Manukau Harbour Intertidal Ecology Monitoring 1987 to February 2018

Barry L. Greenfield, Lisa D. McCartain, Judi E. Hewitt

November 2019 Technical Report 2019/025

RIMU Research and Evaluation Unit

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Te Kaunihera o Tāmaki Makaurau

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Executive summary

This report updates the results of the State of the Environment intertidal marine ecology monitoring programme for the Manukau Harbour between October 1987 and February 2018. The monitoring focuses on intertidal animals in mud and sand flats which form an important link between sediment and water column quality and processes, are important prey items for birds and fish, are relatively stationary and therefore representative of local conditions, and are widely used internationally for monitoring impacts on and health of ecosystems.

The programme is a cost-effective, spatially and temporally nested design monitoring sediment characteristics and selected macrofaunal taxa (chosen to represent different predicted responses to environmental changes). Two intertidal sites, representing the northeast and southwest of the harbour are permanently monitored bimonthly (Auckland Airport and Clarks Beach), and southern intertidal sites Elletts Beach, Karaka Point and Puhinui Stream are monitored with a cycle of five years off, two years on. Monitoring of the northern intertidal site on Te Tau Bank (site Cape Horn) initially followed this alternating cycle, but bimonthly monitoring began again prior to removal of the waste water treatment ponds at Mangere in 2001 and continued until June 2010. Annually in October, all macrofaunal taxa are enumerated for use in the Auckland Council's Benthic Health Models (BHM) and calculation of the Traits Based Index (TBI).

Sediment characteristics (chlorophyll *a* concentration, grain size and organic matter) have returned to previous values following the large increases in April 2015 and have since been variable but generally similar at each site over the current monitoring period.

Abundances of the majority of monitored taxa at the Auckland Airport and Clarks Beach sites continue to exhibit multi-year cycles. While some trends in abundance were detected at all sites, the majority are of no concern. However, some of the taxa selected for monitoring due to their sensitivity to sediment mud content, heavy metals and nutrient enrichment are exhibiting changes in abundance at sites near Auckland Airport (mud content and heavy metals), Clarks Beach (heavy metals and nutrients) and Elletts Beach (nutrients). As there were also changes in species not consistent with increasing mud, metals or nutrients at each, ongoing monitoring to see if those changes persist is required.

The health of the extensive intertidal flats that make up around 40 per cent of the area of Manukau Harbour (excluding estuarine arms or inlets) ranges from "moderate" to "extremely good" health with good functionality. There is a small change in macrofaunal community composition at site Auckland Airport consistent with increasing mud content, however, the site is still scored as "extremely good". Changes in macrofaunal community composition at site Clarks Beach are in species sensitive to heavy metal contamination and the site has decreased in health from "good" to "moderate" health. However, much of this change has coincided with increasing coverage of the site by seagrass and, as the health indices were developed from non-vegetated reference sites, this might be affecting the ability of the index to truly differentiate health.

Conversely, the health of the harbour's inlets, is not as good. The only site which showed "moderate" health is Pahurehure Middle, while the remaining twelve sites monitored in October 2017 are unhealthy, with low functionality and low resilience.

The data obtained from continued bimonthly sampling at Auckland Airport and Clarks Beach are important, providing a template of patterns in species abundance against which to assess both the other intermittently monitored sites in Manukau and elsewhere (e.g., Mahurangi, Kaipara and Waitemata ecological monitoring programmes). In accordance with the site monitoring design, only Auckland Airport and Clarks Beach harbour sites were monitored routinely during the 2015-2018 period. For the first time since the commencement of the programme the other four sites were also monitored in October of each year even though they were not scheduled to be sampled until 2019 consistent with the nested and rotational sampling design. This additional sampling of Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream was for the following reasons:

- The change in community composition at site Cape Horn back to that observed prior to the Mangere wastewater treatment plant upgrade in 2001.
- The elevated sediment mud content found in February and April 2015 and the changes in the community health indices observed at the Puhinui Stream site.
- The changes observed in monitored taxa community composition at the Elletts Beach site together with the elevated mud content levels observed in April 2015 and the patches of *Gracilaria*.

The ongoing monitoring in October of these sites has demonstrated that the elevated mud content and changes in health and community composition at the Puhinui Stream and Elletts Beach sites have not continued. However, community composition at site Cape Horn has become more variable, there are increases in abundance of two species known to prefer slight nutrient enrichment at site Elletts Beach and continuing change in community composition at site Karaka Point.

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1.0 Introduction

In October 1987, the Water Quality Centre (now NIWA) was commissioned to design and implement a monitoring programme for Manukau Harbour that would document important changes in the ecology on a harbour-wide basis (see Thrush et al. 1988 for details). This was initiated in light of concerns for the harbour, due to changing land developments and information that many of the inlets were contaminated (Fox et al. 1988, Roper et al. 1988). As one part of this monitoring programme the ecology of intertidal sandflats was considered appropriate for monitoring given their spatial extent (40% of the area of Manukau Harbour), potential importance to the harbour system, likely sensitivity to most contaminants and the practicalities of cost-effective monitoring. Six sites were located around the harbour, just offshore from major inlets and rivers (Figure 2-1).

- Clarks Beach (CB) – on Poutawa Bank out from the confluence of the Rangiriri Creek, Waiuku River and Taihiki River.
- Elletts Beach (EB) – On the sandflats out from Clarks Creek.
- Karaka Point (KP) – on Hikihiki Bank out from Pahurehure Inlet.
- Puhinui Stream (PS) – on the sandflats out from Puhinui Creek.
- Auckland Airport (AA) – on the sandflats out from Auckland airport and the confluence of Otaimako and Pukaki Creeks.
- Cape Horn (CH) – on the Te Tau Bank opposite French Bay, downstream of Onehunga Port and the former Mangere Oxidation pond site.

This was the first harbour-wide ecological monitoring programme conducted in New Zealand. When monitoring began it was envisaged that six sites would be monitored bimonthly for five years, and then the cost-effectiveness/knowledge obtained of this monitoring would be assessed. An initial frequency of bimonthly monitoring was used to resolve changes in recruitment as a potential early warning signal for detrimental changes in adult populations. In 1993, analysis determined that the most cost-effective strategy was to set up a spatially and temporally nested design, reducing the number of sites sampled in most years, rather than reducing the number of samples collected at a site or sample frequency (Hewitt et al. 1994). The Manukau monitoring programme has a greater ability to resolve and thus remove variability associated with multi-year cycles in recruitment with bimonthly sampling, than the monitoring in Mahurangi that is conducted every three months (Halliday et al. 2013). A programme of alternating monitoring of all sites and reduced sites has continued since then (refer to Section 2.1 and Table 2-1), with two sites situated in different areas of the harbour (Auckland Airport (AA) and Clarks Beach (CB)) being monitored bimonthly permanently. The success of this strategy was analysed after resampling the full six sites in 2001 (Funnel et al. 2001, Hewitt and Thrush 2009) and thus continued. The last full sampling of all six sites was conducted in 2013-2015. Subsequently, due to concerns associated with changes observed at the intermittent sites, a decision was made to continue bi-monthly sampling at all sites (deviating from the previous rotational method) in order to assess these changes (Greenfield et al. 2015).

The monitoring focuses on benthic macrofauna as these animals form an important link between sediment and water column processes, are important prey items for birds and fish, are relatively stationary yet sensitive to anthropogenic activities, and are widely used internationally for monitoring impacts on and health of ecosystems. For cost effectiveness, analysis is based on the abundance of 23 taxa selected for their importance to the ecosystem and to provide a range of responses to different anthropogenic impacts and environmental conditions (Appendix 7.1). However, the analysis of monitored taxa collected in October of each year provides a more complete picture of community composition over time. Monitoring of sediment characteristics (sediment grain size, organic content and chlorophyll *a*) was added in 1999 to increase the ability of the programme to relate changes in communities to specific environmental drivers and occurs every two months. Monitoring of heavy metals associated with storm water contamination (copper, lead and zinc) was added in 2011 to integrate this monitoring with other monitoring conducted by Auckland Council.

This report presents the results of data collected from the intertidal sandflat monitoring from October 1987 until February 2018. It includes other intertidal monitoring conducted as part of the Benthic Health Monitoring sampled in October 2017 (alongside the Regional Sediment Chemistry Monitoring Programme (RSCMP)) from Tarata, Harania, Pukaki (Auckland Airport), Puhinui Upper, Papakura Stream Lower, Pahurehure Upper and Middle, Bottle Top Bay, Drury Creek DoC Island Mud, Drury Creek Inner, Waimahia Creek Central, Waiuku and Whangapouri.

2.0 Methods

2.1 Sample collection and identification

Sites Auckland Airport (AA) and Clarks Beach (CB) (Figure 2-1, Table Appendix 7-1) have been sampled bimonthly between October 1987 and February 2018. Two sampling occasions were missed (October and December 1988) at both sites due to a gap in funding, and another sampling occasion was missed for CB in February 2013 due to field work constraints. Sites Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS) have been sampled from October 1987 to February 1993, from August 1999 to February 2001, from August 2006 to June 2008, from August 2013 to April 2015, and then in October only for 2015-2017. Sampling also continued at site CH from April 2001 to monitor the effects of improvements in water quality discharging from Mangere. Additional sampling was carried out at CH by NIWA, without funding from AC, between February 1993 and December 1995. This data was collected as part of studies conducted on Te Tau Bank and funded by the then Foundation for Research Science and Technology (now Ministry of Business, Innovation and Employment).

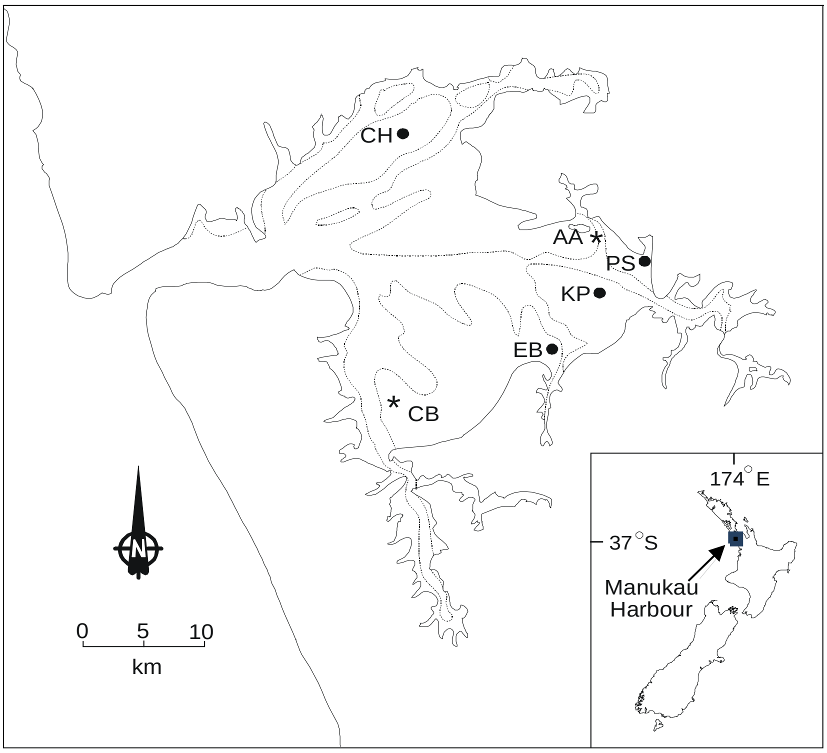


Figure 2-1 Map of Manukau Harbour showing the positions of sites Auckland Airport (AA), Clarks Beach (CB), Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS). The asterisk denotes the two permanently monitored sites, while the others are monitored intermittently.

Samples are collected and processed as follows. Each site (9000 m^2) is divided into 12 equal sectors and one macrofaunal core sample (13 cm diameter, 15 cm depth) is collected from a random location within each sector. To limit the influence of spatial autocorrelation (see Thrush et al. 1989) and preclude localised modification of populations by previous sampling events, core samples are not positioned within a 5 m radius of each other or of any samples collected in the preceding 12 months. After collection, the macrofauna are separated from the sediment by sieving over a 500 µm mesh, preserved with 70% isopropyl alcohol and stained with 2% Rose Bengal. The macrofauna are then sorted, and, in October, all taxa are enumerated and stored in 50% isopropyl alcohol; at other times of the year only the 23 monitored taxa are identified (Table 2-1 for short list and see Appendix 7.2 for detailed list).

Sampling in Tarata, Harania (both Mangere Inlet), Pukaki (Auckland Airport), Puhinui Upper, Papakura Stream Lower, Pahurehure Upper and Middle, Bottle Top Bay, Drury Creek DoC Island Mud, Drury Creek Inner, Waimahia Creek Central, Waiuku and Whangapouri occurred in October 2017, as part of the RSCMP. Sampling follows the same protocol as above, with the exceptions that the sites are smaller and only 10 cores are collected.

Table 2-1 The 23 taxa recommended for long-term monitoring in the Manukau harbour monitoring programme. Where genera and species have changed with taxonomic refinement, the names in brackets indicate a previous name. For example, *Nucula* is now called *Linucula*.

Taxonomic name	Common name/description
Anthopleura aureoradiata	Anemone
Austrovenus (Chione) stutchburyi	Cockle
Macomona (Tellina) liliana	Wedge shell
Linucula (Nucula) hartvigiana	Nut shell
Paphies australis	Pipi
Hiatula (Soletellina) siliquens	Small clam
Colurostylis lemurum	Hooded shrimp
Torridoharpinia hurleyi	Sea flea
Waitangi brevirostris	Sea flea
Methlimedon	Sea flea
Notoacmea scapha (helmsi)	Limpet
Exosphaeroma spp.	Sea slater
Taeniogyrus (Trochodota) dendyi	Sea cucumber
Aonides trifida (oxycephala)	Worm
Prionospio (Aquilaspio) aucklandica	Worm

Boccardia syrtis	Worm
Aglaophamus macroura	Worm
Boccardia syrtis	Worm
Aglaophamus macroura	Worm
Glycinde tifida (Goniada emerita)	Worm
Magelona dakini	Worm
Owenia petersenae (fusiformis)	Worm
Travisia olens novaezealandiae	Worm

2.2 Bivalve size class analysis

After identification, bivalve species *Austrovenus stutchburyi*, *Macomona liliana* and *Paphies australis* are measured (longest shell dimension; mm). Initially, *Hiatula siliquens* was measured, however, for consistency between ecological monitoring programmes at Mahurangi and Waitemata Harbours this was changed to *Paphies australis* in June 2017. Originally a set of nested sieves was used to estimate sizes (1995 to 2001). From 2001 to 2007, monitored bivalves were individually measured (with callipers or digitizing under a stereo microscope) and the results were summarised into the following size classes: <1 mm, 1-2 mm, 2-4 mm, 4-8 mm, 8-11 mm, 11-16 mm, 16-22 mm and >22 mm. However, in consultation with Auckland Council, the methodology and size classes have been modified to enable direct comparison with the Mahurangi and Waitemata ecological monitoring programmes. Individual bivalves are now assigned a size class <5 mm, 5-10 mm, 10-15 mm, 15-20 mm, 20-30 mm, 30-40 mm, 40-50 mm and >50 mm.

2.3 Site and sediment characteristics

During each site visit by Auckland Council staff, attention is paid to the appearance of the site and the surrounding sandflat. In particularly, surface sediment characteristics and the presence of birds, plants, ray pits and epifaunal species are noted. Adjacent to every second macrofaunal core sample at each site, two small sediment cores (2 cm deep, 2 cm diameter) are collected, one to determine grain size and organic content and the other for chlorophyll *a* analysis. Cores from the six locations are pooled and kept frozen in the dark prior to being analysed as described below.

Grain size: Prior to analysis, the samples are homogenised and a subsample of approximately 5 g of sediment taken. They are then digested in 6% hydrogen peroxide until all organic matter is removed and sampled by wet sieving and pipette analysis (Gatehouse 1971). Pipette analysis is used to separate the <63 µm fraction into >3.9 µm and <3.9 µm. All fractions are then dried at 60°C until a constant weight is achieved (fractions are weighed at ~ 40 hr and then again at 48 hr).

The results of the grain size analyses are presented as percentage composition of gravel/shell hash (>2 mm), coarse sand (500- 2000 µm), medium sand (250- 500 µm), fine sand (125- 250 µm), very-fine sand (62.5- 125 µm), silt (3.9- 62.5 µm) and clay (<3.9 µm). Mud content is calculated as the sum of the silt and clay content.

Organic content: Since August 2000, the organic and chlorophyll *a* content of the sediments at each site have been assessed on each sampling occasion. To determine the organic content, approximately 5 g of sediment is placed in a dry, pre-weighed tray. The sample is then dried at 60°C until a constant weight is achieved (the sample is weighed after ~ 40 hr and then again after 48 hr). The sample is then ashed for 5.5 hr at 400°C (Mook and Hoskin 1982) and reweighed.

Chlorophyll *a*: Within one month of sampling, the full sample is freeze dried, weighed, then homogenised and a subsample (~0.5 g) taken for analysis. Chlorophyll *a* is extracted by boiling the sediment in 90% ethanol, and the extract processed using a spectrophotometer (Sartory, 1982). An acidification step is used to separate degradation products from chlorophyll *a*.

Chemical contaminants: Sampling of chemical contaminants are conducted under the Regional Sediment Chemistry Monitoring Programme (RSCMP, see Mills et al. 2012 for the latest report).

2.4 Statistical analysis

The analysis of monitoring programmes is strongly dependent on the length of time the data has been collected. Initially, little can be done other than to graphically determine cyclic patterns. As the time series extends past five years, the data may be analysed for trends (long-term increases or decreases) statistically. However, a trend detected over a time period of less than 10 years may in reality be part of a long-term cyclic pattern. As the time series lengthen, statistical analyses become more likely to detect very small, frequently unimportant, changes, due to increasing degrees of freedom, and it becomes essential to determine that the changes are not part of multi-year cycles and to estimate the magnitude of change relative to natural variability. To investigate ecologically important long-term trends and cycles in environmental and species abundance data at all six sites, we conducted the analyses below. For macrofauna, all analyses were performed on the sum of the 12 cores collected at a site on each sampling occasion. For sediment the analyses were conducted on the grain size and chlorophyll *a* results from each site on each sampling occasion.

Seasonal and multi-year patterns

Plots of total abundance for each monitored population and measured environmental variables were visually examined to identify whether cyclic patterns are occurring, and the types of any potential trends (e.g., step, linear or logarithmic).

Trend analysis

Trend analyses were conducted to formally test the significance of any suggested trends in the abundance of the monitored taxa or measured environmental variables at the monitored sites. Autocorrelation in each time series was investigated using Durban-Watson statistics. Step trends were determined based on the significance of Yule-Walker parameter estimates following the

Autoreg procedure (SAS 9.4) on time series data points grouped before and after a suspected change (if autocorrelation was present, degrees of freedom were adjusted). Gradual changes were investigated by ordinary least squares regression on raw or log transformed data, unless autocorrelation was present. Where autocorrelation was indicated, increasing or decreasing trends were investigated by adjusting parameters and significance levels (AUTOREG procedure, SAS/ETS). Residuals of statistically significant trends were examined for indications of multi-year cycles; where these indicated significant bias the trend was considered to be a multi-year cycle rather than a trend. For the intermittently monitored sites, the October 2015-2018 time series was assessed relative to previous variation and to the time series at the permanently monitored sites.

The size of change for increasing and decreasing trends are the difference in the mean number of individuals in 12 cores between the last sampling occasion and the initial sampling in 1987. For non-step trends these are calculated as the slope estimate multiplied by the length of the time series (Table 3-1).

Community Analysis

Rank abundance tables and multivariate ordinations of macrofaunal community data collected in October of each year were used to determine if there had been temporal variations in community composition between years. Rank abundance tables were constructed for the three most numerically dominant taxa. Ordination of October raw and 4^{th}-root transformed data was performed, using non-metric multidimensional scaling (nMDS) of Bray Curtis similarities and correspondence analysis of chi-square distances. To test the average similarity across the monitored period, a SIMPER test was done for each site using the monitored taxa (PRIMER; Clarke and Gorley, 2006).

2.5 State of the Environment Indicators

To determine the relative health of each site, community compositions based on all identified taxa, were analysed using Benthic Health Models and the TBI index (previously named NIWACOOBII) (Lohrer and Rodil 2011; van Houte-Howes and Lohrer 2010). This was done for the following sites and times: AA, CB, CH, EB, KP and PS in October 2015, 2016, 2017 and Tarata and Harania (both Mangere Inlet), Pukaki (Auckland Airport), Puhinui Upper, Papakura Stream Lower, Pahurehure Upper and Middle, Bottle Top Bay, Drury Creek DoC Island Mud, Drury Creek Inner, Waimahia Creek Central, Waiuku and Whangapouri in October 2017.

2.5.1 Traits-Based Index (TBI)

Organisms can be categorised according to characteristics (traits) that are likely to reflect ecosystem function (i.e., their feeding mode, degree of mobility, position in the sediment column, body size, body shape, capacity to create tubes/pits/mounds, etc.). During 2010 and 2011, an index based on these biological traits was created (van Houte-Howes and Lohrer 2010) and improved (Lohrer and Rodil 2011). The index is based on seven broad trait categories (living position, sediment topography feature created, direction of sediment particle movement, degree of mobility, feeding behaviour, body size, body shape and body hardness). Specifically, the richness of taxa exhibiting seven particular traits: living in the top 2 cm of sediment, having an erect structure or tube, moving sediment around within the top 2 cm, being sedentary or only moving within a fixed tube, being a suspension feeder, being of medium size, or being worm shaped. Values of this index range from 0-1, with TBI scores <0.3 indicating low levels of functional redundancy and highly degraded sites (TBI group 3), and scores of 0.3-0.4 indicating intermediate conditions (TBI group 2). Scores >0.4 indicate high levels of functional redundancy (TBI group 1), which is indicative of healthy areas as high functional redundancy tends to increase the inherent resistance and resilience in the face of environmental changes, (Hewitt et al. 2012)). The index has been refined (Hewitt et al. 2012) with the SUMmax parameter modified to allow the metric to be applied to a wider range of sites and those sampled with differing numbers of replicates (Lohrer and Rodil 2011).

2.5.2 Benthic Health Models

The original benthic health model (**BHMmetals**) was developed by Auckland Regional Council, Marti Anderson (Massey University, then at Auckland University) and Simon Thrush (University of Auckland, then at NIWA) and Judi Hewitt (NIWA), to determine the health of macrofaunal communities relative to storm-water contaminants. The model is based on a multivariate analysis of the variation in macrofaunal community composition related to total sediment copper, lead and zinc concentrations, extracted from the 500 µm fraction of the sediment (Anderson et al. 2006).

In 2010-2011, another model was developed, this time to determine health relative to sediment mud content (**BHMmud**, Hewitt & Ellis 2010). At the time of the development of this model it was determined that, while there was some crossover between community compositions found in response to high mud and high contaminants, the two effects could still be separated.

Both models are based on the community composition observed at 84 intertidal sites in the Auckland Region between 2002 and 2005. The sites are within tidal creeks, estuaries or harbours, but do not include exposed beaches. They cover a range of contaminant concentrations and mud content. The models use Canonical Analysis of Principal Coordinates (CAP, Anderson & Willis 2003) of square root transformed Bray-Curtis dissimilarities to extract variation related to a single environmental variable and produce a score of community composition related to that variable. For the metal model, the concentrations of the three metals have been used in a Principle Component Analysis to create a single axis (PC1) that explains >90% of the variability in contaminant differences between the sites. For the mud model, the % mud content of sediment at the time of sampling is used.

The macrofaunal community composition of sites and sampling times not in the models are compared to model data (using the "*add new samples*" routine in *CAP, PermANOVA addon,* Primer E). The samples are then allotted to five different groups related to health (see Table 2-2).

Table 2-2 Conversion of BHMmetals and BHMmud scores into health groups (1 is most healthy). Cut off point is equal or less than.

Health Group	BHMmetals		BHMmud	
	Cutoff	value	Cutoff	value
1	-0.1640	0.2	-0.12	0.2
2	-0.0667	0.4	-0.05	0.4
3	0.0234	0.6	0.02	0.6
4	0.1000	0.8	0.10	0.8
5		1.0		1.0

The model data for the Benthic Health Model is an average of 10 replicates at each site (which are on average smaller than the Manukau sites). In order to fit the Manukau monitoring data to this only the first 10 replicates are used.

These indices have now been used to assess the health of sites in other regions (e.g., Northland, Waikato and Southland) and the methodology is being explored by a PhD student for use at a national scale.

2.5.3 Combined Indices

Hewitt et al. (2012) recommended the use of the three indices above (TBI index, BHMmud score (CAPmud) and BHMmetals score (CAPmetals)) to provide a complementary assessment of health. Average health values are determined for each site in the following way:

1. If the CAPmud score is ≤ -0.12, the combined Health score is calculated as the average BHMmetals and BHMmud group values. The TBI is not used in the combined score in this case, as it does not work well when mud content is extremely low (Hewitt et al. 2012).
2. If the CAPmetals score is ≥0.10, the combined Health score is equal to the TBI group value. At this level of contaminants, the TBI score itself fully reflects health.
3. Otherwise, Health is the average of the CAPmetals, CAPmud and TBI group values.

Health scores, "x", are then translated as x ≤ 0.2 "extremely good"; 0.2 <x≤ 0.4 "good"; 0.4 <x≤ 0.6 "moderate"; 0.6 <x≤ 0.8 "poor" and x > 0.8 "unhealthy with low resilience". It is important to recognise that the health scores are from particular sites within each estuary, and do not necessarily represent the health status of the estuary as a whole. There may be locations in each estuary that are significantly healthier, or less healthy, than the monitored sites.

3.0 Present Status of Benthic Communities in the Main Body of the Harbour

The Manukau Harbour Ecological Programme was designed to answer the following questions over a long time scale:

1. Are populations and sediment characteristics at the monitored sites generally exhibiting similar patterns?
2. Do any of the observed patterns in population abundances indicate important changes in the benthic communities that may have implications for the rest of the ecosystem?

For the four intermittently monitored sites, we specifically ask:

3. Is the data collected from October 2015, 2016 and 2017 at those sites that are not continuously monitored, (CH, EB, KP and PS) consistent with the time signals previously observed from these sites?

To answer these questions, we analyse for trends over time in sediment characteristics, abundances of monitored taxa and macrofaunal community composition. We also report on: multi-year cycles in sediment characteristics and abundances of monitored taxa; and health scores. Appearance and sediment features of the site and its surrounding area is used to provide a context against which changes in macrofauna can be described. Changes to site characteristics over time, such as expansion of seagrass beds into the monitored area or disturbance by eagle rays, may help explain variability (e.g., Townsend 2010). Large changes, for example, predominantly sandy sediment becoming predominantly muddy, or deoxygenation of the sediment under decomposing algal mats, may signal dramatic changes in macrofauna. Accordingly, a brief description of site appearance and sediment characteristics is given here, although they are not the focus of the monitoring programme.

3.1 General location descriptions

3.1.1 Auckland Airport (AA)

In some ways, the appearance of this site has remained similar over the entire monitoring period (since 1987). The sediment is firm sand and the topography is usually dominated by ripples (1-2 cm wave height, 3-15 cm period), dense *Macomona liliana* feeding tracks and an abundance of ray pits (Figure 3-1b), with a range from newly excavated to various stages of recovery from ray pit disturbance. The gastropod *Zeacumantus lutulentus* and *Cominella glandiformis* continue to be common on site with *Diloma subrostrata* often observed in lower numbers. Worm tubes are very rarely found.

In June and August 2005, small sparse patches of seagrass were observed at the site. Lately, very small patches of the brown algae *Gracilaria* sp. have been observed scattered across the site, mainly attached to cockle shells. In the last year single strands of Ulva have been found also growing on cockle shells.

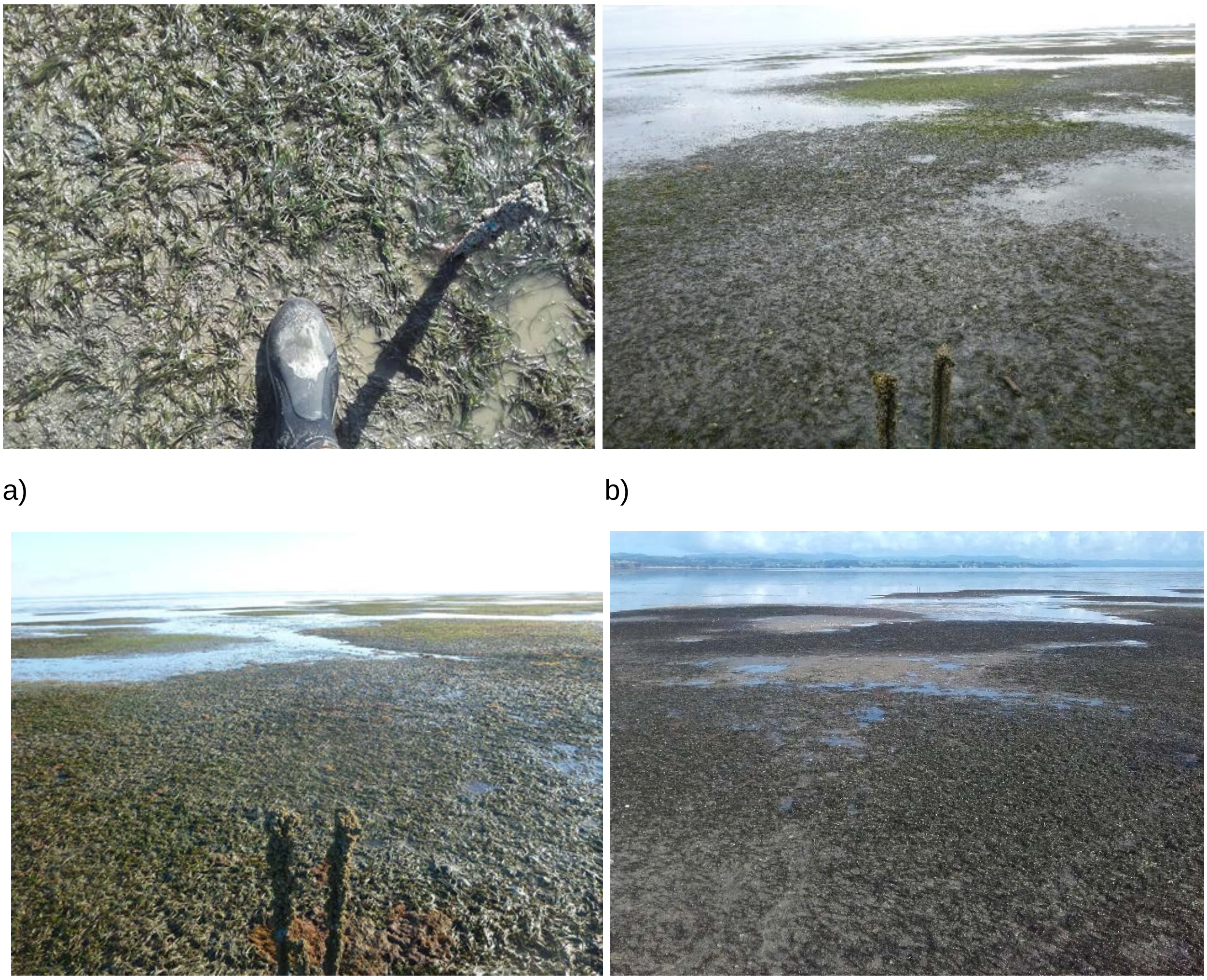
The surrounding area is largely similar to that observed within the monitored area, however the presence of shell hash and whole shells (primarily *Austrovenus stutchburyi* and *Macomona liliana*) on the sediment surface increased up until August 2010, after which no further changes have been observed. There is area of thick *Graciliaria* sp. growth along a small drainage channel to the west of the site, in April 2018 a raised patch of sand with high green microphyte biomass was observed beside the channel.

a) b)

Figure 3-1 Photographs of site Auckland Airport (AA) February 2018 a) sediment surface and b) monitored area.

3.1.2 Clarks Beach (CB)

The appearance of this site is temporally variable. Historically the site topography has been variable changing from being dominated by ripples (1 cm wave height, 5 cm period) and a mosaic of ripples, flat sediment, hillocks and seagrass (*Zostera muelleri*), however the site is now becoming increasingly dominated by *Zostera* (Figure 3-2a-d). *Zostera* has fluctuated in its coverage of the site; first appearing in 1999 (Funnell et al. 1999) and increasing in abundance until disappearing by 2002. Since reappearing in June 2005, its distribution has continued to encroach into the site from the 0,0 corner with coverage of the site reaching approximately 80% in February 2018. Whole shells on the surface, shell hash (low density, primarily *Austrovenus* and *Macomona*), worm tubes, gastropods and *Gracilaria* sp. are observed where *Zostera* is not covering the sediment. The *Gracilaria* is commonly attached to empty *Owenid* tubes. As previously reported a surficial mud layer is often present on the site. Evidence of a thin mud deposition was present during the most recent sampling (Figure 3-2a and d). In the winter months, it has been common to observe a diatom mat on the sediment surface, although this has not been observed since April 2015, likely a result of increased seagrass density and coverage. The surrounding area has remained comparable to the monitored area over the past two years.



a) b) c) d)

Figure 3-2 Photographs of site Clarks Beach a) sediment surface at 0,0 within *Zostera* patch b) *Zostera* coverage at 0,0 corner in February 2015 c) *Zostera* coverage at 0,0 corner in February 2016 d) *Zostera* coverage at February 2018.

3.1.3 Cape Horn (CH)

The site is situated approximately 80 m from the boat access point, approximately 0.5 m away from the low water mark. Sometimes during westerly wind conditions, the site is submerged for longer than the tide charts indicate. Ripples (approximately 1-3 cm in height with a period of 2-8 cm) are still a common feature at this site, along with numerous polychaete tubes (*Macroclymenella stewartensis* and Polydorids) and low-density bivalve (*Macomona liliana*) feeding tracks. Ray pits (usually low frequency) and feeding birds have been observed during the warmer months. During the sampling in August 2013, a diatom mat was present, which is common at this site, particularly at this time of the year (Figure 3-3b). The invasive species *Arcuatula senhousia* has not been observed on site since its disappearance in February 2015 but is still present in the surrounding area and *Arcuatula* shell hash observed on site in June 2016.


a) b)

Figure 3-3 Photographs of site Cape Horn a) the sediment surface with wave ripples, b) Site looking from 0,0 corner in October 2017.

3.1.4 Elletts Beach (EB)

This site is predominantly sandy (Figure 3-4a-b) with ripples (~1 cm wave height, 2 - 8 cm period) throughout the year, however diatom mats have often been present during the winter months. Whole shells, shell hash and gastropods are common on the sediment surface and during the warmer months ray pits are frequently seen. Around the outside of the site, there has been little change, however in June 2008 a mixture of *Soleriaceae* and *Gracilaria* sp. (as found at site CH) was recorded. *Gracilaria* sp. continues to be a common feature of the intertidal sandflat. Close to the shoreline large patches are observed but within the monitored site, patches are smaller and more dispersed. The *Gracilaria* found is often not rooted; rather it appears to be washed into the intertidal zone (Figure 3-4a-b).


a) b)

Figure 3-4 Photographs of site Elletts Beach a) the monitored area June 2016, b) the sediment surface October 2017

3.1.5 Karaka Point (KP)

Site KP remains a mosaic of sand ripples (1 -2 cm wave height, 5 -10 cm period), shell hash (low density, *Austrovenus stutchburyi* and *Macomona liliana*) and patches of *Gracilaria* sp., consistent with previous descriptions (Funnell et al. 2001; Hewitt & Hailes 2007; Hailes & Hewitt 2009). Low density gastropods (e.g., *Zeacumantus lutulentus, Cominella glandiformis and Diloma subrostrata*) have been observed on most sampling occasions since June 2007 (Figure 3-5a). Similar to other sites, ray pits are common during the summer months of December and February. In the past, surficial mud layers across the site have been reported, especially in the winter months, this has not been observed since April 2016, however this is likely due to sampling being reduced to October sampling for the last few years.

a)

b)

Figure 3-5 Photographs of site Karaka Point a) the monitored area October 2015, b) the sediment surface showing a small piece of *Ulva* (bright green strip) in October 2017.

3.1.6 Puhinui Stream (PS)

Site PS has been generally characterised by a mosaic of sand ripples (height 1 - 2 cm, period ~ 10-15 cm) and large numbers of gastropods (*Zeacumantus lutulentus* and *Cominella glandiformis*) over the surface sediment. Like the other monitored sites, abundant ray pits are observed during the summer months and a diatom mat is consistently recorded during the winter months. Since December 2013 the site has experienced periods of increased muddiness. In February 2015 there was an observable increase in mud and reduction in gastropod abundances which persisted through to April 2015 (Figure 3-6a). In April 2015 there were two distinct habitats observed, the western side remained muddy and littered with mangrove seedlings. In contrast the eastern side of the site returned to a mosaic of sand ripples with sparse patches of seagrass. By June 2015 the site had returned to a mosaic of sand ripples and the patches of seagrass had expanded (Figure 3-6b). Throughout this period (April-June 2015) moderate density patches of worm tubes were common (Figure 3-6c) however, these have not been observed since. In October 2017 no seagrass was observed, and the site had returned to pre-2015 state (Figure 3-6d).

a) b)

c) d)

Figure 3-6 Photographs of site Puhinui Stream a) the monitored area April 2015, showing the presence of mangrove seedlings b) the sediment surface showing seagrass expansion in June 2015, c) sediment surface showing a patch of moderate density worm tubes in June 2015, d) the monitored area October 2017.

3.2 Are there any trends in sediment characteristics?

The bimonthly sediment grain size, chlorophyll *a* and organic content data for the six monitoring sites are given in Appendix 7.3.

Grain size

The sediment grain size composition at all sites has remained predominantly sandy, AA and PS more so than CB and EB (Figure 3-7 and Figure 3-8). Seasonal highs of mud content are noticeable at sites CB and EB with the highest percent mud typically observed during the winter months. Site AA continues to have the lowest percent mud content of all the sites, followed by PS, with an average percent mud content over the last two years of 0.82% and 1.30% respectively.

No statistically significant trends were observed for sites AA (p =0.132) or CB (p = 0.402). Elevated mud content had been observed at sites EB (April 2015, 38.42%) and PS (February 2015, 5.11%) which was a cause for concern. Consequently, additional sampling outside of the sample design was conducted in October each following year to monitor this. Data indicates that percent mud at these two sites has been well within the 90th percentile for the last two years (EB values 12 and 4.2 *cf.* 15.8 90th percentile and PS values 1.5 and 0.9 *cf* 3.6 90th percentile).

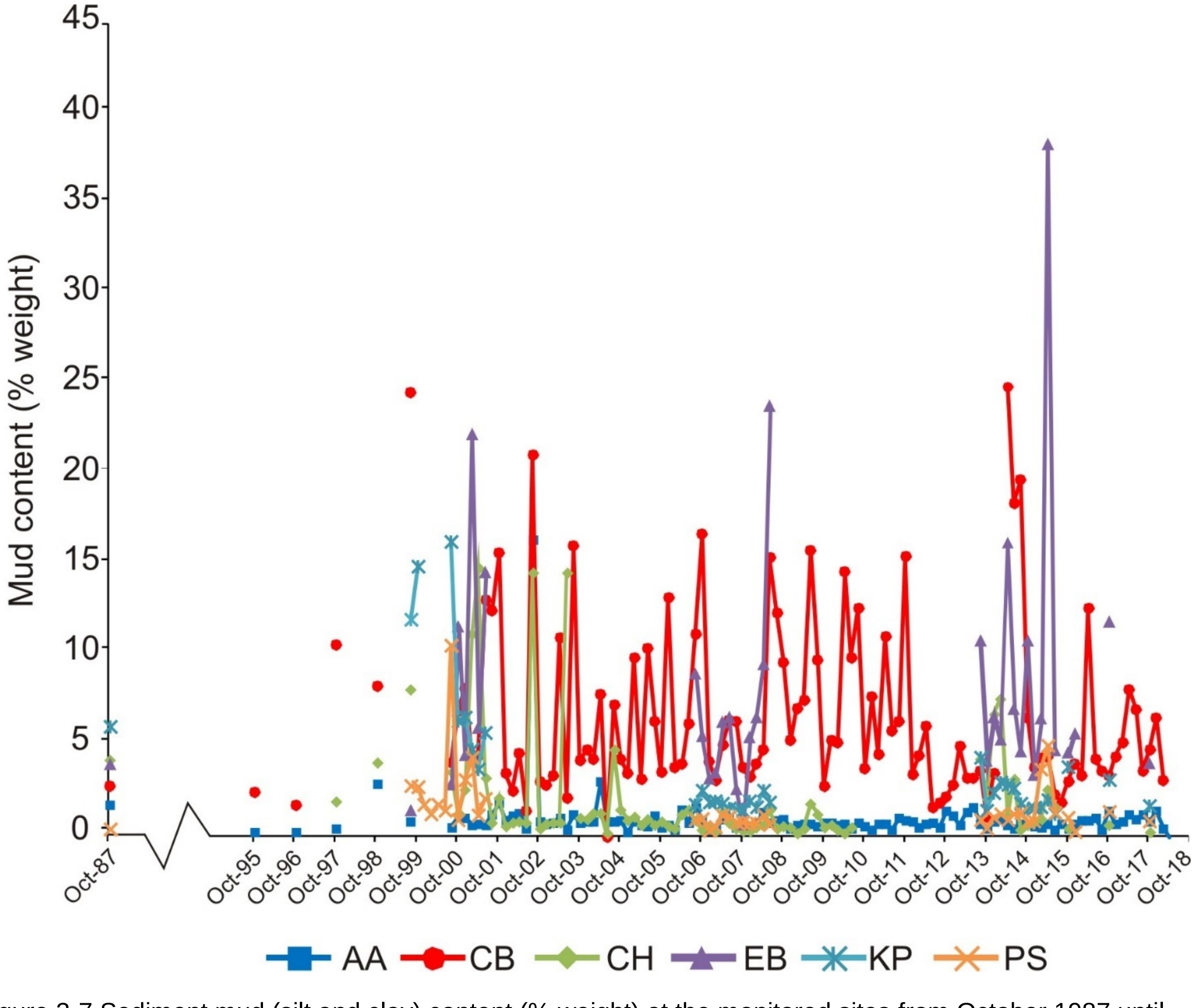


Figure 3-7 Sediment mud (silt and clay) content (% weight) at the monitored sites from October 1987 until February 2018. Note: Sites CH, EB, KP and PS were only sampled in October for 2015-17.

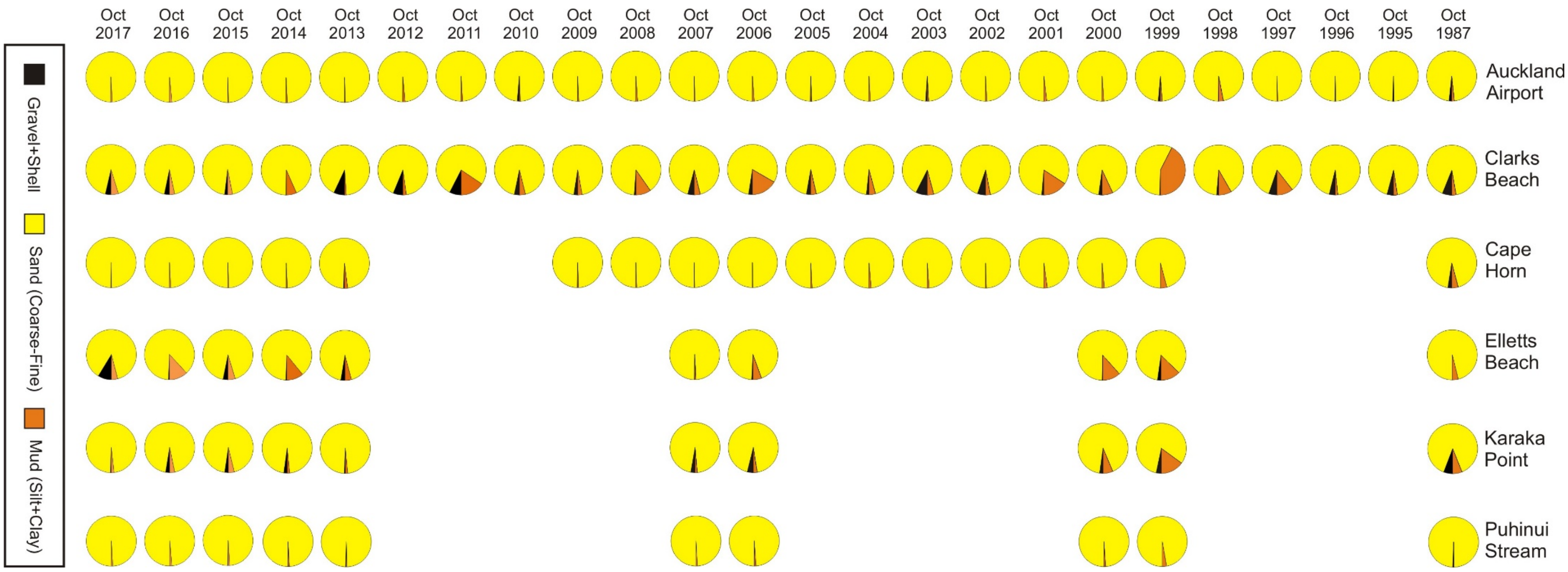


Figure 3-8 Changes in the sediment proportions of gravel/shell (>2000 µm), sand (coarse <2000 µm to fine >63 µm) and silt/clay (i.e., mud <63 µm) at each of the monitored sites (Auckland Airport, Clarks Beach, Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream) from October 1987 until February 2018 (only October months shown).

Chlorophyll *a*

All sites, including the intermittently monitored sites (CH, EB, KP and PS) had high chlorophyll *a* concentrations in the first year that these measurements were made. None of the sites exhibit strong seasonality. Values at the permanently monitored sites (AA and CB) demonstrate irregular short multi-year cycle (approximately 2-3 years) within longer cycles. These patterns are most clearly seen at site CB, where lowest values occurred in 2000, 2003-4 (absolute minimum), 2009-10 and 2017-18. While a $p < 0.001$ was detected for chlorophyll *a* concentrations regressed against time at CB (cf. $p = 0.994$ for site AA), this was driven by high values in the first year, the presence of multiyear cycles and the low values in 2017-2018 (i.e., there were strong biases and cyclic patterns in the residuals). Unless values decrease further in the next three years this cannot be considered a significant trend (see statistical methods section). Chlorophyll *a* concentrations at AA and CB varied between 6.53-15.13 and 6.65-13.06 µg/g sediment respectively over the last two years (Figure 3-9). No significant trends were observed.

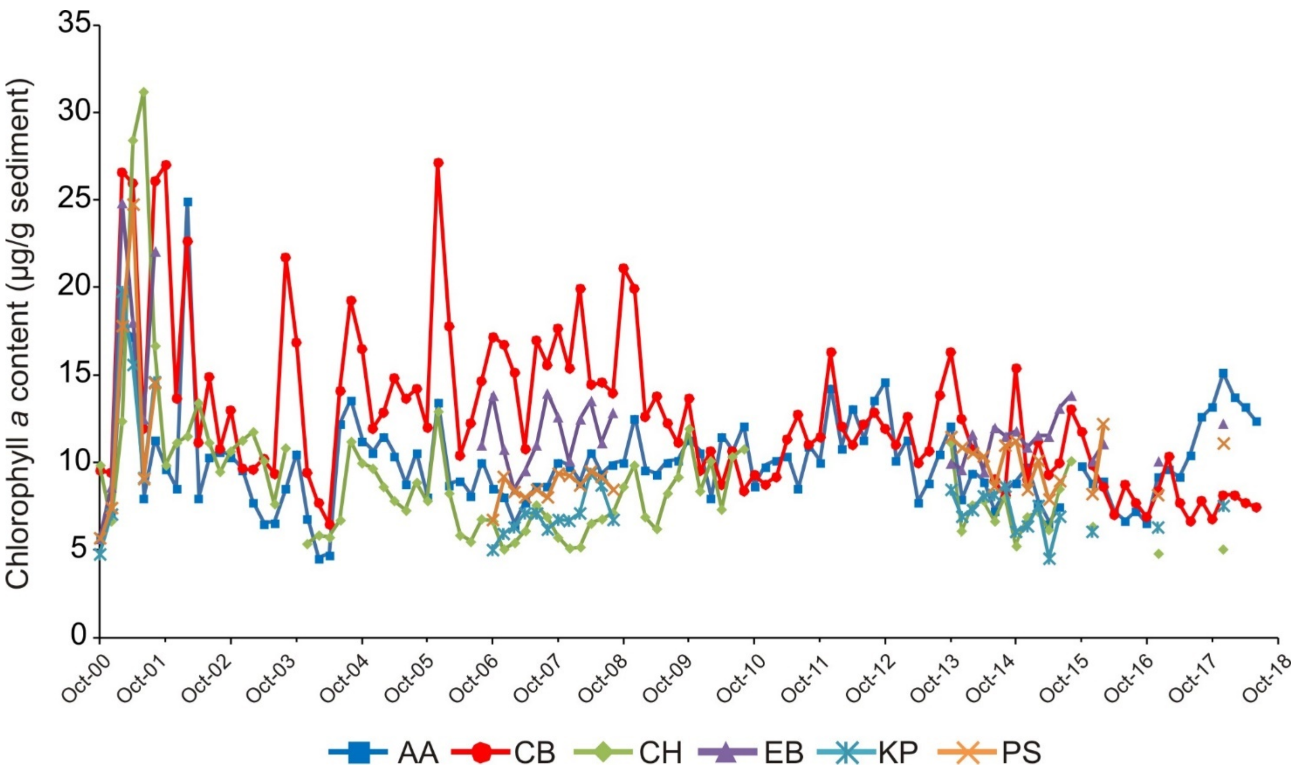


Figure 3-9 Chlorophyll *a* levels (µg/g sediment) of sediment collected from monitoring sites from October 2000 until February 2018. Sites CH, EB, KP and PS were only sampled in October for 2015-2017.

Organic content

Sediment organic content at all sites is generally less than 2.5 %, with no strong seasonality at all sites throughout the monitored period (October 2000 to February 2018) (Figure 3-10) with no significant trends detected at sites AA ($p = 0.119$, nlag=6) or CB ($p = 0.389$). At the permanently monitored sites, annual averages at AA are always lower than CB and the average organic content at AA and CB over the last two years has been 0.59 and 1.13% respectively. For the intermittent sites, average organic content over the last two years have been 0.66, 0.77, 0.69 and 1.35% for PS, KP, CH and EB of respectively.

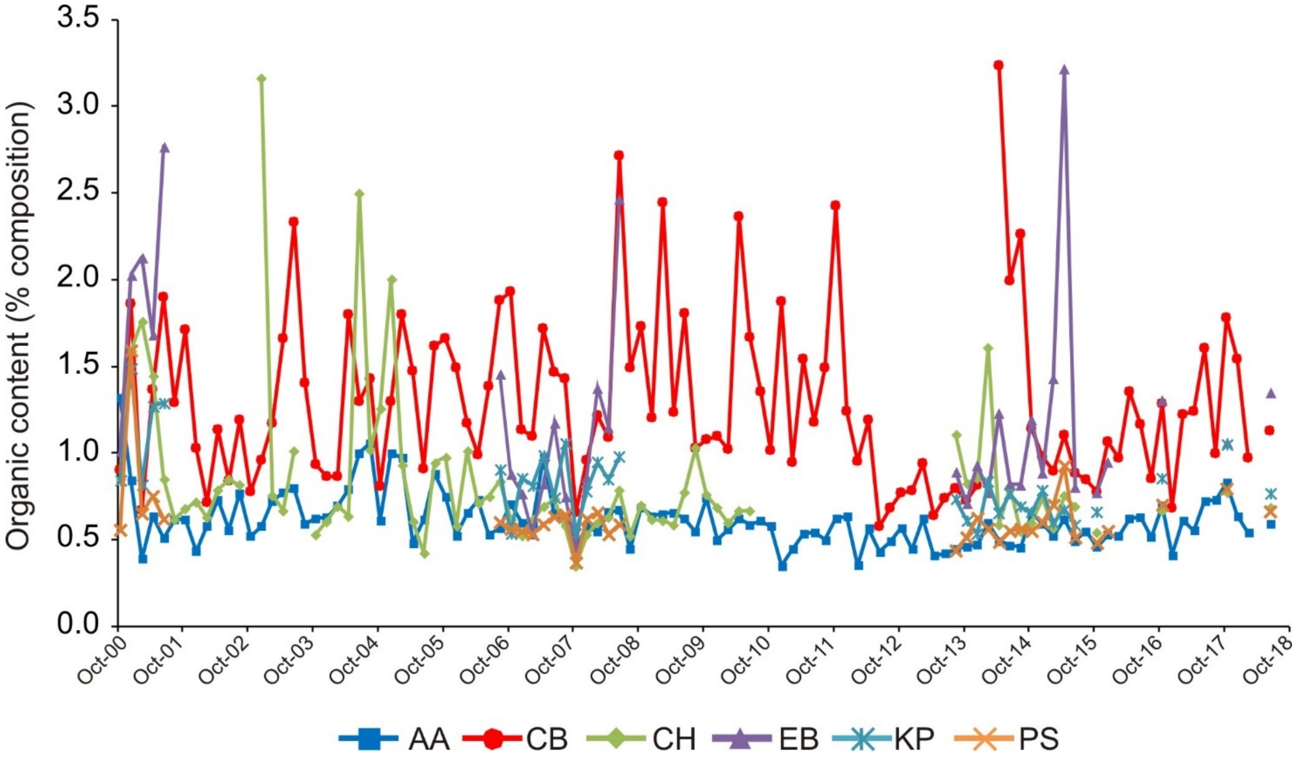


Figure 3-10 Percentage organic content of sediment collected from monitoring sites from October 2000 until February 2018. Sites CH, EB, KP and PS were only sampled in October for 2015-2017.

In summary, no trends in sediment characteristics were observed in the data from 1987 to 2018.

3.3 Are there any trends in abundance of monitored taxa?

Site AA

Over the first 10 years of the monitoring programme a decreasing trend in the abundance of *Aonides trifida* at AA was observed (Figure 3-11A). Then in 2004-2005, abundances increased markedly and in 2009 a step trend was confirmed (Hailes and Hewitt, 2009). With the addition of the recent data it is evident that rather than a step trend there is an increasing trend since 2004.

The step trend in abundances of *Glycinde trifida* at AA (Greenfield et al. 2015) has continued with only rare occurrences and low abundance since 2010 (Figure 3-11B).

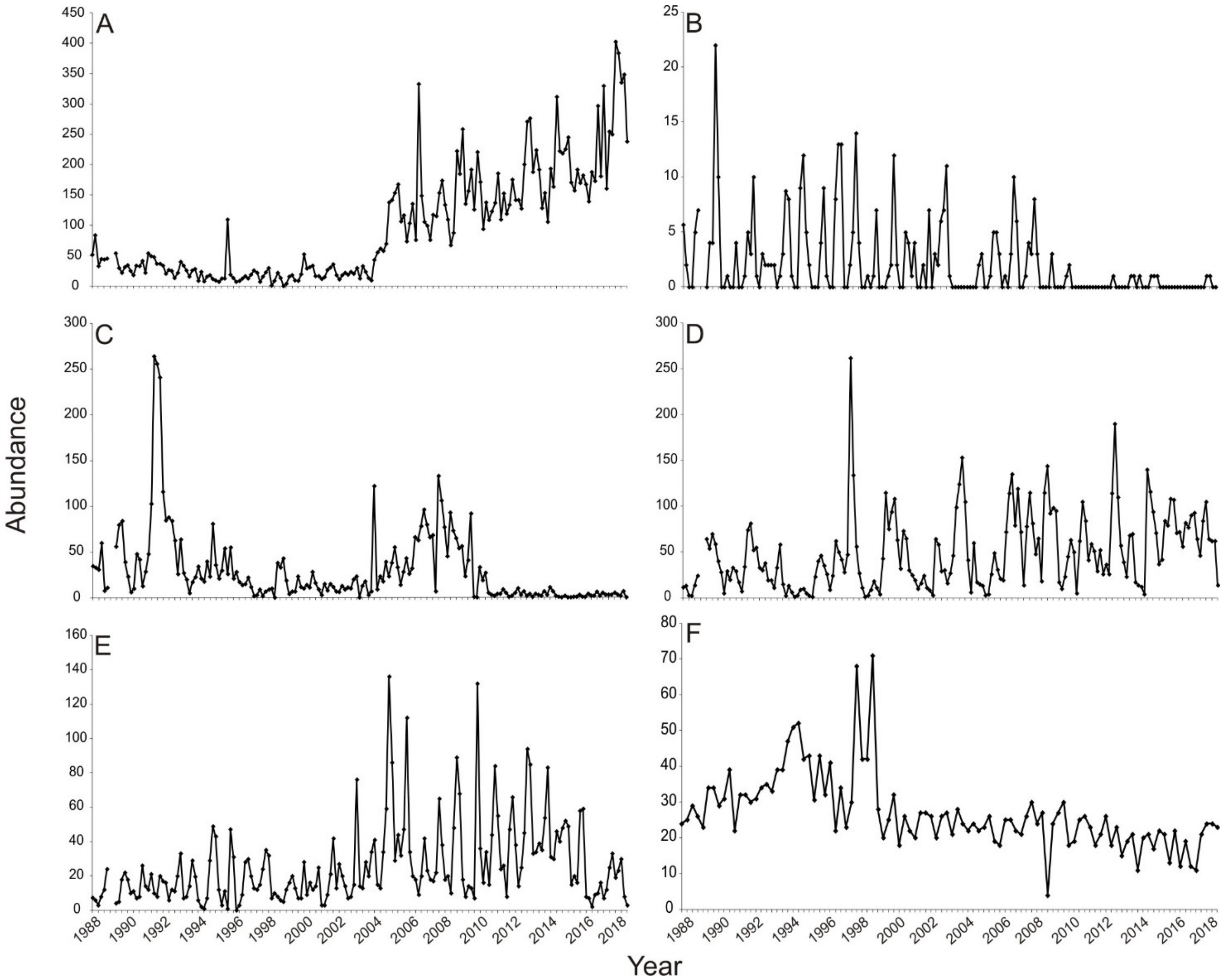


Figure 3-11 Abundance (sum total of 12 replicate cores) of A) *Aonides trifida* B) *Glycinde trifida* C) *Linucula hartvigiana* D) *Orbinia papillosa* E) *Taeniogyrus dendyi* F) Adult *Macomona liliana* at Auckland Airport from October 1987 until February 2018.

Table 3-1 Monitored species for which statistically significant trends in abundance were detected at the six monitored sites. * is a trend that residuals suggest may be revealed as a multi-year cycle with more data. +, indicates that the new data did not return any discernible changes to existing trends so data remains the same as in Greenfield et al. 2015. Note for Cape Horn only trends that are not related to the oxidation pond removal are included here

Site	Taxa	Trend direction and type	Size of change	p-value
AA	Aonides	increase >2004	118.9	<0.0001
	Glycinde	decrease	-4.3	0.0005
	*Linucula	step decrease (2010)	-79.0	<0.0001
	Orbinia	increase	50.4	0.0065
	Macomona adults	decrease >2008	-11.6	<0.0001
	*Taeniogyrus	increase	43.2	0.0018
CB	Anthopleura	step increase (2004/5)	87.8	<0.0001
	Owenia	step increase (2004)	71.0	<0.0001
	Notoacmea	step increase (2010)	72.48	<0.0001
	*Hiatula	decrease	-14.6	<0.0001
CH+	Colurostylis	step increase (2005)	65.5	<0.0001
	Methlimedon	increase	12.1	0.0121
EB+	Anthopleura	step increase (1993 and 2008)	36.9	<0.0001
	Aonides	log10 increase	87.9	<0.0001
	Linucula	step increase (1994)	145.6	<0.0001
	Notoacmea	step increase (2009)	20.0	0.0012
	*Owenia	step increase (2009)	12.7	0.0002
	Hiatula	step decrease (1993 and 2008)	-191.5	0.0037
	Macomona	increase	237.6	<0.0001
	Boccardia	increase	7.6	<0.0001
	Magelona	increase	270.6	<0.0001
KP+	Aonides	Increase	305.3	0.0064
	Austrovenus	increase	36.3	<0.0001
	Colurostylis	step increase (2009)	18.6	0.0013
	*Methlimedon	increase	16.1	<0.0001
	Magelona	step increase (2009)	16.5	<0.0001
	*Linucula	decrease	-105.9	0.0010
	Taeniogyrus	step increase (1993)	11.0	<0.0001
PS	+Colurostylis	step increase (2009)	55.8	<0.0001
	+Macroclymenella	increase	24.0	0.0313
	+Taeniogyrus	increase	22.0	0.0010
	+Magelona	increase	204.6	<0.0001
	Orbinia	step increase (2007)	14.1	0.0048

Site CB

At site CB, an increasing trend of the abundance of *Anthopleura* post 2004-2005 (Figure 3-12A), is still evident with abundances still increasing.

Prior to 2007, baseline abundances of *Owenia petersenae* at CB varied between 0- 15. Since then, abundances have increased, varying between 5 and 31 individuals per 12 cores (Figure 3-12C).

Hiatula has been decreasing steadily and has been rarely found since 2009 (less than 10 individuals per 12 cores).

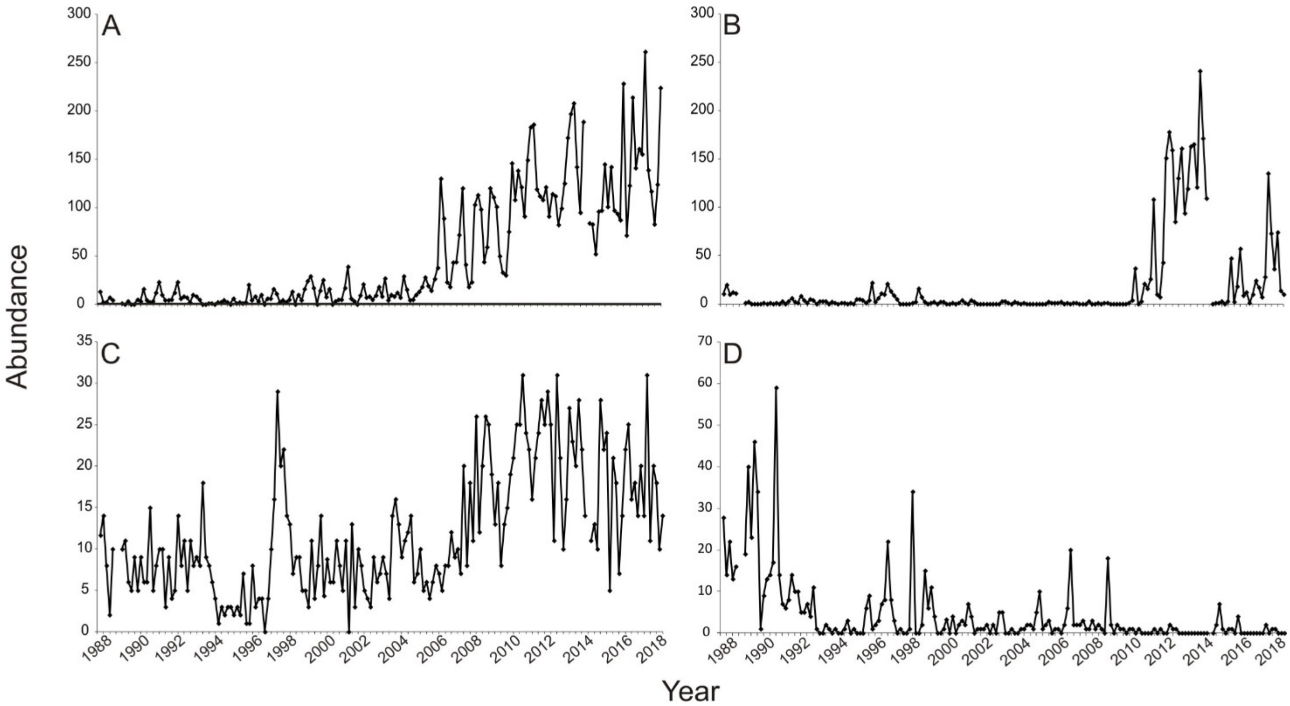


Figure 3-12 Abundance (sum total of 12 replicate cores) of A) *Anthopleura aureoradiata* B) *Notoacmea scapha* C) *Owenia petersenae* D) *Hiatula siliquens* at Clarks Beach from December 1987 until February 2018.

Continued sampling in October at the intermittent sites CH, EB, KP and PS has provided information to enable assessment of pre-existing trends in abundance. All trends in abundance previously reported are still in existence with the following exceptions; the previously increasing trend in abundance of *Methlimedon* at PS is now considered a multi-year cycle as abundances show a decrease since August 2013 (Figure 3-13C), and a step-increase since 2007 (p=0.0048) is now evident for *Orbinia papillosa* at PS (Figure 3-13D).

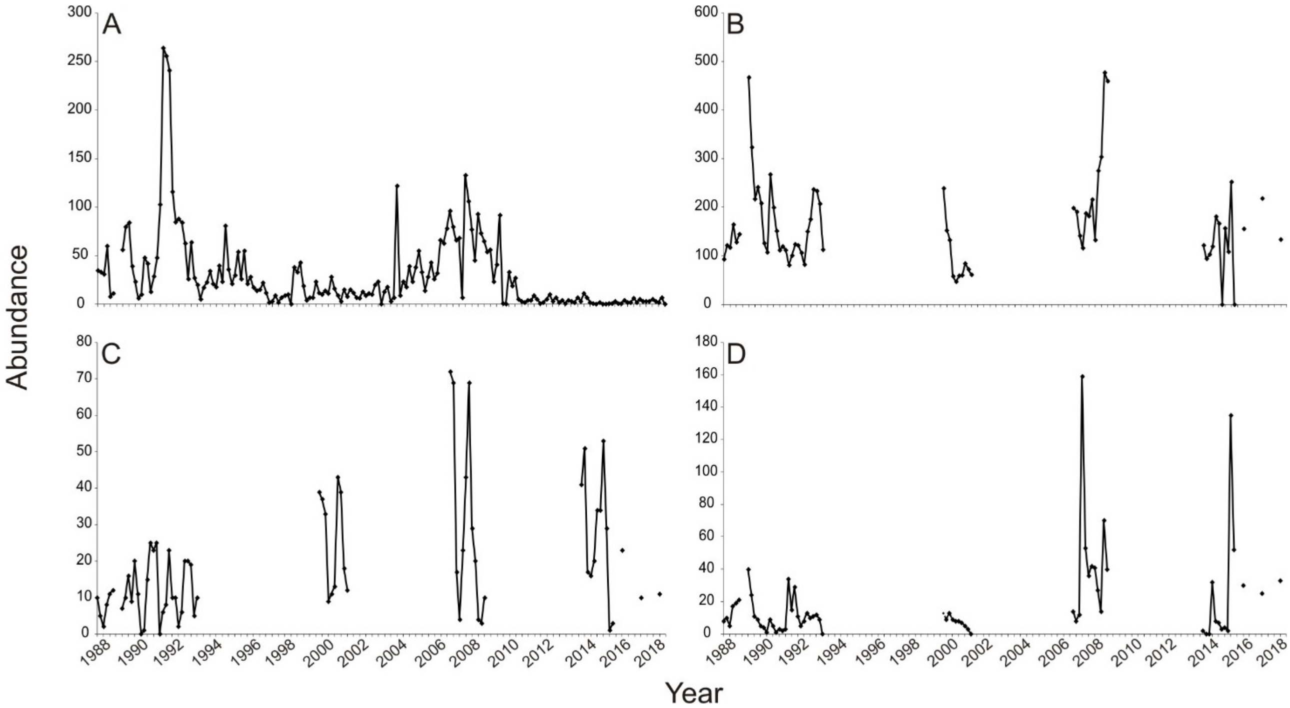


Figure 3-13 Abundance (sum total of 12 replicate cores) of A) *Linucula hartvigiana* at Auckland Airport B) *Macomona liliana* C) *Methlimedon* D) *Orbinia papillosa* at Puhinui Stream from October 1987 until October 2017. Dots not joined by lines in plot A represent a missing sample, in plots B to D represent the sampling frequency as described in the methods.

In summary, of the monitored species, 8 out of 23 showed trends in abundance, with five and four trends detected at AA and CB respectively (Table 3-1, Figure 3-11, Figure 3-12). The same species which showed trends in the 2013-2015 period (Greenfield et al. 2015)) continue to show the same trends. Two new trends in abundance were detected. Abundances of adult *Macomona* at site AA have been decreasing since 2008 (Figure 3-11), and abundances of *Notoacmea* at site CB, although highly variable, show a significant step increase from February 2010 (Figure 3-12).

3.4 Are cyclic patterns in monitored taxa abundances being maintained?

At the two permanently monitored sites, some species have abundances that are consistently low, for example, *Aglaophamus macroura* and *Exosphaeroma spp.* at sites AA and CB and *Aonides trifida* and *Taeniogyrus dendyi* at site CB. Generally, species with such consistently low abundances do not display cyclic patterns.

However, throughout the monitored period, several monitored taxa have exhibited multi-year cycles in abundance, driven by differences in the magnitude of recruitment, mortality or dispersal. For example, the abundance of *Magelona dakini* at both AA and CB sites displays cycles of six-ten years (Table 3-2 and Figure 3-14), while abundances of *Hiatula siliquens* at both sites continues to display cycles of 7-9 years, probably related to the El Niño Southern Oscillation cycle (Hailes & Hewitt 2009) (Figure 3-15).

At site AA, 16 of the monitored taxa are displaying apparent multi-year cycles, including *Colurostylis lemurum* and *Orbinia papillosa* (Table 3-2). At site CB, 16 of the monitored species are displaying multi-year cycle.

The majority of species which have historically shown multi-year cycles continue to do so (visual examination); however, some species have had changes in recruitment patterns which suggest altered or new cycles (discussed herein). Mainly these are the appearance of longer cycles within which the shorter cycles previously mentioned are nested (Table 3-2), e.g., *Taeniogyrus dendyi* at site AA (Figure 3-16). For a complete list of monitored taxa displaying cycles see Table 3-2.

Table 3-2 Monitored species and whether they are exhibiting multi-year cycles of abundance. - indicates that no cyclic patterns were apparent. Periods of multiyear cycles are not given for the intermittently monitored sites as the data is not sufficient to clarify this. *, denotes a change observed in the 2015-2018 monitoring period.

Taxa	AA	CB
Aglaophamus macroura	Multi-year cycles: 2-4 years within a much longer cycle.	-
Aonides trifida	Multi-year cycle: 3-4 years of irregular magnitude.	-
Austrovenus stutchburyi	Multi-year cycle: 7-10 years. Seasonal.	Multi-year cycles: 2 yearly within 10-16 years. Seasonal.
**Boccardia syrtis*	Multi-year cycle: 2-4 years. Seasonal in June.	*Multi-year cycle: 2, 4-5 within a longer >10 year cycle. Seasonal in June.
**Colurostylis lemurum*	*Multi-year cycle: 2-3 years of irregular magnitude in a longer cycle	*Multi-year cycle: 2-4 years within longer cycle.
Exosphaeroma spp.	Multi-year cycle: 2-3 years of irregular magnitude in a longer cycle.	Multi-year cycle: 2-4 years of irregular magnitude in a longer cycle.
Glycinde trifida	-	Multi-year cycle: 3-6 years.
Hiatula siliquens	Multi-year cycle: 7-9 years.	Multi-year cycle: 7-9 years. Usually low in abundance since 1994.
Linucula hartvigiana	Multi-year cycle: 3 and 6-7 years.	Multi-year cycle: 3 and-7 to 9 years.
Macomona liliana	Multi-year cycle: 4-7 years.	Multi-year cycle: 4-7 years.
Macroclymenella stewartensis	-	Multi-year cycle: 3-5 years of irregular magnitude
**Magelona dakini*	*Multi-year cycle: 6-10 years.	*Multi-year cycle: 6-9 years.

Taxa	AA	CB
Methlimedon sp.	-	Multi-year cycle: 2-5 years.
Notoacmea scapha	Multi-year cycle: 2-3 years.	Multi-year cycle: 5-6 years.
Orbinia papillosa	Multi-year cycle: 2-4 years. Seasonal.	-
Owenia petersenae	-	Multi-year cycle: 8-10 years.
Prionospio aucklandica	-	Multi-year cycles: 3-6 years within 10 to 13 years.
**Taeniogyrus dendyi*	*Multi-year cycle: 5-7 years.	Multi-year cycle: 5-6 years.
Torridoharpinia hurleyi	Multi-year cycle: 6-8 years.	Multi-year cycle: 6-8 years.
Travisia olens novaezealandiae	Multi-year cycle: 2-3 and 5-7 years.	-
Waitangi brevirostris	Multi-year cycle: 2-5 years of irregular magnitude.	-

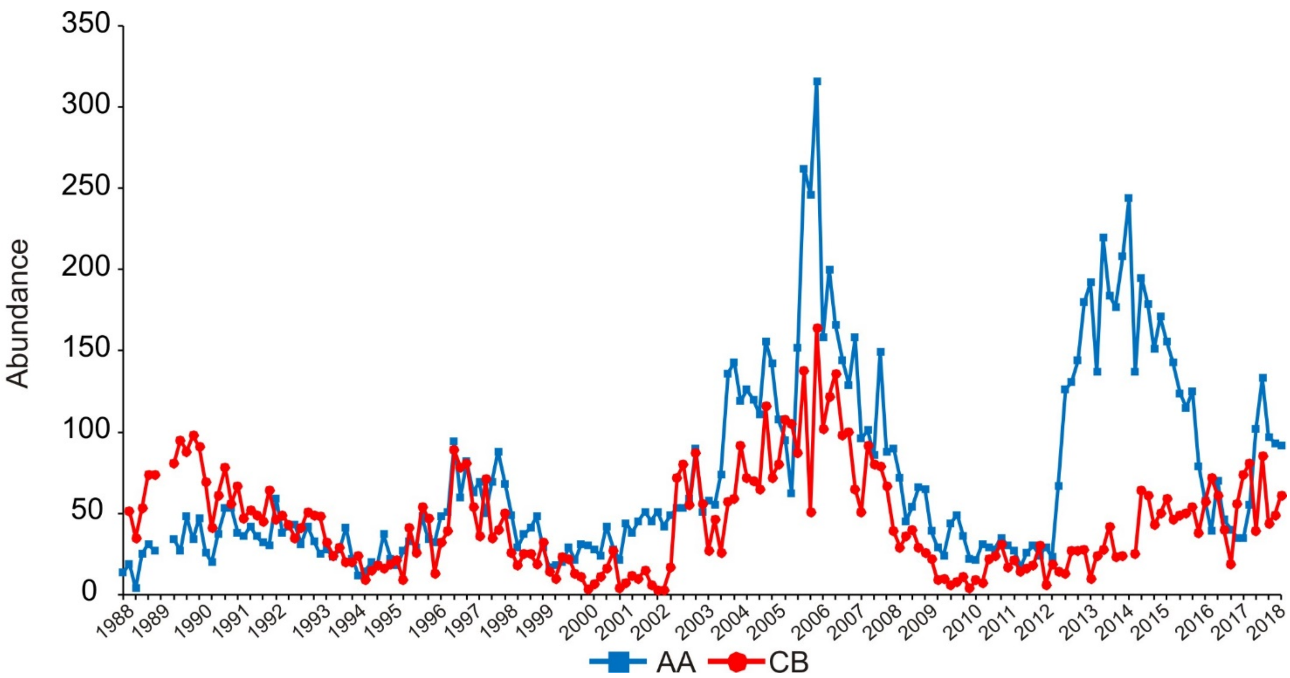


Figure 3-14 Abundance (sum total of 12 replicate cores) of *Magelona dakini* at Auckland Airport and Clarks Beach from October 1987 until February 2018.

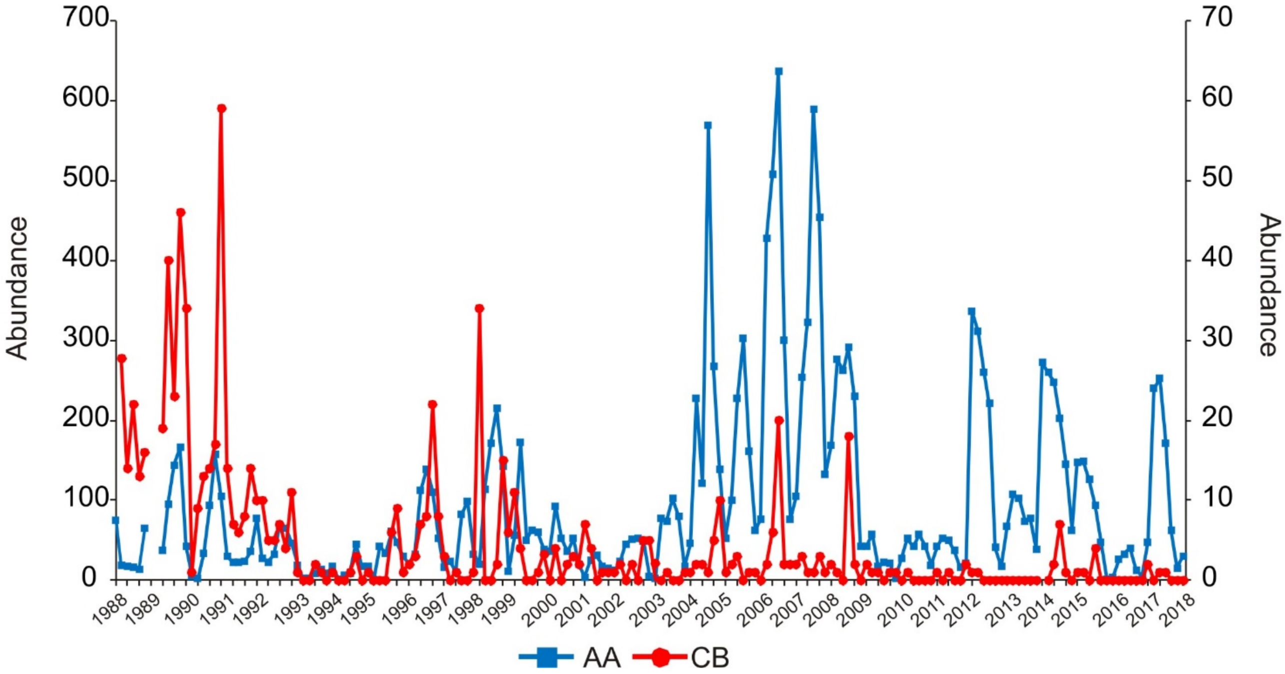


Figure 3-15 Abundance (sum total of 12 replicate cores) of *Hiatula siliquens* at Auckland Airport and Clarks Beach from October 1987 until February 2018.

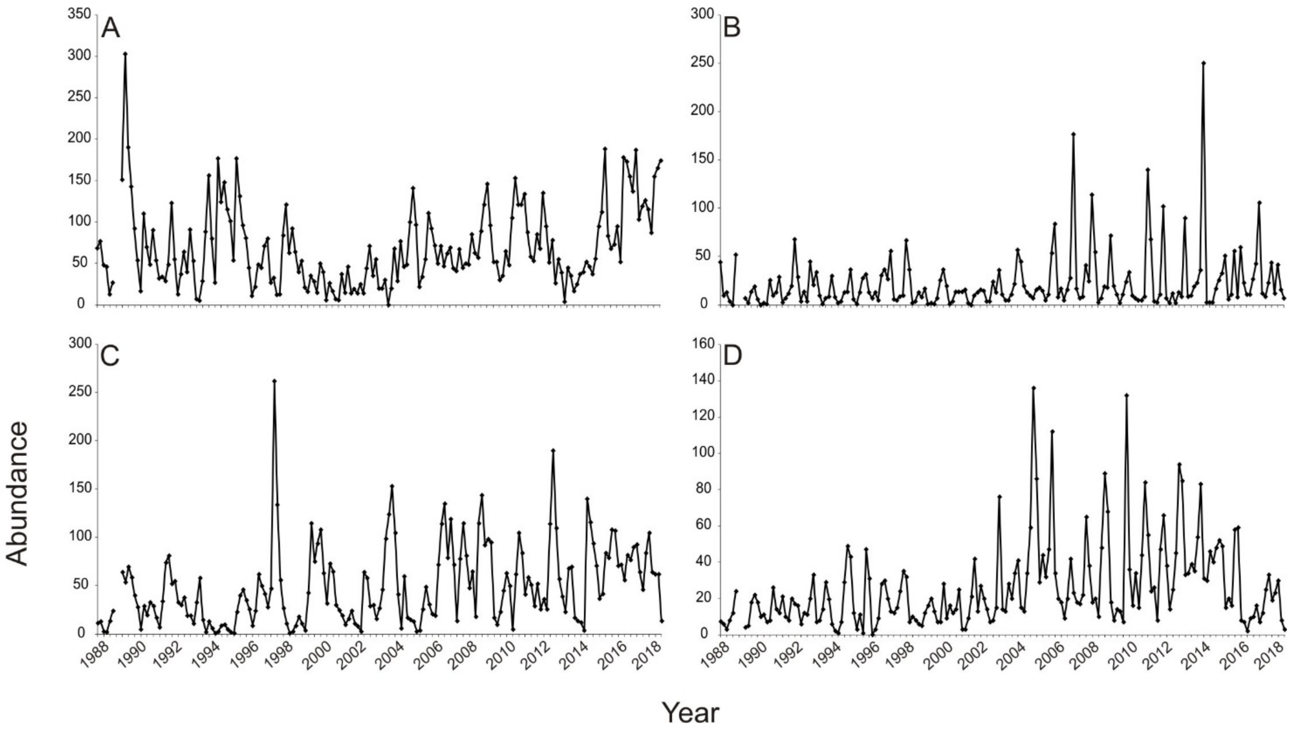


Figure 3-16 Abundance (sum total of 12 replicate cores) of A) *Austrovenus stutchburyi* B) *Colurostylis lemurum* C) *Orbinia papillosa* D) *Taeniogyrus dendyi* at Auckland Airport from October 1987 until February 2018.

The abundance of *Linucula hartvigiana* at CB continues to be highly variable, with a multi-year cycle of three-six years and with very high recruitment peaks during 2011-2012 (Figure 3-17C). At both sites AA (Figure 3-16A) and CB (Figure 3-17A), *Austrovenus* continues to show a large multi-year cycle although overall abundances are far greater at site AA (Figure 3-16, Figure 3-17).

The increase in abundances of *Boccardia syrtis* at CB during the 2016-2018 period have confirmed that cycles at multiple scales occur (Figure 3-17D).

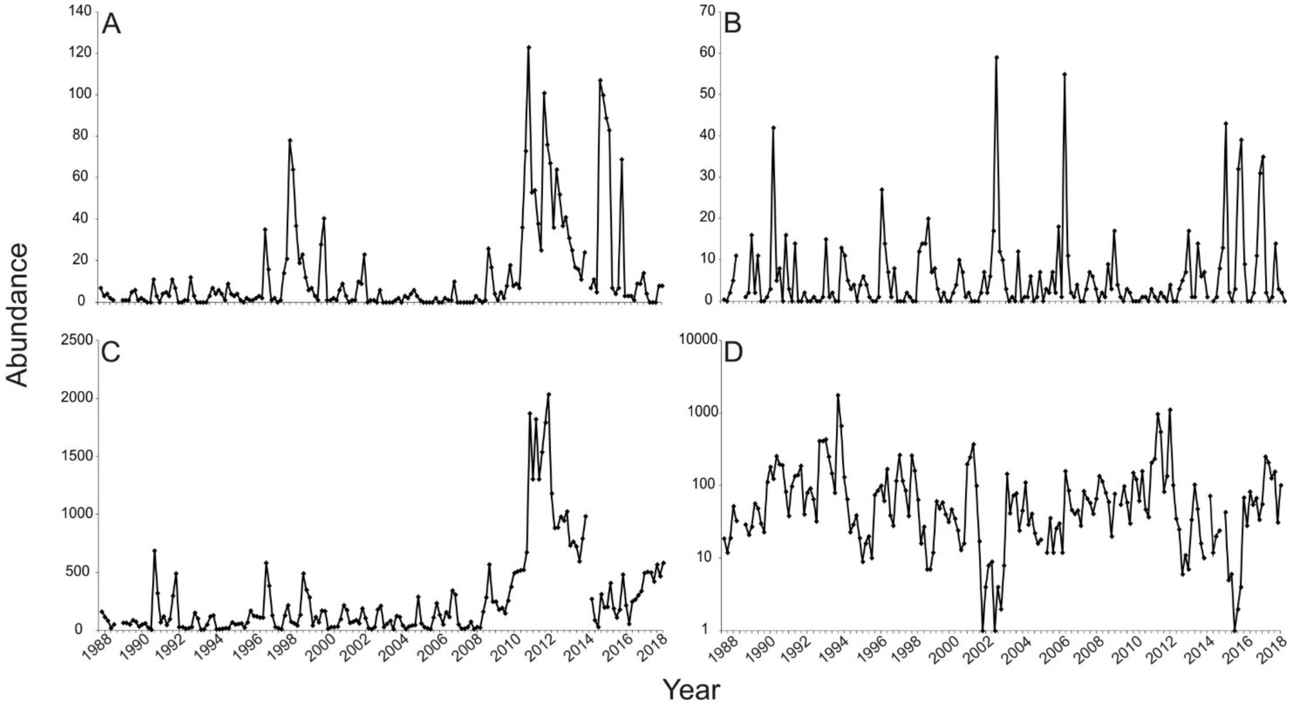


Figure 3-17 Abundance (sum total of 12 replicate cores) of A) *Austrovenus stutchburyi* B) *Colurostylis lemurum* C) *Linucula hartvigiana* D) *Boccardia syrtis* at Clarks Beach from December 1987 until February 2018.

Macomona juveniles at sites AA and CB show strong multi-year cycles of five-seven years and three-four years respectively. There is a time lag of two-four months between sites, possibly due to AA being a likely recruitment source for the rest of the harbour. (Figure 3-18).

The two-three year time signal lag in adult abundances as mentioned in Greenfield et al. (2013) is still in effect at site CB, with an increase in adult abundances observed in early 2018 following a recruitment of juveniles in early 2016 (Figure 3-19). There was a large recruitment of juvenile *Macomona* at site AA in April 2010, and again in 2014, however, there has been no concomitant increase in the abundance of adults sized greater than 20 mm since 2008.

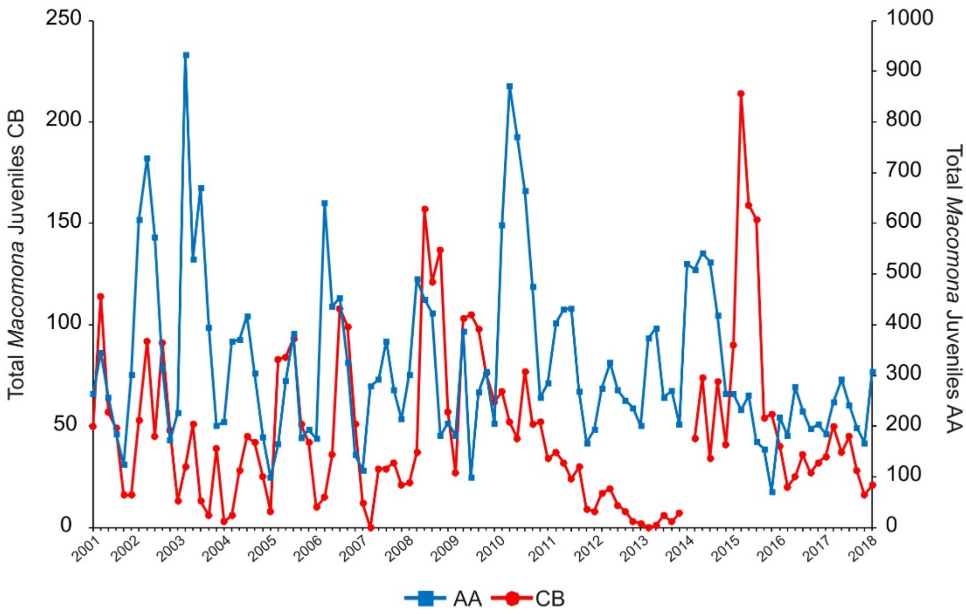


Figure 3-18 Abundance (sum total of 12 replicate cores) of juvenile (<5 mm) *Macomona liliana* from both permanently monitored sites from April 2001 until February 2018. NB: AA is on a secondary axis.

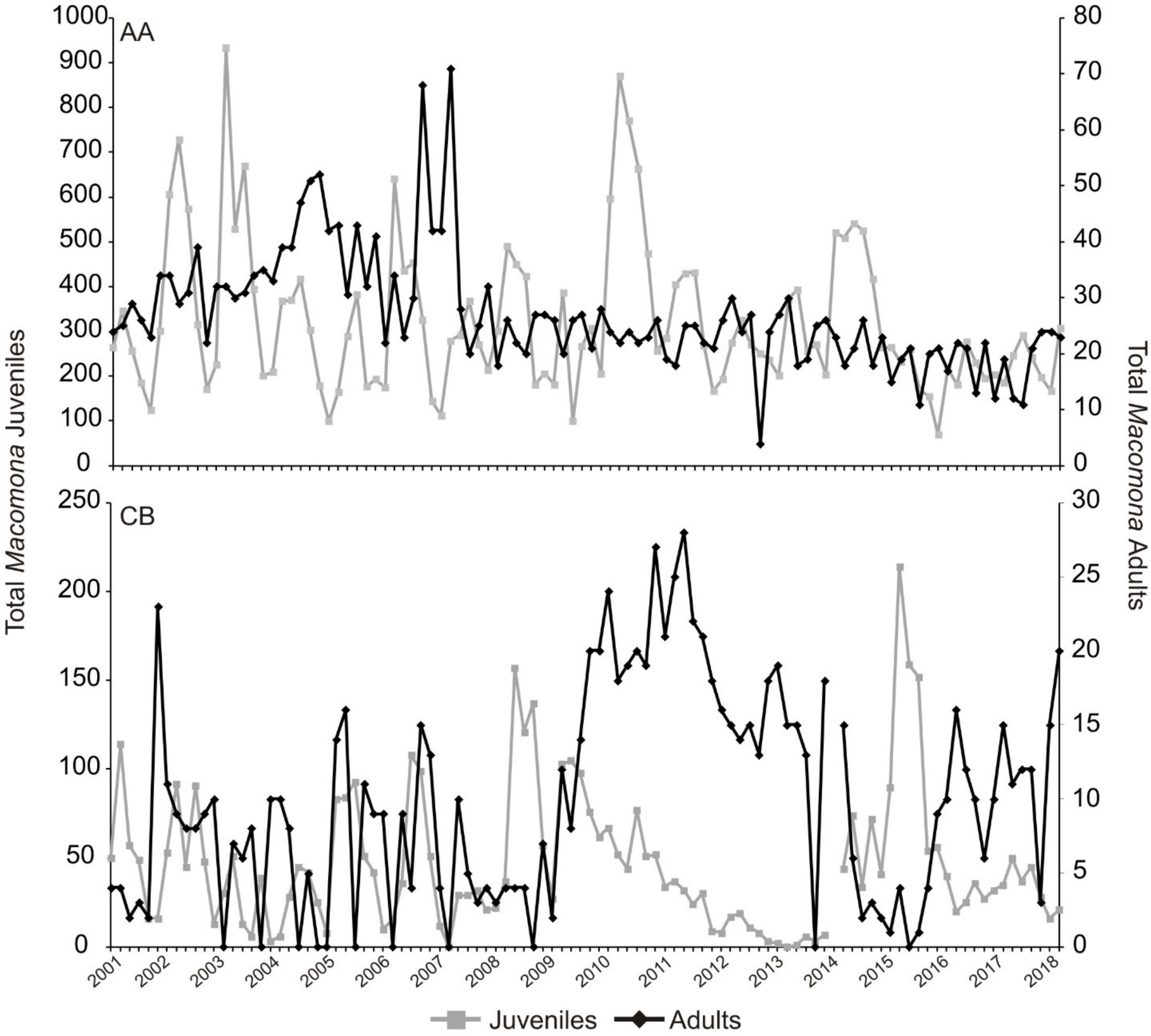


Figure 3-19 Abundance (sum total of 12 replicate cores) of juvenile (grey line; April 2001 to June 2007 <4 mm, from August 2007 <5 mm) and adult (black line; April 2001 to June 2007 >16 mm, from August 2007 >20 mm) *Macomona liliana* from sites Auckland Airport and Clarks Beach from April 2001 until February 2018.

Although the abundance of adult *Austrovenus* at site AA is usually low, the abundance of juveniles is much greater and shows a three to four year cycle (Figure 3-20). At site CB, *Austrovenus* juveniles and adults were rarely present prior to 2009. From 2009 to 2012 higher recruitment peaks of juveniles are apparent, with a concomitant increase in adults from 2010 to 2011. Abundances from October 2014 to April 2015 suggest another large juvenile recruitment event, followed closely by a large peak in adult abundances, the highest to date of 20 adults, in April 2015. Numbers of both adult and juvenile *Austrovenus* has declined following a peak in both in December 2015 (Figure 3-20).

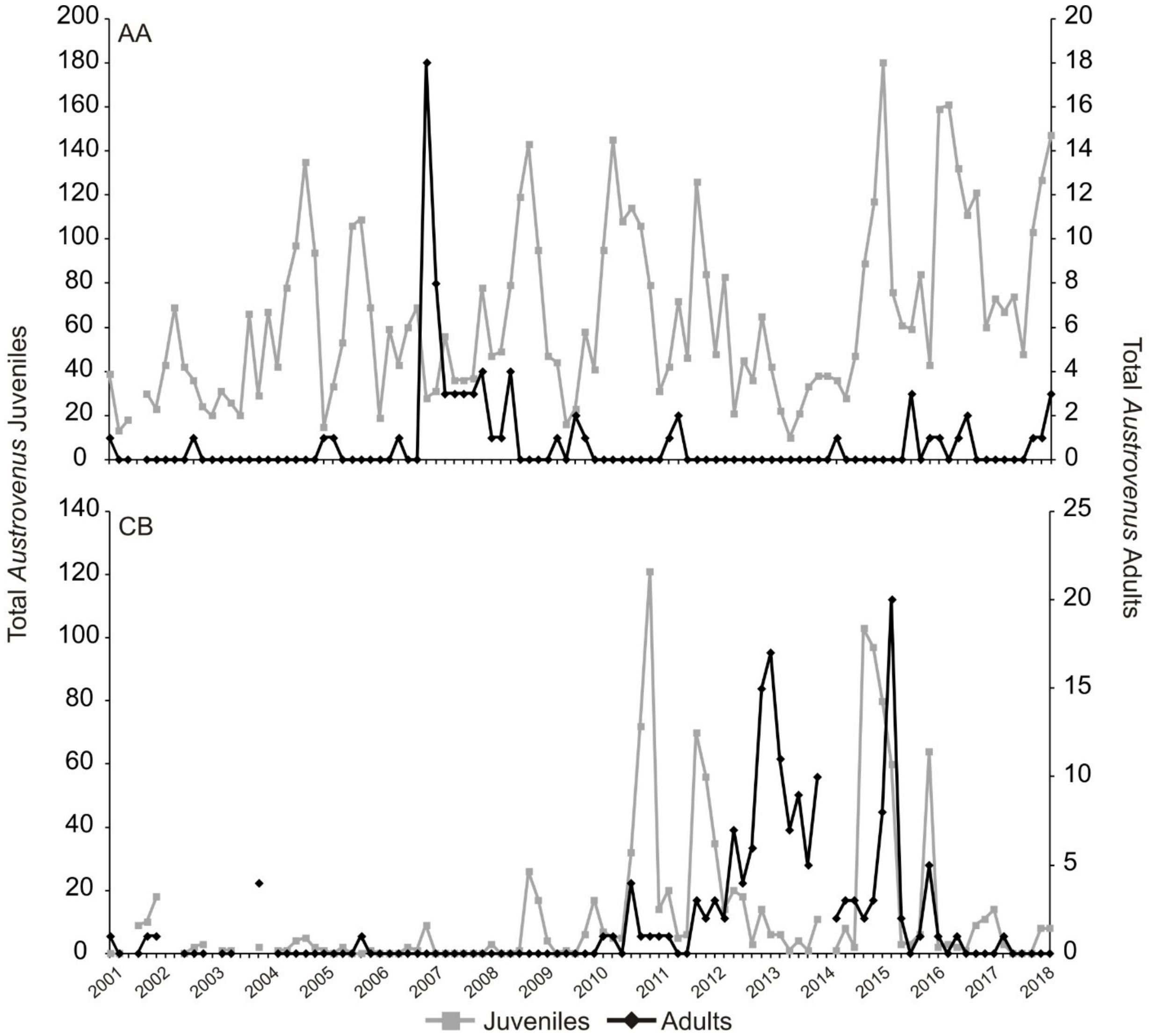


Figure 3-20 Abundance (sum total of 12 replicate cores) of juvenile (grey line; April 2001 to June 2007 <4 mm, from August 2007 <5 mm) and adult (black line; April 2001 to June 2007 >16 mm, from August 2007 >20 mm) *Austrovenus stutchburyi* from Auckland Airport and Clarks Beach from April 2001 until February 2018.

In summary, most monitored species exhibit cyclic patterns, and these have changed little over the last few years.

3.5 Are there any trends in macrofaunal communities?

Variation in community composition, based on the monitored taxa found in October of each year, provides an indication of changes over time and similarities between sites in any such changes.

At site AA, the monitored taxa composition is dominated by bivalves *Macomona* and *Austrovenus* and *Hiatula*. These bivalve species contribute most to the similarity of the communities at AA over time (33% combined based on Bray-Curtis percent similarity). The most abundant polychaetes are *Aonides, Magelona*, *Travisia*, *Orbinia* and *Taeniogyrus*, with the cumacean *Colurostylis* also numerically dominant (Appendix 7.4). The nMDS shows that the monitored taxa composition of AA has been the most stable over the duration of the monitoring period, however, with an average similarity of community composition of 74% (based on Bray-Curtis percent similarity) between October 1987 and October 2017 this site is similar to the other main harbour sites (Figure 3-21).

Site CB is dominated by a mixture of bivalves (*Linucula* and *Macomona*), polychaetes (*Macroclymenella* and *Magelona*) and the amphipod *Torridoharpinia* (Appendix 7.3). When viewed on a 2-dimensional nMDS, this site is more variable over time in monitored taxa than site AA (see Figure 3-21). This site also shows a considerable directional movement over time from the middle of the nMDS plot to the upper right hand corner. However, average similarity of monitored taxa composition over the monitored time period is 79%. The monitored taxa composition at site CH has also changed markedly over time (see Figure 3-21, Figure 3-22). The first change was largely due to the Mangere wastewater treatment plant upgrade, coincident with a strong La Nina event (see Hewitt and Hailes (2007) for a full analysis). However, while the last six October samplings still have the same dominant species as previously (*Magelona*, *Macroclymenella* and *Colurostylis* (Appendix 7.3) the monitored taxa composition has changed somewhat (only 64% similarity with previous 10 years). The monitored taxa composition since October 2013 has become more similar to that observed in the mid-1990s – prior to the wastewater treatment plant upgrade (64% similarity) driven by increases in *Boccardia* (see Appendix 7.3 and Figure 3-21, Figure 3-22), *Aglaophamus*, *Torridoharpinia* and *Methlimedon*. However, the abundances of these species are still lower than they were and other species have become important in defining the composition (*Austrovenus, Linucula*, *Anthopleura* and *Macroclymenella*).

Over the entire monitoring period the monitored taxa composition at site EB exhibits 74% similarity. The top three species contributing to this similarity are *Magelona, Macomona* and *Torridoharpinia*. However, there have been notable shifts in community composition with three distinct groupings (1987-1993, 1999-2007, and 2013-2017) (Figure 3-22). This change is due to changes in abundance of many species. Some of the changes were also observed at other sites, i.e., increases in the abundance of *Aonides* (also observed at site AA), *Anthopleura* and *Owenia* (both also observed at site CB) and decreases in the abundance of Hiatula (also observed at site CB).

Site KP has a similarity in monitored taxa composition of 75%. The top three species contributing to this similarity are *Macomona, Magelona* and *Linucula.* There have been notable shifts in community composition with two distinct groupings (1987-2001 and 2006-2016) (Figure 3-22), and now another shift appears to be occurring. In 2017 *Aonides* contributed most to the similarity.

Site PS is typically dominated by both bivalves and polychaetes, although over the past two years *Colurostylis* has appeared in the top three rank abundance (Appendix 7.3). The site displays a somewhat variable monitored taxa composition, similar to site CB (77% similarity; Figure 3-21, Figure 3-22).

In summary, there are no long-term directional changes in community composition at sites AA, CH and PS. Composition has changed at site CB but mostly this occurred in the first few years of monitoring. Sites EB and KP have demonstrated shifts in community composition over the monitored time period due to changes in the abundance of many species.

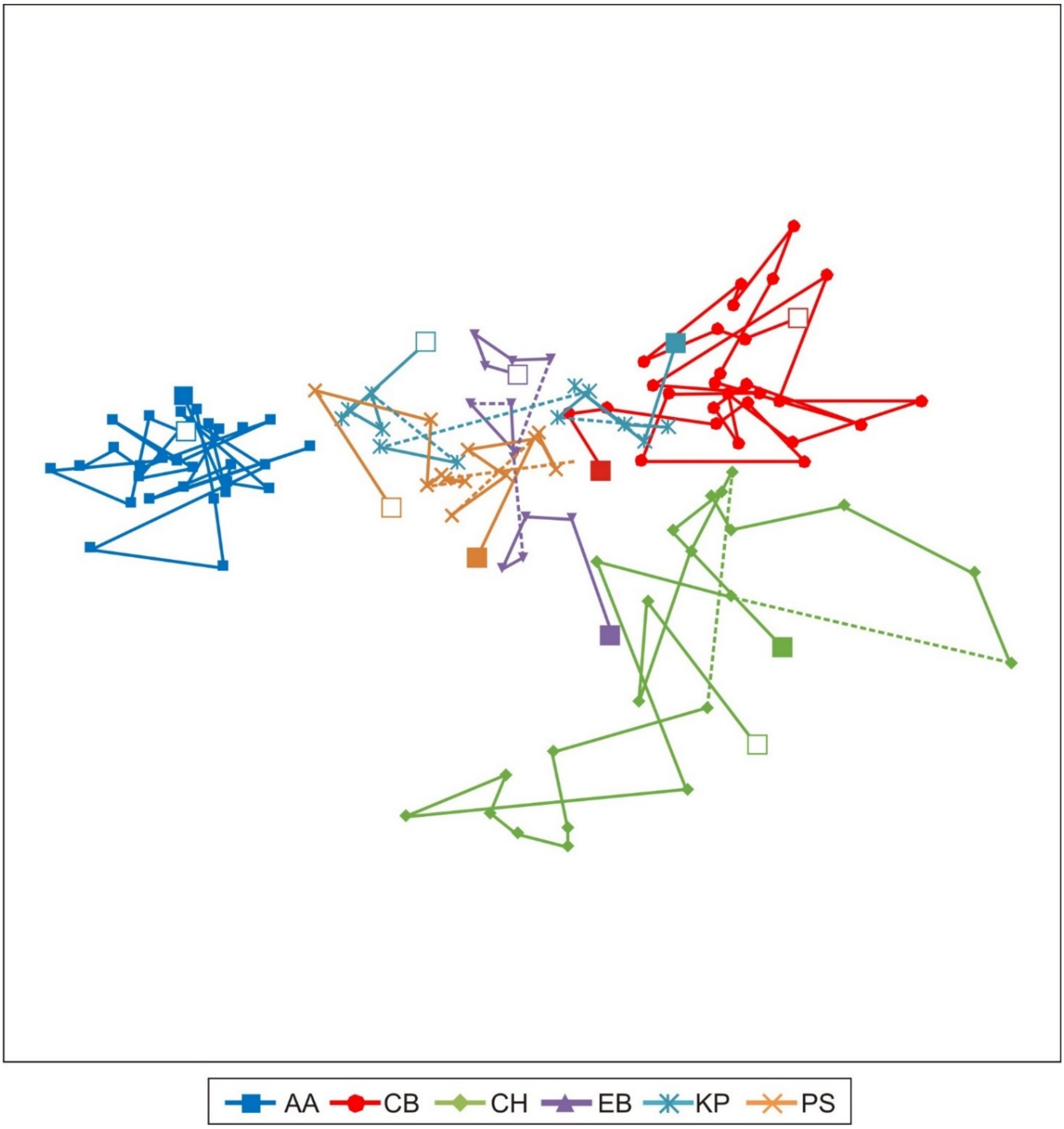


Figure 3-21 Non-metric multi-dimensional Scaling (nMDS) plot of the dissimilarity in macrofaunal communities of monitored taxa over time (October 1987-October 2017) (4^{th}-root transformed data). The earliest sampling occasion is denoted by a closed square and the most recent is denoted by an open square. The further away the points are in the ordination space, the more dissimilar the community composition is. Dashed lines join periods of sampling when times were missed.

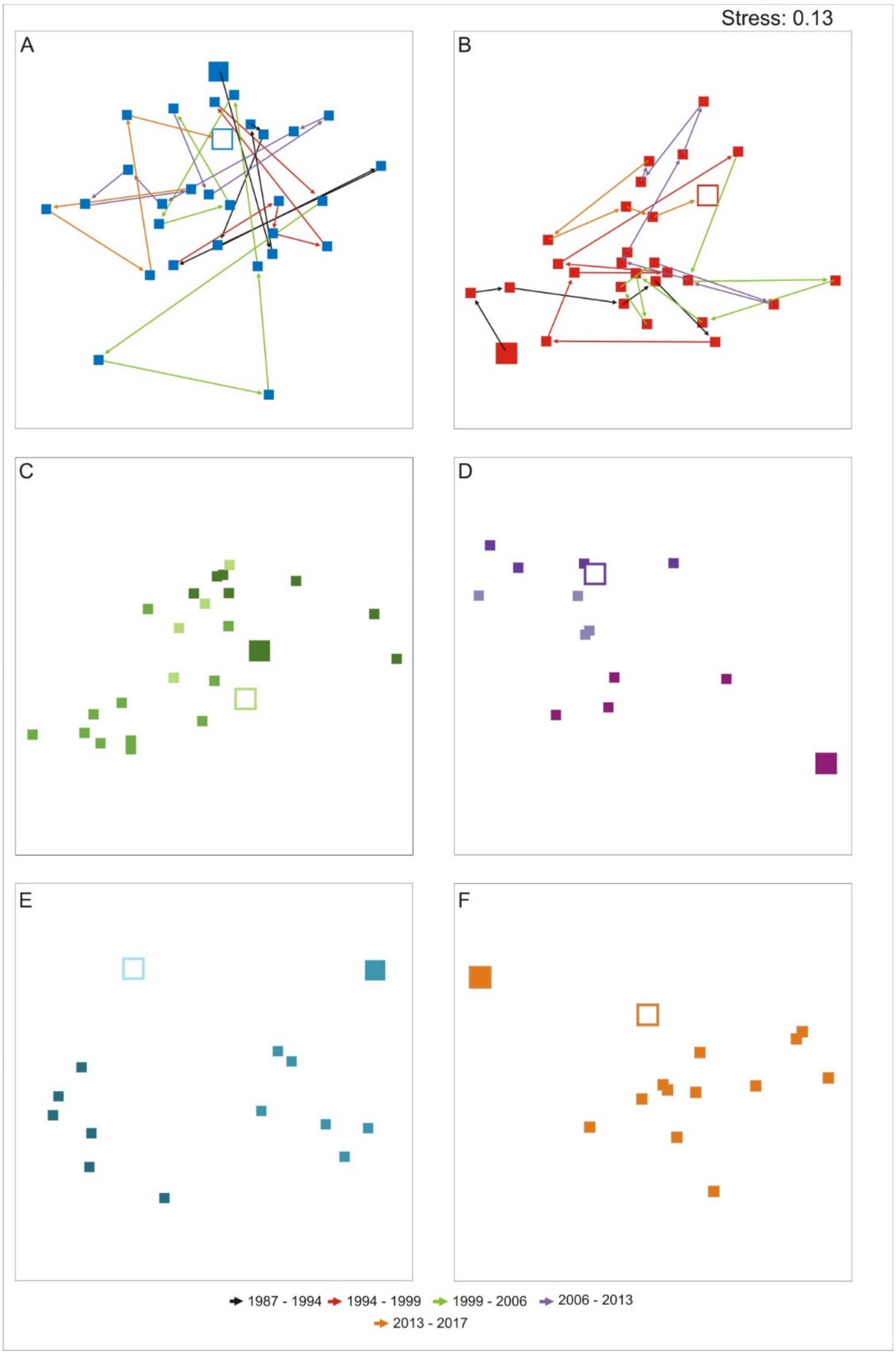


Figure 3-22 Non-metric multi-dimensional Scaling (nMDS) plot of the dissimilarity in macrofaunal communities of monitored taxa over time (October 1987-October 2017) for each site (4^{th}-root transformed data), A) Auckland Airport, B) Clarks Beach, C) Cape Horn, D) Elletts Beach, E) Karaka Point, F) Puhinui Stream. The earliest sampling occasion is denoted by a large closed square and the most recent is denoted by an open square. The further away the points are in the ordination space, the more dissimilar the community composition is. Dashed lines join periods of sampling when times were missed. Different colours represent distinct groupings of communities.

3.6 Relative Health across the Harbour

TBI scores have been calculated using the latest TBI formula (Lohrer and Rodil 2011) and October data from each site. Values closer to 0 indicate low functionality (and possibly an indication of degradation) and values near 1 indicate high ecosystem functionality. Habitats with a high functional redundancy (i.e., many species present in each functional trait group) tend to have a higher inherent resistance and resilience in the face of environmental change (Lohrer and Rodil, 2011). Values <0.3 indicate unhealthy with low redundancy and low resilience. Values between 0.30 and 0.40 indicate potentially reduced functional redundancy but are only concerning if the sediment is <95% sand (site AA is >99% sand). TBI scores for the six monitored Manukau sites for October 2015 and October 2017 lie between 0.92 (CB) and 0.49 (AA) (see Table 3-3). TBI values for the RSCMP sites were all ≤ 0.40, ranging from 0.38 at Pahurehure Middle (76% sand) to 0.18 at Waiuku (5% sand). Small changes in TBI scores are apparent at sites AA and PS but these do not change the health categories.

Benthic health model scores (Anderson et al. 2006; Hewitt and Ellis, 2010) for both mud and metals (copper, zinc and lead) were also calculated (Table 3-3). BHMmetal and BHMmud scores for site AA give an “extremely good” rating, although the BHMmud scores are changing over time in the direction of decreasing health. BHMmetal and BHMmud scores at CB rank the site as “moderate” with a trend over time in the BHMmetal scores moving the site from “good” to just “moderate”. The site CH scores are naturally variable over time but are generally “good”; at present a small change in BHMmud scores towards better health is apparent. The only other trend over time detected is for BHMmud at site EB in the direction of increasing health. The BHMmud scores give “extremely good” and “good” rankings for sites EB and KP respectively, while the BHMmetal scores for sites EB and KP have been variable in the past three years and in 2017 give a “good”, ranking. Site PS has a BHMmetal ranking of “extremely good” and a BHMmud ranking of “good” in 2017.

Conversely, for the upper inlet areas, which are depositional areas, the ratings were considerably lower. Anns Creek, Pahurehure Inlet and Mangere Cemetery were rated as “unhealthy” by their BHMmetal and BHMmud scores

The overall health of each site was determined using benthic health model and TBI scores (Table-3). The combined health scores for site AA is “extremely good”, and for sites CB and CH are “moderate”. Sites EB, KP and PS have an overall health score of “good”” in October 2017. As expected, combined health scores for the RSCMP sites in depositional upper inlet sites are worse than for the main harbour sites. Only Pahurehure Middle returned a “moderate” score, while the other 12 sites are scored as “unhealthy with low resilience” (Figure 3-23).

Table 3-3 Benthic Health Model scores for metals and mud (BHMmetal and BHMmud scores), TBI and combined Health scores for Manukau Harbour main body sites and Regional Sediment Chemistry Monitoring Programme sites (Upper harbour sites, marked in grey). Group 1 = extremely good, Group 2 = good, Group 3 = moderate, Group 4 = poor, Group 5 = unhealthy, Combined ≤ 0.2 "extremely good"; 0.2 < Combined ≤ 0.4 "good"; 0.4 < Combined ≤ 0.6 "moderate"; 0.6 < Combined ≤ 0.8 "poor" and Combined > 0.8 "unhealthy with low resilience". Grey shaded = not applicable for combined health score.

Site	Year	BHMmetal	BHMmud	TBI score	Combined health score
AA	2015	-0.23	-0.16	0.29	0.20
	2016	-0.18	-0.14	0.44	0.20
	2017	-0.21	-0.16	0.49	0.20
CB	2015	-0.06	-0.06	0.67	0.44
	2016	-0.07	-0.06	0.76	0.38
	2017	-0.04	-0.04	0.92	0.51
CH	2015	-0.13	-0.06	0.45	0.38
	2016	-0.15	-0.07	0.47	0.38
	2017	-0.17	-0.75	0.38	0.42
EB	2015	-0.14	-0.10	0.55	0.38
	2016	-0.12	-0.11	0.57	0.38
	2017	-0.13	-0.12	0.54	0.30
KP	2015	-0.16	-0.10	0.61	0.38
	2016	-0.18	-0.12	0.69	0.20
	2017	-0.13	-0.08	0.57	0.38
PS	2015	-0.16	-0.11	0.55	0.31
	2016	-0.16	-0.10	0.61	0.38
	2017	-0.19	-0.10	0.59	0.31
Bottle Top Bay	2017	0.07	0.09	0.24	1.00
Drury Creek Doc Is Mud	2017	0.05	0.09	0.26	1.00
Drury Creek Inner	2017	0.05	0.09	0.28	1.00
Harania	2017	0.10	0.10	0.20	1.00
Pahurehure Middle	2017	-0.09	-0.08	0.38	0.49
Pahurehure Upper	2017	0.09	0.12	0.24	1.00

Site	Year	BHMmetal	BHMmud	TBI score	Combined health score
Papakura Stream Lower	2017	0.11	0.09	0.23	1.00
Puhinui Upper	2017	0.09	0.10	0.27	1.00
Pukaki at Airport	2017	0.03	0.07	0.35	0.67
Tararata	2017	0.10	0.11	0.18	1.00
Waimahia Creek Central	2017	0.05	0.09	0.25	1.00
Waiuku	2017	0.06	0.14	0.18	1.00
Whangapouri	2017	0.11	0.10	0.22	1.00

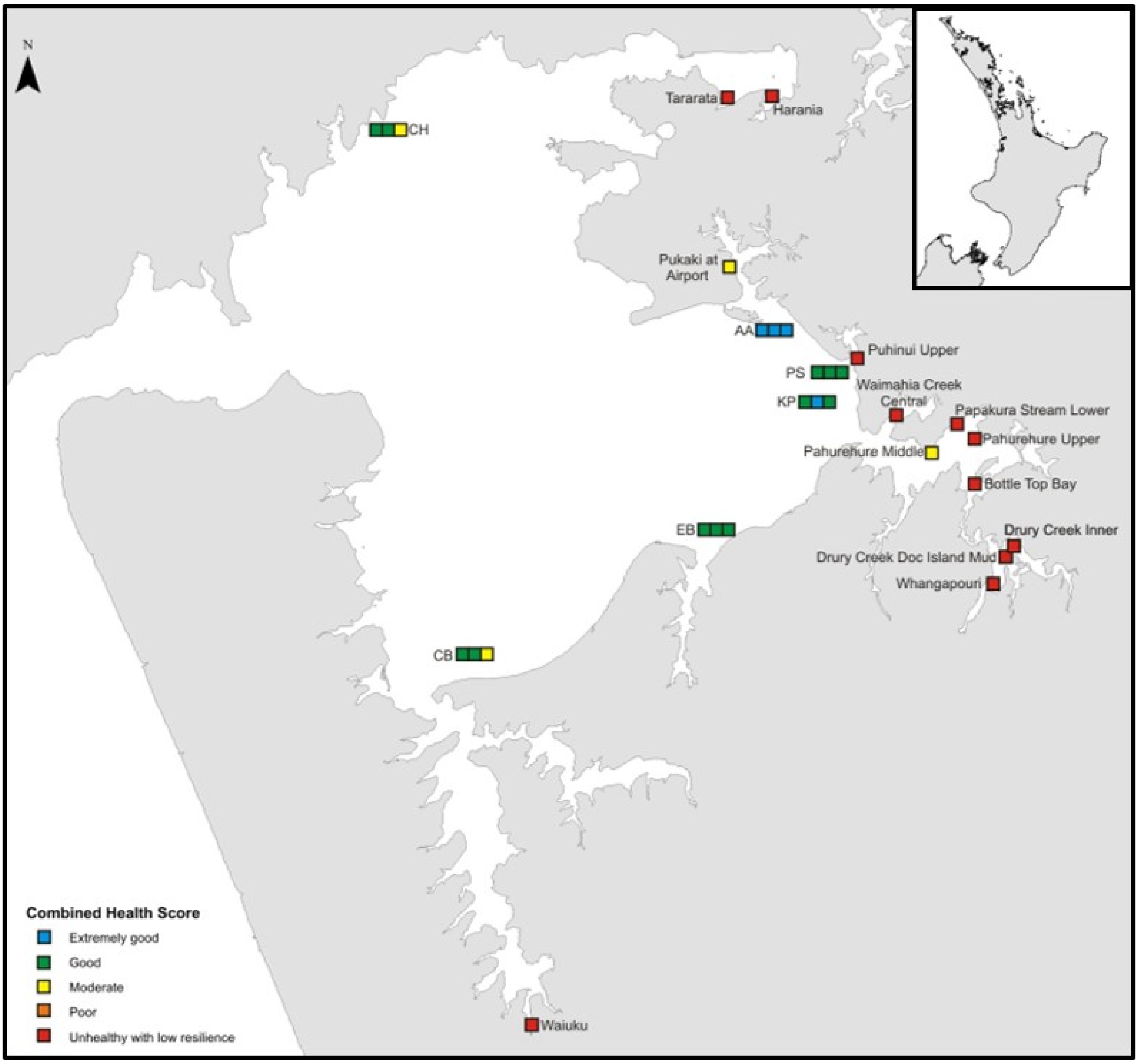


Figure 3-23 Map of the Manukau Harbour showing combined health scores, 2015, 2016, 2017 for all of the monitored Manukau sites (AA, CB, CH, EB, KP and PS) as well as those sampled as part of the AC Regional Sediment Chemistry Monitoring Programme, October 2017 (Bottle Top Bay, DOC Is Mud, Drury Creek Inner, Harania, Pahurehure Middle, Pahurehure Upper, Papakura Stream Lower, Puhinui Upper, Pukaki (Airport), Tararata, Waimahia Creek Central, Waiuku and Whangapouri). The latter sites were not sampled in 2015 or 2016 therefore only one half of the site marker is shown.

4.0 Summary

4.1 Changes in ecology

The overall health of the main body of the Manukau Harbour, which takes into account the influences of metal contaminants, mud content and macrofaunal community functionality (redundancy and resilience to change), is “moderate” to “extremely good”. However, the surrounding sites in tidal arms have far worse overall health scores than the main harbour body sites (Figure 3-23) and are generally classified as “unhealthy” with low resilience.

Trends in the abundance of monitored taxa are apparent. At site Auckland Airport (AA), six taxa are exhibiting trends in abundance; all have been previously identified except for the declining number of adult *Macomona* since 2008. Overall the trends in abundance are not strongly consistent with either increasing heavy metals or sediment mud content (see Table 4.1), as species with known sensitivities to these are showing both increases and decreases. However, three of the four species that are sensitive to copper contamination are decreasing in abundance, and two of the three species sensitive to mud content are decreasing. Little is known of the sensitivity to nutrients of the monitored species that occur at this site.

Table 4-1: Presence of trends of concern at each site based on monitored taxa which are known to be sensitive to, or consistent with environmental variables. Y = number of trends in abundance consistent with concern minus number of trends in abundance inconsistent with concern is greater than 0.

Site	Nutrients	Stormwater contaminants	BHM_{metals}	Mud content	BHM_{mud}	TBI
AA		Y- copper		Y	Y	
CB	Y	Y- zinc	Y			
CH						
EB	Y					
KP						
PS						

Four trends in abundance were observed at the Clarks Beach site (CB): increases in abundances for *Owenia* and *Anthopleura*, and a decrease in the abundance of *Hiatula* and a step-decrease in *Notoacmea* since 2010. Both *Notoacmea* and *Anthopleura* are sensitive to sediment mud content, suggesting this is not driving changes in their abundances. *Notoacmea* is also very sensitive to zinc, while *Anthopleura* is very sensitive to copper. Of the four taxa, only *Owenia* prefers moderately enriched sediments.

None of the trends in abundances of monitored taxa detected at sites Cape Horn (CH), Karaka Point (KP) or Puhinui Stream (PS) are consistent with contaminants, sediment mud content or nutrients.

At site Elletts Beach (EB) trends in abundance were detected were all increases (with the exception of *Hiatula*). Most of the taxa are sensitive to sediment mud content and storm-water contaminants, suggesting that these trends are not concerning. However, two of the taxa exhibiting increases prefer enriched or slightly enriched conditions.

There are, however, some trends of potential concern in community composition at three sites.

- There is a small change in macrofaunal community composition at site AA consistent with increasing mud content, although the site is still scored as “extremely good”. The surface of the site on the last few monitoring occasions has had small patches of Ulva (attached to cockle shells). This could be a result of increased land runoff in combination with warmer temperatures over the summer, extending into autumn.
- Changes in macrofaunal community composition at site CB are consistent with heavy metal contamination and the site has decreased in health from “good” to “moderate” health. Much of this change has occurred coincident with the increasing coverage of the site by seagrass and, as the health indices were developed from non-vegetated reference sites, this might be affecting the ability of the index to truly differentiate health.
- Changes in the monitored taxa community composition at site PS appear to be cyclic and at site EB appear to have stabilised. However, changes in the monitored taxa community composition at site KP, away from that first found in October 1987, continue.

5.0 Acknowledgements

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7.0 Appendices

7.1 Monitoring years of sites AA, CB, CH, EB, KP and PS

Y indicates sampling occurred, - indicates no sampling, ***** indicates missed sampling in October and December 1988 and February 2014. ~ indicates additional sampling conducted at CH as part of a NIWA independent study. + indicates sampling in October only.

	Auckland Airport	Clarks Beach	Cape Horn	Elletts Beach	Karaka Point	Puhinui Stream
1987	Y	Y	Y	Y	Y	Y
1988*	Y*	Y*	Y*	Y*	Y*	Y*
1989	Y	Y	Y	Y	Y	Y
1990	Y	Y	Y	Y	Y	Y
1991	Y	Y	Y	Y	Y	Y
1992	Y	Y	Y	Y	Y	Y
1993~	Y	Y	Y~	Y	Y	Y
1994~	Y	Y	Y~	-	-	-
1995~	Y	Y	Y~	-	-	-
1996	Y	Y	-	-	-	-
1997	Y	Y	-	-	-	-
1998	Y	Y	-	-	-	-
1999	Y	Y	Y	Y	Y	Y
2000	Y	Y	Y	Y	Y	Y
2001	Y	Y	Y	Y	Y	Y
2002	Y	Y	Y	-	-	-
2003	Y	Y	Y	-	-	-
2004	Y	Y	Y	-	-	-
2005	Y	Y	Y	-	-	-
2006	Y	Y	Y	Y	Y	Y
2007	Y	Y	Y	Y	Y	Y
2008	Y	Y	Y	Y	Y	Y
2009	Y	Y	Y	-	-	-
2010	Y	Y	Y	-	-	-
2011	Y	Y	-	-	-	-
2012	Y	Y	-	-	-	-
2013	Y	Y	-	Y	Y	Y
2014	Y	Y*	Y	Y	Y	Y
2015	Y	Y	Y+	Y+	Y+	Y+
2016	Y	Y	Y+	Y+	Y+	Y+
2017	Y	Y	Y+	Y+	Y+	Y+
2018	Y	Y				

7.2 Monitored species for Manukau Harbour and their known sensitivity to mud and contaminants

The species recommended for monitoring are those that would be expected to show different types of changes in response to increased sediment or contaminant inputs and/or are likely to play key roles in influencing the composition of other taxa.

Arthropoda: Amphipoda

- *Methlimedon* sp.

Methlimedon sp. belongs to the amphipod family Exoedicerotidae. It is relatively common in estuarine sediments and is commonly found at monitoring sites in Manukau Harbour. It is most likely to be a deposit-feeder, however, little is known about the genus.

- *Torridoharpinia hurleyi*

Torridoharpinia hurleyi is a large phoxocephalid amphipod often common in intertidal estuarine sediments. It is most likely to feed on detritus and microscopic organisms, although some phoxocephalid species have been shown to be predators. In addition, this amphipod contributes significantly to sediment turnover through its burrowing activities and is an important prey item for birds and small fish (Thrush et al. 1988). Amphipods have been shown to be sensitive to toxic contamination of sediments (Swartz et al. 1982) and there is evidence that *Torridoharpinia* may also be sensitive to pollution (Roper et al. 1988; Fox et al. 1988).

- *Waitangi brevirostris*

Waitangi brevirostris is also a large phoxocephalid amphipod and is likely to play an important role in sediment reworking. Similar to other amphipods, it is probably an important prey item for birds and fish. It is sensitive to lead (Hewitt et al. 2009) and to sediment mud content, preferring <5% mud (Gibbs & Hewitt 2004).

Cnidaria: Anthozoa

- *Anthopleura aureoradiata*

Anthopleura aureoradiata is a predatory sea anemone, living attached to live *Austrovenus*, or broken shells. It is intolerant of high turbidity and requires salinities higher than 20 ppt (Jones 1983). It is sensitive to sediment mud content, preferring <10% (Gibbs & Hewitt 2004), and very sensitive to copper (Hewitt et al. 2009).

Mollusca: Bivalvia

- *Austrovenus stutchburyi*

Austrovenus stutchburyi (previously *Chione stutchburyi*) is a large suspension-feeding bivalve, common throughout much of New Zealand's estuaries intertidal areas. *Austrovenus* is one of the more studied species in New Zealand, potentially growing up to 60 mm (though individuals in the Auckland region are rarely >35 mm) and living for more than three years. Individuals live 0-5 cm below the sediment surface when the tide is out and move up to feed at the surface when the tide comes in. They are highly mobile, both as adults on the surface of the sediment, and as juveniles, moving with bed-load or in the water column. They provide an important recreational and cultural food source for humans, and are also an important prey item for birds (e.g., oyster catchers), rays and other fish. While their filtration rates are not as high as those of oysters and mussels, Pawson (2004) suggested that feeding by cockles controls the availability of food in the water column (as algal biomass) in Papanui Inlet on the Otago peninsula. Effects of *Austrovenus* on the accumulation of contaminants (Townsend et al. 2009), the release of nutrients from the seafloor (Sandwell 2006, Thrush et al. 2006) and sediment destabilisation (Sandwell 2006) have been documented. Importantly, this species has moderate sensitivity to terrestrial sedimentation (Norkko et al. 2002, Thrush et al. 2005), increases in suspended sediment (Hewitt & Norkko 2007) and stormwater contaminants (Hewitt et al. 2009).

- *Macomona liliana*

Macomona liliana is a large deposit feeding bivalve. As an adult it lives well below the sediment surface (~10 cm) and feeds on the sediment surface using a long siphon. As a juvenile it is highly mobile, moving with bed-load and in the water column. While it is mainly a deposit feeder, it can also suspension feed by lifting its siphon into the water column. It lives both intertidally and subtidally, can grow up to 70 mm, and can live for more than five years. Similar to *Austrovenus*, the species is an important prey item for birds (e.g., oyster catchers), rays and other fish and has been demonstrated to affect seafloor productivity and nutrient recycling and surficial oxygen content (Thrush et al. 2006; Volkenborn et al. in press). It is also sensitive to terrestrial sedimentation (Norkko et al. 2002, Thrush et al. 2005), increases in suspended sediment (Nicholls et al. 2003) and stormwater contaminants (Hewitt et al. 2009).

- *Linucula (Nucula) hartvigiana*

Linucula (Nucula) hartvigiana is a small (generally <8 mm) deposit-feeding bivalve that lives near the sediment surface. It is mobile and is probably capable of rapid small scale recolonisation (Thrush et al. 1988, Lohrer et al. 2011). These bivalves are frequently found in the 'undisturbed' zones of an organic pollution gradient (Pearson & Rosenberg 1978). It is somewhat sensitive to sediment mud content (optimum 0- 12, Thrush et al. 2003; Gibbs & Hewitt, 2004; Anderson et al. 2007) and copper (Hewitt et al. 2009).

- *Hiatula (Soletellina) siliquens*

Hiatula (Soletellina) siliquens is a deposit-feeding bivalve, common in the Manukau, of which little is known.

Arthropoda: Cumacea

- *Colurostylis lemurum*

Colurostylis lemurum feeds on detritus and small organisms, making small feeding pits in the sediment surface and spending much of its time in the water column. It has been reported as sensitive to lead (Hewitt et al. 2009) and to prefer low sediment mud content (<5% Anderson et al. 2007; Gibbs & Hewitt, 2004).

Mollusca: Gastropoda

- *Notoacmea scapha*

Notoacmea scapha (previously *N. helmsi*) is a grazing limpet found associated with gravel and cockle shells. Some limpets have been shown to be sensitive to sewage pollution (Smyth 1968). It prefers low amounts of sediment mud content <5% (Gibbs & Hewitt, 2004).

Echinodermata: Holothuroidea

- *Taeniogyrus (Trochodota) dendyi*

Taeniogyrus (Trochodota) dendyi is a small sea cucumber and a detrital-feeder that has not been well studied. Echinoderms are generally very sensitive to any form of pollution (Agg et al. 1978) and New Zealand holothurian species that have been studied, certainly fit into this pattern (Roper et al. 1989). Furthermore, it is likely to be responsible for considerable sediment turnover (Thrush et al. 1988).

Arthropoda: Isopoda

- *Exosphaeroma planulum (*misidentified as *E. chilensis)* and *Exosphaeroma waitemata (*misidentified as *falcatum*)

Little is known about the *Exosphaeroma* genera, although it is one of the more common isopods of our estuaries, with a number of different species. *E. planulum* is the most common in the Auckland region, followed by *E. waitemata*. Isopods are known to be prey for birds and fish.

Annelida: Polychaeta

- *Aglaophamus macroura*

Aglaophamus macroura is the common large predatory nephtyid polychaete found intertidally in New Zealand. Little is known about it, but another New Zealand species of similar size is slow growing and lives for at least five years. Nephtyids generally have been shown to be an important intermediate predator, living off smaller invertebrates (Hailes 2006) and providing an important food source for birds and small fish.

- *Aonides trifida*

Aonides trifida (previously *A. oxycephala*) is a small infaunal deposit feeder, living in a wide range of sediments but preferring those of low mud content (0 - 10%, Thrush et al. 2003, Anderson et al. 2007). It is sensitive to copper contamination (Hewitt et al. 2009).

- *Boccardia syrtis*

Boccardia syrtis is a small polydorid tube worm which forms dense mats capable of stabilising the sediment in energetic environments and trapping small animals moving in the water column (Cummings et al. 1996, Thrush et al. 1996). It is generally a surface deposit feeder but can also suspension feed. It is common in muddier sediments (10-30 % mud, Thrush et al. 2003, Gibbs and Hewitt, 2004), prefers slight nutrient enrichment and polydorids have been shown to be sensitive to lead (Hewitt et al. 2009).

- *Glycinde trifida*

Glycinde trifida (previously *Goniada emerita*, then *Glycinde dorsalis*) is a Goniadidae polychaete and has been found at all monitored sites in Manukau Harbour. It is moderately sized predator, often exhibiting two-yearly recruitment patterns.

- *Macroclymenella stewartensis*

Macroclymenella stewartensis is a maldanid tube worm and is an important bioturbator (feeding on subsurface deposits and ejecting material on to the sediment surface. Its tubes can help stabilise surface sediments. It is sensitive to copper (Hewitt et al. 2009) and prefers sediment mud content between 10 and 15 % mud (Gibbs & Hewitt 2004).

- *Magelona dakini*

Magelona dakini is a small subsurface deposit feeder, living mainly greater than 2 cm below the sediment surface. It is highly sensitive to lead concentrations (Hewitt et al. 2009). Little is known about the species, and its true species name is in doubt.

- *Orbinia papillosa*

Orbinia papillosa is a large subsurface deposit feeder, preferring slightly silty sediment (5 - 10% mud, Gibbs and Hewitt 2004). It is a bioturbator and a prey item for birds and fish. Orbinids have been found to be somewhat sensitive to zinc at concentrations slightly below the TEL guideline (Hewitt et al. 2009).

- *Owenia petersenae*

Owenia petersenae (previously *O. fusiformis*) is a cosmopolitan species frequently abundant in sandflats and builds large tubes from heavy sand grains. Their tube structures may influence larval settlement (including providing an attachment surface for *Arcuatula senhousia*) and provide refuges from epibenthic predators. *Owenia* are principally suspension-feeding animals but may also deposit-feed and they are classified as an intermediate stage species along organic enrichment gradients by Pearson and Rosenberg (1978).

- *Prionospio aucklandica*

Prionospio aucklandica (previously *Aquilaspio aucklandica*) is another small deposit feeder, similar to *Aonides*. However, it is generally larger and lives deeper in the sediment, occurring across a range of mud content (12 - 50 % optimum depending on study: Thrush et al. 2003; Anderson et al. 2007; Gibbs and Hewitt, 2004). Similarly, while still sensitive to copper, it is less sensitive than *Aonides* (Hewitt et al. 2009).

- *Travisia olens* var. NZ

Travisia olens novaezealandiae is a large deposit-feeding opheliid, often seen lying on the sediment surface. It is slightly mobile, and prefers sandy sediment, <5% mud (Gibbs & Hewitt 2004).

7.3 Sediment characteristics from April 2009 to February 2018.

Grain size fractions (% weight) are gravel (>2mm), sand (2 mm-63 µm) and silt/clay (<63µm); organic content (OC; %) and chlorophyll *a* (Chl*a*; µg/g sediment). * denotes no samples collected by AC at this time.

	Auckland Airport (AA)					Clarks Beach (CB)				
	Gravel	Sand	Silt/ Clay	OC	Chl*a*	Gravel	Sand	Silt/ Clay	OC	Chl*a*
Apr-09	0.03	99.21	0.77	0.66	9.98	0.51	91.85	7.64	1.23	12.27
Jun-09	1.37	97.86	0.77	0.62	10.09	0.64	83.43	15.93	1.81	11.12
Aug-09	0.36	99.01	0.64	0.55	11.23	0.05	90.11	9.84	1.03	13.64
Oct-09	0.11	99.07	0.82	0.74	10.54	2.61	94.55	2.84	1.08	9.51
Dec-09	0.55	98.61	0.84	0.50	7.91	0.91	93.69	5.39	1.10	10.66
Feb-10	0.00	99.31	0.69	0.56	11.46	4.84	89.89	5.27	1.02	8.71
Apr-10	0.00	99.23	0.77	0.62	10.54	0.38	84.89	14.73	2.36	10.66
Jun-10	0.12	99.43	0.45	0.59	12.04	1.29	88.73	9.98	1.67	8.37
Aug-10	0.10	99.08	0.82	0.61	8.60	1.16	86.14	12.69	1.36	9.28
Oct-10	1.27	98.11	0.62	0.58	9.74	3.30	92.90	3.80	1.02	8.77
Dec-10	0.00	99.59	0.41	0.35	10.09	1.97	90.25	7.78	1.88	9.17
Feb-11	1.41	97.85	0.74	0.45	10.32	8.77	86.62	4.61	0.94	11.35
Apr-11	0.23	99.00	0.77	0.54	8.48	2.02	86.85	11.13	1.54	12.73
Jun-11	0.03	99.58	0.39	0.55	10.89	4.34	89.74	5.93	1.18	11.01
Aug-11	0.55	98.38	1.07	0.50	9.98	2.52	91.06	6.42	1.49	11.46
Oct-11	0.07	98.99	0.95	0.62	14.22	7.56	76.87	15.58	2.43	16.28
Dec-11	0.07	99.05	0.88	0.63	10.78	2.41	94.07	3.52	1.24	12.03
Feb-12	0.34	99.14	0.53	0.35	13.07	1.80	93.65	4.55	0.96	11.01
Apr-12	0.15	99.09	0.76	0.57	11.23	2.76	91.07	6.17	1.19	12.15
Jun-12	0.09	99.10	0.80	0.43	13.53	2.55	95.78	1.66	0.58	12.84
Aug-12	0.08	99.38	0.54	0.49	14.56	3.84	94.26	1.90	0.68	11.92
Oct-12	0.08	98.46	1.45	0.57	10.09	6.27	91.48	2.26	0.77	11.01
Dec-12	0.11	98.69	1.20	0.45	11.24	5.53	91.54	2.93	0.79	12.61
Feb-13	0.49	98.83	0.67	0.62	7.68	4.75	90.22	5.03	0.94	9.97
Apr-13	0.13	98.45	1.41	0.41	8.83	1.20	95.48	3.32	0.64	10.66
Jun-13	0.07	98.27	1.67	0.42	10.43	1.72	94.99	3.29	0.74	13.87
Aug-13	0.10	99.15	0.75	0.45	12.04	3.21	93.11	3.68	0.80	16.28
Oct-13	0.06	99.47	0.47	0.46	7.87	7.00	91.85	1.15	0.72	12.51
Dec-13	0.18	98.93	0.88	0.47	9.37	1.13	95.33	3.54	0.82	10.75
Feb-14	0.02	98.98	1.01	0.60	8.88	*	*	*	*	*
Apr-14	0.71	98.61	0.68	0.49	7.18	2.97	72.04	24.99	3.23	9.03
Jun-14	3.60	95.92	0.47	0.47	8.25	1.78	79.68	18.54	1.99	8.11
Aug-14	0.31	98.95	0.74	0.46	8.82	0.22	79.96	19.82	2.26	15.36
Oct-14	0.00	99.27	0.73	0.65	9.72	0.23	93.13	6.65	1.14	9.05
Dec-14	2.47	96.89	0.64	0.59	7.64	0.67	95.46	3.88	0.98	11.22
Feb-15	0.00	99.43	0.57	0.52	6.46	2.04	93.57	4.39	0.90	9.31
Apr-15	0.45	98.83	0.73	7.44	0.62	1.07	94.45	4.48	9.95	1.11
Jun-15	0.00	99.58	0.42	*	0.49	0.64	96.97	2.39	13.06	0.88

	Auckland Airport (AA)					Clarks Beach (CB)				
	Gravel	Sand	Silt/ Clay	OC	Chl*a*	Gravel	Sand	Silt/ Clay	OC	Chl*a*
Aug-15	0.21	99.08	0.71	9.79	0.55	1.42	96.65	1.93	11.78	0.85
Oct-15	0.01	99.54	0.46	8.83	0.46	1.88	95.00	3.12	9.85	0.78
Dec-15	0.07	99.20	0.73	8.95	0.53	2.20	93.69	4.10	8.60	1.06
Feb-16	0.05	99.02	0.93	7.15	0.52	3.66	92.91	3.42	6.99	0.97
Apr-16	0.00	99.05	0.95	6.65	0.62	1.08	86.22	12.70	8.72	1.36
Jun-16	0.00	98.95	1.05	7.22	0.63	4.54	91.11	4.35	7.67	1.17
Aug-16	0.17	99.41	0.42	6.52	0.52	1.58	94.75	3.67	6.88	0.85
Oct-16	0.00	98.51	1.49	9.17	0.70	3.26	93.34	3.40	8.36	1.28
Dec-16	0.09	99.19	0.72	9.62	0.41	7.96	87.55	4.49	10.31	0.68
Feb-17	0.05	99.08	0.87	9.15	0.61	9.02	85.69	5.29	7.67	1.23
Apr-17	0.36	98.37	1.27	10.43	0.55	2.35	89.44	8.21	6.65	1.24
Jun-17	0.16	98.85	0.99	12.60	0.73	1.53	91.39	7.08	7.79	1.60
Aug-17	0.6	98.13	1.27	13.18	0.73	1.85	94.46	3.69	6.76	1.00
Oct-17	0.01	99.14	0.85	15.13	0.83	3.63	91.53	4.84	8.13	1.78
Dec-17	0.16	98.39	1.45	13.74	0.64	5.91	87.44	6.65	8.13	1.54
Feb18	0.10	99.06	0.48	13.17	0.54	1.97	94.85	3.19	7.67	0.97

	Cape Horn (CH)					Elletts Beach (EB)				
	Gravel	Sand	Silt/ Clay	OC	Chl*a*	Gravel	Sand	Silt/ Clay	OC	Chl*a*
Apr-09	0.00	99.50	0.50	0.58	8.25					
Jun-09	0.06	98.06	1.88	0.78	9.17					
Aug-09	0.00	98.73	1.27	1.03	11.92					
Oct-09	0.30	99.13	0.57	0.76	8.37					
Dec-09	0.00	99.29	0.71	0.68	10.09					
Feb-10	0.00	99.59	0.41	0.60	7.34					
Apr-10	0.00	99.79	0.21	0.66	10.31					
Jun-10	0.00	99.43	0.57	0.67	10.77					
Aug-13	0.00	95.65	4.35	1.11	11.11	1.26	87.85	10.90	0.89	9.97
Oct-13	0.63	97.25	2.12	0.83	6.09	2.64	93.15	4.21	0.71	9.61
Dec-13	3.00	90.18	6.83	0.85	7.57	2.27	91.03	6.69	0.93	11.65
Feb-14	0.56	91.76	7.68	1.61	7.79	2.08	92.50	5.41	0.77	9.48
Apr-14	0.19	98.58	1.23	0.59	6.65	7.81	75.88	16.31	1.23	12.02
Jun-14	0.04	96.72	3.24	0.81	8.02	2.74	90.13	7.13	0.82	11.53
Aug-14	0.00	99.59	0.41	0.55	5.26	2.18	93.08	4.74	0.82	11.79
Oct-14	0.00	99.34	0.66	0.60	*	0.58	88.50	10.92	1.20	10.87
Dec-14	0.00	99.10	0.90	0.74	7.18	1.27	95.30	3.42	0.89	11.56
Feb-15	0.00	98.98	1.02	0.56	6.13	1.45	91.98	6.58	1.43	11.52
Apr-15	0.00	97.38	2.62	0.75	8.50	0.00	61.58	38.42	3.22	13.11
Jun-15	0.00	98.28	1.72	0.69	10.11	3.32	91.82	4.86	0.80	13.83
Oct-15	0.00	99.54	0.46	0.54	6.35	3.18	92.14	4.68	0.78	10.09
Oct-16	0.00	99.30	0.70	0.67	4.81	0.63	87.41	11.96	1.31	10.07
Oct-17	0.11	99.61	0.28	0.77	5.04	8.79	87.12	4.09	1.06	12.27

	Karaka Point (KP)					Puhinui Stream (PS)				
	Gravel	Sand	Silt/ Clay	OC	Chl*a*	Gravel	Sand	Silt/ Clay	OC	Chl*a*
Aug-13	1.57	94.00	4.43	0.74	8.48	0.00	99.04	0.96	0.44	11.45
Oct-13	0.70	97.80	1.50	0.61	6.90	0.40	99.11	0.49	0.51	10.89
Dec-13	2.73	94.76	2.51	0.53	7.30	0.03	98.89	1.08	0.63	10.55
Feb-14	4.49	92.46	3.05	0.84	8.08	0.14	98.59	1.27	0.57	10.35
Apr-14	1.13	95.90	2.96	0.65	8.16	0.08	98.95	0.97	0.49	8.67
Jun-14	4.03	93.25	2.72	0.77	8.65	0.03	98.64	1.33	0.55	10.96
Aug-14	3.12	95.02	1.86	0.69	6.06	0.52	98.12	1.37	0.57	11.21
Oct-14	2.15	96.27	1.58	0.66	6.40	0.03	99.15	0.81	0.55	8.45
Dec-14	1.57	96.77	1.66	0.78	7.52	0.27	98.83	0.91	0.60	10.11
Feb-15	0.95	97.36	1.70	0.60	4.53	0.56	95.67	3.77	0.70	7.88
Apr-15	4.50	93.41	2.09	0.68	6.95	0.00	94.89	5.11	0.93	8.94
Jun-15	3.63	95.04	1.33	0.59	*	0.02	98.65	1.33	0.52	*
Oct-15	2.38	93.72	3.91	0.66	6.05	0.24	98.65	1.12	0.48	8.24
Oct-16	2.64	94.15	3.21	0.85	6.30	0.00	98.55	1.45	0.70	8.13
Oct-17	0.53	97.70	1.77	1.05	7.57	0.01	99.07	0.92	0.79	11.12

7.4 The three most abundant species found in October each year at AA, CB, CH, EB, KP and PS

AA	Rank 1	Rank 2	Rank 3
1987	*Macomona liliana*	*Hiatula siliquens*	*Austrovenus stutchburyi*
1989	*Macomona liliana*	*Austrovenus stutchburyi*	*Magelona dakini*
1990	*Macomona liliana*	*Hiatula siliquens*	*Austrovenus stutchburyi*
1991	*Macomona liliana*	*Austrovenus stutchburyi*	*Linucula hartvigiana*
1992	*Macomona liliana*	*Travisia olens*	*Austrovenus stutchburyi*
1993	*Macomona liliana*	*Austrovenus stutchburyi*	*Travisia olens*
1994	*Macomona liliana*	*Austrovenus stutchburyi*	*Travisia olens*
1995	*Macomona liliana*	*Austrovenus stutchburyi*	*Hiatula siliquens*
1996	*Macomona liliana*	*Hiatula siliquens*	*Magelona dakini*
1997	*Macomona liliana*	*Hiatula siliquens*	*Austrovenus stutchburyi*
1998	*Macomona liliana*	*Hiatula siliquens*	*Austrovenus stutchburyi*
1999	*Macomona liliana*	*Orbinia papillosa*	*Hiatula siliquens*
2000	*Macomona liliana*	*Hiatula siliquens*	*Orbinia papillosa*
2001	*Macomona liliana*	*Magelona dakini*	*Taeniogyrus dendyi*
2002	*Macomona liliana*	*Magelona dakini*	*Taeniogyrus dendyi*
2003	*Macomona liliana*	*Magelona dakini*	*Linucula hartvigiana*
2004	*Macomona liliana*	*Hiatula siliquens*	*Aonides trifida*
2005	*Macomona liliana*	*Magelona dakini*	*Hiatula siliquens*
2006	*Macomona liliana*	*Hiatula siliquens*	*Colurostylis lemurum*
2007	*Hiatula siliquens*	*Macomona liliana*	*Aonides trifida*
2008	*Aonides trifida*	*Macomona liliana*	*Hiatula siliquens*

AA	Rank 1	Rank 2	Rank 3
2009	*Macomona liliana*	*Aonides trifida*	*Travisia olens novaezealandiae*
2010	*Macomona liliana*	*Aonides trifida*	*Colurostylis lemurum*
2011	*Macomona liliana*	*Aonides trifida*	*Austrovenus stutchburyi*
2012	*Macomona liliana*	*Aonides trifida*	*Magelona dakini*
2013	*Macomona liliana*	*Colurostylis lemurum*	*Aonides trifida*
2014	*Macomona liliana*	*Aonides trifida*	*Magelona dakini*
2015	*Macomona liliana*	*Aonides trifida*	*Magelona dakini*
2016	*Macomona liliana*	*Aonides trifida*	*Austrovenus stutchburyi*
2017	*Aonides trifida*	*Macomona liliana*	*Austrovenus stutchburyi*

CB	Rank 1	Rank 2	Rank3
1989	*Macroclymenella stewartensis*	*Macomona liliana*	*Torridoharpinia hurleyi*
1990	*Linucula hartvigiana*	*Boccardia syrtis*	*Macroclymenella stewartensis*
1991	*Linucula hartvigiana*	*Macomona liliana*	*Macroclymenella stewartensis*
1992	*Macroclymenella stewartensis*	*Macomona liliana*	*Torridoharpinia hurleyi*
1993	*Macroclymenella stewartensis*	*Boccardia syrtis*	*Linucula hartvigiana*
1994	*Macomona liliana*	*Macroclymenella stewartensis*	*Torridoharpinia hurleyi*
1995	*Linucula hartvigiana*	*Magelona dakini*	*Macroclymenella stewartensis*
1996	*Linucula hartvigiana*	*Boccardia syrtis*	*Torridoharpinia hurleyi*
1997	*Linucula hartvigiana*	*Boccardia syrtis*	*Macomona liliana*
1998	*Linucula hartvigiana*	*Macomona liliana*	*Torridoharpinia hurleyi*
1999	*Macroclymenella stewartensis*	*Linucula hartvigiana*	*Macomona liliana*

CB	Rank 1	Rank 2	Rank3
2000	*Linucula hartvigiana*	*Macomona liliana*	*Macroclymenella stewartensis*
2001	*Macomona liliana*	*Linucula hartvigiana*	*Macroclymenella stewartensis*
2002	*Linucula hartvigiana*	*Macomona liliana*	*Magelona dakini*
2003	*Macroclymenella stewartensis*	*Linucula hartvigiana*	*Macomona liliana*
2004	*Macroclymenella stewartensis*	*Magelona dakini*	*Macomona liliana*
2005	*Macroclymenella stewartensis*	*Linucula hartvigiana*	*Torridoharpinia hurleyi*
2006	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2007	*Macroclymenella stewartensis*	*Torridoharpinia hurleyi*	*Linucula hartvigiana*
2008	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2009	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2010	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2011	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Notoacmea scapha*
2012	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Anthopleura*
2013	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Notoacmea scapha*
2014	*Linucula hartvigiana*	*Torridoharpinia hurleyi*	*Austrovenus stutchburyi*
2015	*Linucula hartvigiana*	*Macomona liliana*	*Anthopleura*
2016	*Linucula hartvigiana*	*Anthopleura*	*Torridoharpinia hurleyi*
2017	*Linucula hartvigiana*	*Anthopleura*	*Boccardia syrtis*

CH	Rank 1	Rank 2	Rank3
1987	*Magelona dakini*	*Glycinde trifida*	*Macroclymenella stewartensis*
1989	*Boccardia syrtis*	*Magelona dakini*	*Macroclymenella stewartensis*
1990	*Boccardia syrtis*	*Macomona liliana*	*Macroclymenella stewartensis*
1991	*Boccardia syrtis*	*Macroclymenella stewartensis*	*Macomona liliana*
1992	*Macroclymenella stewartensis*	*Colurostylis lemurum*	*Torridoharpinia hurleyi*
1993	*Macroclymenella stewartensis*	*Torridoharpinia hurleyi*	*Magelona dakini*
1994	*Macroclymenella stewartensis*	*Magelona dakini*	*Glycinde trifida*
1995	*Boccardia syrtis*	*Magelona dakini*	*Glycinde trifida*
1996-1998 not sampled			
1999	*Torridoharpinia hurleyi*	*Macroclymenella stewartensis*	*Magelona dakini*
2000	*Magelona dakini*	*Boccardia syrtis*	*Colurostylis lemurum*
2001	*Magelona dakini*	*Macroclymenella stewartensis*	*Colurostylis lemurum*
2002	*Magelona dakini*	*Colurostylis lemurum*	*Hiatula siliquens*
2003	*Magelona dakini*	*Macroclymenella stewartensis*	*Colurostylis lemurum*
2004	*Magelona dakini*	*Macroclymenella stewartensis*	*Colurostylis lemurum*
2005	*Magelona dakini*	*Macroclymenella stewartensis*	*Waitangi brevirostris*

CH	Rank 1	Rank 2	Rank3
2006	*Magelona dakini*	*Macroclymenella stewartensis*	*Hiatula siliquens*
2007	*Magelona dakini*	*Macroclymenella stewartensis*	*Colurostylis lemurum*
2008	*Colurostylis lemurum*	*Magelona dakini*	*Macroclymenella stewartensis*
2009-2012 not sampled			
2013	*Macroclymenella stewartensis*	*Magelona dakini*	*Linucula hartvigiana*
2014	*Magelona dakini*	*Colurostylis lemurum*	*Macroclymenella stewartensis*
2015	*Magelona dakini*	*Colurostylis lemurum*	*Torridoharpinia hurleyi*
2016	*Magelona dakini*	*Colurostylis lemurum*	*Boccardia syrtis*
2017	*Magelona dakini*	*Boccardia syrtis*	*Colurostylis lemurum*

EB	Rank 1	Rank 2	Rank3
1987	*Magelona dakini*	*Macroclymenella*	*Torridoharpinia hurleyi*
1989	*Macroclymenella*	*Hiatula siliquens*	*Macomona liliana*
1990	*Hiatula siliquens*	*Magelona dakini*	*Linucula hartvigiana*
1991	*Hiatula siliquens*	*Macroclymenella*	*Methlimedon* sp.
1992	*Torridoharpinia hurleyi*	*Hiatula siliquens*	*Macomona liliana*
1993-1998 not sampled			
1999	*Macomona liliana*	*Austrovenus stutchburyi*	*Magelona dakini*
2000	*Macomona liliana*	*Austrovenus stutchburyi*	*Linucula hartvigiana*
2001-2005 not sampled			

EB	Rank 1	Rank 2	Rank3
2006	*Macomona liliana*	*Linucula hartvigiana*	*Magelona dakini*
2007	*Magelona dakini*	*Macomona liliana*	*Hiatula siliquens*
2008-2012 not sampled			
2013	*Magelona dakini*	*Linucula hartvigiana*	*Austrovenus stutchburyi*
2014	*Magelona dakini*	*Macomona liliana*	*Linucula hartvigiana*
2015	*Macomona liliana*	*Magelona dakini*	*Austrovenus stutchburyi*
2016	*Linucula hartvigiana*	*Magelona dakini*	*Macomona liliana*
2017	*Linucula hartvigiana*	*Magelona dakini*	*Aonides trifida*

KP	Rank 1	Rank 2	Rank3
1987	*Anthopleura aureoradiata*	*Magelona dakini*	*Macomona liliana*
1989	*Macomona liliana*	*Linucula hartvigiana*	*Magelona dakini*
1990	*Linucula hartvigiana*	*Macomona liliana*	*Magelona dakini*
1991	*Linucula hartvigiana*	*Macomona liliana*	*Magelona dakini*
1992	*Magelona dakini*	*Linucula hartvigiana*	*Macomona liliana*
1993-1998 not sampled			
1999	*Linucula hartvigiana*	*Macomona liliana*	*Torridoharpinia hurleyi*
2000	*Macomona liliana*	*Linucula hartvigiana*	*Magelona dakini*
2001-2005 not sampled			
2006	*Magelona dakini*	*Macomona liliana*	*Hiatula siliquens*
2007	*Magelona dakini*	*Hiatula siliquens*	*Macomona liliana*
2008-2012 not sampled			
2013	*Aonides trifida*	*Magelona dakini*	*Macomona liliana*

KP	Rank 1	Rank 2	Rank3
2014	*Magelona dakini*	*Aonides trifida*	*Macomona liliana*
2015	*Aonides trifida*	*Magelona dakini*	*Macomona liliana*
2016	*Aonides trifida*	*Macomona liliana*	*Magelona dakini*
2017	*Aonides trifida*	*Magelona dakini*	*Macomona liliana*

PS	Rank 1	Rank 2	Rank3
1987	*Macomona liliana*	*Hiatula siliquens*	*Exosphaeroma falcatum*
1989	*Macomona liliana*	*Linucula hartvigiana*	*Hiatula siliquens*
1990	*Linucula hartvigiana*	*Hiatula siliquens*	*Macomona liliana*
1991	*Macomona liliana*	*Linucula hartvigiana*	*Exosphaeroma falcatum*
1992	*Macomona liliana*	*Exosphaeroma falcatum*	*Boccardia syrtis*
1993-1998 not sampled			
1999	*Linucula hartvigiana*	*Macomona liliana*	*Boccardia syrtis*
2000	*Linucula hartvigiana*	*Macomona liliana*	*Boccardia syrtis*
2001-2005 not sampled			
2006	*Macomona liliana*	*Magelona dakini*	*Linucula hartvigiana*
2007	*Magelona dakini*	*Exosphaeroma falcatum*	*Orbinia papillosa*
2008-2012 not sampled			
2013	*Magelona dakini*	*Colurostylis lemurum*	*Linucula hartvigiana*
2014	*Magelona dakini*	*Macomona liliana*	*Colurostylis lemurum*
2015	*Colurostylis lemurum*	*Magelona dakini*	*Macomona liliana*
2016	*Colurostylis lemurum*	*Macomona liliana*	*Magelona dakini*
2017	*Magelona dakini*	*Macomona liliana*	*Boccardia syrtis*

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