NZ coastal waters, and recommended further work be undertaken to develop this. The guidelines recommended that until this occurred, consideration could be given to the use of the South-Eastern Australian guidelines outlined in the document.

The preferred approach for developing a guideline or trigger value with which to contextualise the impacts humans may have had on the aquatic environment, is to provide either baseline data of measurements taken prior to disturbance occurring, or to provide a comparison to a ‘reference’ area which can be considered ‘undisturbed’ (ANZECC, 2000). Both of these approaches are problematic for the Hawke’s Bay estuarine and nearshore waters, as the long history of modification makes a baseline comparison impossible, and the wide spread modification of the landscape means that a suitable reference area is not available.

Recent work has identified the issues with trying to compare water quality within large biogeographical areas in New Zealand with varying catchments and hydrology (Madarasz-Smith, raw data), and therefore use of the South-Eastern Australian estuarine and marine water quality guidelines is not without risk. However some work has been undertaken to look at developing regional specific standards (Griffiths, 2016), trigger levels (Madarasz-Smith, 2018), and objectives for estuarine and coastal waters (Sea Change, 2016).

Where appropriate, estuarine and coastal waters of Hawke’s Bay are compared to information held for other sites in New Zealand using reference documents, including those described above, to provide some context as to the approximate level of impact.

State and trends of coastal waters in New Zealand was described in Dudley and Jones-Todd (2018). These data have been used to provide context to the results obtained for Hawkes’ Bay coastal water quality. Data from Dudley and Jones-Todd (2018) was queried, and 5- year medians for New Zealand hydrosystems described (Table 2-1).

Table 2-1: New Zealand coastal water quality medians by hydrosystem type from Dudley and Jones-Todd (2018)
SIDE = Shallow Intertidal Dominated Estuary, SSRTRE = Shallow, Short Residence Tidal River Estuary.

Parameter	Estuarine Trophic Index (ETI) Class					
	SIDE		SSRTRE		Open Coast	
	n=	5 year Median	*n=*	5 year Median	*n=*	5 year Median
Chlorophyll *a* (mg/L)	10394	0.00145	1313	0.00125	5256	0.00150
Dissolved oxygen (mg/L)	11615	7.95	3143	8.12	8000	7.94
Dissolved Reactive Phosphorus (mg/L)	11428	0.01205	2013	0.01088	5788	0.01200
Enterococci (cfu/100mL)	14545	5.3	2750	6.0	20238	5.2
Faecal Coliforms (cfu/100mL)	13467	8.0	2773	9.2	18097	8.0
Ammoniacal Nitrogen (mg/L)	12259	0.01894	2465	0.01894	5933	0.01801
Nitrate + Nitrite Nitrogen	11711	0.02000	2130	0.02060	5268	0.01997
pH	11791	8.06	4321	8.09	14414	8.07
Salinity (ppt)	7157	32.8	1663	32.9	8472	32.8
Suspended Sediment (mg/L)	4623	12	2088	11.1	9375	12.0
Temperature (^oC)	15137	16.6	5466	16.3	24410	16.6
Total Nitrogen (mg/L)	3782	0.20326	1840	0.21750	5051	0.20250
Total Phosphorus (mg/L)	5689	0.02988	2038	0.02841	5800	0.02985
Turbidity (NTU)	5920	5.10	4083	5.00	6713	5.02

2.1.2 Data summaries and visualisation

Box plots have been used throughout Section 2 to summarise water quality data for data collected between November 2016 and June 2018 for estuarine water quality, and for the five-year period between July 2013 and June 2018 for nearshore sites. A five-year period is used to describe 'current' state, however where this is not available a shorter period has been described (e.g. estuaries). Box plots graph data as a box representing statistical values. The lower boundary of each box indicates the 25th percentile, a line within the box marks the median, and the higher boundary of each box indicates the 75th percentile. The line at the end of the whiskers (error bars) above and below the box indicate the 90th and 10th percentiles respectively.

The sites are ordered from left to right in order from the most northerly to the most southerly site.

2.1.3 Trend analyses

Trend analysis of environmental monitoring data can highlight areas for further investigation to determine whether a trend is resulting in adverse environmental effects (e.g. crossing an ecological threshold), and/or whether the trend is driven by anthropogenic causes which could be minimised through management.

Trend analyses in this section use non-parametric statistical approaches which involve seasonal Kendall trend tests (Jowett, 2019). Trend testing has been conducted for nearshore water quality and HAWQi data, which have appropriate temporal coverage to do so. No trend testing has been conducted for estuarine sites as temporal coverage is insufficient. An assessment of trend was made using seasonal Kendall test and slope analysis, using all values in each of the four specified 'seasons'. January was used as the 'start' month, i.e. the seasons were: Jan-Mar; Apr-Jun, Jul-Sep; Oct-Dec, as this best described the seasonality observed in the data.

The seasonal Kendall tests help to identify whether variability in the data is randomly distributed, or whether a significant trend exists over time. For example, did most of the higher ranked values occur in the last few years, or did higher values occur randomly over time? A 'significant' trend existed where there was a less than 5% probability that the observed trend was obtained by chance ($P<0.05$).

To estimate the strength of trends over time, a Theil-Sen slope estimator was used. The non-parametric Theil-Sen slope estimator estimates the median slope amongst lines through all pairs of points in the dataset. This approach is effective at estimating the true slope in water quality data series because it is less sensitive to outliers.

The values derived from the Theil-Sen slope estimator are referred to as "Percent Annual Change" (PAC). A trend in PAC was considered meaningful if the PAC was greater than 1% of the median per year.

In all tables that present trend results, a significant result is presented in bold. Given a significant trend for a particular variable, the PAC is highlighted in blue if there was a significant improvement in the water quality variable and highlighted in red if there was a significant deterioration in the water quality variable. Any trend that is not associated on its own with an improvement or deterioration is highlighted grey and discussed further.

2.2 Results - Estuarine Water Quality

Estuaries are the first point of the cumulative discharges of the freshwater system. As wetlands, estuaries are areas that can process nutrients through uptake and transformation. They work to protect coastal marine waters from the effects of land based activities. The ability of an estuary to process inputs without expressing adverse effects will depend on several factors including estuary type, the current state and health of the estuary, as well as the level of contaminants that enter the estuary (Bricker et al., 2003). Hawke's Bay estuaries are defined as one of two hydrosystem types. Shallow Intertidal Dominated Estuaries (SIDE) such as Ahuriri Estuary, Maungawhio Lagoon and Pōrangahau Estuary, and Shallow, Short Residence Tidal River Estuaries (SSRTRE) such as Wairoa, Waitangi and Tukituki Estuaries.

SIDE estuaries typically have a higher residence time than SSRTRE estuaries, and therefore may be more susceptible to land based influences.

2.2.1 Sediments in estuarine waters

Sediments can be transported into the estuary from land, and from the banks and beds of streams as water flows over them. As water enters estuaries from the turbulent water that has entrained them, they can either settle out in the calmer waters and become part of the substrate (see section 3.3.1), or can remain in the water column making the estuarine water turbid and lowering visibility for predators, and light penetration for photosynthesis.

Suspended sediment is the measure of the weight of sediment retained after filtering a known quantity of water, whereas turbidity is a measure of the optical properties of light passed through a water sample. These measurements may also be affected by phyto and zooplankton living in the water column.

Both suspended sediment concentrations and turbidity levels in Hawke's Bay estuaries show the influence of episodic events such as rainfall related peaks in levels in estuarine waters (Figure 2-2). Pōrangahau Estuary had the highest 75th and 90th percentile for suspended sediments indicating that at times, this estuary can be subjected to some of the highest delivery of sediments in the region. However, the highest median levels were observed at Waitangi Estuary which had consistently high results and less flashiness in the data, indicating consistent high levels of sediment delivery. Wairoa Estuary also had high peaks in suspended sediments which were likely during flood events.

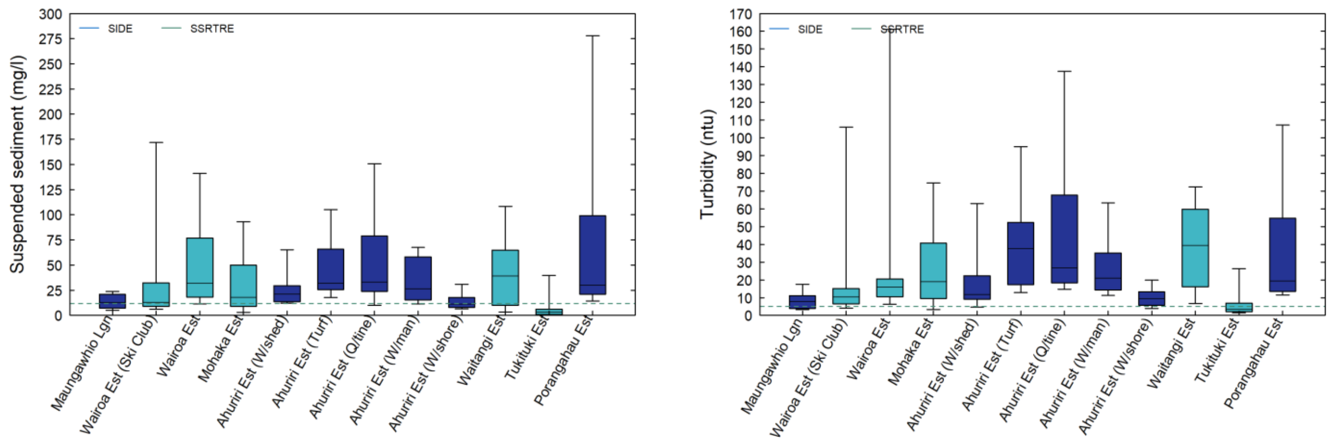


Figure 2-2: Suspended sediment and turbidity levels for Hawke's Bay estuaries Nov-16 to June-18 (*n=19*). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

The highest median turbidity levels were observed at the Waitangi Estuary and the Ahuriri site opposite Quarantine Rd. In general most Hawke's Bay estuarine sites exceeded median levels of turbidity observed at other national sites (Dudley and Jones-Todd, 2018).

2.2.2 Nutrients in estuarine waters

Healthy estuarine systems are able to filter nutrients, which are essential for organic production. They are able to assimilate large quantities of nutrients which are incorporated in plant material, cycled, released and exported. As discussed above, the ability of an estuary to assimilate nutrients will depend on the hydrosystem type, quantity of nutrients delivered and antecedent health of the estuary. For example, an estuary with extensive and healthy bivalve beds can filter high volumes of water therefore reducing the potential impacts of high phytoplankton levels. If this balance is tipped then estuaries can show symptoms of eutrophication, which can include nuisance algal growth, phytoplankton blooms, reduced dissolved oxygen levels and high levels of total organic carbon.

Typically, nitrogen is considered a limiting nutrient in estuarine systems, although nutrient limitation does transition between the freshwater (where phosphorus is most often limiting) to the open ocean (where nitrogen amongst other micronutrients are most limiting). Previous work in Hawke's Bay river and estuary systems has shown that nutrient limitation is often varied, and at many times, unlimited (Haidekker et al., 2016).

Levels of total nitrogen (Figure 2-3) are highest at the Ahuriri Estuary upstream sites (see Figure 2-1; Ahuriri Est Turf to Ahuriri Est (W/man)), and Tukituki Estuary. Similarly to the pattern observed for sediments, Pōrangahau Estuary has a moderate median level of total nitrogen, but a larger spread of data between the 50th and 90th percentiles. This indicates higher levels of total nitrogen at the top end of the data compared to other estuarine sites. Given that this also occurs with turbidity, it is likely that this may be associated with flood events.

Total phosphorus levels are again highest at the Ahuriri upstream sites and Pōrangahau, although the difference between Ahuriri and Pōrangahau is much greater (Figure 2-3).

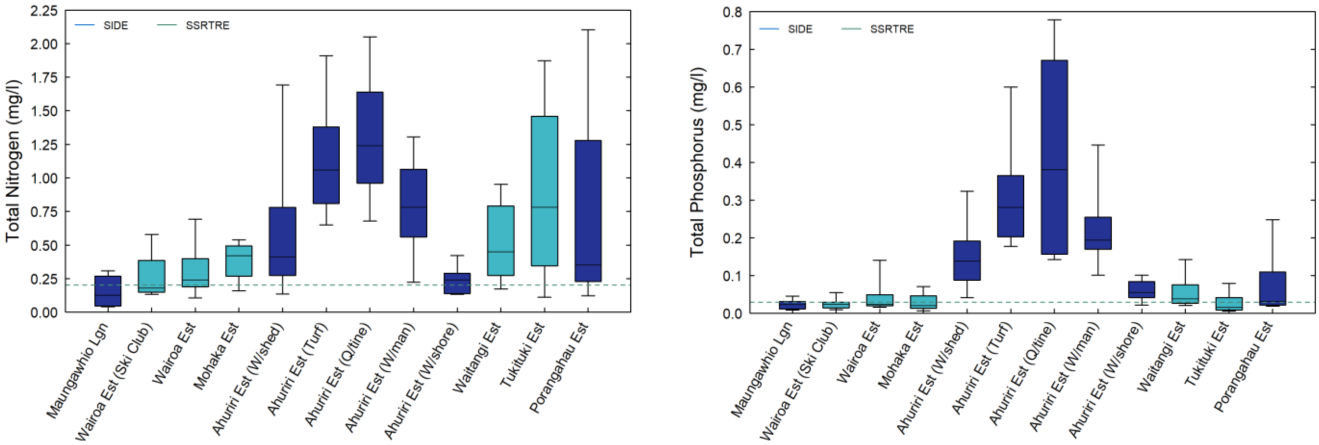


Figure 2-3: Total Nitrogen and Total Phosphorus levels for Hawke's Bay estuaries Nov-16 to June-18 (*n=19*). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Levels of dissolved inorganic nitrogen do not conform to the patterns observed in total nitrogen for estuarine water quality (Figure 2-4). Whereas levels of total nitrogen were highest in the Ahuriri, Tukituki and Pōrangahau Estuary sites, this pattern is not consistent with that for dissolved inorganic nitrogen. This would suggest that for the Ahuriri and Pōrangahau sites a considerable portion of the total nitrogen is made up of organic nitrogen (e.g. urea, amino acids, peptides, proteins etc and dead organic material). This is not the case for Tukituki Estuary which shows a similar pattern between both the total and dissolved nutrient fraction, indicating that the majority of the nitrogen at this site is in the inorganic form.

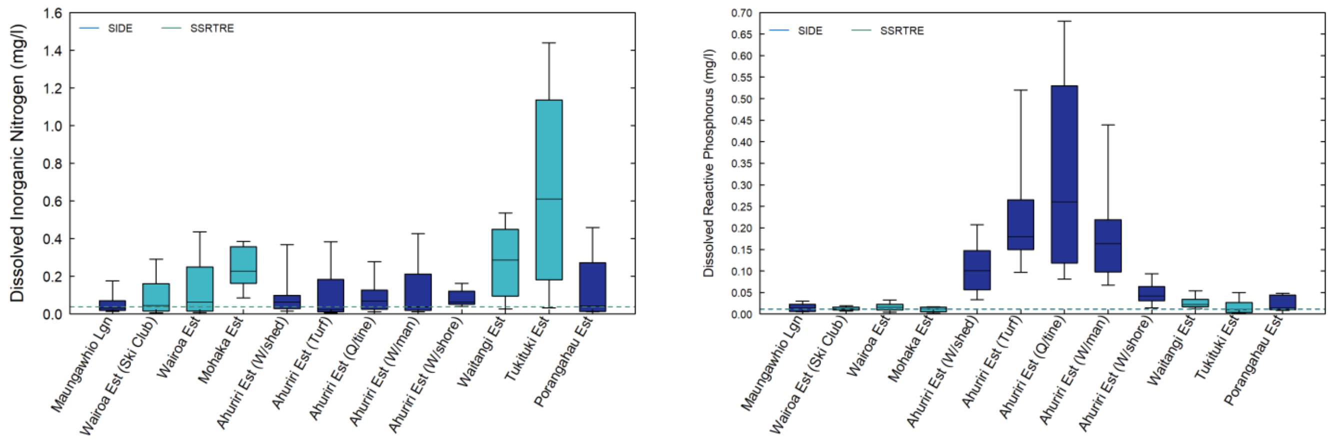


Figure 2-4: Dissolved Inorganic Nitrogen (DIN) and Dissolved Reactive Phosphorus (DRP) levels for Hawke's Bay estuaries Nov-16 to June-18 (*n=19*). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Dissolved reactive phosphorus levels in Hawke's Bay estuaries show similar patterns and levels to total phosphorus levels, indicating that the majority of phosphorus at these sites is in the dissolved form. Ahuriri Estuary has the highest levels of both total and dissolved reactive phosphorus compared to other regional estuaries, indicating either a natural source from the historic marine geology of this area, or anthropogenic sources. Further work needs to be undertaken to apportion natural and anthropogenic sources of phosphorus in this catchment.

Trends at Ahuriri Estuary Westshore Bridge (Ahuriri Est (W/shore)

As discussed in 2.1.3, temporal coverage for the majority of estuarine water quality sites is currently insufficient to conduct trend analyses. The exception to this is Ahuriri Estuary at Westshore Bridge which was initially included in the Nearshore Coastal Water Quality Programme and therefore has approximately 12 years of data. Trend analyses for this site indicated statistically significant reductions in total nutrient forms for both nitrogen and phosphorus (Table 2-2). This aligns with some of the other reductions observed in the nearshore waters for these nutrients (Table 2-4).

Table 2-2: Trend analyses for Ahuriri Estuary at Westshore site over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Parameter	n	Median	Trend	Percent Annual Change
Suspended Sediment (mg/L)	93	10.00	0.065	-4.050
Turbidity (NTU)	86	6.080	0.305	-1.479
Total Nitrogen (mg/L)	78	0.201	**0.000**	**-7.521**
Total Phosphorus (mg/L)	93	0.049	**0.000**	**-6.529**
Dissolved Inorganic Nitrogen (mg/L)	93	0.048	0.831	-0.356
Dissolved Reactive Phosphorus (mg/L)	94	0.032	0.026	-3.859

2.3 Results - Nearshore Water Quality

2.3.1 Sediments in the nearshore waters (Suspended sediment and Turbidity)

Suspended sediment and turbidity are measures used to provide information on the amount of light that can penetrate the water column. These can be used to determine water clarity, as well as provide information on the amount of fine sediment that is being delivered to the marine environment from either the erosion of land, or the resuspension of seabed sediments. Light penetration in marine waters can determine the depth at which species such as macroalgae are able to establish. If light penetration is low, organisms that photosynthesise will not be able to obtain energy from the sun and the food web will be interrupted.

Figure 2-5: Satellite imagery showing the influence of rain on turbidity in the CMA. Left prior to Cyclone Pam, right, after Cyclone Pam (March 2015).

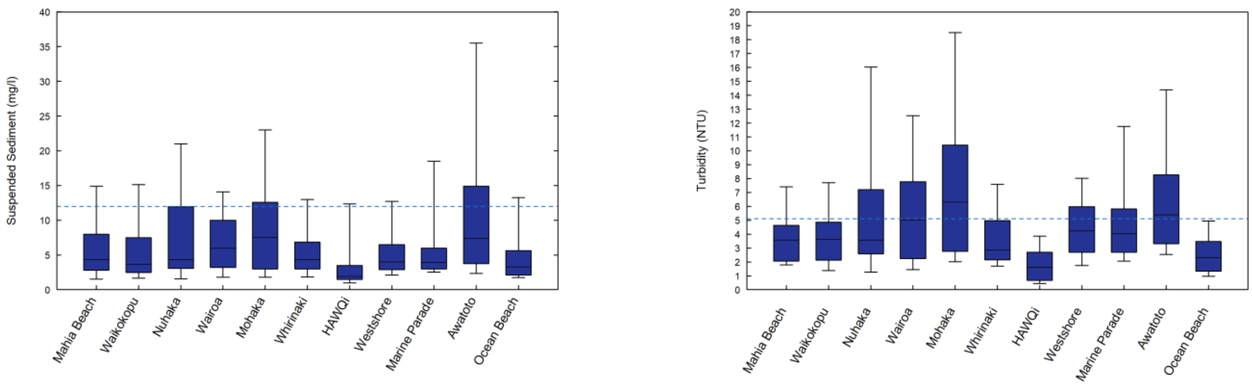


Figure 2-6: Suspended sediment and turbidity at nearshore water quality monitoring sites (2013-2018). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Blue dashed line indicates NZ median for open coast sites from (Dudley, B. and Jones-Todd, C., 2018).

State

Median suspended sediment levels at nearshore water quality monitoring sites were well within the range observed in other New Zealand open coast sites (Dudley and Jones-Todd, 2018; Griffiths, 2016). However, peaks in suspended sediment levels are noticeable between the 75th and 90th percentiles (i.e. from the top of the box to the top of the whisker) and were outside the range observed in other NZ sites. This confirms the influence of large riverine inputs in peak rainfall periods observed in Hawke's Bay.

Awatoto site had the highest 75th and 90th percentiles which is to be expected, given that this site is directly influenced by the two municipal sewerage outfalls, and three major river systems: the Tūtaekurī, the Ngaruroro and the Tukituki, as well as the smaller Karamu system.

Turbidity shows similar patterns to suspended sediments, with median levels similar to other open coast and SIDE estuaries in NZ. Interestingly, Mohaka has the highest levels of turbidity, which is similar to the data reported for the 2009-2013 SOE period (Wade et al., 2016).

Trends

No trends were observed in suspended sediment levels over the monitoring period, however an improving trend was observed in turbidity at the Whirinaki site (Table 2-3). This contrasts with the findings of the previous reporting period where no trend at this site was observed.

Table 2-3: Trend analyses of suspended sediment (mg/L) and Turbidity (NTU) at nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Suspended Solids (mg/L)				Turbidity (NTU)			
	n	Median	Trend p value	Percent Annual Change	n	Median	Trend p value	Percent Annual Change
Mahia	45	4.0	0.768	-1.235	44	3.17	0.618	-1.918
Waikokopu	49	4.0	0.552	-7.328	47	2.98	0.832	-0.769
Nuhaka	47	4.1	0.972	0.000	45	3.48	0.457	6.200
Wairoa	47	5.5	0.060	10.799	46	4.10	0.128	9.210
Mohaka	95	7.3	0.673	0.000	86	5.45	0.328	1.721
Whirinaki	94	5.0	0.612	0.000	87	3.23	**0.019**	**-5.499**
HAWQi	41	1.8	0.591	-2.954	36	1.60	0.279	-12.121
Westshore	95	4.6	0.940	0.000	86	4.11	0.865	-0.387
Marine Parade	95	4.2	0.625	-0.434	90	3.90	0.137	3.188
Awatoto	96	7.0	0.912	0.000	89	5.37	0.869	0.313
Ocean Beach	96	3.4	0.940	0.000	87	2.18	0.680	-1.220

Visual analysis of the plotted data did not highlight the presence of a trend (Figure 2-7), and therefore an ordinary least squares regression (OLS) and generalised least squares (GLS) was undertaken to provide further information on this. Both returned non-significant results ($p = 0.2838$, $R^2 = 0.0135$ and $p = 0.3981$, $R^2 = 0\ 0135$ respectively), suggesting that the non-parametric Mann-Kendall was not the best test to use in this instance.

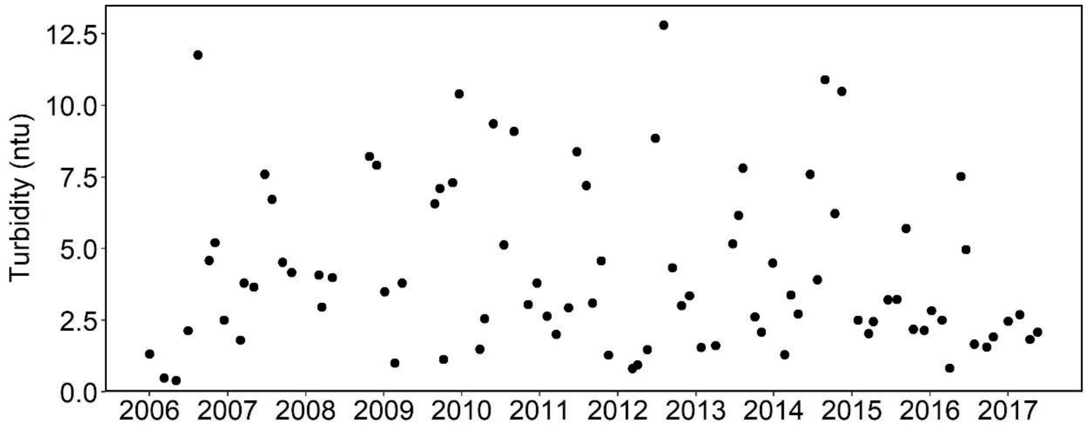


Figure 2-7: Turbidity (NTU) data from Whirinaki nearshore water quality monitoring site between 2006 and 2018.

2.3.2 Nutrients in the nearshore waters

The nutrients Nitrogen (N) and Phosphorus (P) can influence the health of the community structure found in nearshore coastal waters. As with sediments, nitrogen and phosphorus can be added to the marine environment through transport from land based activities and geological weathering. Additionally, waters can rise to the nearshore surface through a process of upwelling, which can supply cooler, nutrient rich water to surface, replacing warmer, nutrient poor waters.

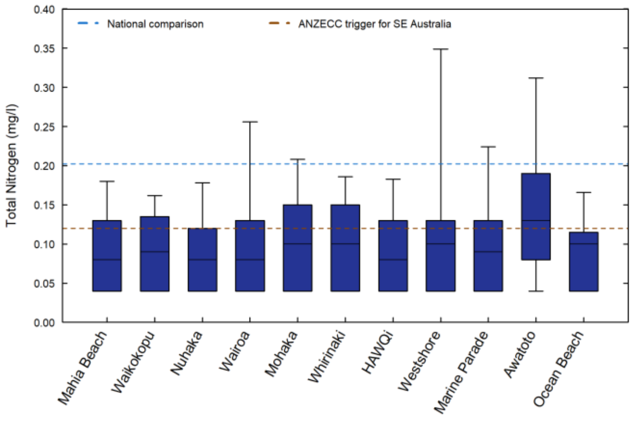
As with rivers, lakes and estuaries, the addition of nutrients into coastal waters can fuel the growth of marine plants. Specifically, at times phytoplankton can grow in abundance when sufficient nutrients are present. Most algae require certain ratios of different nutrients for optimal growth so when one of these nutrients is not present in sufficient quantities, growth is 'limited' by that nutrient.

In most marine systems, nitrogen (specifically nitrate) tends to be the limiting nutrient (i.e. there is not enough nitrogen in the water to support further algal growth). Therefore the addition of nitrogen into nitrogen limited systems can 'fuel' algal growth.

Total Nutrients State

Levels of total nitrogen are consistent with those observed in other New Zealand open coast sites (Figure 2-8). Awatoto site reported the highest median level of total nitrogen, and exceeds ANZECC guidelines for open coast sites (0.12mg/L), however this may not represent an ecological meaningful result due to those considerations described in section 2.1.1. This site is directly influenced by the two municipal sewerage outfalls, and three major river systems: the Tūtaekurī, the Ngaruroro and the Tukituki, as well as the smaller Karamu system.

Levels of total phosphorus appear low when compared to those observed in other New Zealand open coast sites. Median levels of total phosphorus for Hawke's Bay marine sites are between 0.009 and 0.017 mg/L, compared with the median reported for all NZ open coast sites of approximately 0.03 mg/L (Dudley and Jones-Todd, 2018).



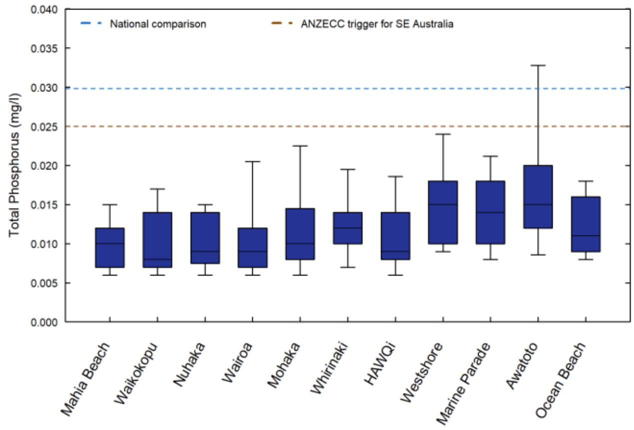


Figure 2-8: Total nitrogen and total phosphorus levels at nearshore water quality monitoring sites (2013-2018). Blue dashed line indicates NZ median for open coast sites (Dudley and Jones-Todd, 2018), orange dashed line indicates ANZECC default guideline for South-East Australia (ANZECC, 2000)

Total Nutrients Trends

An improving trend in total nitrogen was observed at the Marine Parade site, and five of the 12 nearshore monitoring sites reported improving trends for total phosphorus (Table 2-4). The reduction in suspended sediment observed at the Whirinaki site (see 2.3.1), aligns well with the observed reduction in total phosphorus and is likely to have influenced this trend, as total phosphorous is often bound to sediment.

Table 2-4: Trend analyses of Total Nitrogen (mg/L) and Total Phosphorus (mg/L) at nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Total Nitrogen (mg/L)				Total Phosphorus (mg/L)			
	n	Median	Trend p value	Percent Annual Change	n	Median	Trend p value	Percent Annual Change
Mahia	36	0.080	0.876	0.000	45	0.010	0.391	-2.512
Waikokopu	40	0.090	0.430	0.000	49	0.009	0.052	-5.719
Nuhaka	38	0.080	0.642	0.000	46	0.010	0.396	-3.458
Wairoa	38	0.085	0.621	0.000	47	0.010	0.574	2.001
Mohaka	71	0.094	0.833	0.000	94	0.012	**0.010**	**-4.042**
Whirinaki	68	0.100	0.713	0.000	96	0.013	**0.031**	**-2.865**
HAWQi	34	0.080	0.318	0.000	41	0.010	0.213	-9.801
Westshore	75	0.100	0.259	-1.236	97	0.017	**0.016**	**-2.708**
Marine Parade	73	0.110	**0.035**	**-5.736**	90	0.014	0.271	-1.210
Awatoto	75	0.140	0.487	-1.404	96	0.016	0.082	-2.518
Ocean Beach	75	0.100	0.146	-1.964	97	0.013	**0.001**	**-3.269**

Dissolved Nutrients State

Dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) are two of the most bioavailable forms of nutrients available for plant growth. Addition of these nutrient forms are the most likely to result in increased algal growth.

The majority of Hawke's Bay open coast sites had levels of dissolved inorganic nitrogen below the median levels observed nationally (Figure 2-9). The Mohaka, Awatoto and Ocean Beach sites exceed ANZECC trigger levels for dissolved inorganic nitrogen (SE Australia).

All open coast sites had median levels of dissolved reactive phosphorus well below the ANZECC guidelines default trigger levels of 0.010 mg/L, and well below those recorded nationally.

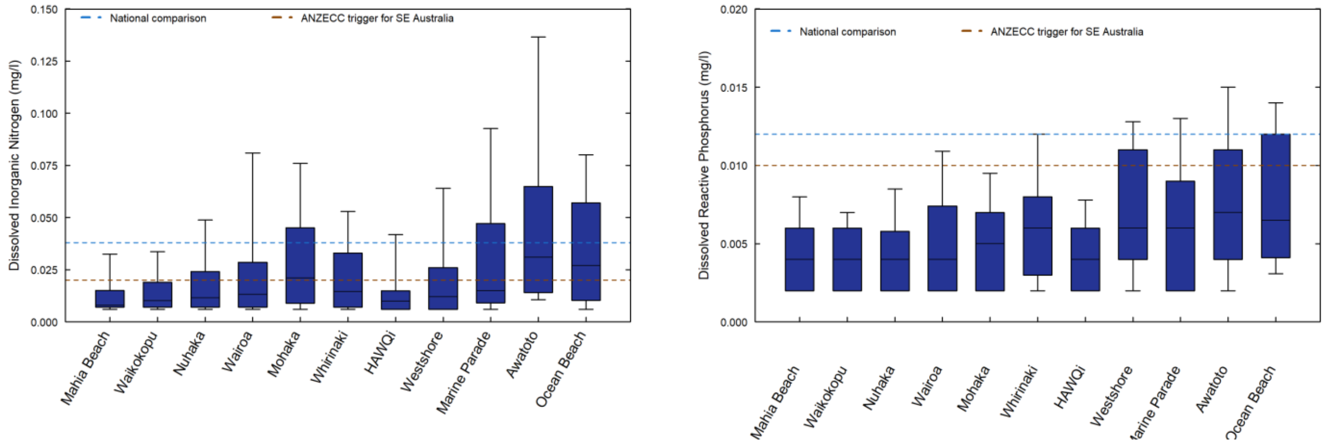


Figure 2-9: Dissolved Inorganic Nitrogen and Dissolved Reactive Phosphorus levels at nearshore sites (2013-2018). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Blue dashed line indicates NZ median for open coast sites (Dudley and Jones-Todd, 2018), orange dashed line indicates ANZECC default guideline for South-East Australia (ANZECC, 2000).

Dissolved Nutrients Trends

Decreasing levels of dissolved inorganic nitrogen were observed at Ocean Beach, while an increasing trend was observed in dissolved reactive phosphorus for Wairoa (Table 2-5).

Table 2-5: Trend analyses of Dissolved Inorganic Nitrogen (mg/L) and Dissolved Real Phosphorus (mg/L) at nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Dissolved Inorganic Nitrogen (DIN mg/L)				Dissolved Reactive Phosphorus (DRP mg/L)			
	n	Median	Trend p value	Percent Annual Change	n	Median	Trend p value	Percent Annual Change
Mahia	44	0.008	0.603	-1.526	45	0.004	0.164	0.000
Waikokopu	48	0.010	0.484	3.609	49	0.004	0.459	0.000
Nuhaka	46	0.010	0.572	-2.234	45	0.004	0.185	0.000
Wairoa	46	0.010	0.381	5.307	47	0.004	**0.002**	**6.615**
Mohaka	95	0.017	0.872	0.000	95	0.004	0.734	0.000
Whirinaki	96	0.140	0.096	-2.032	96	0.005	0.675	0.000
HAWQi	41	0.010	0.061	-10.062	41	0.004	0.700	0.000
Westshore	97	0.012	0.248	-1.124	97	0.006	0.323	0.000
Marine Parade	96	0.017	0.405	-0.790	90	0.005	0.184	0.000
Awatoto	97	0.028	0.808	-0.384	97	0.005	0.071	0.000
Ocean Beach	97	0.029	**0.007**	**-3.538**	97	0.008	0.228	0.000

2.3.3 Productivity in the nearshore waters (Chlorophyll *a* and Dissolved oxygen)

Whether the nutrients described in the previous chapter result in growth of small algae (phytoplankton) can be measured by looking that the Chlorophyll *a* concentrations in the water column. Chlorophyll *a* is the green pigment found in plants and cyanobacteria that absorbs light to provide energy through photosynthesis. A healthy system requires sufficient levels of phytoplankton to underpin the food chain (energy from light transforms into energy through to higher trophic levels). However when a system has an excess of nutrients, these levels can grow into a 'bloom'. Blooms may be naturally induced (e.g. through ocean upwelling), or induced through anthropogenic influences of nutrients.

Hawke's Bay open coast levels of Chlorophyll *a* are generally within ANZECC default guideline values for SE Australia (Figure 2-10). ANZECC guidelines describe marine waters with median levels less than 0.001mg/L (1.0 mg/m^3) as low risk of eutrophication, and this is consistent with other national (Dudley and Jones-Todd, 2018), and international sources (Bricker et al., 2003, 1999; Swedish EPA, 2002).

Three Hawke's Bay open coast sites exceed these levels; Westshore, Marine Parade and Awatoto. These sites also experienced higher levels of dissolved inorganic nitrogen (see above) which may be acting to drive local elevations in Chlorophyll *a* concentrations. That said, levels are still within those described as 'slight' risk of eutrophication (Swedish EPA, 2002), and within the levels observed in national open coast sites (Dudley and Jones-Todd, 2018).

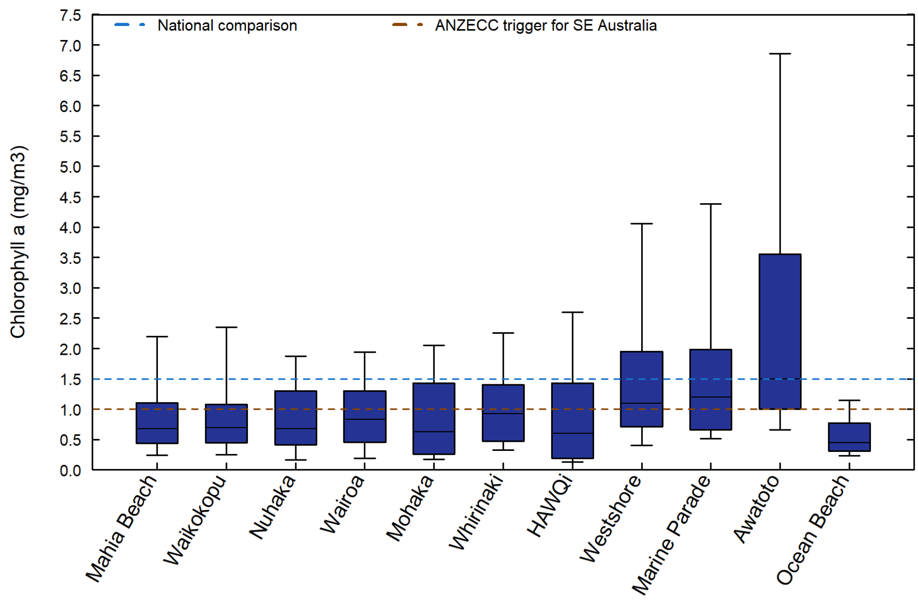


Figure 2-10: Chlorophyll *a* levels at nearshore water quality sites (2013-2018). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Blue dashed line indicates NZ median for open coast sites (Dudley and Jones-Todd, 2018), orange dashed line indicates ANZECC default guideline for South-East Australia (ANZECC, 2000)

No trends were observed in Chlorophyll *a* levels over time (Table 2-6).

Table 2-6: Trend analyses of Chlorophyll a (mg/m^3) at nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**.

Site	n	Chlorophyll a (mg/m3)		
		Median	Trend p value	Percent Annual Change
Mahia	43	0.62	0.842	-1.476
Waikokopu	47	0.69	0.548	-2.057
Nuhaka	45	0.63	0.650	-3.737
Wairoa	45	0.75	0.164	5.142
Mohaka	89	0.78	0.084	-3.462
Whirinaki	88	0.66	0.780	0.530
HAWQi	37	0.59	0.495	2.593
Westshore	93	1.10	0.887	0.000
Marine Parade	91	1.10	0.613	0.979
Awatoto	92	1.40	0.440	1.742
Ocean Beach	90	0.48	0.128	-2.158

Dissolved oxygen

Dissolved oxygen is the amount of oxygen within the water column available for marine organisms to exchange gases across gill structures. As with land based animals, most marine organisms require oxygen to function and a lack of oxygen (hypoxia) or an absence of oxygen (anoxia) can have lethal effects.

Dissolved oxygen levels in marine waters are generally stable due to the well flushed, dynamic nature of these open coastal areas. However if large quantities of organic material enters the system either through natural (e.g. algal blooms) or anthropogenic sources (e.g. sewerage outfalls), the excess microbial activity that takes place then consumes vast quantities of oxygen and can lead to hypoxic or anoxic events. These can become more prevalent when waters are stratified, and the exchange between bottom waters and the atmosphere is limited.

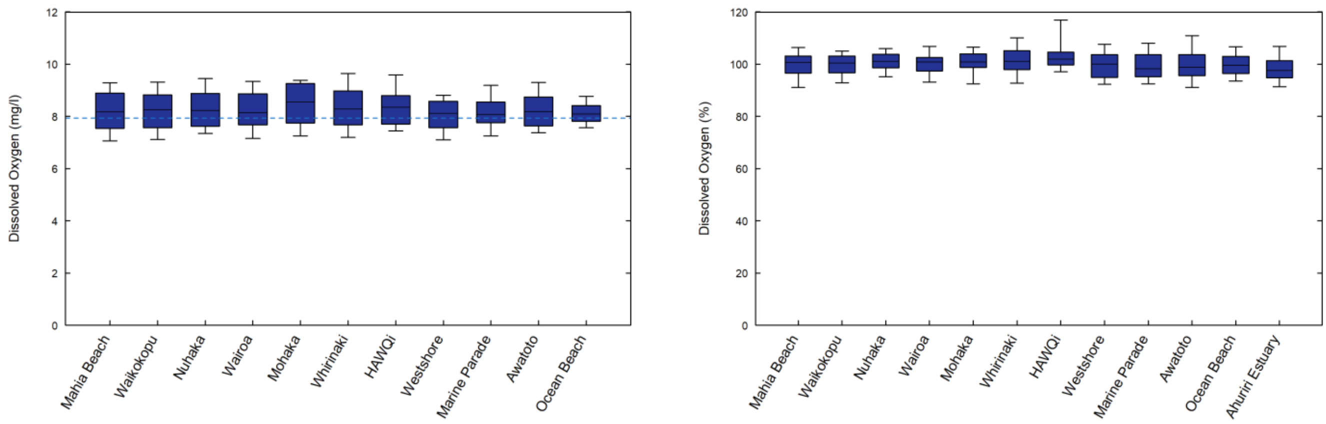


Figure 2-11: Dissolved oxygen levels (mg/L and % saturation) at nearshore sites (2013-2018). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Blue dashed line indicates NZ median for open coast sites (Dudley and Jones-Todd, 2018).

Median levels of dissolved oxygen generally fall around 8mg/L and 100% saturation (Figure 2-11). This relates to a healthy level for both marine and estuarine waters, and would indicate that coastal waters are neither over-producing, nor over-consuming oxygen. Dissolved oxygen concentrations greater than 8.0 mg/L are typically capable of supporting the full range of aquatic organisms (Davies-Colley et al., 2013)

Dissolved oxygen levels were analysed to determine any long term trends within sites (Table 2-7). Westshore reported a statistically significant increase in dissolved oxygen saturation over the monitoring period. Given that this site has the lowest median level (although still healthy) for open coast sites, this is a positive trend.

Table 2-7: Trend analyses of Dissolved oxygen (mg/L and % saturation) at nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Dissolved oxygen (mg/L)				Dissolved oxygen saturation (%)			
	n	Median	Trend p value	Percent Annual Change	n	Median	Trend p value	Percent Annual Change
Mahia	45	8.12	0.441	-1.335	45	100.6	0.187	-0.712
Waikokopu	49	8.03	0.338	-0.872	49	100.5	0.075	-0.658
Nuhaka	47	8.15	0.184	-0.679	47	101.0	0.221	-0.497
Wairoa	46	8.10	0.944	-0.245	46	100.5	0.305	-0.733
Mohaka	90	8.51	0.790	-0.121	90	100.5	0.273	0.200
Whirinaki	88	8.36	0.762	-0.132	87	100.3	0.062	0.510
HAWQi	41	8.34	0.345	-0.862	41	101.8	0.345	-0.484
Westshore	89	8.26	0.200	-0.448	87	99.2	**0.036**	**0.501**
Marine Parade	88	8.31	0.119	-0.565	88	99.5	0.954	0.000
Awatoto	90	8.45	0.295	-0.362	88	100.05	0.944	0.045
Ocean Beach	89	8.17	0.203	-0.282	86	99.3	0.171	0.274

2.3.4 Faecal contaminants in the nearshore waters

At times coastal water quality can contain faecal material that has make its way in to estuaries and coastal waters through rivers, streams or direct discharges such as sewerage outfalls. The presence of faecal bacteria (enterococci and faecal coliforms) is monitored as indicators of faecal contamination. Monitoring for the purposes of recreational activities is outlined in Madarasz-Smith et al. (2019). The nearshore coastal waters are also monitored for these indicators to provide information on potential faecal contamination at a distance from the immediate coastline. This provides additional context for freshwater inputs into coastal environments and provides information on other sources (e.g. vessels discharging) that may require further regulation should an issue be observed.

Enterococci and faecal coliform levels are generally low, however peak events are evidenced by the large distance between the 75th percentile and the 90th percentile (top of the box and the top of the whisker; Figure 2-12). This highlights the influence that large rain events may have on contaminant delivery to the coast. The Awatoto site has high levels of enterococci and faecal coliforms compared to the other open coastal sites, and this is likely to reflect the two municipal sewerage outfalls, and the river mouths adjacent to this location.

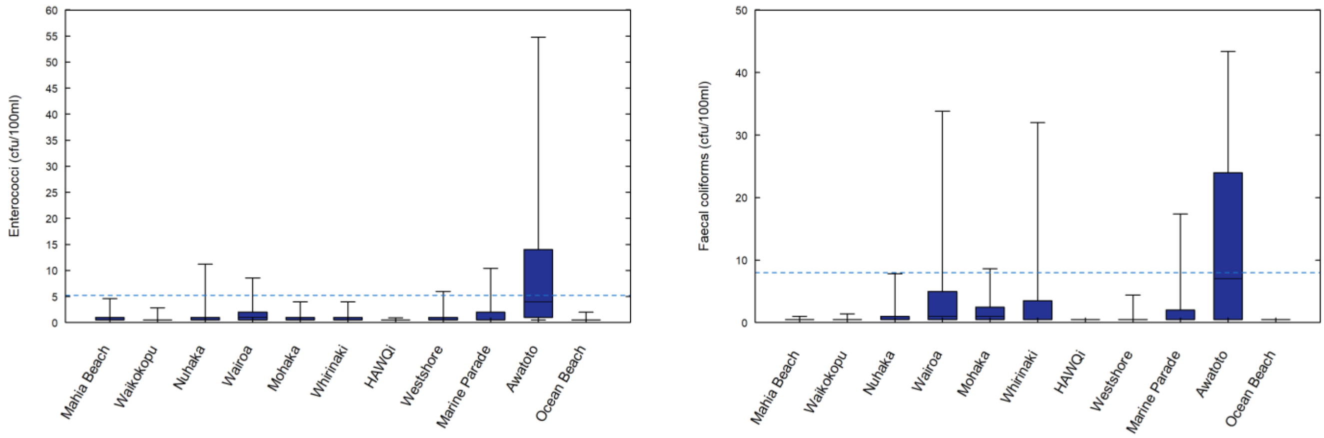


Figure 2-12: Enterococci and Faecal coliform levels (cfu/100ml) at nearshore coastal sites (2013-2018). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Blue dashed line indicates NZ median for open coast sites (Dudley and Jones-Todd, 2018).

No trends were observed for faecal contaminants in the nearshore waters (Table 2-8).

Table 2-8: Trend analyses of Enterococci and Faecal coliforms in nearshore water quality sites over the monitoring period. Statistically significant trends are indicated in **bold**.

Site	n	Enterococci (cfu/100mL)			n	Faecal coliforms (cfu/100mL)		
		Median	Trend p value	Percent Annual Change		Median	Trend p value	Percent Annual Change
Mahia	44	0.5	0.755	0.000	44	0.5	0.865	0.000
Waikokopu	48	0.5	0.782	0.000	48	0.5	1.000	0.000
Nuhaka	46	0.5	0.394	0.000	46	0.5	0.789	0.000
Wairoa	45	1.0	0.033	0.000	46	1.0	0.108	0.000
Mohaka	90	0.5	1.000	0.000	93	1.0	0.145	0.000
Whirinaki	92	0.5	0.988	0.000	95	1.0	0.145	0.000
HAWQi	40	0.5	0.596	0.000	40	1.0	0.066	0.000
Westshore	94	0.5	0.416	0.000	97	0.5	0.127	0.000
Marine Parade	97	0.5	0.872	0.000	97	0.5	0.035	0.000
Awatoto	94	4.5	0.969	0.000	97	7.0	0.318	0.000
Ocean Beach	93	0.5	0.407	0.000	97	0.5	0.006	0.000

2.4 Results - HAWQi Coastal Monitoring Platform

Since 2012, Hawke's Bay Regional Council has supplemented the nearshore coastal water quality monitoring programme with real-time telemetered date from the HAWQi (**HA**wke's Bay **W**ater **Q**uality **i**nformation) buoy. HAWQi provides HBRC with continuous, real-time, time-series data which provides context to "point-in-time" grab samples. These data also allow transient events such as algae blooms to be identified and monitored.

2.4.1 Temperature

Temperature data from HAWQi shows the strong seasonal influence, with peaks in water temperature occurring in approximately February each year, and lows in August (Figure 2-13). Over the last seven years the minimum temperature recorded was 10.1°C in 2013, and the highest temperature recorded was 24.4°C in 2018. The time-series data shows the marine heatwave experienced by Hawke's Bay in summer 2017/18. Unfortunately there is a gap in the data for the preceding summer which was also recorded by NIWA as a marine heatwave. Marine heatwaves are defined as periods of five or more days with temperatures greater than the 90th percentile for the last 30 years. These are expected to increase in frequency and possibly duration under climate change predictions (Oliver et al., 2018).

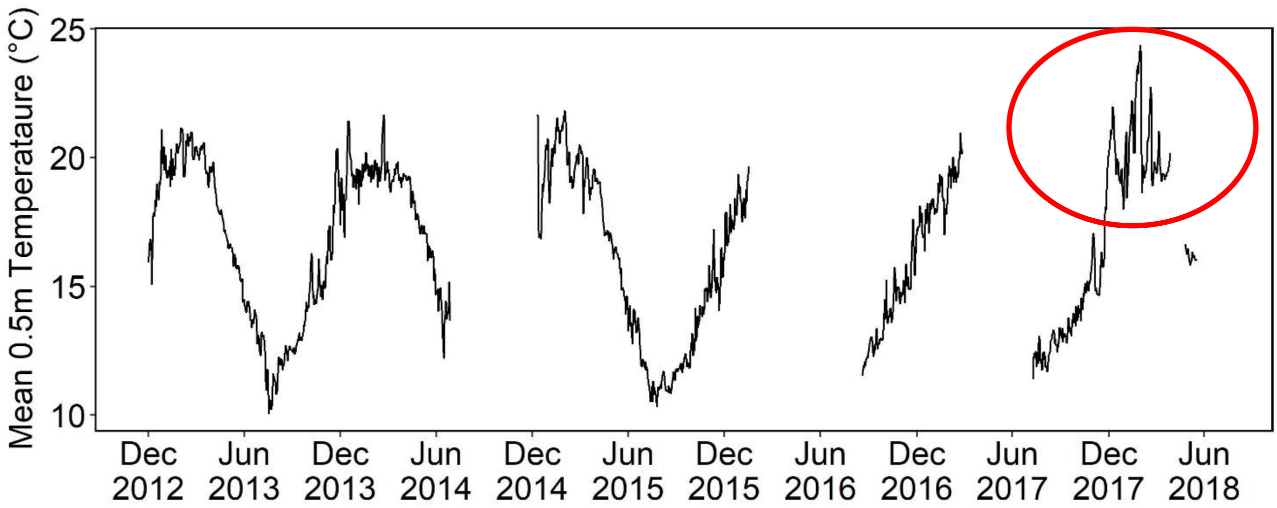


Figure 2-13: Temperature from 0.5m at HAWQi buoy between December 2012 and June 2018. Red circle denotes period of time defined as a marine heatwave.

2.4.2 Chlorophyll *a*

The lowest chlorophyll *a* concentration (0.046 mg/m^3) was observed in winter 2014 and the highest concentration (12.79 mg/m^3) in autumn 2014 (Figure 2-14). In Hawke's Bay, the highest chlorophyll *a* concentration is expected in spring and autumn, and lower concentrations in winter and summer (Knight and Jiang, 2014; Nodder et al., 2005). The drivers of these processes are complex, but increasing temperatures in the spring creates stratified layers, trapping the algae and nutrients at the surface supporting increased algal growth (Chiswell et al., 2013). Gaps in the data prevent a clear seasonal pattern in chlorophyll concentration. However, HAWQi recorded chlorophyll *a* concentration spikes in spring in 2013, 2015, and 2016 and one autumn spike in 2013. Other local processes not necessarily driven by season, such as increases in nutrients, can also lead to spikes in chlorophyll *a* concentration. Knight and Jiang (2014) used satellite observations, HAWQi and State of the Environment monitoring data to create a hindcast time series of chlorophyll *a* concentration in Hawke's Bay from 2002-2013. Analysis of that time series revealed a slight increase in chlorophyll *a* concentration.

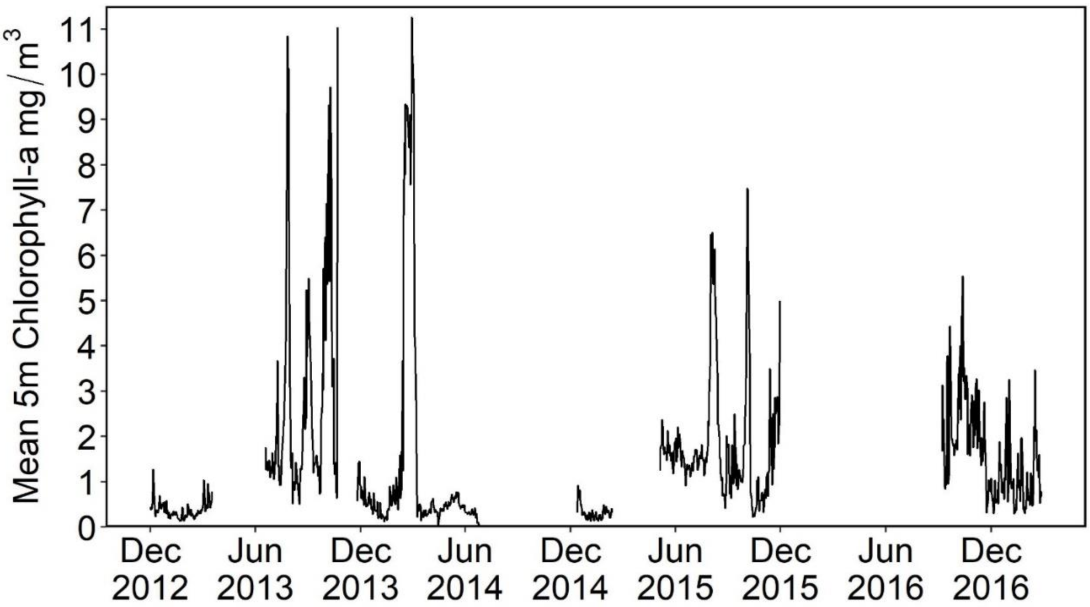


Figure 2-14: Chlorophyll *a* concentration from 5m HAWQi buoy between December 2012 and December 2016.

2.4.3 Dissolved oxygen

HAWQi recorded dissolved oxygen at two depths 5m and 15m between 2014 and 2018 (Figure 2-15). As expected, dissolved oxygen is higher at 5m compared to 15m due to regular aeration from oxygen in the surrounding atmosphere. Peak dissolved oxygen at 5m was 12.5 mg/L while peak dissolved oxygen at 15m was 10.0 mg/L. In well mixed water, dissolved oxygen through the water column is expected to be relatively similar. However, during an upwelling event, for example, low dissolved oxygen can be seen close to the surface (O'Callaghan, 2019). Alternatively, if stratification occurs in the water column from either temperature or salinity, deeper water will have lower dissolved oxygen without the aeration from surface waters. In extreme cases, this can lead to hypoxic (<2-3 mg/L) or anoxic (0 mg/L) water. At HAWQi, the minimum dissolved oxygen at 15m was 4.7 mg/L (recorded in 2018) and at 5m was 7.5 mg/L (recorded in 2017).

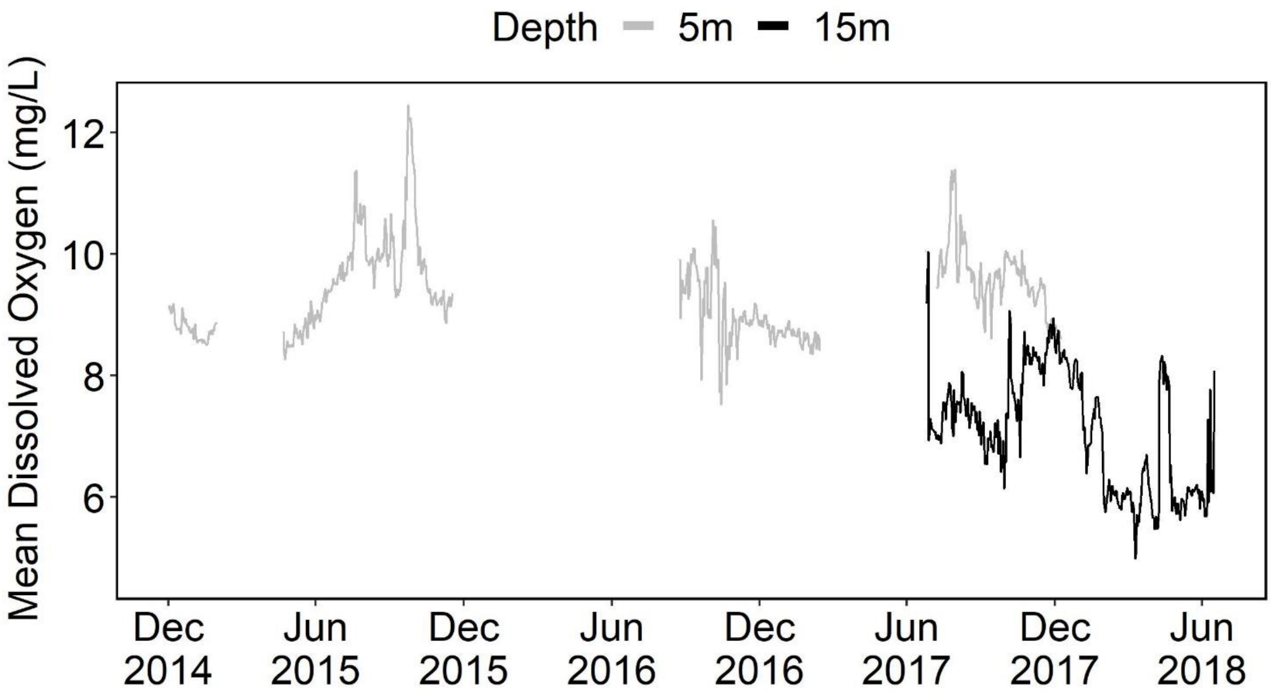


Figure 2-15: Dissolved oxygen from 5m and 10m at HAWQi buoy between December 2014 and June 2018.

2.4.4 Wind Speed

Wind speed was variable from 2012-2018 with no clear seasonal or annual pattern (Figure 2-16). On average wind speed was 10.9 km/h with a minimum of 3.6 km/h and a maximum of 26.3 km/h. Trend analysis revealed that since 2012, there is a significant declining trend in wind speed (0.195 km/h per year), which aligns with the declining trends observed at many of HBRC's climate stations (Kozyniak, 2019).

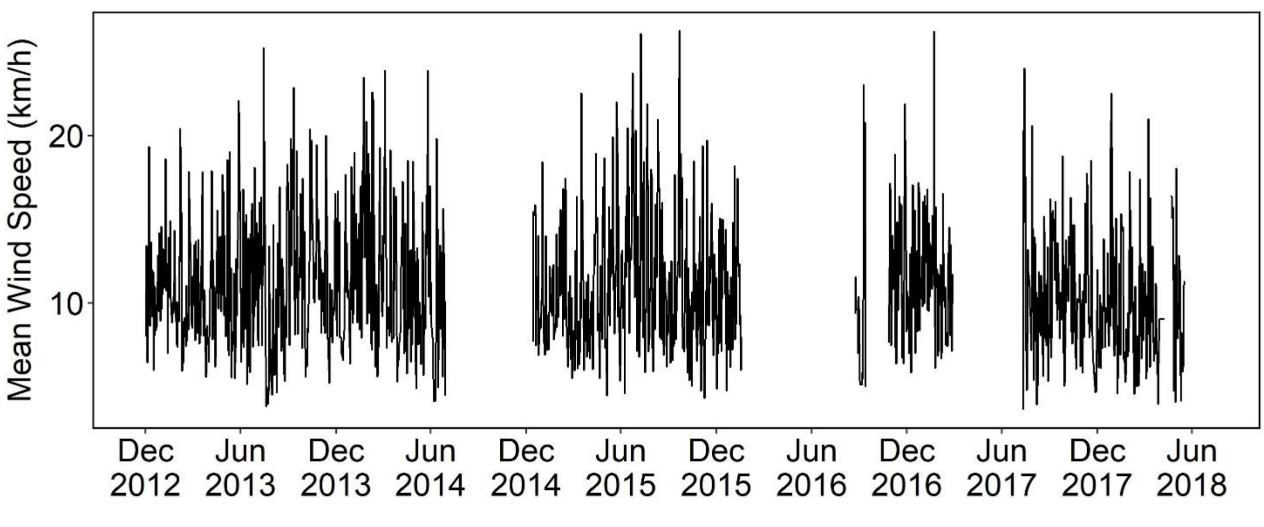


Figure 2-16: Wind speed at HAWQi buoy between December 2012 and June 2018.

2.4.5 Turbidity

Turbidity remained relatively low from 2012 to 2016, with an average turbidity of 0.34 NTU (Figure 2-17). Peaks in turbidity can be driven by runoff from large storm events. For example, Cyclone Lusi hit New Zealand in March 2014 increasing turbidity to a maximum of 9.15 NTU (Figure 2-17 – red circle). However, not all peaks are associated with large rain event runoff (e.g. Figure 2-17 – orange circle). Recent wave conditions are also a good predictor of coastal turbidity levels (Seers and Shears, 2015), however HAWQi does not currently have the capability to record local wave conditions.

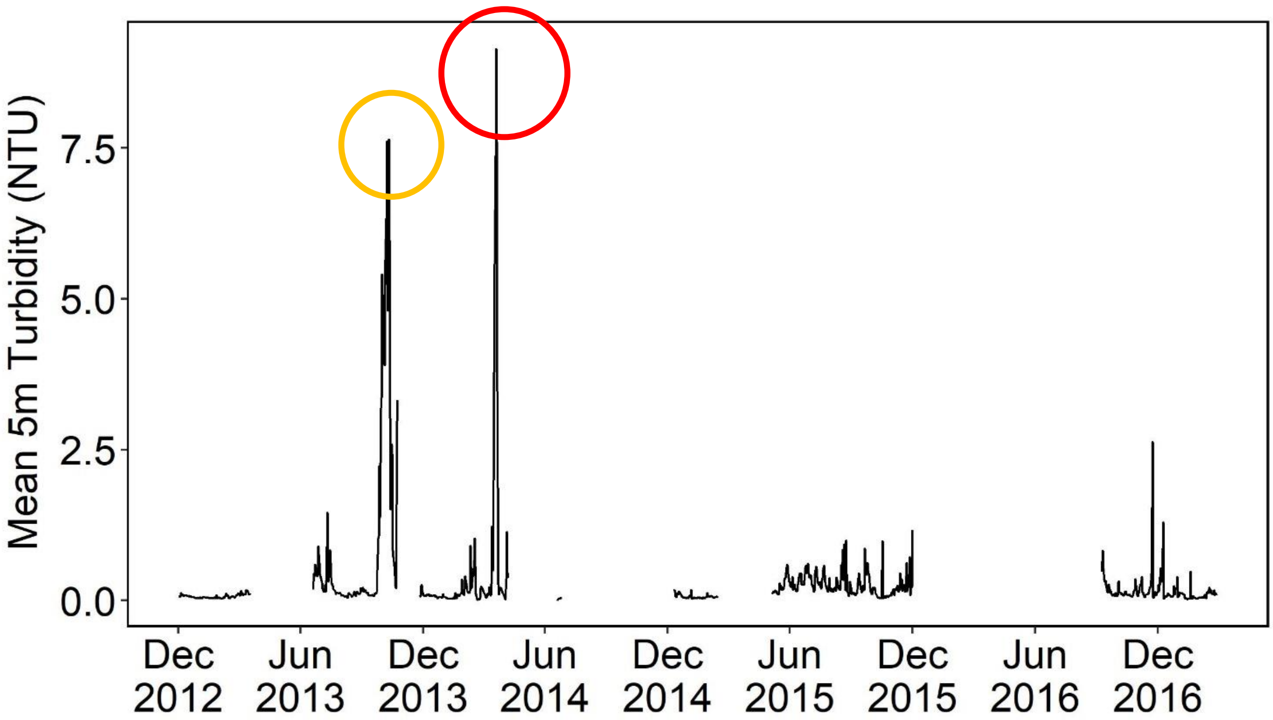


Figure 2-17: Turbidity from 5m at HAWQi buoy between December 2012 and June 2018. Red circle denotes when Cyclone Lusi hit New Zealand. Orange circle denotes second highest peak in turbidity.

2.4.6 Salinity

Average salinity from 2012-2018 was 33.8 PSU at 0.5m, 34.5 PSU at 5m, 34.8 PSU at 10m, 34.3 PSU at 15m (Figure 2-18). Maximum salinity values were between 35.1-35.4 PSU across all depths and minimum salinity values ranged from 23.1-33.4 PSU across all depths. Sudden dips in salinity are most likely due to rainfall, however a specific relationship could not be found (i.e., the amount of rainfall did not consistently explain the salinity patterns). Dips in salinity were recorded most frequently at 0.5m because fresh water (e.g., rainfall and river outflow) is slightly less dense then salt water and tends to form a layer overlying more saline waters below. The lowest minimum salinity recorded (23.1 PSU) was at 0.5m. However, dips were recorded across all depths (Figure 2-18 – red circle).

It is predicted through climate change scenarios that evaporation-dominated (e.g. tropical) ocean regions are likely to experience higher salinity, while precipitation-dominated ocean regions are likely to become fresher, with lower salinity (Durack and Wijffels, 2010). A long-term data record is required to provide information on these predictions for Hawke's Bay coastal waters.

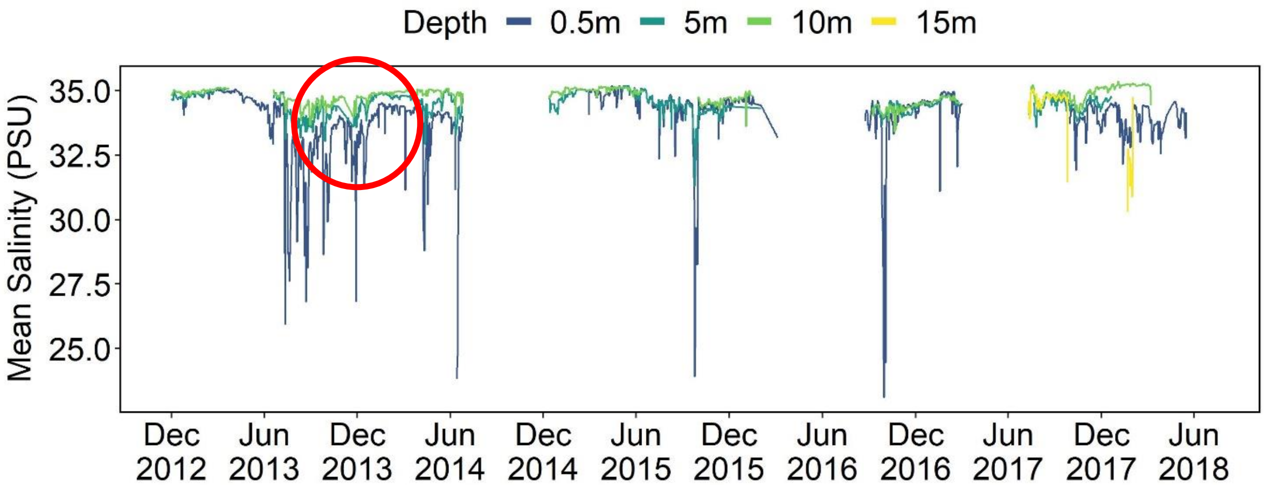


Figure 2-18: Salinity from 0.5m, 5m, 10m, and 15m at HAWQi buoy between December 2012 and June 2018. Red circle denotes a salinity drop at 3 depths.

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2.5 Conclusions

Water quality parameters within Hawke's Bay's estuaries and nearshore are generally within the levels observed for similar systems within New Zealand. Although no effects-based guidelines exist for New Zealand marine waters, comparisons have been made with other national data in order to identify areas where further work may be necessary.

Water quality in the regions estuaries appears to have high turbidity levels compared to other national sites, and the data reflects the flashiness of Hawke's Bays rivers system with high levels at the 90th percentiles compared to the 75th percentile. This is likely due to the highly erodible nature of Hawke's Bay geology, the current land use, and flood events which can transport large quantities of sediments to regional estuaries and nearshore. High turbidity can decrease the amount of light penetration into the water column, supressing algal growth and reducing visibility for predators.

The quality of the nearshore waters of Hawke's Bay appear to be consistent with other New Zealand open coast sites. The waters offshore of Awatoto have the highest median levels of total nitrogen which exceeds ANZECC guidelines for marine waters, and this can also be observed in the chlorophyll *a* levels at this site, which indicate these nutrients are contributing to higher primary production. Phosphorus levels are low compared to other sites in New Zealand.

Dissolved oxygen levels taken from discrete samples show healthy levels within Hawke's Bay waters. These samples are taken from 0.5m depth and may not accurately describe the more sensitive bottom waters. Dissolved oxygen levels from HAWQi monitoring equipment show dissolved oxygen levels can drop to levels consistent with those observed in the 'oxygen depleted' Firth of Thames. Dissolved oxygen can be reduced through land-based inputs of nutrients that fuel algal blooms, leading to oxygen depletion as these blooms die-off. A follow up study undertaken by the NIWA Glider 'Betty' was undertaken in February 2019 to describe the spatial extent of this depletion (O'Callaghan, 2019).

Faecal contaminants were generally low within nearshore waters, although the Awatoto site had both the highest median and maximum levels of both enterococci and faecal coliforms. This is consistent with the site being located adjacent to (but not within the mixing zone) of two municipal sewerage outfalls and river mouths. Further work should be undertaken to determine the contribution of human to animal faecal material at this site.

The HAWQi monitoring platform demonstrates the value of high frequency monitoring data. These instruments detected both dissolved oxygen depletion that was not observed in discrete sampling, and the marine heatwave in the summer of 2017/2018. Unfortunately there are gaps in the data which meant that a previous heatwave was unable to be detected, and it is recommended that a suite of instruments be available to replace instruments to ensure a better consistency of data capture.

Although variable, wind speed decreased between 2012 and 2018. This is consistent with other HBRC climate sites (Kozyniak, 2019), and is likely due to an increase in the Southern Annular Mode since 1970 (becoming more positive) which is associated with light winds and more settled weather (MfE and StatsNZ, 2017). Wind speed can influence wind driven waves, and is therefore a supporting variable when looking at water quality information in marine systems.


Estuaries

3 Estuaries Ecology

As the interface between land and sea, intertidal, estuarine and fringing coastal habitats are uniquely distinctive and dynamic environments. The animals and plants living in estuaries must contend with the harsh physical and chemical parameters such as prolonged periods of emersion and immersion, and the associated changes in salinity, temperature and oxygen availability.

In addition to providing valuable habitat for bird roosting, feeding and breeding, and important spawning and nursery grounds for fish, estuaries also provide the ecological services that help to sustain environmental quality and integrity. They are productive habitats and have an important role in water regulation, water quality enhancement, and can assist in the mitigation of erosion caused by scouring and wave action.

Estuaries represent the downstream receiving environment of the freshwater drainage network, so it is understandable that they are sensitive to the same effects of land-use activities as streams and rivers throughout the catchment. In New Zealand, estuaries are being recognised as the most at risk coastal environments, as they are the depositional end-point for the cumulative contaminants (e.g. nutrients, sediments, trace metals, pesticides etc.) from the surrounding catchment.

Given the importance of estuary ecosystems and the services they provide, and the real risk to the integrity of the system from the threats they are facing, monitoring of the long-term health and state is required to ensure that these vital ecosystems are being managed in a way that will retain these key functions.

3.1 Methods

The Estuarine Ecology Monitoring Programme (EEMP) sets out annual monitoring of six regional estuaries; Ahuriri (Ahuriri sites A, B (mid-estuary), sites D, E (lower estuary), site F (upper estuary), Pōrangahau, Waitangi, Tukituki and Wairoa Estuary, and Maungawhio Lagoon (Figure 3-1). This programme focuses on monitoring sediment characteristics, and animals living within the sediment (infauna) as indicators of wider ecosystem pressure, state and health. Monitoring is conducted annually between January and March, and is undertaken in-line with the Estuarine Environmental Assessment and Monitoring National Protocol (Robertson 2002).

The indicators measured include:

- Sediment grain-size, organic material, nutrients and trace metals;
- Sediment-dwelling animals (infauna).

Benthic infauna were used to determine the state and health of the estuarine infaunal community. They are commonly used as bio-indicators as they are relatively sedentary (i.e. cannot avoid adverse conditions) and have relatively long generation times, therefore integrate environmental conditions over time. Twelve replicate infaunal macroinvertebrates samples were collected at each site, using a circular PVC 130mm diameter corer (total area 0.013m^2). This was manually driven into the sediment to approximately 150mm depth and removed with the core contents intact. The contents of the core were washed through a 0.5mm sieve mesh, and the animals retained were stored in 75% ethanol, before transportation to the laboratory for identification and enumeration.

At ten of the replicate sites, sediment samples were taken from the top 2cm of the sediment. These were analysed for grain size, trace metals, nutrients, total organic carbon, total sulphur (1 rep at each site), and chlorophyll *a*.

A further description of methods for the collection of samples for the estuarine ecology monitoring programme were outlined in detail by Madarasz-Smith (2007).

To account for differences in sediment composition over time, which can affect contaminant retention capacity, results for sediment metal and nutrient analyses were normalised to 100% mud content before trend testing was undertaken and spatial and temporal comparisons were made.[2]

All data collection and analyses were undertaken in accordance with internal quality assurance and quality control processes and procedures.

3.1.1 Data summaries and visualisation

Box plots have been used throughout Section 3 to summarise sediment quality data and diversity indices for the five year period between 2009 and 2013 unless otherwise specified. Box plots graph data as a box representing statistical values. The lower boundary of each box indicates the 25th percentile, a line within the box marks the median, and the higher boundary of each box indicates the 75th percentile. The line at the end of the whiskers (error bars) above and below the box indicate the 90th and 10th percentiles respectively.

[2] For further information on the normalisation process, refer to Robertson et al. (2002).

Figure 3-1: Map of sites included in the Estuarine Ecology Monitoring Programme. Ahuriri Estuary (top), Waitangi Estuary (middle), Pōrangahau Estuary (bottom right), Maungawhio Lagoon (bottom)

3.1.2 Trend and multivariate analyses

Trend analyses

Trend analysis of environmental monitoring data is important because environmental characteristics may exhibit trends which indicate particular issues are changing in significance.

Trend analyses of univariate data in this section use non-parametric statistical approaches, which involve Mann- Kendall trend tests. Sites had been sampled annually and January was used as the 'start' month.

Further information on trend testing can be found in section 2.1.3.

Table 3-1: Data on regional estuaries included in the Estuarine Ecology Monitoring Programme (EEMP).

Estuary	Estuary Type	Estuary Volume (m^3)	Catchment Size (Ha)	Catchment Land-use (>70%)	Monitoring record
Ahuriri Estuary	Shallow Intertidal Dominated Estuary (SIDE)	6,347,333	14,583	Sheep and Beef (53%) Built-up Area (15%) Short-rotation crops (10%)	Ahuriri A 2006 – present Ahuriri B 2006 – 2015 Ahuriri D 2007 - present Ahuriri E 2010 - present Ahuriri F 2016 - present
Pōrangahau Estuary	Shallow Intertidal Dominated Estuary (SIDE)	1,667,332	80,085	Sheep and Beef (79%) Exotic Forest (6.5%)	2007 - present
Wairoa Estuary	Shallow, short residence time, tidal river (SSRTRE)	9,734,902	264,547[3]	Indigenous Forest (36%) Sheep and Beef (34.5%)	2011 - present
Waitangi Estuary	Shallow, short residence time, tidal river (SSRTRE))	2,485,690	337,058	Sheep and Beef (42%) Manuka/Kanuka (16%) Indigenous Forest (13%)	2013, 2016-18
Maungawhio Lagoon	Shallow Intertidal Dominated Estuary (SIDE)	1,034,215	7,361	Sheep and Beef (44%) Exotic Forest (13%) Indigenous Forest (11%) Dairy (9%)	2017 - present
Tukituki Estuary	Shallow, short residence time, tidal river (SSRTRE)	-	250,185	Sheep and Beef (65%) Indigenous Forest (9%)	2016,2018

Diversity analyses

The nature of estuarine infaunal assemblages are diverse and variable. Therefore several tests are used in conjunction to describe biodiversity of estuarine and marine assemblages. Collectively these tests are referred to as 'diversity indices', and describe certain attributes of a community relating to how the individuals and species within the sample community are mixed and spread.

Diversity indices were calculated using the PRIMER v6 'Diverse' routine (Clarke and Gorley, 2006) with the PERMANOVA+ add on (Anderson et al., 2008). Macrofaunal data were transformed (log (x+1)) to meet the assumptions of ANOVA. A Log (x+1) transformation was used to retain information concerning relative abundance, and to ensure that commonly occurring species did not dominate the analysis (Clarke and Warwick 2001, Zar 1996).

[3] This value only refers to Wairoa catchment land within the Hawke's Bay Regional boundary. A catchment area lies outside this boundary, however land-use information was not available for this part of the catchment at the time of writing.

Diversity indices included in the analyses were:

- **Total number of individuals (n):** This refers to the sum of all individuals found within a core.
- **Total number of species/Taxa richness (s):** This is the sum of the different species found within a core.
- **Margalef's richness (d):** Margalef's richness is a measure of biodiversity based on the number of species, adjusted for the number of individuals sampled. Values for this index increase with the number of species, and decreases with relative increases in the number of individuals.
- **Peilou's evenness:** Peilou's evenness is a measure of how evenly the abundance is represented over the species total. As an example if a community is dominated by a single species of high abundance with only single representatives from others species present, then this community would be described as 'uneven' and would score close to 0. If a community was represented by equivalent numbers of individuals across a range of species, then it would be described as 'even' and would score close to 1.
- **Shannon diversity (H'):** Shannon diversity is a measure of the biodiversity of a sample and is based on the probability that an individual in a sample will be the same species as the next individual of a sample. Values close to 0 describe low diversity (higher probability of the same species), while values close to 1 describe high diversity (higher probability of a different species).
- **Simpson diversity (λ):** Simpson's diversity is similar to Shannon diversity with slightly different arithmetic processes to derive the values. As with the Shannon index, values close to 0 describe low diversity (higher probability of the same species), while values close to 1 describe high diversity (higher probability of a different species).

Multivariate analyses

A PERMANOVA (permutational multivariate analysis of variance) was used to examine differences in the community structure based on a model using the permutation of raw data for the fixed factor of 'year' on individual sites (PERMANOVA +). Spatial and temporal variations in species composition were also assessed using non-metric multi-dimensional scaling (nMDS, PRIMER 6).

3.2 Broadscale Habitat Mapping

Habitat mapping has been undertaken in line with the Estuarine Monitoring Protocol (Robertson et al. 2002). Broadscale habitat mapping describes an estuary based on the different vegetation and sediment characteristics that help to make up the habitats within the estuary. Changes in the areal extent and health of different habitat types within an estuary can help provide information on the structure of, and stressors to, the estuary.

Habitat maps for the Ahuriri (Figure 3-2), Tukituki (Figure 3-3) and Waitangi Estuaries (Figure 3-4) have been included to provide context for the results from the Estuarine Ecology Monitoring programme that follows. Details on methodology are available in the National Estuary Monitoring Protocol (Robertson et al. 2002).

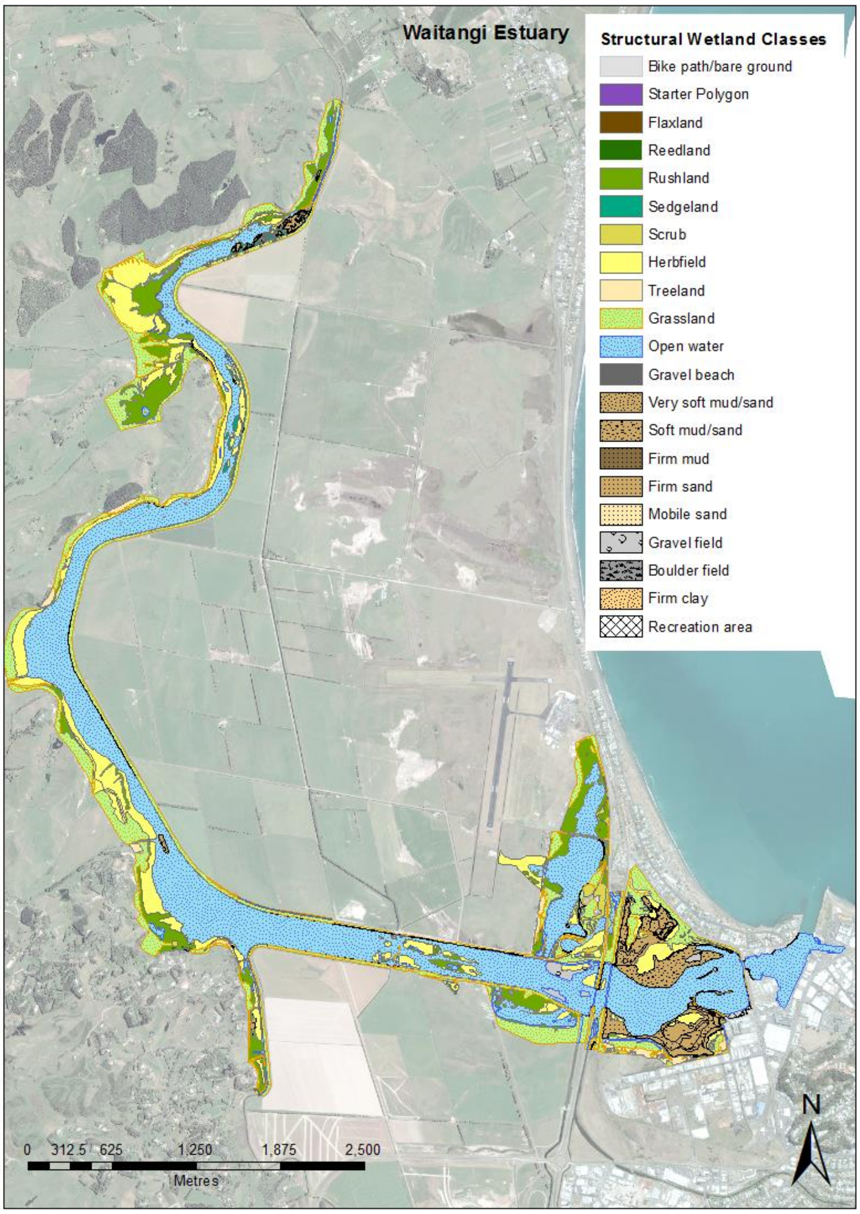


Figure 3-2: Broadscale habitat map of Ahuriri Estuary, 2015.

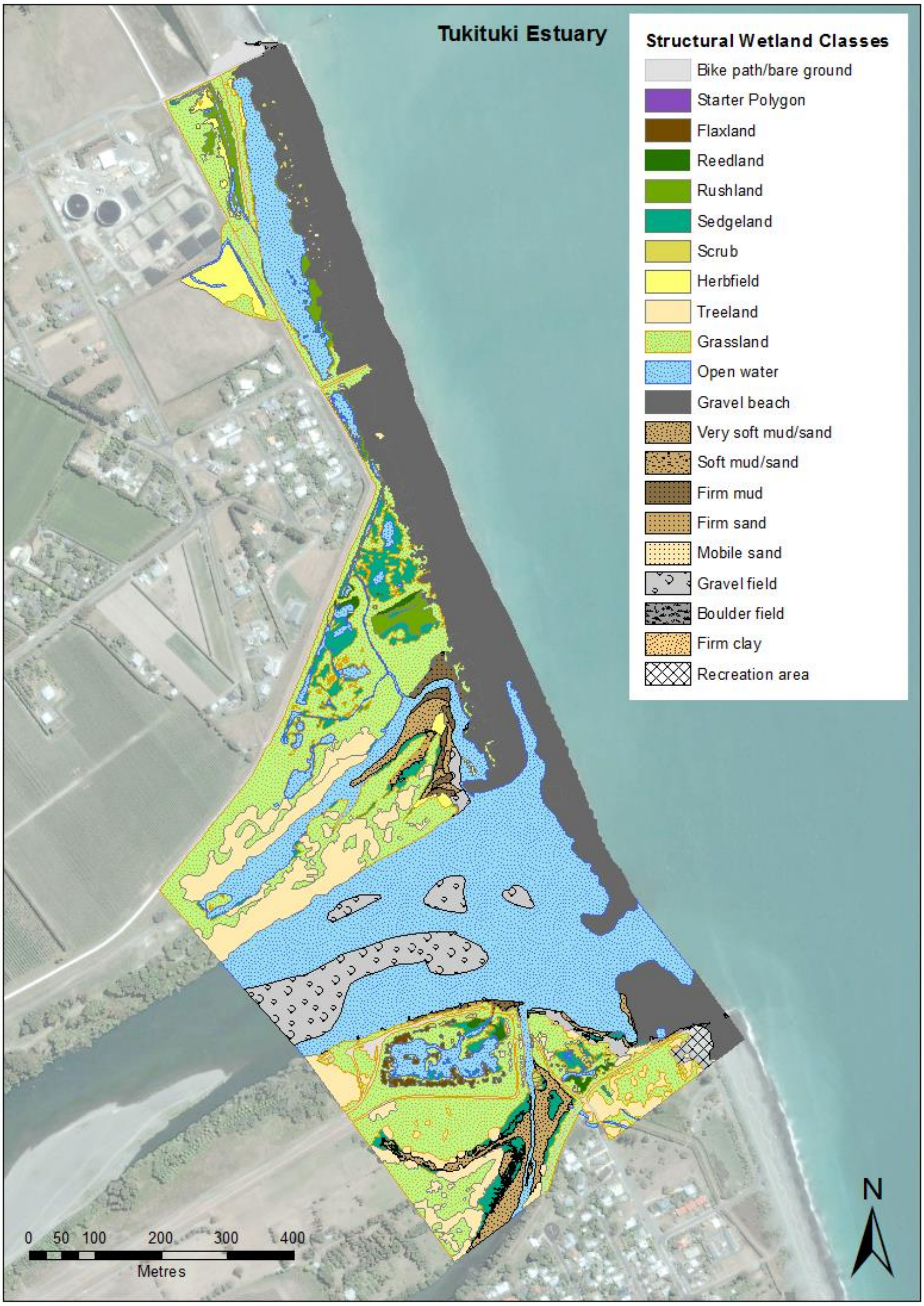


Figure 3-3: Broadscale habitat map of Tukituki Estuary, 2017.

Figure 3-4: Broadscale habitat map of Waitangi Estuary, 2014.

3.3 Results - Sediment Quantity, Composition and Quality

Estuarine and marine sediments form the complex habitats that support the diverse communities found within the benthic environment. Sediment quality is as fundamental to ensuring a healthy and functioning ecosystem as the quality of the surrounding waters (Figure 3-5).

As naturally depositional environments, estuaries and other coastal areas can become contaminant 'sinks', accumulating toxic compounds within the sediment matrix. Trace metals, hydrocarbons, organotins and organopesticides typically enter the coastal marine area via stormwater and diffuse discharges. During periods of wet weather, contaminants can be washed off road surfaces, industrial sites, roofs, and other surfaces into the stormwater network, or into rivers and streams. These contaminants are present either in solution, or bound to the sediment or suspended particulate matter that is also washed off during the rainfall events.

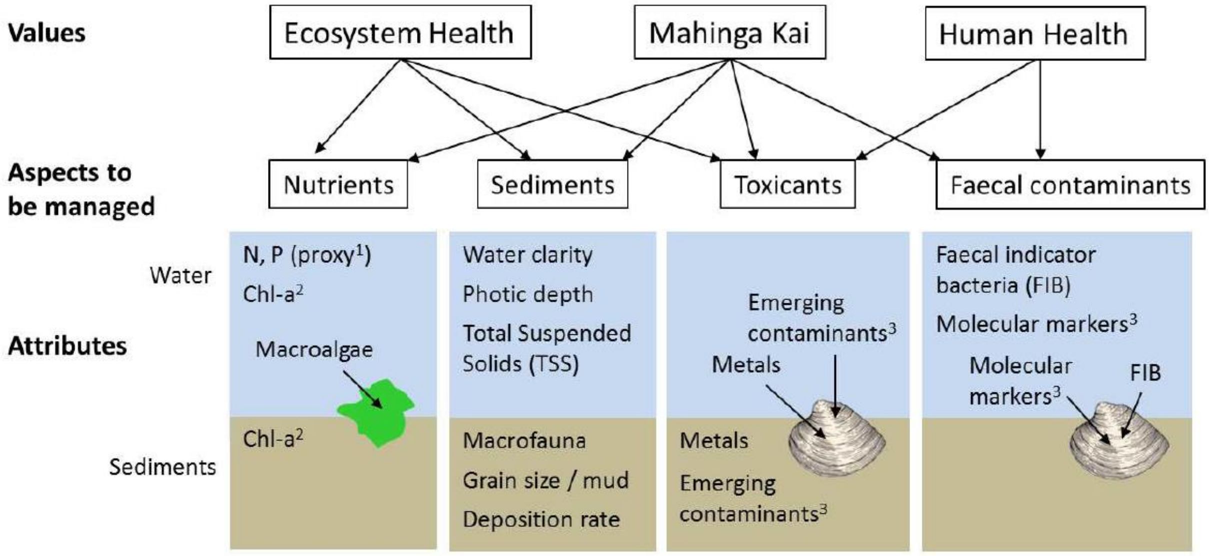


Figure 3-5: Schematic of management aspects to achieve values for estuarine sediments. From **(Zaiko et al., 2018)**

Sediments begin to settle out as soon as the water loses enough energy to no longer be able to keep them in suspension, meaning that larger, coarser sediments will begin to settle earlier than smaller, lighter, fine-grained particles. It is the smaller silt/clay particles (<63µm = 'mud') that tend to accumulate in the settling or depositional low energy environments such as estuaries and shallow embayments. These finer sediments have reactive surface properties that bind trace metals so that metals are primarily retained to fine grained particles, making these depositional areas vulnerable to contaminant accumulation.

Contaminants bound to sediments may continue to break down and leach into the interstitial waters, continuing to pollute for some time, or may be ingested by bottom feeders (e.g. flounder) and may bioaccumulate, causing sub lethal or lethal effects in the surrounding flora and fauna.

Many of the trace metals, hydrocarbons, organotins and organopesticides can have significant adverse effects on aquatic life when they accumulate in sediments. The reproductive system can be affected, causing genetic abnormalities, and affecting growth and reproductive success (e.g. Tributyltin (TBT), zinc, mercury, lead, DDT). These contaminants can also cause muscular and neurological degeneration (e.g. lead), affect plant growth and photosynthesis (e.g. copper, lead, DDT), interfere with respiration and affect the microstructure of the gills (e.g. copper), and may accumulate in marine biota causing illness in human consumers (e.g. methyl mercury poisoning).

Therefore, monitoring the quality of sediments gives a measure of environmental health as marine and estuarine animals and plants are as strongly influenced by the quality of the sediments surrounding them as they are by the waters above them.

3.3.1 Sediment Composition

Sediment composition is a key driver in the macroinvertebrate community composition present within estuary sites. Estuary systems with silt/clay content <25-30% generally exhibit communities with higher diversity and abundance than those with >25-30% silt/clay (Robertson et al., 2015), although much lower concentrations have been shown to impact on the health of macroinvertebrate communities (Norkko et al., 2002). Systems with silt/clay fractions of 10% or under generally have been shown to have conditions suitable for 11 of the most sensitive taxa (Robertson et al., 2015), while those with silt/clay fractions of 5% or under have been shown to have conditions suitable for the 5 most sensitive macrofaunal taxa (Norkko et al., 2002).

Sediments in the lower Ahuriri Estuary (A B, D and E) are generally dominated by medium sands, with lower levels of muds (silt/clay) compared to other regional estuaries (Figure 3-6). This is typical of transitory systems where channels and currents transport finer grained sediments offshore, and shallow intertidal areas where muds can be resuspended by waves and wind.

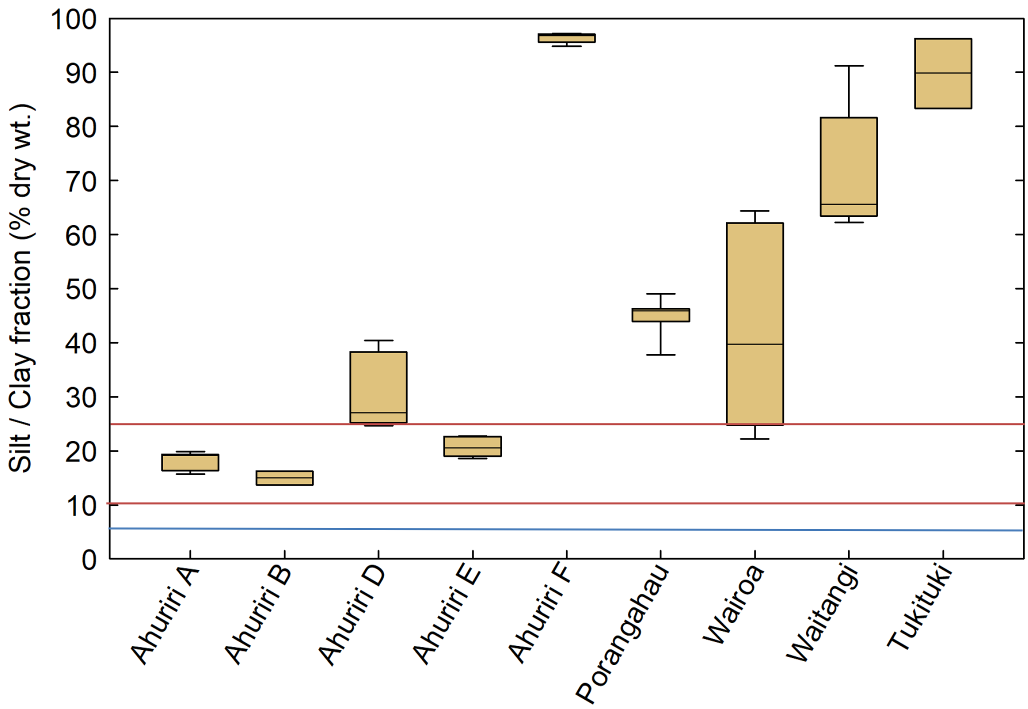


Figure 3-6: 5 year median levels of silt/clay (mud) in sediments 2013-2018. Blue line refers to 5% mud, amber line 10% mud content, red line 25% mud content. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

By contrast, the Ahuriri D, F and Waitangi are more characteristic of depositional environments, with higher levels of muds within the sediment complex. Noticeably Ahuriri F with a median silt/clay fraction of 97% demonstrates an almost complete infilling by muds.

All Hawke's Bay estuarine sites (except Ahuriri B) exceed the national median level of 12.4% mud content (n=338) described by Berthelsen et al. (2020). The median mud content for Ahuriri B sits directly at this median level of 12.4%.

Trend analysis of the data indicates significant increases in the silt/clay fraction of the sediments at two of the eight sample sites, suggesting a 'muddying' of the sediments at these sites (Table 3-2). Of importance, this appears to be occurring at the sites that generally displayed lower concentrations of silt/clay, and therefore communities that could be considered closer to 'less disturbed'. Ahuriri E recorded a significant decrease in the amount of silt/clay present. As this site is adjacent to the main channel, a decrease may represent a period of erosion at this site.

Pōrangahau Estuary also reported a significant decrease in the amount of silt/clay present, however this site sits above recognised ecological thresholds for silt/clay content. A decrease of -1.7 percent annual change would indicate that a reduction to 'healthier' levels may not occur for some time.

Table 3-2: Trend analysis of silt/clay (mud) fraction in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Silt/Clay fraction (<63um) %		
		Median	Trend p value	Percent Annual Change
Ahuriri A	130	16.4	**0.000**	**4.575**
Ahuriri B	100	12.4	**0.000**	**5.798**
Ahuriri D	110	26.7	0.398	0.914
Ahuriri E	100	22.4	**0.000**	**-3.844**
Ahuriri F	14	97.0	2 year	2 year
Pōrangahau	110	47.6	**0.010**	**-1.715**
Wairoa	80	47.0	0.448	-2.438
Waitangi	30	65.6	3 year	3 year

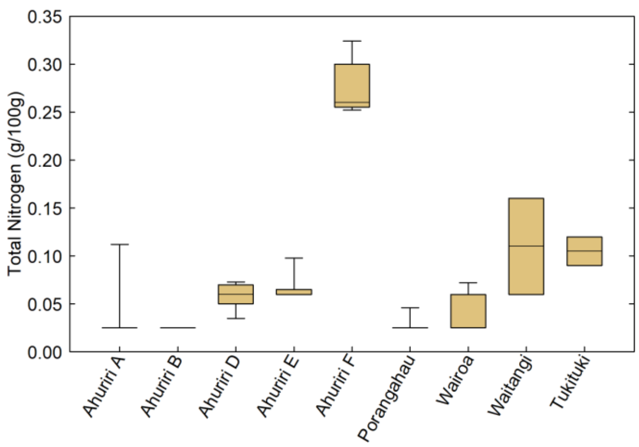
The results suggest that the mid-Ahuriri Estuary appears moderately disturbed in relation to sediments, however the upper Ahuriri (F), Pōrangahau, Wairoa, Waitangi and Tukituki estuaries are likely to be sediment 'stressed'. Wairoa Estuary tends towards highly variable mud content (between 21-66%) and therefore a wider sediment study or additional ecological monitoring sites may be warranted.

A comparison with 25 estuaries throughout New Zealand (Robertson et al., 2015) shows that Hawke's Bay estuaries report some of the higher sediment mud content (silt/clay %) recorded when compared to the published dataset. Median levels of silt/clay recorded in the Pōrangahau, Wairoa, and Waitangi estuaries were recorded at 47.6, 47 and 65.6% respectively. These sites are approaching, to exceeding, published literature on sediment stress in estuary infauna (Robertson et al., 2015; Thrush et al., 2006) . Tukituki Estuary has only been monitored twice in this period and care should be taken in assigning a current state, although the results to date suggest a high level of sediment stress in areas of this estuary also (Figure 3-6).

Some areas of an estuary will naturally be more prone to deposition of sediments than others. This can occur in the quiescent areas of an estuary which provide the opportunity for sediments to drop out of the water column. In itself small pockets of muddy sediments would not define an area as 'sediment stressed' and this is acknowledged in the Estuarine Trophic Index (Robertson et al., 2016), which moves towards using the spatial extent of the estuary and changes in the muddiness of sediments to describe 'sediment stress'.

3.3.2 Sediment Nutrients

Sediment nutrient concentrations were lowest at sites Ahuriri A, B, and Pōrangahau and highest at sites Ahuriri F (Figure 3-7) Ahuriri F reported the highest sediment total nitrogen (TN) and total recoverable phosphorus (TRP) levels of all the monitored estuarine sites. While some of the variability may be contributed to differences in the silt/clay fraction (in that contaminants tend to preferentially bind to the smaller sediment sizes), the large difference in nutrient concentrations observed between the levels at Ahuriri F and levels at sites with similar silt/clay content (e.g. Waitangi and Tukituki) would indicate that this is not the dominant cause of differences between sites.



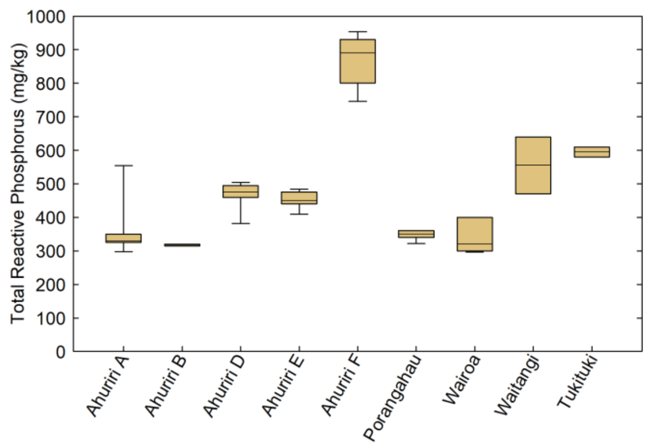


Figure 3-7: Sediment total nitrogen and total recoverable phosphorus. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Ahuriri A, B and Pōrangahau appear to reflect background concentrations of total nitrogen, with many samples returning results <0.05g/100g (= <500mg/kg). Sites Ahuriri D, E, and the Tukituki, Wairoa and Waitangi Estuaries vary with median concentrations of sediment total nitrogen between 0.05 and 0.09g/100g (500-900 mg/kg). These results do not suggest significant eutrophication of the estuary sediments by nitrogen in the lower Ahuriri, Pōrangahau and Wairoa.

Conversely, median levels of total nitrogen in the sediments at Waitangi and Tukituki Estuaries would suggest moderate stress, and concentrations at Ahuriri site F would suggest significant, persistent stress (Robertson et al., 2016).

Total Recoverable Phosphorus (TRP) concentrations within sediments of the lower and mid Ahuriri, Pōrangahau, and Wairoa Estuaries do not appear to suggest significant eutrophication of the estuary sediments by phosphorus. Levels of TRP in the sediments of Waitangi and Tukituki Estuaries appear slightly enriched, and would be classed as ‘high risk’ (>500-1000 mg/kg) according to the risk framework described by Robertson and Robertson (2014). This framework is interim and relies on very limited data, however is one of the only documents to characterise phosphorus as a stressor in estuarine sediments. Nationally more work is required to understand the role of phosphorus in estuarine enrichment. The concentrations of TRP at site Ahuriri F suggest high level enrichment, which may be due to the marine geology of the area coupled with the high silt/clay fraction, or due to anthropogenic inputs.

Ahuriri D, E, F, Waitangi and Tukituki exceed the national median level of 349.8 TP (mg/kg) described by Berthelsen et al. (2020).

Decreasing trends in the normalised sediment total nitrogen concentrations were observed at four of the six sites monitored (Table 3-3**Error! Reference source not found.**). These were Ahuriri A, B, D and Pōrangahau. This is consistent with the previous reporting period. Normalised sediment nitrogen did not appear to increase at any of the monitored sites. Trends in total nitrogen content in sediments at Ahuriri F could not be analysed due to insufficient length of record.

No trends were observed in sediment total reactive phosphorus for any sites as, although they were statistically significant, they did not meet the criteria of exceeding 1% of the median per year (Table 3-4).

Table 3-3: Trend analysis of normalised total nitrogen in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Total Nitrogen (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	115	0.258	**0.001**	-4.998
Ahuriri B	100	0.270	**0.000**	-6.806
Ahuriri D	95	0.262	**0.000**	-8.157
Ahuriri E	85	0.314	0.496	0.971
Pōrangahau	95	0.124	**0.000**	-10.023
Wairoa	65	0.111	0.784	-0.841

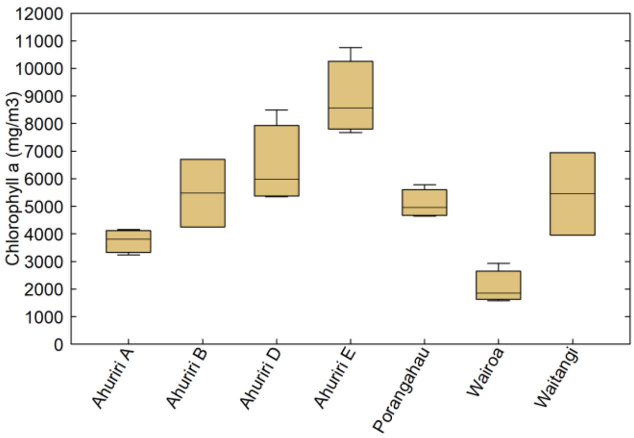
Table 3-4: Trend analysis of normalised total recoverable phosphorus in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**.

Site	n	Normalised Total Recoverable Phosphorus (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	115	2043.48	0.000	-7.102
Ahuriri B	100	2673.56	0.000	-6.602
Ahuriri D	95	2191.42	0.000	-6.733
Ahuriri E	85	2123.89	0.000	3.917
Pōrangahau	95	746.00	0.044	-2.121
Wairoa	65	723.34	0.200	3.082

3.3.3 Sediment Chlorophyll *a* and Total Organic Carbon

Sediment chlorophyll *a* measures the levels of photosynthetic activity occurring on the sediment surface and is used to measure the trophic state of the sediment. Trophic state describes the productivity of the sediment. Most systems will have a trophic state that is 'natural' (i.e. which they function at their best), however productivity can be increased through the addition of nutrients and organic material which can then lead to expressions of an altered trophic state which may be considered adverse (e.g. increase in nuisance macroalgal growth, changes to the dissolved oxygen maxima and minima).

The highest median concentration of sediment chlorophyll *a* was observed at Ahuriri E in the lower Ahuriri Estuary (Figure 3-8). This is an interesting result given the composition of the sediment at this site (shell hash and gravels) and nutrient profile. The presence of shell hash may provide more stable substrate for the growth of photosynthetic mats, or may be an artefact of the sample processing. Wairoa Estuary reported the lowest concentrations of chlorophyll *a,* accompanied by some of the lower levels of nutrients.



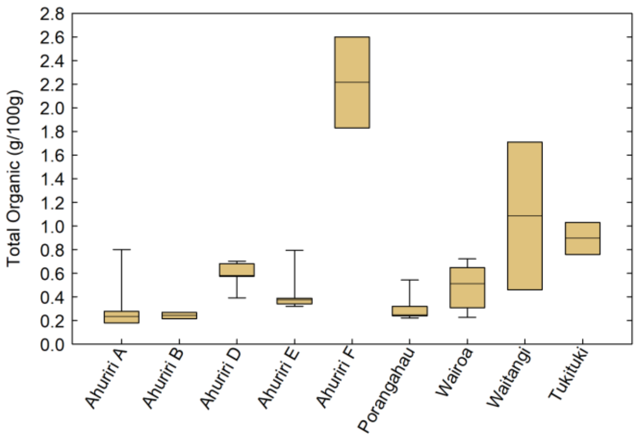


Figure 3-8: 5 year median levels of sediment chlorophyll *a*. and total organic carbon. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Total organic carbon levels were highest at site Ahuriri F, which is consistent with being the most eutrophic site in the monitoring suite. That said, levels observed at Ahuriri F would be considered 'fair' according to (Robertson and Stevens, 2013). Median total organic carbon levels at Ahuriri F, Waitangi and Tukituki estuaries exceed national median levels observed from 81 estuaries (Berthelsen et al., 2020).

Trend analyses failed to detect any trends in sediment chlorophyll *a* concentrations between the beginning of sampling and 2018, as they did not meet the significance criteria of exceeding 1% of the median per year (Table 3-5).

Table 3-5: Trend analyses of chlorophyll *a* in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**.

Site	n	Chlorophyll *a* (µg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	110	3150	0.000	5.715
Ahuriri B	90	3250	0.000	11.558
Ahuriri D	90	5600	0.054	2.679
Ahuriri E	80	6950	0.000	9.350
Pōrangahau	90	4150	0.000	7.831
Wairoa	60	1850	0.086	-13.514

Levels of total organic carbon appear to be decreasing within the sampling period (Table 3-6), however this parameter has only been measured since 2013 (5 years) and therefore any trend should be interpreted with caution until a longer term dataset (>10 years) has been generated. Irrespective, the levels of total organic carbon observed at these sites are well within references levels for eutrophic conditions (Robertson and Stevens, 2013), and therefore decreases would not be expected to improve conditions at these sites.

Table 3-6: Trend analyses of total organic carbon in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Total Organic Carbon (g/100g)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	45	0.26	**0.000**	-24.619
Ahuriri B	30	0.27	3 years	3 years
Ahuriri D	45	0.65	**0.001**	-13.837
Ahuriri E	45	0.38	**0.004**	-7.895
Pōrangahau	45	0.32	**0.000**	-40.625
Wairoa	45	0.59	**0.005**	-17.373

It is important to note that while the results of sediment nutrient and chlorophyll *a* concentrations do not appear indicative of eutrophic systems, the sampling approach in the national monitoring protocol has a focus on downstream environments. New guideline approaches (Robertson et al., 2016) suggest focusing on upper reaches and other sensitive environments, along with additional indicators for determining trophic status. These guidelines were implemented in 2015 at sites Ahuriri F and Tukituki and therefore provide an assessment of sensitive areas within the estuary.

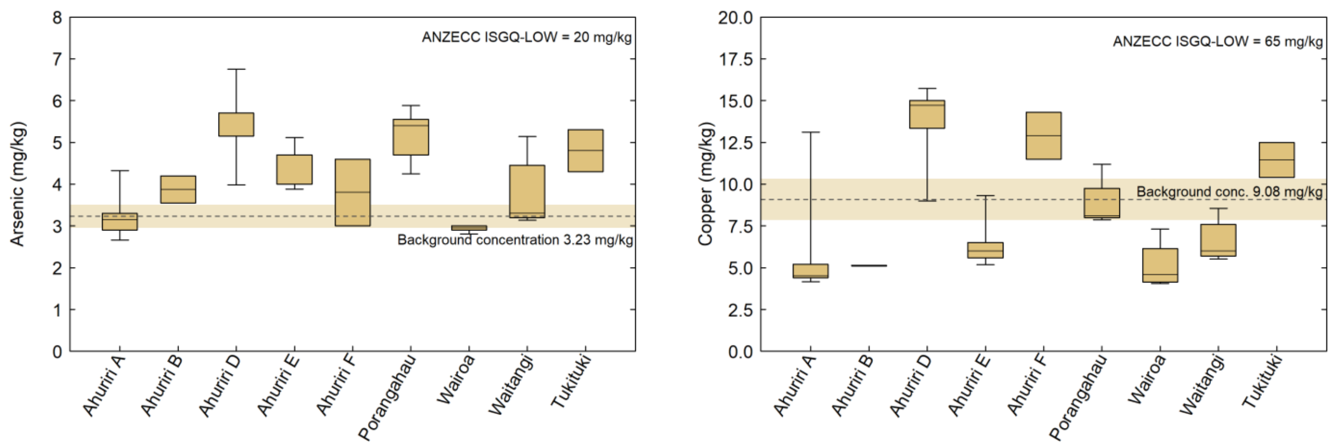
3.3.4 Sediment Toxicants

Concentrations of toxicants in the estuary sediments generally fell well within ANZECC guidelines for likely ecological effects (Figure 3-9). Where results fall below ANZECC ISQG – Low, adverse ecological effects can be expected to occur rarely (ANZECC, 2000). ANZECC guidelines provide the toxicological level at which adverse effects are expected to occur occasionally (ISQG-Low) or frequently (ISQG-High). In recognition that changes to community structure can occur prior to ecotoxicological effects on species, Auckland Council developed the Environmental Response Criteria (ERC) as an early warning of environmental degradation (ARC, 2004). Environmental Response Criteria were derived for copper, lead and zinc, Poly-Aromatic Hydrocarbons (PAH's) and other organics.

Site Ahuriri D, which is located adjacent to the stormwater discharge in to the Ahuriri Estuary from the Thames/Tyne (Pandora) Industrial Estate showed concentrations of toxicants that were higher than all other sites, particularly for the trace metals chromium, lead and zinc. Specifically the toxicants chromium, lead and zinc are associated with many of the industrial practises occurring in the adjacent catchment, and point source control would be expected to reduce the amounts making their way in to the estuary.

When comparing Hawke's Bay sediment quality data to the environmental response criteria, zinc at site Ahuriri D is the only site and toxicant that exceeds these levels (>124 mg/kg - Figure 3-9). These are based on the interim sediment quality guidelines for the Canadian Council of Ministers for the Environment (CCME, 1999). Where levels exceed the amber level, contaminant levels are elevated and the biology of the site is possibly impacted.

This suggests that while other monitored contaminants do not appear to be occurring at levels of concern, zinc may be present in the receiving water sediments at levels which may be impacting biology.



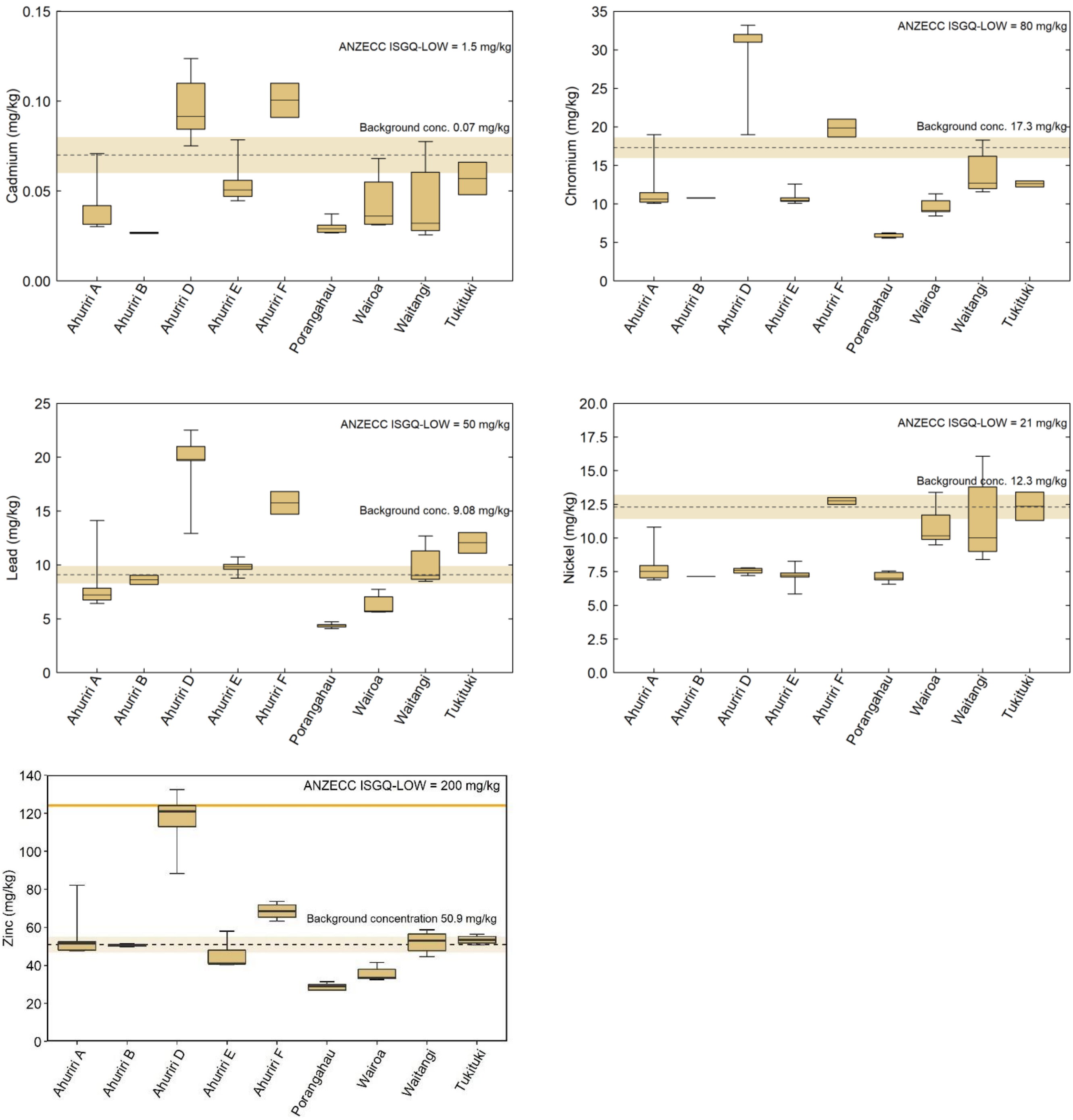


Figure 3-9: 5 year median levels of trace metal contaminants in estuary sediments (Ahuriri A, D, E, Pōrangahau and Wairoa = 5 years, Ahuriri F and Waitangi = 3 years, Ahuriri B and Tukituki = 2 years). Dashed line indicates background levels as described by Strong (2005), ISQG = Interim sediment quality guidelines, Low and High are denoted in text when unable to fit the scale (ANZECC, 2000). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. Amber line denotes Auckland Council Environmental Response Criteria – Amber.

To account for differences in sediment composition over time which can affect contaminant retention capacity, results for sediment metal and nutrient analyses were normalised to 100% mud content before trend testing was undertaken and spatial and temporal comparisons were made.[4]

Normalised arsenic concentrations showed significant declines at site Ahuriri A, but a significant increase at site Ahuriri B (Table 3-7). This significant increase was not observed in the last reporting period, indicating that the results obtained between 2013 and 2015 (when sampling at this site ceased) have influenced this trend.

Table 3-7: Trend analyses of normalised arsenic in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Arsenic (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	100	16.51	**0.035**	**-2.358**
Ahuriri B	80	24.50	**0.031**	**2.806**
Ahuriri D	100	18.88	0.522	-1.019
Ahuriri E	90	20.40	0.006	3.829
Pōrangahau	100	10.49	0.314	-1.677
Wairoa	70	6.05	0.124	2.970

Significant declines in normalised cadmium were observed for all sites excluding Wairoa and Ahuriri E. No trend was observed in Wairoa Estuary, while Ahuriri E showed increasing levels of normalised cadmium in estuary sediments (Table 3-8).

Table 3-8: Trend analysis of normalised cadmium in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Cadmium (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	0.27	**0.000**	**-9.387**
Ahuriri B	100	0.25	**0.000**	**-7.039**
Ahuriri D	100	0.47	**0.000**	**-16.811**
Ahuriri E	90	0.23	**0.001**	**4.529**
Pōrangahau	100	0.08	**0.000**	**-2.623**
Wairoa	70	0.09	0.075	4.503

Normalised sediment chromium levels decreased at sites Ahuiriri A, B and D, and at Pōrangahau over the sampling period. These decreases are consistent with those observed in the 2013 reporting period (Table 3-9).

[4] For further information on the normalisation process, refer to Robertson et al., 2002.

Table 3-9: Trend analyses of normalised chromium in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Chromium (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	69.67	**0.000**	**-6.487**
Ahuriri B	100	87.28	**0.000**	**-6.870**
Ahuriri D	100	137.60	**0.000**	**-11.722**
Ahuriri E	90	52.14	0.105	1.463
Pōrangahau	100	13.17	**0.004**	**-2.153**
Wairoa	70	16.81	0.486	1.645

Normalised copper levels decreased at Ahuriri sites A, B and D (Table 3-10). No other trends were observed. This decrease is consistent with the previous reporting period for these sites.

Table 3-10: Trend analyses of normalised copper in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Copper (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	33.14	**0.000**	**-8.289**
Ahuriri B	100	44.01	**0.000**	**-6.798**
Ahuriri D	100	60.17	**0.000**	**-8.382**
Ahuriri E	90	33.81	0.031	0.091
Pōrangahau	100	19.33	0.309	0.634
Wairoa	70	11.16	0.083	3.551

Normalised sediment nickel levels decreased at site Ahuriri A and B and at Pōrangahau and increased at site Ahuriri E (Table 3-11). The Ahuriri results are consistent with the results observed in the previous reporting period, however Pōrangahau has shifted from no trend to a decreasing trend.

Table 3-11: Trend analyses of normalised nickel in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Nickel (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	46.41	**0.000**	**-5.826**
Ahuriri B	100	57.39	**0.000**	**-6.877**
Ahuriri D	100	30.30	0.298	-1.461
Ahuriri E	90	34.10	**0.017**	**2.659**
Pōrangahau	100	15.55	**0.011**	**-1.432**
Wairoa	70	19.28	0.992	-0.017

Levels of normalised lead in estuary sediments decreased at Ahuriri sites A, B and D, but reported a significant increase at Wairoa (Table 3-12). This increasing trend was not observed in the last reporting period for Wairoa, however there was limited data at that time.

Table 3-12: Trend analyses of normalised lead in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Lead (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	48.27	**0.000**	**-7.753**
Ahuriri B	100	67.14	**0.000**	**-5.965**
Ahuriri D	100	91.42	**0.000**	**-10.829**
Ahuriri E	90	50.16	0.674	0.414
Pōrangahau	100	9.81	0.382	-0.540
Wairoa	70	14.18	**0.012**	**7.334**

Normalised zinc levels decreased at site Ahuriri A, B, and D, and at Pōrangahau (Table 3-13). An increase in sediment normalised zinc levels was observed for Wairoa.

Table 3-13: Trend analyses of normalised zinc in estuary sediments over the monitoring period. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	n	Normalised Zinc (mg/kg)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	120	332.54	**0.000**	**-27.351**
Ahuriri B	100	425.67	**0.000**	**-7.113**
Ahuriri D	100	507.84	**0.000**	**-10.972**
Ahuriri E	90	227.44	0.835	0.748
Pōrangahau	100	64.56	**0.022**	**-1.460**
Wairoa	70	72.73	**0.005**	**4.888**

The normalisation technique is used to account for differences in sediment composition that may account for higher levels of contaminants at a site, rather than the activities contributing contaminants to this site. In this way, it attempts to remove the bias of sediment composition. However, as with all transformations, it has its own inherent issues. In order to improve trend detection without having to transform the data, the estuarine ecology monitoring project was adapted in 2016 and trace metal and nutrient analyses undertaken on the <63µm fraction of sediments. This will allow for direct comparison of sites in the next reporting period.

Concentrations of toxicant contaminants in the estuary sediments generally fell well within ANZECC guidelines for likely ecological effects. Where results fall below ANZECC ISQG – Low, adverse ecological effects can be expected to occur rarely (ANZECC, 2000). The exception to this was at site Ahuriri D, which is located adjacent to the stormwater discharge in to the Ahuriri Estuary from the Thames/Tyne (Pandora) Industrial Estate. This site showed concentrations of toxicants that were significantly higher than all other sites, although still below ANZECC ISQG – Low guidelines.

Specifically the toxicants chromium, lead and zinc are associated with many of the industrial practices occurring in the adjacent catchment, and point source control would be expected to reduce the amounts making their way in to the estuary.

Although levels of measured 'priority' toxicants were below ANZECC guidelines for sediment health, ecotoxicological studies undertaken over the past decade have demonstrated lethal and sub-lethal effects on animals living with the sediment at several sites flowing into the Ahuriri (Charry et al., 2018). It is possible that the toxicity observed is due to synergistic or additive effects of contaminants, or due to contaminants that are not monitored as part of the USEPA priority suite. Further work should be undertaken to identify baseline concentrations of contaminants of emerging concern.

3.4 Results - Community Composition and Diversity Indices

The communities that inhabit estuaries are diverse and variable. In order to describe these communities in a way that helps us to interpret their state and health, various community metrics and indices are used. These are described below:

- **Total number of individuals (n):** This refers to the sum of all individuals found within a core.
- **Total number of species/Taxa richness (s):** This is the sum of the different species found within a core.
- **Margalef's richness (d):** Margalef's richness is a measure of biodiversity based on the number of species, adjusted for the number of individuals sampled. Values for this index increase with the number of species, and decreases with relative increases in the number of individuals.
- **Peilou's evenness:** Peilou's evenness is a measure of how evenly the abundance is represented over the species total. As an example if a community is dominated by a single species of high abundance with only single representatives from others species present, then this community would be described as 'uneven' and would score close to 0. If a community was represented by even numbers of individuals across a range of species, then it would be described as 'even' and would score close to 1.
- **Shannon diversity (H'):** Shannon diversity is a measure of the biodiversity of a sample and is based on the probability that an individual in a sample will be the same species as the next individual of a sample. Values close to 0 describe low diversity (higher probability of the same species), while values close to 1 describe high diversity (higher probability of a different species).
- **Simpson diversity (λ):** Simpson's diversity is similar to Shannon diversity with slightly different arithmetic processes to derive the values. As with the Shannon index, values close to 0 describe low diversity (higher probability of the same species), while values close to 1 describe high diversity (higher probability of a different species).

3.4.1 Abundance and Richness

Ahuriri D and Pōrangahau reported the lowest number of individuals per core (abundance per 0.013m^2) with median numbers of 10 (Figure 3-10). These sites also reported the lowest number of species per core. Waitangi Estuary reported the highest median number of individuals per core, however this was dominated by the amphipod *Paracorophium excavatum* and the estuarine snail *Potamopyrgus estuarinus.* These species averaged 77 and 46 individuals per core respectively.

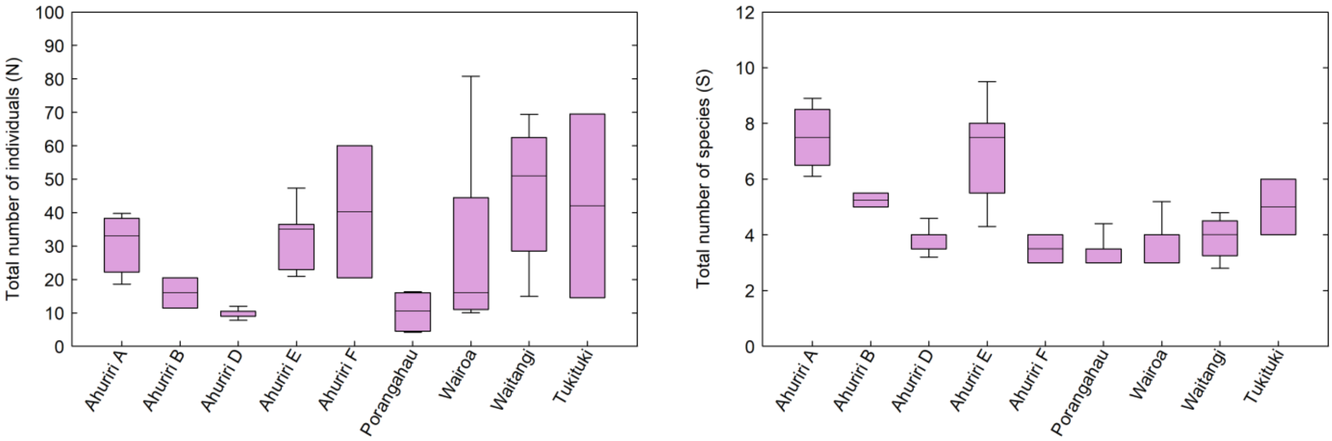


Figure 3-10: Total number of individuals and species per core (0.013m^2) by estuarine site. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Trends in diversity indices over time can provide further information on the health of estuarine sites. Tukituki, Waitangi and Ahuriri F have only been monitored for 3 years, and therefore these sites are unable to be analysed for trends due to the insufficient monitoring period.

Ahuriri E and Wairoa reported significant decreases in the total number of individuals over the monitoring period (Table 3-14). No increasing trends were observed. This does not necessarily denote either a positive or negative trend (grey highlight), as increased numbers of single opportunistic species may in fact represent an environmental decline, whereas a reduction may represent improvement. Instead, these data need to be considered alongside data on diversity (Shannon, Simpson), evenness (Peilou's) and richness (number of species) before a conclusion can be reached.

Table 3-14: Trend analysis of total number of individuals in estuary infaunal samples per core (0.013m^2). Statistically significant trends are indicated in **bold**.

Site	n	Total number of species (S)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	144	7	0.158	0.000
Ahuriri B	120	5	0.607	0.000
Ahuriri D	144	4	0.095	0.000
Ahuriri E	120	7	**0.003**	**-4.761**
Pōrangahau	155	4	0.017	0.000
Wairoa	96	4	**0.000**	**-6.250**

Ahuriri A and E reported the highest species richness per core (0.013m^2) with median number of 7.0 species. Ahuriri D, Pōrangahau and Wairoa reported the lowest species richness per core with a median of 4.0 species per core.

As with number of individuals, Ahuriri E and Wairoa reported significant decreases in the total number of species over the monitoring period (Table 3-15).

Table 3-15: Trend analysis of total number of species in estuary infaunal samples per core (0.013m^2). Statistically significant trends are indicated in **bold**.

Site	n	Total number of individuals (N)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	144	33	0.625	-0.758
Ahuriri B	120	19	0.127	-2.633
Ahuriri D	144	10	0.387	0.000
Ahuriri E	120	37	**0.000**	**-6.949**
Pōrangahau	155	10	0.283	-1.666
Wairoa	96	24	**0.000**	**-17.87**

3.4.2 Margalef's Richness and Peilou's Evenness

Unlike species richness measure described in Figure 3-10, Margalef's richness also accounts for abundance of individuals within each species (Figure 3-11). The results from this index demonstrate the dominance of abundance found in Waitangi and Ahuriri F, and closely aligns with the median levels observed in Ahuriri E and Wairoa reported significant decreases in the total number of individuals over the monitoring period (Table 3-14). No increasing trends were observed. This does not necessarily denote either a positive or negative trend (grey highlight), as increased numbers of single opportunistic species may in fact represent an environmental decline, whereas a reduction may represent improvement. Instead, these data need to be considered alongside data on diversity (Shannon, Simpson), evenness (Peilou's) and richness (number of species) before a conclusion can be reached.

Table 3-14, with high levels observed at Ahuriri A and E, and lower levels at Ahuriri F and Waitangi.

Peilou's evenness is a measure of how evenly the abundance is represented over the species total. As an example if a community is dominated by a single species of high abundance with only single representatives from others species present, then this community would be described an 'uneven' and would score close to 0. If a community was represented by even numbers of individuals across a range of species, then it would be described an 'even' and would score close to 1.

As observed in Figure 3-11, evenness is highest at Ahuriri D and Pōrangahau (0.89 and 0.86 respectively) and lowest at Waitangi (0.46; likely because they're dominated by specific species as mentioned above).

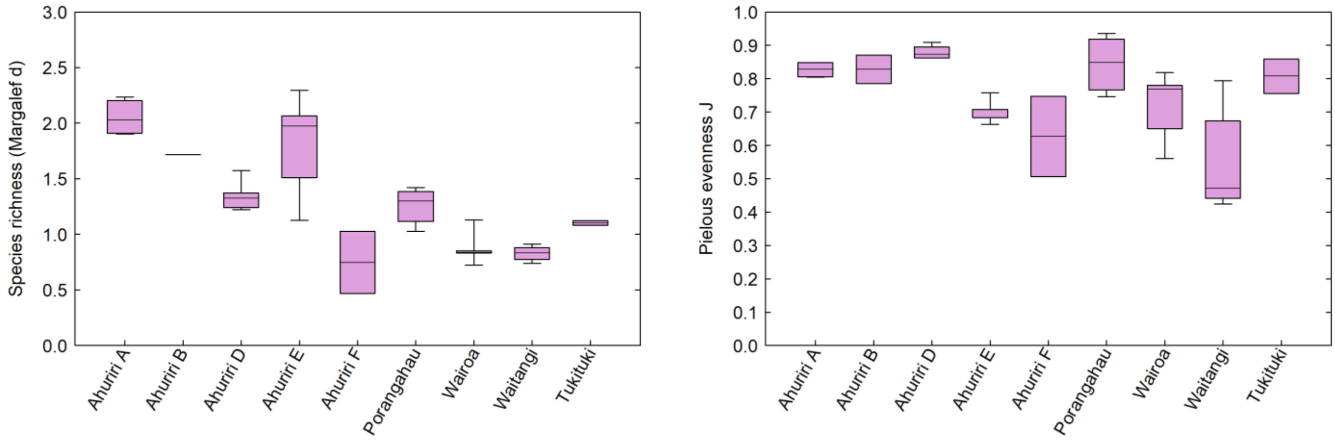


Figure 3-11: Margalef's species richness (d) and Peilou's evenness (J) per core (0.013m^2) by estuarine site. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki).

Margalef's richness appears to be significantly decreasing at sites Ahuriri A and E (Table 3-16).

Table 3-16: Trend analysis of Margalef's richness (d) in estuary infaunal samples per core (0.013m^2). Statistically significant trends are indicated in **bold**.

Site	n	Species richness (Margalef (d))		
		Median	Trend p value	Percent Annual Change
Ahuriri A	141	1.842	**0.005**	**2.175**
Ahuriri B	120	1.508	0.973	0.000
Ahuriri D	144	1.427	0.055	-1.844
Ahuriri E	120	1.646	**0.042**	**-3.637**
Pōrangahau	153	1.443	0.110	-1.459
Wairoa	94	0.883	0.124	-2.540

Evenness within the community assemblage appears to be increasing at sites Ahuriri A and E, indicating the community is moving toward one that is more evenly distributed, than dominated by certain species (Table 3-17).

Table 3-17: Trend analysis of Peilou's evenness in estuary infaunal samples per core (0.013m^2). Statistically significant trends are indicated in **bold.**

Site	n	Peilou's evenness (J)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	141	0.819	**0.001**	**0.999**
Ahuriri B	116	0.790	0.461	-0.313
Ahuriri D	141	0.887	0.378	-0.184
Ahuriri E	119	0.662	**0.028**	**1.741**
Pōrangahau	147	0.864	0.971	0.000
Wairoa	93	0.746	0.192	1.784

3.4.3 Shannon and Simpson Diversity

Median Shannon diversity is highest at Ahuriri A and Ahuriri B at 1.57 and 1.36 respectively (Figure 3-12). Site Ahuriri E appears to have variable diversity, and the lowest infaunal diversity was observed at Ahuriri F, Wairoa and Waitangi estuaries, with scores of 0.90, 0.89 and 0.76 respectively.

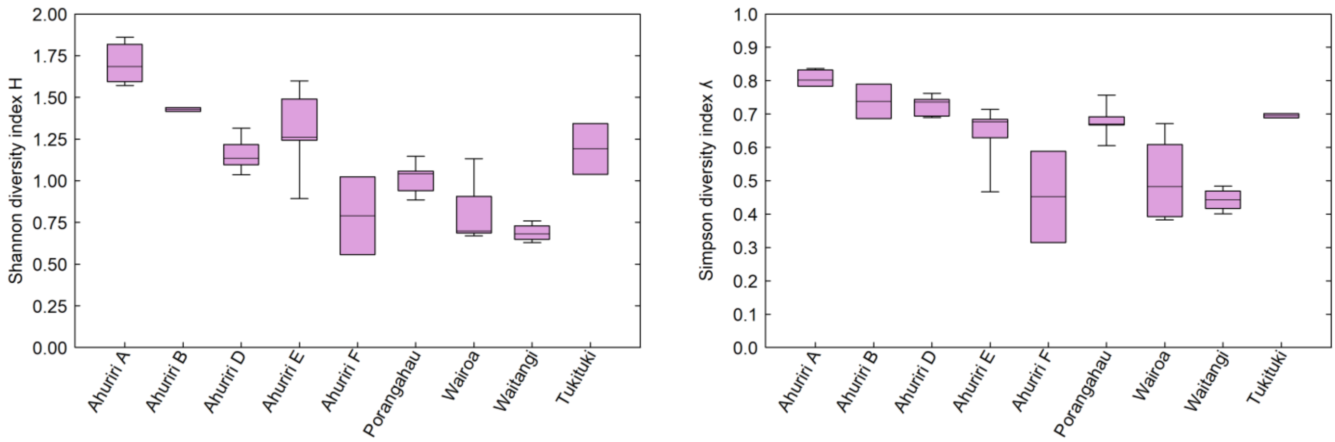


Figure 3-12: Shannon diversity and Simpson diversity index per core (0.013m^2) by estuarine site. Medians based on 5 years 2013-2018 (Ahuriri A, D, E, Pōrangahau, and Wairoa), 4 years (Waitangi), 3 years (Ahuriri B, F), 2 years (Tukituki). Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles.

Pōrangahau and Wairoa reported decreasing trends in Shannon diversity over the monitoring period, while diversity at Ahuriri A appears to be increasing (Table 3-18).

Table 3-18: Trend analysis of Shannon diversity index for estuary infaunal samples per core (0.013m2). Statistically significant trends are indicated in **bold**.

Site	n	Shannon diversity (H')		
		Median	Trend p value	Percent Annual Change
Ahuriri A	144	1.568	**0.008**	**1.590**
Ahuriri B	120	1.363	0.392	-1.008
Ahuriri D	144	1.230	0.094	-1.226
Ahuriri E	120	1.187	0.356	-1.328
Pōrangahau	155	1.179	**0.006**	**-2.237**
Wairoa	96	0.890	**0.040**	**-4.105**

Shannon and Simpson diversity index use slightly different arithmetic processes to derive the index result[5], however, the relative patterns appear similar. Simpson diversity appeared highest at sites Ahuriri A, B, D and Pōrangahau with scores of 0.78, 0.72, 0.73 and 0.72 respectively and lowest at Ahuriri F, Wairoa and Waitangi with 0.52, 0.55 and 0.44 respectively.

Trend analysis for Simpson diversity detected the significant increase observed in Shannon diversity at Ahuriri A, but did not detect the declines observed at Pōrangahau and Wairoa (Table 3-19).

Table 3-19: Trend analysis of Simpson diversity index for estuary infaunal samples per core (0.013m2). Statistically significant trends are indicated in **bold**.

Site	n	Simpson diversity (λ)		
		Median	Trend p value	Percent Annual Change
Ahuriri A	142	0.782	**0.000**	**1.132**
Ahuriri B	120	0.715	0.572	-0.387
Ahuriri D	144	0.731	0.031	-0.953
Ahuriri E	120	0.606	0.592	0.531
Pōrangahau	153	0.717	0.172	-0.817
Wairoa	94	0.548	0.673	-0.850

[5] Simpson diversity index uses the squared result of the proportional abundance of interest itself as the weighting, whereas Shannon diversity index uses the natural log of the proportional abundance of interest for weighting.

3.5 Results - Multivariate Infaunal Analyses

The high variability of estuarine community assemblages through time was visually assessed using non-metric multi-dimensional scaling (nMDS). The nMDS plots presented in Appendix C show little visually identifiable separation by year for sites Ahuriri A, Ahuriri D, Ahuriri E and Pōrangahau. This is supported by the relatively high 'stress[6]' reported for these plots (0.21-0.23) which indicates this is not a good fit for the model. However a PERMANOVA did detect significant differences in the community structure between years for individual sites (Table 3-20). *A posterior* pairwise comparison determined which years were significantly different.

nMDS of all years by site highlights that 'site' is the best determining factor for variability of infauna. This indicates that the specific infaunal assemblage of each site is characteristic, and similar between years (Appendix C).

Table 3-20: PERMANOVA results examining the effect of year on individual sites. All data ln(x+1) transformed and based on Bray-Curtis[7](Bray and Curtis, 1957).

Site	PERMANOVA (Site by Year)		
	SS	p(perm) value	Pairwise
Ahuriri A	89978	0.001	All (58/66) except 2009:2012,13, 2012:2013,15, 2013:2015, 2014:2015,18, 2015:2018
Ahuriri B	68908	0.001	All (37/45) except 2006:2008,2007:2008,13,14, 2009:2011, 2012:2013,14, 2013:2014
Ahuriri D	50160	0.001	All (34/66) except 2007:2008, 2008:2014, 2009:2011,12,13,14,16,17, 2011:2012,14,16,17, 2012:2013,14,15,17,18, 2013:2014-18, 2014:15-18, 2015:16-18, 2016:17-18, 2017:18
Ahuriri E	64197	0.001	All (41/45) except 2009:2011, 2015:2016, 2016:2017, 2017:2018
Pōrangahau	13838	0.001	All (77/78) except 2013:2014
Wairoa	66446	0.001	All (27/28) except for 2017:2018
Waitangi	11287	0.001	All (only 3 sample occasions)
Tukituki	6343.5	0.001	All (only 2 sample occasions)

While nMDS plots did not show stark groupings based on years (Appendix C), a PERMANOVA did detect significant differences in the community structure between years for individual sites (Table 3-20). This is likely due to the high stress observed in the nMDS which indicates that this is not a good representation of the data. *A posterior* pairwise comparison noted exceptions to these differences. This confirms the high temporal variability in estuarine community assemblages.

A two-way PERMANOVA on the combined dataset revealed significant differences between all years and all sites, with a significant interaction factor indicating that each site was affected differently in each year (Table 3-21).

[6] 'Stress' levels in MDS represent a 'goodness of fit' of the data to the model.
[7] In ecology and biology, the Bray–Curtis dissimilarity is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site.

Table 3-21: PERMANOVA results examining the effect of year and site. All data ln(x+1) transformed and based on Bray-Curtis similarity.

Factor	PERMANOVA (All Sites/All Years)		
	SS	p(perm) value	Pairwise
Year	170080	0.001	All years
Site	972460	0.001	All sites
Year*Site	376820	0.001	'Year' affects sites differently

A SIMPER analysis was undertaken using the complete dataset (all sites, all years) based on the factor site. SIMPER analysis identifies the importance of specific taxa in accounting for the variability (or similarity) between individual sites. The species that 'characterise' a particular site contribute to ≤90% of the similarity.

At sites where mud content is relatively low (sites Ahuriri A and Ahuriri B), the species that characterise these sites tend to be those intolerant or sensitive to muds (Table 3-22). *Macomona liliana* (wedge shell) has been shown to have an optimal mud concentration of 16.7%, while the cockle, *Austrovenus stutchburyi*, has an optimal concentration of 11.5% (Anderson, 2007). Interestingly, at those sites where mud concentrations were moderate-high (~20-40% - Ahuriri D and E), *Austrovenus stutchburyi* were still fairly abundant (see Figure 3-13). However, at these sites, species that more commonly reach optimal abundance with higher mud concentrations such as *Helice crassa* (41.2% mud; Anderson 2007), and *Scolecolepides sp.*(25-30% mud; Norkko, 2002), were also species that explained more than 90% of the variability within the site. When mud concentrations exceeded 40%, species with known tolerances for high mud content became more common (e.g. *Arthritica* bifurca (55-60% mud) and *Paracorphium excavatum* (95-100%)).

Table 3-22: Species responsible for up to 90% of the similarity in a site.

Species	Ahuriri A (Av. Sim. 40%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Macomoa liliana	1.86	13.28	1.45	33.15	33.15
Austrovenus stutchburyi	1.39	8.90	1.18	22.22	55.37
Aonides trifida	1.52	6.94	0.87	17.33	72.70
Nicon aestuariensis	0.63	2.68	0.63	6.70	79.40
Heteromastus filiformis	0.70	2.02	0.52	5.04	84.44
Helice crassa	0.35	1.14	0.32	2.86	87.30
Prionospio sp.	0.41	1.07	0.41	2.68	89.98
*Scolecolepides sp_*	0.29	0.91	0.30	2.27	92.24
Species	Ahuriri B (Av. Sim. 41%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Austrovenus stutchburyi	1.96	21.0	1.55	51.02	51.02
Macomoa liliana	1.44	10.98	1.02	26.67	77.69
Aonides trifida	0.84	2.66	0.53	6.46	84.15
Helice crassa	0.33	1.60	0.32	3.89	88.05
Nicon aetuariensis	0.37	1.06	0.35	2.57	90.61
Species	Ahuriri D (Av. Sim. 47%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Austrovenus stutchburyi	1.32	17.76	1.30	38.06	38.06
Helice crassa	1.05	14.09	1.11	30.18	68.24
Scolecolepides sp.	0.79	7.85	0.81	16.83	85.07
Nicon aestuariensis	0.61	5.68	0.67	12.18	97.25
Species	Ahuriri E (Av. Sim.47%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Austrovenus stutchburyi	3.04	28.22	2.67	60.69	60.69
Helice crassa	1.04	6.71	0.92	14.42	75.11
Elminius modestus	0.63	2.27	0.49	4.87	79.98
Aonides trifida	0.72	2.24	0.55	4.82	84.81
Notoacmea helmsi	0.51	1.33	0.41	2.85	87.66
Nicon aestuariensis	0.36	1.21	0.43	2.60	90.26
Species	Ahuriri F (Av. Sim.60%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Nicon aestuariensis	2.46	27.76	2.07	45.92	45.92
Halopyrgus (Potamopyrgus) estuarinus	2.14	26.53	1.88	43.88	89.80
Paracorphium excavatum	0.76	4.57	0.60	7.56	97.36
Species	Pōrangahau (Av. Sim. 29%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Scolecolepides sp.	1.14	11.15	0.85	37.87	37.87
Nicon aestuariensis	0.76	6.99	0.72	23.73	61.60
Arthritica bifurca	0.80	4.63	0.46	15.73	77.33
Austrovenus stutchburyi	0.43	2.76	0.39	9.36	86.68
Helice crassa	0.31	2.19	0.35	7.43	94.12
Species	Wairoa (Av. Sim. 52%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Nicon aestuariensis	2.11	23.08	1.84	44.41	44.41
Halopyrgus (Potamopyrgus) estuarinus	1.71	11.93	0.87	22.95	67.36
Scolecolepides sp.	0.98	8.17	1.02	15.73	83.09
Paracorphium excavatum	1.55	7.94	0.69	15.28	98.37

Species	Waitangi (Av. Sim. 49%)				
	Av. Abund	Av. Sim	Sim/SD	Contrib %	Cum. %
Paracorphium excavatum	3.10	18.99	1.24	38.71	38.71
Halopyrgus (Potamopyrgus) estuarinus	2.83	16.62	1.03	33.89	72.61
Nicon aestuariensis	1.01	9.93	1.06	20.25	92.85

3.6 Results - Species Distributions across Mud Gradients

As observed in Table 3-22, the dominant species for each site closely relates to known mud tolerances for many of the more sensitive species. Sites Ahuriri A and B which have low levels of mud, tend to be dominated by species with known preference for low mud (e.g. *Macomona liliana).* Interestingly site Ahuriri E contains species both sensitive to high mud content (e.g. *Austrovenus stutchburyi* and *Aonides trifida*), as well as those typical of more sediment disturbed areas (e.g. *Helice crassa*). This site has the most abundance of cockles of all the sites sampled and also contains significant portions of shell hash (average 18%) which may act to moderate some of the effects of the mud.

This is supported by site Ahuriri E being the only site with moderately high mud content to contain significant numbers of cockles (*Austrovenus stutchburyi* - Figure 3-13)

Negative binomial regressions[8] evaluated the relationship between mud content and species abundances. The results confirmed a negative relationship between species abundance and mud content for the cockle *Austrovenus stutchburyi* (χ^2=254.59, p<0.0001), the polychaete worm *Aonides trifida* (χ^2=307.31, p<0.0001), the bivalve *Macomona liliana* (χ^2=386.33, p<0.0001) and the spionid polychaete *Scolecolepides spp.* (χ^2=42.938, p<0.0001).

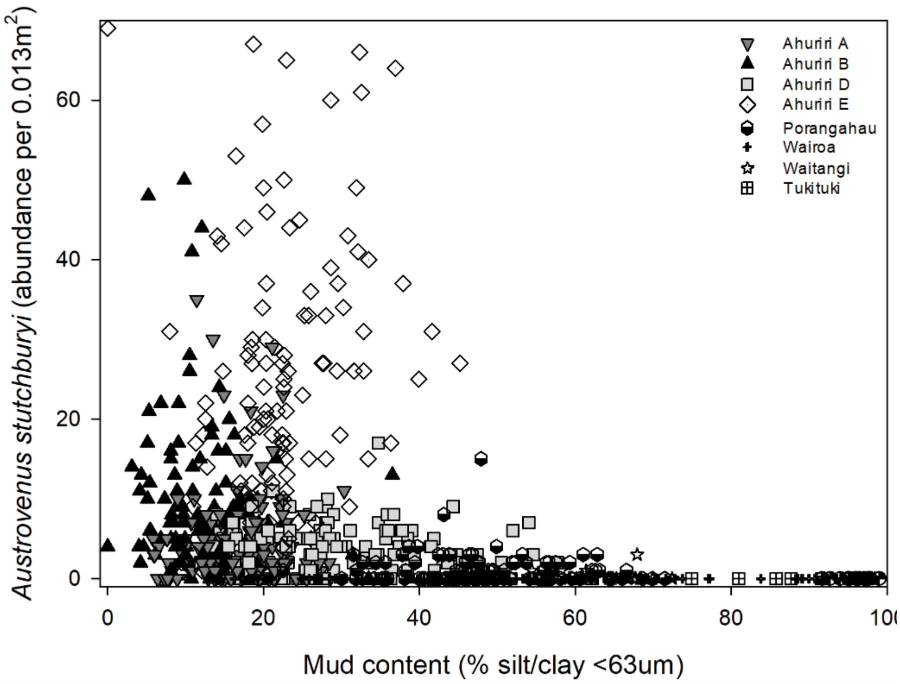


Figure 3-13: Abundance of cockle (*Austrovenus stutchburyi*) per core as a factor of mud content (% silt/clay).

[8] Negative binomial regressions were used because data was over dispersed.

In general all species/site relationships corresponded well to those expected for varying silt/clay (mud) concentrations. Mud sensitive species such as *Aonides trifida* (Figure 3-14) and *Macomona liliana* appear in high abundance at sites where mud content tends to be below 25% (Figure 3-15). This indicates a loss of species in Hawke's Bay estuaries where mud concentrations exceed 25%. These species are valued as an important food source for fish and birds, and play an influential role in the community and ecosystem dynamics including nutrient cycling (Thrush, 2006) and bioturbation (Volkenborn, 2012), therefore loss of these species can have concomitant effects on site health and integrity.

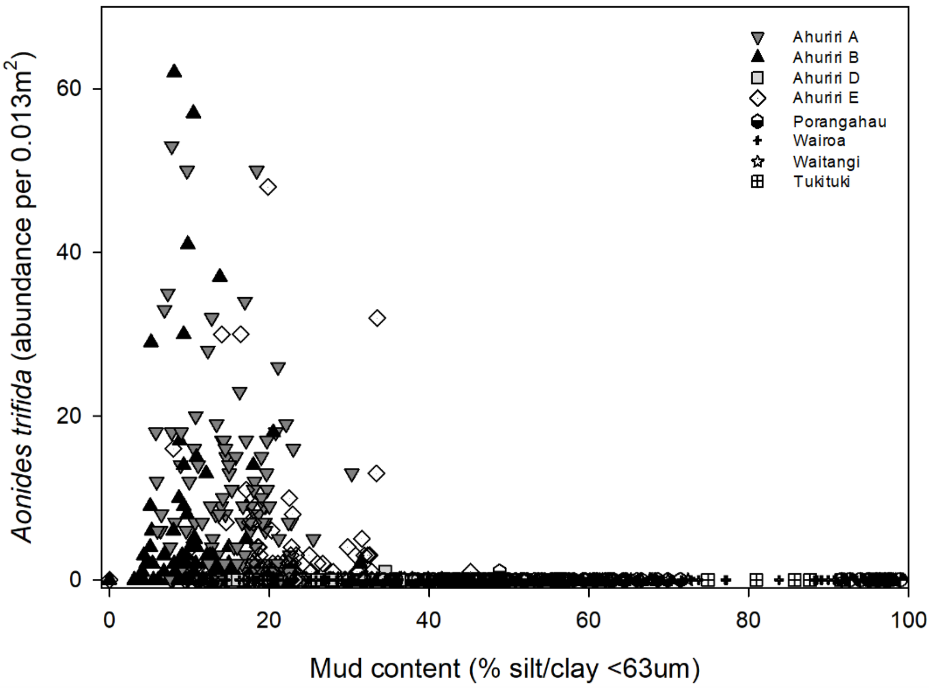


Figure 3-14: Abundance of *Aoinides trifida* per core as a factor of mud content (% silt/clay).

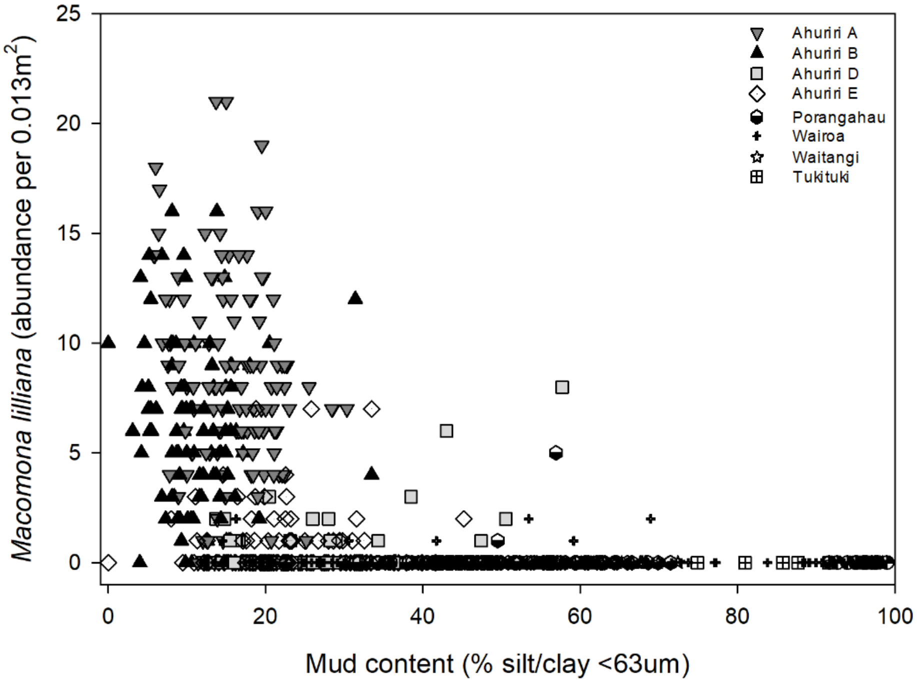


Figure 3-15: Abundance of the bivalve *Macomona liliana* per core as a factor of mud content (% silt/clay).

Mud tolerant species such as the spionid polychaete *Scolecolepides spp.* again follow expected patterns with the highest concentrations found at Pōrangahau Estuary, and in sediments with a mud content around 35-70% (Figure 3-16). This is slightly higher than the published optimal range for this species at 25-30% mud (Norkko, 2002). Interestingly, if Pōrangahau results are removed, the highest abundance falls well within the published optimal range.

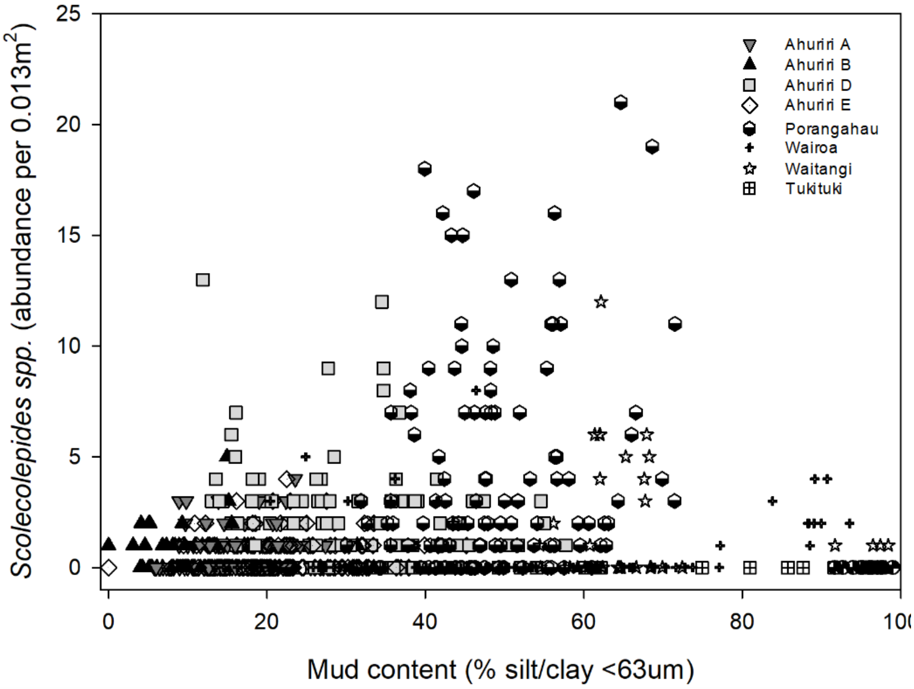


Figure 3-16: Abundance of the spionid polychaete *Scolecolepides spp*. per core as a factor of mud content (% silt/clay).

In addition to the sediment composition being an important driver in macrofaunal assemblages, deposition events of land-based sediments can have a dramatic effect on the community. Events that deposit as little as 3mm of sediment <63µm in size, can have observable effects on the community structure (Lohrer, 2004) and are likely to be pervasive throughout New Zealand.

3.7 Conclusions

Hawke's Bay estuaries are the receiving environment for the land and freshwater based catchments. In these areas sediments and contaminants can settle out, compromising the function of estuarine areas.

Sediment stress is one of the key issues observed through estuarine state of the environment monitoring. Moderate sediment stress was observed at sites in the middle Ahuriri Estuary (Ahuriri A and B – median mud content of 12.4% and 16.4% respectively), with higher levels of sediment stress likely at sites in the lower Ahuriri (Ahuriri D and E - median mud content of 26.7% and 22.4% respectively). Of concern, the sites with only moderate sediment stress also reported increasing trend in mud content, indicating that they may become more sediment stressed over time. The upper Ahuriri Estuary (Ahuriri F) had the highest level of sediment stress with a median of 97% mud content.

Similarly, other regional estuaries also showed high levels of sediment stress with median levels ranging from 47.0% to 65.6% (Wairoa and Waitangi Estuaries respectively).

A comparison with 25 estuaries throughout New Zealand (Robertson et al., 2015) indicates that these Hawke's Bay estuaries comprise some of the higher sediment mud content (silt/clay %) recorded when compared to the published dataset.

Sediment nitrogen levels in the lower Ahuriri, Pōrangahau and Wairoa were not indicative of excessive eutrophication, however Waitangi and Tukituki Estuaries reported levels of sediment nitrogen that would indicate moderate stress, and Ahuriri F (upper Ahuriri) reported levels at which significant, persistent stress was likely. At this level a loss of ecological integrity may occur.

Several estuaries suggested enrichment of sediments by phosphorus which may equate to a high risk of eutrophication. These include Ahuriri F, Waitangi and Tukituki estuaries. Whether these estuaries express eutrophication symptoms or not will depend on the nutrient ratio and uptake at a specific site, however these estuaries did not appear to have high levels of sediment chlorophyll *a* or total organic carbon, suggesting that phosphorus levels were not contributing to expressions of eutrophication. That said, further work is required to understand potential impacts of these phosphorus levels on estuarine health.

Although levels of measured 'priority' toxicants were below ANZECC guidelines for sediment health (excepting zinc), ecotoxicological studies undertaken over the past decade have demonstrated lethal and sub-lethal effects on animals living with the sediment at several sites flowing into the Ahuriri. It is possible that the toxicity observed is due to synergistic or additive effects of contaminants, or due to contaminants that are not monitored as part of the USEPA priority suite. Further work should be undertaken to identify baseline concentrations of contaminant of emerging concern.

The infauna associated with individual estuary sites appears to be responding to mud concentrations. Ahuriri F and Waitangi estuaries which reported the highest mud concentrations, had low species richness, evenness and diversity compared to other estuaries. The community at these sites was driven by species such as *Paracorphium excavatum*, *Halopyrgus estuarinus* and *Nicon aestuariensis* which are more tolerant to higher extents of mud content (Robertson et al., 2015). Conversely, sites where sediment mud content was lower, were characterised by species such as *Macomona liliana* and *Aonides trifida* which are intolerant of high mud content.

Species distributions across mud gradients largely conformed to the patterns expected from known tolerances to mud content, and indicates the loss of some species at sites where mud content exceeds thresholds for species. This is likely to have effects on the overall function and services of estuaries where this loss is occurring.


Estuarine Fish

4 Estuarine Fish

Estuaries play a significant role in the life-cycles of many fish species, providing nursery areas for juveniles, spawning habitats and feeding areas for many species. They are an important migratory route for diadromous fish species, and play an important role in cycling nutrients through the food chain.

Water quality and habitat integrity is essential to maintain the role of the estuary within the lifecycle of fish. Lowe (2013) found that large-scale environmental changes within estuaries affected the functioning of snapper nursery areas both directly (reducing the fitness of individual fish) and indirectly (by reducing the area of biogenic habitats). There have undoubtedly been large habitat changes in both the Ahuriri and Waitangi Estuaries, although the impact of these changes on fish populations is unknown.

Estuaries are important areas for both customary and recreational fishing which rely on the health of spawning, nursery and feeding habitats. The importance of these areas is exemplified by there being several monitoring and restoration programmes in these areas.

4.1 Methods

Sampling was conducted quarterly and around the low tide. At each estuary, sites were chosen to encompass a large geographic spread and potentially differing habitat types. At each site, samples were collected using a fine mesh (6mm) beach seine net ten metres long with a three metre drop. Three replicate tows were taken with one end of the net anchored on the shore and the other walked around in a semi-circular motion, pulling the net into the wind and/or current. After each tow, all fish were identified, measured (to fork length), weighed, and released. To date, fish populations have been monitored in three regional estuaries.

All data collection and analyses were undertaken in accordance with internal quality assurance and quality control processes and procedures.

Ahuriri Estuary

The Ahuriri Estuary is the most intensely studied estuary within Hawke's Bay due to its close proximity to Napier, and development plans in the latter part of the 20th century. The first recorded fish monitoring was undertaken by (Kilner and Akroyd, 1978) which identified over 20 species of fish in the estuary, with a further nine records from anecdotal evidence. A 2008 study replicated the sampling methodology (Ataria et al., 2008), and reported 16 species over the sampling period (Table 4-1).

Monitoring was undertaken at three sites within the Ahuriri Estuary over six sampling occasions from January 2015 to August 2016. A total of 1106 individual fish were caught, measured, identified and returned to the estuary.

Waitangi Estuary

The Waitangi Estuary supports an important customary fishery for the black flounder (*Rhombosolea retiaria).* The degradation of the fishery has led to the establishment of a black flounder monitoring programme by Kohupatiki Marae. The programme monitors flounder numbers using gill nets, and captured fish are tagged, weighed and released.

State of the Environment monitoring was undertaken at one site within the Waitangi Estuary over four sampling occasions from January 2017 to January 2018. A total of 526 individual fish were caught, measured, identified and returned to the estuary.

Pōrangahau Estuary

Monitoring was undertaken at two sites within the Pōrangahau Estuary over four sampling occasions from March 2018 to April 2019. A total of 951 individual fish were caught, measured, identified and returned to the estuary.

Table 4-1: Reported fish species caught in the Ahuriri Estuary based on Kilner and Ackroyd, 1978; Ataria, 2018 and HBRC Monitoring.

	Akroyd and Kilner 1978	Ataria et al., 2008	HBRC Monitoring
Observed species	Long-finned eel		
	Short-finned eel	Short-finned eel	Short-finned eel
	Sand flounder	Sand flounder	Sand flounder
	Yellow bellied flounder	Yellow bellied flounder	Yellow bellied flounder
	Yellow eyed mullet	Yellow eyed mullet	Yellow eyed mullet
	Spotted stargazer		Spotted stargazer
	Common sole		Common sole
	Common smelt	Common smelt	Common smelt
	Spotty	Spotty	Spotty
	Black flounder		Species not caught
	Parore	Parore	
	Kahawai	Kahawai	
	Grey mullet	Grey mullet	
	Cockabully	Cockabully	
	Common bully	Common bully	
	Inanga	Inanga	
	Trevally	Trevally	
	Red cod		
	Gurnard		
	Garfish		
	Species not caught	Herring	
		Wrasse	
			Leather Jacket
			Rainbow trout
			Anchovy
		Clingfish	Clingfish
			Gambusia
			Estuarine triplefin
			Sand stargazer
Number of species	**20**	**16**	**15**
Reported but not observed	Snapper		
	Moki		
	Spiny dogfish		
	School shark		
	Skate		
	Brown trout		
	Barracouta		
	Blue mackerel		
	Kingfish		

4.2 Results – Estuarine Fishing

By far the most dominant species caught at each of the three estuarine fishing sites was the yellow mullet, *Aldrichetta forsteri*. This species made up 46%, 64% and 75% of the catch at the Ahuriri, Waitangi and Pōrangahau estuaries respectively (

Figure 4-1).

State of the Environment monitoring has recorded 16 species of fish using the Ahuriri Estuary. This is similar to the numbers observed by Ataria et al. (2008), but lower than the 20 species observed by Kilner and Ackroyd (1976). Most of this difference can be explained by the differences in fishing techniques used by the studies, which included a number of different nets in the 1976 study, including fyke, gill, dip and whitebait nets. The species not encountered in the current study are generally those larger, faster moving species which may be able to avoid the seine net

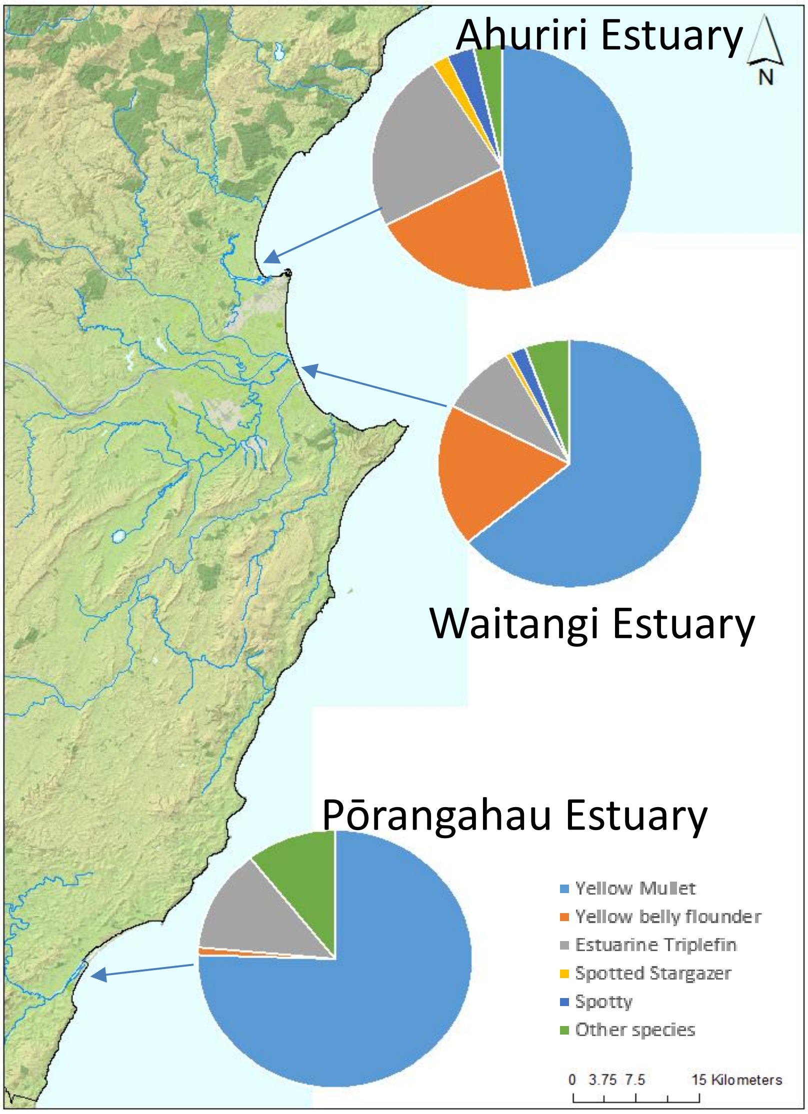


Figure 4-1: Proportion of fish in the top 5 species caught in Ahuriri, Waitangi and Pōranghau estuaries. Data from 2015 to 2019. n=42 (Pōrangahau: 12, Waitangi: 12, Ahuriri: 18)

The capture of juveniles of leather jacket, anchovy and sand stargazer (species not previously encountered) along with juveniles of many other species confirms the role of the estuary as a nursery area for a variety of species.

4.3 Conclusions

Estuaries play a significant role in various life history stages of fish species, and are support cultural and recreational fisheries, while contributing to offshore fisheries stock.

Estuarine fish monitoring is a relatively new programme for Hawke’s Bay Regional Council, and the results presented here provide the first insight into fish populations across estuaries. The most dominant species caught was the yellow mullet, *Aldrichetta forsteri,* which made up between 46% and 75% of the fish caught through the monitoring period.

It is recommended that this programme is reviewed, and that the objectives of the programme inform the monitoring and fishing techniques to better represent the usage of different habitats within the estuary.

Sandy beaches

5 Sandy Beaches

Sandy beaches dominate the Hawke's Bay coastal area, making up 48% of the coastal habitats (Stevens and Robertson, 2005). As a source of recreation, scenic views, and cultural identity, sandy beaches are highly valued ecosystems (Dugan and Hubbard, 2016). Despite this, recognition of the role sandy beach ecosystems play has generally lagged behind the understanding of other coastal environments (Defeo and McLachlan, 2005; Nel et al., 2014). Sandy beaches store and transport sediment, dissipate waves, break down organic materials, filter large volumes of seawater, cycle nutrients, provide nesting, foraging, and nursery areas, and serve as a buffer zone, protecting the terrestrial edges from the sea (Schlacher et al., 2008, Defeo et al., 2008).

In spite of their often sparse appearance, sandy beaches support a range of fauna and coastal fisheries (Schlacher et al., 2013). The environment between grains in the sand provide habitat for a number of small organisms (bacteria, protozoans, and meiofauana) and larger invertebrates (crustaceans, molluscs, polychaete worms), while shorebirds nest in the berms. Dune vegetation provides habitat and food for a variety of native birds, reptiles and insects, including moths and the katipo spider in New Zealand.

Like other coastal environments, sandy beaches are dynamic, and the biota within them are subjected to a number of pressures. Tidal inundation alone causes substantial changes in oxygen, temperature, salinity, and varying wave force and swash environments. Many species found in beach environments are not found elsewhere because of their specific adaptations for life on sandy beaches (Schlacher et al., 2008).

Sandy beaches face a number of external pressures that compromise the integrity of communities therein and reduce the ecosystem services provided by, and the resilience of, these habitats. Natural environmental pressures associated with sandy beach ecosystems can sometimes be augmented or even eclipsed by the effects of both on-beach and adjacent land-based activities.

Threats to sandy beach ecosystems in Hawke's Bay include vehicle traffic which can negatively impact populations of infaunal species, lower habitat stability, and damage dune vegetation (Defeo et al., 2008; Schlacher et al., 2013); decreased biomass through food collection; disturbance of nesting shorebirds; and litter which can entangle organisms or be ingested (Defeo et al., 2008; Turra et al., 2014)

The development of coastal areas for residential use is a burgeoning trend in many parts of New Zealand, and in the Hawke's Bay Region, with over 350km of coastline, this trend is currently being realised (e.g. Waipatiki, Opoutama, Mahia, Mahanga). At beaches with coastal development on one side and sea level rise on the other, coastal squeeze is likely to influence sandy beach communities (Defeo et al., 2008; Schlacher et al., 2008).

Sandy beach monitoring was implemented in 2007 to:

- Provide baseline information relating to soft-shore beach biodiversity;
- Assess benthic community state and health in terms of species richness and relative abundance; and
- Monitor Council's progress towards achieving the objectives set for specific Significant Conservation Areas.

5.1 Methods

Monitored beaches were selected to represent soft-sediment ecosystems within the Hawke’s Bay region (Figure 5-1; Table 5-1). Selection was guided by the results of an inventory of beach and reef systems within Hawke’s Bay (Madarasz-Smith, 2007b).

Sites were selected according to the following criteria:

- Beach type being suitable for monitoring over time;
- Contributing to regional knowledge of soft-sediment communities; and
- Likelihood of development in the short to medium term.

Figure 5-1: A) Map of sandy beach monitoring sites, B) Photo of Pourerere Beach, C) Photo of Opoutama Beach, D) Photo of Mahanga Beach.

Table 5-1: Sandy beach sites included in the Soft-Sediment Ecological Monitoring Programme.

Beach	Sampling years	Mean Wave Height[9]	Sediment type	Development status
Mahanga	2007-2008; 2013-2014	Moderate	Medium	Existing baches and new development approved
Opoutama	2009-2013; 2015-2016; 2018	Moderate	Medium/Coarse	Previously subdivided and recent development of a number of baches
Rangaiika	2016-2015; 2018	Moderate/ High	Medium	No development
Ocean Beach	2007-2008; 2013-2014	Moderate/ High	Medium	Existing baches to the south, no current development plans to the north.
Waimarama	2007-2008; 2015-2016	Moderate	Medium	Existing development, more pending, semi-urban.
Pourerere	2009-2012	Moderate/ High	Medium	Existing baches
Blackhead	2007-2008; 2013-2014	Moderate/ High	Medium	Small settlement of existing baches. Blackhead beach forms the southern end of the Te Angiangi Marine Reserve.
Pōrangahau	2017	High/Moderate	Medium	Existing baches only

Sandy Beach Infauna

Sampling at the selected beaches was designed to provide comparable information around the infaunal communities at different tide heights, years and where applicable, different levels of anthropogenic influence.

The initial aim of the sandy beach ecological monitoring programme was to provide information for trend detection in future years (*see* Madarasz-Smith, 2007c). However, results of inaugural sampling indicated low-abundance and highly variable communities, which would not be suitable for detecting trends over time in a statistically robust fashion. As a consequence, the objectives of the study were changed in 2008 to provide a robust baseline inventory (*see* Madarasz-Smith, 2008), while maintaining a BACI (before-after-control-impact) based design to allow for "development"/"control" analysis if appropriate in future years.

Benthic infauna were used to determine the state and health of the sandy beach community. They are commonly used as bio-indicators as they are relatively sedentary (i.e. cannot avoid adverse conditions) and have relatively long generation times, therefore integrate environmental conditions over time. Infaunal macroinvertebrates were sampled at three replicate sites within low and mid tidal heights (Figure 5-2). A circular PVC 130mm diameter corer (total area 0.013m^2) was manually driven into the sediment to approximately 150mm depth and removed with the core contents intact. The contents of the core were washed through a 0.5mm sieve mesh, and the animals retained were stored in 75% ethanol, before transportation to the laboratory for identification and enumeration.

[9] Derived from the Sandy Beach and Rock Platform Inventory found in the Hawke's Bay Coastal Inventory Report (2007b)

All data collection and analyses were undertaken in accordance with internal quality assurance and quality control processes and procedures.

Figure 5-2: Picture of Low and Mid transects from Ocean Beach. Note that this photo was taken during high tide and sites are exposed at low tide.

Dune Condition Index

Sand dunes make up 22% of the Hawke's Bay coastline (Stevens and Robertson, 2005). However, the condition of these sand dunes is currently unknown and their current extent is uncertain. One of the most pristine sand dune systems is at Rangaiika on the end of Cape Kidnappers and this is considered one of the best condition sand dune systems on the east coast of New Zealand (Walls, 2002).

Overall dune conditions were assessed using the dune condition index, a way of rapidly examining the ecological integrity of a dune system by describing the state of it and the pressures on it using aerial imagery. The dune condition index was developed by the Regional Sector's Biodiversity Working Group to determine the environmental quality of sand dunes in a standardised way. This technique scores the dune for a number of pressures and indicators:

- Presence of ungulates (hoofed mammals – cattle, deer, goats, horses, pigs and sheep)
- Presence of lagomorphs (rabbits and hares) & possums
- Presence of other predators (cats, hedgehogs, mustelids, rats and mice)
- Presence of dogs
- Problem plants (% aerial cover)
- Uncontrolled pedestrians (% area accessed)
- Vehicles (% area accessed)
- Mining (% area disturbed)
- Indigenous plant cover dominance (% aerial cover)
- Indigenous animal dominance (% of indigenous species)
- Unnatural vegetation disturbance (% bare sand)
- Buffering from surrounding land (highest % indigenous land cover class)
- Buffering from surrounding land (% aerial cover of class)

Each pressure and indicator was given a score between zero and five. A low score represents negative condition (e.g., large numbers of predators seen or low indigenous vegetation cover) and a high score represents positive condition (e.g., low predator numbers or limited vegetation disturbance). The scores were added up and compared against a possible maximum score of 65 to determine a percentage of condition. A pristine condition would be 100%.

Infaunal Diversity Analyses

Infaunal communities of organisms that inhabit sandy beaches are diverse and variable. To describe these communities in a way that helps us interpret their state and health, various community metrics and indices (collectively 'diversity indices') were used. These are described above in section 3.1.2 and were calculated using the PRIMER v6 'Diverse' routine (Clarke and Gorley, 2006).

Multivariate analysis

Using the complete dataset (all sites, all years), SIMPER analysis was used to compare between sites. SIMPER analysis identifies how important specific taxa may be in accounting for the variability between sites. The species that 'characterised' a particular site contributed to ≤90% of the similarity.

Species were grouped into five types to assess their abundance through time at each site and compare differences in infaunal communities between beaches. These types include marine worms, crustaceans, bivalves, marine snails, and other.

5.2 Results - Species Richness and Diversity

The concentration of infauna at the sampled sites was generally low in total number of species (S) with few individuals present (Figure 5-3). Results are comparable to previous results seen at these sites (Wade et al. 2016), with the median total S across all sites ranging from one to three species. Species numbers tended to be similar between tidal levels.

The median total number of individuals (N) ranged from two to twelve across tidal heights within sites. The maximum difference between tidal heights was 7.5 at Rangaiika beach. Blackhead was the only beach with more individuals in the mid zone compared to the low zone. Median number of individuals at Ocean, Opoutama, and Pourerere beaches only differed by zero or one individuals between tidal heights.

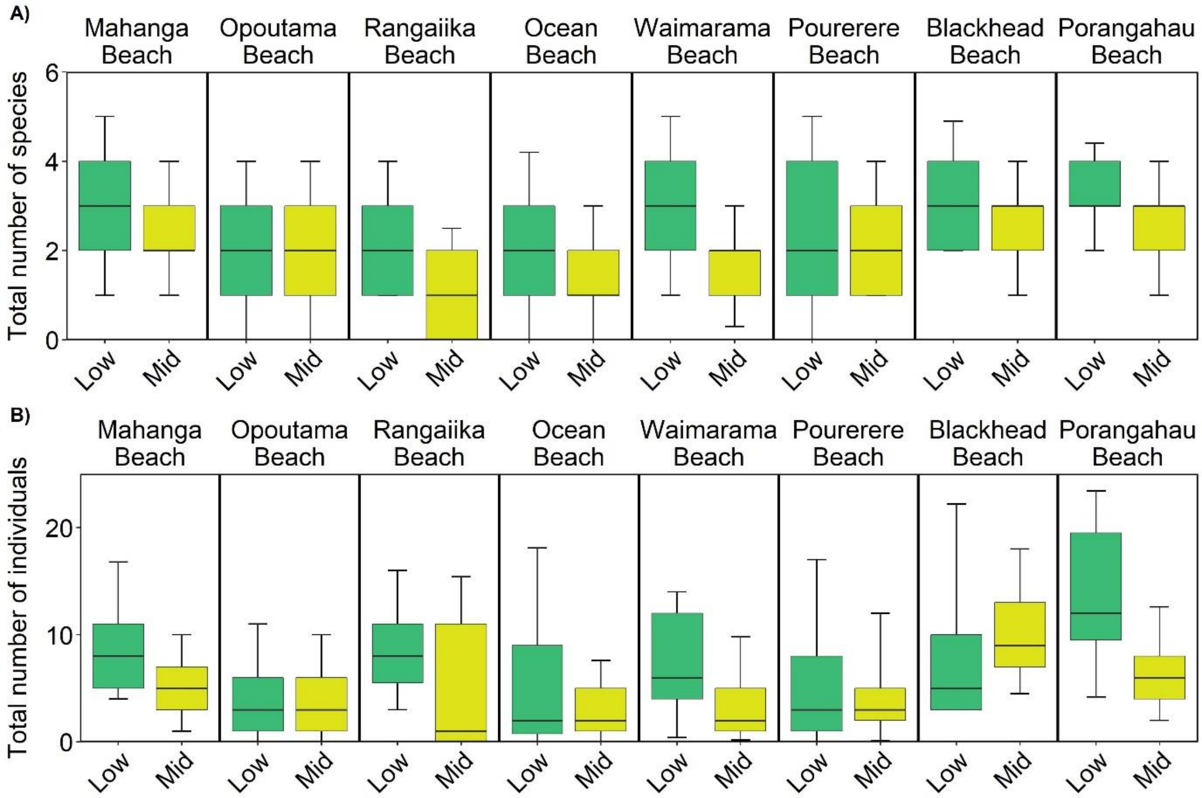


Figure 5-3: Medians (2008-2018) of A) Total number of species (S) and B) Total number of individuals (N) by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles**.** n=1126

Margalef's richness was higher in the low zone at all sites except for Pōrangahau beach (Figure 5-4). The greatest difference in richness between tidal heights was at Waimarama beach and the smallest differences were at Mahanga, Pourerere, and Pōrangahau Beaches. The low zone at Blackhead Beach had the highest median Margalef's richness while Ocean and Rangaiika Beaches had the lowest richness at the mid zone.

Peilou's Evenness was higher in the low zone at all sites except for Pōrangahau and Mahanga Beaches, although the difference at Mahanga Beach was negligible. The highest difference between low and mid tidal heights was at Waimarama Beach. The mid zone at Pōrangahau was most even while the mid zones at Ocean and Rangaiika Beaches were the least even.

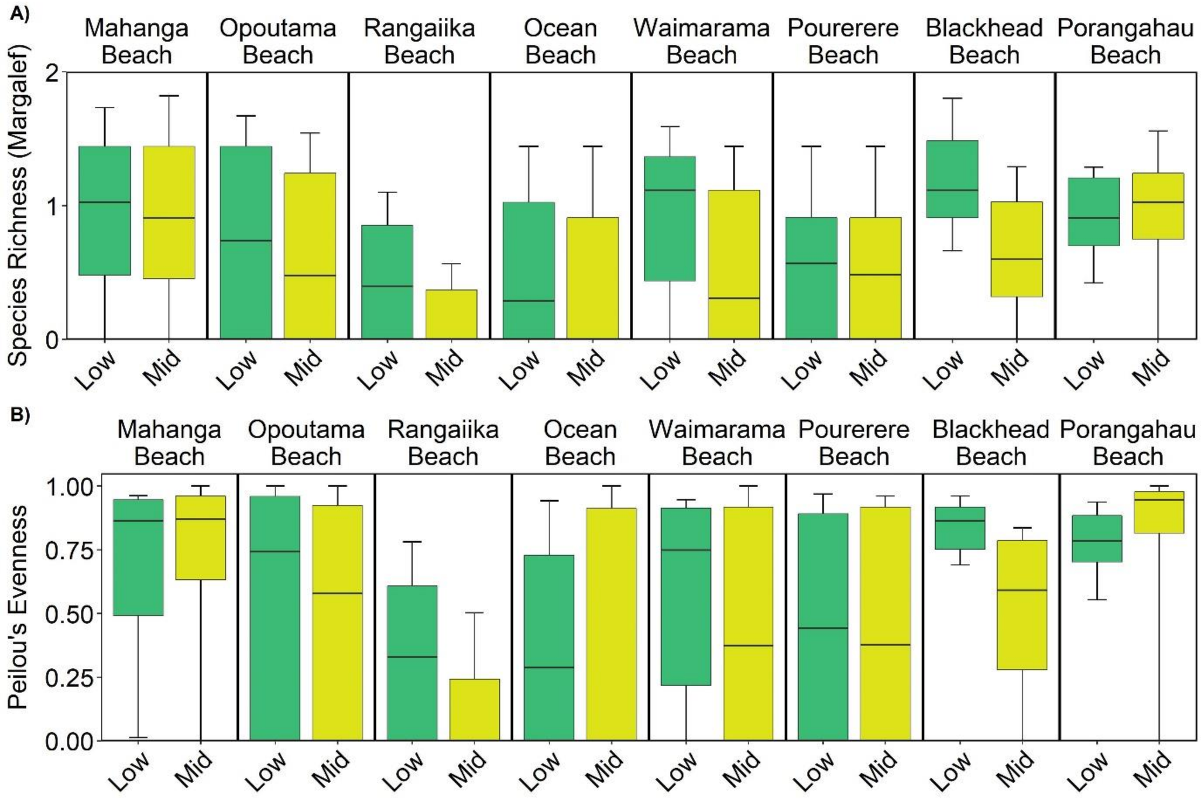


Figure 5-4: Medians (2008-2018) of A) Maragelf's species richness (d) and B) Pielou's evenness (J') by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. n=1126

Shannon's diversity was higher in the low zone at all beaches except for Pōrangahau (Figure 5-5). The largest differences between tidal heights were at Blackhead and Waimarama Beaches. The smallest difference between tidal heights was at Pourerere Beach. The low zone at Blackhead beach had the highest Shannon's diversity while the mid zones at Ocean and Rangaiika beaches were the least diverse.

Simpson's diversity shared a similar trend to Shannon's diversity. However, the smallest difference was at Mahanga Beach and the mid zone at Pōrangahau had the highest Simpson diversity.

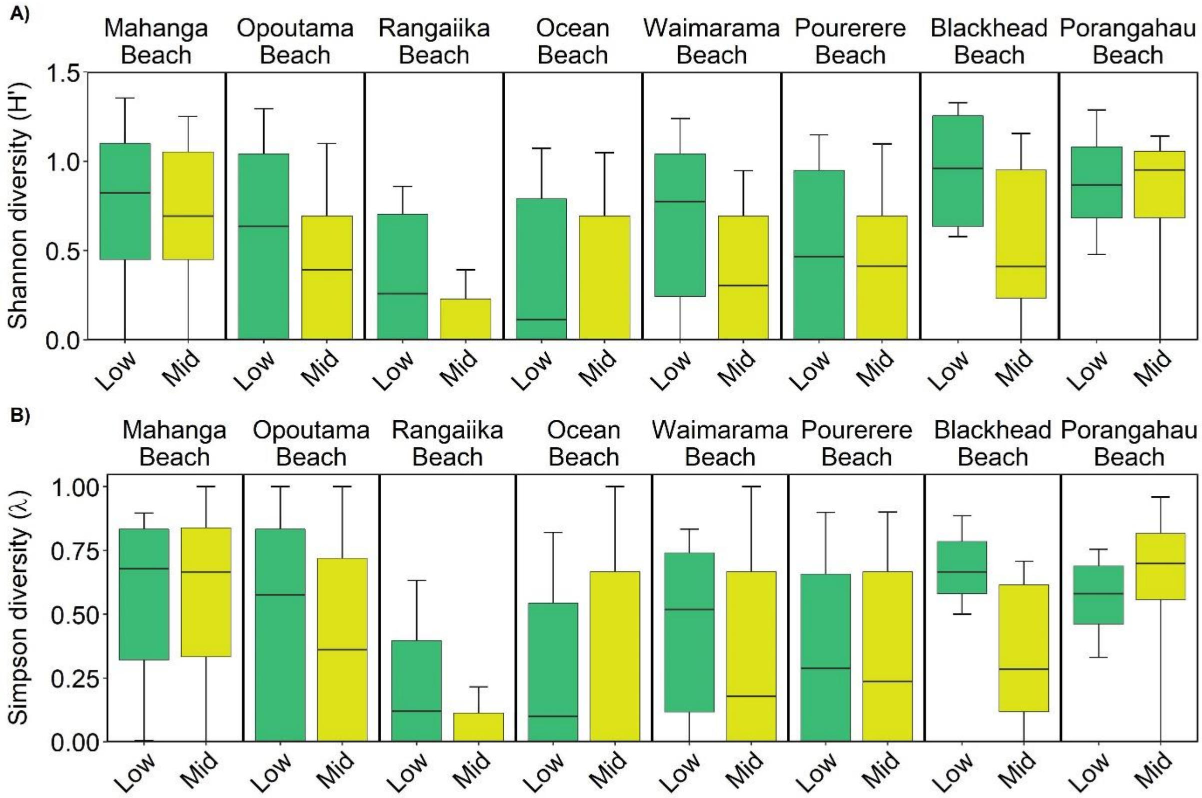


Figure 5-5: Medians (2008-2018) of A) Shannon diversity index (H') and B) Simpson diversity index (λ) by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. n=**1126**

Overall, cores taken from the low zone had more species, more individuals, were richer, were more even, and were more diverse compared to the mid zone. In areas influenced by tidal inundation, the low zone is expected to have a higher diversity because organisms spend less time out of the water between tides, although diversity indices can be similar between low and mid tidal heights (Scrosati et al., 2011). Waimarama Beach had the highest differences between low and mid zones while Mahanga and Pourerere Beaches were most similar between tidal heights.

Pōrangahau had higher richness, evenness and diversity in the mid zone compared to the low zone. Due to the depauperate and variable nature of sandy beach infaunal communities, the presence of only one species or a few individuals can influence overall diversity. A possible explanation for differences between tidal heights is differences in abundance between species (see Appendix – Table E-1). Low and mid tidal heights at Pōrangahau were 66.2% dissimilar, almost half of that dissimilarity was driven by differences in abundances of hooded shrimp (Cumacea) and *Waitangi chelatus*.

5.3 Results - Community composition

Investigating the frequency distribution of key groups of infauna revealed that communities varied greatly in abundance, species type, and distribution through time (Figure 5-6).

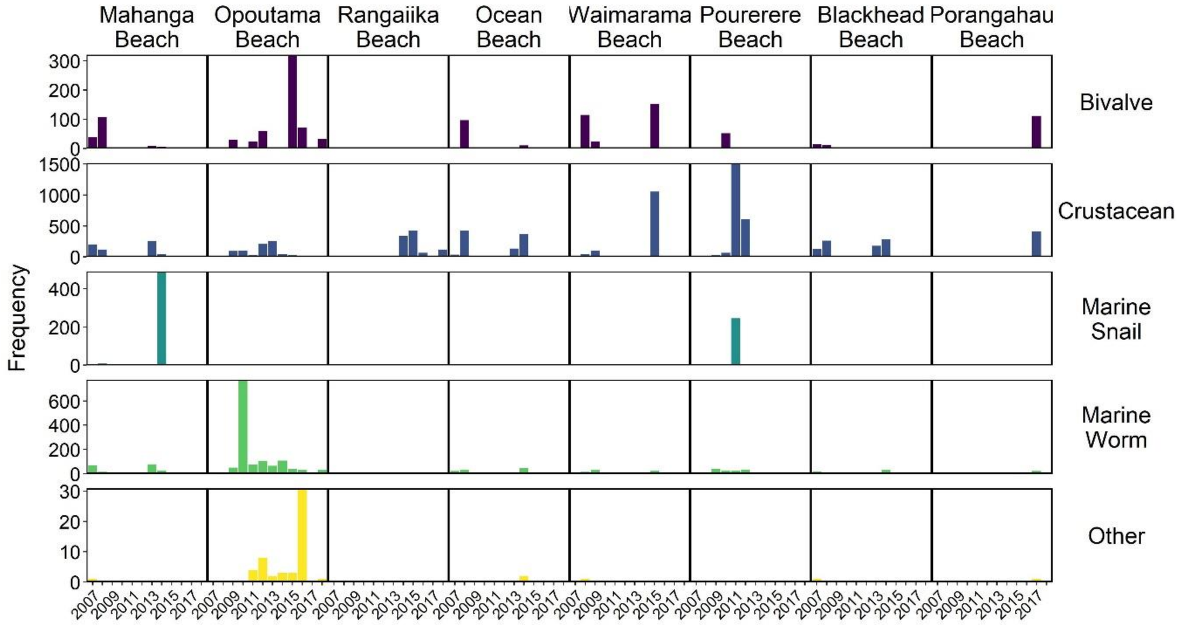


Figure 5-6: Frequency distribution (total number of individuals) of infaunal communities at each site for each year sampled. Organisms were divided into 5 groups: marine worms, crustaceans, bivalves, marine snails, and other. n=1126

SIMPER analysis revealed *Waitangi chelatus* was the most common species at Rangaiika, Ocean, Pourerere, Blackhead, and Porangahu beaches. Tuatua (*Paphies subtriangulata*) was recorded as the most common species at Mahanga and Waimarama beaches and second most abundant species at Pōrangahau beach. Toke moana (*Glycera ovigera*) was the most common species at Opoutama Beach. At all beaches, the most common species have remained similar to previous years (Wade et al., 2016), with the exception of Waimarama beach, which was formerly dominated by *W. chelatus*.

Waitangi chelatus is an amphipod species commonly found on beaches in New Zealand (Fincham, 1977). These amphipods are highly sensitive to silt/clay concentrations over 5% (Norkko et al., 2002) which likely explains their preference for open beaches and ability to tolerate a wide range of wave exposures. *W. chelatus* was most abundant at Rangaiika with average abundance of 1.9 individuals per core (see Appendix – Table E-2). Over time, crustaceans were the most abundant species type at all beach sites, likely due to the prevalence of this species, and other highly abundant crustaceans including hooded shrimp, *Patuki breviuropodus* (amphipod), and *Waitangi brevirostris* (amphipod; Figure 5-6).

The most common bivalve species, the tuatua, was present at all beaches except Rangaiika. Tuatua and juvenile green lipped mussels (*Perna canaliculus*) were the most abundant bivalves in cores over time. The presence of green lipped mussel spat in cores are likely to be seeking appropriate settlement habitat. Tuatua were most abundant at Waimarama beach with an average abundance of 0.6 individuals per core (see Appendix – Table E-2). Bivalves were the fourth most abundant species type over time at all beach sites.

The community composition at Opoutama Beach was quite different from the other beaches (see Appendix – Table E-2). Opoutama beach had the best representation of all species types over time with cores dominated by the polychaete worm *Glycera ovigera* and juvenile green lipped mussels. The community composition at Opoutama is likely to be driven by its natural depositional nature with large amounts of organic material present on the beach in the form of marine algae, wood chips and other material. This depositional environment is likely why green lipped mussel spat and *G. ovigera* are so prevalent at Opoutama beach. *G. ovigera* is a carnivorous polychaete worm which feeds on other smaller worms, such as Nematoda. These smaller worms are detrital feeders that play important roles in breaking down organic material that comes ashore and are most abundant at Opoutama beach.

Historically, all beaches in Hawke's Bay have been used for shellfish gathering for kaimoana. Currently, three species of edible shellfish are found in SOE monitored beaches of Hawke's Bay; ringed dosinia surf clam (*Dosinia anus*)*,* tuatua*,* and triangle shell surf clam (*Spisula aequilatera*). Edible shellfish were most often found in cores at Waimarama, Pōrangahau, and the low zone of Mahanga beach (Figure 5-7).

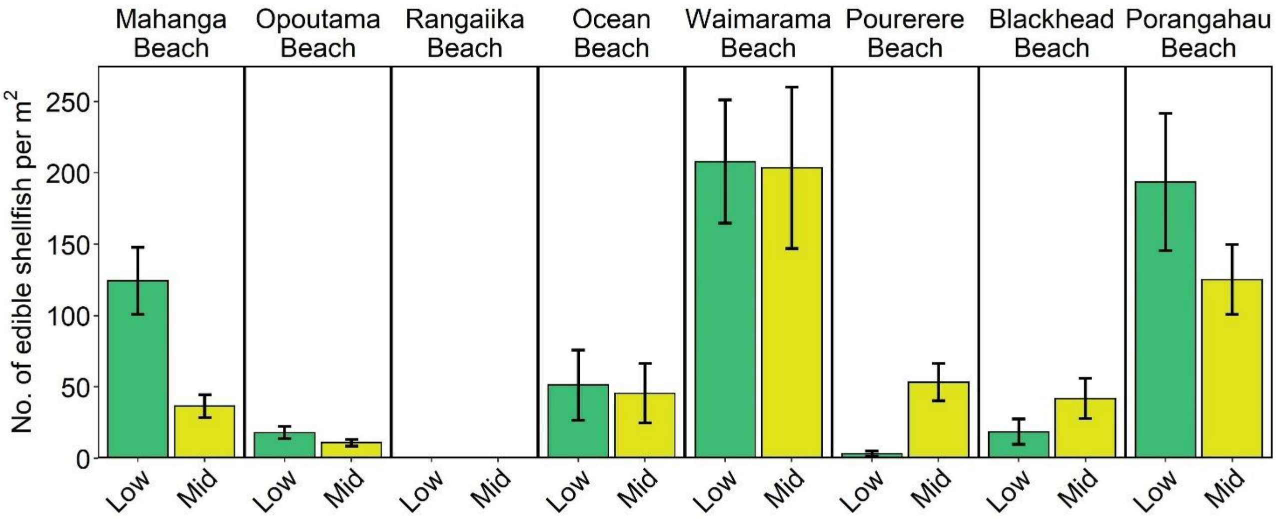


Figure 5-7: Mean abundance (±SE) of edible bivalve species recorded at each site scaled up to 1m². Edible bivavle species include *Dosinia anus* – Ringed dosinia surf clam, *Paphies subtriangula*ta - tuatua, and *Spisula aequilatera* – triangle shell surf clam. n=1088

Even though sandy beach species had variable and patchy distributions (Schlacher et al., 2008), there didn't appear to be major differences at sites over time. This is consistent with other, nearby beach sites in New Zealand (Robertson and Stevens, 2014, 2009; Stevens, 2018) and previous results at these sites (Wade et al., 2016).

5.4 Results - Dune condition

Mapping of vegetation within dune systems at Opoutama and Rangaiika demonstrated the dominance of sedge at both monitored beaches (Figure 5-8). Sedge includes 7 species, all native to New Zealand including the native Pīngao. Pīngao, the golden sand sedge, was once common on sand dunes throughout New Zealand and was highly prized by weavers for its golden colour. Pīngao is reported as declining from New Zealand dune systems due to grazing and trampling from animals, and competition from introduced plant species, such as the marram grass. Pīngao provides for the active transport of sand from the dune to the nearshore environment and back, which supports a healthy sand budget. Introduced grasses such as marram act to trap sand, meaning that it can become undercut from large swells. Of the 52 species of vegetation at Opoutama and Rangaiika, 18 species (or 35%) were found to be exotic species.

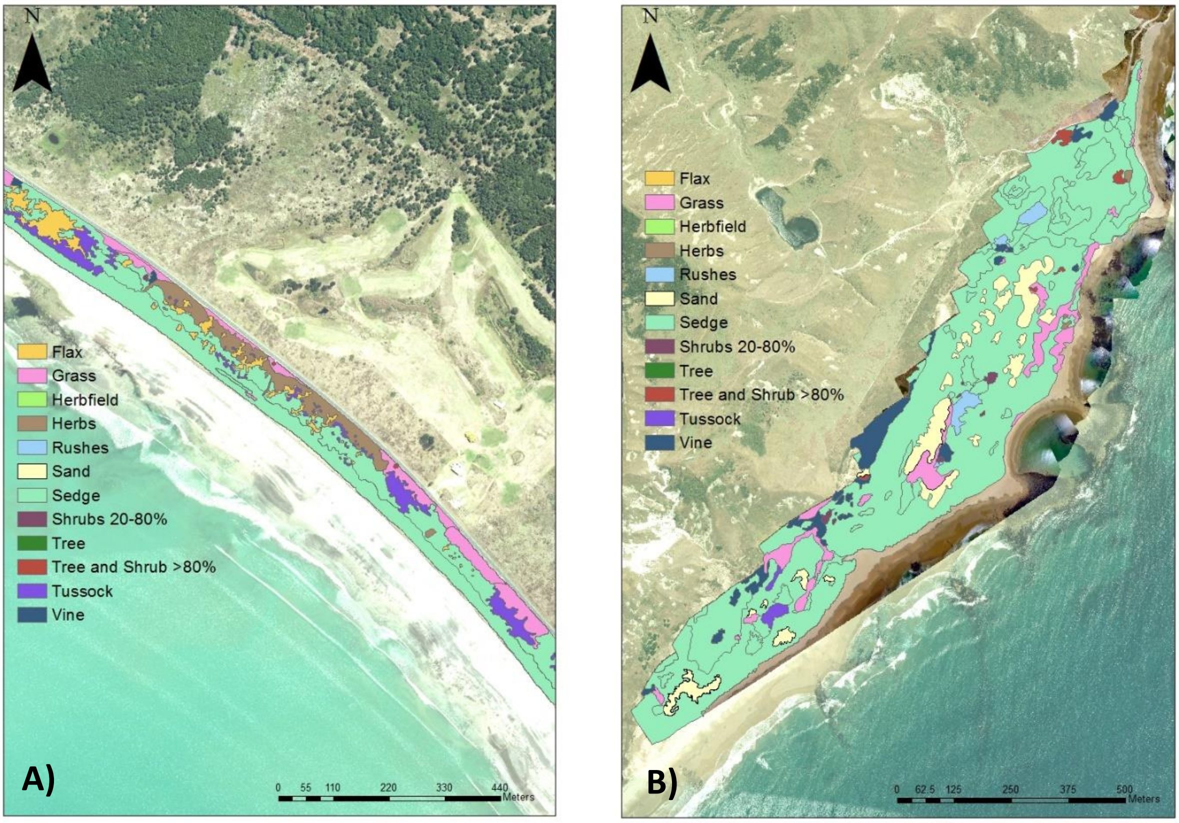


Figure 5-8: Maps of A) Opoutama Beach and B) Rangaiika Beaches.

The dunes at Opoutama suffer from a large variety of pressures and understandably the overall state of the dune system was much poorer than Rangaiika (Table 5-2). Despite the protected location of Rangaiika as part of the Cape Sanctuary and its recognised status as one of the best surviving dune systems, the condition index highlights the pressure it is under. This pressure mainly comes from the large number of rabbits found on and around it. It also suffers from having very minimal buffering from the surrounding farmland.

Table 5-2: Dune condition index for Opoutama and Rangaiika Beaches.

		Opoutama	Rangaiika
Pressures	Deer, cattle, pigs, sheep & goats	4	4
	Rabbits, Hares & Possums	2	0
	Predators	2	2
	Dogs	0	4
	Problem plants	0	3
	People walking on the dunes	0	5
	People driving on the dunes	4	5
	Mining	5	5
State	Indigenous cover dominance	3	4
	Indigenous animal dominance	2	4
	Unnatural vegetation disturbance	5	5
	Buffering - indigenous land cover	0	0
	Buffering - indigenous cover dominance	0	0
TOTAL (out of a possible 65)		27	41
PERCENTAGE		42%	63%

Currently, plastic litter is not an SOE monitoring focus, however, it was noted in a sample from Opoutama beach in 2017. With increasing understanding of spread of plastic waste in the marine environment (Bergmann et al., 2015), determining its presence on sandy beaches would be worthwhile to quantify how much, if any, plastic litter exists on Hawke's Bay beaches. Additionally, the impact of vehicle traffic on the beaches of Hawke's Bay is currently unquantified. Most of the beaches included in this monitoring programme are regularly exposed to vehicular traffic. Quantifying the amount of traffic on these beach sites may highlight management initiatives.

5.5 Conclusions

As described in previous reports, the infaunal community composition found at sandy beach systems throughout Hawke's Bay is depauperate. Monitoring these systems provides baseline biodiversity information, and hopefully over time more studies of similar systems will enable better contextualisation of the data. Monitoring the biodiversity of Hawke's Bay sandy beach systems is also an important step in understanding Hawke's Bays native biodiversity, a critical aspect of the New Zealand Coastal Policy Statement, 2010. A programme review is recommended to ensure current sampling methods are appropriately capturing trends in sandy beach infaunal communities.

Levels of edible shellfish were highest at Waimarama Beach, although the sampling programme was not designed to target shellfish beds. As an important resource which may be facing high pressure, it is recommended that monitoring of biomass at shellfish gathering sites be considered for future monitoring.

Dune systems throughout the region are facing pressure from subdivision, planting and pests and it is important that consideration is given to their current state. Monitoring dune systems using the condition index can help to identify high risk dunes, as well as potential management interventions that may improve their health. Rangaiika Beach is considered a pristine dune system within the Hawke's Bay context, however its condition suggests it's still facing pressures, particularly from animal pests.

Currently, plastic litter is not an SOE monitoring focus, however the presence of plastic particles is starting to be noted in both estuarine and sandy beach cores. With increasing understanding of the spread of plastic waste in the marine environment (Bergmann et al., 2015), determining it's presence/absence in sandy beach systems may provide further advice on the magnitude of this issue. It is recommended that plastic fragments (microplastics) are reported during sandy beach sampling, and potentially a plastics programme be set up to specifically document the presence of plastics in beaches around Hawke's Bay.

Additionally, the impact of vehicle traffic on the beaches of Hawke's Bay is currently unquantified, and may play a significant role in structuring intertidal communities. Most of the beaches included in this monitoring programme are regularly exposed to vehicular traffic and therefore it is recommended that further work be undertaken to quantify the amount of traffic these sites are exposed to.


Intertidal reefs

6 Intertidal Reefs

Rocky intertidal platforms (‘rockfields’ and ‘boulder fields’) represent the second most common habitat of the total coastal habitat in Hawke’s Bay (42%; Stevens and Robertson, 2005). Like estuaries and sandy beaches, these reefs are an important interface between land and sea. Organisms that live on these reefs are subjected to pressures from both systems, warmth from sunlight during low tide and wave action during high tide. Despite this harsh and dynamic environment, rocky reefs contain high levels of diversity (Connell, 1978), are highly productive (Leigh et al., 1987), and provide a number of services to the coastal ecosystems (Bouma et al., 2014). These services include, but are not limited to: food for harvesting, shelter, nursery, and/or feeding areas for several species, and coastal protection through stabilising shore lines and/or attenuating waves.

Quantifying community composition on rocky reefs provides information on the state and health of the coastal marine environment. However, the high biodiversity found on rocky reefs can lead to substantial natural variation both spatially (at different sites along the coast) and temporally (monthly, seasonally, annually, etc.; Steinbeck et al., 2005). Long term monitoring of multiple sites captures both spatial and temporal variation and clarifies the impacts of one-off disturbance events (i.e., floods or extreme storm events; Chainho et al., 2010), and the influence of long-term environmental stressors within the region (Steinbeck et al., 2005).

Intertidal species can serve as indicators of local ecosystem health, providing information about stressors in the marine environment (Mieszkowska et al., 2013). For example, the presence of certain algal species can suggest a system is coping with increases in pollution or nutrient loading (Smale et al., 2011). Additionally, increases in sedimentation or proximity to areas with high nutrient input can largely influence species’ spatial distribution (Díaz-Tapia et al., 2013; O’Connor, 2013). This information can potentially highlight management priorities for the coastal marine environment to ensure the integrity of these systems is maintained.

Intertidal reefs face a number of external environmental and biological pressures, many of them human-induced. Sedimentation is a major influence on marine systems in Hawke’s Bay; mainly due to erosion, particularly during heavy rainfall events (Haggit and Wade, 2016). For example, in September 2018, a 1 in 5 year flood event resulted in approximately 390,000 tonnes of sediment released from the Tukituki Catchment alone (Norris, 2019). This increase in sediment loads can have major impacts on intertidal species leading to distinct morphological or life history traits, weakened species interactions, or direct smothering (Airoldi, 2003; Macpherson, 2013). A layer of deposited sediment can increase post settlement mortality of certain algal species (Alestra and Schiel, 2015) or limit the response of juvenile paua (*Haliotis iris*) to right themselves after being dislodged (Chew et al., 2013).

Changes in composition of reef assemblages have also been attributed to water quality. For example, while higher nutrient inputs can increase growth of some algal species (Alestra and Schiel, 2015), those communities are less diverse and contain less morphologically complex algal species (Bellgrove et al., 2017; Díez et al., 2012).

Seafood harvesting/gathering is common on Hawke’s Bay reefs, particularly for paua, kina (*Evechnius chloroticus*), and crayfish (*Jasus edwardsii*). In general, in areas where shellfish gathering is common, target species are less abundant and have a smaller average size (Crowe et al., 2000). Removal of certain species also has implications for the overall assemblages and diversity. This pressure is further exacerbated by disturbance to the reef from trampling and vehicles driven onto the reef. These activities can lead to habitat loss and subsequent reduction in species abundance (Brown and Taylor, 1999; Schiel and Taylor, 1999).

In New Zealand, marine exotic species are also a threat to local biodiversity. Exotic species can outcompete native species for resources (Thomsen et al., 2014). Currently, the presence of wakame (*Undaria pinnatifida*) is well established at one of the focal sites, Hardinge Road. This is likely due to its proximity to Napier Port, Napier City, and Ahuriri Harbour, all providing pathways for exotic species introductions through vessels and recreational use (Murray et al., 2014). Other invasive species threats include the Mediterranean fanworm (*Sabella spallanzanii*) and the clubbed tunicate (*Styela clava*) but have not yet been found at Hawke's Bay's monitoring sites.

As a result of climate change, New Zealand's oceans are already experiencing warmer surface temperatures, increasing sea surface height, and changes in primary productivity (Hurst et al., 2012; Pinkerton, 2016; Sutton and Bowen, 2019). Decreases in primary productivity, further increases in temperature, and decreases in pH are predicted to occur with climate change (Law et al., 2018). However, the impacts of these changes on rocky intertidal reefs are variable and can differ by region (Schiel et al., 2016), highlighting the importance of long-term monitoring.

6.1 Methods

Survey methods

Intertidal reef monitoring began by Hawke's Bay Regional Council as part of the SOE programme in spring 2011; monitoring only the low and mid intertidal zones. In autumn 2013, the upper zone was added at each site. Each reef was visited seasonally (quarterly) to survey community composition, weather permitting. Sampling dates were chosen to target particularly large low tides (Mean Low Water Springs - height ≤ 0.1 m) at an appropriate time to allow the maximum amount of time for sampling.

Methods for determining the intertidal extent of the reef and transect positioning are detailed in Wade (2012) and Wade et al. (2016). Transects in each tidal zone were extended for 20m from the starting location determined from the cross shore transect photographs. The first 1m^2 quadrat of the alongshore transect was placed with the mid-point of the quadrat edge on the start point. Subsequent 1m^2 quadrats were placed at 2m intervals along the transect to make up 10 quadrats in total. Macroscopic flora and fauna (>4mm) were identified and classified to the lowest practical taxonomic grouping for each quadrat.

Quadrats were divided into 10cm x 10cm squares resulting in 100 squares per quadrat. Proportional cover of macroalgal species, sessile invertebrates, and non-biological cover groups (i.e., bare rock and sand) were counted based on the number of squares they occupied. Species present, but not abundant enough to occupy an entire square were noted as 0.5 percent. Density of mobile invertebrates were assessed in a 2 dimensional space by only including those species directly visible without disturbing the algae cover or turning rocks. A digital photograph was taken of each quadrat to allow for verification of recorded cover and counts.

Reef monitoring sites

Sites were initially chosen to represent reef structures typical of Hawke's Bay and range from being heavily modified to areas of national significance (Henriques et al., 1990; Figure 6-1). They are spread along the coastline and have been sampled consistently since 2013. For detailed reef topography descriptions, see Wade (2012) and Wade et al. (2016).

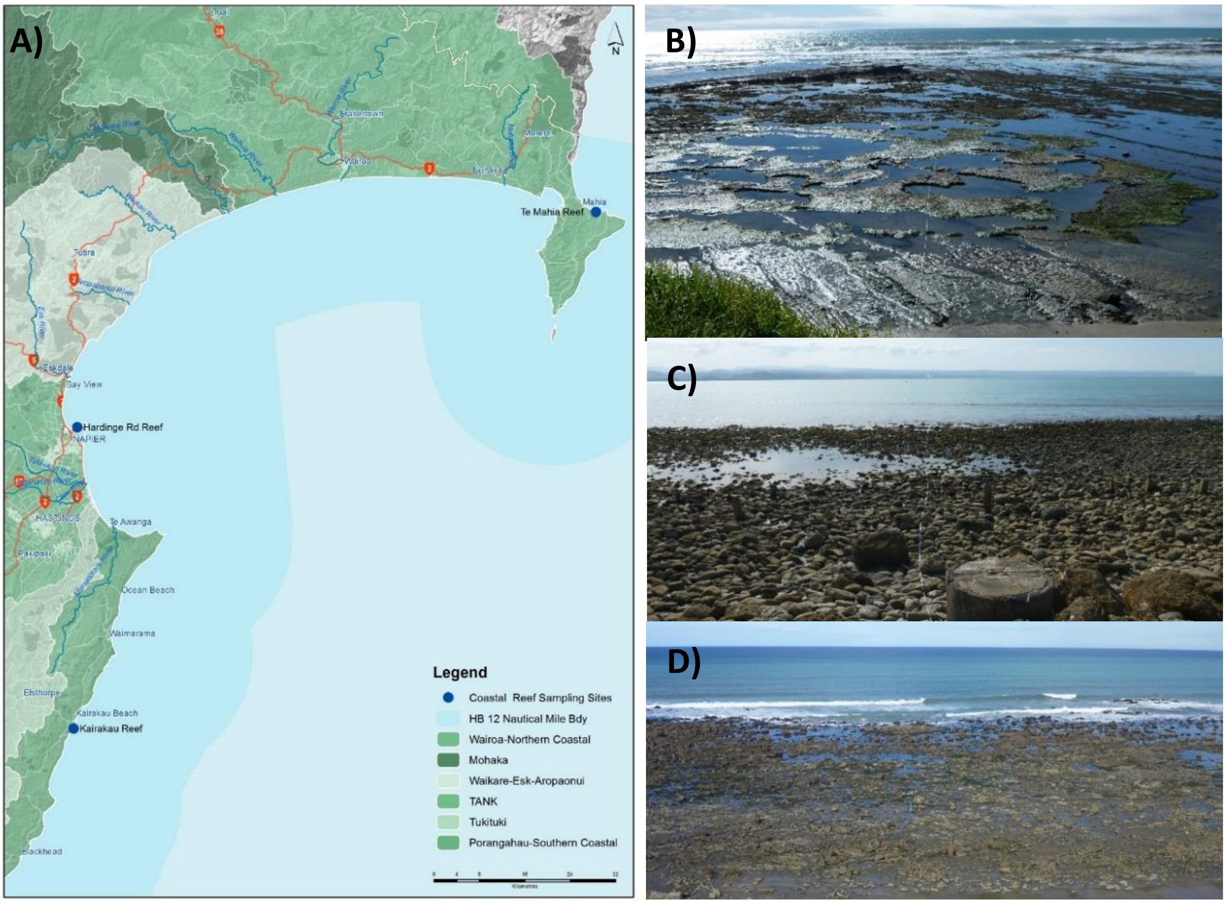


Figure 6-1: A) Map of reef monitoring sites, A) Photo of Te Mahia intertidal reef, B) Photo of Hardinge Rd intertidal reef, C) Photo of Kairākau intertidal reef.

All data collection and analyses were undertaken in accordance with internal quality assurance and quality control processes and procedures.

6.1.1 Data summaries and visualisations

Although transects were placed as close as possible to previous surveys, quadrats were not placed in exactly the same position from survey to survey. Therefore, quadrats have been treated as random replicates through time and community composition is discussed at a tidal height level.

Diversity Analyses

The communities of organisms that inhabit intertidal reefs are diverse and variable. To describe these communities in a way that helps us interpret their state and health, various community metrics and indices (collectively 'diversity indices') were used. These are described in section 3.1.1. Diversity indices were calculated using the PRIMER v6 'Diverse' routine (Clarke and Gorley, 2006) with the PERMANOVA+ add on (Anderson et al., 2008).

Trend analyses

Trend analysis of monitoring data is important because community composition may exhibit trends which indicate significant changes in external drivers (e.g.., environmental conditions). For a detailed description of the trend analysis methods, see section 2.1.3. October was used as the 'start' month, i.e. the seasons were: Oct-Dec; Jan-Mar; Apr-Jun; Jul-Sep. This also best described the seasonality observed in the data. Time Trends software was used for this analysis (Jowett, 2019).

Multivariate analyses

A permutational multivariate analysis of variance (PERMANOVA) was used to examine differences in community composition. PERMANOVA is a standard technique used to determine whether the intertidal reef community composition varies within space and/or time. It can help ecologists to determine whether a particular site is dynamically stable or changing.

The log(x+1) data transformation was used to retain information concerning relative abundance, and to ensure that commonly occurring species did not dominate the analysis (Clarke, 1994; Zar, 1996). Resemblance matrices for our PERMANOVA models were calculated using the Bray-Curtis similarity measure. Because the differences across seasons and tidal heights was of interest, they were analysed as fixed factors instead of nesting them within year and site. The model used the permutation of raw data for the fixed factors of 'year', 'season', 'site', 'tidal height', and all interactions on communities.

Spatial variations in species composition were also assessed using non-metric multi-dimensional scaling (nMDS). This technique presents a graphical display of communities in two dimensional space. Points close to each other are similar and points separate from each other are different.

Univariate analyses

Common species were separated by site because the coastal geology between sites is different (Figure 6-1) and they are subjected to differing pressures (e.g., sediment loads and human accessibility). Therefore, species abundances are not expected to be uniform across all three sites. For the twenty most common species at each site, seasonal averages were calculated for each year at each tidal height. Variation in abundance that might be attributable to different years, seasons, tidal heights, and all interactions for each species was evaluated. A generalised least squares model (GLS) with a spatial power correlation structure was used to account for the temporal autocorrelation between quadrats recorded in the same tidal height over irregular time intervals (i.e., missing sampling seasons; Wolfinger, 1993). The log (x+1) transformed data was used to better meet model assumptions. Heat maps were used to visualise relative species distributions over time at each of the monitored intertidal reef sites. A gls model was also used to evaluate the influence of site and tidal height on seasonal averages of total algal cover. R ver 3.6.1 (R Core Team, 2019) with the 'gls' function of the 'nlme' package for GLS models (Pinheiro et al., 2019) and the 'emmeans' and 'multcompView' packages for post hoc tests (Hothorn et al., 2009; Lenth, 2019) were used for these analyses.

6.2 Results - Species Richness and Diversity

As is commonly observed in intertidal communities, total number of species (S) decreased as tidal height increased at all sites (Figure 6-2). Higher tidal heights are out of the water longer at low tide and the number of species that can tolerate that stressful environment is limited (Scrosati et al., 2011). A significant decrease in number of species over time was identified at Te Mahia (upper), Kairākau (mid) and all tidal heights at Hardinge Road (Table 6-1). As mentioned in section 3.4.1, determining the ecological significance of this decrease is only possible when considering these trends alongside diversity (Shannon, Simpson), evenness (Peilou's evenness) and richness (number of species) indices.

The greatest number of individuals (N) in the low and mid zones was observed at Te Mahia (Figure 6-2). This site recorded substantially higher numbers of individuals than other reef sites, but similar numbers of species indicating that the higher numbers of individuals are within the same number of species groups described at other sites. Hardinge Road reef recorded the highest number of individuals in the upper intertidal zone.

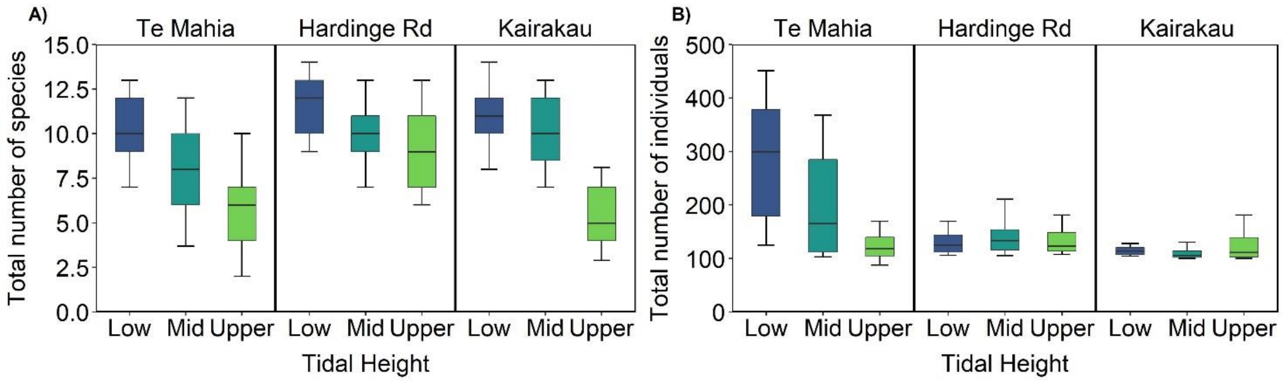


Figure 6-2: Five year medians (2013-2018) of A) Total number of species (S) and B) Total number of individuals (N) by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. n=1579 (Te Mahia [low: 170, mid: 170, upper: 160], Hardinge Rd [low: 180, mid: 180, upper: 179], Kairākau [low: 180, mid: 180, upper: 180])

Table 6-1: Trend analyses of total number of species (S) per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**.

Site	Tidal Height	Species Richness (S)								
		n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	9	10.0	11.0	11	**<0.0001**	10	0.150	0.000
	Mid	170	7	8.0	9.0	8	0.893	8	0.223	0.000
	Upper	160	6	6.0	5.5	5	0.944	6	**<0.0001**	**-11.109**
Hardinge Rd	Low	220	13	11.5	11.5	12	**<0.0001**	12	**0.0002**	**-2.777**
	Mid	230	10	11.0	11.0	10	0.4410	11	**<0.0001**	**-4.549**
	Upper	189	9	8.0	9.0	10	**0.026**	9	**<0.0001**	**-5.559**
Kairākau	Low	230	11	10.5	10.0	12	**0.001**	11	0.202	0.000
	Mid	230	11	9.0	10.0	11	**<0.0001**	10	**<0.0001**	**-5.000**
	Upper	190	5	5.0	6.0	6	0.275	6	0.367	0.000

Statistically significant reductions in individuals over time were observed at Te Mahia (upper), Kairākau (low and mid) and Hardinge Road (all zones). An increase in the number of individuals was observed at Te Mahia in the low intertidal zone. The high number of individuals and increasing trend at Te Mahia may be due to a high abundance of horn snails (*Zeacumantus* spp.) in the low zone. Similar to species richness, the ecological significance in total abundance trends can only be understood in conjunction with other diversity indices and taxonomic identity.

Table 6-2: Trend analyses of total number of individuals (N) per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**.

Site	Tidal Height	Total Individuals (N)								
		n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	471	439.5	227.0	343.5	**<0.0001**	343.5	**<0.0001**	**10.630**
	Mid	170	284	155.5	167.5	300.5	0.0750	243.5	0.0990	-4.517
	Upper	160	128	123.5	119.0	113.0	0.7760	119.0	**<0.0001**	**-5.878**
Hardinge Rd	Low	220	125	135.5	168.0	116.0	**<0.0001**	128.0	**<0.0001**	**-6.237**
	Mid	230	130	152.0	152.5	115.5	**<0.0001**	140.0	**<0.0001**	**-8.577**
	Upper	189	130	152.4	135.9	126.2	0.3360	124.0	**0.003**	**-2.419**
Kairākau	Low	230	112	121.0	121.0	110.0	**<0.0001**	115.0	**<0.0001**	**-1.739**
	Mid	230	110	110.5	106.5	107.5	0.3370	109.0	**<0.0001**	**-1.836**
	Upper	190	109	107.0	119.0	113.5	**0.0300**	111.5	0.6900	0.000

As observed with total number of species (S), Margalef's species richness decreased with tidal height at all sites (Figure 6-3). The largest difference in Margalef's richness was observed between the mid and upper zones at Kairākau. Because Margalef's richness also accounts for the abundance of individuals, trends were slightly different than for species richness above (Table 6-3). Over time, Margalef's richness significantly decreased in the upper zone at Te Mahia and Hardinge Road and in the mid zone at Hardinge Road and Kairākau. In the upper zone at Te Mahia and Hardinge Road, fewer number of species and high variation mean that small changes influence trends. Margalef's richness significantly increased only at Te Mahia in the mid zone.

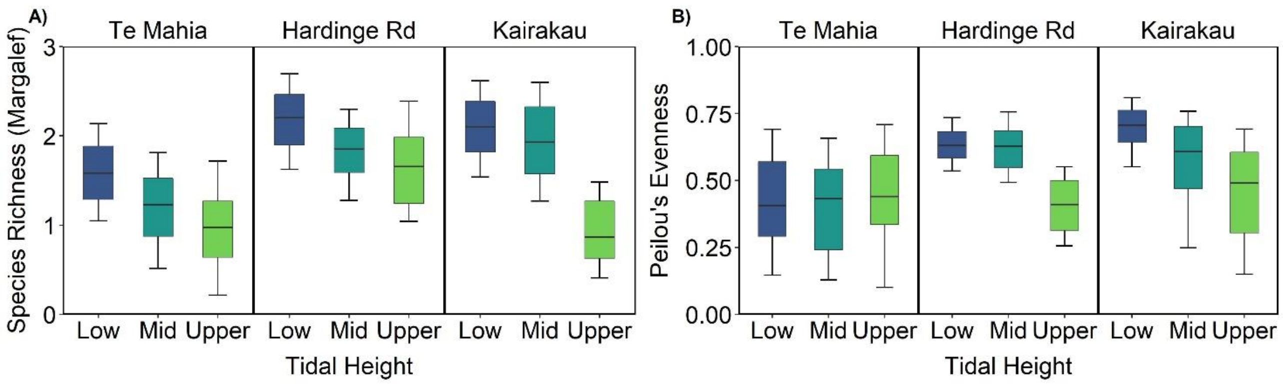


Figure 6-3: Five year medians (2013-2018) of A) Margalef's species richness (d) and B) Pielou's evenness (J') by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90tt percentiles.n=1579 (Te Mahia [low: 170, mid: 170, upper: 160], Hardinge Rd [low: 180, mid: 180, upper: 179], Kairākau [low: 180, mid: 180, upper: 180])

Table 6-3: Trend analyses of Margalef's species richness (d) per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Tidal Height	Margalef's Species Richness (d) n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	1.301	1.459	1.844	1.718	**<0.0001**	1.573	0.5520	-0.610
	Mid	170	1.124	1.184	1.362	1.189	0.4680	1.232	**0.0430**	**4.186**
	Upper	160	0.941	1.01	0.934	0.858	0.9310	0.975	**<0.0001**	**-12.701**
Hardinge Rd	Low	220	2.464	2.148	2.046	2.250	**<0.0001**	2.211	0.0510	-1.833
	Mid	230	1.948	1.881	2.016	1.928	0.8460	1.933	**0.0010**	**-3.113**
	Upper	189	1.657	1.476	1.560	1.884	**0.006**	1.657	**<0.0001**	**-6.138**
Kairakau	Low	230	2.104	1.959	1.917	2.314	**<0.0001**	2.090	0.0710	1.277
	Mid	230	2.148	1.693	1.900	2.132	**<0.0001**	1.941	**<0.0001**	**-4.082**
	Upper	190	0.854	0.856	0.876	1.068	0.2860	0.870	0.2910	0.895

At Kairākau and Hardinge Road, Pielou's evenness (a measure of how abundance is spread over the number of species present), decreased with increasing tidal height (Figure 6-3). At Te Mahia, Pielou's eveness at all tidal heights was similar.

Communities at Te Mahia (low), Hardinge (upper) and Kairākau (mid and upper) became less even over time likely due to dominance by one species as evidenced in Figure 6-2B (e.g. horn snails in Te Mahia (low), seagrass (*Zostera muelleri*) in Kairākau (mid); Table 6-4). The mid zone at Hardinge Road became significantly more even over time.

Table 6-4: Trend analyses of Pielou's evenness (J') per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Tidal Height	Pielou's Evenness (J') n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	0.379	0.376	0.569	0.437	**<0.0001**	0.453	**<0.0001**	**-7.545**
	Mid	170	0.400	0.414	0.468	0.409	0.645	0.433	0.0770	4.196
	Upper	160	0.509	0.455	0.436	0.393	0.186	0.441	1.0000	0.000
Hardinge Rd	Low	220	0.675	0.663	0.583	0.635	**<0.0001**	0.637	0.3930	-0.435
	Mid	230	0.646	0.618	0.665	0.548	**<0.0001**	0.633	**0.0060**	**1.723**
	Upper	189	0.380	0.425	0.467	0.397	**0.025**	0.417	**0.0340**	**-2.976**
Kairākau	Low	230	0.706	0.697	0.717	0.709	0.502	0.708	0.2840	0.505
	Mid	230	0.666	0.627	0.624	0.596	**0.017**	0.627	**<0.0001**	**-4.413**
	Upper	190	0.500	0.467	0.537	0.391	**0.025**	0.497	**0.0070**	**-5.401**

Shannon diversity decreased at each site with increasing tidal height, although the range differed between sites (Figure 6-4). Median diversity at Kairākau more than doubled from upper to low tide, whereas the diversity at Te Mahia was more consistent across tidal levels

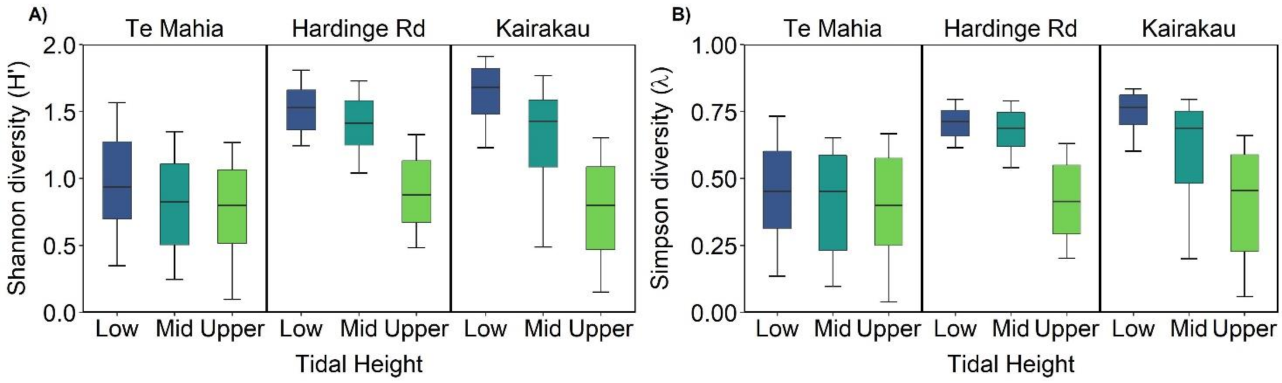


Figure 6-4: Five year medians (2013-2018) of A) Shannon diversity index (H') and B) Simpson diversity index (λ) by tidal site at each site. Boxes represent 25th, 50th and 75th percentiles. Whiskers represent 10th and 90th percentiles. n=1579 (Te Mahia [low: 170, mid: 170, upper: 160], Hardinge Rd [low: 180, mid: 180, upper: 179], Kairākau [low: 180, mid: 180, upper: 180])

Shannon diversity significantly decreased over time in the low zone at Te Mahia, upper zone at Hardinge Road, and mid zone at Kairākau and significantly increased in the mid zone at Te Mahia (Table 6-5).

Table 6-5: Trend analyses of Shannon diversity (H') per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Tidal Height	Shannon Diversity (H')								
		n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	0.828	0.932	1.359	1.027	**<0.0001**	1.045	**<0.0001**	**-6.971**
	Mid	170	0.665	0.764	1.042	0.823	0.2780	0.826	**0.0170**	**7.321**
	Upper	160	0.891	0.877	0.694	0.672	0.3190	0.799	0.0680	-5.661
Hardinge Rd	Low	220	1.673	1.572	1.402	1.581	**<0.0001**	1.553	0.0530	-1.441
	Mid	230	1.486	1.381	1.546	1.306	**<0.0001**	1.444	0.7610	-0.271
	Upper	189	0.781	0.875	0.947	0.920	0.1400	0.882	**0.0020**	**-5.904**
Kairakau	Low	230	1.739	1.641	1.683	1.755	0.0850	1.691	0.0880	0.931
	Mid	230	1.541	1.425	1.477	1.443	**0.0120**	1.484	**<0.0001**	**-6.05**
	Upper	190	0.825	0.764	0.975	0.726	0.1730	0.820	0.070	-4.473

Simpson diversity reported similar patterns and trends to those observed for Shannon diversity (Figure 6-4, Table 6-6).

Table 6-6: Trend analyses of Simpson diversity (λ) per tidal height at each site. Includes all sampled data from 2011-2018. Statistically significant trends are indicated in **bold**. BLUE highlight for PAC indicates an improving trend, RED indicates a deterioration.

Site	Tidal Height	Simpson Diversity (λ)								
		n	Long-term Spring Median	Long-term Summer Median	Long-term Autumn Median	Long-term Winter Median	Seasonal Influence p-value	Long-term Median	Trend p-value	Percent Annual Change
Te Mahia	Low	220	0.389	0.413	0.633	0.483	**<0.0001**	0.4870	**<0.0001**	**-7.0600**
	Mid	170	0.381	0.431	0.538	0.451	0.3890	0.4530	**0.022**	**5.7640**
	Upper	160	0.487	0.438	0.372	0.325	0.1740	0.4000	0.17600	-4.2270
Hardinge Rd	Low	220	0.744	0.724	0.679	0.710	**<0.0001**	0.7140	0.4750	-0.3360
	Mid	230	0.722	0.682	0.732	0.637	**<0.0001**	0.6910	0.3270	0.5590
	Upper	189	0.388	0.429	0.469	0.409	0.1440	0.4160	**0.0130**	**-5.0160**
Kairakau	Low	230	0.773	0.754	0.763	0.774	0.2830	0.7670	0.1570	0.5140
	Mid	230	0.722	0.700	0.714	0.676	**0.0400**	0.7020	**<0.0001**	**-3.7340**
	Upper	190	0.453	0.452	0.532	0.350	0.1300	0.4650	0.1050	-3.5250

Diversity is an important indicator of community resilience; more diverse communities recover better from environmental disturbances (e.g., increasing temperature or sediment loads). As with richness, because the upper tidal zone had fewer species and high variability, small changes in abundance of individuals may have had a strong impact on trends which could explain the declining trend at Hardinge Road. As with evenness, declining diversity in the mid zone at Kairākau is likely driven by the increasing dominance of seagrass, reducing the number of algal species.

Some diversity indices were significantly influenced by season, although this was not consistent across tidal zones or sites for all indices. Seasonal differences in community composition are expected because weather conditions such as winter storms or high summer temperatures influence species abundances. Seasonal recruitment and growth patterns also affect the abundance of some intertidal species subsequently influencing diversity.

6.3 Results - Community composition

Community composition varied significantly across years, seasons, sites, tidal heights, and all interactions (see Appendix – Table F-1). This means community composition changed differently over time at each tidal height within site.

To better visualise how communities changed over time, the Bray-Curtis similarity of each tidal height community at each site over time was assessed (Figure 6-5). This shows how communities at each tidal height changed in relation to the first observation. A higher similarity (80-90%) might be expected in the surveys soon after the first survey because communities are not expected to change much over time unless a significant disturbance event occurred. While this was the case at some tidal heights within sites (e.g., Hardinge Road upper tidal zone, Te Mahia mid tidal zone), tidal heights within sites were initially, on average, 65% similar to one another. Communities may be expected to decrease in similarity over time. While this appeared to be true for some sites (e.g., the Kairākau mid zone), many did not display this pattern. While there are a few seasons where similarity dropped, similarity across all tidal heights within sites generally returned to comparable similarity values. Of note, drops in similarity occurred in at least two tidal heights at each site in summer 2018, during the marine heat wave (section 2.4.1).

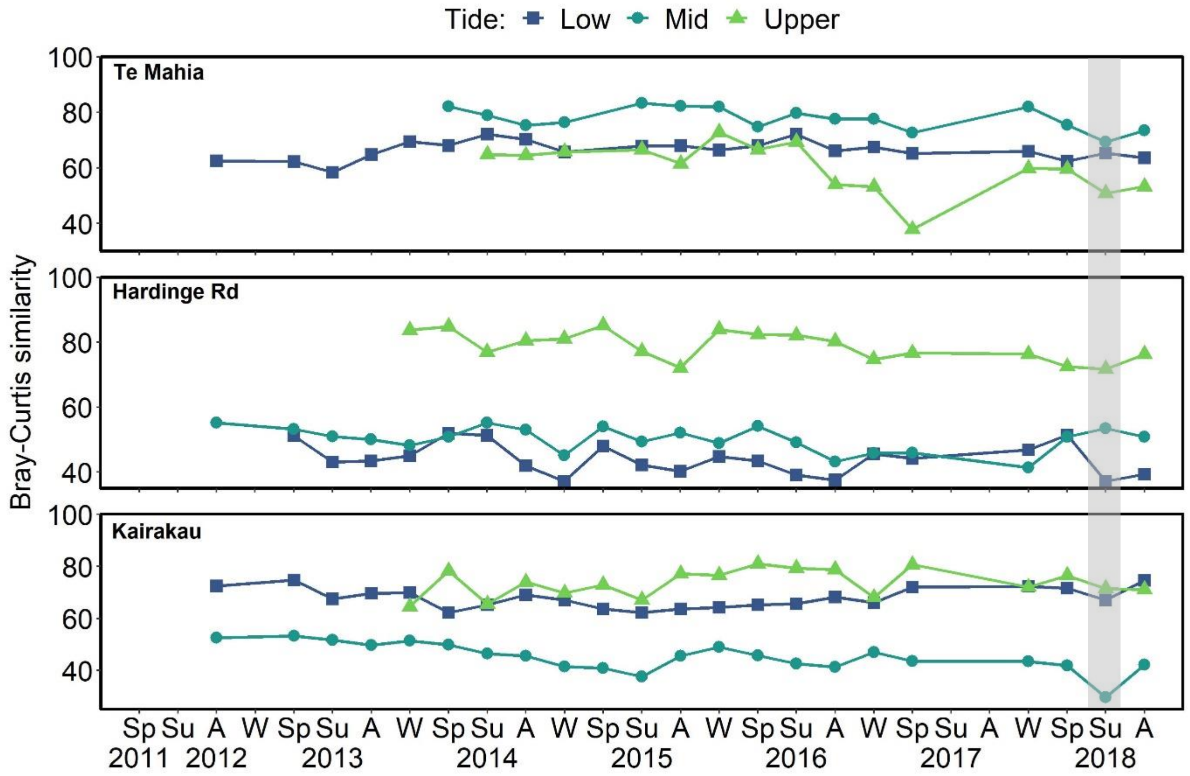


Figure 6-5: Bray-Curtis similarity of species abundance at each tidal height from the first survey. n=183. The grey square is the marine heat wave of 2017/2018 (see section 2.4.1).

nMDS plots better highlight how similar communities are in composition. Groupings of points represent communities that are similar, and points further apart represent communities that differ from each other. There was no clear overall pattern in community composition between years and seasons (see Appendix – Figure F-1).

However, differences were observed between tidal heights; upper tidal zones across sites were more similar to each other than the low and mid tidal heights at each site (Figure 6-6A). As mentioned previously (see sections 5.2 and 6.2), the upper zone is a stressful environment. Since the number of species able to thrive in this environment is limited (Scrosati et al., 2011) it's likely the species compositions at these sites would be similar to one another and different from the low and mid zones. The upper zones are largely characterised by horn snails, sand, top snails (*Diloma aethiops*), bare rock, cushion sea stars (*Patriella regularis*), and *Gigartina* spp. (Figure 6-6B). The influence of these differs by site (e.g., high abundance of cushion sea stars characterises Hardinge Road).

The main drivers of community composition at each of the sites/tidal heights were the dominant fucoid algae species (Figure 6-6). Fucoid algae are an important group of seaweeds that serve as foundation species, supporting a variety of associated epifauna (Lilley and Schiel, 2006). They ameliorate environmental conditions, provide habitat, support the growth of microalgal food sources, and are themselves a source of food (Moore et al., 2007). The low and mid zones at Hardinge Road were characterised by *Sargassum sinclarii*. The low zone at Kairākau was dominated by *Cystophora torulosa* and presence of *Sargassum sinclarii*. The low and mid zones at Te Mahia and the mid zone at Kairākau were characterised by neptune's necklace (*Hormosira banksii*).

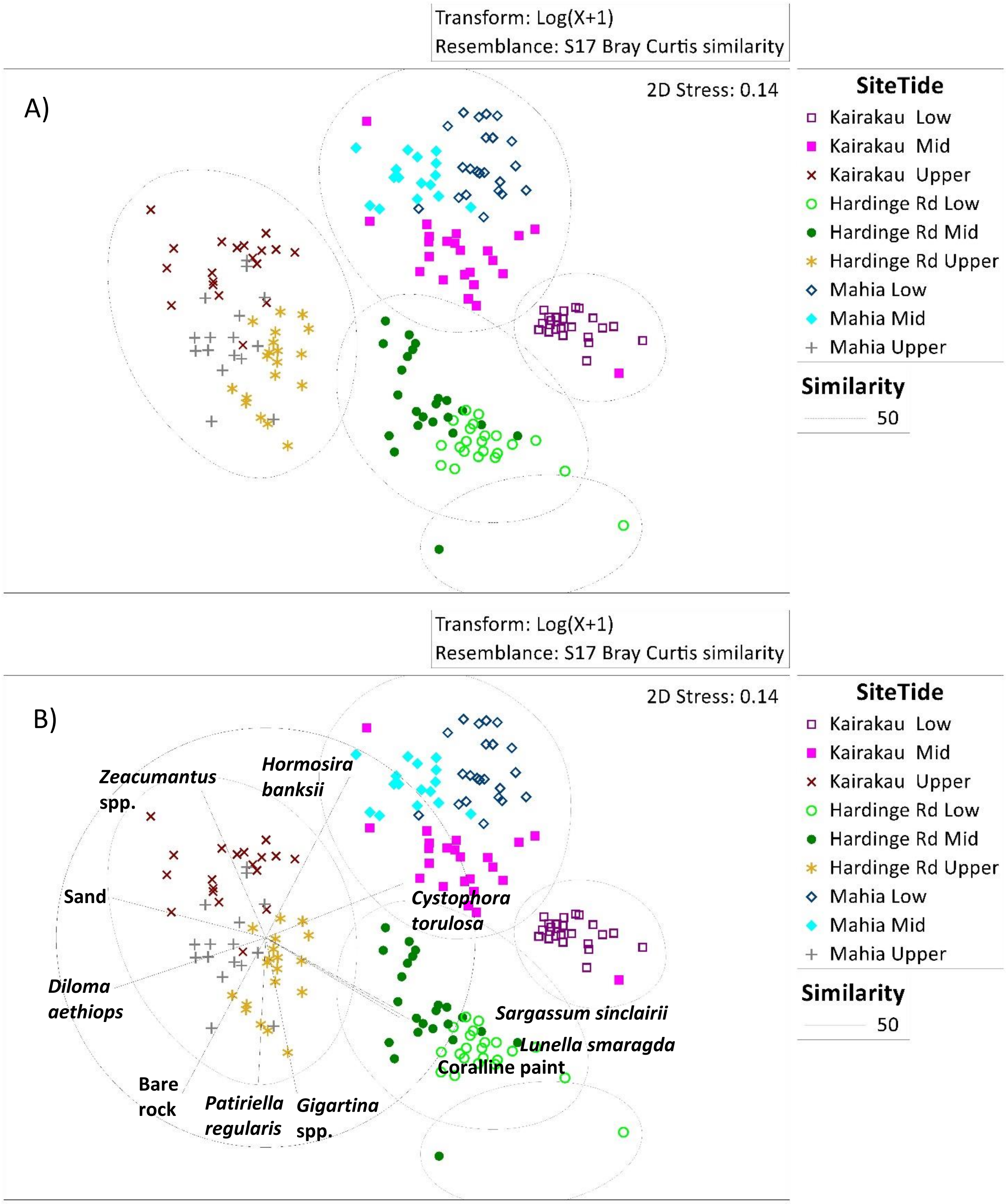


Figure 6-6: A) nMDS ordination of community composition of surveys from each tidal height at each site with data from 2011-2018. B) Vector overlay of dominant species. n=1839. Circles represent 50% similarity based on cluster analysis. Species overlay based on Spearman correlations over 0.7.

Average algal cover varied significantly by site ($F_{(2,175)}$=74.612, p<0.0001), tide ($F_{(2,175)}$=415.164, p<0.0001) and their interaction ($F_{(4,175)}$=12.096, p<0.0001). In the low zone at Te Mahia, average algal cover was higher than all other sites/tidal heights (87.1% ±5.8). The mid zone at Te Mahia had 82.5% ±6.6 average algal cover which was not significantly different from Kairākau mid (75.2% ±11.1) and low zones (73.4% ±6.9). Average algal coverage at Hardinge Road low (49.6% ±14.4) and mid (41.6% ±11.6) zones was the lowest of the low and mid zones of all three sites. Algal cover in the upper zones of Te Mahia 13.7% (±16), Kairākau (5.8% ±6.8) and Hardinge Road (2.3% ±4.5) did not significantly differ from one another.

6.4 Results - Species abundances

Te Mahia

The top algal species at Te Mahia include coralline turf, neptune's necklace*, Cladostephus spongiosus,* seagrass *(Zostera muelleri)*, and brown crust (*Ralfsia* spp.; Figure 6-7). These algae provide important services including trapping sediment (coralline turf and seagrass) and facilitating recruitment of invertebrates (coralline turf; (Diaz-Pulido et al., 2012)). Both coralline turf and *C. spongiosus* provide an environment for epiphytic algae, which could explain the high algal cover at this site. Horn snails*,* top snails*,* cat's eye snails (*Lunella smaragda),* hermit crabs (*Pagarus* spp.), and oyster borer snails (*Haustrum scobina)* were the five most abundant invertebrate species observed in Te Mahia. The high algal cover in the low zone explains the high abundances of herbivorous snails at this site, particularly horn snails. Species abundance varied differently and significantly for all common species by tide, year, season, and all subsequent interactions (see GLS model results: Appendix – Table F-2).

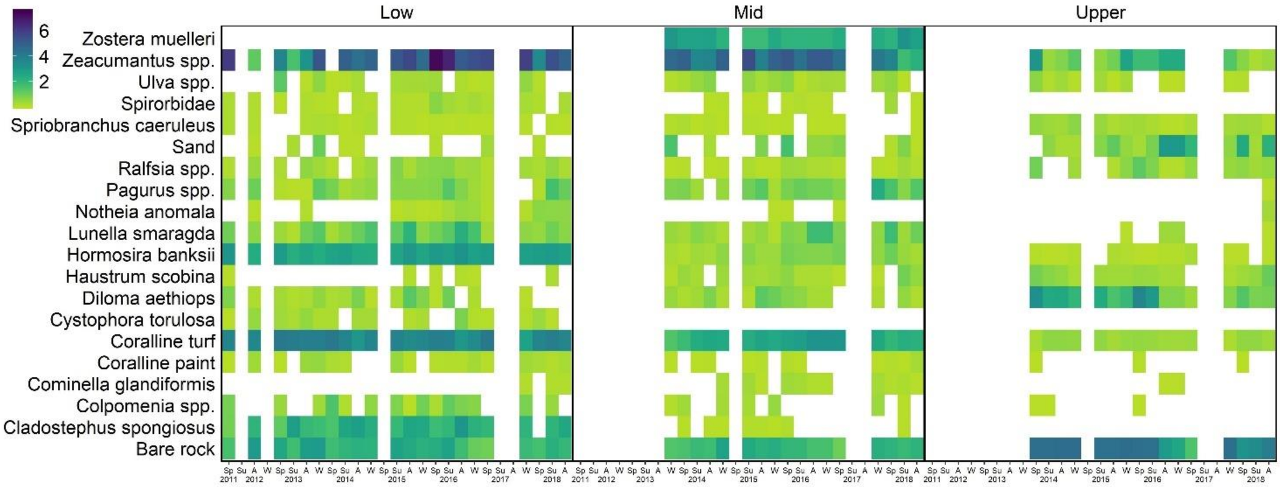


Figure 6-7: Heat map of most common species at Te Mahia by tidal height using transformed data (log(x+1)) from 2011-2018. Darker colours represent higher abundance, lighter colours represent lower abundance. White squares represent either absence of that species in that survey or seasons where sampling wasn't possible at that site due to weather limitations. (Sp = Spring, Su = Summer, A = Autumn, W = Winter). n=550

Hardinge Road

Coralline turf*, Gigartina* spp.*,* coralline paint*,* brown crust*,* and *Colpomenia spp*. were the five most abundant algal species at Hardinge Road (Figure 6-8). Cat's eye snails*,* top snails*,* cushion sea stars*,* horn snails, and hermit crabs were the five most abundant invertebrate species in Hardinge Road (Figure 6-8). Cushion sea stars are known to scavenge, but most often feed on coralline paint (Palmer, 2010). High abundances of cushion sea stars at Hardinge Road could be because coralline paint is one of the most abundant algal species at this site. Species abundances varied differently and significantly for all common species by tide, year, season, and all subsequent interactions (see GLS model results: Appendix – Table F-3). Species abundances most frequently significantly differ by tidal height. Abundance for many species didn't follow a linear trend, but instead has seasonal patterns (e.g., cat's eye snails; Figure 6-8, Table F-3).

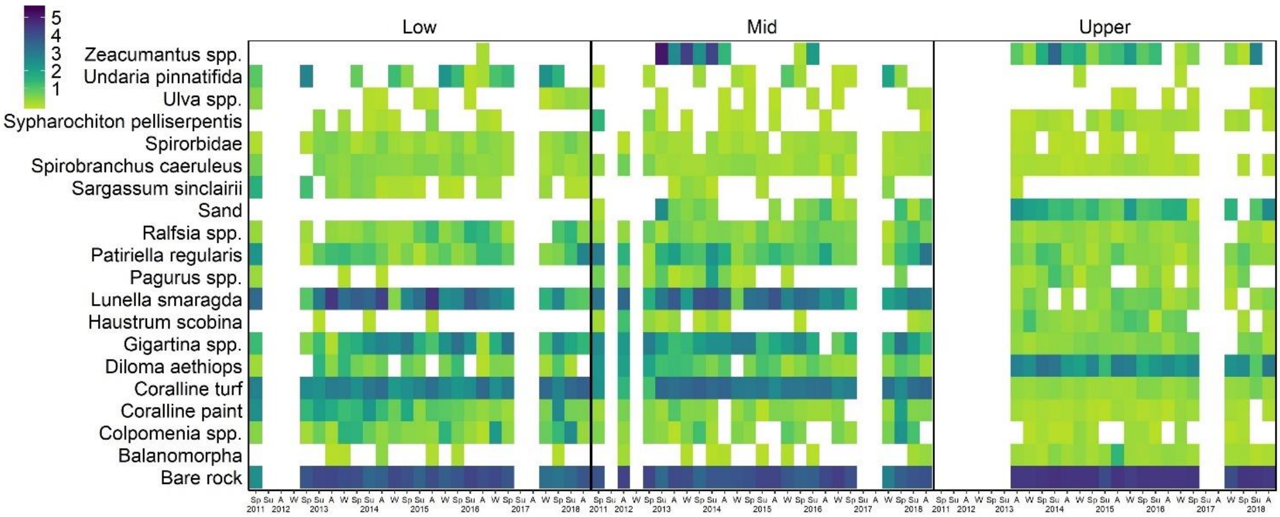


Figure 6-8: Heat map of most common species at Hardinge Road by tidal height using transformed data (log(x+1)) from 2011-2018. Darker colours represent higher abundance, lighter colours represent lower abundance. White squares represent either absence of that species in that survey or seasons where sampling wasn't possible at that site due to weather limitations. (Sp = Spring, Su = Summer, A = Autumn, W = Winter). n=640

Hardinge Road observed the lowest percent cover of algae cover of all three sites, potentially due to the mobile nature of the reef (i.e., large boulders that roll with swell events) and its close proximity to a populated area. Neptune's necklace, while prevalent elsewhere in Hawke's Bay, is conspicuously absent at Hardinge Road. In Australia, (Bellgrove, 2010) recorded the deleterious effect of wastewater on neptune's necklace communities and their inability to recolonise due to competition from coralline turfs, which are abundant at Hardinge Road. Additionally, cat's eye snails are highly abundant at this site and have been shown to graze on neptune's necklace germlings (Schiel et al., 2006) potentially limiting recruitment.

Of the three SOE monitored sites, the invasive alga, wakame, is present and established at only Hardinge Road. Wakame is an annual seaweed with peak abundance in winter and spring in the low tidal zone and, during some years, is completely absent in summer and autumn.

Kairākau

Coralline turf, neptune's necklace, seagrass, *Cystophora torulosa,* and coralline paint were the five most abundant algal species in Kairākau (Figure 6-9). As mentioned previously, these algae serve important ecosystem services. Coralline paint is an important algal species that releases chemicals that attract invertebrate settlement, including paua (*Haliotis iris*; Roberts et al., 2004). Cat's eye snails, top snails, horn snails, hermit crabs, and snakeskin chitons (*Sypharochiton pelliserpentis)* were the five most abundant invertebrate species in Kairākau (Figure 6-9). Species abundances varied differently and significantly for all common species by tide, year, season, and all subsequent interactions (see GLS model results: Appendix – Table F-4). Significantly different species abundances were most often a consequence of the interaction of tide and season; meaning that abundances varied at tidal heights differently in each season. Spiny tube worms (*Spriobranchus caeruleus)* and red crust did not significantly differ due to any of the tested factors at Kairākau. Abundances for many species did not follow a linear trend, but instead had seasonal patterns in their abundance (e.g., *Pterocladia* spp.; Figure 6-9, Table F-4). Antagonistic effects were observed between coverage of bare rock and seagrass in the mid zone (decreasing bare rock and increasing seagrass).

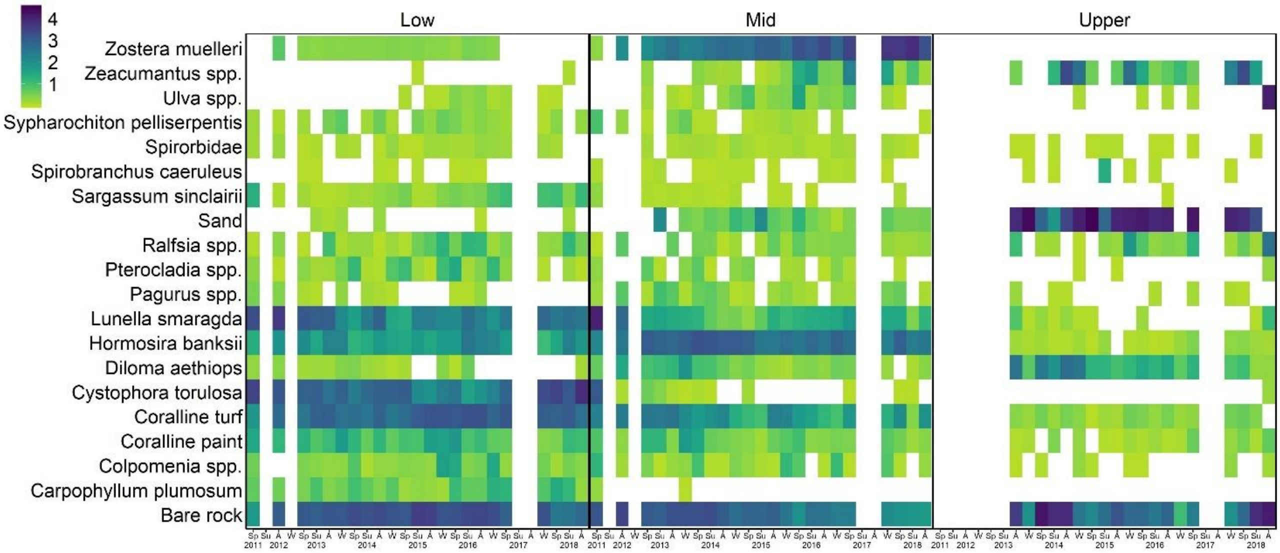


Figure 6-9: Heat map of most common species at Kairākau by tidal height using transformed data (log(x+1)) from 2011-2018. Darker colours represent higher abundance, lighter colours represent lower abundance. White squares represent either absence of that species in that survey or seasons where sampling wasn't possible at that site due to weather limitations. (Sp = Spring, Su = Summer, A = Autumn, W = Winter). n=650

6.5 Results - Status of *Zostera muelleri*

In New Zealand, seagrass is represented by a single species, *Zostera muelleri*. This species has an important role in ecosystem services, contributing the equivalent of $1.9 trillion per year in nutrient cycling, carbon sequestration, sediment retention, habitat and food provision (Lundquist et al., 2018; Waycott et al., 2009). In the last century, seagrass beds have been decreasing both nationally and internationally, driven by changes in land-use, resulting in high levels of sediment and nitrogen.

Seagrass is present at both Te Mahia and Kairākau reefs. While Te Mahia populations of seagrass have remained relatively stable over time (Figure 6-7, Appendix – Table F-2), changes have been observed at the Kairākau site.

Patches of seagrass in the low intertidal area of Kairākau have declined over time, while percent cover in the mid-intertidal area has significantly increased over time. Coverage at this site has increased from, on average, 20% in 2012 to 49% in 2018. This increasing trend is promising and could suggest that some of the seagrass beds in Hawke's Bay are re-establishing as observed elsewhere in New Zealand (Lundquist et al., 2018).

Current monitoring only captures a small area of the seagrass beds present over the extensive length of the reef system. To adequately determine and monitor the extent of seagrass cover, an aerial imagery approach is recommended. Currently, cost effective methodologies for this are being considered. In addition, monitoring seagrass blade size and biomass would elucidate overall health of beds to assess their long-term viability.

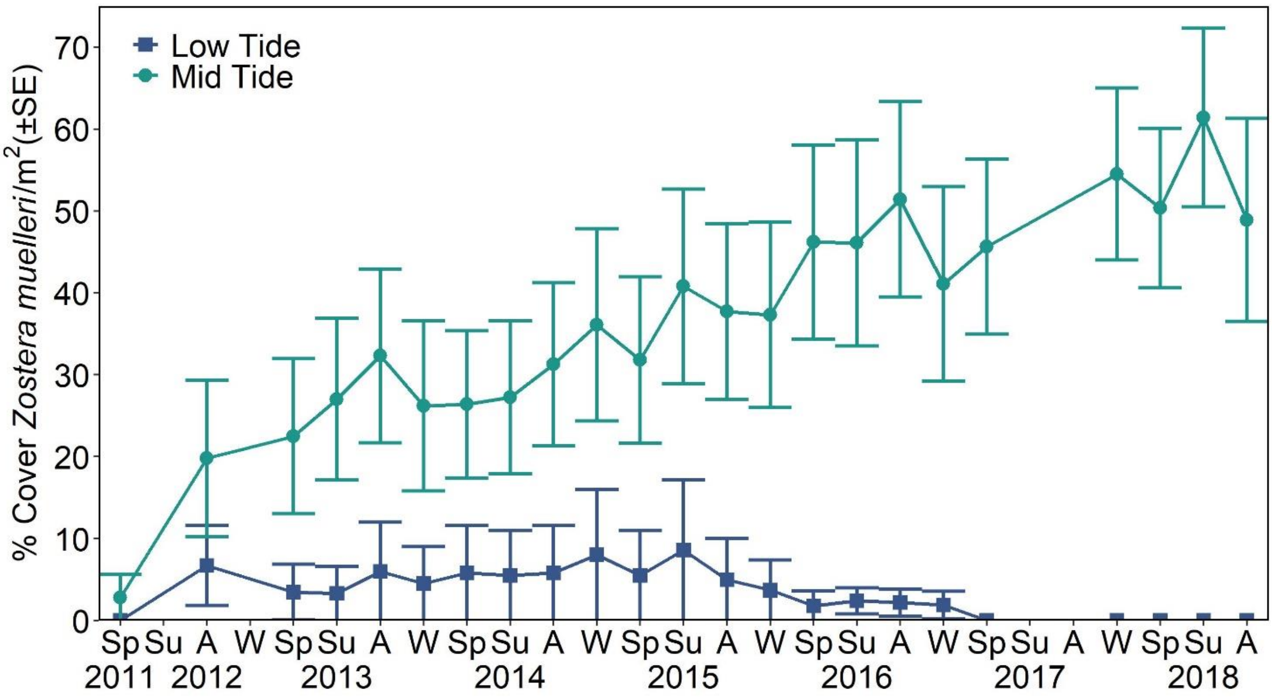


Figure 6-10: Average percent cover (±SE) of seagrass over time at low and mid tidal height at Kairākau. (Sp = Spring, Su = Summer, A = Autumn, W = Winter). n=460

6.6 Conclusions

The current report represents the first comprehensive analysis of the intertidal reef monitoring data collected through the HBRC state of the environment monitoring programme. The results illustrate the patterns of indigenous biodiversity in these high value areas over time. Kairākau and Hardinge Road reef systems had the highest community diversity and richness. Te Mahia reef system showed slightly lower diversity and richness, although reported higher levels of abundance within the species present. Generally, diversity has remained consistent over time. The few negative trends in diversity are likely attributable to either low abundance and high variation in the upper zone, or dominance by one particular species in the low and mid zones (e.g., horn snails (*Zeacumantus* spp.) at Te Mahia and seagrass (*Zostera muelleri*) at Kairākau).

In the low and mid zones, Hardinge Road had lower algal cover than Kairākau and Te Mahia. Upper zones across all sites had low overall algal cover. Communities were most characterised by the foundation seaweed species *Sargassum sinclarii*, *Cystophora torulosa*, and/or neptune's necklace (*Hormosira banksii*) that should continue to be monitored. Any notable declines in these foundation seaweeds could lead to severe changes in biodiversity (Schiel, 2006).

All sites have demonstrated a high level of stability over time, although community similarity appears to have reduced in the summer period of 2018. A corresponding marine heatwave is likely to have resulted in significant temperature stress for intertidal communities which may help to explain the changes in community structure observed at this time. Further monitoring will help to determine whether these communities return to their previous composition.

Although stable, analyses of the influence of tide, season, year and all interactions demonstrated significant, but variable, effects on each of the species tested. This variability indicates that patterns of influence or direction are unpredictable and highlights the necessity of further monitoring of these systems. Long term monitoring has revealed that species recovery to an environmental disturbance can take decades (Mieszkowska et al., 2007). Therefore, continued monitoring is recommended to ensure analysis of trends in community composition adequately account for natural variation. Additionally, with the ongoing influence of climate change, it is recommended that environmental data be considered in conjunction with community composition in the future.

Percent cover of the New Zealand seagrass was found to be increasing at the most prolific site, Kairākau mid zone. This is promising given the role this species plays in important ecosystem services and functions, and the sensitivity of this species to disturbance. Natural seagrass recolonization has been observed elsewhere in New Zealand (Lundquist et al., 2018). Although the mechanisms behind the recolonization are not well understood, legacy impacts of land clearance may have led to its initial decline or absence (Booth, 2019). It is recommended that further monitoring investigates the overall extent of seagrass beds in the Hawke's Bay area, and that health indicators such as blade length and biomass be measured to assess long-term viability.

7 Summary and Conclusions

Hawke's Bay's coastal environments are subject to the combined pressures of activities occurring on land, in freshwater bodies and in the ocean, and are the cumulative receiving environment for the land and freshwater drainage network. This report provides analysis of the state of the environment monitoring undertaken by HBRC within the Coastal Marine Environment, to describe how the coastal environments are responding to these pressures. This is the second comprehensive report of the coastal monitoring network, and build on the information obtained in the 2016 document (Wade et al., 2016).

The report outlines the state and trends of Hawke's Bay's:

- Coastal waters (section 2)
- Estuaries (section 3)
- Estuarine fish (section 4)
- Sandy beaches (section 5); and
- Intertidal reefs (section 6).

Coastal waters

Coastal waters within Hawke's Bay are generally within the levels observed elsewhere in New Zealand. Estuarine water quality tends to have higher levels of sediment and nutrients, and at times these appear to be in the upper levels compared to national sites. This is likely due to the highly erodible nature of Hawke's Bay landscapes, the current land use and flood events which can transport large quantities of sediments to regional estuaries and nearshore.

Phosphorus levels in the Ahuriri Estuary waters appear enriched, and while this may indicate natural sources resulting from the marine geology of the surrounding catchment, the absence of significant enrichment in the estuarine sediments compared to other regional estuaries, but the high levels of sediment phosphorus across the regional estuaries compared to national comparisons, means that this is an area that would benefit from further investigation.

Parameters for nearshore coastal waters tend to be within or below levels observed elsewhere in New Zealand. Dissolved oxygen depletion at depth has prompted further investigation. The quality of the waters offshore of Awatoto are conspicuously different to other sites along the coastline. As this area receives freshwater from the Tūtaekurī, Ngaruroro Rivers, the Karamu Stream and two municipal sewerage outfalls, source apportionment work would contribute to a greater understanding of the relative influence these may have on water quality.

Estuaries

Sediments remain the key stressor for Hawke's Bay estuarine systems, with some regional estuaries showing significant sediment stress. At these sites, sensitive species are largely absent, and this can compromise the integrity and resilience of the estuary as well as reducing its value for other species such as birds and fish.

Sediments at Ahuriri, Waitangi and Tukituki Estuary may be enriched with Phosphorus, and further work is required to understand potential impacts.

Sandy beaches

Beach systems remain depauperate, resulting in qualitative assessments of health. These areas contain significant resources that contribute to the diet of many fish species, and so understanding our soft sediment biodiversity is critical to sustainable management. Sensitive areas such as sand dunes appear to be under pressure from animal pests.

Intertidal reefs

Intertidal reef systems throughout Hawke's Bay are highly diverse and spatially explicit. Within each site and tidal level however, a high level of stability is apparent. However, even though assemblages tended to show stability over time, a period when changes to the abundance and diversity were significant coincided with a recorded marine heatwave in Hawke's Bay. Therefore it is likely that while we see stability under 'normal' weather conditions, any increase in extreme events may drive less stable assemblages (more difference in the community structure between seasons and years).

Percent cover within seagrass beds is increasing along the southern Hawke's Bay coast, and although the cause of the increase is largely unknown, continued monitoring will enable tracking of these important habitats.

The Hawke's Bay Regional Council Marine and Coast State of the Environment Monitoring has developed over the past 10 years to enable the provision of robust, defensible information on the state and trends associated with land based impacts in the coastal margin of the coastal marine area. This area is most sensitive to disturbances from land based activities due to its close proximity, and often depositional nature. However, these impacts are unlikely to be constrained to the coastal margin and nearshore, and the subtidal area of the Hawke's Bay region needs to be considered. This area has historically suffered from a lack of local research due to its exposed nature, and absence of research organisations working in the area.

A significant effort has been underway to fill some of these knowledge gaps, and it is envisaged that this work will continue to increase over the next five years. Specifically work within the subtidal marine area is expected to increase to enable information to be gathered on the response of these environments to land-based impacts.

Overall Conclusion

Estuaries remain the key areas that highlight stress from land-based activities. Levels of nutrient and sediment inputs appear to be impacting the community structure and function of these systems. In part, the identification of stress in these areas is due to current understanding of anthropogenic impacts. Unfortunately, similar understanding has not yet been developed on a national scale for many of our other marine systems, and therefore continued monitoring is fundamental to enable this. Much of our subtidal area remains undescribed in terms of structure and health, and therefore assessments on land-based impacts cannot be made until this work is undertaken.

7.1 Recommendation for future work

The preceding report details our current understanding of how our coastal environments may be responding to land based impacts. It has highlighted several areas that require further information in order to increase our understanding of how activities on land may impact our coastal marine area.

The following areas are recommended for further investigations:

- Anthropogenic and natural sources of high phosphorus in the Ahuriri Estuary
- Source apportionment for coastal waters of Awatoto.
- Spatial extent and magnitude of dissolved oxygen depletion in coastal waters.
- Spatial extent of mud and nutrients in regional estuaries.
- The potential impacts of phosphorus enrichment in regional estuaries.
- Biotic indices for estuaries (e.g. Benthic Health Model, Traits Based Index etc).
- Vehicular traffic and plastics in sandy beach systems.
- The full extent and health of seagrass (*Zostera muelleri*) beds in Hawke's Bay, including in the remaining estuary Pōrangahau.
- Subtidal habitat assessments including describing structure, and moving towards assessments of health.

8 Acknowledgements

The authors acknowledge the Hawke's Bay Regional Council Environmental Information team who have undertaken the collection and management of the data discussed in this report. We also acknowledge Anna Berthelsen and Dana Clark (Cawthron Institute) for reviewing the document and providing valuable feedback and comments.

9 Glossary of abbreviations and terms

ANZECC	Australian New Zealand Environment and Conservation Council
CME	Coastal Marine Environment
CMA	Coastal Marine Area
DIN	Dissolved Inorganic Nitrogen
DRP	Dissolved Reactive Phosphorus
ECC	East Cape Current
cfu	Colony forming units
ERC	Environmental Response Criteria
ETI	Estuarine Trophic Index
HAWQi	Hawke's Bay Water Quality information (Coastal monitoring buoy)
HBRC	Hawke's Bay Regional Council
ISQG	Interim Sediment Quality Guideline (from ANZECC)
LAWA	Land, Air, Water Aotearoa
MfE	Ministry for the Environment
N	Nitrogen
nMDS	Non parametric Multi-Dimensional Scaling
NZ	New Zealand
NZCPS	New Zealand Coastal Policy Statement
P	Phosphorus
PAC	Percent Annual Change
RCEP	Regional Coastal Environment Plan
RMA	Resource Management Act
SIDE	Shallow Intertidal Dominated Estuary
SSRTRE	Shallow, Short Residence Time River Estuary
SOE	State of the Environment
TOC	Total Organic Carbon
TRP	Total Recoverable Phosphorus
WCC	Wairarapa Coastal Current

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Appendix A Hawke's Bay Significant Conservation Areas

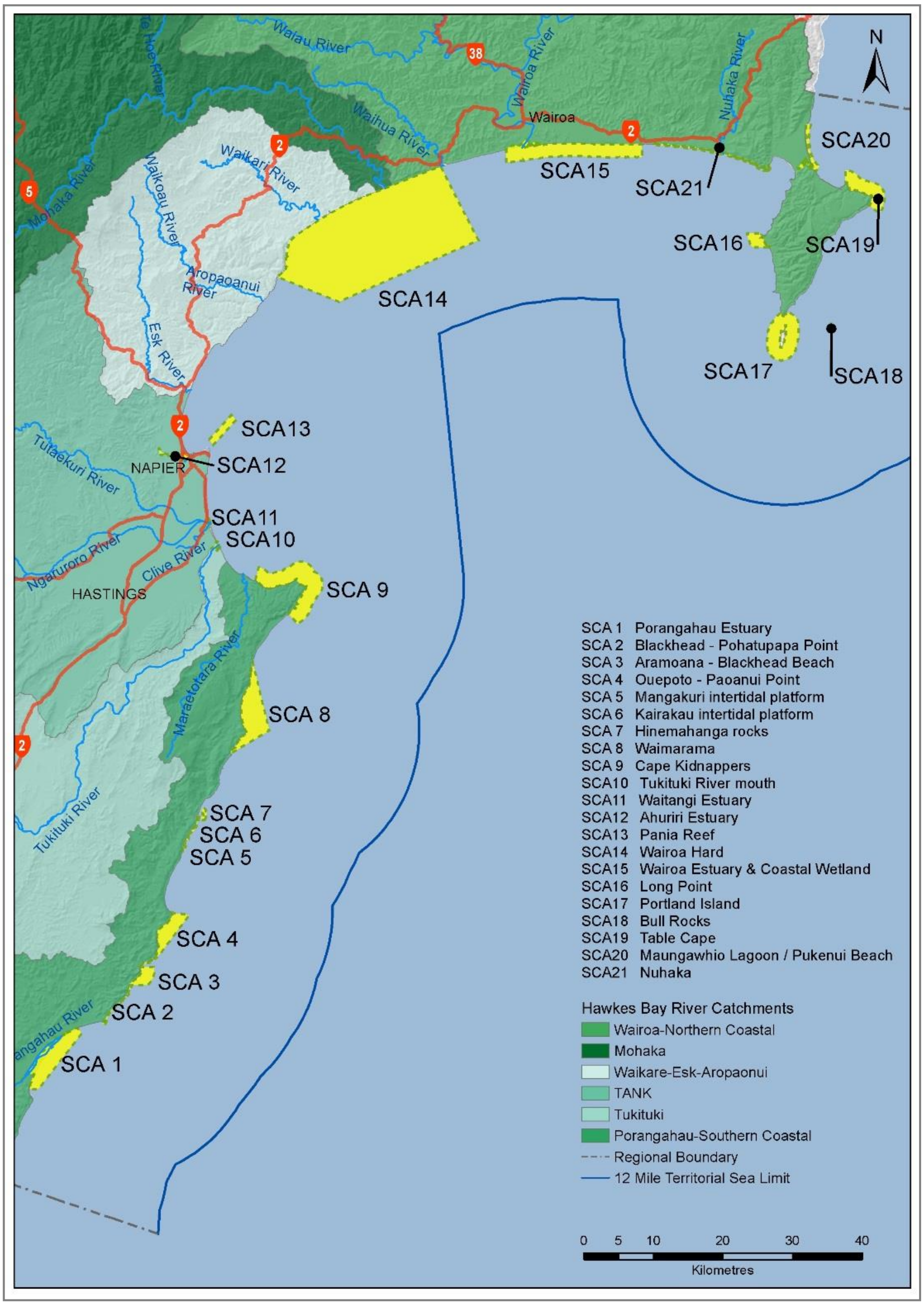


Figure A-1: Significant Conservation Areas identified in the Hawke's Bay Regional Coastal Environment Plan.

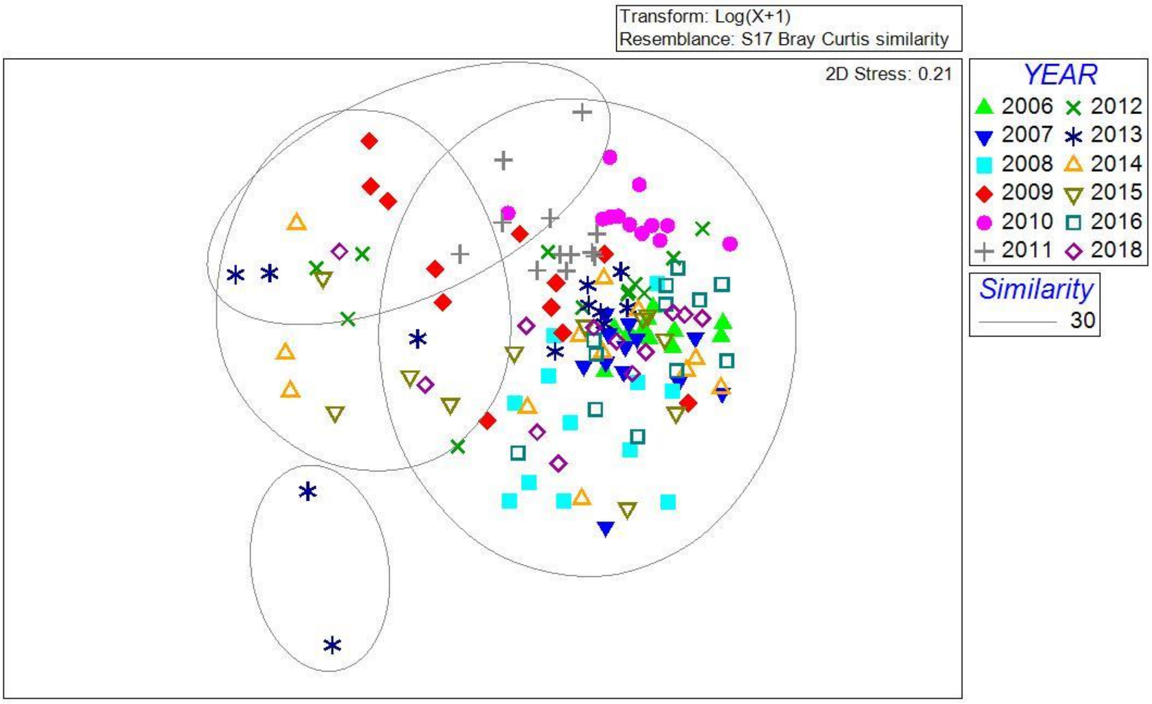
Appendix B Water and Sediment Quality Detection Limits

Table B-1: Laboratory detection limits used in analyses.

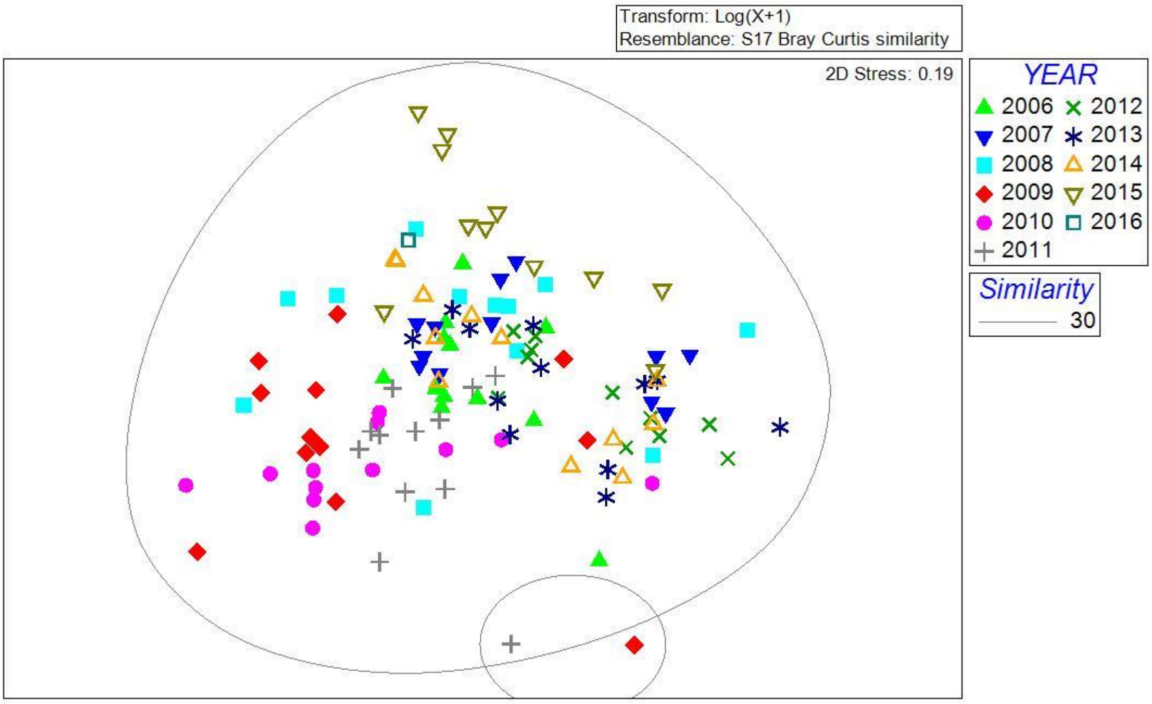
Sample Matrix		
Water	**Parameter**	**Detection Limit**
	Volatile Suspended Solids	0.5 g/m3
	Total Suspended Solids	0.5 g/m3
	Total Nitrogen	0.010 g/m3
	Total Nitrogen _Estuarine	0.05 g/m3
	Total Ammoniacal-N	0.005 g/m3
	Nitrite-N	0.0010 g/m3
	Nitrate-N	0.0010 g/m3
	Nitrate-N + Nitrite-N	0.0010 g/m3
	Dissolved Reactive Phosphorus	0.0010 g/m3
	Total Phosphorus	0.004 g/m3
	Faecal Coliforms	1 cfu / 100mL
	Enterococci	1 cfu / 100mL
	Chlorophyll a	0.00002 g/m3
Sediment	Total Nitrogen	0.05 g/100g dry wt
	Total Recoverable Phosphorus	40 mg/kg dry wt
	Total Organic Carbon	0.05 g/100g dry wt
	Total Sulphur	0.005 g/100g dry wt
	Chlorophyll a	0.1 mg/kg as rcvd
	Trace metals (As,Cd,Cr,Cu,Ni,Pb,Zn,Hg)	0.010 - 0.4 mg/kg dry wt

Appendix C Non-metric MulitDimensional Scaling (nMDS) for infauna sites by year.

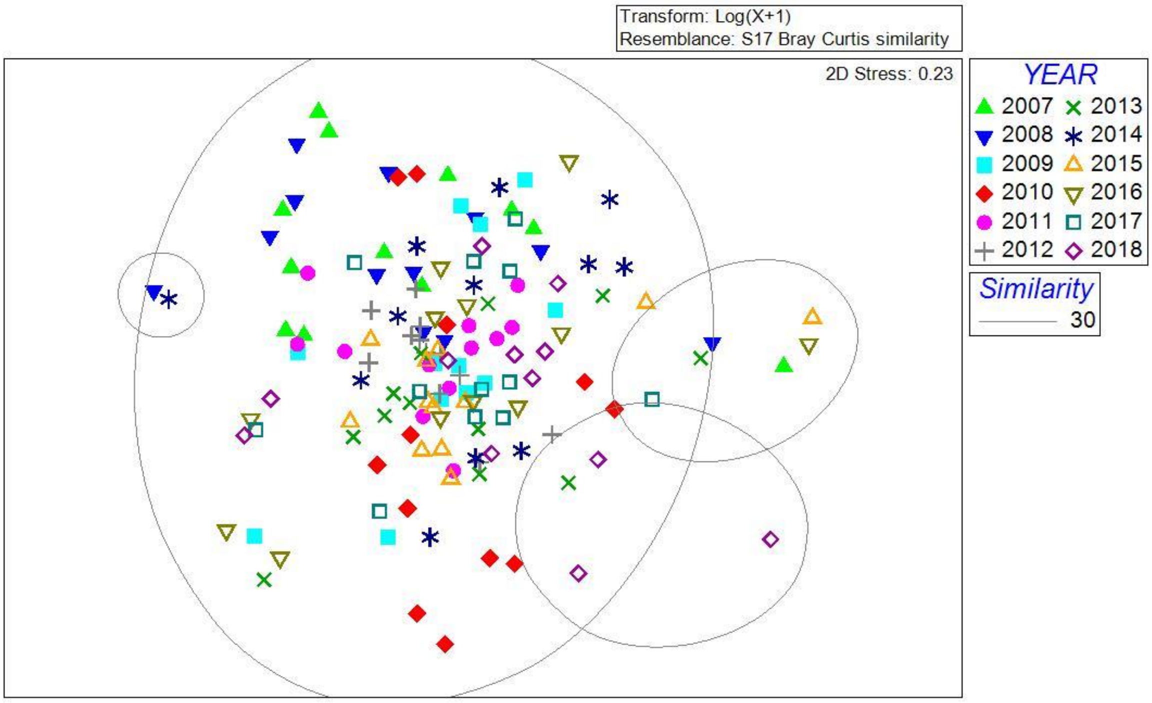
Ahuriri A



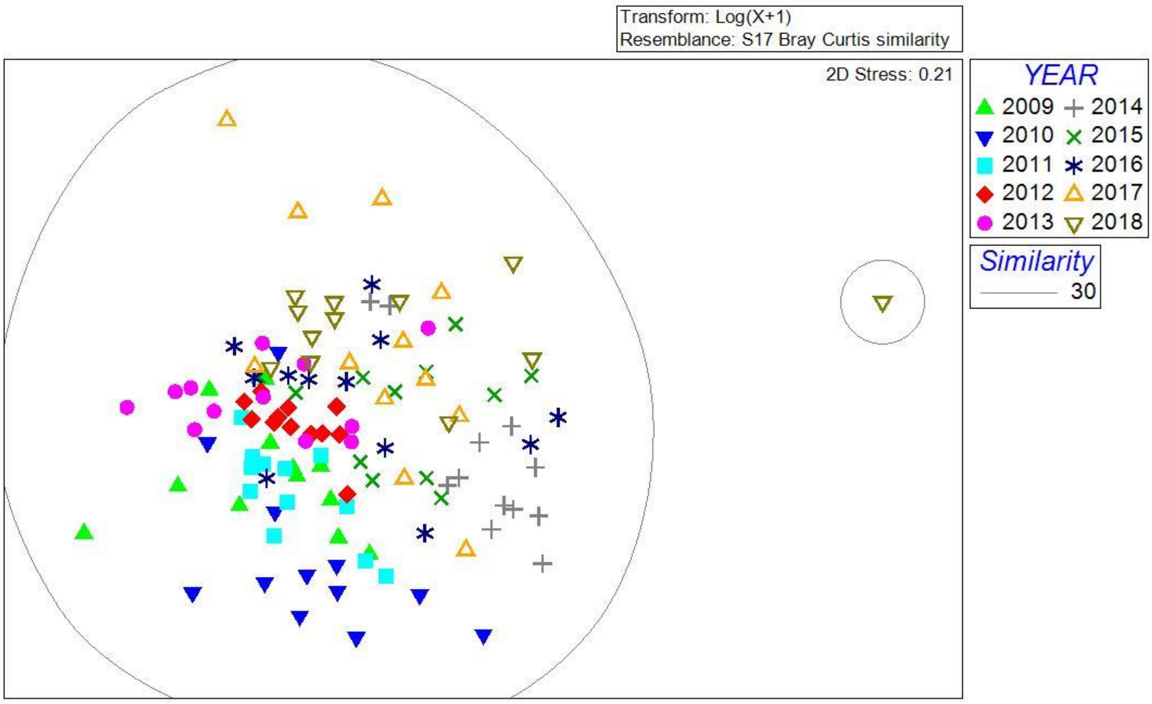
Ahuriri B



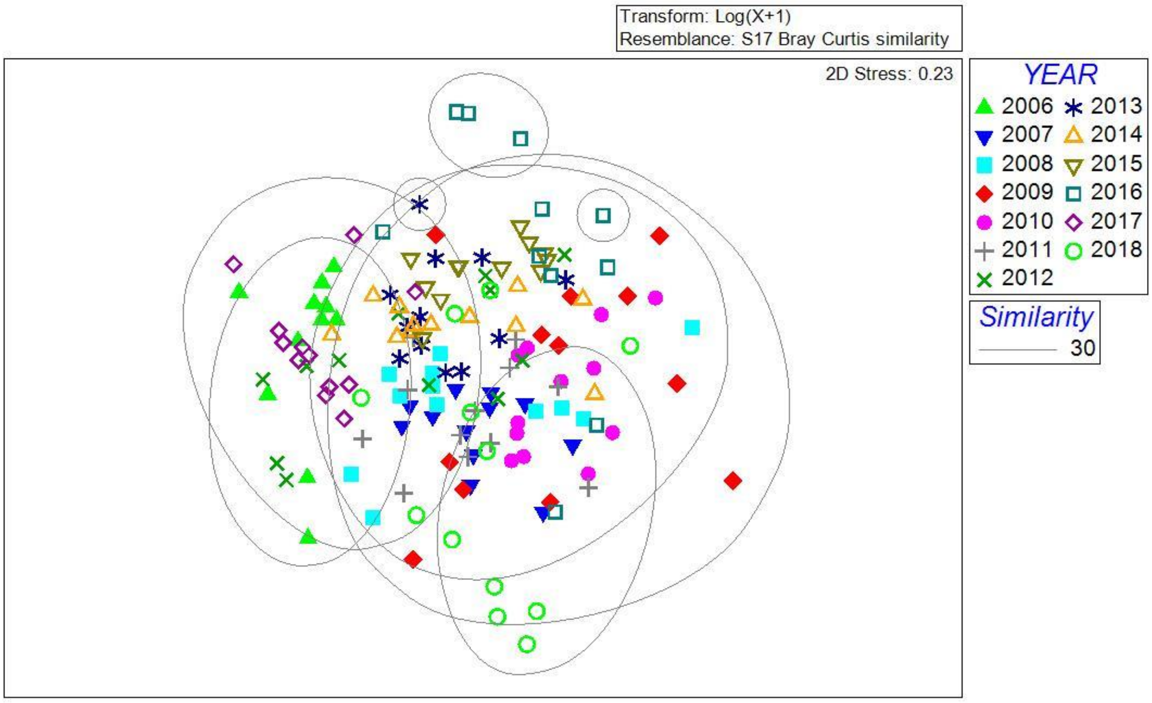
Ahuriri D



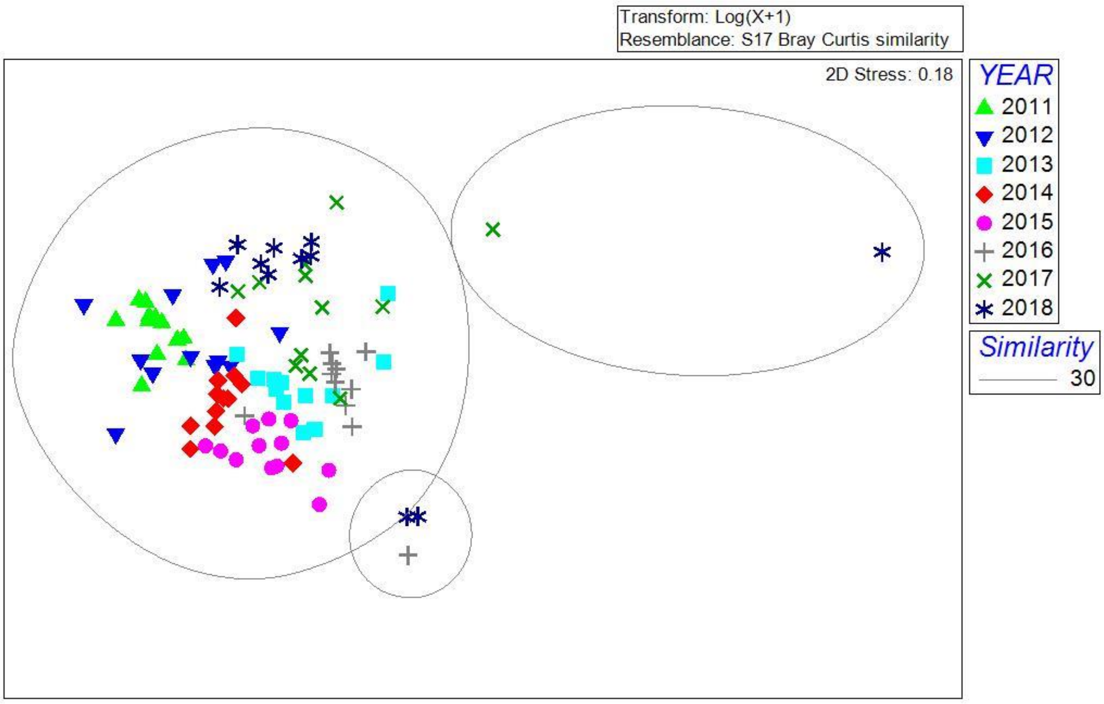
Ahuriri E



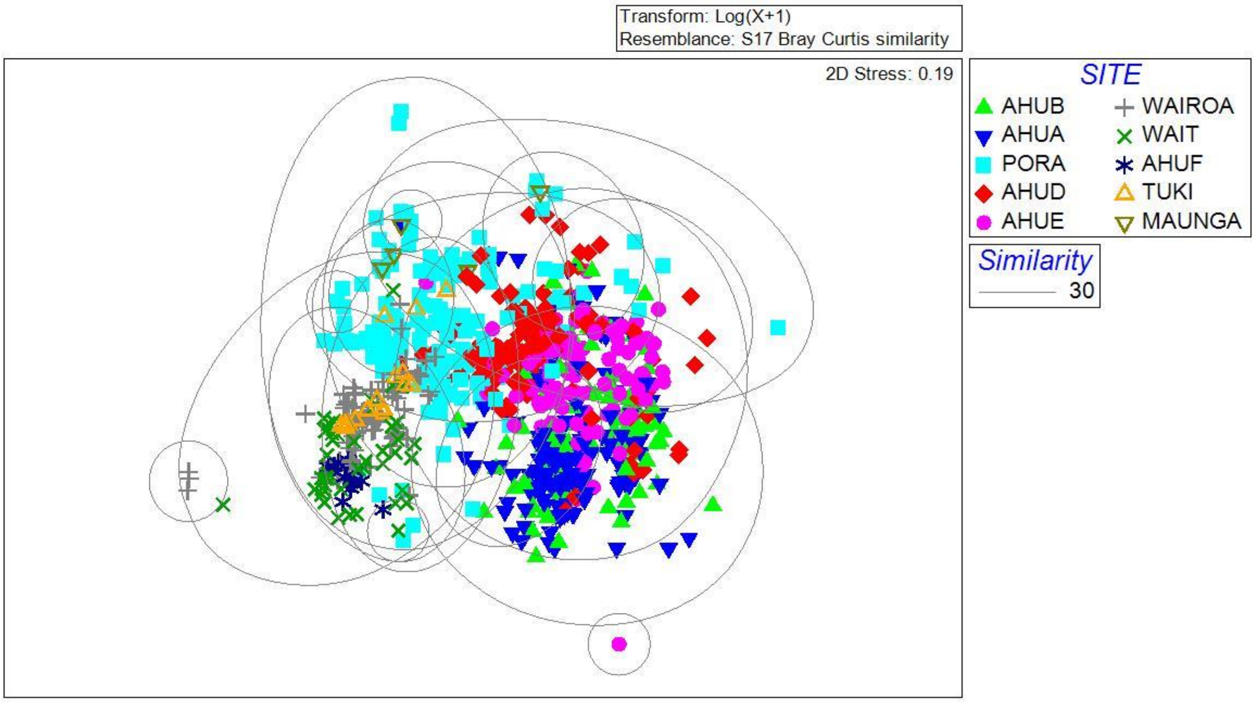
Pōrangahau



Wairoa



Appendix D Nonparametric MultiDimensional Scaling (nMDS) for estuary infauna all sites by year.



Appendix E SIMPER results at Sandy Beach sites

Table E-1: SIMPER analysis comparing low and mid tide zone infaunal species at Pōrangahau Beach.

Species	Opoutama Beach (Av. Dissimilarity 66.24%)				
	Low - Av. Abundance	Mid - Av. Abundance	Av. Dissimilarity	Dissimilarity Contribution %	Dissimilarity Cumulative %
Cumacea	1.22	0.18	16.13	24.36	24.36
Waitangi chelatus	1.05	1.06	14.66	22.14	46.49
Paphies subtriangulata	0.91	0.79	11.5	17.36	63.85
Flabellifera	0.39	0.64	8.7	13.13	76.99
Patuki breviuropodus	0.54	0.05	7.19	10.85	87.83
Nemertea	0.18	0.03	2.24	3.39	91.22

Table E-2: SIMPER analysis results of infaunal cores at sandy beach sites.

Species	Mahanga Beach (Av. Similarity 14.50%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Paphies subtriangulata	0.48	4.71	32.52	32.52
Cumacea	0.4	1.79	12.36	44.88
Waitangi brevirostris	0.23	1.51	10.38	55.26
Orbinia papillosa	0.2	1.19	8.22	63.49
Aglaophamus macroura	0.24	1.12	7.74	71.23
Gastropoda	0.39	1.05	7.23	78.46
Harpacticoid copepod	0.22	0.99	6.81	85.27
Haustorius spp.	0.23	0.86	5.91	91.17
Species	Opoutama Beach (Av. Similarity 10.31%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Glycera ovigera	0.34	4.86	47.18	47.18
Perna canaliculus (spat)	0.3	2.38	23.07	70.25
Waitangi brevirostris	0.16	0.6	5.87	76.11
Nematoda	0.17	0.5	4.89	81.01
Nemertea	0.15	0.38	3.64	84.65
Patuki breviuropodus	0.16	0.3	2.96	87.61
Bryozoa	0.09	0.29	2.85	90.46
Species	Rangaiika Beach (Av. Similarity 37.92%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Waitangi chelatus	1.9	36.35	95.87	95.87
Species	Ocean Beach (Av. Similarity 7.10%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Waitangi chelatus	0.59	3.19	44.85	44.85
Flabellifera	0.14	0.7	9.79	54.64
Cumacea	0.25	0.59	8.34	62.98
Haustorius spp.	0.12	0.54	7.61	70.59
Paphies subtriangulata	0.17	0.44	6.25	76.84
Patuki breviuropodus	0.2	0.44	6.17	83.01
Glycera ovigera	0.07	0.33	4.6	87.61
Nematoda	0.07	0.2	2.84	90.46
Species	Waimarama (Av. Similarity 14.76%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Paphies subtriangulata	0.68	6.03	40.87	40.87
Waitangi chelatus	0.55	5.75	38.99	79.86
Cumacea	0.52	1.14	7.72	87.58
Austrovenus stutchburyi	0.15	0.51	3.48	91.06

Species	Pourerere Beach (Av. Similarity 13.70%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Waitangi chelatus	1.04	7.54	55.06	55.06
Orbinia papillosa	0.22	2.09	15.28	70.34
Paphies subtriangulata	0.17	0.93	6.81	77.15
Waitangi brevirostris	0.27	0.78	5.72	82.87
Aglaophamus macroura	0.11	0.58	4.23	87.1
Pisinna spp.	0.27	0.54	3.98	91.07
Species	Blackhead Beach (Av. Similarity 35.24%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Waitangi chelatus	1.45	18.98	53.85	53.85
Waitangi brevirostris	0.73	10.03	28.45	82.3
Cumacea	0.62	3.17	9	91.31
Species	Pōrangahau Beach (Av. Similarity 37.34%)			
	Av. Abundance	Av. Similarity	Contribution %	Cumulative %
Waitangi chelatus	1.05	14.08	37.71	37.71
Paphies subtriangulata	0.85	11.64	31.18	68.89
Flabellifera	0.52	5.98	16.01	84.9
Cumacea	0.7	4.29	11.49	96.39

Appendix F Intertidal community composition and species abundances

Table F-1: PERMANOVA results using log (x+1) abundance data from 2011 to 2018. . Fixed factors include fixed factors of 'year', 'season', 'sites', 'tidal heights'. and all interactions (denoted with an x). df=degrees of freedom, SS (III)=partial sum of squares with type III errors, ECV=estimates of components of variation, Pseudo-F=the PERMANOVA F ratio, Perms=the number of unique values of test statistic, P=p-value obtained with permutations.

	PERMANOVA results						
Factor	df	SS (III)	ECV	Pseudo-F	Perms	P	
Year	7	77709	57.82	17.326	995	0.001	*
Season	3	21495	20.45	11.183	998	0.001	*
Site	2	234200	469.06	182.76	999	0.001	*
Tidal Height	2	694620	956.85	542.07	997	0.001	*
Year x Season	12	42344	39.39	5.5074	997	0.001	*
Year x Site	14	99804	102.10	11.126	997	0.001	*
Year x Tidal Height	12	51928	52.33	6.7539	998	0.001	*
Season x Site	6	29699	40.14	7.7254	994	0.001	*
Season x Tidal Height	6	18627	21.46	4.8454	998	0.001	*
Site x Tidal Height	4	306340	522.80	119.53	997	0.001	*
Year x Season x Site	23	68219	90.71	4.6293	996	0.001	*
Year x Season x Tidal Height	22	37281	40.00	2.6448	998	0.001	*
Year x Site x Tidal Height	22	80457	114.49	5.7079	999	0.001	*
Season x Site x Tidal Height	12	31456	49.55	4.0912	998	0.001	*
Year x Season x Site x Tidal Height	36	55848	91.13	2.4212	993	0.001	*
Residual	1655	1060400	640.72				

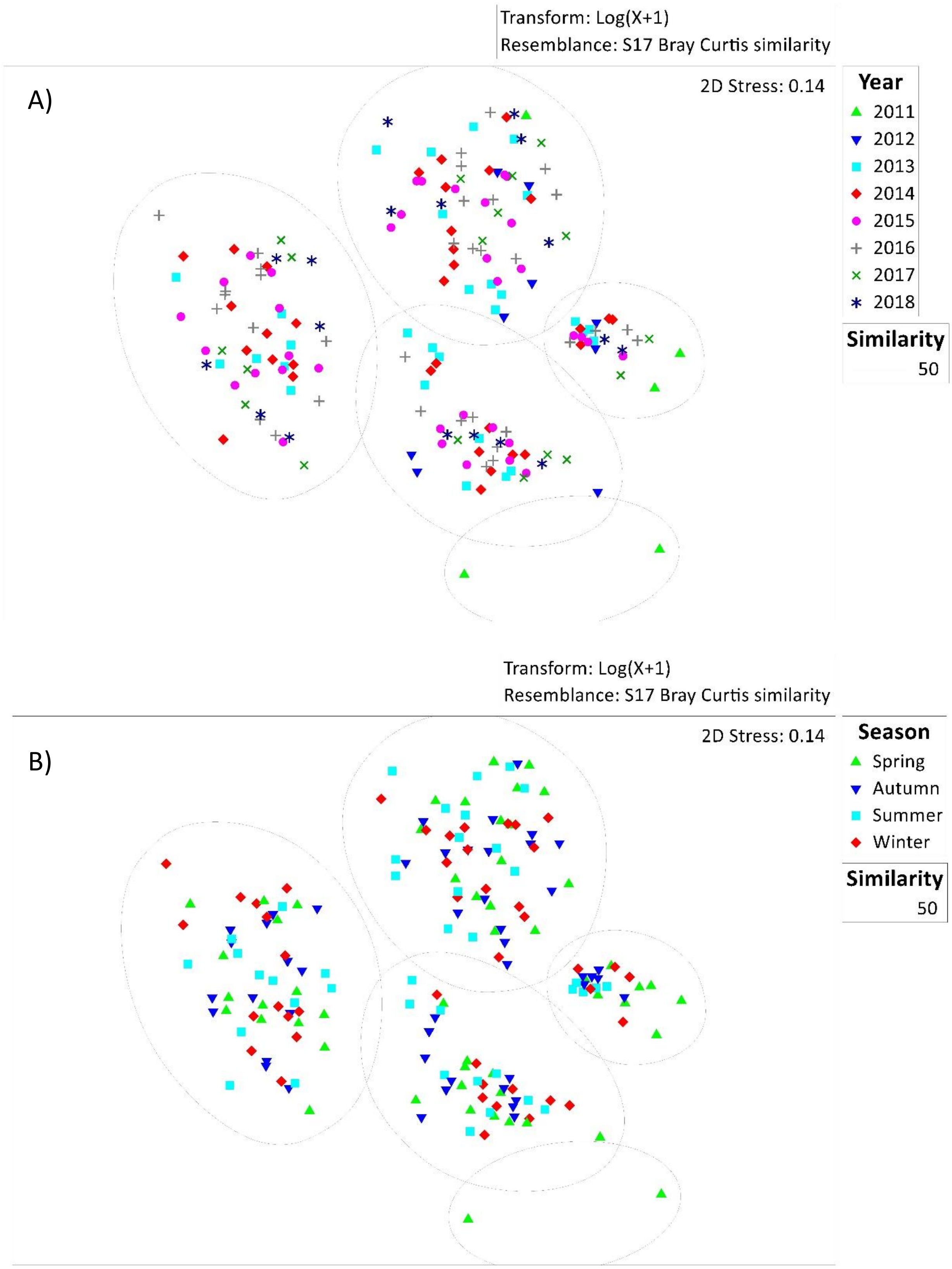


Figure F-1: nMDS ordination of community composition of surveys by A) year and B) season with data from 2011-2018.

Table F-2: Results from GLS models testing the influence of tidal height, season, year and their interactions (denoted by an x) on most common species at Te Mahia.

Species	Factor	df	F-value	p-value	Species	Factor	df	F-value	p-value
Bare rock	Tide	2	0.00	1	*Melagraphia aethiops*	Tide	2	19.97	<.0001
	Season	3	5.67	**0.0033**		Season	3	0.26	0.8510
	Year	1	2.06	0.161		Year	1	6.61	0.0152
	Tide x Season	6	1.05	0.4109		Tide x Season	6	1.73	0.1473
	Tide x Year	2	0.10	0.9057		Tide x Year	2	3.46	**0.0440**
	Season x Year	3	0.57	0.6412		Season x Year	3	0.63	0.6022
	Tide x Season	6	2.02	0.0924		Tide x Season	6	0.41	0.8647
	Residual	7				Residual	7		
Cladostephus spongiosus	Tide	2	218.03	<.0001	*Notheia anomala*	Tide	2	7.79	0.0018
	Season	3	6.26	0.0019		Season	3	1.41	0.2573
	Year	1	0.06	0.8017		Year	1	20.34	0.0001
	Tide x Season	6	4.28	**0.003**		Tide x Season	6	0.72	0.6363
	Tide x Year	2	0.01	0.9894		Tide x Year	2	5.82	**0.0071**
	Season x Year	3	0.98	0.413		Season x Year	3	0.55	0.6535
	Tide x Season	6	0.56	0.7612		Tide x Season	6	0.66	0.6823
	Residual	7				Residual	7		
Colpomenia spp.	Tide	2	11.76	**0.0002**	*Pagarus* spp.	Tide	2	27.04	<.0001
	Season	3	3.01	0.0448		Season	3	0.17	0.9186
	Year	1	0.14	0.7134		Year	1	5.89	0.0212
	Tide x Season	6	0.95	0.477		Tide x Season	6	0.51	0.7931
	Tide x Year	2	0.01	0.991		Tide x Year	2	3.95	0.0296
	Season x Year	3	4.39	**0.011**		Season x Year	3	1.89	0.1515
	Tide x Season	6	0.91	0.4978		Tide x Season	6	3.31	**0.0123**
	Residual	7				Residual	7		
Cominella glandiformis	Tide	2	6.09	**0.0059**	*Pomatoceros caeruleus*	Tide	2	15.36	<.0001
	Season	3	0.71	0.5526		Season	3	2.54	0.0747
	Year	1	2.58	0.118		Year	1	6.72	**0.0144**
	Tide x Season	6	0.70	0.6503		Tide x Season	6	5.38	**0.0007**
	Tide x Year	2	0.50	0.6132		Tide x Year	2	0.54	0.5889
	Season x Year	3	0.87	0.4652		Season x Year	3	2.35	0.0918
	Tide x Season	6	0.15	0.9884		Tide x Season	6	0.81	0.5700
	Residual	7				Residual	7		
Coralline paint	Tide	2	7.75	**0.0019**	*Ralfsia* spp.	Tide	2	3.16	0.0564
	Season	3	0.26	0.8512		Season	3	1.74	0.1801
	Year	1	0.34	0.5621		Year	1	0.73	0.3988
	Tide x Season	6	0.49	0.8099		Tide x Season	6	4.96	**0.0012**
	Tide x Year	2	0.21	0.8096		Tide x Year	2	0.03	0.9735
	Season x Year	3	0.25	0.8612		Season x Year	3	4.08	**0.0150**
	Tide x Season	6	0.35	0.9056		Tide x Season	6	1.60	0.1791
	Residual	7				Residual	7		
Species	Factor	df	F-value	p-value	Species	Factor	df	F-value	p-value
Coralline turf	Tide	2	0.00	1.0000	Sand	Tide	2	8.96	0.0008
	Season	3	6.30	0.0018		Season	3	1.11	0.3598
	Year	1	0.42	0.5204		Year	1	0.83	0.3696
	Tide x Season	6	3.75	**0.0064**		Tide x Season	6	0.91	0.5027
	Tide x Year	2	0.08	0.9262		Tide x Year	2	3.66	**0.0373**
	Season x Year	3	2.07	0.1244		Season x Year	3	2.09	0.1222
	Tide x Season	6	1.05	0.4149		Tide x Season	6	1.55	0.1948
	Residual	7				Residual	7		
Cystophora torulosa	Tide	2	14.97	**<.0001**	Spirorbidae	Tide	2	7.11	**0.0029**
	Season	3	2.01	0.1333		Season	3	1.06	0.3806
	Year	1	0.92	0.3446		Year	1	2.08	0.1593
	Tide x Season	6	1.40	0.2474		Tide x Season	6	0.41	0.8667
	Tide x Year	2	0.29	0.7498		Tide x Year	2	0.35	0.7104
	Season x Year	3	0.56	0.6467		Season x Year	3	0.53	0.6674
	Tide x Season	6	0.19	0.9763		Tide x Season	6	0.54	0.7705
	Residual	7				Residual	7		
Haustrum scobina	Tide	2	25.50	<.0001	*Ulva* spp.	Tide	2	1.81	0.1803
	Season	3	1.18	0.334		Season	3	1.02	0.398
	Year	1	0.57	0.4566		Year	1	3.02	0.0924
	Tide x Season	6	0.91	0.4976		Tide x Season	6	0.35	0.9057
	Tide x Year	2	0.45	0.6423		Tide x Year	2	0.47	0.6283
	Season x Year	3	5.34	0.0044		Season x Year	3	0.71	0.5539
	Tide x Season	6	3.89	**0.0052**		Tide x Season	6	0.91	0.498
	Residual	7				Residual	7		
Hormosira banksii	Tide	2	659.90	<.0001	*Zeacumantus* spp.	Tide	2	6.82	**0.0035**
	Season	3	4.85	0.007		Season	3	7.12	0.0009
	Year	1	4.46	0.0428		Year	1	0.05	0.8184
	Tide x Season	6	1.37	0.2556		Tide x Season	6	1.84	0.1239
	Tide x Year	2	0.96	0.3929		Tide x Year	2	0.89	0.422
	Season x Year	3	0.38	0.7698		Season x Year	3	7.80	**0.0005**
	Tide x Season	6	2.81	**0.0265**		Tide x Season	6	1.64	0.1703
	Residual	7				Residual	7		
Lunella smaragda	Tide	2	7.47	**0.0023**	*Zostera muelleri*	Tide	2	51.96	**<.0001**
	Season	3	2.00	0.1341		Season	3	1.21	0.3242
	Year	1	0.65	0.4252		Year	1	0.23	0.6368
	Tide x Season	6	0.93	0.4885		Tide x Season	6	1.30	0.2874
	Tide x Year	2	0.62	0.5431		Tide x Year	2	0.18	0.8325
	Season x Year	3	0.52	0.6697		Season x Year	3	1.66	0.1962
	Tide x Season	6	1.55	0.1956		Tide x Season	6	2.14	0.0765
	Residual	7				Residual	7		

Table F-3: Results from GLS models testing the influence of tidal height, season, year and their interactions (denoted by an x) on most common species abundances at Hardinge Road.

Species	Factor	df	F-value	p-value	Species	Factor	df	F-value	p-value
Bare rock	Tide	2	10.61	**0.0002**	*Patriella regularis*	Tide	2	6.38	**0.0039**
	Season	3	0.87	0.467		Season	3	3.04	**0.0398**
	Year	1	0.00	0.9996		Year	1	0.31	0.5788
	Tide x Season	6	0.36	0.9007		Tide x Season	6	1.12	0.3672
	Tide x Year	2	0.54	0.586		Tide x Year	2	0.08	0.9230
	Season x Year	3	2.00	0.1294		Season x Year	3	1.63	0.1971
	Tide x Season	6	0.37	0.8945		Tide x Season	6	0.42	0.8592
	Residual	16				Residual	16		
Balanomorpha	Tide	2	24.23	**<.0001**	*Pomatoceros caeruleus*	Tide	2	17.61	**<.0001**
	Season	3	2.94	**0.0447**		Season	3	0.14	0.9386
	Year	1	0.09	0.769		Year	1	5.72	**0.0215**
	Tide x Season	6	0.39	0.8831		Tide x Season	6	0.36	0.9023
	Tide x Year	2	0.75	0.481		Tide x Year	2	0.00	0.9953
	Season x Year	3	0.20	0.8927		Season x Year	3	0.17	0.9182
	Tide x Season	6	1.01	0.4335		Tide x Season	6	0.82	0.5633
	Residual	16				Residual	16		
Colpomenia spp.	Tide	2	11.44	**0.0001**	*Ralfsia* spp.	Tide	2	4.66	**0.0152**
	Season	3	10.66	**<.0001**		Season	3	3.11	0.0371
	Year	1	1.35	0.2527		Year	1	4.24	0.0460
	Tide x Season	6	1.81	0.1211		Tide x Season	6	0.90	0.5072
	Tide x Year	2	0.44	0.6493		Tide x Year	2	3.17	0.0525
	Season x Year	3	1.40	0.257		Season x Year	3	4.93	**0.0052**
	Tide x Season	6	0.34	0.9136		Tide x Season	6	0.52	0.7926
	Residual	16				Residual	16		
Coralline paint	Tide	2	26.03	<.0001	Sand	Tide	2	33.88	<.0001
	Season	3	1.46	0.2391		Season	3	1.54	0.2202
	Year	1	2.50	0.1216		Year	1	0.01	0.9127
	Tide x Season	6	0.61	0.7191		Tide x Season	6	5.36	0.0004
	Tide x Year	2	3.56	**0.0376**		Tide x Year	2	0.89	0.4179
	Season x Year	3	1.17	0.3322		Season x Year	3	4.53	0.0079
	Tide x Season	6	0.21	0.9722		Tide x Season	6	7.98	**<.0001**
	Residual	16				Residual	16		
Coralline turf	Tide	2	100.70	**<.0001**	*Sargassum sinclairii*	Tide	2	15.09	<.0001
	Season	3	2.76	0.0547		Season	3	1.96	0.1362
	Year	1	3.09	0.0864		Year	1	12.33	0.0011
	Tide x Season	6	1.78	0.127		Tide x Season	6	1.74	0.1359
	Tide x Year	2	0.40	0.6719		Tide x Year	2	8.16	0.0011
	Season x Year	3	0.56	0.6462		Season x Year	3	5.02	0.0048
	Tide x Season	6	0.54	0.7765		Tide x Season	6	2.84	**0.0213**
	Residual	16				Residual	16		
Species	**Factor**	**df**	**F-value**	**p-value**	**Species**	**Factor**	**df**	**F-value**	**p-value**
Gigartina spp.	Tide	2	13.17	**<.0001**	Spirorbidae	Tide	2	47.64	**<.0001**
	Season	3	9.52	**0.0001**		Season	3	3.54	0.0229
	Year	1	0.09	0.7605		Year	1	4.39	0.0425
	Tide x Season	6	0.93	0.4832		Tide x Season	6	1.40	0.2398
	Tide x Year	2	1.39	0.2601		Tide x Year	2	2.48	0.0969
	Season x Year	3	2.57	0.0675		Season x Year	3	3.41	**0.0264**
	Tide x Season	6	0.47	0.8229		Tide x Season	6	0.94	0.4807
	Residual	16				Residual	16		
Haustrum scobina	Tide	2	9.79	0.0003	*Sypharochiton pelliserpentis*	Tide	2	2.49	0.0961
	Season	3	1.50	0.2295		Season	3	1.04	0.3844
	Year	1	4.26	**0.0455**		Year	1	8.07	0.007
	Tide x Season	6	2.36	**0.0484**		Tide x Season	6	2.09	0.0758
	Tide x Year	2	1.18	0.3168		Tide x Year	2	2.19	0.1252
	Season x Year	3	0.39	0.7593		Season x Year	3	2.23	0.0996
	Tide x Season	6	1.00	0.4417		Tide x Season	6	2.66	**0.0288**
	Residual	16				Residual	16		
Lunella smaragda	Tide	2	45.69	**<.0001**	*Ulva* spp.	Tide	2	0.00	0.9997
	Season	3	4.00	**0.0139**		Season	3	2.98	**0.0429**
	Year	1	1.79	0.1885		Year	1	0.12	0.7315
	Tide x Season	6	0.72	0.6341		Tide x Season	6	1.09	0.3858
	Tide x Year	2	0.67	0.5178		Tide x Year	2	0.47	0.6313
	Season x Year	3	0.92	0.4395		Season x Year	3	1.39	0.2586
	Tide x Season	6	1.74	0.1378		Tide x Season	6	0.46	0.8304
	Residual	16				Residual	16		
Melagraphia aethiops	Tide	2	78.52	<.0001	*Undaria pinnatifida*	Tide	2	27.68	<.0001
	Season	3	1.60	0.2036		Season	3	19.54	<.0001
	Year	1	14.50	0.0005		Year	1	3.05	0.0883
	Tide x Season	6	1.87	0.1092		Tide x Season	6	7.48	**<.0001**
	Tide x Year	2	2.17	0.1272		Tide x Year	2	0.64	0.5325
	Season x Year	3	1.56	0.2149		Season x Year	3	4.46	**0.0086**
	Tide x Season	6	3.02	**0.0156**		Tide x Season	6	1.12	0.369
	Residual	16				Residual	16		
Pagarus spp.	Tide	2	2.82	0.0717	*Zeacumantus* spp.	Tide	2	2.56	0.0897
	Season	3	5.06	0.0046		Season	3	7.82	0.0003
	Year	1	5.60	0.0229		Year	1	1.72	0.1978
	Tide x Season	6	1.91	0.1031		Tide x Season	6	2.45	**0.0415**
	Tide x Year	2	0.69	0.5098		Tide x Year	2	0.53	0.5926
	Season x Year	3	7.07	0.0006		Season x Year	3	0.14	0.9339
	Tide x Season	6	2.78	**0.0235**		Tide x Season	6	2.04	0.0827
	Residual	16				Residual	16		

Table F-4: Results from GLS models testing the influence of tidal height, season, year and their interactions (denoted by an x) on most common species abundances at Kairākau.

Species	Factor	df	F-value	p-value	Species	Factor	df	F-value	p-value
Bare rock	Tide	2	1.13	0.3318	*Pomatoceros caeruleus*	Tide	2	0.66	0.5233
	Season	3	6.02	0.0017		Season	3	1.63	0.1963
	Year	1	3.13	0.0843		Year	1	0.69	0.4126
	Tide x Season	6	4.26	**0.002**		Tide x Season	6	1.71	0.1443
	Tide x Year	2	3.57	**0.0372**		Tide x Year	2	0.23	0.7934
	Season x Year	3	0.05	0.9845		Season x Year	3	0.67	0.5780
	Tide x Season	6	0.50	0.8028		Tide x Season	6	0.40	0.8763
	Residual	17				Residual	17		
Carpophyllum plumosum	Tide	2	79.44	**<.0001**	*Pterocladia* spp.	Tide	2	7.13	0.0022
	Season	3	2.39	0.0829		Season	3	14.80	<.0001
	Year	1	0.18	0.6733		Year	1	0.72	0.4002
	Tide x Season	6	1.29	0.282		Tide x Season	6	2.88	**0.0195**
	Tide x Year	2	1.57	0.2207		Tide x Year	2	0.19	0.8281
	Season x Year	3	0.46	0.7095		Season x Year	3	0.96	0.4192
	Tide x Season	6	1.25	0.3022		Tide x Season	6	0.32	0.9234
	Residual	17				Residual	17		
Colpomenia spp.	Tide	2	11.53	0.0001	*Ralfsia* spp.	Tide	2	0.81	0.4533
	Season	3	16.65	<.0001		Season	3	1.08	0.3676
	Year	1	0.05	0.8289		Year	1	3.81	0.0580
	Tide x Season	6	2.45	**0.0404**		Tide x Season	6	0.80	0.5780
	Tide x Year	2	1.02	0.3694		Tide x Year	2	0.54	0.5884
	Season x Year	3	9.21	**0.0001**		Season x Year	3	1.62	0.1988
	Tide x Season	6	0.85	0.5406		Tide x Season	6	0.99	0.4439
	Residual	17				Residual	17		
Coralline paint	Tide	2	32.20	<.0001	Sand	Tide	2	250.84	<.0001
	Season	3	3.34	0.0283		Season	3	1.57	0.2106
	Year	1	2.67	0.11		Year	1	0.38	0.5432
	Tide x Season	6	2.37	0.0464		Tide x Season	6	3.73	0.0048
	Tide x Year	2	1.75	0.187		Tide x Year	2	0.54	0.5851
	Season x Year	3	2.91	0.0457		Season x Year	3	1.68	0.1862
	Tide x Season	6	3.06	**0.0144**		Tide x Season	6	3.48	**0.0072**
	Residual	17				Residual	17		
Coralline turf	Tide	2	222.51	<.0001	*Sargassum sinclairii*	Tide	2	0.00	1.0000
	Season	3	2.91	**0.0457**		Season	3	8.34	0.0002
	Year	1	0.36	0.5494		Year	1	0.64	0.4295
	Tide x Season	6	1.50	0.204		Tide x Season	6	3.58	**0.0060**
	Tide x Year	2	8.75	**0.0007**		Tide x Year	2	0.11	0.8929
	Season x Year	3	2.49	0.0737		Season x Year	3	2.85	**0.0488**
	Tide x Season	6	1.46	0.2171		Tide x Season	6	1.21	0.3229
	Residual	17				Residual	17		
Species	**Factor**	**df**	**F-value**	**p-value**	**Species**	**Factor**	**df**	**F-value**	**p-value**
Cystophora torulosa	Tide	2	0.09	0.9122	Spirorbidae	Tide	2	8.83	0.0006
	Season	3	6.42	0.0011		Season	3	3.23	0.0319
	Year	1	1.47	0.2328		Year	1	0.01	0.9357
	Tide x Season	6	3.18	0.0117		Tide x Season	6	2.57	**0.033**
	Tide x Year	2	1.73	0.1898		Tide x Year	2	0.25	0.7811
	Season x Year	3	4.15	0.0118		Season x Year	3	0.76	0.5254
	Tide x Season	6	4.21	**0.0022**		Tide x Season	6	0.13	0.9926
	Residual	17				Residual	17		
Hormosira banksii	Tide	2	274.94	**<.0001**	*Sypharochiton pelliserpentis*	Tide	2	15.36	**<.0001**
	Season	3	0.22	0.8830		Season	3	1.20	0.3233
	Year	1	0.53	0.4716		Year	1	3.64	0.0636
	Tide x Season	6	1.13	0.3596		Tide x Season	6	0.54	0.773
	Tide x Year	2	0.64	0.5327		Tide x Year	2	2.89	0.067
	Season x Year	3	2.57	0.0677		Season x Year	3	0.97	0.4179
	Tide x Season	6	2.32	0.0508		Tide x Season	6	0.85	0.542
	Residual	17				Residual	17		
Lunella smaragda	Tide	2	0.00	1	*Ulva* spp.	Tide	2	0.58	0.5656
	Season	3	4.00	**0.0138**		Season	3	9.71	0.0001
	Year	1	2.04	0.161		Year	1	0.14	0.7125
	Tide x Season	6	2.02	0.0849		Tide x Season	6	3.00	**0.0159**
	Tide x Year	2	0.79	0.4609		Tide x Year	2	0.10	0.905
	Season x Year	3	1.02	0.392		Season x Year	3	0.40	0.7562
	Tide x Season	6	2.18	0.0647		Tide x Season	6	0.52	0.7874
	Residual	17				Residual	17		
Melagraphia aethiops	Tide	2	56.96	**<.0001**	*Zeacumantus* spp.	Tide	2	6.35	0.004
	Season	3	0.63	0.601		Season	3	0.39	0.76
	Year	1	30.80	**<.0001**		Year	1	3.28	0.0776
	Tide x Season	6	1.14	0.3579		Tide x Season	6	3.28	**0.01**
	Tide x Year	2	2.32	0.111		Tide x Year	2	1.71	0.1931
	Season x Year	3	0.16	0.9215		Season x Year	3	0.69	0.5621
	Tide x Season	6	0.62	0.7097		Tide x Season	6	1.96	0.0944
	Residual	17				Residual	17		
Pagarus spp.	Tide	2	2.94	0.0641	*Zostera muelleri*	Tide	2	0.00	1
	Season	3	2.68	0.0597		Season	3	6.43	0.0011
	Year	1	3.45	0.0704		Year	1	2.82	0.1006
	Tide x Season	6	0.58	0.742		Tide x Season	6	1.53	0.1928
	Tide x Year	2	1.09	0.3444		Tide x Year	2	2.40	0.1034
	Season x Year	3	7.71	0.0003		Season x Year	3	5.67	**0.0024**
	Tide x Season	6	7.75	**<.0001**		Tide x Season	6	0.65	0.6869
	Residual	17				Residual	17		