Manukau Harbour Ecological Monitoring Programme: Report on Data Collected Up Until February 2013

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Manukau Harbour ecological monitoring programme: report on data collected up until February 2013

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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 with two intertidal sites, representing the northeast and southwest of the harbour, permanently monitored bimonthly (Auckland Airport and Clarks Beach). Southern intertidal sites near Elletts Beach, Karaka Point and Puhinui Stream alternate monitored with unmonitored years on 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 cycle, but monitoring began again prior to removal of the wastewater treatment ponds at Mangere in 2001. Monitoring at this site continued until June 2010 when the site was returned to rotational monitoring. Selected macrofaunal taxa and sediment characteristics are monitored at all sites; chosen to represent different predicted responses to environmental changes. Annually in October, all macrofaunal taxa are enumerated for use of the Auckland Council's Benthic Health Models (BHM) and calculation of the Traits Based Index (TBI).

Sediment characteristics (sediment chlorophyll *a* concentrations, grain size and percentage organic matter) appear to be maintaining levels observed in February 2011. Abundances of the majority of the monitored taxa at the Auckland Airport and Clarks Beach sites continue to exhibit multi-year cycles. Recently three species (the cockle *Austrovenus stutchburyi,* the small bivalve *Nucula hartvigiana* and the limpet *Notoacmea scapha*) have shown larger than previously observed recruitment events at Clarks Beach; if future sampling also observes increased abundances, analyses will be conducted to determine whether these are driven by climatic or environmental variations. However, these recruitment events have not to date affected overall community composition, with only small and non-significant patterns in community composition apparent at both sites over time.

There is no evidence of declining ecosystem health within the extensive intertidal flats that make up the main body of the Manukau Harbour, with neither of the two sites monitored showing changes of concern. This is supported by application of BHMs and TBI which find sites AA and CB to continue to be in good or very good health with good functionality. This year we also report on the health of some of the harbours inlets, monitored under the Benthic Health Monitoring Programme. The only site monitored in Waiuku Inlet is in poor health, with low functionality, as is the only site monitored in Waimuku. The sites monitored in Mangere Inlet range from poor to unhealthy and both have low functionality, similar to results from 2002 – 2005. Threes sites are monitored in Pahurere Inlet and these range from those having good health, although with reduced functionality, to being of poor health with low functionality.

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 are to be monitored during the 2013/14 period. This will enable determination whether any specific parts of the harbour are undergoing detrimental changes, or whether overall health of the main harbour continues to be good.

Contents

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 sand flats 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.

- Clarkes 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 sand flats 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 sand flats out from Puhunui Creek, now associated with the Weymouth and Papakura Channel water quality monitoring sites
- Auckland Airport (AA) – on the sand flats 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 then Mangere Oxidation ponds, 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 continuously 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)) always being monitored. The success of this strategy was analysed after resampling the full six sites in 2001 (Funnel et al 2001, Hewitt and Thrush 2007) and thus continued. The last full sampling was conducted in 2006-2008 (Hailes and Hewitt 2009) and is scheduled to reoccur in 2013.

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, it is 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). Monitoring of sediment characteristics (sediment grain size, organic content and chlorophyll a) was added in 1999 to increase the ability of the programme to relate changes in communities to specific 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 sand flat monitoring from October 1987 until February 2013. It also includes other intertidal monitoring conducted as part of the Benthic Health Monitoring in the last two years, in Pahurehure Inlet, Waiuku Inlet, Waimahia Creek (all sampled in October 2012), Mangere Inlet and Anns Creek (sampled in October 2011).

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 2013. Two sampling occasions were missed (October and December 1988) due to a gap in funding. Sites Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS) have been sampled for the ARC 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 Cape Horn by NIWA, without funding from ARC, between February 1993 and December 1995. This data was collected as part of studies conducted on Te Tau Bank, and funded by the Foundation for Research Science and Technology. Sampling at sites EB, KP and PS commenced again in August 2006 on the recommendation of Funnell and Hewitt (2005) for 2 years until June 2008. Monitoring of Cape Horn ceased in June 2010, whilst Auckland Airport and Clarks Beach have remained ongoing.

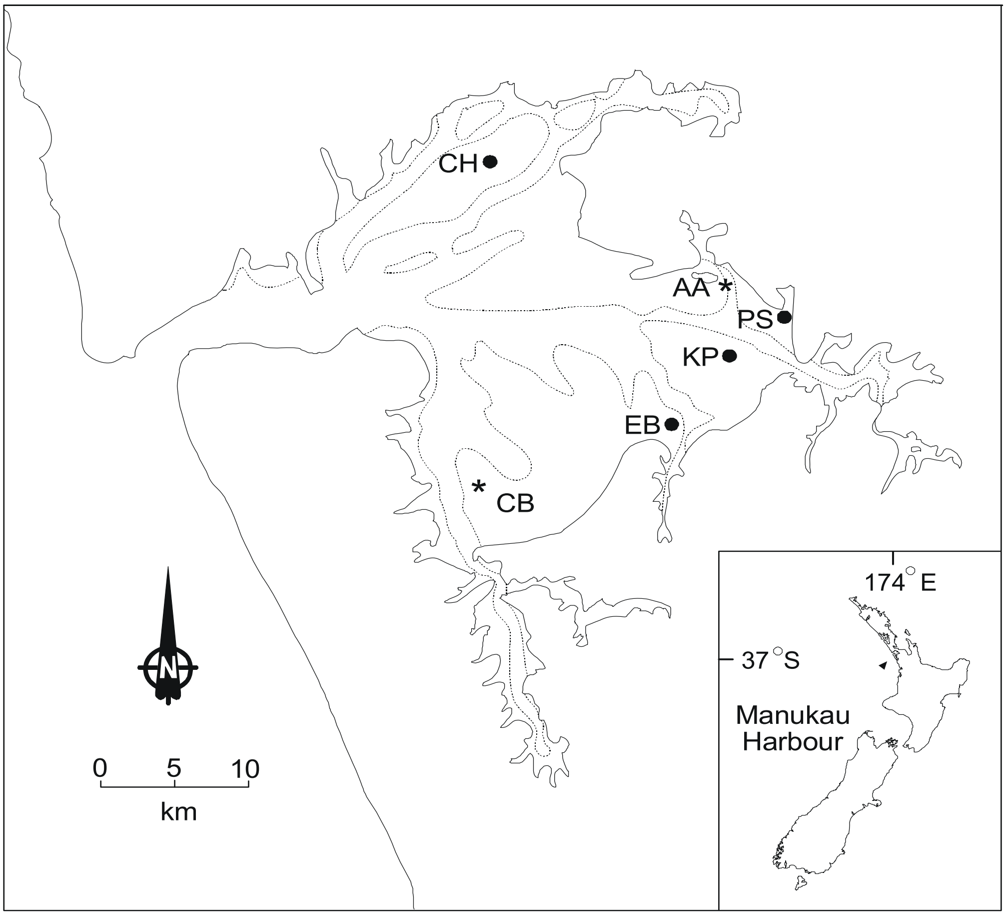

Figure 2-1 Map of Manukau Harbour showing the positions of sites Auckland Airport (AA), Clarks Beach (CB), Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS). The asterisk denotes the two continuously monitored sites, while the others are monitored intermittently.

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, - no sampling,* indicates that no sampling was conducted for AA and CB in October and December 1988 due to a gap in funding. ~ denotes additional sampling conducted at CH as part of NIWA independent study.

	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	-	-	-	-

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 six 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 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 Pahurehure Inlet, Waiuku Inlet and Waimahia Creek was conducted in October 2012, and in Mangere Inlet and Anns Creek in October 2011. 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*, *Macomona liliana*, and *Soletellina siliquens* are measured (longest shell dimension; mm). Originally, a set of nested sieves was used to estimate sizes (1995 – 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 visit, the appearance of the site and the surrounding sand flat is recorded. Any unusual surface sediment characteristics and the presence of ray pits, foraging birds, gastropods and vegetation are noted.

Since August 1999, two small sediment cores (2 cm deep, 2 cm diameter) have been collected from every second macrofauna core location and amalgamated into two containers; one to determine grain-size and organic content and the other for chlorophyll *a* analysis.

Organic matter is removed from a sub-sample of the sediment sample by digestion in hydrogen peroxide. Sediment grain size analysis is then carried out by wet sieving into fractions of gravel (particles >2 mm), coarse sand (particles 500 µm-2 mm); medium sand (particles 250 µm-500 µm); fine sand (particles 63 µm- 250 µm); and mud (particles <63 µm), which are then dried and weighed. Before drying, the mud fraction is analysed by pipette analysis for proportions of silt and clay. A similar procedure was used to determine the sediment characteristics for each in October 1987, although only the gravel, sand and mud fractions were determined.

To determine the organic content, the remainder of the homogenised sediment sample is dried at 60°C to a constant weight and combusted for 5.5 hours at 400 °C. Organic content is determined by the difference in weight of the sample before and after combustion.

Chlorophyll *a* (a proxy of microalgae abundance and food supply to benthic animals) is extracted by freeze-drying then homogenising the sediment, boiling in 90% ethanol, and completing an acidification step to separate degradation products from chlorophyll *a,* this is then measured using a spectrophotometer (Sartory, 1982).

Again, sampling in Pahurehure Inlet, Waiuku Inlet, Waimahia Creek, Mangere Inlet and Anns Creek follows a similar protocol, with the exceptions that chlorophyll a is not analysed for and no site descriptions are taken.

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 ten 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 AA and CB we conducted the following analyses:

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 tested for using Wilcoxon rank tests and, if autocorrelation was present, degrees of freedom were adjusted. Gradual changes were investigated by ordinary least squares regression unless autocorrelation was present. Where autocorrelation was indicated, increasing or decreasing trends were investigated by adjusting parameters and significance levels (AUTOREG procedure, SAS/ETS). In this report, only linear trends and step trends were assessed as investigation of residual variability suggested no other responses. Residuals of statistically significant trends were examined for indications of multi-year cycles; magnitudes of change were assessed relative to previous variation.

Community Analysis

To make an overall assessment of stability of sites over time, we constructed multivariate ordination plots (based on Bray-Curtis dissimilarities of log-transformed data) using monitored taxa only (October abundances). 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 Relative health

To determine the relative health of each site, community compositions, including both monitored and non-monitored taxa, from AA and CB in October 2011 and 2012, Mangere Inlet and Anns Creek in October 2011, and Pahurehure Inlet, Waiuku Inlet and Waimahia Creek in October 2012 were analysed using Benthic Health Models (BHM) and the functional Traits Based Indicator (TBI) index (previously named NIWACOOBII) (Lohrer and Rodil, 2011; van Houte-Howes and Lohrer 2010).

The TBI index was developed for the Auckland Council by NIWA to provide an understandable and scientifically defensible indicator of the ecological integrity of its estuarine and coastal areas. The index is based upon the richness of macrofaunal taxa in each of seven defined functional trait groups (e.g., organism size, mobility, feeding mode, position in the sediment, etc.). The index value ranges from 0 to 1, with 0 indicating highly degraded sites and 1 indicating a functionally rich site. Declines in TBI scores with increases in mud and heavy metal concentrations are interpreted as losses of functional redundancy. Habitats with high functional redundancy (i.e., many species present in each functional trait group) will tend to have higher inherent resistance and resilience in the face of environmental changes, as the higher numbers of species per functional group provide “insurance” for stochastic or stress-induced losses of particular species.

The list of taxa found in a particular set of samples (i.e., the 12 replicates from a specific site in October 2011) was matched to the functional traits database and scores were assigned. The scores were added together (SUM_{actual}) and used in the formula below:

$$1 - (SUM_{max} - SUM_{actual})/SUM_{max} \quad ,$$

Where SUM_{max} is a maximum summed score for 12 replicates derived from empirical data by Lohrer and Rodil (2011) to indicate a maximally healthy site. The SUM_{max} value for 12 replicates is

226.39. SUM_{actual} is a summed score based on the 12 replicates collected at a particular site of interest at a particular time.

The BHM was developed by the Auckland Council to provide a tool for classifying sites within the region according to categories of relative ecosystem health, based on multivariate analysis of community composition responses to storm-water contamination (now called BHM_{metal}). Stormwater contamination was represented by a single composite variable produced by PCA (Principle Components Analysis) of copper, lead and zinc concentrations in the sediment. Later, the BHM_{mud} was added, a multivariate analysis of community composition responses to sediment mud content. The Benthic Health Models (BHM_{mud} and BHM_{metal}) were used to assess the influence of mud content and contamination by copper, lead and zinc, respectively, on all taxa from October 2011 and 2012 benthic communities (Anderson et. al 2006, Hewitt and Ellis 2010) using the first 10 replicates[1] only for the AA and CB sites

[1] 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.

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?

3.1 General site descriptions

Site characteristics such as appearance and sediment features 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.

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 3-1) and an abundance of ray pits, 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 2013 gastropods (i.e., *Zeacumantus lutulentus* and *Cominella glandiformis*) have been common. 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.

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*) on the sediment surface increased up until August 2010,after which no further change have been observed. A diatom mat was present towards the shore near 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 AA a) monitored area and b) sediment surface.

Clarks Beach (CB)

The appearance of this site is temporally variable. The site topography changes between being dominated by ripples (1 cm wave height, 1 cm period) and a mosaic of ripples, flat sediment, hillocks and *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 (Figure 3-2). Patches of *Zostera* are still common within the monitored area and at present are covering 5% of the site. *Zostera* fluctuates in its coverage of the site, first appearing in 1999 (Funnell et al. 1999) and increasing in abundance until disappearing by 2002. Upon reappearing in June 2005, its distribution has varied between 2-30 m^{-2}. Since February 2011 *Zostera* has been encroaching into the site in the 0,0 corner (Figure 3-2c-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)

e)

f)

Figure 3-2 Photographs of site CB of a) sediment surface, b) the sediment surface when *Gracilaria* sp. is abundant, c-f) encroachment of *Zostera muelleri* at 0,0 corner in April 2011, April 2012, August 2012 and April 2013, respectively.

3.2 Are there any trends in sediment characteristics?

The bimonthly sediment grain size, chlorophyll *a* and organic content data for both monitoring sites AA and CB are given in Appendix 7.2. No significant changes have been observed in the past two years, and no long-term trends are apparent. A summary is presented below.

Grain size

Between February 2011 and February 2013, there have been no changes in the sediment grain size composition with both sites remaining predominantly sandy, AA more so than CB (Figure 3-3 and Figure 3-4). The per cent mud content at site CB continues to be variable and has ranged between 1.66 – 15.58% within the last two years. Seasonal peaks of high mud content are particularly noticeable at site CB with the highest per cent mud typically observed during the winter months. Site AA continues to have the lowest per cent mud content of the two sites, with an average per cent mud content over the last two years of 0.83%. The gravel and sand fractions of the sediment at each of the sites are also consistent with that reported in February 2010 (Figure 3-4).

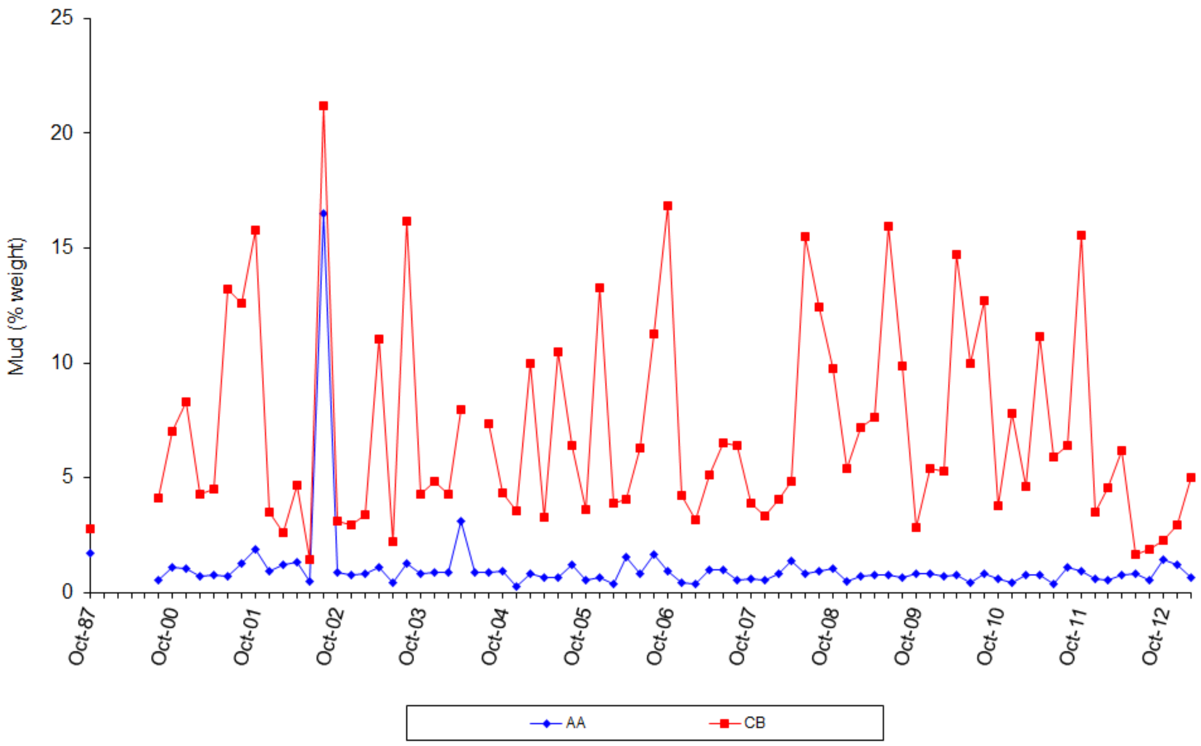

Figure 3-3 Sediment mud (silt and clay) content (% weight) at the monitored sites between October 1989 and February 2013.

Figure 3-4 Changes in the proportions of gravel/shell (>2 mm), sand (coarse <2 mm to fine >63 um) and silt/clay (i.e., mud <63 um) at each of the monitored sites (Auckland Airport, Clarks Beach, Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream) over the entire monitoring period (October months only).

Chlorophyll *a*

The chlorophyll *a* values at both sites have remained consistent with the past time series, showing an irregular multi-year cycle of 2 -3 years at both sites. Chl *a* concentrations at AA and CB varied between 7.68-14.56 and 9.97-16.28 µg/g sediment respectively over the last two years.

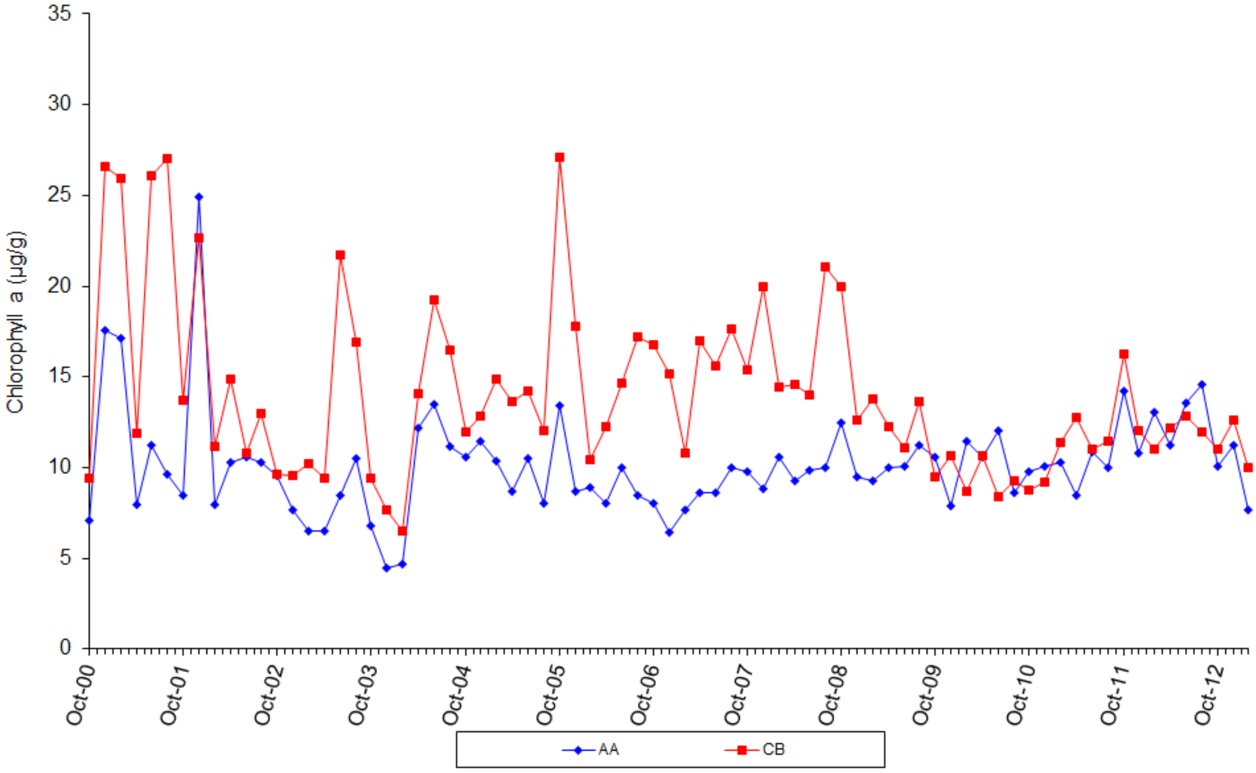

Figure 3-5 Chlorophyll *a* levels (µg/g sediment) of sediment collected from monitoring sites between August 2000 and February 2013.

Organic content

Sediment organic content at the AA and CB sites has been low and variable throughout the monitored period (October 2000 – February 2013, Figure 3-6). Annual averages at AA are always lower than at CB and average organic content at AA and CB over the last two years has been 0.53 and 1.15% respectively.

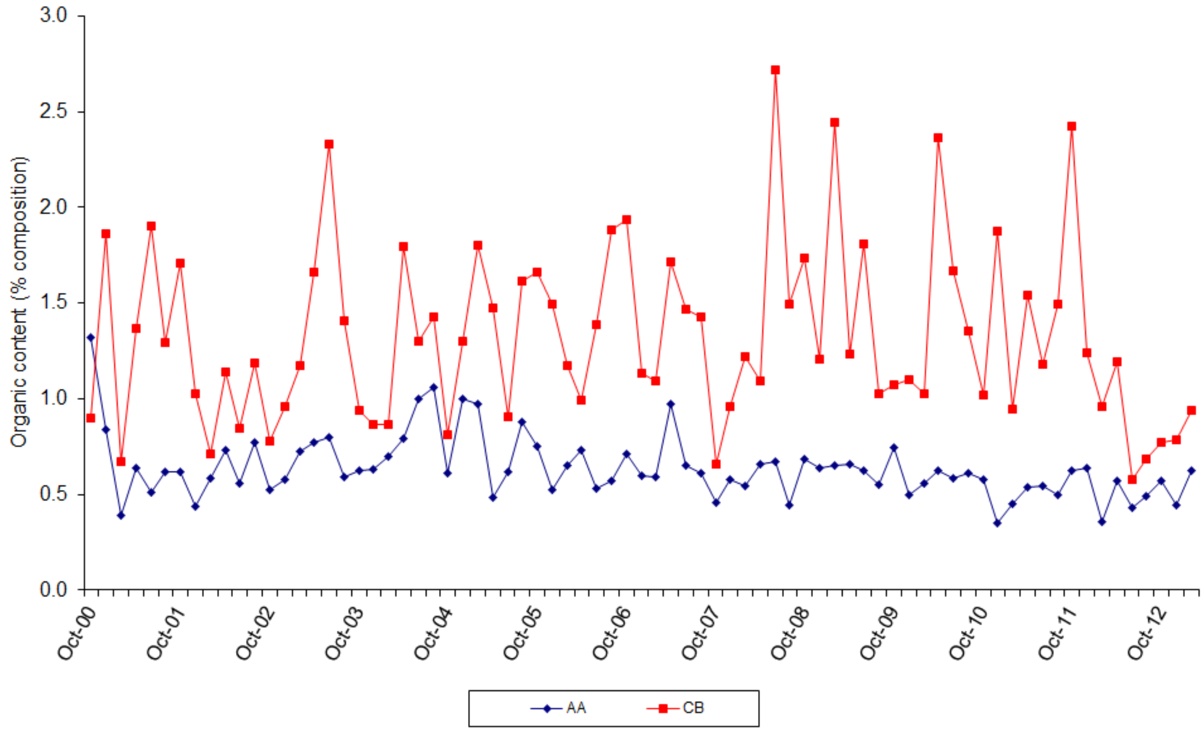

Figure 3-6 Percentage organic content of sediment collected from monitoring sites between October 2000 and February 2013.

3.3 Are there any trends in abundance of monitored taxa?

Over the first 10 years of the monitoring programme a decreasing trend in the abundance of *Aonides* at AA was observed (Figure 3-7). 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). Since then, there are indications that another increase in abundance is occurring, however this is not statistically significant and may prove to be part of a long-term cycle.

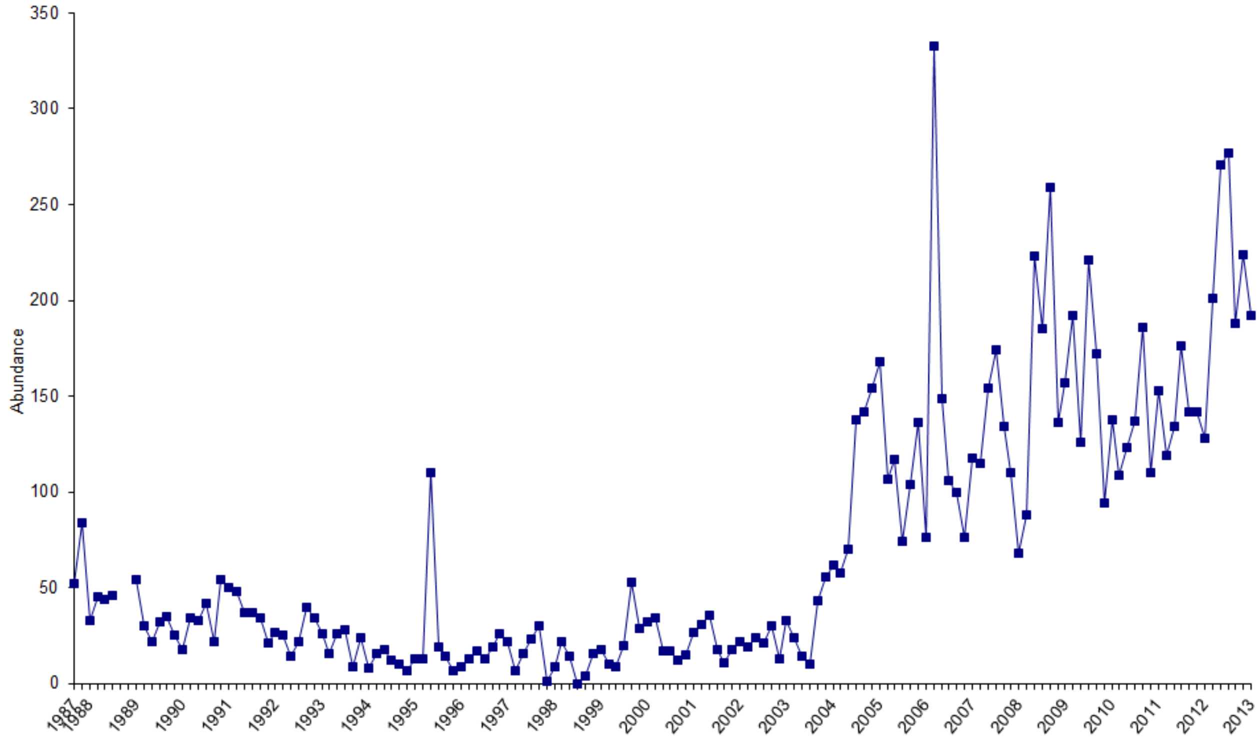

Figure 3-7 Abundance (sum total of 12 replicate cores) of *Aonides trifida* at Auckland Airport from October 1987 until February 2013.

At site CB, with an additional two years of data, the increasing trend of the abundance of *Anthopleura* post 2004 (Figure 3.9), reported by Hailes and Hewitt (2011) is now recognised as a step trend in abundance (p = 0.001), where, since February 2010, abundances appear to have stabilised at a new level.

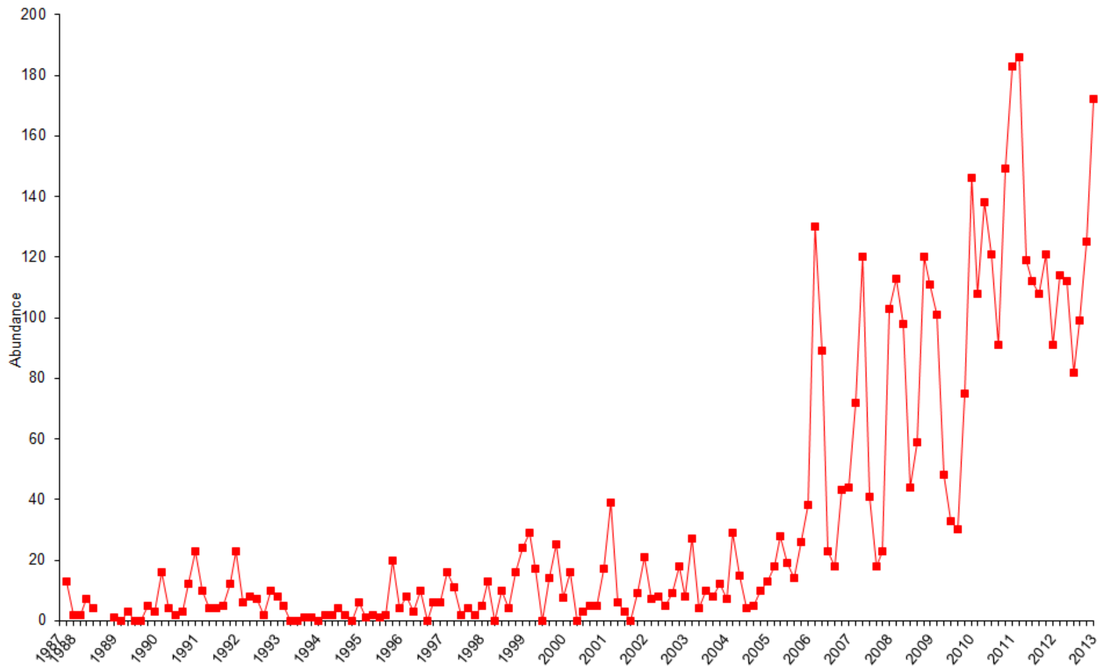

Figure 3-8 Abundance (sum total of 12 replicate cores) of *Anthopleura aureoradiata* at Clarks Beach from October 1987 until February 2013.

Prior to 2007, baseline abundances of *Owenia petersonae* at CB varied between 0 – 15. Since then, they have been steadily increasing ($p = 0.0021$) (Figure 3-9).

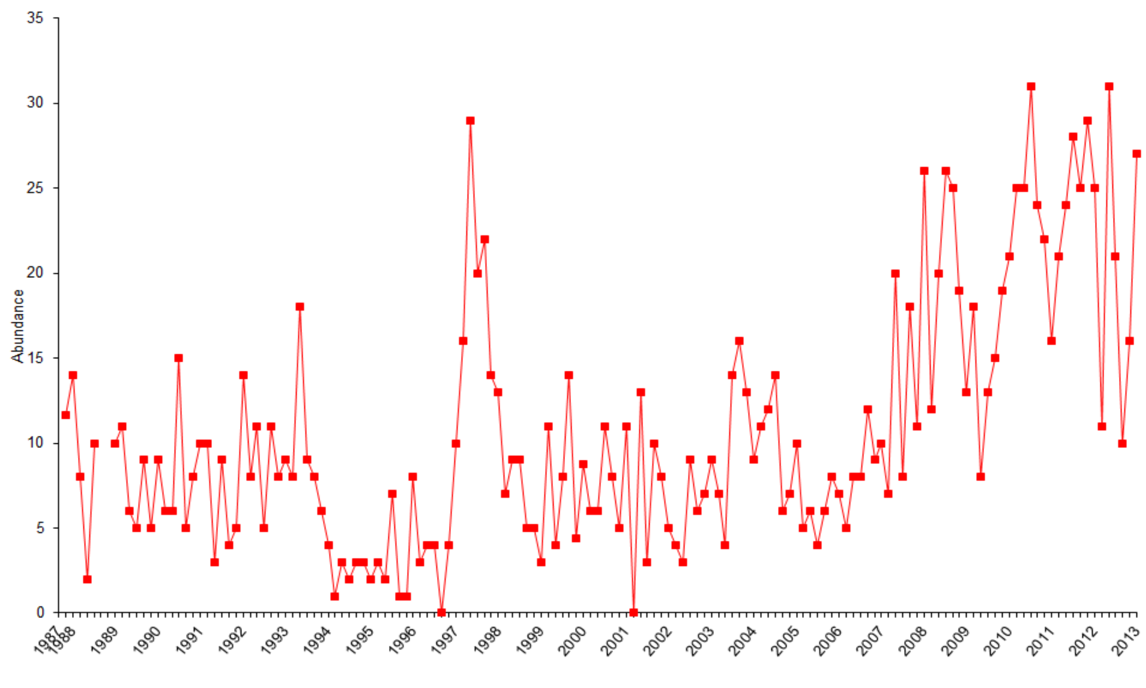

Figure 3-9 Abundance (sum total of 12 replicate cores) of *Owenia petersonae* at Clarks Beach from October 1987 until February 2013.

3.4 Are cyclic patterns in monitored taxa abundances being maintained?

Throughout the monitored period, a number of the monitored taxa have exhibited seasonality in abundance with definite recruitment peaks, although these have varied in terms of timing and magnitude. As reported by Hailes and Hewitt (2009) and Hewitt and Thrush (2009), long term population dynamics can be correlated with environmental variables including El Niño Southern Oscillation cycles and local changes in wind and water temperature and management activities. Many species were reported to correlate well with the El Niño Southern Oscillation cycles, although not necessarily at all sites. Such cycles will continue to affect species abundances in the Manukau to varying extents. For example, the abundance of *Magelona* at all sites is still maintaining this greater than annual cycle (6-10 years) detectable over the entire monitoring period (Figure 3-10).

Table 3-1 Monitored species and whether they are exhibiting multi-year cycles of abundance, seasonal patterns or no detectable pattern. - indicates that no trends were present; usually due to low numbers.

2012/13	AA	CB
Aglaophamus macroura	Multi-year cycles: 2-4years within much longer cycle.	-
Anthopleura aureoradiata	Seasonal cycle.	Seasonal cycle.
Aonides trifida	Seasonal cycle.	-
Austrovenus stutchburyi	Seasonal cycle. Multi-year cycle: 7-9 years	Multi-year cycle: 2 and 6 years.
Boccardia syrtis	-	Seasonal cycle. Multi-year cycle: 5-7 years.
Colurostylis lemurum	Multi-year cycle: 2-6 years of irregular magnitude.	Multi-year cycle: 2 and 6 years.
Exosphaeroma spp.	Multi-year cycle: 2-4 years of irregular magnitude.	Multi-year cycle: 2-4 years of irregular magnitude.
Glycinde trifida	Multi-year cycle: 6 to in excess of 20years with peak in middle of time series. Has been absent at site generally since late 2010.	Multi-year cycle: 3-6 years. Has been absent at site generally since late 2010.

2012/13	AA	CB
Macomona liliana	Multi-year cycle: 4-7 years.	Multi-year cycle: 4-7 years.
Macroclymenella stewartensis	-	Multi-year cycle: 3-5 years of irregular magnitude
Magelona dakini	Multi-year cycle: 6-10 years.	Multi-year cycle: 6-9 years.
Methalimedon sp.	-	Seasonal cycle. Multi-year cycle: 2-5 years.
Notoacmea scapha	Multi-year cycle: 2-3 years.	Multi-year cycle: 5-6 years. NB: very high abundances 2010-13.
Nucula hartvigiana	Multi-year cycle: 3 and 6-7 years.	Multi-year cycle: 3-6 years. NB very high recruitment occurred in 2011.
Orbinia papillosa	Multi-year cycle: 2-4 years.	-
Owenia petersonae	-	Multi-year cycle: 8-10 years. Numbers have been increasing since 2009-10.
Prionospio aucklandica	Seasonal cycle.	Multi-year cycle: 4-6 years.
Soletellina siliquens	Multi-year cycle: 7-9 years.	Multi-year cycle: 7-9 years.
Torridoharpinia hurleyi	Multi-year cycle: 6-8 years.	Multi-year cycle: 6-8 years.
Travisia olens	Multi-year cycle: 2-3 and 5-7 years.	-

2012/13	AA	CB
Trochodota dendyi	Multi-year cycle: 5-7 years. Recruitment peaks have been higher since 2003.	Multi-year cycle: 5-6 years.
Waitangi brevirostris	Multi-year cycle: 2-5 years of irregular magnitude.	-

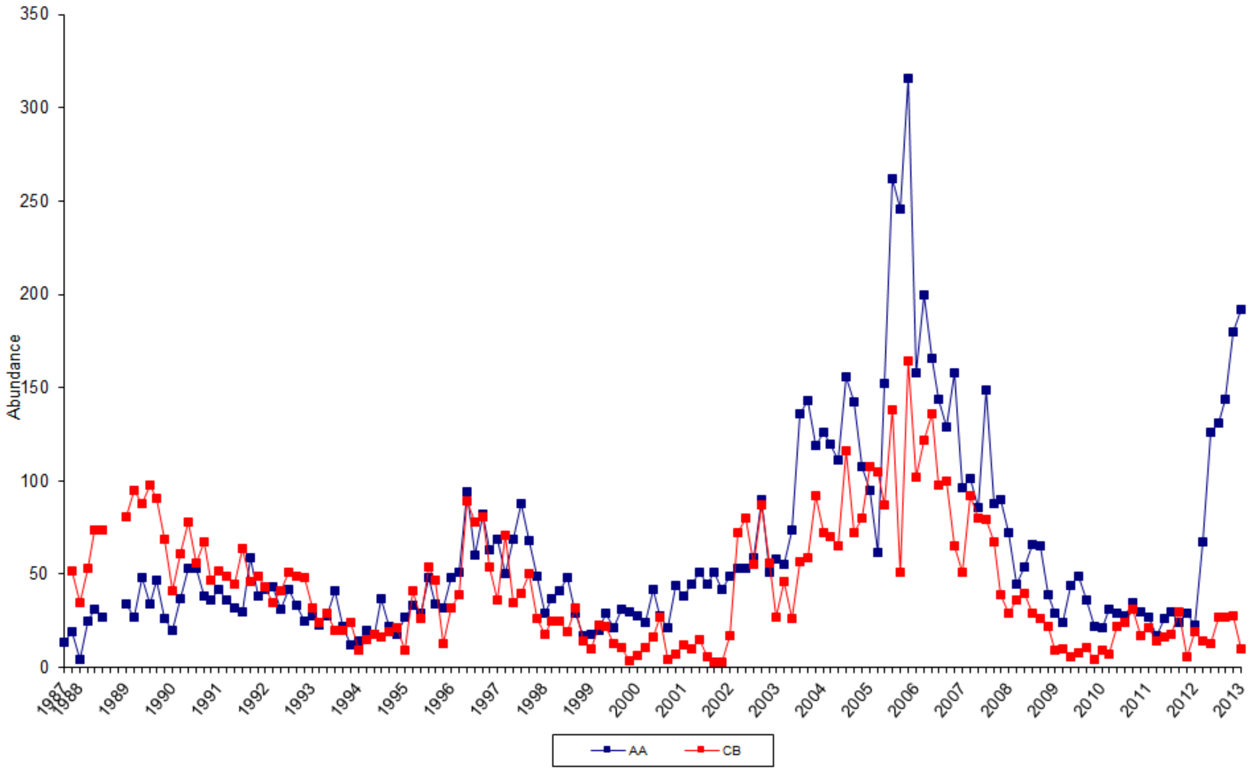

Figure 3-10 Abundance (sum total of 12 replicate cores) of *Magelona dakini* at Auckland Airport and Clarks Beach from October 1987 until February 2013.

Soletellina siliquens is also displaying a multi-year cycle of 7-9 years and was also reported by Hailes and Hewitt (2009) to be correlated with the El Niño Southern Oscillation cycle. After two more years of data, this cycle is still being maintained (Figure 3-11). At AA, 15 of the monitored taxa are displaying obvious multi-year cycles, including *Colurostylis lemurum*, *Glycinde trifida* and *Orbinia papillosa* (Table 3-1). At site CB, 16 of the monitored species are displaying multi-year cycles (Table 3-1), e.g., *Prionospio aucklandica* has a 4 – 6 year cycle (Figure 3-12). 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 *Trochodota dendyi* (CB).

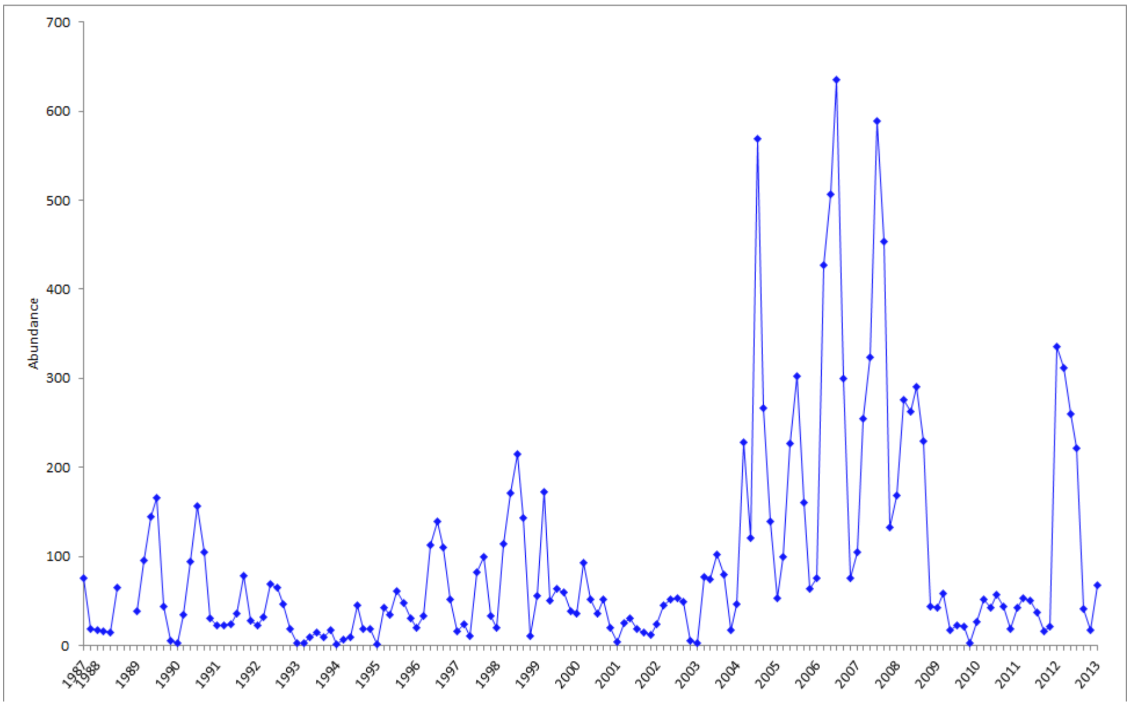

Figure 3-11 Abundance (sum total of 12 replicate cores) of *Soletellina siliquens* at Auckland Airport from October 1987 until February 2013.

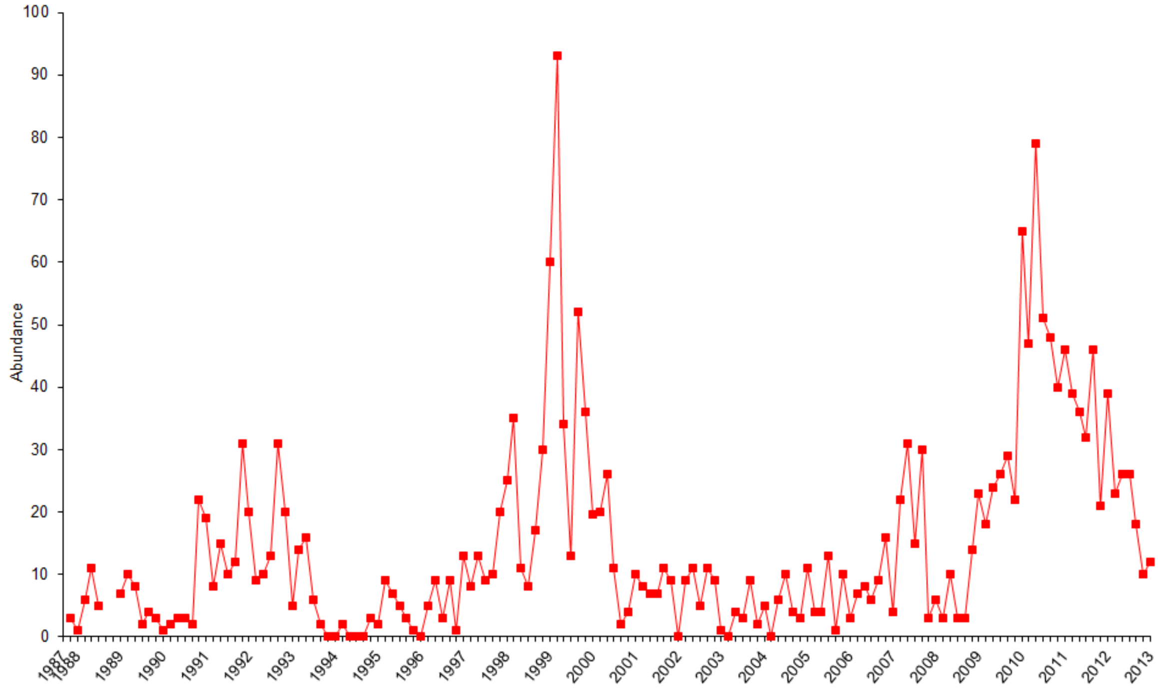

Figure 3-12 Abundance (sum total of 12 replicate cores) of *Prionospio aucklandica* at Clarks Beach from October 1987 until February 2013.

The abundance of *Nucula hartvigiana* at CB continues to be highly variable, with very high recruitment peaks during 2011 and 2012 (Figure 3-13), similar to those in 1997/8. Other species that have recently had a large recruitment peak include *Austrovenus* (peak abundance of 123 individuals in 12 replicate cores, in December 2010; Figure 3-17) and *Notoacmea scapha* (reaching an abundance of 108 individuals in 12 replicate cores, in February 2011). However, abundances of *Austrovenus* have declined in the past two years, while abundances of *Notoacmea* have remained high, peaking in December 2011 with 178, with an average of 108 (total per 12 replicate cores) (Figure 3-14). For both *Nucula* and *Notoacmea*, a further two years of data is necessary to confirm whether these higher abundances will persist.

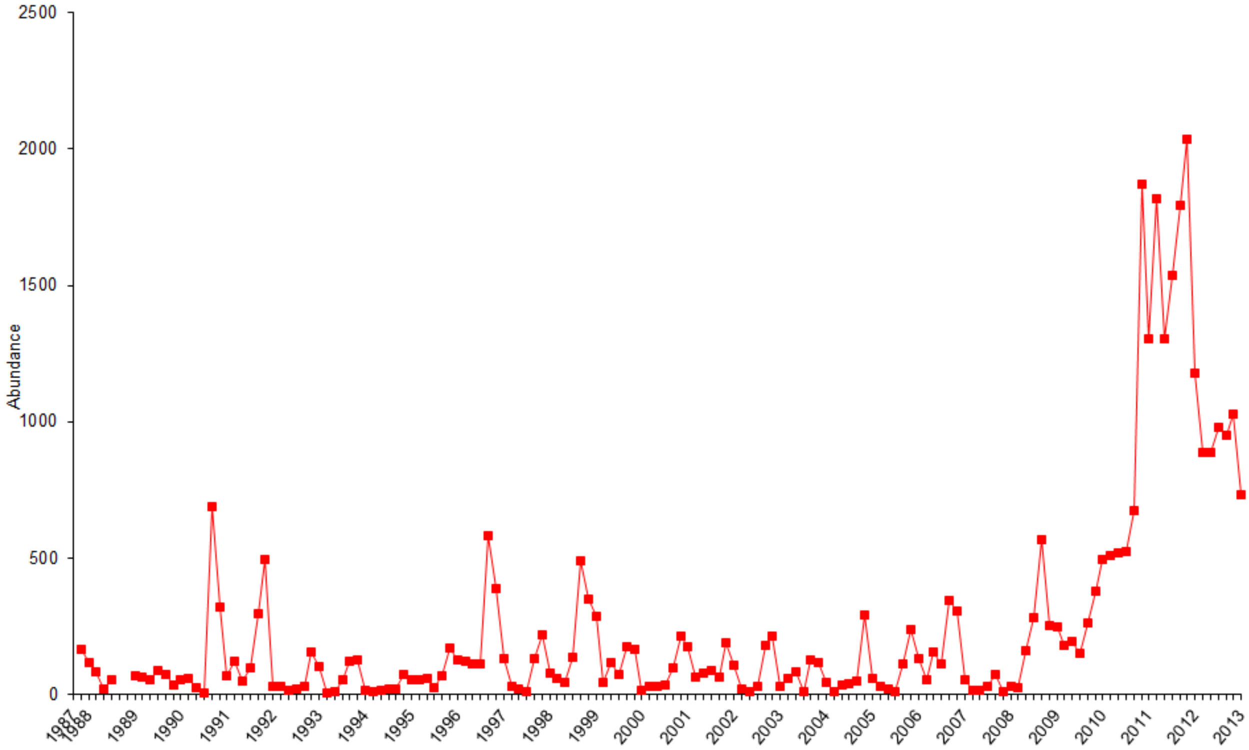

Figure 3-13 Abundance (sum total of 12 replicate cores) of *Nucula hartvigiana* at Clarks Beach from October 1987 until February 2013.

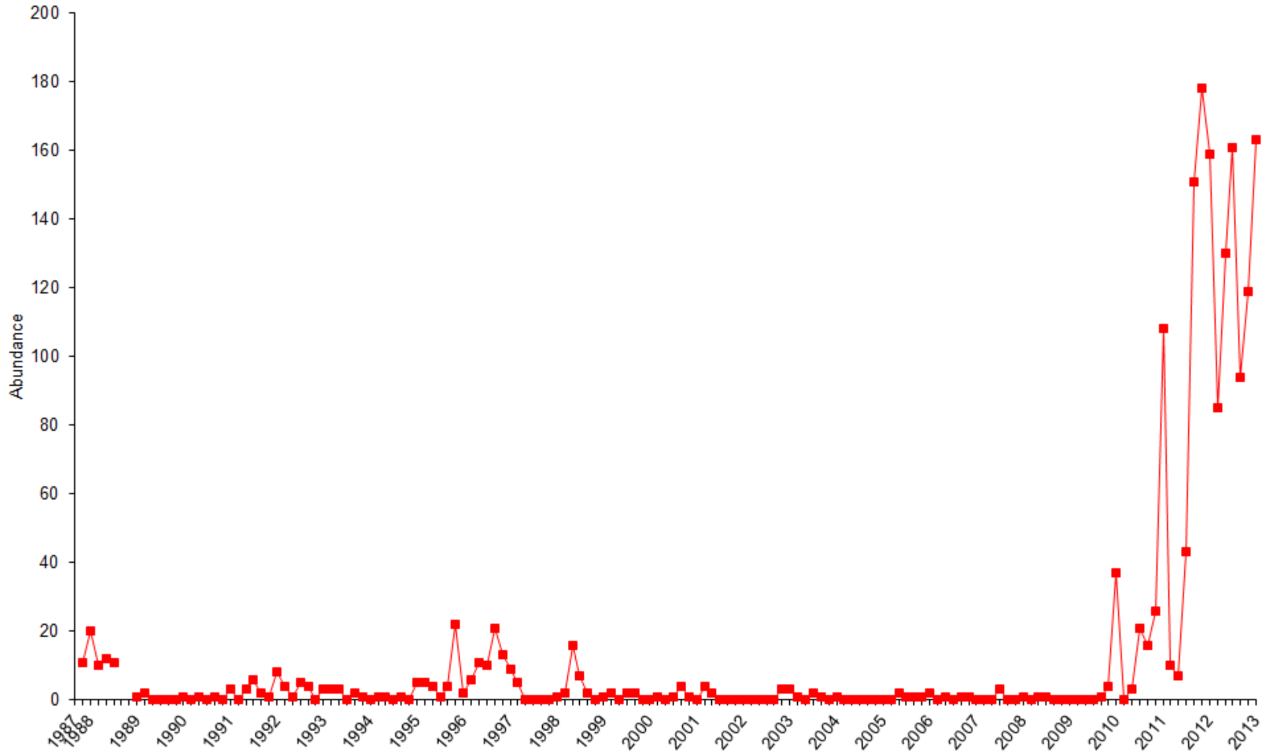

Figure 3-14 Abundance (sum total of 12 replicate cores) of *Notoacmea scapha* at Clarks Beach from October 1987 until February 2013.

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 (Figure 3-15). Although there is notably low abundance of adults sized greater than 20 mm in October 2012 (Figure 3-15), there were 19 individuals in the 15-20 mm size class (highest total of this size class recorded to date). Had we been plotting individuals sized greater than 15 mm there would have been no drop in abundances observed in October 2012. Current data shows a continuation of the decreasing trend from 2008 of *Macomona* juveniles at CB, to levels previously observed at some sampling times between 2003 and 2007. A three year lagged decrease in adult abundances was observed during 2011 and much of 2012, but in December 2012 and February 2013 increased abundances were observed (Figure 3-15).

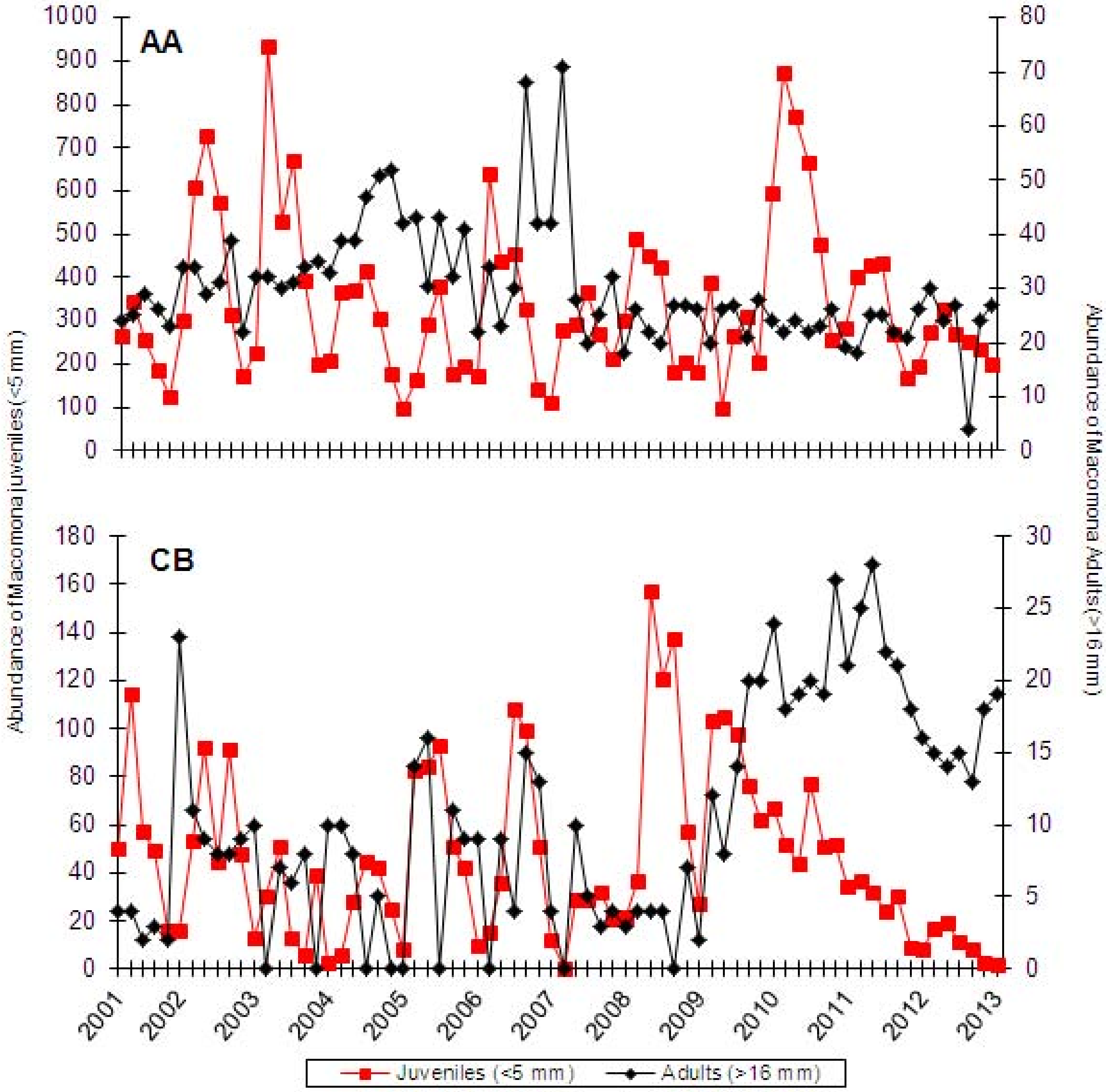

Figure 3-15 Abundance (sum total of 12 replicate cores) of juvenile (<5 mm; red line) and adult (>16 mm; black line) *Macomona liliana* from sites Auckland Airport and Clarks Beach from April 2001 until February 2013.

Although the abundance of adult *Austrovenus* at site AA is usually low across the entire monitoring period, the abundance of juveniles is much greater and shows a 3 – 4 year cycle (Figure 3-16). At 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 2010/2011 (Figure 3-17).

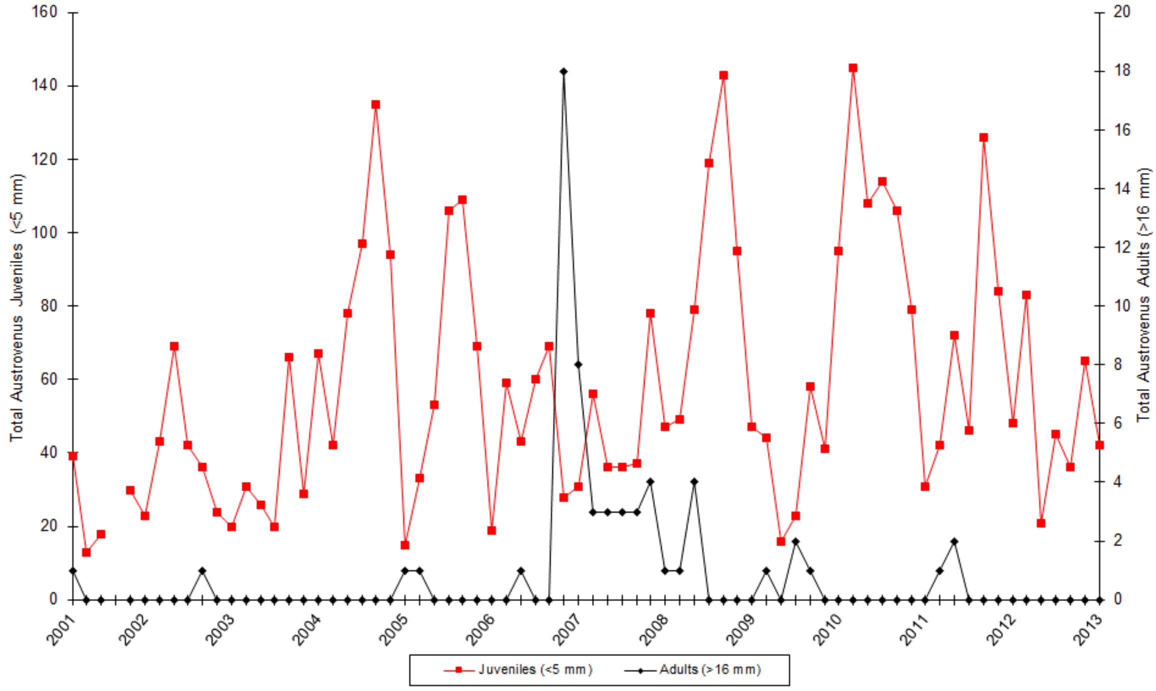

Figure 3-16 Abundance (sum total of 12 replicate cores) of juvenile (<5 mm) *Austrovenus stutchburyi* from Auckland Airport April 2001 until February 2013.

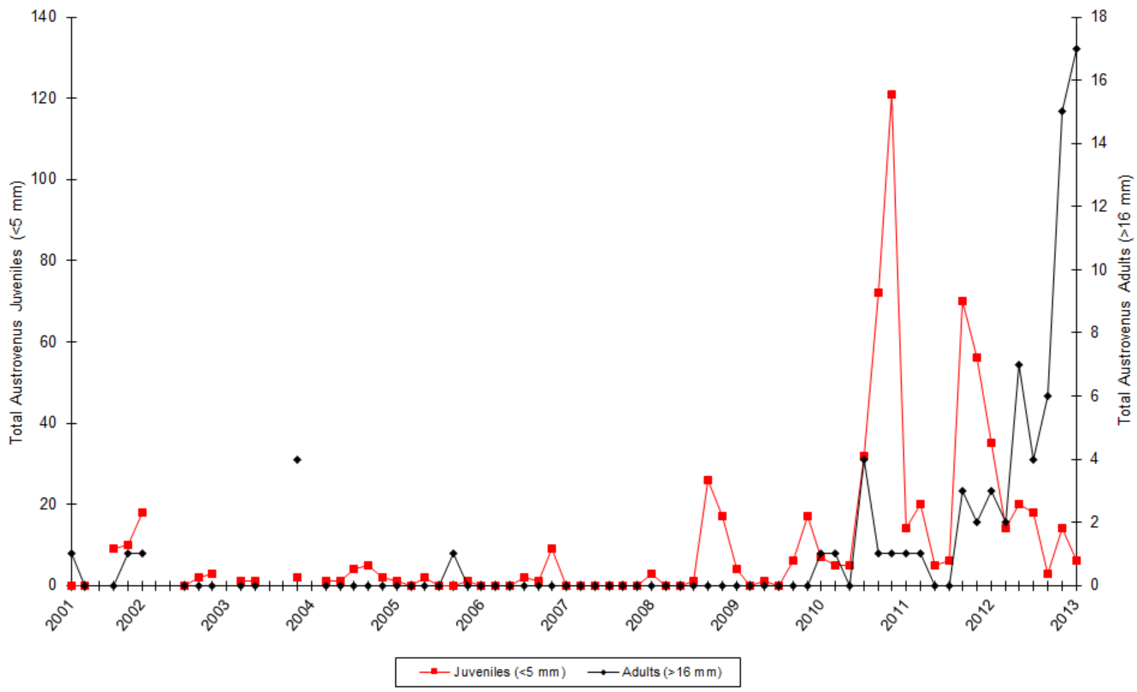

Figure 3-17 Abundance (sum total of 12 replicate cores) of juvenile (<5 mm) and adult (>16 mm) *Austrovenus stutchburyi* from Clarks Beach from April 2001 until February 2013.

3.5 Are there any trends in benthic 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 community is almost always largely dominated by bivalves *Macomona liliana*, *Soletellina siliquens* and *Austrovenus stutchburyi*. These bivalve species contribute most to the similarity of the communities at AA over time. The most abundant polychaetes are *Aonides trifida, Magelona dakini*, *Travisia olens*, *Orbinia papillosa* and *Trochodota dendyi*, with the cumacean *Colurostylis lemurum* 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 81.41% (based on Bray-Curtis index) between October 1987 and October 2012) and it remains the site most distinct from the others (Figure 3-18). AA demonstrates very little change over time, with the October 2012 sampling well within the ambit of previous years (Figure 3-18).

Site CB is dominated by a mixture of bivalves (i.e., *Nucula hartvigiana* and *Macomona*), polychaetes (i.e., *Macroclymenella stewartensis* and *Magelona dakini*) and the amphipod *Torridoharpinia hurleyi* (Appendix 7.3). This site is more variable over time in monitored species than AA (communities exhibited 76.2% similarity in community composition (based on Bray-Curtis index) between October 1987 and October 2012). CB generally shows more variability over time, with the past 2 years just outside its previous ambit (Figure 3-18).

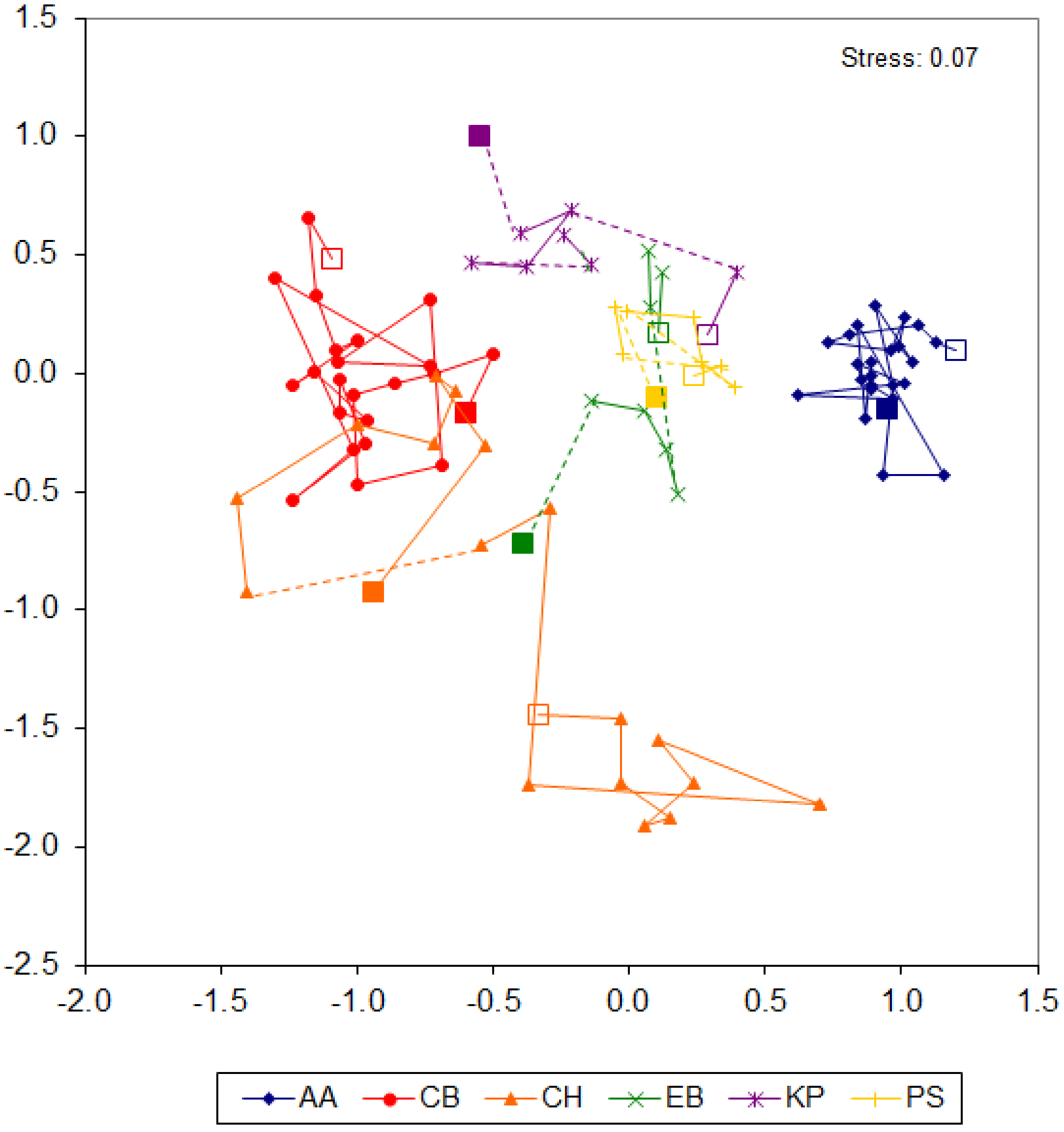

Figure 3-18 Multi-dimensional Scaling (MDS) plot of the dissimilarity in macrofaunal communities over time (October 1987-October 2010) (Log transformed data).The earliest sampling occasion is denoted by a closed square and the most recent is denoted by an open square. The further away the points are in the ordination space, the more dissimilar the community composition is. Dashed lines join periods of sampling when times were missed. Sites not presently monitored have been left in the analysis for comparison.

4.0 Benthic health within the harbour

4.1 Do any of the observed temporal patterns indicate important changes?

Most of the monitored taxa exhibit seasonal and multi-year cycles in abundance at both sites, likely correlated with environmental variables including local temperature and the El Niño Southern Oscillation cycle (Hailes and Hewitt, 2009). The step trends in abundance that occurred for *Aonides* at site AA and *Anthopleura* at CB in 2004-05 are still in existence, with indications that another increase may be occurring for *Aonides* at AA.. Since 2007 abundances of *Owenia* have increased at site CB. However, none of these species are showing changes at both sites, suggesting that they may be a result of local variations. If they continue, the next sequential report will investigate whether climatic conditions or environmental variation are driving the changes.

During the last two years, there has been no evidence to suggest there have been detrimental effects on communities at sites in the main body of Manukau Harbour. Abundances of monitored species have remained similar to that described in 2011 and long multi-year cycles are still maintained. Communities are still healthy and exhibiting natural temporal variability rather than trends associated with anthropogenic stressors. Site AA is only showing a trend in one species (*Aonides*: an increasing trend in a species that prefers sandy conditions). Site CB exhibits trends in two species (increases in *Anthopleura* and *Owenia*), *Anthopleura* also prefers sandy conditions.

4.2 Relative health across the harbour

TBI scores have been calculated using the latest TBI formula (Lohrer and Rodil 2012) and October data from each site. Note that the values quoted in this report will not be directly comparable to NIWACOOBII results presented by Hailes and Hewitt (2011) because improvements to the formula have been made in the intervening period (for example, to allow the formula to be used across a greater range of sites and when those sites are sampled with differing numbers of replicates). However, a valid assessment of temporal trends in TBI scores over time at Manukau's AA and CB sites is presented in Hewitt et al. (2012); no trends over time were reported for AA and CB in that report. TBI scores for October 2011 and October 2012 were 0.38 and 0.44 for AA, and 0.65 and 0.75 for CB. 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 0.3 and 0.4 indicate potentially reduced functional redundancy, but are only concerning if the sediment is <95% sand (site AA is >97% sand). The TBI value for Pahurere Middle was 0.32, less than site AA and in a muddier environment, indicating reduced functional redundancy. TBI values for all the other sites were < 0.3, ranging from 0.23 at Waimahia to 0.15 at Waiuku. Thus, all the other sites indicate 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 4-1). CAPmetal and CAPmud scores for AA are within the ambit observed over the rest of the monitoring period (Hewitt et al. 2012) and give a “very good” score. Both CAPmetal and CAPmud scores have shown slight improvements for CB since 2010, and are within ambit of the full monitoring period rating a “good”. Pahurere Middle is also classified as “good” health relative to metal contamination and mud content. Waimahia, Puhurere Upper and Papakura are all classified as “poor” for contamination and mud, while Anns Creek is classified as “unhealthy” for both. Mangere and Waiuku are both classified as “poor” with respect to contaminants, but “unhealthy” with respect to mud content. Data from Mangere Inlet (specifically from Anns creek in 2002 and 2005 and from a number of other sites in 2005) formed part of the BHM model dataset. At this time, Anns Creek was classified as in poor health for contaminants and unhealthy for mud, with other sites being similar.

Table 4-1 Benthic Health Model scores for metals and mud (CAPmetal, CAPmud) and TBI scores for AA and CB for October 2010, 2011 and 2012 and additional sediment tidal creek sites for 2011 or 2012.

Site	Year	CAPmetal	group	CAPmud	group	TBI
AA	2011	-0.202	1	-0.150	1	0.38
	2012	-0.21872	1	-0.148	1	0.44
CB	2011	-0.063	3	-0.079	2	0.65
	2012	-0.089	2	-0.100	2	0.75
Anns Creek	2011	0.134	5	0.137	5	
Mangere	2011	0.100	4	0.109	5	
Waimahia	2012	0.035	4	0.047	4	0.23
Pahurere Middle	2012	-0.090	2	-0.077	2	0.32
Pahurere Upper	2012	0.043	4	0.079	4	
Papakura	2012	0.055	4	0.041	4	
Waiuku	2012	0.080	4	0.128	5	0.15

5.0 Summary and recommendations

The ecological monitoring of Manukau Harbour over the last 25 years has allowed the Auckland Council to state with authority that despite ongoing urbanisation and industrialisation in catchments adjacent to Manukau Harbour, and the poor health of some of the inlets, the extensive sand flats within the main body are not becoming degraded. The continuation of bimonthly monitoring at sites AA and CB is recommended and is important, as they provide a template for temporal patterns of species abundance against which the other sites are assessed. In accordance with the site monitoring design, all six sites are to be monitored during the 2013/14 period. This will allow us to determine whether any specific areas of the Manukau are changing relative to the others.

Furthermore, 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).

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8.0 Appendices

8.1 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 and 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 and 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 bedload 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 and Norkko 2007) and stormwater contaminants (Hewitt et al. 2009).

- *Macomona liliana*

Macomona liliana (previously *Tellina 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 bedload 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).

- *Nucula hartvigiana*

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 and Rosenberg 1978). It is somewhat sensitive to sediment mud content (optimum 0–12, Thrush et al. 2003; Gibbs and Hewitt, 2004; Anderson et al. 2007) and copper (Hewitt et al. 2009).

- *Soletellina siliquens*

Soletellina siliquens (previously *Hiatulasiliqua*) 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 and 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 and Hewitt, 2004).

Echinodermata: Holothuroidea

- *Trochodota dendyi*

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. waitematensis*. 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) 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 and 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 petersonae*

Owenia petersonae (previously *O. fusiformis*) is a cosmopolitan species frequently abundant in sand flats and builds large tubes from heavy sand grains. Their tube structures may influence larval settlement (including providing an attachment surface for *Musculista 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 is a large deposit-feeding opheliid, often seen lying on the sediment surface. It is slightly mobile, and prefers sandy sediment, <5% mud (Gibbs and Hewitt 2004).

8.2 Sediment characteristics from April 2009 to February 2013

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).

	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

8.3 The three most abundant species found in October each year at AA and CB

AA	Rank 1	Rank 2	Rank 3
1987	*Macomona liliana*	*Soletellina siliquens*	*Austrovenus stutchburyi*
1989	*Macomona liliana*	*Austrovenus stutchburyi*	*Magelona dakini*
1990	*Macomona liliana*	*Soletellina siliquens*	*Austrovenus stutchburyi*
1991	*Macomona liliana*	*Austrovenus stutchburyi*	*Nucula 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*	*Soletellina siliquens*
1996	*Macomona liliana*	*Soletellina siliquens*	*Magelona dakini*
1997	*Macomona liliana*	*Soletellina siliquens*	*Austrovenus stutchburyi*
1998	*Macomona liliana*	*Soletellina siliquens*	*Austrovenus stutchburyi*
1999	*Macomona liliana*	*Orbinia papillosa*	*Soletellina siliquens*
2000	*Macomona liliana*	*Soletellina siliquens*	*Orbinia papillosa*
2001	*Macomona liliana*	*Magelona dakini*	*Trochodota dendyi*
2002	*Macomona liliana*	*Magelona dakini*	*Trochodota dendyi*
2003	*Macomona liliana*	*Magelona dakini*	*Nucula hartvigiana*

AA	Rank 1	Rank 2	Rank 3
2004	*Macomona liliana*	*Soletellina siliquens*	*Aonides trifida*
2005	*Macomona liliana*	*Magelona dakini*	*Soletellina siliquens*
2006	*Macomona liliana*	*Soletellina siliquens*	*Colurostylis lemurum*
2007	*Soletellina siliquens*	*Macomona liliana*	*Aonides trifida*
2008	*Aonides trifida*	*Macomona liliana*	*Soletellina siliquens*
2009	*Macomona liliana*	*Aonides trifida*	*Travisia olens*
2010	*Macomona liliana*	*Aonides trifida*	*Colurostylis lemurum*
2011	*Macomona liliana*	*Aonides trifida*	*Austrovenus stutchburyi*
2012	*Macomona liliana*	*Aonides trifida*	*Magelona dakini*

CB	Rank 1	Rank 2	Rank3
1989	*Macroclymenella stewartensis*	*Macomona liliana*	*Torridoharpinia hurleyi*
1990	*Nucula hartvigiana*	*Boccardia syrtis*	*Macroclymenella stewartensis*
1991	*Nucula hartvigiana*	*Macomona liliana*	*Macroclymenella stewartensis*
1992	*Macroclymenella stewartensis*	*Macomona liliana*	*Torridoharpinia hurleyi*
1993	*Macroclymenella stewartensis*	*Boccardia syrtis*	*Nucula hartvigiana*
1994	*Macomona liliana*	*Macroclymenella stewartensis*	*Torridoharpinia hurleyi*
1995	*Nucula hartvigiana*	*Magelona dakini*	*Macroclymenella stewartensis*
1996	*Nucula hartvigiana*	*Boccardia syrtis*	*Torridoharpinia hurleyi*
1997	*Nucula hartvigiana*	*Boccardia syrtis*	*Macomona liliana*
1998	*Nucula hartvigiana*	*Macomona liliana*	*Torridoharpinia hurleyi*
1999	*Macroclymenella stewartensis*	*Nucula hartvigiana*	*Macomona liliana*
2000	*Nucula hartvigiana*	*Macomona liliana*	*Macroclymenella stewartensis*
2001	*Macomona liliana*	*Nucula hartvigiana*	*Macroclymenella stewartensis*
2002	*Nucula hartvigiana*	*Macomona liliana*	*Magelona dakini*

CB	Rank 1	Rank 2	Rank3
2003	*Macroclymenella stewartensis*	*Nucula hartvigiana*	*Macomona liliana*
2004	*Macroclymenella stewartensis*	*Magelona dakini*	*Macomona liliana*
2005	*Macroclymenella stewartensis*	*Nucula hartvigiana*	*Torridoharpinia hurleyi*
2006	*Nucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2007	*Macroclymenella stewartensis*	*Torridoharpinia hurleyi*	*Nucula hartvigiana*
2008	*Nucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2009	*Nucula hartvigiana*	*Macroclymenellastewartensis*	*Macomona liliana*
2010	*Nucula hartvigiana*	*Macroclymenella stewartensis*	*Macomona liliana*
2011	*Nucula hartvigiana*	*Macroclymenella stewartensis*	*Notoacmea scapha*
2012	*Nucula hartvigiana*	*Macroclymenella stewartensis*	*Anthopleura*