Manukau Harbour Ecological Monitoring Programme:

Report on Data Collected up Until February 2015

July 2016 Technical Report 2016/029

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Name: Jacqueline Anthony
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Cover image: Manukau Harbour view by Adele Krantz

Manukau Harbour Ecological Monitoring Programme: Report on data collected up until February 2015

Barry L Greenfield
Judi E Hewitt
Sarah F Hailes
National Institute for Water and Atmospheric Research, NIWA

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Executive summary

This report updates the results of the Manukau Harbour Ecological Monitoring Programme, which was established in October 1987 as an initiative of the Auckland Regional Council (now Auckland Council). The programme was designed to provide: stocktaking of resources under stewardship; feedback on harbour management activities; and a baseline against which future cause-effect or impact studies could be conducted. 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* concentrations, grain size and organic matter) have been variable but generally similar at each site over the monitoring period. However, the site at Clarks Beach experienced its highest percentage mud contents recorded to-date during April to August 2013 and site Puhinui Stream experienced elevated levels in February 2015. Site Elletts Beach, has had high and variable per cent mud content during the past two years, with elevated mud content levels observed in April 2015.

Abundances of the majority of the monitored taxa at the Auckland Airport and Clarks Beach sites continue to exhibit multi-year cycles. Large recruitment events at Clarks Beach for the cockle *Austrovenus stutchburyi,* the small bivalve *Linucula hartvigiana* and the limpet *Notoacmea scapha* have not continued. While a number of consistent trends in abundance were detected at all sites, the directions of change of the individual species at each site do not suggest that the majority of these are driven by contaminant or sediment inputs.

In the past two years, the monitored taxa community composition at site Cape Horn has returned to that observed prior to the upgrade of the Mangere wastewater treatment plant in 2001. Monitored taxa community composition at Elletts Beach has shown a steady change over time.

Sites at Elletts Beach, Karaka Point, Puhinui Stream and Karaka Point often exhibit sediment and abundance patterns similar to the permanently monitored sites, Auckland Airport and Clarks Beach. Importantly, without the data from the permanently monitored sites, a number of multi-year cycles would have been erroneously identified as trends (44%, 43% and 60% at EB, KP and PS respectively), demonstrating that the long-term monitoring of these two sites is essential for the assessment of ecosystem health in the Manukau Harbour.

There is no evidence of declining ecosystem health within the extensive intertidal flats that make up around 40 per cent of the area of Manukau Harbour. The BHMs and TBI health scoring systems find sites Auckland Airport, Clarks Beach, Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream continue to be in “good” or “extremely good” health with good functionality.

However, some of the harbours inlets, monitored under the Benthic Health Monitoring Programme (now Regional Sediment Chemistry Monitoring Programme), are not so healthy. The only site monitored over the last two years in Pahurehure Inlet is in poor health, with low functionality. The two sites monitored in Mangere Inlet are unhealthy and have low functionality, similar to results from 2002 to 2005. The two less sheltered sites, Little Muddy and Blockhouse Bay, both have low functionality, but are in moderate to good health otherwise.

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, all six main harbour sites were monitored during the 2013-2014 period. From 2015 to 2020 only the two Auckland Airport and Clarks Beach sites are to be monitored.

Three further recommendations based on the data collected from April 2013 to February 2015 are:

- Site Cape Horn be sampled in conjunction with Auckland Airport and Clarks Beach for a further two years (at least) to monitor the change detected in community composition. The proximity of site Cape Horn to the Mangere wastewater treatment plant and its community composition change back to that observed prior to the plant upgrade in 2001 is of concern.
- Further monitoring to be conducted at site PS. In particular for sediment mud content due to the elevated mud per cent content found in February and April 2015 and the changes in the community health indices observed at this site.
- The changes observed in monitored taxa community composition at Elletts Beach together with the elevated mud content levels observed in April 2015 (re-check in progress) and the patches of *Gracilaria* observed at this site suggest the need for some future monitoring at this site.

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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). Intertidal sandflats were considered most appropriate for monitoring given their spatial extent (40% of the area of Manukau Harbour), potential importance to the harbour system, and the practicalities of cost-effective monitoring. Six sites were located around the harbour, generally located near water quality monitoring sites (Smith and Nagels 1988) and just off-shore from major inlets and rivers (Figure 2-1), in order to determine whether specific inlets were having an adverse effect on the main body of the harbour.

- Clarks Beach (CB) – on Poutawa Bank out from the confluence of the Rangiriri Creek, Waiuku River and Taihiki River, now associated with the Waiuku Channel water quality monitoring site.
- Elletts Beach (EB) – On the sandflats out from Clarks Creek.
- Karaka Point (KP) – on Hikihiki Bank out from Pahurehure Inlet, now associated with the Weymouth water quality monitoring site.
- Puhinui Stream (PS) – on the sandflats out from Puhunui Creek, now associated with the Weymouth and Papakura Channel water quality monitoring sites.
- Auckland Airport (AA) – on the sandflats out from Auckland airport and the confluence of Otaimako and Pukaki Creeks, now associated with the Papakura Channel water quality monitoring site.
- Cape Horn (CH) – on the Te Tau Bank opposite French Bay, downstream of Onehunga Port and the former Mangere Oxidation pond site, now associated with the Shag Point, Puketutu Island, Mangere Bridge and Channel water quality monitoring sites.

This was the first harbour-wide ecological monitoring programme conducted in New Zealand. However, while it provides a harbour-wide perspective on change, it also provides information on changes in sub-areas of the harbour. Changes in one or more areas of the harbour that are not reflected in other areas give information on the potential source and extent of problems (or management successes).

When monitoring began it was envisaged that six sites would be monitored bimonthly for five years, and then the cost-effectiveness of this monitoring would be assessed. A frequency of bimonthly monitoring was used in order to increase the ability of the programme 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 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. Until this recent 2013-2015 cycle, the last full sampling was conducted in 2006-2008 (Hailes and Hewitt 2009).

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 mainly based on the abundance of 22 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 all 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 1999-2000 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 and occurs in alternate years.

This report presents the results of data collected from the intertidal sandflat monitoring from October 1987 until February 2015. It includes other intertidal monitoring conducted as part of the Benthic Health Monitoring (including the Regional Sediment Chemistry Monitoring Programme (RSCMP)) from Anns Creek, Blockhouse Bay, Little Muddy, Mangere Inlet and Pahurehure Inlet (at Papakura) all sampled in October 2013.

2.0 Methods

2.1 Sample collection and identification

Sites Auckland Airport (AA) and Clarks Beach (CB) (Figure 2-1, Table 2-1) have been sampled bimonthly between October 1987 and February 2015. Two sampling occasions were missed (October and December 1988) due to a gap in funding, and another 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 for the AC from October 1987 to February 1993, and again from August 1999 to April 2001. Sampling 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). Sampling at sites EB, KP and PS commenced again in August 2006 on the recommendation of Funnell and Hewitt (2005) for two years until June 2008. Monitoring of site CH ceased in June 2010, whilst monitoring at sites AA and CB remains ongoing. Between August 2013 and June 2015, all six sites were sampled.

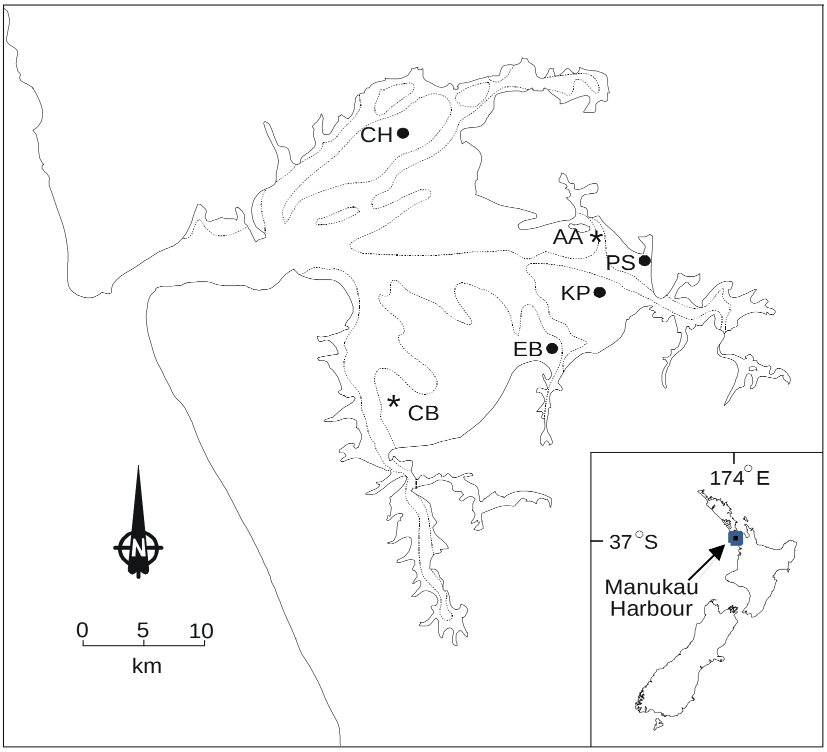


Figure 2-1 Map of Manukau Harbour showing the positions of sites

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.

Table 2-1 Monitoring years of sites AA, CB, CH, EB, KP and PS since the commencement of the Manukau Harbour Ecological Monitoring Programme in October 1987.

Y indicates sampling occurred, - indicates no sampling,***** indicates that no sampling was conducted for AA and CB in October and December 1988 due to funding constraints. ~ indicates additional sampling conducted at CH as part of a NIWA independent study. ^ indicates a missed sampling in February 2014 by AC due to weather conditions.

	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

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 22 monitored taxa are identified (Appendix 7.1).

Sampling in Anns Creek, Blockhouse Bay, Little Muddy, Mangere Inlet and Pahurehure Inlet (Papakura) occurred in October 2013, 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.

2.2 Bivalve size class analysis

After identification, bivalve species *Austrovenus stutchburyi* and *Macomona liliana* are measured (longest shell dimension; mm). 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 AC, 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 particular, 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 (62.5–500 µm), silt (3.9–62.5 µm) and clay (<3.9 µm). Mud content is calculated as the sum of the silt and clay content.

Organic content: Since August 2000, the organic and chlorophyll *a* content of the sediments at each site have been assessed on each sampling occasion (as recommended by Hewitt 2000). 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: For Benthic Health Model. 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 9.3) 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 2013-2015 time series was assessed relative to previous variation and to the time series at the permanently monitored sites.

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 4th-root transformed data was performed, using non-metric multidimensional scaling (MDS) 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, 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 using both monitored and non-monitored taxa, from AA, CB, CH, EB, KP and PS in October 2013 and 2014 and Anns Creek, Blockhouse Bay, Little Muddy, Mangere Cemetery and Pahurehure Inlet (at Papakura) in October 2013,

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 values close to 0 indicating low levels of functional redundancy and highly degraded sites. Values closest to 1 indicate high levels of functional redundancy, which is indicative of healthy areas (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).

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.

2.5.3 Combined Indices

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

1. If the BHMmud score is ≤ -0.12, the site is allocated to Mud group 1 (Table 2-2), and 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 BHMmetals score is ≥0.10, the site is allocated to group 4 or 5, and 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 BHMmetals, BHMmud 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.

Table 2-2 Conversion of BHMmetals and BHMmud scores into health groups (1 is least healthy). Cut off point is equal or less than. These groups are then converted (along with TBI scores) into values of similar scale (0-1) that run in the same direction (higher values indicating more degraded conditions), to facilitate their combination into overall health scores.

Group	BHMmetals		BHMmud		TBI	
	Cut-off	value	Cut-off	value	Cut-off	value
1	-0.164	0.2	-0.12	0.2	0.4	0.33
2	-0.0667	0.4	-0.05	0.4	0.3	0.67
3	0.0234	0.6	0.02	0.6		1.0
4	0.10	0.8	0.10	0.8		
5		1.0		1.0		

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 at sites CH, EB, KP and PS from April 2013 to February 2015 consistent with the time signals previously observed from these sites? If not, is the time signal similar to that seen at one of the two permanently monitored sites (i.e., AA or CB)?

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. Finally, appearance and sediment features of the site and its surrounding area 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)

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, 3-6 cm period), dense *Macomona liliana* feeding tracks (Figure 3-1a) and an abundance of ray pits (Figure 3-1b), with a range from newly excavated to various stages of recovery from ray pit disturbance. In June and August 2005, small sparse patches of seagrass were observed at the site. From April 2010 to February 2015 gastropods (i.e., *Zeacumantus lutulentus* and *Cominella glandiformis*) have been common, with the exception of June 2013 where very few were found. Worm tubes were observed in April and June 2010 and not since. *Gracilaria* sp. was observed in June and October 2009 and December 2010; however it has not been seen since. In June 2013 worm deposits were observed on the sediment surface within the site and have been common since. Patches of micro algae mat were observed at the site in June 2014.

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. A diatom mat was present towards the shore near to the mangroves in April 2012. *Gracilaria* sp. (that has taken root) occurs very sparsely throughout the surrounding area.

a) b)

Figure 3-1 Photographs of site Auckland Airport (AA) February 2015

a) sediment surface and b) monitored area.

3.1.2 Clarks Beach (CB)

The appearance of this site is temporally variable. The site topography has changed between being dominated by ripples (1 cm wave height, 1 cm period) and a mosaic of ripples, flat sediment, hillocks and seagrass (*Zostera muelleri*) (Figure 3-2a-f). Whole shells on the surface, shell hash (dense coverage, primarily *Austrovenus* and *Macomona*), worm tubes and gastropods are usually common or abundant throughout much of the year. Furthermore, a surficial mud layer and the presence of *Gracilaria* sp. in small patches on the surface are also common throughout most of the year. In April 2012 a red filamentous algae (no further information given by AC) was present within the site. *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 varied between 2-30 m^{-2}. From February 2011, *Zostera* has been encroaching into the site in the 0,0 corner (Figure 3-2d-f). In October 2014, a surface mud layer covered the site, smothering the existing *Zostera* patches (Figure 3-2e) however, by December 2014 the mud layer was no longer present. The deposition of mud appears to have slowed down the encroachment of the *Zostera* and there has been minimal increase in extent from April 2014 to February 2015 (Figure 3-2d-f). In the winter months, it is common to observe a diatom mat covering the sediment surface and in June 2009 and August 2010, a green algae *Lyngbya* sp. was observed in small clumps across the monitored site and surrounding area. 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 outside of Zostera patch, b) sediment surface within Zostera patch c) encroachment of Zostera at 0,0 corner in April 2014, d) Zostera coverage at February 2015.

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 2-4 cm) are still a common feature at this site, along with numerous polychaete tubes (*Macroclymenella stewartensis* and Polydorids) (Figure 3-3a) and 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 3-3d). In December 2013 a large mound of the invasive species *Arcuatula senhousia* was observed (Figure 3-3e-f) but as of February 2015, and consistent with its life-cycle (see Crooks 1996), this has since cleared from the site although it remains in the surrounding area to the east off-site. In addition, dense patches of *Gracilaria* sp. have been observed, and have been found to be distinct (through molecular sequencing techniques) but morphologically very similar to the widespread native *Gracilaria chilensis* (Wilcox et al. 2001, 2007).

a) b)

c) d)

Figure 3-3 Photographs of site Cape Horn

a) the sediment surface with *Macroclymenella* tubes, b) sediment surface with diatom mat August 2013, c-d) extent and close-up of *Arcuatula* mats in December 2013.

3.1.4 Elletts Beach (EB)

This site is predominantly sandy (Figure 3-4a-b) with ripples (~1 cm wave height, 1 - 5 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, and occasionally *Ulva lactuca* is found amongst these patches (Figure 3-4c-d). In April 2014 a mud layer was present on the surface of the site (Figure 3-4d) and this remained through to June 2014 (Figure 3-4e). By December 2014 the sediment surface had returned to its pre April 2014 state (Figure 3-4a-b).

a)

b)

c)

d)

Figure 3-4 Photographs of site Elletts Beach

a) the monitored area February 2015, b) the sediment surface February 2015, c) patches of Gracilaria sp and Ulva lactuca debris, d) surface mud layer first noticed in April 2014 still present in June 2014 with bird tracks.

3.1.5 Karaka Point (KP)

Site KP remains a mosaic of sand ripples (1 -2 cm wave height, 1 - 5 cm period) and surficial mud (Figure 3-5a), consistent with previous descriptions (Funnell et al. 2001; Hewitt & Hailes 2007; Hailes & Hewitt 2009). Shell hash, whole shells and gastropods (e.g. *Zeacumantus lutulentus*) have been observed on most sampling occasions since June 2007. Similar to other sites, ray pits are common during the summer months of December and February. The inside and outside of the site were similar in appearance until April 2008 when outside became muddier and a diatom mat was observed. *Ulva lactuca* was recorded by Hewitt and Hailes (2007) to be abundant outside the site in December 2006 but this has not been observed there since. In December 2013 a thin layer of fine sediment was present in the depressions of the sand flat (Figure 3-5c-d). This sediment deposit has slowly disappeared over time but was present through to October 2014. Since August 2013 *Gracilaria* sp. patches have been common across the site in varying abundances (Figure 3-5a-d). Additionally, in April 2014 *Ulva* debris were observed (red circles) amongst the *Gracilaria* sp. patches (Figure 3-5d).

a)

b)

c)

d)

Figure 3-5 Photographs of site Karaka Point

a) the monitored area February 2015, b) the sediment surface February 2015, c) fine sediment deposited in depressions December 2013, d) patches of *Gracilara* sp. and *Ulva* (within red circles) April 2014.

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. Similar to the other monitored sites, abundant ray pits are observed during the summer months and a diatom mat is consistently recorded during the winter months (Figure 3-6a). 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 (Figure 3-6b-c). *Gracilara* sp. is becoming more common on the sandflat and in December 2014 it covered the majority of the surrounding sand flat (Figure 3-6d), although rarely observed within the site itself.

a)

b)

c)

d)

Figure 3-6 Photographs of site Puhinui Stream

a) the monitored area October 2014, b) the sediment surface at December 2013, c) sediment surface increased mud layer February 2015, d) *Gracilara* sp. on surrounding sandflat, December 2014.

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 7.2.

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 per cent mud typically observed during the winter months. Site AA continues to have the lowest per cent mud content of all the sites, followed by PS, with an average per cent mud content over the last two years of 0.82% and 1.30% respectively. However, elevated mud content was observed at site PS in February 2015 (3.77%) (see also Figure 3-6a-d).

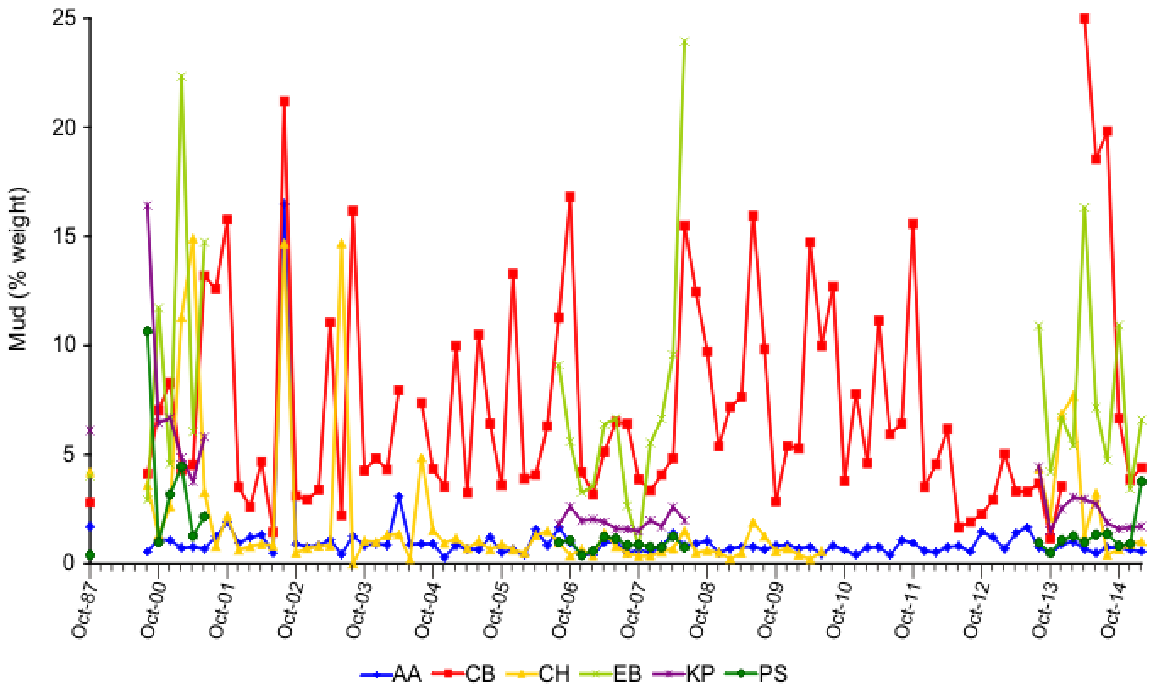


Figure 3-7 Sediment mud (silt and clay) content (% weight) at the monitored sites from October 1987 until February 2015.

Figure 3-8 Changes in the 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 2015 (only October months shown).

Chlorophyll *a*

The chlorophyll *a* values at the permanently monitored sites (AA and CB) have remained consistent to each other within the past time series, showing an irregular multi-year cycle of 2-3 years. The intermittently monitored sites (CH, EB, KP and PS) compare well with the two permanently monitored sites suggesting they follow the same 2-3 year multi-year cycle. Chlorophyll *a* concentrations at AA and CB varied between 6.46-12.04 and 8.11-16.28 µg/g sediment respectively over the last two years. Ranking the sites based on average chlorophyll *a* concentrations over the past two years gives the same ranking order as the full time-series with highest-to-lowest average µg/g sediment being CB, EB, PS, AA, CH and KP. With the exception of CB, all sites showed more variability in chlorophyll *a* concentrations during 2000 to 2002; for site CB, variability has decreased since 2008.

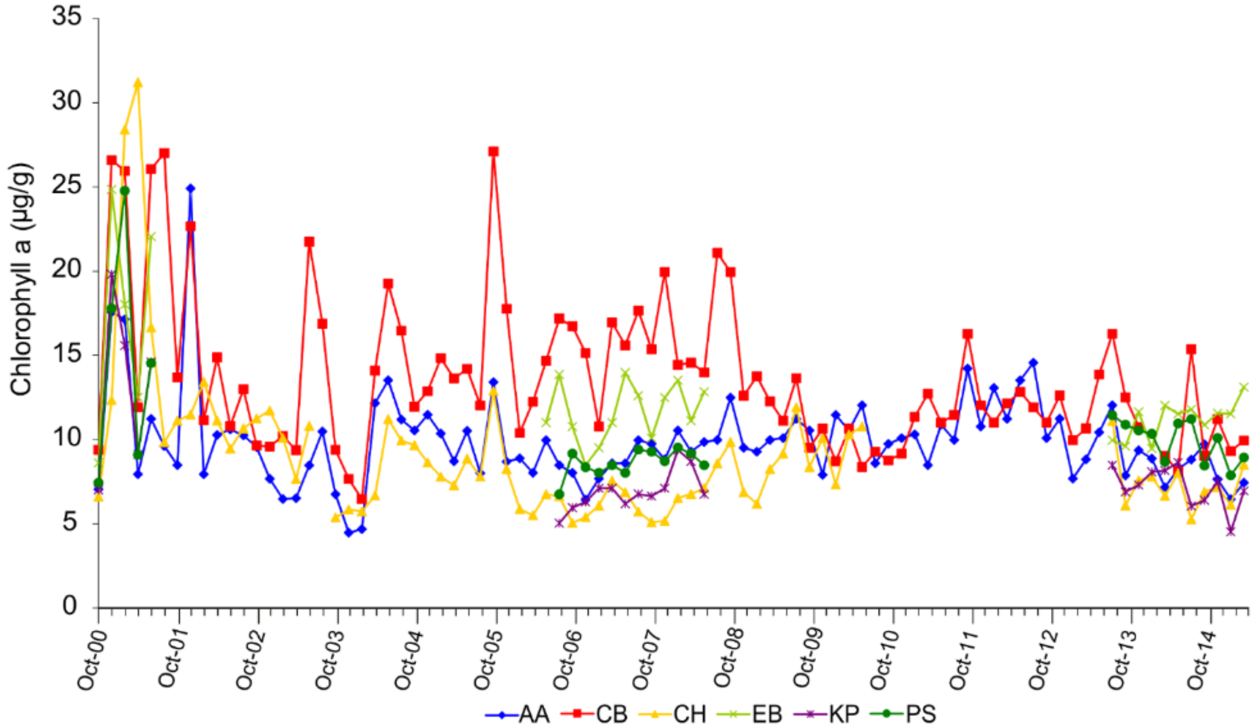


Figure 3-9 Chlorophyll *a* levels (µg/g sediment) of sediment collected from monitoring sites from October 2000 until February 2015.

Organic content

Sediment organic content at all sites has been low and variable throughout the monitored period (October 2000 to February 2015) (Figure 3-10). 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 0.51 and 1.26% respectively. For the intermittent sites, annual averages occur between the lower and upper limits set by sites AA and CB; with PS, KP, CH and EB having average organic content over the last two years of 0.56, 0.69, 0.82 and 0.97% respectively. No sampling was conducted at CB in February 2013 due to weather restrictions (high rainfall) preventing sampling.

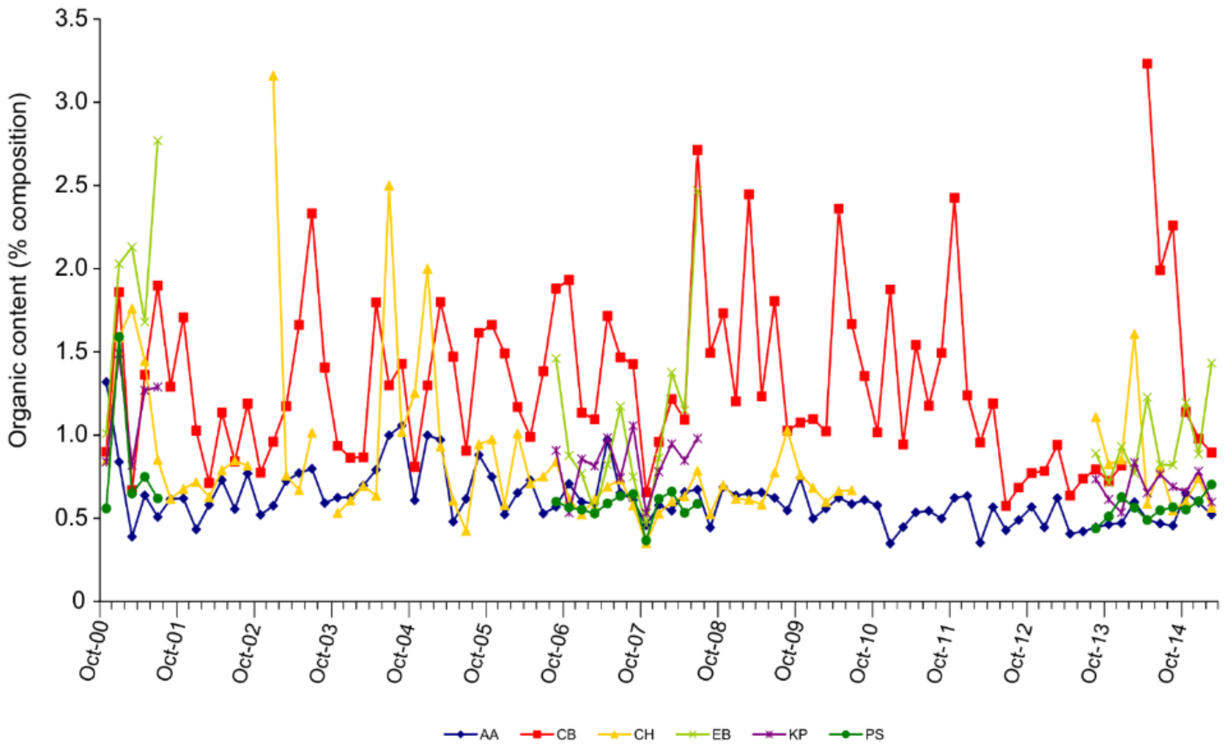


Figure 3-10 Percentage organic content of sediment collected from monitoring sites from October 2000 until February 2015.

3.3 Are there any trends in abundance of monitored taxa?

Of the monitored species, 16 out of 22 showed trends in abundance, with between three and nine trends detected at each site (Table 3-1). Six species showed trends across three of the six sites: *Aonides* and *Linucula* at sites AA, EB, KP; *Colurostylis* and *Methalimedon* at sites CH, KP and P; *Taeniogyrus* at sites AA, KP and PS, and *Magelona* at sites EB, KP and PS. Site EB showed the greatest number of significant trends (nine), followed by KP (seven), AA (five), PS (five) and sites CB and CH had the least (three and two respectively). Both positive and negative trends were found and the direction of the trends were often consistent for individual species across sites. For example, *Glycinde* showed a step decrease in abundance at sites AA (February 2010) and CH (April 2002, post the oxidation pond removal) and *Colurostylis* showed a step increase in abundance at site CH (April 2004), and KP and PS (in the non-monitored interval of 2001 to 2006) (see Table 3-1). *Hiatula* exhibited significant decreases in abundance across sites CB and EB. Magelona exhibited significant increases at EB, KP and PS.

Table 3-1 Monitored species for which statistically significant trends in abundance were detected at the six monitored sites.

Site	Taxa	Trend direction and type	Size[1] of change	p-value
AA	*Aonides* *Glycinde* **Linucula* *Orbinia* **Taeniogyrus*	increase step decrease (2010) decrease increase increase	98.9 -2.0 -41.4 44.3 38.9	<0.0001 0.0027 0.0238 0.0102 <0.0001
CB	*Anthopleura* **Owenia* **Hiatula*	step increase (2004/5) step increase (2004) log10 decrease	90.7 11.7 -29.0	<0.0001 <0.0001 0.0002
CH[2]	*Colurostylis* **Methalimedon*	step increase (2005) increase	65.5 12.0	<0.0001 0.0006
EB	*Anthopleura* *Aonides* *Linucula* **Notoacmea* **Owenia* *Hiatula* **Macomona* *Boccardia* *Magelona*	step increase (>1993 and > 2008) log10 increase step increase (1994) step increase (2009) step increase (2009) step decrease (>1993 and > 2008) increase increase increase	36.9 87.9 145.6 20.0 12.7 -191.5 237.6 7.6 270.6	<0.0001 <0.0001 <0.0001 0.0012 0.0002 0.0037 <0.0001 <0.0001 <0.0001
KP	*Aonides* *Austrovenus* *Colurostylis* **Methalimedon* *Magelona* **Linucula* **Taeniogyrus*	Increase increase step increase (2009) increase step increase (2009) decrease step increase (1993)	305.3 36.3 18.6 16.1 16.5 -105.9 11.0	0.0064 <0.0001 0.0013 <0.0001 <0.0001 0.0010 <0.0001
PS	*Colurostylis* **Methalimedon* **Macroclymenella* **Taeniogyrus* *Magelona*	step increase (2009) increase increase increase increase	55.8 23.8 21.4 22.0 204.6	<0.0001 0.0189 0.0113 0.0010 <0.0001

* is a trend that residuals suggest may be revealed as a multi-year cycle with more data.

[1] The size of change for increasing and decreasing trends are the difference in 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).

[2] Only trends that are not related to the oxidation pond removal are included here

For some species at the intermittent sites (EB, KP and PS), statistically significant trends were detected (p = <0.05) that when compared with time series at the continually monitored sites (AA and CB) appeared most likely to be parts of multi-year cycles. Of the nine trends detected at EB, the time signals of abundance data from either AA or CB suggested that four were most likely to be trends, while four more are likely to be multi-year cycles. At KP, seven trends were detected, with two likely to be trends and four likely to be multi-year cycles. At PS, five trends were detected with one most likely to be a trend and three more likely to be multi-year cycles. Thus the majority of changes at each of the intermittently monitored sites were able to be clarified by using the abundance data at either AA or CB (88%, 86% and 80% at sites EB, KP and PS respectively). Importantly, without the data from either AA or CB a number of multi-year cycles would have been erroneously identified as trends (44%, 43% and 60% at EB, KP and PS respectively). For the rest of the report, only trends that do not appear likely to be multi-year cycles will be commented on further.

Table 3-2 Monitored species showing trends at the three intermittently monitored sites
and the extent to which they were confirmed by examination of the time signal at the two continually monitored sites to which they were compared for trend analysis.

Site	Trend	Context
EB	*Anthopleura*	Step increase also observed at CB
	Aonides	Increase also observed at AA
	Linucula	Not confirmed but clear evidence
	Notoacmea	Not confirmed, likely to be multi-year cycle similar to CB
	Owenia	Increase also observed at CB where it is possibly a multi-year cycle
	Hiatula	Decrease also observed at CB
	Macomona	Not confirmed, may be multi-year cycle as at AA and CB
	Boccardia	Not confirmed, may be multi-year cycle as at CB
	Magelona	Not confirmed, likely to be multi-year cycle as at AA
KP	*Aonides*	Increase also observed at AA
	Colurostylis	Not confirmed
	Methalimedon	Not confirmed, likely to be multi-year cycle similar to CB
	Linucula	Not confirmed, likely to be multi-year cycle similar to CB
	Taeniogyrus	Increase also observed at AA, possibly a multi-year cycle
	Austrovenus	Not confirmed, likely to be multi-year cycle as at CB
	Magelona	Not confirmed, likely to be multi-year cycle as at AA
PS	*Colurostylis*	Not confirmed
	Methalimedon	Not confirmed, likely to be multi-year cycle similar to CB
	Macroclymenella	Not confirmed, likely to be multi-year cycle similar to CB
	Taeniogyrus	Increase also observed at AA, possibly a multi-year cycle
	Magelona	Not confirmed, likely to be multi-year cycle as at AA

Over the first 10 years of the monitoring programme a decreasing trend in the abundance of *Aonides trifida* at AA was observed (Figure 3-11). From 1999 to 2004, abundance increased slightly back to its original level. Then in 2004-05, 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 (p = <0.0001). This increasing trend is also evident at two of the intermittent sites, EB and KP (p = <0.0001 and 0.0064 respectively) (Figure 3-11).

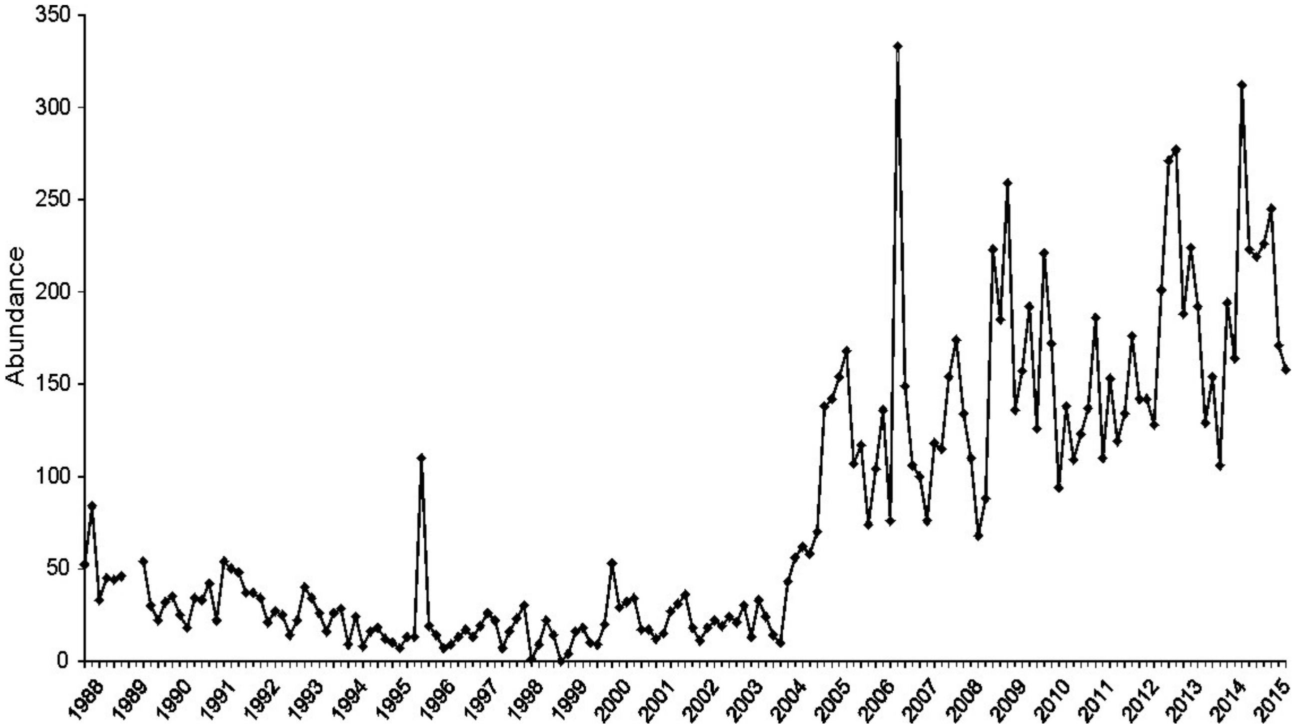


Figure 3-11 Abundance (sum total of 12 replicate cores) of *Aonides trifida* at Auckland Airport, Elletts Beach and Karaka Point from October 1987 until February 2015.

At site CB, an increasing trend of the abundance of *Anthopleura* post 2004-5 was reported by Hailes and Hewitt (2011) and later, when base abundances remained at this new level, identified as a step trend in abundance ($p = 0.001$) by Greenfield et al. (2013). With an additional two years of data, the step trend remains significant ($p = <0.0001$) despite the reduction in abundances observed in the past two years (Figure 3-12).

Prior to 2007, baseline abundances of *Owenia petersenae* at CB varied between 0–15. Since then, they have been steadily increasing ($p = 0.0037$) (Figure 3-13).

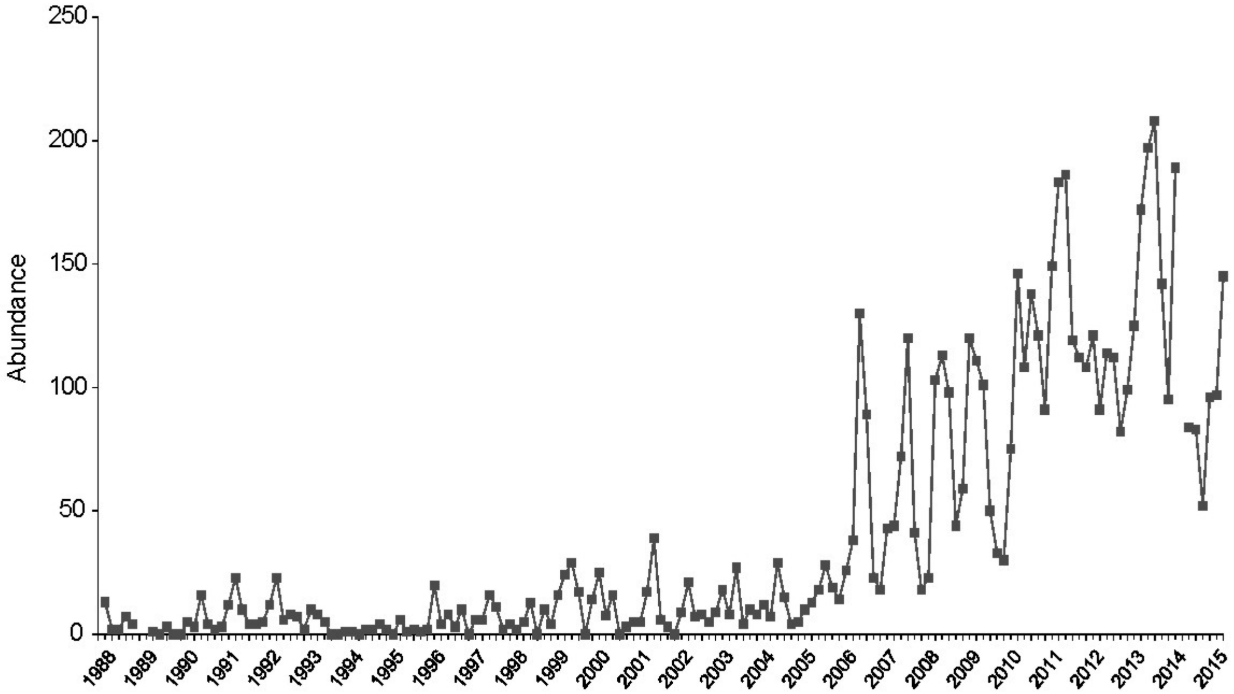


Figure 3-12 Abundance (sum total of 12 replicate cores) of *Anthopleura aureoradiata* at Clarks Beach from October 1987 until February 2015.

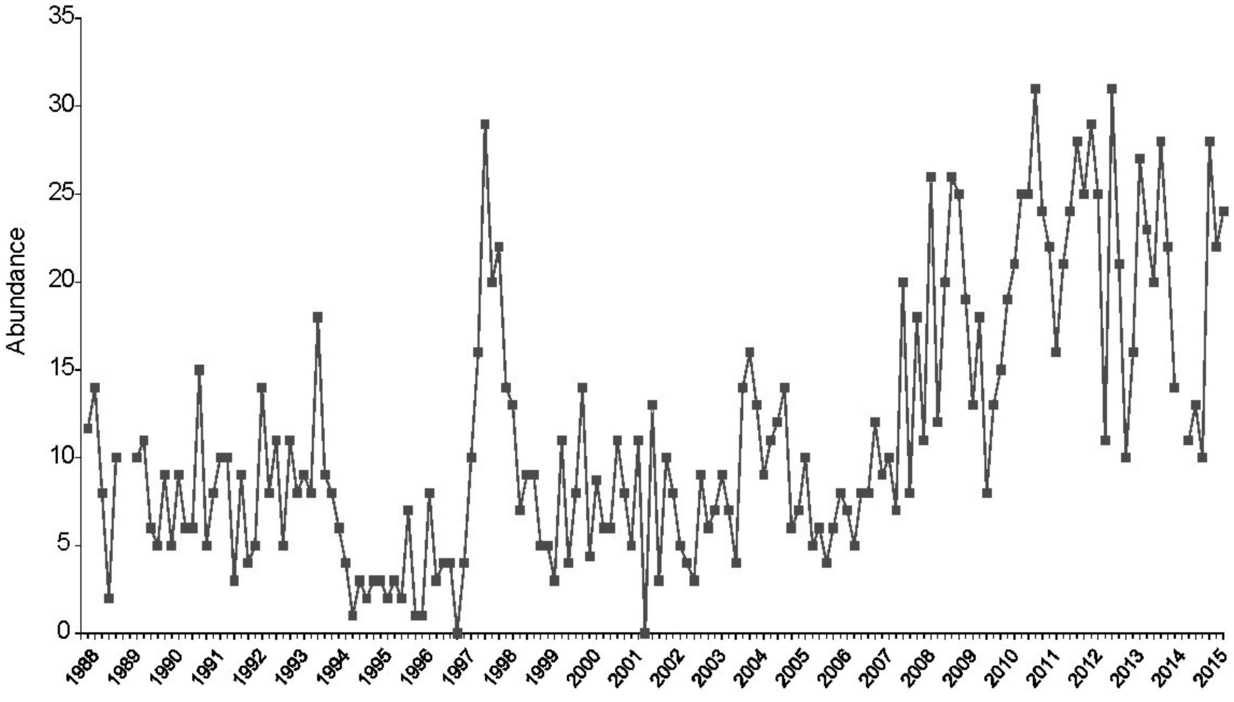


Figure 3-13 Abundance (sum total of 12 replicate cores) of *Owenia petersenae* at Clarks Beach from October 1987 until February 2015.

3.4 Are cyclic patterns in monitored taxa abundances being maintained?

Throughout the monitored period, a number of the monitored taxa have exhibited patterns in recruitment, varying in terms of timing and magnitude, creating multi-year cycles in abundance. For example, the abundance of *Magelona dakini* at all sites has a multi-year cycle (6-10 years) detectable over the entire monitoring period (Table 3-3 and

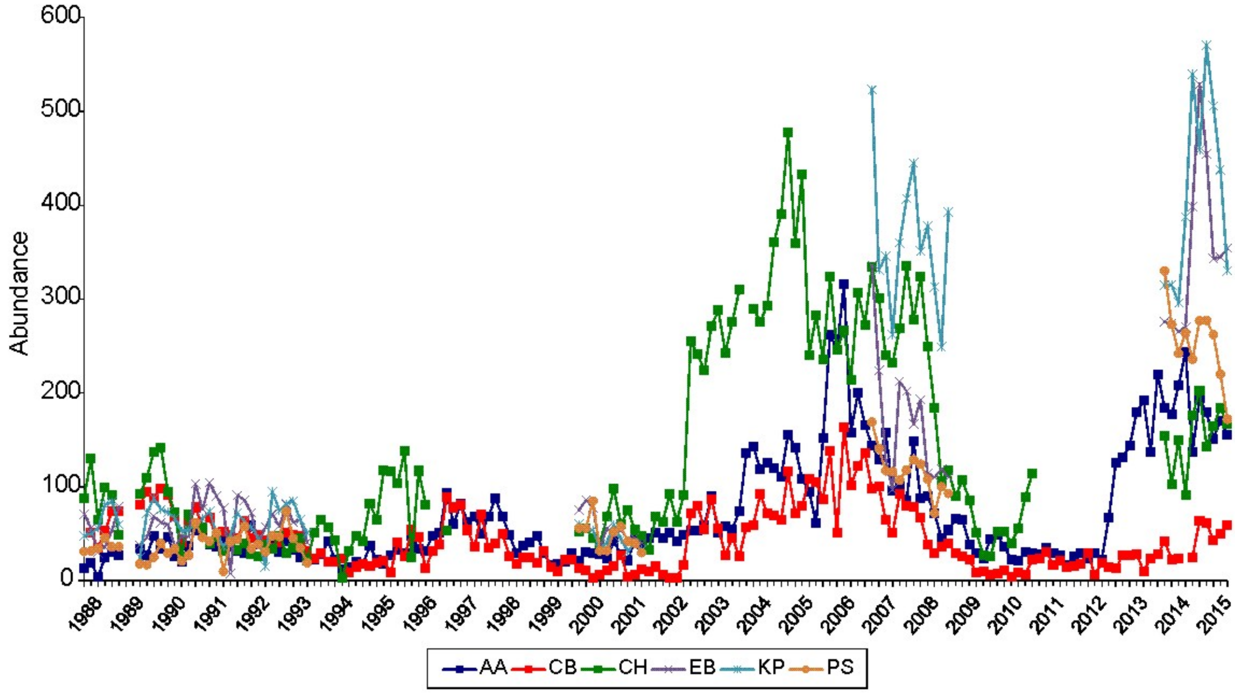


Figure 3-14). The majority of species which have historically shown multi-year cycles continue to do so;

however some species have had changes in recruitment patterns which suggest altered or new cycles (discussed herein). For a complete list of monitored taxa and displaying seasonal patterns and/or multi-year cycles see Table 3-3.

Table 3-3 Monitored species and whether they are exhibiting multi-year cycles of abundance.

- indicates that no cyclic patterns were apparent. Periods of multi-year cycles are not given for the intermittently monitored sites as the data is not sufficient to clarify this.

2013/14	AA	CB	CH	EB	KP	PS
Anthopleura aureoradiata	-	-	Multi-year cycle	-	Multi-year cycle	-
Prionospio aucklandica	-	Multi-year cycle: 4-6 years.	-	-	Similar to CB.	Multi-year cycle
Aglaophamus macroura	Multi-year cycles: 2-4years within much longer cycle.	-	Multi-year cycle	-	-	-
Aonides trifida	Multi-year cycle: 3-4 years of irregular magnitude.	-	-	Similar to AA	Similar to AA	Similar to AA.
Boccardia syrtis	-	Multi-year cycle: 5-7 years.	Similar to CB. Except post oxidation pond removal	-	Similar to CB.	Similar to CB.
Colurostylis lemurum	Multi-year cycle: 2-3 years of irregular magnitude.	Multi-year cycle: 2-4 years.	Multi-year cycle	Similar to CB.	-	-
Austrovenus stutchburyi	Multi-year cycle: 7-9 years	Multi-year cycle: 12-16 years.	Showing signs of similarity to CB	-	Showing signs of similarity to CB	Similar to AA.
Exosphaeroma spp.	Multi-year cycle: 2-3 years of irregular magnitude within a longer cycle.	Multi-year cycle: 2-4 years of irregular magnitude within a longer cycle.	-	Similar to CB.	Similar to CB.	Multi-year cycle
Glycinde trifida	-	Multi-year cycle: 3-6 years.	Multi-year cycle	Similar to CB.	Similar to CB.	Similar to CB.
Magelona dakini	Multi-year cycle: 6-10 years.	Multi-year cycle: 6-9 years.	Similar to AA.	Similar to AA.	Similar to AA.	Similar to AA.
Methalimedon sp.	-	Multi-year cycle: 2-5 years.	Multi-year cycle	-	-	Multi-year cycle: similar to CH
Macroclymenella stewartensis	-	Multi-year cycle: 3-5 years of irregular magnitude	Multi-year cycle	-	Multi-year cycle	-
Linucula hartvigiana	Multi-year cycle: 3 and 6-7 years.	Multi-year cycle: 3-6 years.	Multi-year cycle	-	Similar to AA.	-

2013/14	AA	CB	CH	EB	KP	PS
Notoacmea scapha	Multi-year cycle: 2-3 years.	Multi-year cycle: 5-6 years.	-	-	Multi-year cycle	-
Owenia petersenae	-	Multi-year cycle: 8-10 years.	-	Similar to CB	Multi-year cycle	Similar to CB.
Orbinia papillosa	Multi-year cycle: 2-4 years.	-	-	Similar to AA	Multi-year cycle	Multi-year cycle
Torridoharpinia hurleyi	Multi-year cycle: 6-8 years.	Multi-year cycle: 6-8 years.	-	Similar to AA, CB	Multi-year cycle	Multi-year cycle
Hiatula siliquens	Multi-year cycle: 7-9 years.	Multi-year cycle: 7-9 years. Usually low in abundances since 1994.	Multi-year cycle	Similar to CB.	Similar to AA.	Similar to AA.
Taeniogyrus dendyi	Multi-year cycle: 5-7 years.	Multi-year cycle: 5-6 years.	-	Similar to CB.		
Macomona liliana	Multi-year cycle: 4-7 years.	Multi-year cycle: 4-7 years.	-	-	-	Multi-year cycle
Travisia olens novaezealandiae	Multi-year cycle: 2-3 and 5-7 years.	-	-	-	-	-
Waitangi brevirostris	Multi-year cycle: 2-5 years of irregular magnitude.	-	-	-	-	Multi-year cycle

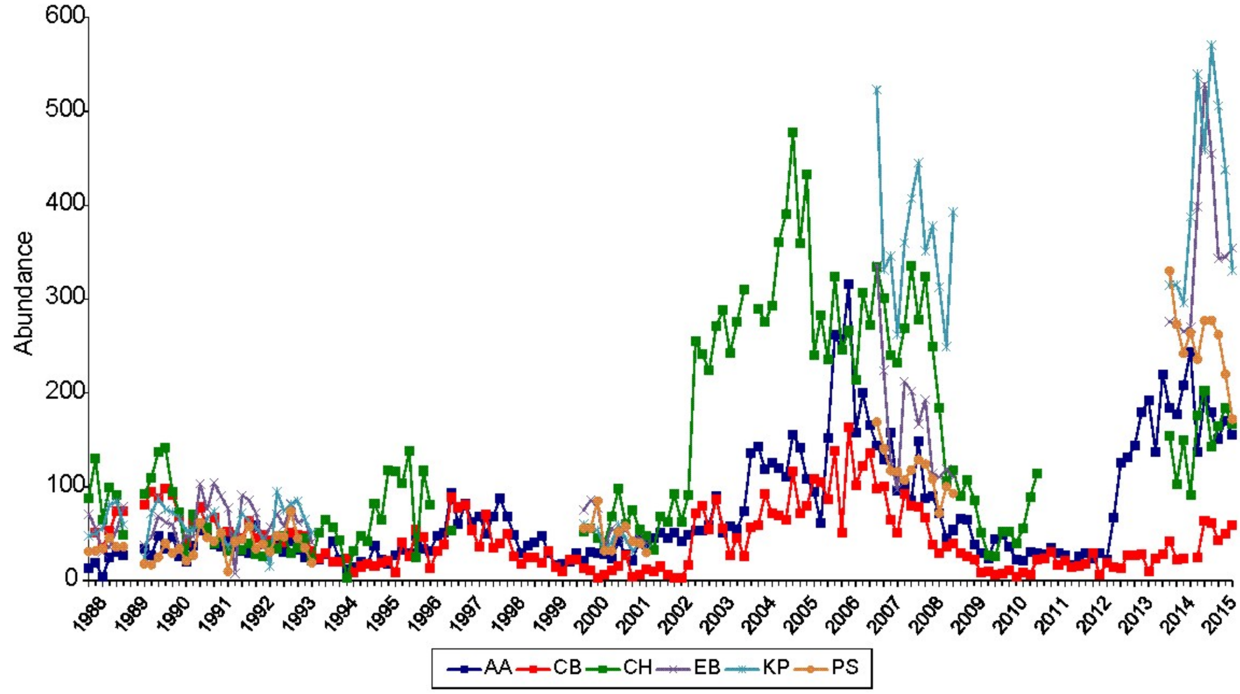
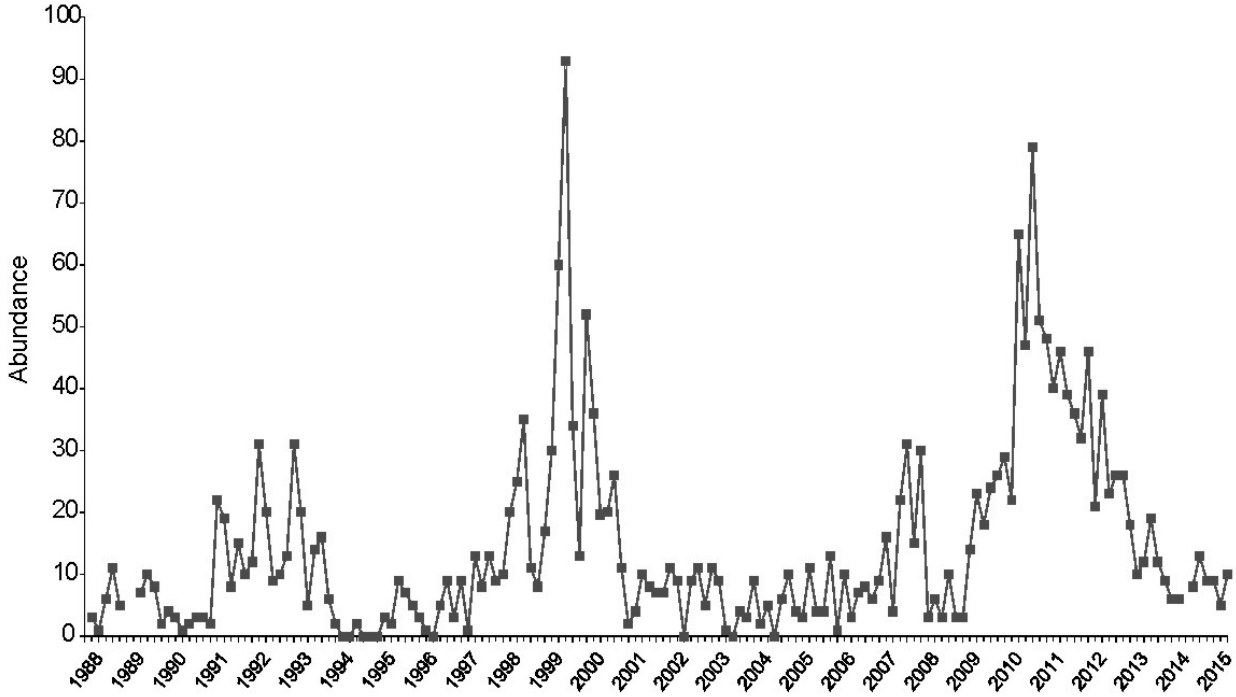


Figure 3-14 Abundance (sum total of 12 replicate cores) of *Magelona dakini*

at Auckland Airport, Clarks Beach, Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream sites from October 1987 until February 2015.

Hiatula siliquens continues to display a multi-year cycle of 7-9 years at most sites (Figure 3-15), probably related to the El Niño Southern Oscillation cycle (Hailes & Hewitt 2009). At site AA, 14 of the monitored taxa are displaying apparent multi-year cycles, including *Colurostylis lemurum* and *Orbinia papillosa* (Table 3-3). At site CB, 16 of the monitored species are displaying multi-year cycles (Table 3-3), e.g. *Prionospio aucklandica* has a 4-6 year cycle



(Figure 3-16). At site CH, seven of the monitored species are displaying multi-year cycles, e.g. *Anthopleura aureoradiata* has a 6-7 year cycle.

Similarities between the time signals observed at the intermittently monitored sites with those of sites AA and CB suggest that a number of the monitored species are displaying multi-year cycles at the intermittent sites. Site EB, KP and PS each have between nine and ten species exhibiting these cycles e.g. *Glycinde trifida* at sites EB, KP and PS demonstrates aspects similar to the multi-year cycle found at site CB (Figure 3-17). Additionally, abundances of *Magelona dakini* at sites EB, KP and PS show similar temporal patterns to site AA (

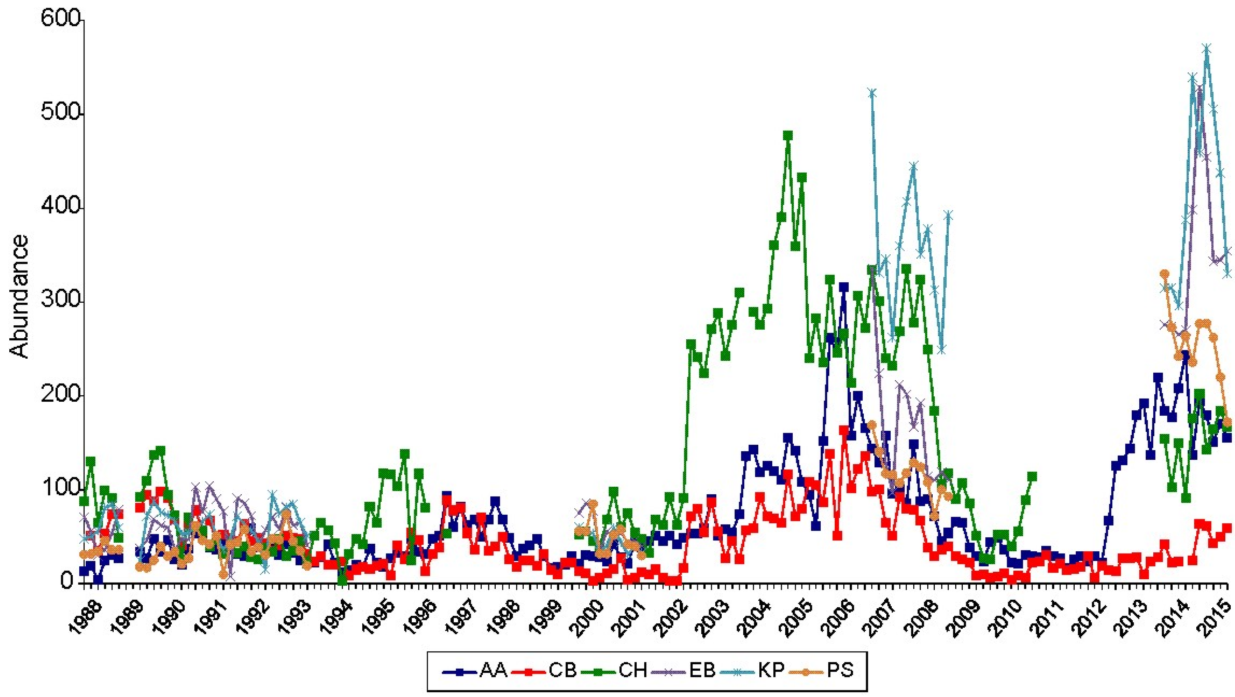


Figure 3-14). Some species have abundances that are consistently low

including Aglaophamus macroura (AA and CB), Exosphaeroma spp. (AA and CB) and Methalimedon sp. (AA), Aonides trifida and Taeniogyrus dendyi (CB).

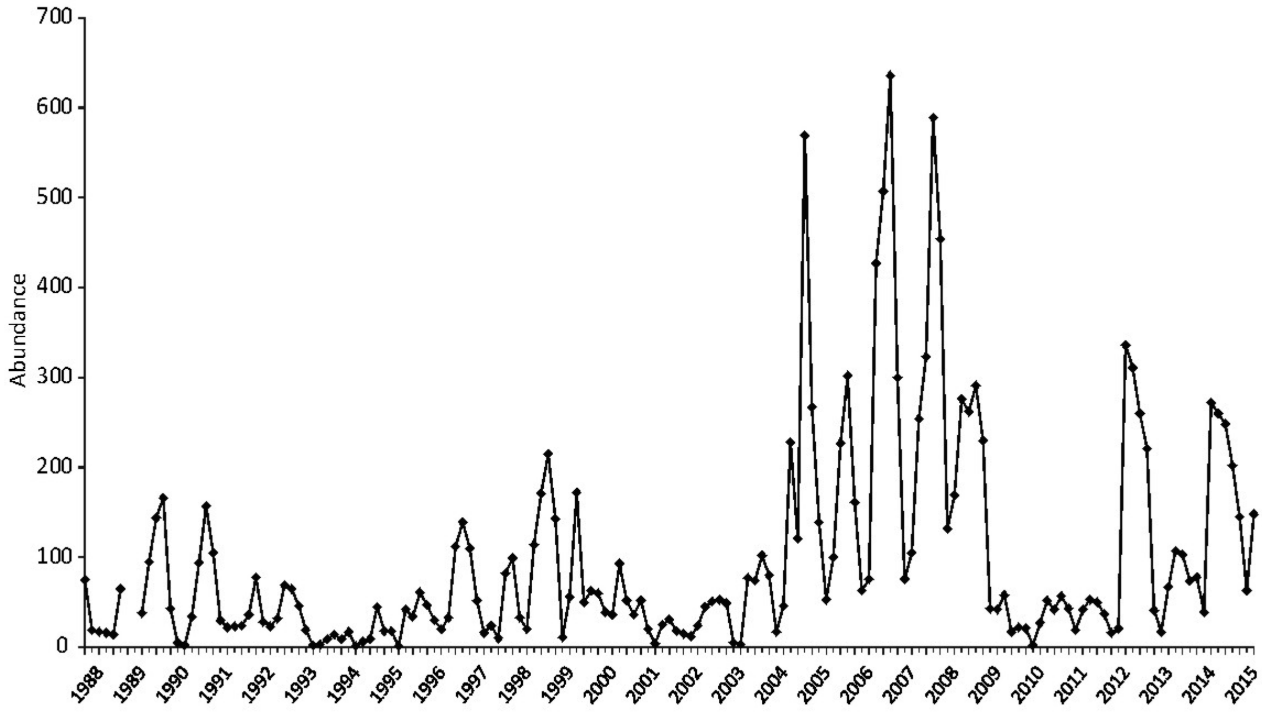


Figure 3-15 Abundance (sum total of 12 replicate cores) of *Hiatula siliquens* at Auckland Airport from October 1987 until February 2015.

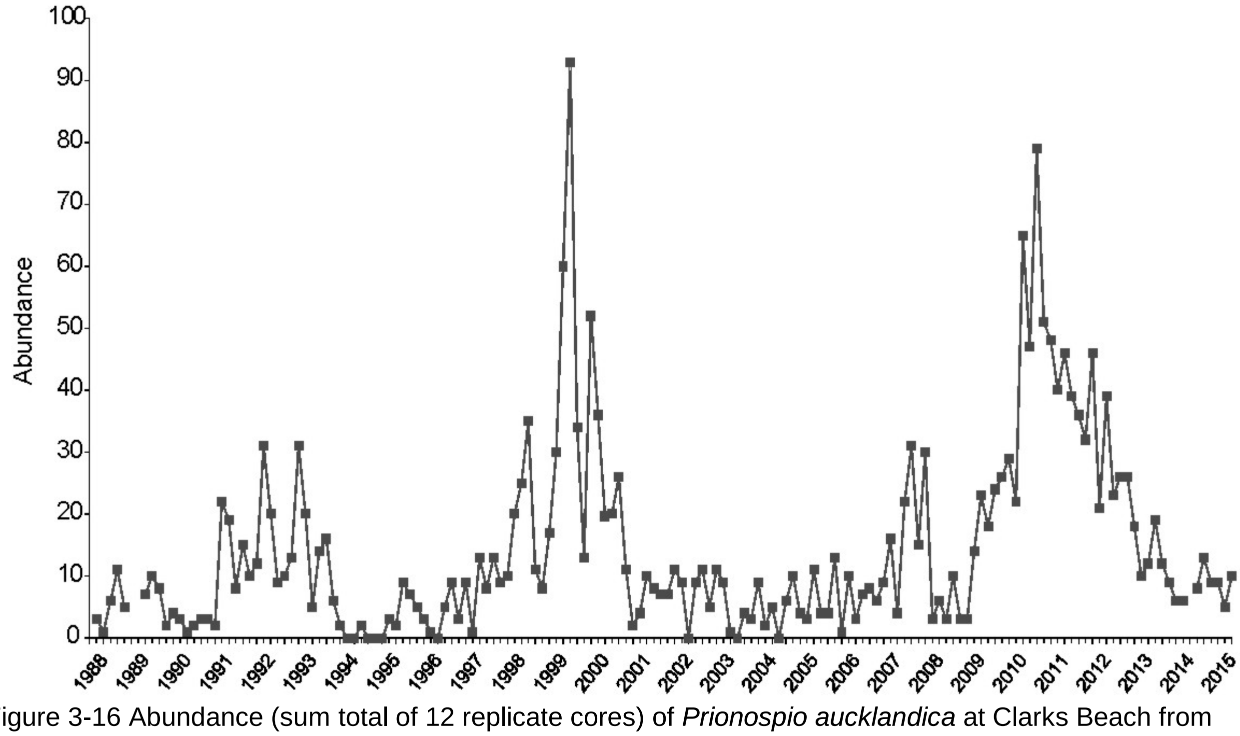


Figure 3-16 Abundance (sum total of 12 replicate cores) of *Prionospio aucklandica* at Clarks Beach from October 1987 until February 2015.

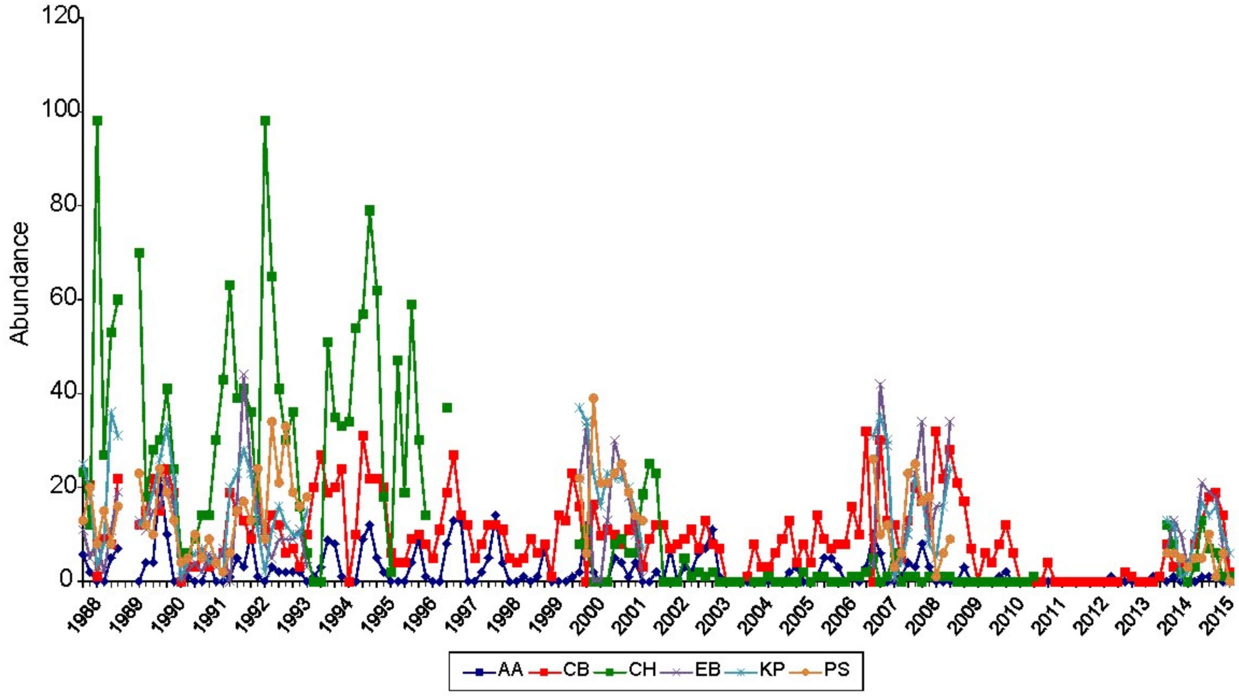


Figure 3-17 Abundance (sum total of 12 replicate cores) of *Glycinde trifida* at Auckland Airport, Clarks Beach, Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream from October 1987 until February 2015.

The abundance of *Linucula hartvigiana* at CB continues to be highly variable, with a multi-year cycle of 3-6 years and with very high recruitment peaks during 2011-2012 (Figure 3-18). Since then abundances have returned to pre-2010 abundances. Another species which exhibits high variability (while maintaining a multi-year cycle of 5-6 years) in abundance at CB is *Notoacmea scapha* (reaching an abundance of 108 individuals in 12 replicate cores in February 2011, then peaking in December 2010 with 178, and again at 241 in August 2013) (

Figure 3-19). It was noted for both *Linucula* and *Notoacmea* in Greenfield et al. (2013) that a further two years of data was necessary to assess whether these high abundances would persist. It is clear they did not and, in the instance of *Notoacmea*, the decrease in abundance was rapid. At site CB, the past two years of data for *Austrovenus* have indicated changes to the 12-16 year multi-year cycle (

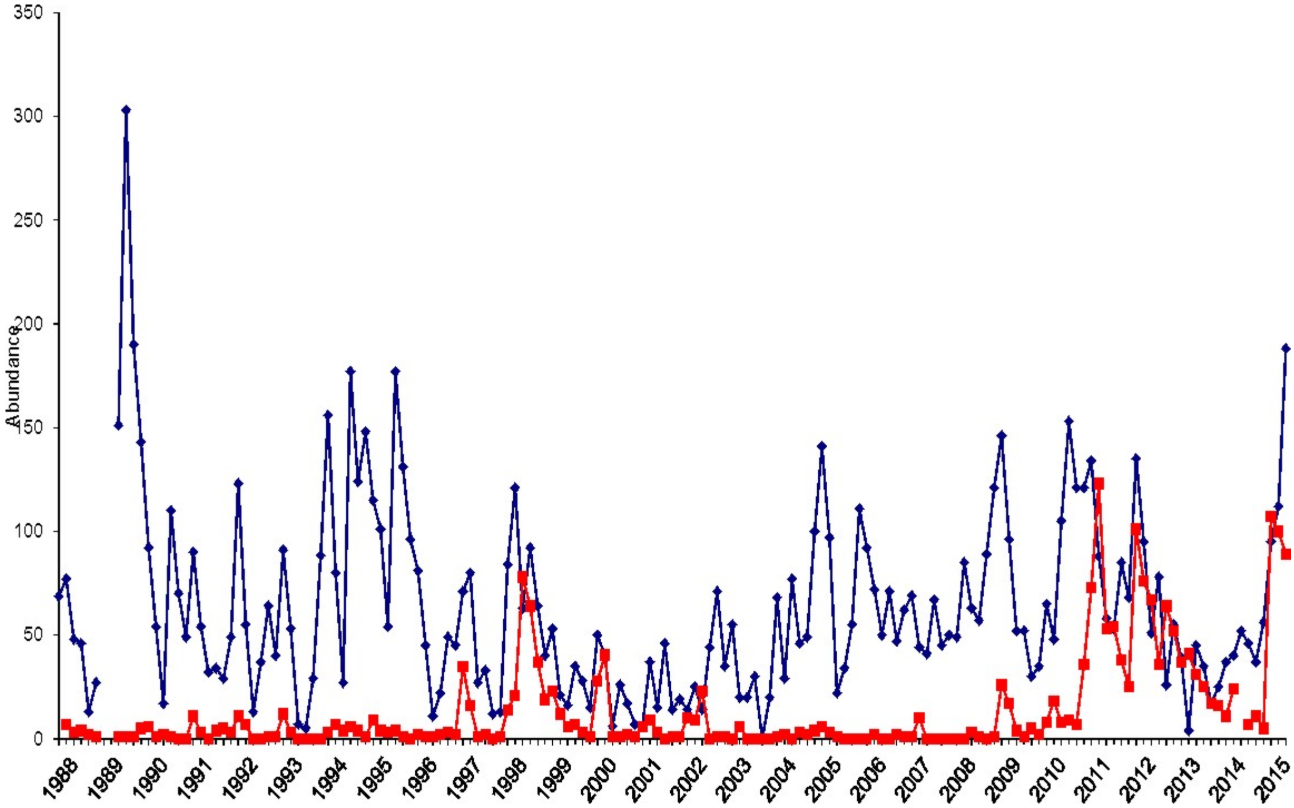


Figure 3-20). A further two years of data is necessary to record what will become of this multi-year cycle. The temporal pattern of this 12-16 year multi-year cycle is generally similar to that observed at site AA although overall abundances are far greater at site AA (

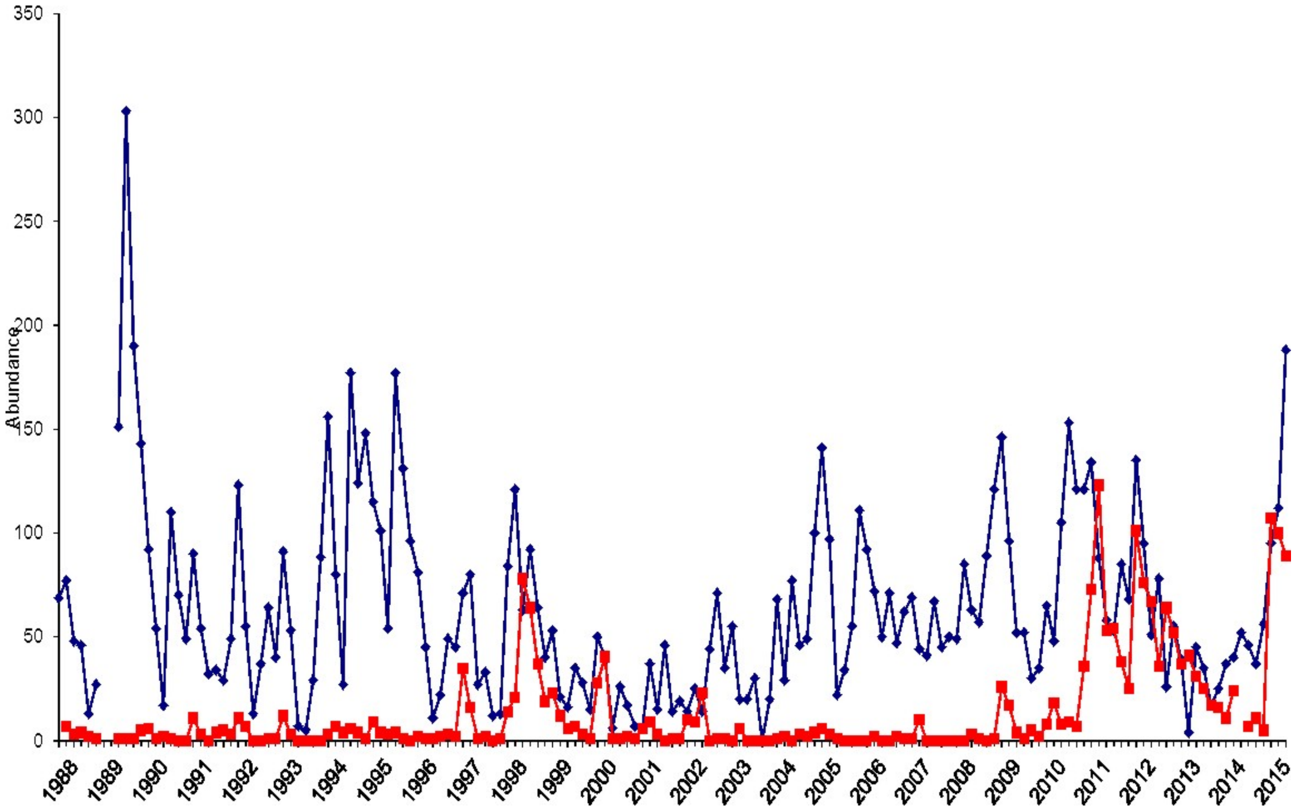


Figure 3-20).

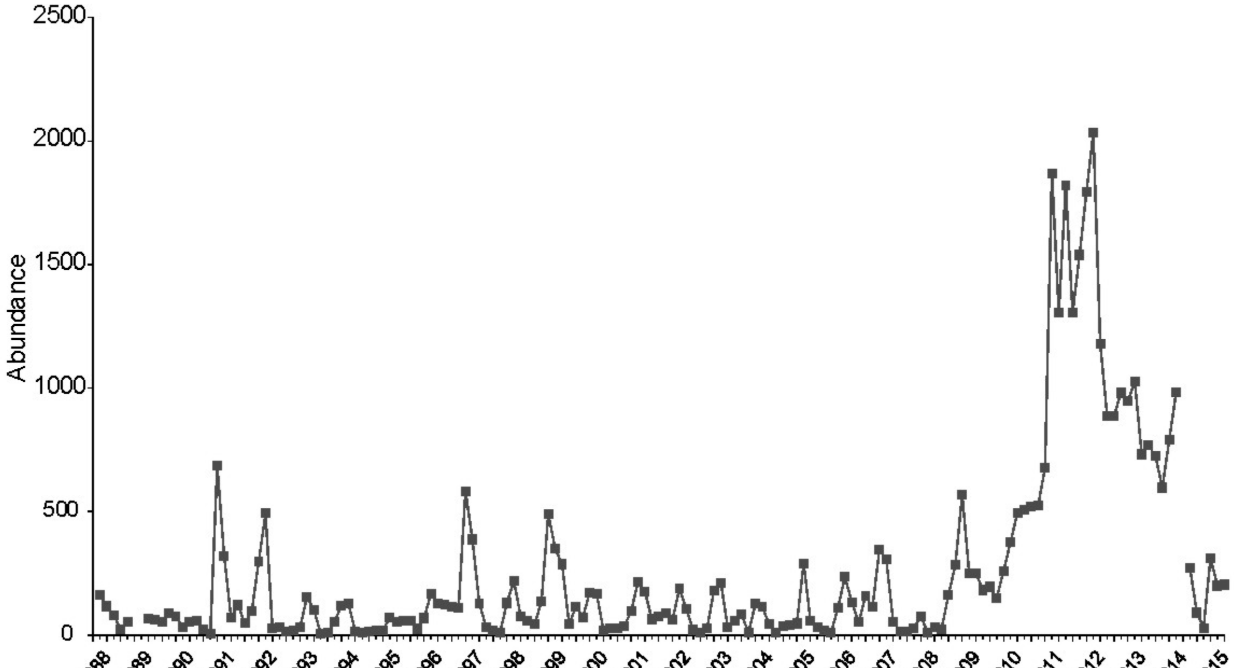


Figure 3-18 Abundance (sum total of 12 replicate cores) of *Linucula hartvigiana* at Clarks Beach from October 1987 until February 2015.

Figure 3-19 Abundance (sum total of 12 replicate cores) of *Notoacmea scapha* at Clarks Beach from October 1987 until February 2015.

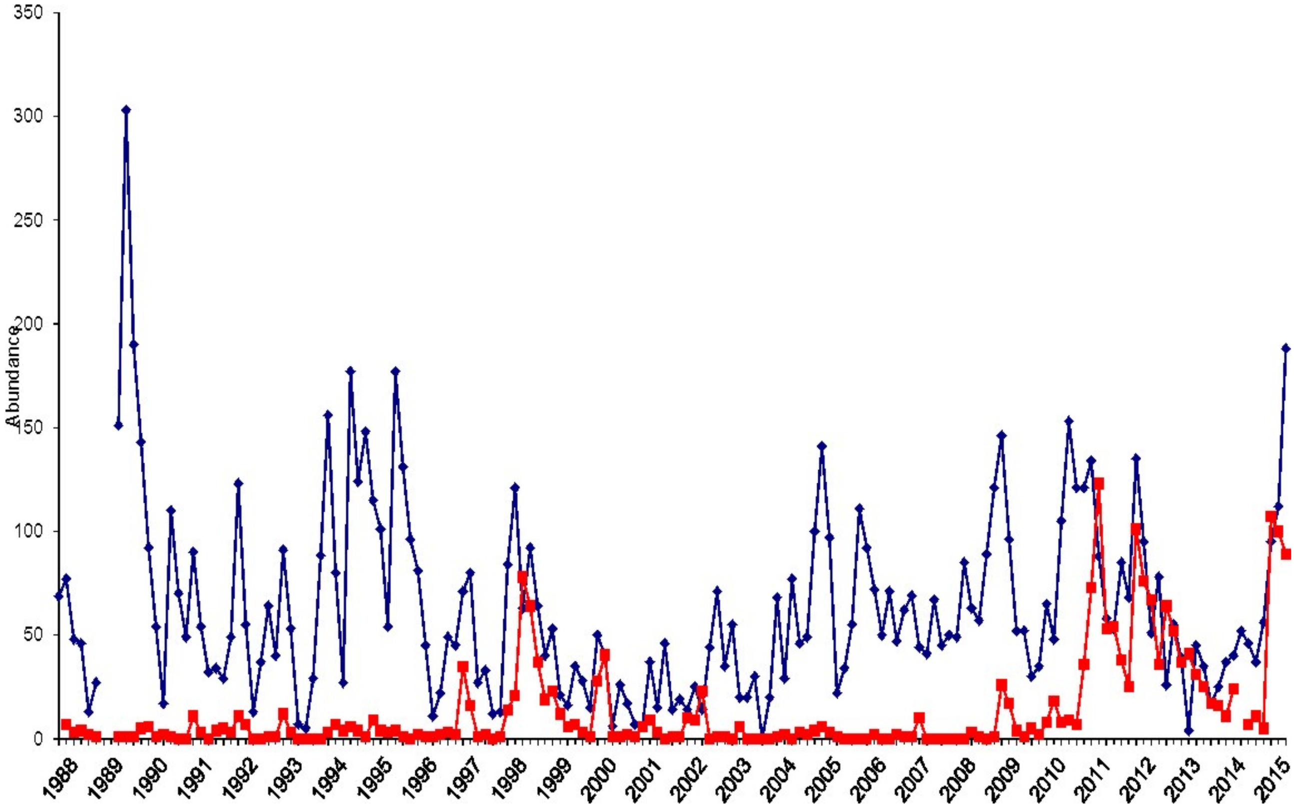
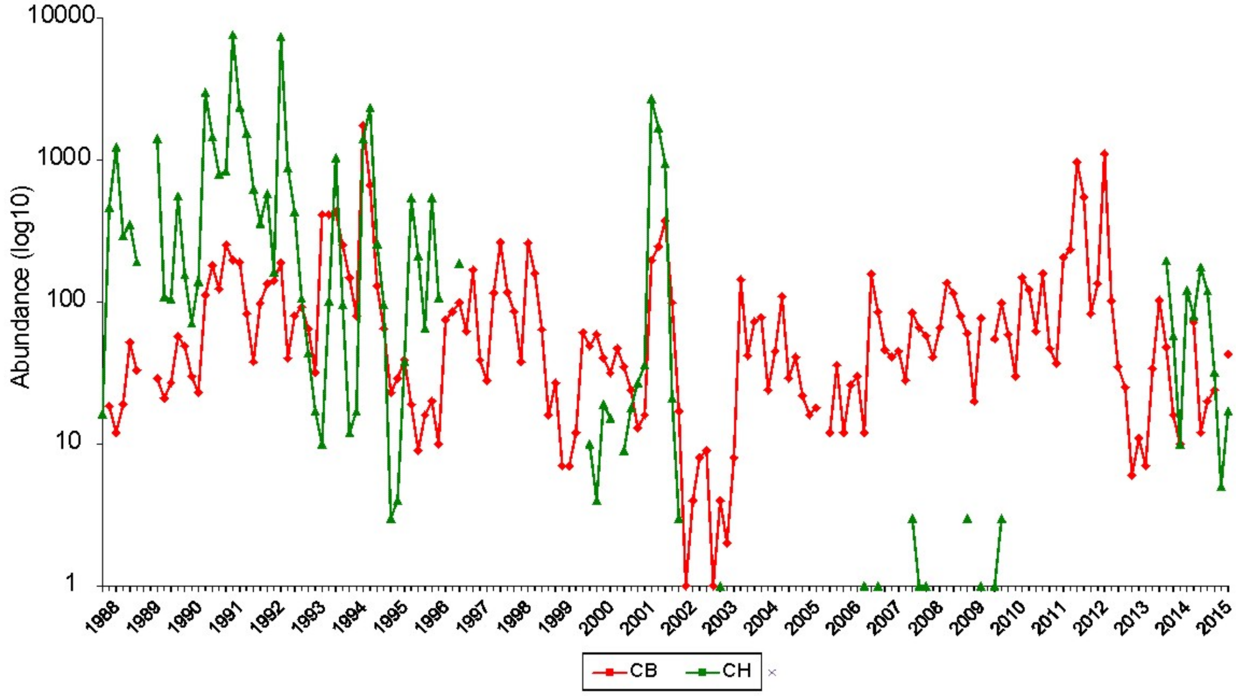


Figure 3-20 Abundance (sum total of 12 replicate cores) of *Austrovenus stutchburyi* at Auckland Airport (blue) and Clarks Beach (red) from October 1987 until February 2015.

Boccardia abundances have followed a similar temporal pattern at site CB and CH until August 2001 since when *Boccardia* became essentially absent at site CH (average of one individual per 12 replicate cores from August 2001 to August 2013), compared to the previously observed abundances averaging 754 (October 1987 to June 2001) and peaking at 7643 individuals per 12 replicate cores in December 1990



(Figure 3-21). Sampling at CH was conducted from August 1999 to June 2010 before pausing, then sampling commenced in August 2013 where *Boccardia* has shown a marked increase in abundance in the past two years, averaging 81 individuals per 12 replicate cores. For *Boccardia* at site CH, a further two years of data is necessary to confirm whether these abundances will persist (

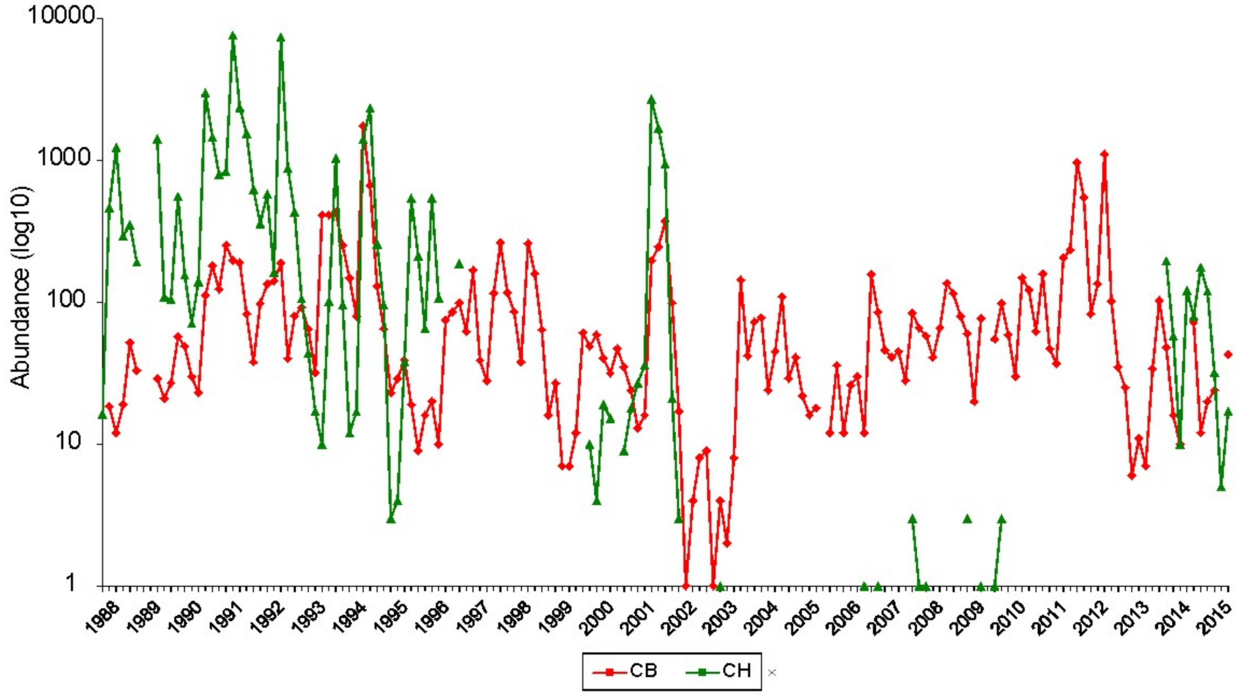


Figure 3-21).

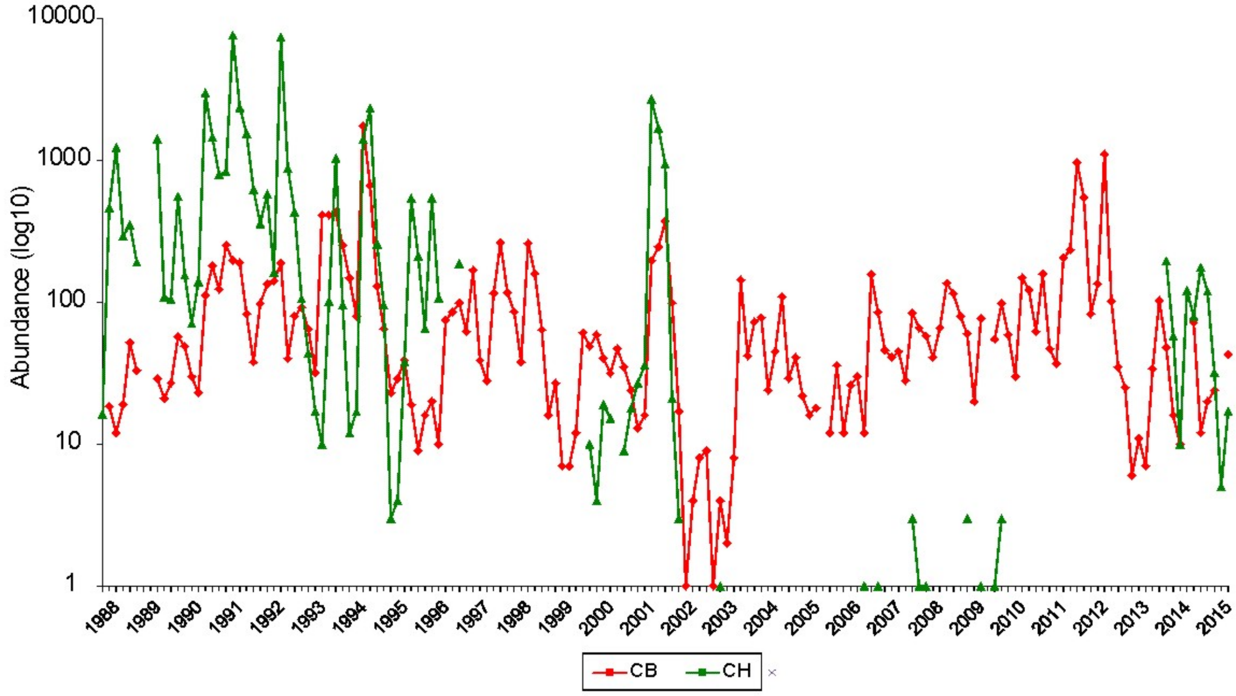


Figure 3-21 Log abundance (sum total of 12 replicate cores) of *Boccardia syrtis* at Clarks Beach and Cape Horn from October 1987 until February 2015.

Macomona juveniles at sites EB, KP and PS exhibited similar seasonal patterns and recruitment peaks to that observed at site AA (Figure 3-22). In contrast, site CH had typically low abundances up until June 2010 (average of 3.2 juvenile and 0.5 adult per 12 replicate cores), however abundances of both juveniles and adults did show a large increase from August 2013 to February 2015 (average of 22 juveniles and 1.3 adults per 12 replicate cores) (juveniles shown on Figure 3-22).

The 2-3 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 2014 following a recruitment of juveniles in early 2012 (Figure 3-23). There was a large recruitment of juvenile *Macomona* at site AA in April 2010, however, as yet there has been no concomitant increase in the abundance of adults sized greater than 20 mm in October 2012 (Figure 3-23), although there were 19 individuals in the 15-20 mm size class (highest total of this size class recorded to date). Current data shows an end to the decreasing trend from 2008 of *Macomona* juveniles at CB (Figure 3-23), with a very high recruitment period during summer of 2014-15.

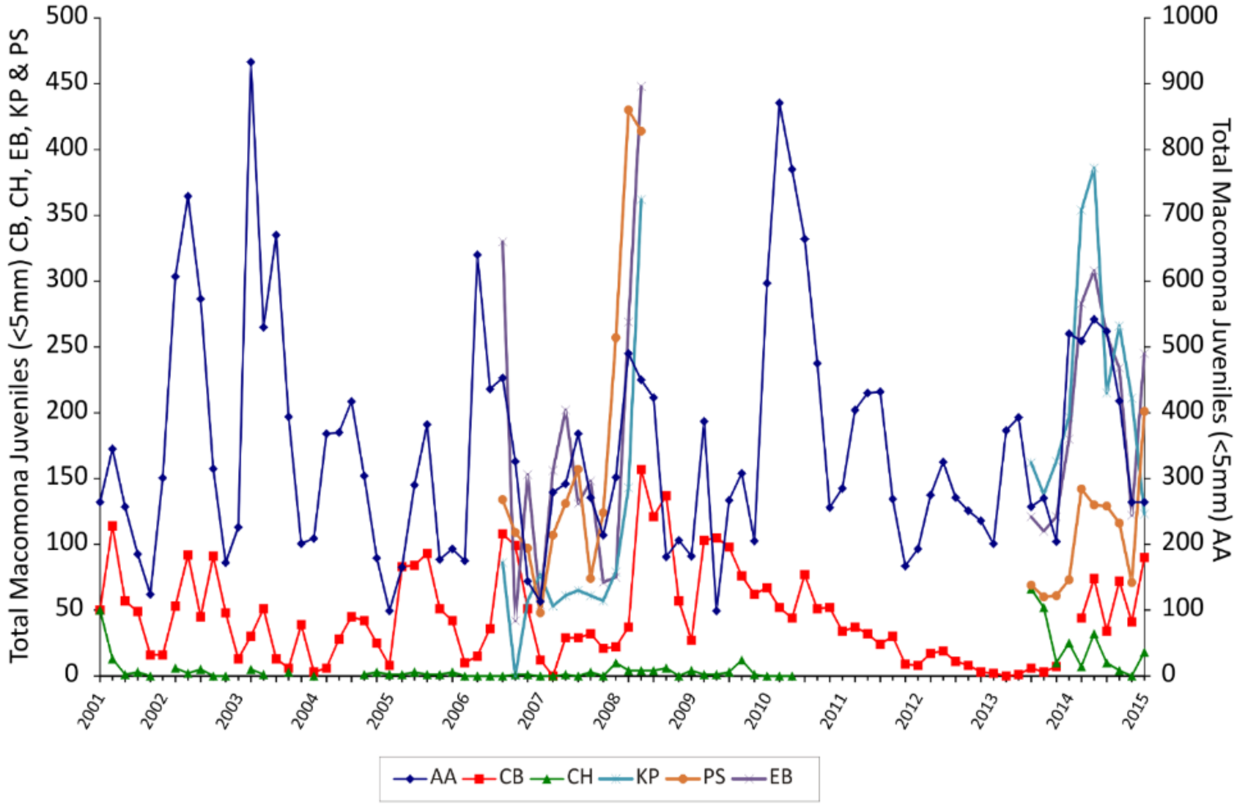


Figure 3-22 Abundance (sum total of 12 replicate cores) of juvenile (<5 mm) *Macomona liliana* from all monitored sites from April 2001 until February 2015. NB: AA is on a secondary axis.

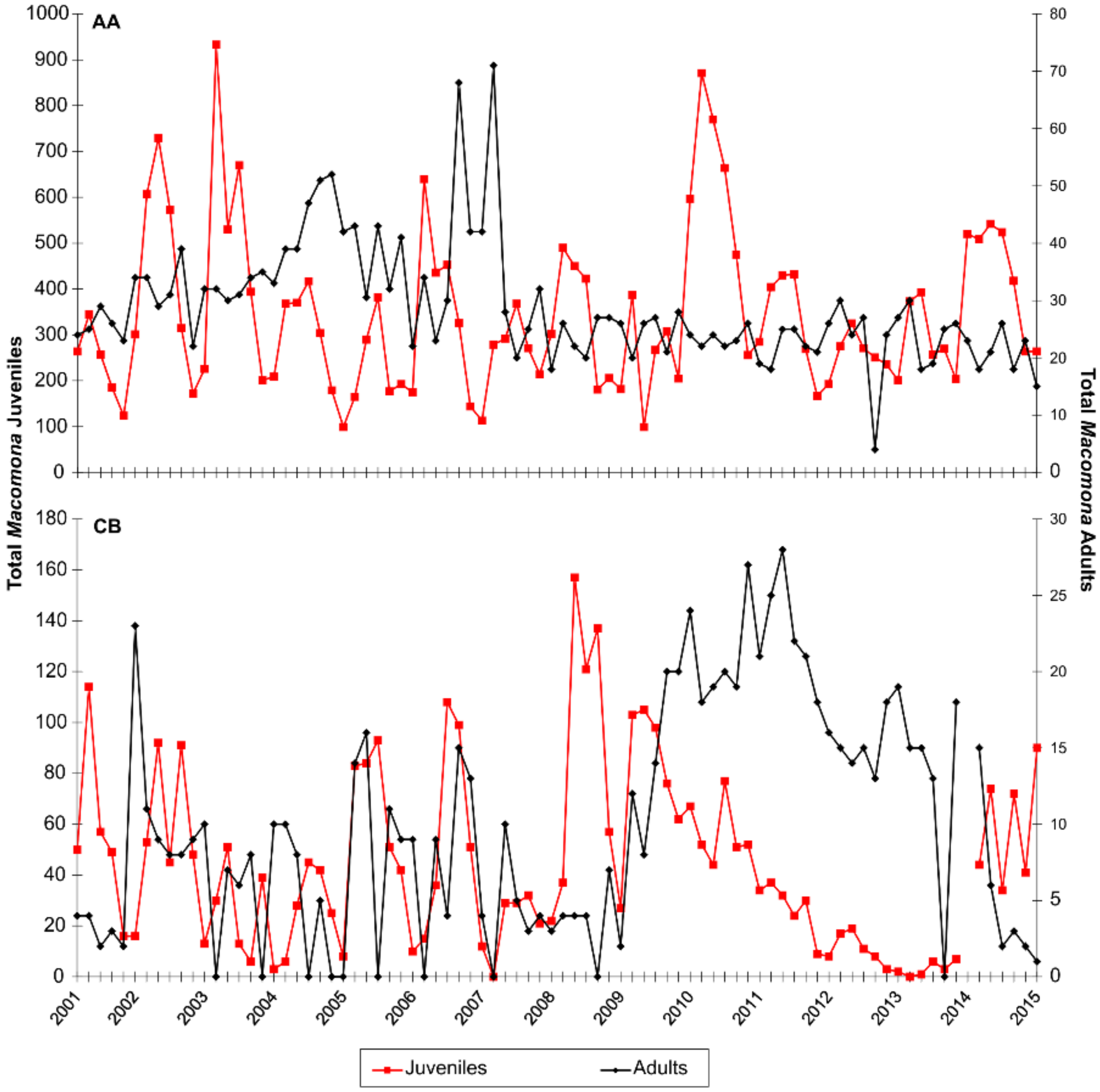


Figure 3-23 Abundance (sum total of 12 replicate cores) of juvenile (red line; April 2001 to June 2007 <4 mm, from August 2007 <5 mm) and adult (black line; April 2001 to June 2007 >16 mm, from August 2007 >20 mm) Macomona liliana from sites Auckland Airport and Clarks Beach from April 2001 until February 2015.

Although the abundance of adult *Austrovenus* at site AA is usually low, the abundance of juveniles is much greater and shows a 3-4 year cycle (Figure 3-24). 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 present (February 2015) demonstrate another large juvenile recruitment event. Further monitoring will confirm whether this results in an anticipated peak in adult abundances in 2-3 years' time (Figure 3-24).

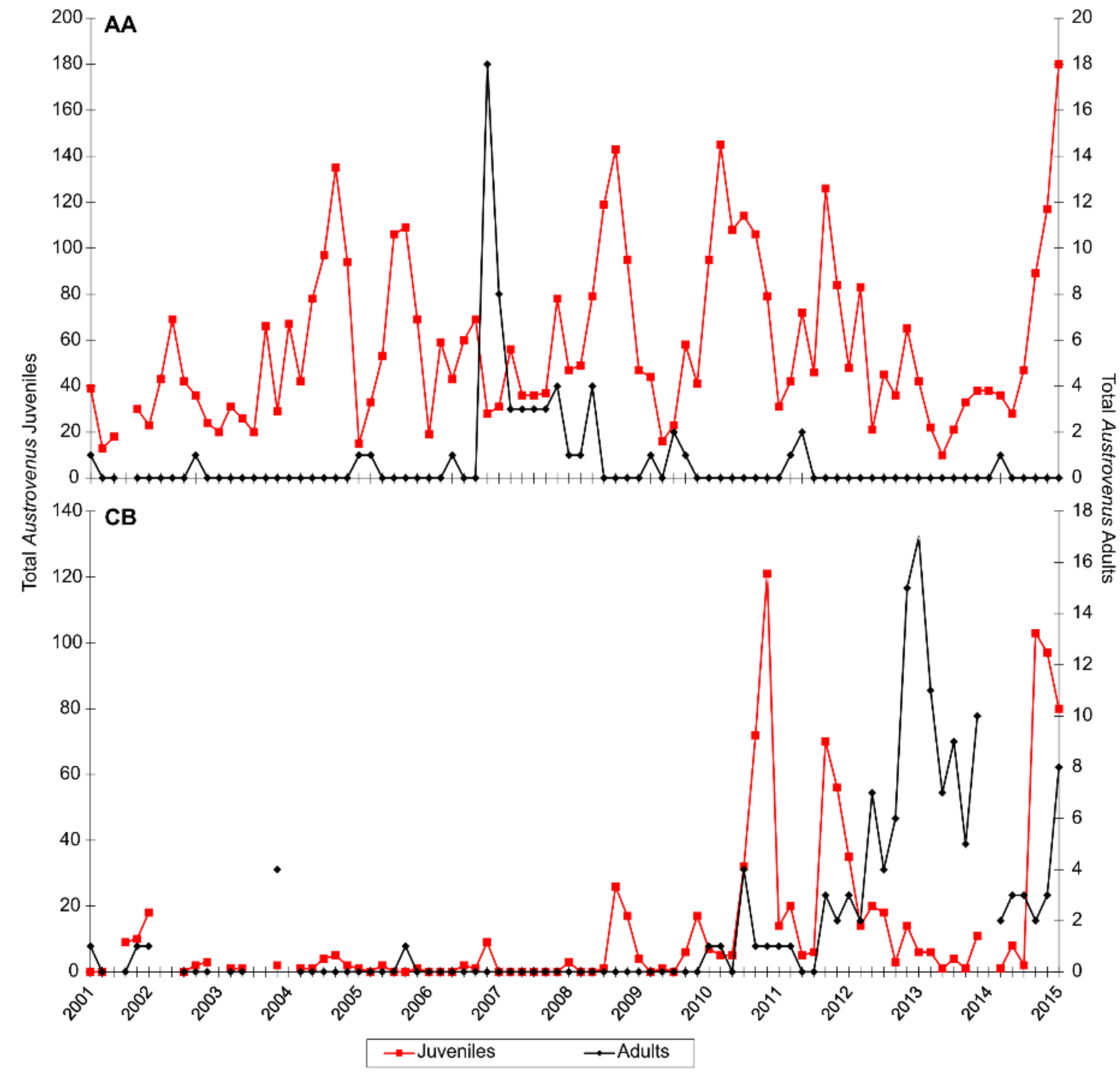


Figure 3-24 Abundance (sum total of 12 replicate cores) of juvenile

(red 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 2015.

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 community is dominated by bivalves *Macomona*, *Austrovenus* and *Hiatula*. These bivalve species contribute most to the similarity of the communities at AA over time (32% combined based on Bray-Curtis per cent similarity). The most abundant polychaetes are *Aonides, Magelona*, *Travisia*, *Orbinia* and *Taeniogyrus*, with the cumacean *Colurostylis* also numerically dominant (Appendix 7.3). The community composition of AA has been the most stable over the duration of the monitoring period (communities exhibited an average similarity of community composition of 81% (based on Bray-Curtis per cent similarity) between October 1987 and October 2014) and it remains the site most distinct from the others (Figure 3-25).

Site CB is dominated by a mixture of bivalves (i.e., *Linucula* and *Macomona*), polychaetes (i.e., *Macroclymenella* and *Magelona*) and the amphipod *Torridoharpinia* (Appendix 7.3). This site is more variable over time in monitored species than AA (monitored taxa communities exhibited 76% similarity in community composition between October 1987 and October 2014); Figure 3-25).

Conversely, the monitored taxa community at site CH has changed markedly over time (see Figure 3-25). The first change was largely due to the Mangere wastewater treatment plant upgrade (see Hewitt and Hailes (2007) for a full analysis). However, while the last two October samplings still have the same dominant species as previously (*Magelona*, *Colurostylis, Macroclymenella* and *Linucula;* Appendix 7.3), the community composition has changed somewhat (38% dissimilarity with previous 10 years). The monitored taxa community in October 2013 and 2014 has become more similar to that observed in the mid-1990s – prior to the wastewater treatment plant upgrade (75% similarity) driven by increases in *Boccardia* (see Appendix 7.3 and

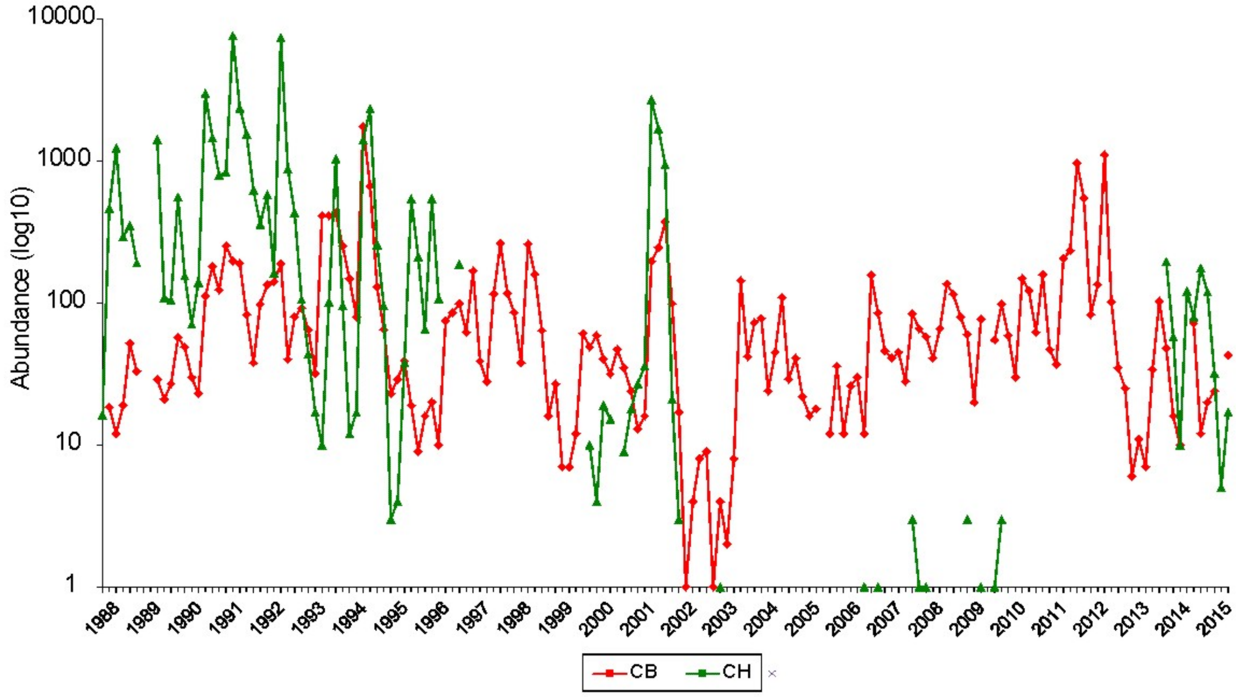


Figure 3-21), *Glycinde*, *Torridoharpinia* and *Owenia*. However, the abundances of these species are still lower than they were and a number of other species have become important in defining the composition (*Austrovenus, Linucula*, *Anthopluera* and *Macroclymenella*).

Over the entire monitoring period the monitored taxa community composition at site EB has remained 75% similar. The top three species contributing to this similarity are *Magelona, Macomona* and *Torridoharpinia* However, there was a notable shift in community composition from 1993 to 2001, again from 2002 to 2008 and then again in the last two years data (see Figure 3-25). This change is due to changes in abundance of a number of 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). Other changes seem likely to be part of multi-year cycles (see Table 3.2).

Site KP has a similarity in monitored taxa community composition of 77%. The top three species contributing to this similarity are *Macomona, Magelona* and *Linucula* (followed closely by *Hiatula*). The past two years data for site KP is consistent with that observed for 2006-2007 when a change in community composition was observed and the community is now dissimilar to that observed prior to 2006 (Figure 3-25). This is when *Hiatula* and *Aonides* began appearing in the top three most abundant species (see Appendix 7.3).

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). However, the site continues to have a very stable monitored taxa community composition (81% similarity; Figure 3-25.

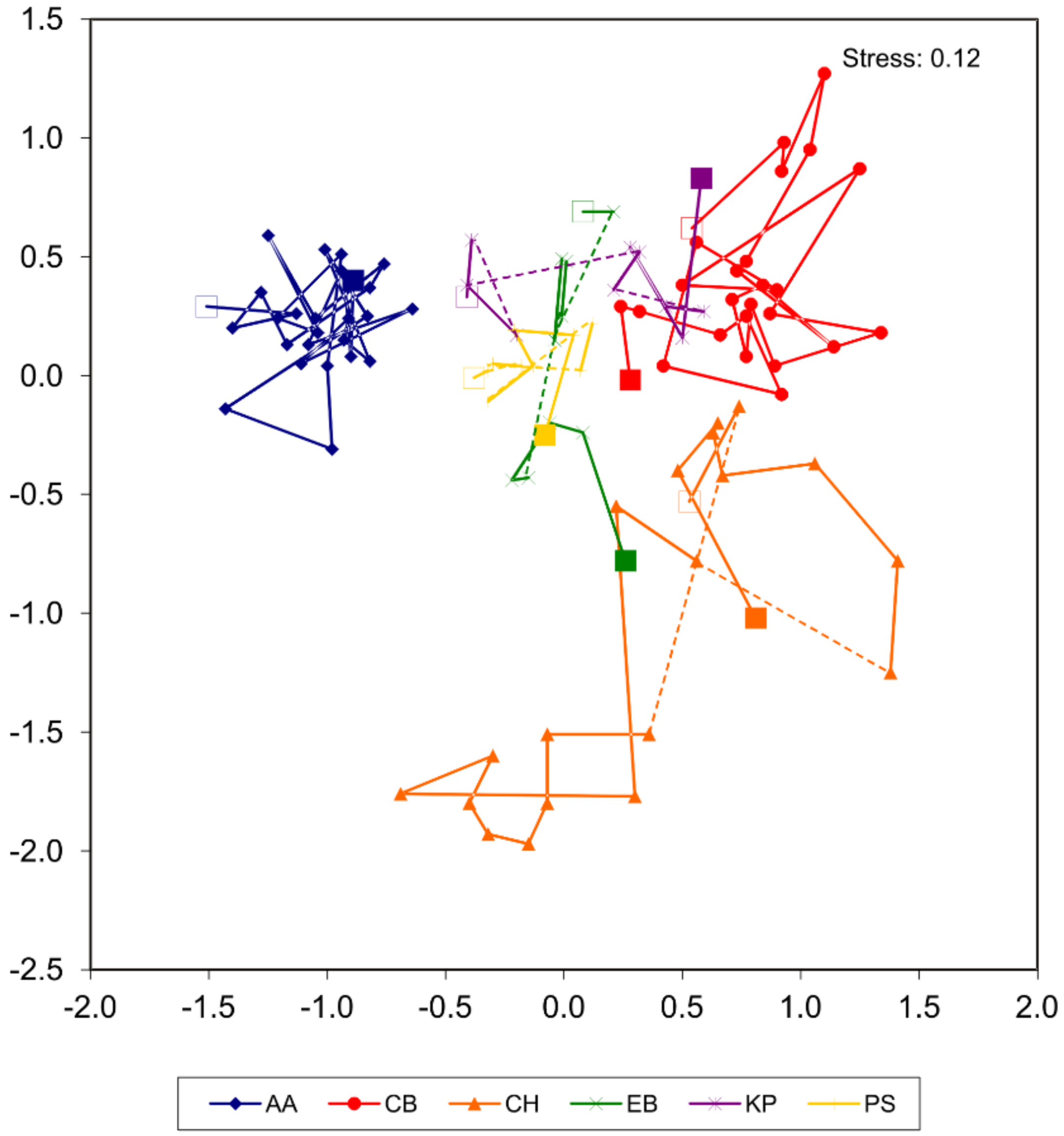


Figure 3-25 Multi-dimensional Scaling (MDS) plot of the dissimilarity in macrofaunal communities of monitored taxa over time

(October 1987-October 2014) (4th-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.

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. TBI scores for the six monitored Manukau sites for October 2013 and October 2014 fell between 0.76 (CB) and 0.36 (AA) (see Table 3-4). 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 between 0.30 and 0.40 indicate potentially reduced functional redundancy, but are only concerning if the sediment is <95% sand (site AA is >97% sand). TBI values for the RSCMP sites were ≤ 0.40, ranging from 0.40 at Blockhouse Bay (95% sand) and Little Muddy (62% sand) to 0.17 at Anns Creek. Thus, all indicating low levels of functional redundancy.

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 3-4). CAPmetal and CAPmud scores for site AA are within the ambit observed over the rest of the monitoring period (Hewitt et al. 2012) and give an “extremely good” rating. Both CAPmetal and CAPmud scores have shown slight improvements for site CB since 2010, and are within ambit of the full monitoring period rating a “good”. CAPmetal and CAPmud scores for site CH give an overall rating of “good” for both October 2013 and 2014. With the exception of KP 2013 CAPmetal and EB 2013 CAPmud both having “extremely good” ratings, the remaining scores for the two sites give ratings of “good”. Site PS has “extremely good” CAPmetal and CAPmud ratings for 2013, however, in 2014 CAPmud drops to a rating of “good”. For the upper inlet areas, the RSCMP sites, the ratings were considerately different. Anns Creek, Pahurehure Inlet and Mangere Cemetery had the highest CAPmetal and CAPmud scores and gave the lowest possible health rating of “unhealthy with low resilience”. The more exposed of the RSCMP sites gave lower CAPmetal and CAPmud scores with Little Muddy rating “moderate” and Blockhouse Bay exhibiting similar scores to those observed at EB in October 2014 resulting in a rating of “good”.

The overall health of each site was determined using benthic health model and TBI scores giving each site a combined health rating. The combined health scores for AA are “extremely good”, CB, CH, EB and KP “good”, while PS experienced a slight increase in CAPmud which resulted in an overall drop to “good” from “extremely good” between October 2013 and October 2014. Combined health scores for the upper harbour sites are worse than for the main harbour sites. Anns Creek and Mangere Cemetery were “unhealthy with low resilience”, Pahurehure Inlet “poor”, Little Muddy “moderate” and Blockhouse Bay was “good” (Figure 3-26) with the lowest combined health score.

Table 3-4 Benthic Health Model scores for metals and mud (BHMmetal and BHMmud scores), TBI and combined Health scores for Manukau Harbour main body sites (AA, CB, CH, EB, KP, PS) for October 2013 and October 2014, and Regional Sediment Chemistry Monitoring Programme sites (Upper harbour sites, marked in grey) Anns Creek, Blockhouse Bay, Little Muddy, Mangere Cemetery and Pahurehure Inlet for October 2013. 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".

Site	Year	BHMmetal	group	BHMmud	group	TBI score	Combined health score
AA	2013	-0.22	1	-0.15	1	0.43	0.20
	2014	-0.23	1	-0.15	1	0.36	0.20
CB	2013	-0.08	2	-0.09	2	0.72	0.38
	2014	-0.08	2	-0.06	2	0.76	0.38
CH	2013	-0.14	2	-0.08	2	0.68	0.38
	2014	-0.15	2	-0.06	2	0.63	0.38
EB	2013	-0.15	2	-0.12	1	0.61	0.30
	2014	-0.13	2	-0.10	2	0.57	0.38
KP	2013	-0.17	1	-0.12	2	0.53	0.31
	2014	-0.15	2	-0.10	2	0.64	0.38
PS	2013	-0.20	1	-0.13	1	0.50	0.20
	2014	-0.17	1	-0.09	2	0.61	0.31
Anns Creek	2011	0.14	5	0.14	5	0.19	1.00
	2013	0.09	4	0.10	4	0.17	1.00
Blockhouse Bay	2013	-0.13	2	-0.90	2	0.40	0.38
Little Muddy	2013	0.00	3	0.01	3	0.40	0.51
Mangere Cemetery	2011	0.10	4	0.11	5	0.20	1.00
	2013	0.07	4	0.10	5	0.25	1.00
Pahurehure Inlet (Papakura)	2011	0.10	5	0.08	4	0.26	1.00
	2013	0.08	4	0.07	4	0.37	0.67

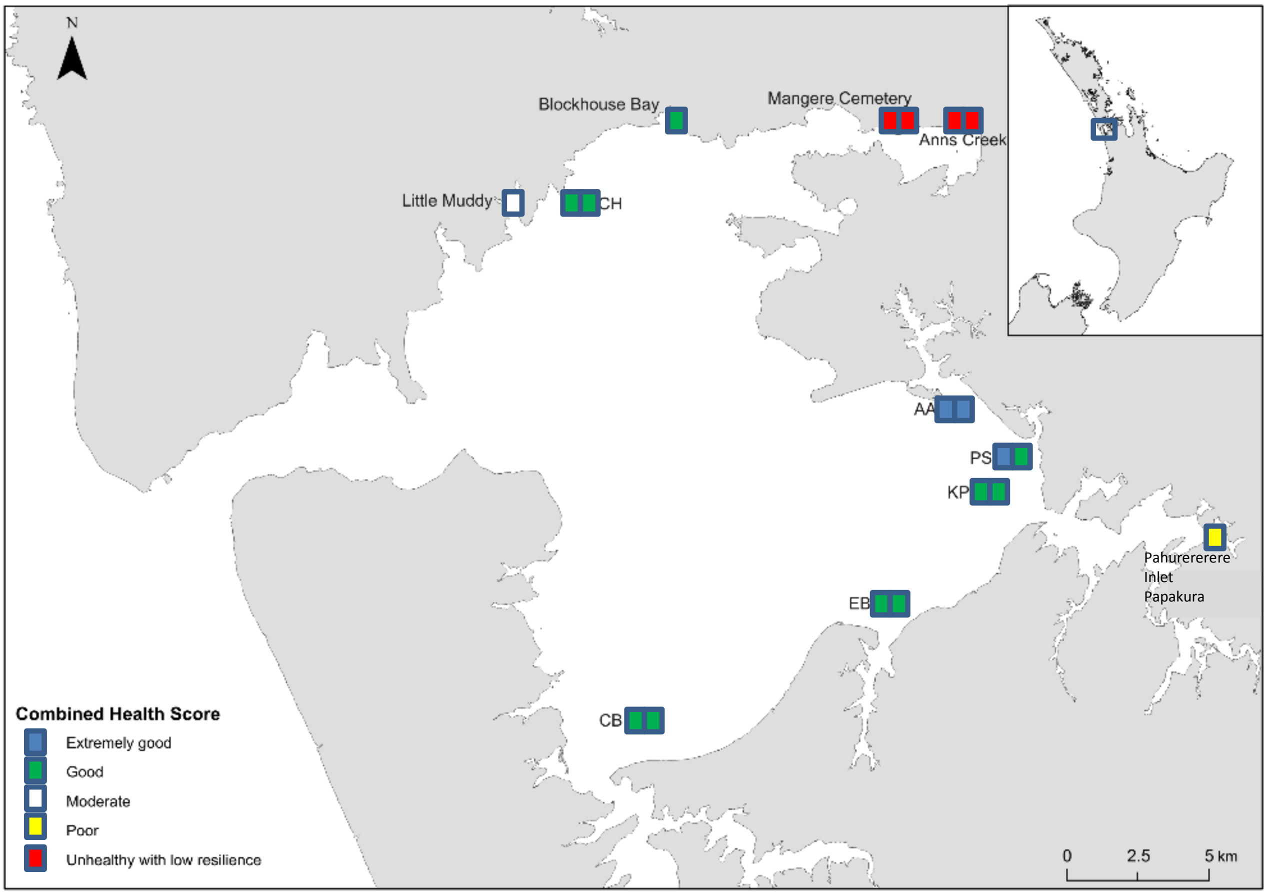


Figure 3-26 Map of the Manukau Harbour showing October 2013 and October 2014

(left and right half of coloured site marker respectively) combined health scores (TBI and BHM) 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 (Anns Creek, Blockhouse Bay, Little Muddy, Mangere Cemetery and Pahurehure (Papakura)). The latter sites were not sampled in 2014 therefore only one half of the site marker is shown.

4.0 Summary and recommendations

4.1 Changes of concern

During the last two years, the monitored sites in the main body of the Manukau Harbour continue to demonstrate good overall health corresponding to sediment contaminants and mud content, and monitored taxa community composition. Abundances of monitored species have varied between sites; while some remained similar to that described in Greenfield et al. (2013) with long multi-year cycles (e.g. *Magelona dakini*), others, such as *Linucula* and *Austrovenus* (both at Clarkes Beach (CB)) have had substantial recruitment decreases and increases respectively, which is different from the previously observed temporal pattern.

With an additional two years of data, a total of five trends in abundance have become apparent at the Auckland Airport Site (AA); three more than in 2013 (Greenfield et al. 2013). An increasing trend in abundance was detected for three species (*Aonides, Orbinia* and *Taeniogyrus*), while *Linucula* showed a decreasing trend and *Glycinde* a step decrease. However, the latter two species would not be expected to be more sensitive to either contaminant or sediment inputs than the first three so these trends are most likely to be natural variation. This suggestion is supported by the fact that trends in *Aonides* and *Taeniogyrus* are also observed at sites at nearby sites. No changes of concern are observed at this site (Table 4-1).

Table 4-1: Presence of trends of concern at each site.
Y = number of trends consistent with concern minus number of trends inconsistent with concern is greater than 0.

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

Trends in abundance at the Clarks Beach site (CB) are also found at the nearby Elletts Beach site (EB): increases in abundances for *Owenia* and *Anthopleura*, and a decrease in the abundance of *Hiatula*. Again, we would expect these three species to exhibit similar directions of change if the drivers were contaminants or sediments. However, of the three only *Owenia* prefers moderately enriched sediments (Table 4-1).

The site at Cape Horn (CH) is showing trends in two species (*Colurostylis* and *Methalimedon*), *Colurostylis* prefers sandy sediments with low lead concentrations, but little is known of the sensitivity of *Methlimedon*. The community composition of Site CH appears to be returning to the community composition observed prior to the upgrade of the Mangere wastewater treatment plant in 2001, driven by increases over the last two years in *Boccardia, Glycinde*, *Torridoharpinia* and *Owenia* (trends in the abundances of these species are not yet statistically significant). Another species of Polydorid (*Pseudopolydora paucibranchiata*) and mats of *Arcuatula senhousia* have also been observed at this site.

Generally more trends were detected at the intermittently monitored sites: EB nine trends; Karaka Point (KP) seven trends; and Puhinui Spit (PS) five trends. However, the majority of changes at each of the intermittently monitored sites were able to be clarified by using the abundance data at either sites AA or CB, resulting in there likely only being five, three and one trends in abundance of monitored species at EB, KP and PS respectively. Regardless, some concerns exist for each site as: at site EB as species that prefers moderate enrichment is increasing, as are the BHMmud scores; at site KP the BHMmetal scores have increased; and at site PS both the BHMmetal and BHMmud scores have increased (Table 4-1).

Despite these observations, the overall health of the main body of the Manukau Harbour, which takes into account metal contaminants, mud content and macrofaunal community functionality (redundancy and resilience to change), is "good" to "extremely good". The surrounding RSCMP sites had far worse overall health scores than the main harbour body sites indicating that the main harbour, which makes up 40% of the harbour area, is in much better condition than the upper channels and inlets (Figure 3-26)

The rotational concept of sampling sites appears to be working well for the Manukau Harbour monitoring programme. The data collected at the intermittent sites CH, EB, KP and PS from April 2013 to February 2015 was not always consistent with the data previously observed for these sites (August 2006 to June 2008), therefore, in many instances the time signals were fitted against the permanently monitored sites, AA and CB, in order to attain conclusive patterns and trends. Importantly, without the data from either AA or CB a number of multi-year cycles would have been erroneously identified as trends (44%, 43% and 60% at EB, KP and PS respectively). Accordingly, the continuation of bimonthly monitoring at sites AA and CB is recommended and is important, as they provide a crucial template for temporal patterns of species abundance against which the other sites are assessed.

The data and information gathered from this extensive data set can be used and applied as a comparison for other monitoring conducted by the Auckland Council (e.g. Mahurangi, Kaipara and Waitemata ecological monitoring programmes). The data has also been invaluable with respect to enhancing knowledge of natural variability in taxa abundances and responses of taxa to both environmental (i.e., El Niño Southern Oscillation patterns; Hailes and Hewitt 2009) and anthropogenic disturbances (i.e., decommissioning of the Mangere wastewater treatment plant; Funnell et al. 2003). Furthermore, the data has been a pivotal resource for exploration of tools to measure the health of estuarine systems in New Zealand (Anderson et al. 2006; Hewitt and Ellis 2010; Lohrer and Rodil 2011; van Houte-Howes and Lohrer 2010) and to assess risk (Senior et al. 2003).

4.2 Recommendations

Upon review of the findings of the Manukau Harbour Monitoring programme data from October 1987 until February 2015, in order to maintain a comprehensive dataset and subsequent guide for harbour management, we recommend the following actions be taken by Auckland Council:

- The continuation of bimonthly monitoring of macrofaunal community composition and sediment characteristics at sites Auckland Airport and Clarks Beach. This will continue to provide a template for temporal patterns of species abundances and sediment characteristics against which the other sites can be assessed.
- Site Cape Horn be sampled in conjunction with Auckland Airport and Clarks Beach for a further two years (at least) to monitor the change detected in community composition.
- Further monitoring to be conducted at site PS. In particular for sediment mud content due to the elevated mud% content found in February and April 2015 and the changes in the community health indices observed at this site.
- The changes observed in monitored taxa community composition at Elletts Beach together with the elevated mud content levels observed in April 2015 (re-check in progress) and the patches of *Gracilaria* observed at this site suggest the need for some future monitoring at this site.

5.0 Acknowledgements

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7.0 Appendices

7.1 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

- *Methalimedon* sp.

Methalimedon 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 3 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 5 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 chilensis* and *Exosphaeroma 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. chilensis* is the most common in the Auckland region, followed by *E. falcatum* and the recently discovered *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 2 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).

7.2 Sediment characteristics from April 2009 to February 2015.

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

	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

	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

7.3 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*
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*

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*
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*

CB	Rank 1	Rank 2	Rank 3
2011	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Notoacmea scapha*
2012	*Linucula hartvigiana*	*Macroclymenella stewartensis*	*Anthopleura*
2013	*Linucula hartvigiana*	*Macrocylmenella stewartensis*	*Notoacmea scapha*
2014	*Linucula hartvigiana*	*Torridoharpinia hurleyi*	*Austrovenus stutchburyi*

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*
2006	*Magelona dakini*	*Macroclymenella stewartensis*	*Hiatula siliquens*

CH	Rank 1	Rank 2	Rank3
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*

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*	*Methalimedon* 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			
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*

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*

KP	Rank 1	Rank 2	Rank3
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*
2014	*Magelona dakini*	*Aonides trifida*	*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*

Find out more: phone 09 301 0101, email
rimu@aucklandcouncil.govt.nz or visit
aucklandcouncil.govt.nz and knowledgeauckland.org.nz