Auckland
Regional Council
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Ecological Monitoring Programme for Manukau Harbour: Report on data collected up to February 2005

May 2005 Technical Publication 293

Auckland Regional Council
Technical Publication No. 293, May 2005
ISSN 1175 205X ISBN 1-877-416-24-X
www.arc.govt.nz

Ecological Monitoring Programme for Manukau Harbour: Report on data collected up to February 2005

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Prepared for

Auckland Regional Council

NIWA Client Report: HAM2005-061
May 2005

NIWA Project: ARC05206

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Contents

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1 Executive Summary

This report updates the results of the Manukau Harbour Ecological Monitoring Programme, established in October 1987. The original 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. Since April 2001, only three of the six original sites have been sampled (Auckland Airport, Clarks Beach and Cape Horn). This report encompasses all data collected at these sites from the start of the programme to February 2005.

The most significant changes that have been identified, considering the last two years of data, have occurred at the Cape Horn site. Analysis of community structure over the monitoring period has shown a difference in overall community composition, with Cape Horn becoming more similar to the Clarks Beach site.

Additional analyses were conducted to assess whether changes seen at Cape Horn could be related to the decommissioning of the Mangere waste water treatment ponds (May 2001). Findings suggest that a number of species have exhibited changes in abundances consistent with the timing of pond breaching.

Considering that the Mangere ponds are approximately 7km away from the site at Cape Horn, we would expect any effects to be quite subtle. Nevertheless, the current results fit well with what might be predicted to occur with improved waste water treatment. These include; a reduction of suspension feeding polychaetes, reduced silt levels and reduced Chlorophyll *a* concentrations. The changes that we are seeing at Cape Horn are consistent with improving water quality, however, as this monitoring programme has shown, sand flat communities can be highly variable and can exhibit natural cycles of abundance. To determine if the changes persist over time at Cape Horn, further monitoring will be required.

On evidence from the principle two sites at Auckland Airport and Clarks Beach, we are able to identify a number of greater-than-annual cycles. Previous reports have shown the high value that these continuous data sets have in enabling us to assess what is happening at the other sites around the Manukau. They have also provided important information for other studies carried out on behalf of the Auckland Regional Council, such as the Mahurangi monitoring programme, Waitamata monitoring programme and the Whitford urban development project. They have greatly improved our understanding of sandflat communities and improved our ability to assess ecosystem health. Based on the above we recommend that the monitoring of the Auckland Airport, Clarks Beach and Cape Horn sites continue.

At this stage of the monitoring programme there is no evidence to suggest detrimental effects on ecosystem health within the extensive intertidal flats that make up the main body of the Manukau harbour.

2 Introduction

In October 1987 the Water Quality Centre (now NIWA) was commissioned to design and conduct a biological monitoring programme for Manukau Harbour. This was initiated in light of concerns for the harbour due to changing land developments and potential impacts that this may have on harbour health. Six sites around the harbour were chosen and monitored in order to document changes in the ecology of the intertidal sandflat communities on a harbour-wide basis and to provide information important for ecosystem management. This was the first harbour-wide ecological monitoring conducted in New Zealand.

When monitoring was initiated, it was envisaged that the programme would be maintained in its original form for five years. The monitoring programme was reduced in 1993 to monitoring only the Auckland Airport and Clarks Beach sites (based on recommendations from Hewitt et al., 1994). Resumption of the full monitoring programme commenced in August 1999 and ran for 2 years, up until April 2001. Since April 2001 the monitoring programme has again been reduced, and now includes the continuously monitored sites at Auckland Airport and Clarks Beach, as well as the Cape Horn site. The Cape Horn site was included as it was decided, in consultation with the ARC, that due to the improvements in water treatment discharging into the Manukau at Mangere, the Cape Horn site might provide interesting changes relating to the expected improved water quality.

A previous report (Funnell et al. 2001), which included data from all six sites, clearly indicated the benefits of having the two continuous data sets at Auckland Airport and Clarks Beach. These sites have provided information on long term cycles and natural variability that short studies of only a few years duration would not be able to detect. This information has been used in a number of different ways and has been of considerable help in our understanding of sandflat community dynamics. It has been used in work for the Auckland Regional Council on the Whitford urban development project (to help define natural variability in sandflat habitats); provided information on ecosystem health and it has provided a contrast to the Mahurangi harbour monitoring programme that has shown significant changes occurring within that harbour.

While changes to monitored species have occurred over the timeframe of the monitoring programme, in general, there is no cause to suspect that there have been changes detrimental to the health of the main body of the Manukau harbour. Several instances of species' trends have appeared, some comprising part of a longer term cyclic pattern. Declines followed by increasing trends could be due to disturbance events and subsequent recovery. At this stage, however, it appears that there are no changes occurring within the sandflat habitats monitored that require intervention.

This report presents results of data collected in the last two years (April 2003 to February 2005) of the reduced monitoring programme.

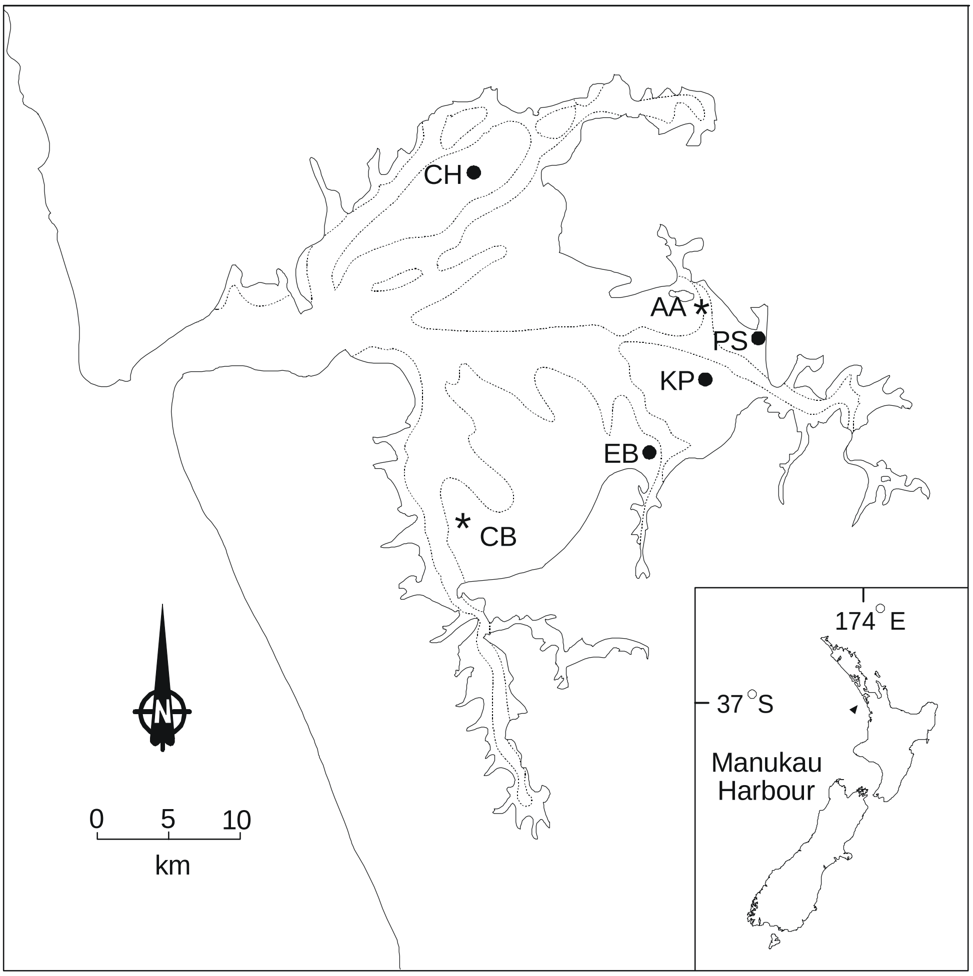
3 Methods

3.1 Sample collection and identification

The sites at Auckland Airport and Clarks Beach (Figure 1) have been sampled every two months between October 1987 and April 2005. Two sampling occasions were missed (October and December 1988) due to lack of continuity of funding. The site at Cape Horn has been sampled for the ARC from October 1987 to February 1993, and again from August 1999 to April 2005. Additional sampling was carried out at Cape Horn by NIWA, without funding by the ARC, from February 1993 to December 1995. This data was collected as part of studies conducted on Te Tau bank, and funded via the Foundation for Research Science and Technology.

Samples are collected and processed as follows. Each site (9000m^2) is divided into twelve equal sectors and one core sample (13cm diameter, 15cm depth) is taken from a random location within each sector. To limit the influence of spatial autocorrelation (see Thrush et al. 1989) and preclude any localised modification of populations by previous sampling events, core samples are not positioned within a 5m radius of each other or of any samples collected in the preceding six months. After collection, the macrobenthos are separated from the sediments by sieving (500µm mesh), preserved with 70% isopropyl alcohol in seawater and stained with rose bengal. The macrofauna are then sorted, identified, counted and stored in 50% isopropyl alcohol.

Figure 1
Map of Manukau Harbour showing the position of the two continuously monitored intertidal sandflat sites (marked with an asterisk), together with the position of the other four intermittently monitored sites. Sites: AA (Auckland Airport), CB (Clarks Beach), CH (Cape Horn), PS (Puhinui Stream), KP (Karaka Point) and EB (Elletts Beach).



3.2 Bivalve size class analysis

After identification all bivalves are measured. Bivalves less than 10mm (longest shell dimension) are measured using a digitiser attached to a microscope. Larger bivalves are measured with digital callipers. Individuals are then allotted to particular size classes corresponding to the mesh sizes of the sieves used in previous years (i.e., ≤1mm, >1-2mm, >2-4mm, >4-8mm, >8-11mm, >11-16mm, >16-22mm and >22mm).

3.3 Site characteristics

During each site visit, attention is paid to the appearance of the site and the surrounding sandflat. In particular, surface sediment characteristics and the presence of birds, gastropods and plants are noted.

Between 1995 and 1998, a pooled sample of surface sediment (<2 cm deep) was collected by haphazardly sampling areas within the site for grain size analysis (October times only). Since August 1999, scoops have been taken from every second core location, on each sampling occasion. A composite sample is made for each site, and organic matter is removed from the sample by digestion in hydrogen peroxide. Sediment grain size analysis is then carried out by wet sieving into fractions of gravel (particles >2mm), sand (particles 63μm-2mm) and silt/clay (particles <63μm), which are then dried and weighed. This same procedure was used to determine the sediment characteristics for each site in October 1987. To determine the organic content, the remainder of the homogenised sediment sample collected for grain size analysis is dried at 60°C to a constant weight and combusted for 5.5 h at 400°C. Also, on each sampling occasion, 6 core samples (adjacent to every second macrofauna core, 2.5cm diameter and 2cm deep) are collected and bulked for chlorophyll *a* analysis. Chlorophyll *a* (a measure of food supply to benthic animals) is extracted by freeze drying the sediment, boiling in 90% ethanol, and measured spectrophotometrically. An acidification step was used to separate degradation products from chlorophyll *a* (Sartory, 1982).

3.4 Statistical Analyses[1]

Statistical analyses were performed to identify significant linear trends, step trends or changes in temporal cycles. Methods for analysing temporal variations are given in detail in the fifth year summary report (Hewitt et al. 1994) and are briefly described below.

1. For all monitored populations at a site, graphs of abundance vs. time are drawn and temporal autocorrelation analyses are carried out.

2. The time series of each population is tested to determine whether the variation in the temporal series contains a cyclic component.

3. Trend analyses are conducted on:

   a. the raw time series data

   b. the residuals if a cyclic model can be fitted

   c. the basal population where a basal period can be detected

[1] Analyses presented are based on the total numbers of individuals found in the 12 core samples collected on each sampling occasion.

d. annual averages for those species where a basal period could not be detected and the raw time series data suggested that long-term cyclic variability in recruitment may allow a trend in the raw time series to be detected.

4. When a dataset exhibits significant temporal autocorrelation, adjustments are made to the calculation of standard errors and significance values.

5. For all populations in which a trend in abundance is detected, the fit of the trend to the observed data is examined by analysis of the residuals.

6. Ordinations of the monitored species at each site were conducted using correspondence analysis (ter Braak, 1986). This technique summarizes the changes occurring in all monitored taxa, however, since the analysis only uses data for the relatively few monitored species, patterns do not necessarily mirror community dynamics. Due to the large number of data points since the start of the programme only the October sampling times were analysed. October sampling times are the least likely to be effected by the recruitment peaks that occur for some of the monitored species.

Additionally, at site CH, the potential for the change in waste water treatment to affect the site was investigated by intervention analysis (Box and Taio, 1975, Hewitt et al., 2001), using May 2001 (the time when the first two ponds were breached) as the time of intervention. Data were tested for stationarity in the period before the intervention and transformed as required. ARIMA models for use were determined from autocorrelation plots (including partial and inverse autocorrelations) according to Chatfield (1980) and tested for goodness of fit.

4 Present status of the benthic communities of the Manukau Harbour

This monitoring programme was designed to address the following questions:

"Are populations at the monitored sites generally exhibiting similar patterns?"

"Do any of the observed patterns in population abundances indicate important changes in the benthic communities?"

In order to answer these two general questions a series of more specific questions can be posed:

4.1 Have there been any changes in the general appearance of the sites or the areas nearby?

4.1.1 General site descriptions[2]

Auckland Airport – The appearance of this site largely changes due to the presence or absence of ray pits. During summer large numbers of pits can cause a major change in surface topography, creating a mottled appearance with shell hash surrounding the pits. In winter the incidence of ray pits is low and the site is largely flat with relatively little shell hash. The sediment surface is normally covered in sand ripples. Over the last 2 years, on occasion, very small patches of seagrass have been reported.

Clarks Beach – This site generally has few surface features other than minor sand ripples. The site's appearance continues to be largely determined by the presence or absence of a surficial mud and/or diatom layer. At times deep muddy hummocks have covered the site. For example, in October 1999 the site had an obviously muddy surface with 2-3 cm deep hummocks.

Cape Horn – The appearance of Cape Horn has in the past changed due to the presence/absence of the polychaete *Boccardia syrtis*, which at times forms dense tube mats at the sediment surface and acts to stabilise sediments. At times during the year dense mats of *Boccardia syrtis* tubes have created large patches of soft mud several centimetres thick. Areas not covered by this mud/*Boccardia* layer tended to have sand ripples, and a few ray pits. However, over the last 3 years the abundances of *Boccardia syrtis* have dropped to very low levels and are at times not present in the samples. Site reports over the last 3 years indicate that these muddy hummocks due to *Boccardia syrtis* tubes have

[2] Over the last four years site description reports have been completed by ARC staff.

not occurred and sand ripples are the dominant feature of the site. Since the monitoring programme began the elevation of this site has changed, resulting in the need to move the site up shore by 50m in 1999 to keep the area sampled in the intertidal zone.

4.1.2 Sediment characteristics

Silt/clay levels remain generally low at Auckland Airport. In the past 3 years they have decreased slightly compared to previous years, and are less than those levels recorded at the start of the monitoring programme in 1987 (Table 1). At Clarks Beach, silt levels have varied considerably over the monitored period. For example, in October 1999 a large percentage of silt was found in the samples. This coincided with the presence of large muddy hummocks noted at the site over this sampling time. Also, in October 2001, the silt/clay level recorded was ~5 times higher than that recorded in 1987. Site descriptions for October 2001 indicated the presence of a surface mud layer. During 2003 and 2004 October sampling times, silt levels have been slightly higher than those first reported although still below levels found between 1997 and 2001 (Table 1). The sediment silt levels for Cape Horn in October continues to be lower than the levels found at the beginning of the monitoring programme. This is likely due, at least in part, to the declining amount of '*Boccardia* mat' and associated mud layer that has been observed at this site compared to earlier in the monitoring programme.

Table 1

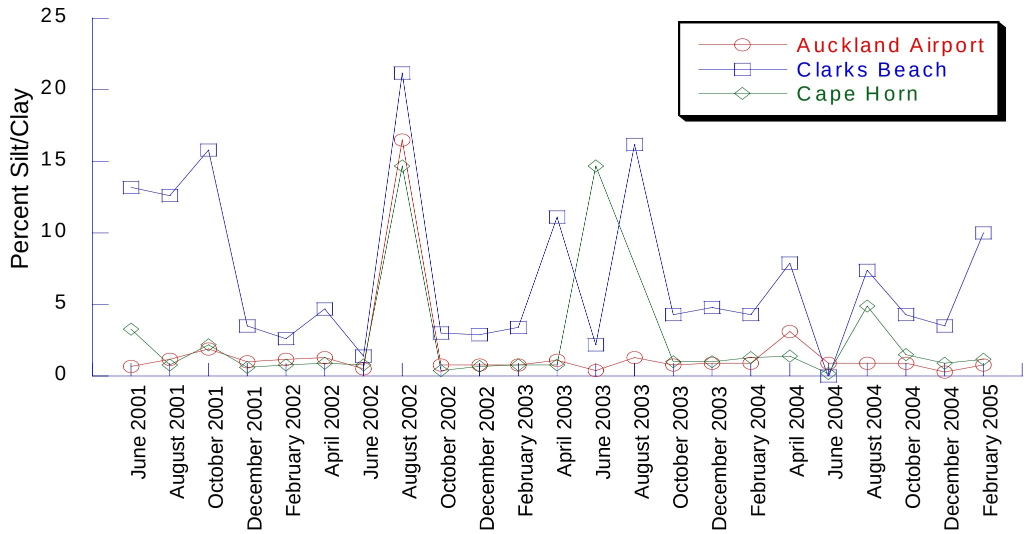
Sediment grain size (percent composition) at the Auckland Airport and Clarks Beach sites for the whole period of sediment sampling, and at Cape Horn for the initial sampling time and since the reinstatement of the full programme (October sampling times only). Gravel particles >2mm, Sand particles 63µm-2mm, Silt/clay particles <63µm.

Site		1987	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
AA	%gravel	1.6	0.6	0.4	0.02	0.3	1.3	0.0	0.0	0.2	1.0	0.0
	% sand	96.7	99.1	99.3	99.5	96.7	97.5	98.9	98.1	99.0	98.2	99.1
	%silt/clay	1.7	0.3	0.3	0.51	3.0	1.2	1.1	1.9	0.8	0.8	0.9
CB	%gravel	6.1	4.3	3.9	5.15	1.31	0.5	2.1	1.5	5.2	7.5	1.8
	% sand	91.1	93.2	94.3	84.2	90.3	56.9	90.9	82.7	91.8	88.2	93.9
	%silt/clay	2.8	2.5	1.8	10.7	8.4	42.6	7.0	15.8	3.0	4.3	4.3
CH	%gravel	2.5					0.1	0.0	0.0	0.0	0.0	0.0
	% sand	93.3					95.6	98.7	97.8	99.6	98.8	98.5
	%silt/clay	4.2					4.3	1.3	2.2	0.4	1.1	1.5

Results for the more intensive sampling carried out over the last four years of monitoring (i.e. sediment collected at each sampling time for each site), show that the silt levels tend to be quite variable, as might be expected in a harbour with extensive intertidal areas and strong, variable wind patterns (Figure 2). Variability can both be at the individual site or harbour scale, as seen in August 2002 where a substantial peak of silt content was observed at all three sites (possibly due to climatic factors). Levels have ranged from 0.3-3.1% at the Auckland Airport site, from 0-16.2% at the Clarks Beach site and from 0.2-14.7% at the Cape Horn site over the last two years (full grain size results are given in Appendix 9.2).

Figure 2

Sediment silt content (percent composition) since intensive sediment sampling began in June 2001.



Chlorophyll *a* results show that levels were variable between sites and times of the year Appendix 9.3. Chlorophyll *a* at Auckland Airport and Clarks Beach, while variable, have not changed overall compared to previous years. In contrast Chlorophyll *a* levels at Cape Horn have declined since October 2001. This is corroborated by regression analysis that shows a significant negative trend at this site (p=0.011).

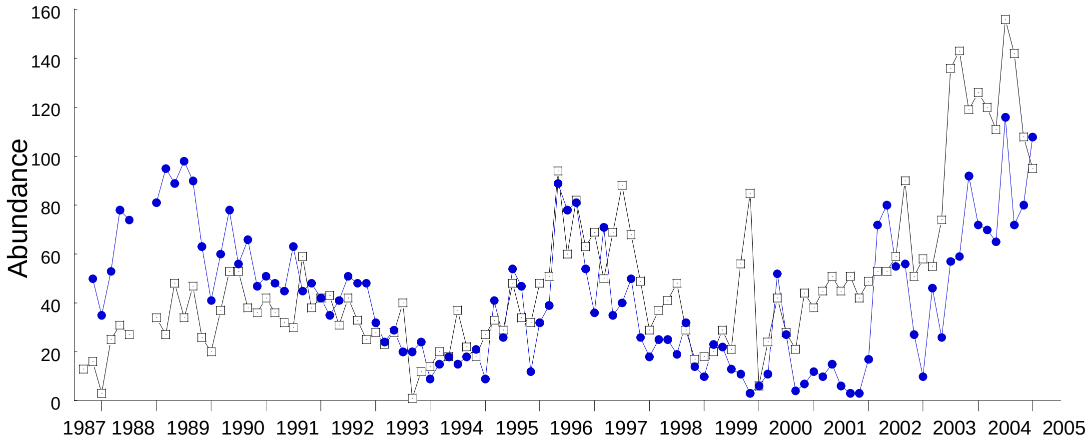
Sediment organic matter content varies only slightly throughout the year (Appendix 9.4). A very high value found in October 2002 at the Cape Horn site was probably due to the presence of a large dead worm in the sample. No such peaks were evident within the last 2 years sampling.

4.2 Are annual cycles in abundance being maintained?

All cyclic patterns in the abundance of populations identified in previous reports are still present at the Auckland Airport and Clarks Beach sites. With 17 years of uninterrupted data, 5 - 7 yearly cycles for some populations are apparent. An example of this is *Magelona ?dakini* at both sites as shown in Figure 3. Based on the timeseries at Auckland Airport and Clarks Beach, we have been able to interpret the recent increase in *Magelona ?dakini* at Cape Horn as part of a harbour wide increase for this species.

Figure 3

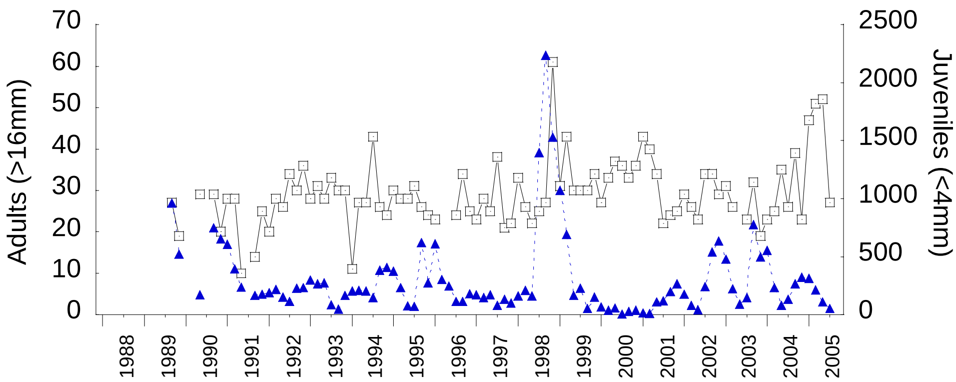
Greater than annual cycles are apparent for some monitored populations, for example *Magelona ?dakini* at Clarks Beach (closed circles) and Auckland Airport (open squares).



The recruitment of the bivalve *Macomona liliana* continues to be variable and shows a possible 3-5 year cyclic pattern (Figure 4). This variability has not significantly impacted the abundances of adults greater than 16mm in size. That is, the abundances of adults is variable but stable over the monitored period. It is likely that a variable recruitment with occasional high peaks is the norm for this species.

Figure 4

Abundances of *Macomona liliana* sized <4mm (triangles) and adults sized >16mm (squares) at the Auckland Airport site.



4.3 Are trends in abundance being maintained?

As the length of the monitored period increases, some trends prove to be part of longer term cycles. In the data collected up to February 2003 (presented in Funnell, 2003), we had detected thirteen trends in abundance at Auckland Airport and Clarks Beach (Tables 2 and 3). We also conducted trend analysis for the reduced data set at Cape Horn, which detected six trends in abundance (Table 4).

A further two years of data have altered some of these trends and in addition, new trends have appeared.

4.3.1 Auckland Airport

Table 2

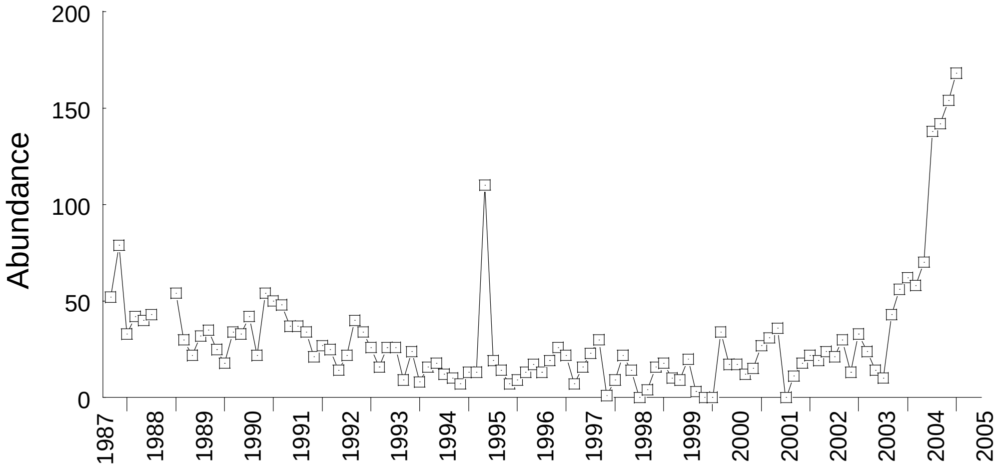
Statistically significant trends in abundance detected at Auckland Airport over the whole monitoring period. Direction (increase '+' or decrease '-') and magnitude of the trend are indicated by slope estimates and are presented as the difference in number of individuals in 12 cores, compared to initial sampling in 1987..

Taxa	October 1987 to February 1999	October 1987 to February 2001	October 1987 to February 2003	October 1987 to February 2005
Aonides oxycephala	-34.5	-26.9	-23.6	
Aquilaspio aucklandica		+1.7	+1.6	
Hiatula siliqua				+61.0
Magelona ?dakini			+19.8	+60.9
Nucula hartvigiana		-24.9	-27.9	
Trochodota dendyi				+7.8

In past reports, *Aonides oxycephala* has shown a negative trend based on continually low numbers compared to the first few years of sampling. However, this trend has been decreasing in magnitude over the last several years as abundances slowly increase. Probably due to a substantial recruitment over the last 2 years, this trend is no longer significant at the 5% level, with abundances much higher than at the start of the monitoring period (Figure 5). A further 2 years of data should be able to indicate whether these higher abundances will persist or if they will return to levels seen previously.

Figure 5

Abundance of *Aonides oxycephala* at Auckland Airport

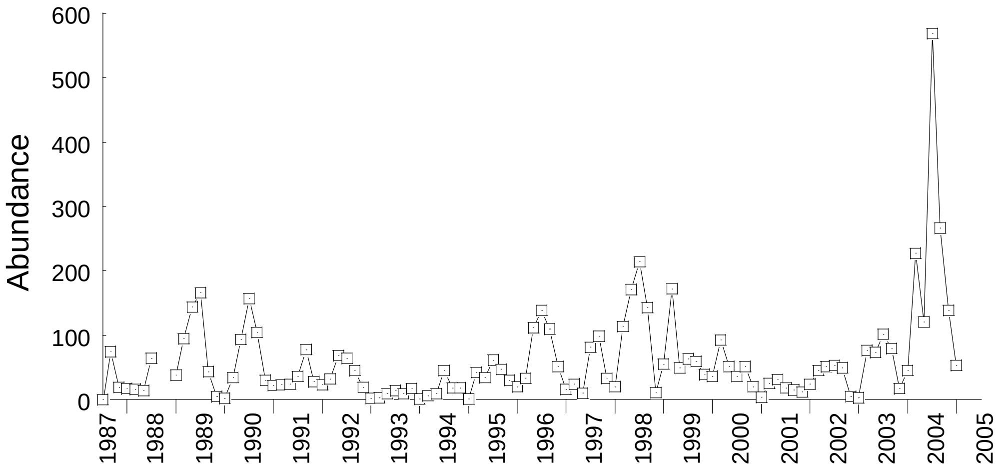


The previous positive trend in abundance for *Aquilaspio aucklandica* is no longer showing a continuation and numbers remain at low levels.

Hiatula siliqua appears to be exhibiting seasonal peaks embedded within 7-9 year abundance cycles. There has been an increase in abundance due to high recruitment over the last year (Figure 6).

Figure 6

Abundance of *Hiatula siliqua* at Auckland Airport



Over the last 3 years, *Magelona ?dakini* has shown an increasing trend above that observed due to the long term cycle (see Figure 3). The last 2 years have seen the magnitude of the positive trend increase 3 fold.

The negative trend for *Nucula hartvigiana* since 2001 is no longer present with a further two years of data.

The holothurian *Trochodota dendyi* has shown a trend at this site for the first time since the start of the monitoring period. Generally the abundance of this species has been relatively constant until the last 3 years when recruitment has increased.

4.3.2 Clarks Beach

Table 3

Statistically significant trends in abundance detected at Clarks Beach over the whole monitoring period. Direction (increase '+' or decrease '-') and magnitude of the trend are presented as model slope estimates.

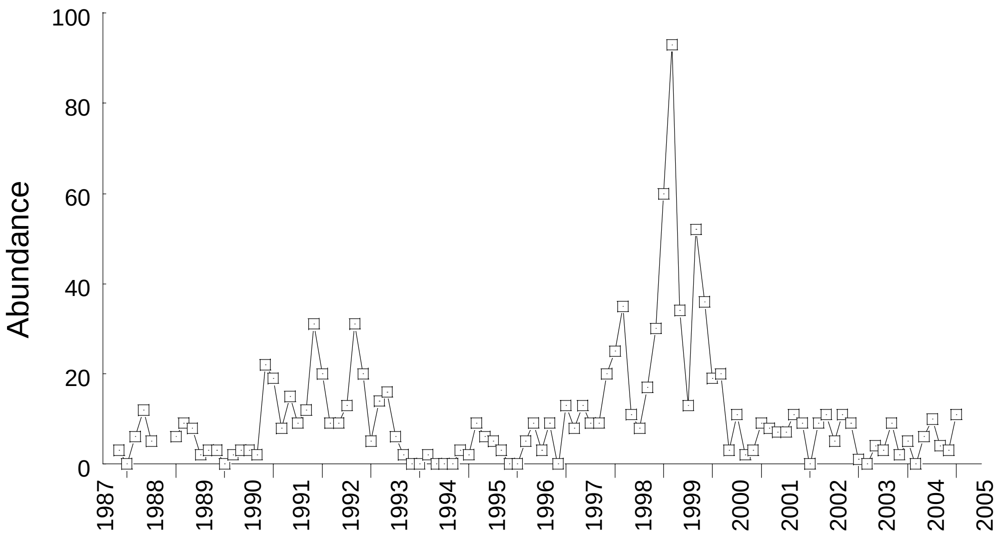
Taxa	October 1987 to February 1999	October 1987 to February 2001	October 1987 to February 2003	October 1987 to February 2005
Anthopleura aureoradiata			+6.5	
Aonides oxycephala	-7.2	-6.0	-5.6	-5.1
Aquilaspio aucklandica		+19.0	+10.8	
Boccardia syrtis			-57.5	-35
Exosphaeroma spp.	-5.61	-5.3	+0.9	
Goniada emerita				-7.1
Hiatula siliqua	-9.52	-8.2	-7.7	-6.8
Magelona ?dakini	-20.3	-24.3	-20.5	
Orbinia papillosa	-1.3	-1.2	-1.0	-0.8
Trochodota dendyi			-3.3	

The increasing trend for *Anthopleura aureoradiata* found in the last report appears to be due to variable recruitment and is no longer significant based on the moving average analysis completed in this report.

Aonides oxycephala continues to occur at very low levels, as it has since 1992. The decreasing magnitude of the trend compared to the previous year is due to change in the temporal scale of sampling (i.e., increasing length of the data set) rather than an increase in abundance.

The previous trend for *Aquilaspio aucklandica* is not evident in the last 2 years' data. However, based on the graph of abundances (Figure 7) and the cycle exhibited at this site, we would expect that over the next year or 2 increased abundance is likely.

Figure 7
Abundance of *Aquilaspio aucklandica* at Clarks Beach.



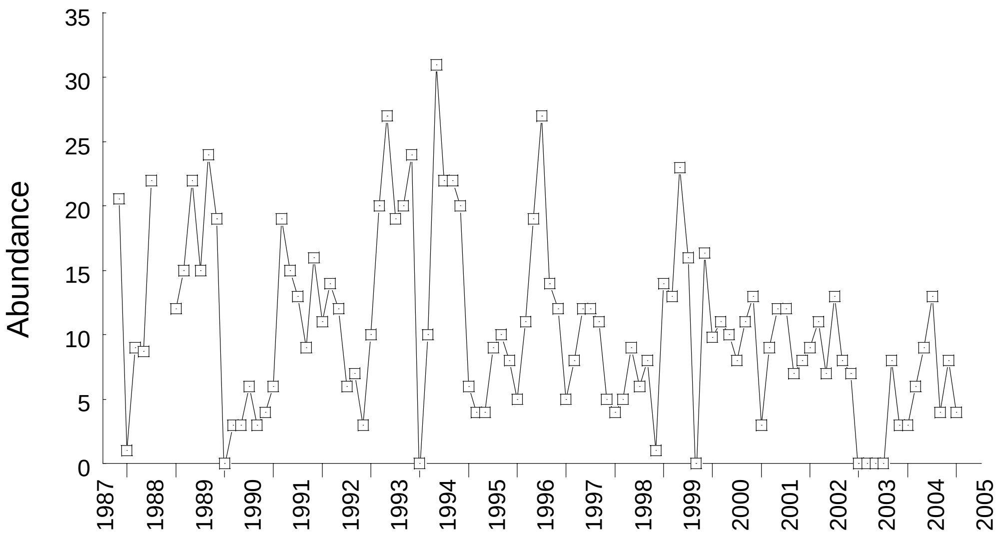
Boccardia syrtis is characterized by having very high but temporally variable recruitment peaks and previous trends associated with this species at this site are due to high recruitment peaks early in the monitoring period. The current trend shows a decrease in base abundances.

Exosphaeroma sp. exhibits small periods of recruitment over the monitored period. Recruitment over the last year has reversed the trend for this species although numbers remain generally very low.

Goniada emerita has started to show a declining trend of general abundances and recruitment peaks over the last several years (Figure 8).

Figure 8

Abundances of *Goniada emerita* at Clarks Beach



Hiatula siliqua continues to have low abundances at this site, although a small recruitment event occurred within the last year and the magnitude of the declining trend became smaller.

A major *Magelona ?dakini* recruitment period over the last 3 years has removed the previous negative trend. This species exhibits 5-7 years cycles of abundance (refer to Figure 3) and the increase in abundance from 2002-2005 fits this pattern.

Orbinia papillosa continues to show a negative trend with a slight decrease in the magnitude.

Trochodota dendyi trends identified previously were due to large recruitment during early- and mid-monitoring periods. There is no real trend occurring for this species over the monitoring period as a whole.

4.3.3 Cape Horn

Table 4

Statistically significant trends in abundance detected at Cape Horn over the whole monitoring period. Direction (increase '+' or decrease '-') and magnitude of the trend are presented as model slope estimates.

Taxa	October 1987 to February 1999	October 1987 to February 2001	October 1987 to February 2003	October 1987 to February 2005
Aquilaspio aucklandica				-0.7
Aglaophamus macroura				+0.9
Austrovenus stutchburyi				-0.7
Boccardia syrtis				-881.6
Goniada emerita			-11.0	-8.6
Magelona ?dakini			+33.0	+51.2
Orbinia papillosa				-1.2
Owenia fusiformis			-7.5	-9.4
Hiatula siliqua		+3.5	+4.9	+3.4
Trochodota dendyi			+0.3	+0.4
Macomona liliana				-6.3
Waitangi brevirostris			+1.8	+10.6

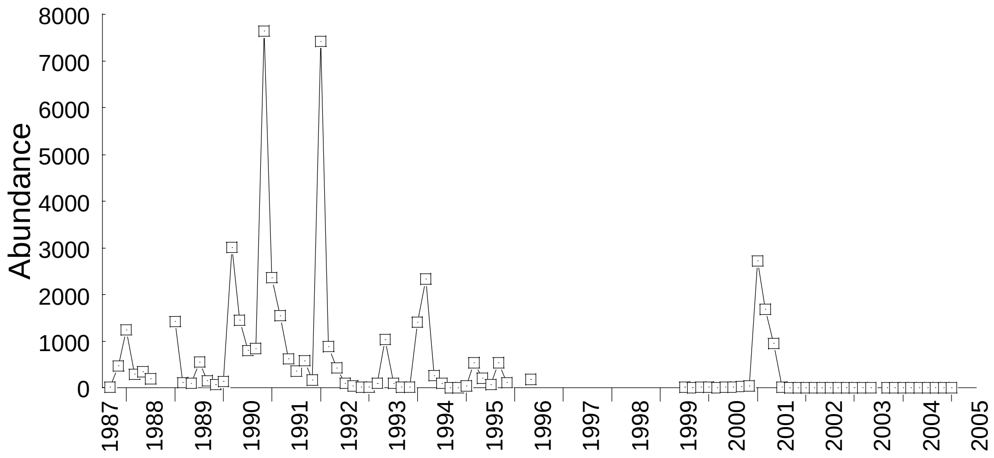
At CH, *Aquilaspio aucklandica* shows a weak negative trend, and over the last 4 years has been rare at this site.

Generally the abundances of *Aglaophamus macroura* have been quite low and variable at this site. A small increasing trend has been identified.

Austrovenus stutchburyi has always been at low numbers at this site. A small negative trend is due to it being virtually absent over the last 3 years.

Figure 9

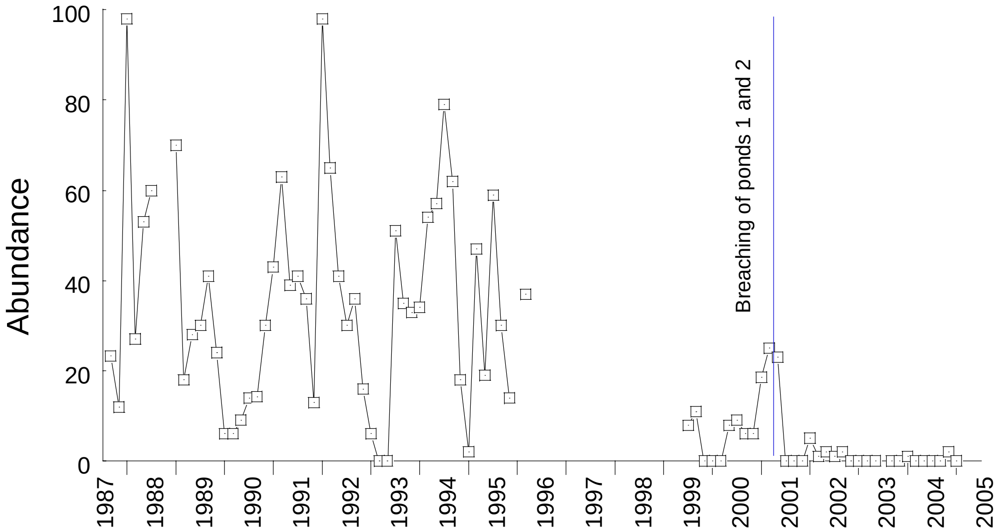
Abundance of *Boccardia syrtis* at Cape Horn



Apart from a time in 2001, where abundances were recorded greater than 2000 individuals per 12 cores, *Boccardia syrtis* has been present at relatively low numbers for the last 5-6 years. The very high abundances early in the monitoring programme and the extended period of low abundances recently both contribute to this exceptionally large negative trend (Figure 9).

Figure 10

Abundance of *Goniada emerita* at Cape Horn



The negative trend found for *Goniada emerita* in the last report has continued and this polychaete was rarely found at this site over the last 4 years (Figure 10). *Goniada emerita* has also exhibited a decrease at the Clarks Beach site, although not nearly as pronounced as at Cape Horn (Figure 8).

Magelona ?dakini has shown a marked increase in abundance over the last 3 years with a positive trend and a magnitude much greater than the previous report (Figure 11).

Abundances of *Orbinia papillosa* have been lower over the last 2 years resulting in an overall negative trend.

Owenia fusiformis has not been found over the last 3.5 years at this site, hence the negative trend.

Hiatula siliqua has increased in abundance (although quite variable) over the last 5.5 years to levels similar to those at the start of the monitoring programme. After a time of very low numbers or being absent, this has resulted in a significant positive trend.

Very low numbers of *Trochodota dendyi* are found at this site although a slight increase in abundance over the last 2 years has occurred.

Continuing low abundances of *Macomona liliana* have resulted in a significant negative trend overall. The abundances at this site have always been low but over the last 5.5 years they have decreased compared to the first 8 years of monitoring.

Waitangi brevirostris was absent for most of the initial 10 years of monitoring, but over the last 3 years, has shown a significant increase in abundance with the last year being the most abundant on record.

4.4 Are changes in observed trends due to specific events in time?

As changes in trends were evident from the results over the last two years of data at Cape Horn, intervention analyses were conducted to investigate if changes could be related to a specific event. In particular, we wanted to determine if there were significant changes in species' trends since the breaching of the waste water treatment ponds at Mangere. Intervention analysis is performed by splitting the data set into two sections, before the supposed intervention, and after. Cyclic patterns and trends in the pre-intervention data are modelled using autogressive and moving average (ARIMA) models. The ability of the best fit model to predict the time series post intervention (e.g. Figure 11 for *Magelona ?dakini*) is tested. May 2001 was used as the 'time of intervention' (the time when the first two ponds were breached). The results indicated that the abundances for several species were significantly altered from 2001 (Table 5).

Figure 11

Abundance of *Magelona ?dakini* (open squares) and 'predicted' abundances (closed circles) based on intervention analysis at Cape Horn. The time of intervention used in the analysis is also shown (the breaching of waste water treatment ponds 1 and 2).

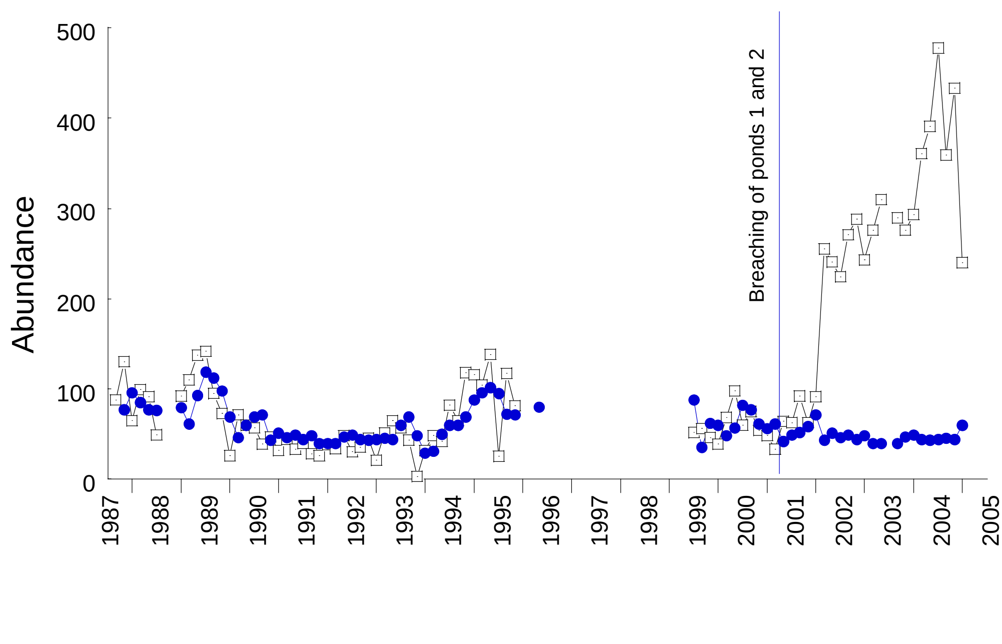


Table 5

Species showing different patterns than that could be predicted from pre-intervention time-series. Time of intervention May 2001.

Species	p-value	Increase/ Decrease
Aquilaspio aucklandica	0.0050	(-)
Austrovenus stutchburyi	0.0704	(-)
Boccardia syrtis	0.0669	(-)
Hiatula siliqua	0.0012	(+)
Macomona liliana	0.0010	(-)
Magelona ?dakini	0.0051	(+)
Waitangi brevirostris	0.0360	(+)

4.5 Are dominant species consistent over time?

Table 6 shows the changes in the three most dominant species in February of each year at all sites. At the Auckland Airport site, the dominant species present has consistently been *Macomona liliana*, with changes in the second and third most abundant species reflecting long-term trends and cycles in abundance (Table 6a). However, due to a high recruitment of *Aonides oxycephala* since 2004, *Macomona liliana* is now the second most abundant species. This is the first time since 1991 that *Aonides oxycephala* has been included in the list of dominant taxa.

The Clarks Beach site exhibits a greater degree of change in the most dominant species, but these again reflect long-term cycles in abundance (Table 6b). For example, the appearance of *Boccardia syrtis* amongst the dominant taxa from 1991 to 1994 reflects the five to seven year cycle common for this species around the Manukau. *Magelona ?dakini* was not included in this table from 1990 to 2003. Over the last two years, however, *Magelona ?dakini* has been the most abundant taxa observed during February. This is due to both a 5-7 year cycle and an increasing trend occurring over the last 2 years.

Cape Horn tended to be dominated by the polychaete *Boccardia syrtis,* which can occur at abundances of greater than 7000 individuals per sampling time at this site (i.e., an average of 583 individuals per core, or 132cm^2 of sediment surface). However, over the last 4 years, *Boccardia syrtis* has not been dominant. Instead *Magelona ?dakini* has been the most numerically dominant species. It was previously reported that the cumacean *Colurostylis lemurum*, the bivalve *Hiatula siliqua* and the amphipod *Methalimedon* sp. all became dominant for the first time since 2001 (Table 6c). Over the last year, another monitored amphipod, *Waitangi brevirostris*, has appeared in the table.

Generally, it appears that most changes in the dominant taxa are due to long term trends and cycles of abundance, and therefore many are driven by recruitment. Shifting environmental conditions that may be driving trends at Cape Horn will be addressed below (Section 5).

Table 6a

The three most abundant species found in February each year at the monitored sites[3].

a) Auckland Airport

Year	Auckland Airport		
1988	*Macomona liliana*	*Austrovenus stutchburyi*	*Aonides oxycephala*
1989	*Macomona liliana*	*Austrovenus stutchburyi*	*Orbinia papillosa*
1990	*Macomona liliana*	*Austrovenus stutchburyi*	*Exosphaeroma spp.*
1991	*Macomona liliana*	*Nucula hartvigiana*	*Aonides oxycephala*
1992	*Macomona liliana*	*Nucula hartvigiana*	*Magelona ?dakini*
1993	*Macomona liliana*	*Travisia olens*	*Orbinia papillosa*
1994	*Macomona liliana*	*Austrovenus stutchburyi*	*Travisia olens*
1995	*Macomona liliana*	*Austrovenus stutchburyi*	*Nucula hartvigiana*
1996	*Macomona liliana*	*Magelona ?dakini*	*Travisia olens*
1997	*Macomona liliana*	*Magelona ?dakini*	*Orbinia papillosa*
1998	*Macomona liliana*	*Austrovenus stutchburyi*	*Magelona ?dakini*
1999	*Macomona liliana*	*Hiatula siliqua*	*Orbinia papillosa*
2000	*Macomona liliana*	*Mactra ovata*	*Hiatula siliqua*
2001	*Macomona liliana*	*Waitangi brevirostris*	*Magelona ?dakini*
2002	*Macomona liliana*	*Orbinia papillosa*	*Magelona ?dakini*
2003	*Macomona liliana*	*Magelona ?dakini*	*Orbinia papillosa*
2004	*Macomona liliana*	*Magelona ?dakini*	*Austrovenus stutchburyi*
2005	*Aonides oxycephala*	*Macomona liliana*	*Magelona ?dakini*

b) Clarks Beach

Year	Clarks Beach		
1988	*Nucula hartvigiana*	*Macomona liliana*	*Magelona ?dakini*
1989	*Magelona ?dakini*	*Nucula hartvigiana*	*Macomona liliana*
1990	*Nucula hartvigiana*	*Magelona ?dakini*	*Macomona liliana*
1991	*Boccardia syrtis*	*Macroclymenella*	*Nucula hartvigiana*
1992	*Boccardia syrtis*	*Macroclymenella*	*Macomona liliana*
1993	*Boccardia syrtis*	*Macroclymenella*	*Nucula hartvigiana*
1994	*Boccardia syrtis*	*Macomona liliana*	*Nucula hartvigiana*
1995	*Macroclymenella*	*Nucula hartvigiana*	*Macomona liliana*
1996	*Nucula hartvigiana*	*Boccardia syrtis*	*Macomona liliana*
1997	*Macroclymenella*	*Nucula hartvigiana*	*Macomona liliana*
1998	*Boccardia syrtis*	*Macomona liliana*	*Austrovenus stutchburyi*
1999	*Nucula hartvigiana*	*Macomona liliana*	*Aquilaspio aucklandica*
2000	*Torridoharpinia hurleyi*	*Macroclymenella*	*Macomona liliana*
2001	*Boccardia syrtis*	*Nucula hartvigiana*	*Macomona liliana*
2002	*Nucula hartvigiana*	*Macomona liliana*	*Macroclymenella*
2003	*Macomona liliana*	*Nucula hartvigiana*	*Macroclymenella*
2004	*Magelona ?dakini*	*Macroclymenella*	*Macomona liliana*
2005	*Magelona ?dakini*	*Nucula hartvigiana*	*Macomona liliana*

[3] *Macroclymenella stewartensis,* for convenience, is referred to by genus only in this table.

c) Cape Horn

Year	Cape Horn		
1988	*Boccardia syrtis*	*Goniada emerita*	*Magelona ?dakini*
1989	*Boccardia syrtis*	*Magelona ?dakini*	*Macomona liliana*
1990	*Boccardia syrtis*	*Magelona ?dakini*	*Macroclymenella*
1991	*Boccardia syrtis*	*Goniada emerita*	*Torridoharpinia hurleyi*
1992	*Boccardia syrtis*	*Goniada emerita*	*Macroclymenella*
1993	*Macroclymenella*	*Magelona ?dakini*	*Boccardia syrtis*
:			
2000	*Magelona ?dakini*	*Macroclymenella*	*Torridoharpinia hurleyi*
2001	*Boccardia syrtis*	*Torridoharpinia hurleyi*	*Magelona ?dakini*
2002	*Magelona ?dakini*	*Colurostylis lemurum*	*Macroclymenella*
2003	*Magelona ?dakini*	*Hiatula siliqua*	*Methalimedon sp.*
2004	*Magelona ?dakini*	*Colurostylis lemurum*	*Macroclymenella*
2005	*Magelona ?dakini*	*Macroclymenella*	*Waitangi brevirostris*

4.6 Do any of the sites exhibit differences in time over all monitored species?

Variability in the composition of the monitored taxa assemblages over time was examined for each site using Correspondence Analysis. The closer together points are in the ordination space the more similar the community composition. Conversely, the larger the area taken up by points, the more the communities change over time. Figure 12a shows how the three currently monitored sites have changed since the start of the monitoring programme (February sampling dates only). Note that the Auckland airport site shows very little variation in community composition over time. The Cape Horn site shows several periods where community composition has deviated from the community observed at the start of the monitoring. These changes relate to periods of high abundance of *Boccardia syrtis*. Over the last four years the community composition has moved closer to that of Clarks Beach and has been relatively stationary.

Figures 12b and c show how the correspondence plots relate to actual species abundances. Periods of high *Boccardia syrtis* and *Magelona ?dakini* are observed for both Clarks Beach and Cape Horn. These corroborate the trend analysis that show decreasing and increasing trends for these two species. For example, *Boccardia syrtis* was the most dominant species at Cape Horn early in the monitoring period (as indicated in Figure 12c), but over the last 4 years *Magelona ?dakini* has dominated. Clarks Beach has also had periods where *Boccardia syrtis* has been the most dominant species (Figure 12b), and when *Magelona ?dakini* has been abundant.

Note that for 3 years between 1995 and 1999 the site at Cape Horn was not monitored (marked on the Figure 12 by the dashed line).

Historically the dominant species and Correspondence Analysis have been conducted in February. To determine if using data from other times would alter results, further analyses were conducted to compare February and October sampling times over the course of the monitored period. While differences between times were observed (as would be expected considering the natural variability of the sites), the conclusions were consistent between sampling times.

Figure 12a

Correspondence Analysis ordination plots of the monitored community composition for February sampling times since the start of the monitoring programme. Auckland Airport, Clarks Beach and Cape Horn sites are marked by circles, squares and triangles respectively. The earliest sampling occasion is marked by open circles, and the most recent sampling time by open squares. The dashed circle indicates the location of the four most recent sampling times for Cape Horn, occurring after the breaching of the treatment ponds..

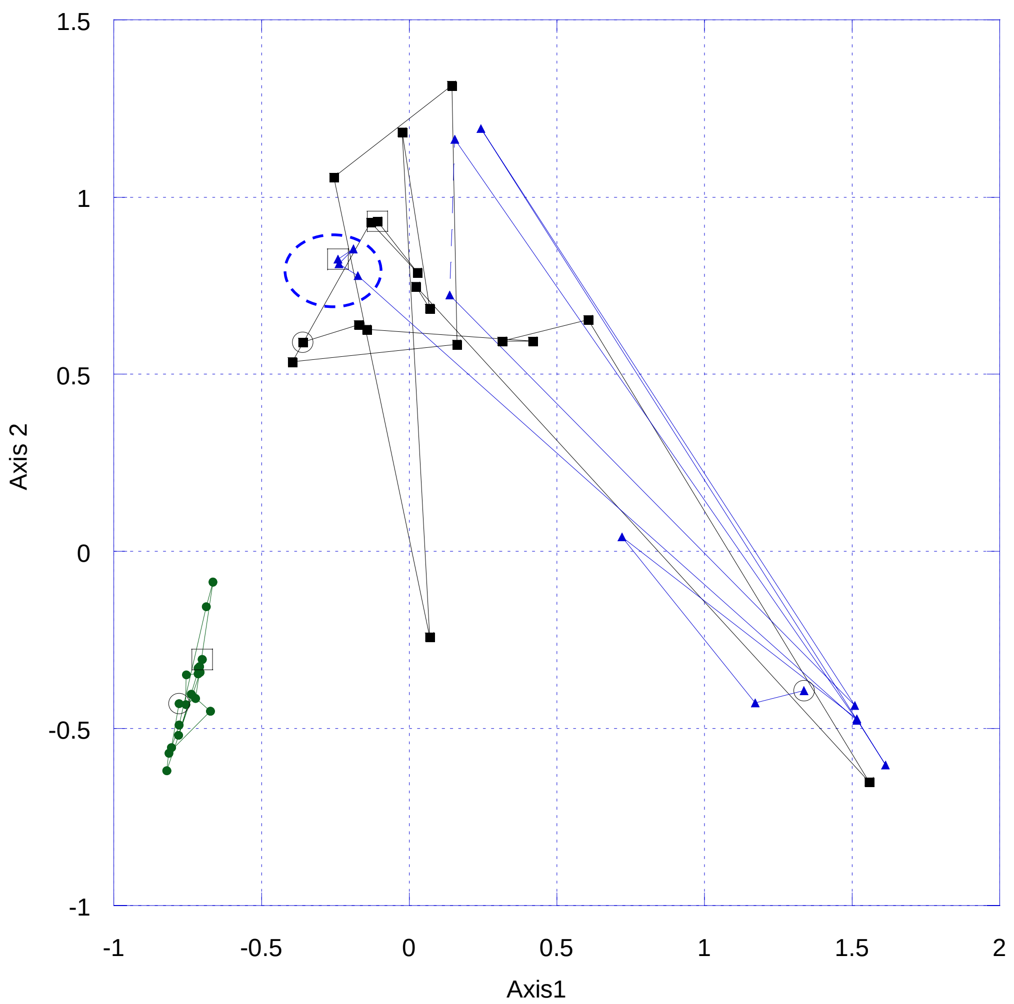
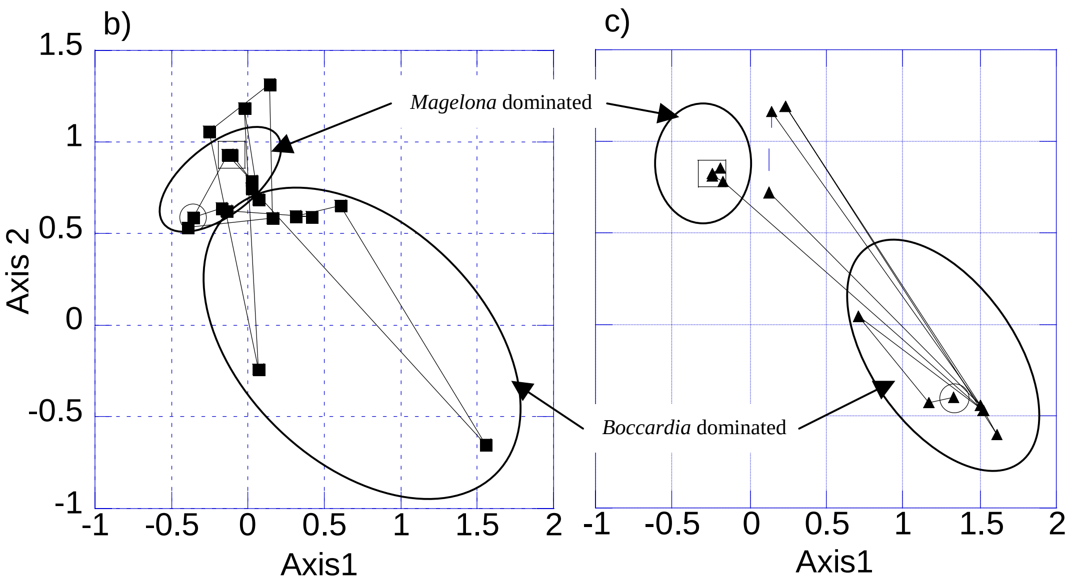


Figure 12b & c

Correspondence Analysis ordination plot of the monitored community composition at b) Clarks Beach and c) Cape Horn. The earliest sampling occasion is marked by an open circle, and the most recent sampling time by an open square. Regions reflecting high abundances of *Magelona ?dakini* and *Boccardia syrtis* are also indicated.



5 Conclusions

5.1 "Are populations at the three sites generally exhibiting similar patterns?"

Cyclic abundance patterns are observed for several species at all three sites (e.g., for *Magelona ?dakini* and *Aonides oxycephala*). Thus, while differences in trends are occurring, we can conclude that the same populations are generally exhibiting similar patterns at the three monitored sites.

5.2 "Do any of the observed patterns in population abundances indicate important changes in the benthic communities?"

The 2001 report (Funnell et al, 2001) identified a number of concerning trends that could possibly be related to increasing silt levels. The species involved were *Aonides oxycephala* and *Magelona ?dakini* which prefer wave exposed, sandy conditions and may be adversely affected by increased silt levels, and *Aquilaspio aucklandica* that has intermediate sediment preferences and have been found to be abundant at silt levels of up to 65-70% (Gibbs and Hewitt, 2004). It was reported that both *Aonides oxycephala* and *Magelona ?dakini* were decreasing at a number of sites and that *Aquilaspio aucklandica* was increasing. The following report in 2003 (Funnell et al, 2003) indicated that these potentially adverse trends were being reversed and that this may be related to the decreasing silt levels observed over the previous two years. Results from the most recent two years of data show that *Magelona ?dakini* has dramatically increased at both Auckland Airport and Cape Horn. *Aquilaspio aucklandica* has also continued to decrease at Cape Horn. These trends occur at a time when silt levels at both Auckland Airport and Cape Horn are lower than those recorded at the initiation of the monitoring programme. Compared to the silt levels over the entire programme, levels at these sites have been fairly stable for the last 5 years (based on October grainsize results). At Clarks Beach, where the highest silt levels have been recorded for the sites, *Aonides oxycephala* continues to be only present at very low numbers.

There are no clear and consistent patterns that can account for the changes seen at the monitored sites. It is possible climatic variation may be a factor, for example, a change in wind direction and/or strength may change wave exposure, creating conditions that favour certain species. Periods of sediment events and consequent recovery may be the cause of some of the variation observed. Overall, however, there are no signs to date that sediment loading into the harbour is seriously impacting the sand flat assemblages at the monitored sites.

At Cape Horn there have been a number of changes in the benthic populations that may relate to a change at the site as a whole. Over the last four years of monitoring a number of previously rare taxa have been becoming abundant (*Magelona ?dakini*, *Colurostylis lemurum*, *Hiatula siliqua*, *Methalimedon* sp. and *Waitangi brevirostris*) and conversely, a few other taxa have shown a significant decrease in abundance (*Owenia fusiformis*, *Orbinia papillosa*, *Goniada emerita* and *Boccardia syrtis*). The multivariate analysis shows a possible change in overall community composition over the last four years, with points clustering very close in ordination space and within the space occupied by Clarks Beach. Further sampling over the next couple of years should indicate if this really is a shift in overall community composition to becoming more like that at Clarks Beach.

In May 2001 ponds 1 and 2 at the Mangere sewage treatment plant were breached as part of the upgrading of Mangere waste water treatment and pond recovery. Ponds 3 and 4 were breached in August 2002. Based on this information and changes observed at Cape Horn over the last 4 years, extra intervention analyses were completed to determine if a link could be established between the releasing of the ponds and changes in taxa abundances. The results show that abundances predicted to occur from 2001 until February 2005, based on previous years trends and cyclic patterns, did not match the abundances observed. Seven species are showing differences between predicted and actual abundances. In particular, *Magelona ?dakini*, while showing a harbour wide increase in abundance over the last couple of years, has increased at Cape Horn by a far greater magnitude than would be expected from past cycles and trends. In addition, the chlorophyll *a* levels at Cape Horn have shown a negative trend over this period, which would be expected had water quality improved. Intervention analysis could not be run on this data as sampling of chlorophyll didn't start until 2001. Chlorophyll *a* levels at both Auckland Airport and Clarks Beach do not show a significant trend. It seems plausible that the improved water quality from the upgrading of Mangere waste water treatment has, at least in part, contributed to the changes occurring in certain taxa.

The current results fit well with what might be predicted to occur with an increase in water quality from the improved waste water treatment. It would be expected that with the improvements to the water quality there would be a subsequent decrease in nutrients, phytoplankton and suspended organic matter. This would have the greatest effect on suspension feeding polychaetes, for example, *Boccardia syrtis*, *Aquilaspio aucklandica* and *Owenia fusiformis*. Polychaete mats, such as those formed by dense aggregations of *Boccardia syrtis*, are well known to bind fine particles together creating muddy hummocks as seen at Cape Horn in past years. It is also well documented that there is a positive relationship between sediment silt content and amount of chlorophyll *a.* Therefore, with a decrease in *Boccardia syrtis* due to reduced food supply, it could be expected that less silt would be trapped on the sandflat and hence a reduction in chlorophyll would be observed. The results at Cape Horn indicate that silt levels are generally lower than they were at the beginning of the monitoring programme and that there has been a significant decreasing trend in Chlorophyll *a*.

Monitoring of water quality in the vicinity of the ponds has not shown a significant change in phytoplankton (based on chlorophyll *a,* only reported on from 2001), although a strong reduction in ammonia-nitrogen and nitrite-nitrogen has occurred since pond breaching (ARCTP #234). Generally in marine environments, nitrogen is the limiting nutrient for phytoplankton. Thus, the reduction in ammonia- and nitrite-nitrogen that has occurred since the breaching might be expected to have an effect on phytoplankton. Considering the lack of pre-breach chlorophyll *a* data, identifying significant declines in phytoplankton at the water quality monitoring sites closest to Cape Horn is difficult. Furthermore, the monthly monitoring of the water quality may not be at a scale that is well linked to the subtle changes influencing benthic communities over long time-frames.

An alternative reason for the shift in community composition at Cape Horn relating to site elevation was put forward in the previous monitoring report (Funnell et al, 2003). Based on the extent of the sampled area (90 by 100m) and the magnitude of changes occurring, it is considered unlikely that such a great shift in species composition is likely with a small shift in elevation. This is supported by the previous repositioning pf the site in 1999 (from low intertidal to mid intertidal) which did not show changes in community composition in subsequent reports. It is still possible, however, that a change in elevation may have occurred since and is contributing in some way to differences observed at this site. No site elevation measurements are available for this site and therefore it is difficult to speculate further. It would be beneficial for a site elevation survey to be carried out for future reference.

Considering that the Mangere ponds are approximately 7km away from the site at Cape Horn, we would expect that any effect would be quite subtle. The changes that we are seeing at Cape Horn are consistent with improving water quality, however, as this monitoring programme has shown, sand flat communities can be highly variable and can exhibit natural cycles of abundance. To determine if the changes persist over time at Cape Horn further monitoring will be required.

6 Recommendations

We recommend that monitoring continue at all three of the sites in the reduced monitoring programme. The sites at Auckland Airport and Clarks Beach continue to provide an invaluable data set for determining the presence of greater-than-annual cycles of abundance for several taxa, which in turn provides important information for other studies carried out on behalf of the Auckland Regional Council (e.g., the Mahurangi monitoring programme, Waitamata monitoring programme, and the Whitford urban development project). It has also greatly improved our understanding of sandflat communities and improved our ability to assess ecosystem health.

With the changes observed at Cape Horn, it is considered that further monitoring at this site would provide a better understanding of changes within the benthic community and if they are related to changes in water quality. A site visit to Cape Horn by NIWA staff (who carried out the sampling prior to field sampling by ARC staff) that looks not just at the site, but at the surrounding environment and communities is also recommended. We also suggest that it would be useful to carry out an elevation survey of the site. This would provide valuable evidence if future elevation changes were suspected.

At this stage of the monitoring programme there is no evidence to suggest detrimental effects on ecosystem health within the main body of the Manukau harbour. The scope of this monitoring programme is to assess intertidal sandflat communities, and while these habitats cover approximately 60% of the intertidal zone, it does not incorporate other areas such as tidal streams and fringing habitats (e.g. mangroves). Given this, it appears that current management practices are effective, at least in respect to intertidal sandflats, and no remedial action is required.

7 Acknowledgements

The authors of this report would like to thank Mike McMurtry and Dominic McCarthy (ARC Environment) for their assistance in sample collection, and Nicole Hancock, Haylie Stevens, Holly Ferguson, Aaron Harnett and Luca Chiaroni for their help with preliminary sorting, identification and statistics.

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9 Appendix

9.1 Summary of temporal data[4] collected every 2 months at the Auckland Airport (AA), Clarks Beach (CB) and Cape Horn (CH) sites, between April 2003 (Series 94) and February 2005 (Series 105).

		AA		CB		CH	
Species	Series	Total	Mean	Total	Mean	Total	Mean
Aglaophamus macroura	94	2	0.2	0	0.0	4	0.3
Aglaophamus macroura	95	0	0.0	0	0.0	6	0.5
Aglaophamus macroura	96	2	0.2	0	0.0	-	-
Aglaophamus macroura	97	12	1.0	1	0.1	14	1.2
Aglaophamus macroura	98	11	0.9	0	0.0	10	0.8
Aglaophamus macroura	99	1	0.1	1	0.1	6	0.5
Aglaophamus macroura	100	3	0.3	1	0.1	7	0.6
Aglaophamus macroura	101	3	0.3	0	0.0	6	0.5
Aglaophamus macroura	102	0	0.0	0	0.0	4	0.3
Aglaophamus macroura	103	6	0.5	0	0.0	10	0.8
Aglaophamus macroura	104	7	0.6	0	0.0	3	0.3
Aglaophamus macroura	105	6	0.5	0	0.0	5	0.4
Anthopleura aureoradiata	94	0	0.0	27	2.3	0	0.0
Anthopleura aureoradiata	95	0	0.0	4	0.3	0	0.0
Anthopleura aureoradiata	96	0	0.0	10	0.8	-	-
Anthopleura aureoradiata	97	1	0.1	8	0.7	0	0.0
Anthopleura aureoradiata	98	0	0.0	12	1.0	0	0.0
Anthopleura aureoradiata	99	0	0.0	7	0.6	1	0.1
Anthopleura aureoradiata	100	2	0.2	29	2.4	0	0.0
Anthopleura aureoradiata	101	0	0.0	15	1.3	0	0.0
Anthopleura aureoradiata	102	0	0.0	4	0.3	0	0.0
Anthopleura aureoradiata	103	0	0.0	5	0.4	0	0.0
Anthopleura aureoradiata	104	0	0.0	10	0.8	0	0.0
Anthopleura aureoradiata	105	1	0.1	0	0.0	0	0.0
Aonides oxycephala	94	24	2.0	0	0.0	0	0.0
Aonides oxycephala	95	14	1.2	0	0.0	0	0.0
Aonides oxycephala	96	10	0.8	1	0.1	-	-
Aonides oxycephala	97	43	3.6	2	0.2	0	0.0
Aonides oxycephala	98	56	4.7	0	0.0	0	0.0
Aonides oxycephala	99	62	5.2	0	0.0	0	0.0
Aonides oxycephala	100	58	4.8	0	0.0	0	0.0
Aonides oxycephala	101	70	5.8	0	0.0	0	0.0
Aonides oxycephala	102	138	11.5	0	0.0	0	0.0
Aonides oxycephala	103	142	11.8	0	0.0	0	0.0
Aonides oxycephala	104	154	12.8	0	0.0	0	0.0
Aonides oxycephala	105	168	14.0	0	0.0	0	0.0

[4] Data is only given if, during the first 2 years of the monitoring programme, the taxa occurred at that site on each sampling time, or if its abundance on at least one sampling time per year was greater than 5.

Aquilaspio aucklandica	94	3	0.3	0	0.0	0	0.0
Aquilaspio aucklandica	95	3	0.3	4	0.3	0	0.0
Aquilaspio aucklandica	96	0	0.0	3	0.3	-	-
Aquilaspio aucklandica	97	2	0.2	9	0.8	0	0.0
Aquilaspio aucklandica	98	1	0.1	2	0.2	0	0.0
Aquilaspio aucklandica	99	1	0.1	5	0.4	0	0.0
Aquilaspio aucklandica	100	1	0.1	0	0.0	0	0.0
Aquilaspio aucklandica	101	1	0.1	6	0.5	1	0.1
Aquilaspio aucklandica	102	0	0.0	10	0.8	0	0.0
Aquilaspio aucklandica	103	0	0.0	4	0.3	0	0.0
Aquilaspio aucklandica	104	1	0.1	3	0.3	0	0.0
Aquilaspio aucklandica	105	0	0.0	11	0.9	0	0.0
Austrovenus stutchburyi	94	30	2.5	0	0.0	0	0.0
Austrovenus stutchburyi	95	0	0.0	0	0.0	1	0.1
Austrovenus stutchburyi	96	20	1.7	0	0.0	-	-
Austrovenus stutchburyi	97	68	5.7	1	0.1	0	0.0
Austrovenus stutchburyi	98	29	2.4	2	0.2	1	0.1
Austrovenus stutchburyi	99	77	6.4	0	0.0	0	0.0
Austrovenus stutchburyi	100	46	3.8	3	0.3	0	0.0
Austrovenus stutchburyi	101	49	4.1	2	0.2	0	0.0
Austrovenus stutchburyi	102	0	0.0	4	0.3	0	0.0
Austrovenus stutchburyi	103	141	11.8	6	0.5	0	0.0
Austrovenus stutchburyi	104	97	8.1	3	0.3	0	0.0
Austrovenus stutchburyi	105	0	0.0	1	0.1	0	0.0
Boccardia syrtis	94	0	0.0	144	12.0	0	0.0
Boccardia syrtis	95	0	0.0	42	3.5	0	0.0
Boccardia syrtis	96	0	0.0	73	6.1	-	-
Boccardia syrtis	97	1	0.1	78	6.5	0	0.0
Boccardia syrtis	98	1	0.1	24	2.0	0	0.0
Boccardia syrtis	99	0	0.0	45	3.8	0	0.0
Boccardia syrtis	100	0	0.0	110	9.2	0	0.0
Boccardia syrtis	101	0	0.0	29	2.4	0	0.0
Boccardia syrtis	102	0	0.0	41	3.4	0	0.0
Boccardia syrtis	103	1	0.1	22	1.8	0	0.0
Boccardia syrtis	104	0	0.0	16	1.3	0	0.0
Boccardia syrtis	105	0	0.0	18	1.5	0	0.0
Colurostylis lemurum	94	5	0.4	0	0.0	23	1.9
Colurostylis lemurum	95	11	0.9	1	0.1	21	1.8
Colurostylis lemurum	96	22	1.8	0	0.0	-	-
Colurostylis lemurum	97	57	4.8	12	1.0	26	2.2
Colurostylis lemurum	98	45	3.8	0	0.0	11	0.9
Colurostylis lemurum	99	20	1.7	1	0.1	68	5.7
Colurostylis lemurum	100	13	1.1	1	0.1	23	1.9
Colurostylis lemurum	101	10	0.8	6	0.5	108	9.0
Colurostylis lemurum	102	7	0.6	0	0.0	94	7.8
Colurostylis lemurum	103	16	1.3	1	0.1	36	3.0
Colurostylis lemurum	104	18	1.5	7	0.6	48	4.0
Colurostylis lemurum	105	15	1.3	0	0.0	5	0.4

Exosphaeroma spp.	94	0	0.0	0	0.0	0	0.0
Exosphaeroma spp	95	2	0.2	0	0.0	0	0.0
Exosphaeroma spp	96	1	0.1	0	0.0	-	-
Exosphaeroma spp	97	2	0.2	0	0.0	0	0.0
Exosphaeroma spp.	98	2	0.2	0	0.0	1	0.1
Exosphaeroma spp.	99	1	0.1	0	0.0	0	0.0
Exosphaeroma spp.	100	1	0.1	0	0.0	0	0.0
Exosphaeroma spp.	101	0	0.0	1	0.1	0	0.0
Exosphaeroma spp.	102	1	0.1	0	0.0	0	0.0
Exosphaeroma spp.	103	4	0.3	0	0.0	0	0.0
Exosphaeroma spp.	104	11	0.9	14	1.2	1	0.1
Exosphaeroma spp.	105	17	1.4	0	0.0	0	0.0
Goniada emerita	94	0	0.0	0	0.0	0	0.0
Goniada emerita	95	0	0.0	0	0.0	0	0.0
Goniada emerita	96	0	0.0	0	0.0	-	-
Goniada emerita	97	0	0.0	8	0.7	0	0.0
Goniada emerita	98	0	0.0	3	0.3	0	0.0
Goniada emerita	99	0	0.0	3	0.3	1	0.1
Goniada emerita	100	0	0.0	6	0.5	0	0.0
Goniada emerita	101	0	0.0	9	0.8	0	0.0
Goniada emerita	102	2	0.2	13	1.1	0	0.0
Goniada emerita	103	3	0.3	4	0.3	0	0.0
Goniada emerita	104	0	0.0	8	0.7	2	0.2
Goniada emerita	105	0	0.0	4	0.3	0	0.0
Hiatula siliqua	94	77	6.4	0	0.0	30	2.5
Hiatula siliqua	95	74	6.2	1	0.1	34	2.8
Hiatula siliqua	96	102	8.5	0	0.0	-	-
Hiatula siliqua	97	80	6.7	0	0.0	11	0.9
Hiatula siliqua	98	17	1.4	1	0.1	1	0.1
Hiatula siliqua	99	46	3.8	1	0.1	22	1.8
Hiatula siliqua	100	228	19.0	2	0.2	2	0.2
Hiatula siliqua	101	121	10.1	2	0.2	78	6.5
Hiatula siliqua	102	569	47.4	1	0.1	34	2.8
Hiatula siliqua	103	267	22.3	5	0.4	13	1.1
Hiatula siliqua	104	139	11.6	10	0.8	1	0.1
Hiatula siliqua	105	53	4.4	1	0.1	5	0.4
Macomona liliana	94	994	82.8	64	5.3	5	0.4
Macomona liliana	95	596	49.7	63	5.3	2	0.2
Macomona liliana	96	852	71.0	36	3.0	-	-
Macomona liliana	97	446	37.2	101	8.4	4	0.3
Macomona liliana	98	268	22.3	66	5.5	0	0.0
Macomona liliana	99	346	28.8	47	3.9	4	0.3
Macomona liliana	100	461	38.4	30	2.5	0	0.0
Macomona liliana	101	417	34.8	61	5.1	2	0.2
Macomona liliana	102	524	43.7	97	8.1	5	0.4
Macomona liliana	103	380	31.7	59	4.9	2	0.2
Macomona liliana	104	253	21.1	54	4.5	4	0.3
Macomona liliana	105	163	13.6	46	3.8	2	0.2

Macroclymenella stewartensis	94	0	0.0	49	4.1	1	0.1
Macroclymenella stewartensis	95	0	0.0	25	2.1	1	0.1
Macroclymenella stewartensis	96	0	0.0	90	7.5	-	-
Macroclymenella stewartensis	97	0	0.0	179	14.9	107	8.9
Macroclymenella stewartensis	98	0	0.0	67	5.6	108	9.0
Macroclymenella stewartensis	99	0	0.0	65	5.4	62	5.2
Macroclymenella stewartensis	100	0	0.0	56	4.7	19	1.6
Macroclymenella stewartensis	101	0	0.0	47	3.9	7	0.6
Macroclymenella stewartensis	102	0	0.0	86	7.2	3	0.3
Macroclymenella stewartensis	103	0	0.0	101	8.4	59	4.9
Macroclymenella stewartensis	104	0	0.0	85	7.1	74	6.2
Macroclymenella stewartensis	105	0	0.0	36	3.0	57	4.8
Magelona ?dakini	94	55	4.6	46	3.8	276	23.0
Magelona ?dakini	95	74	6.2	26	2.2	310	25.8
Magelona ?dakini	96	136	11.3	57	4.8	-	-
Magelona ?dakini	97	143	11.9	59	4.9	290	24.2
Magelona ?dakini	98	119	9.9	92	7.7	276	23.0
Magelona ?dakini	99	126	10.5	72	6.0	293	24.4
Magelona ?dakini	100	120	10.0	70	5.8	361	30.1
Magelona ?dakini	101	111	9.3	65	5.4	391	32.6
Magelona ?dakini	102	156	13.0	116	9.7	478	39.8
Magelona ?dakini	103	142	11.8	72	6.0	359	29.9
Magelona ?dakini	104	108	9.0	80	6.7	433	36.1
Magelona ?dakini	105	95	7.9	108	9.0	240	20.0
Methalimedon sp.	94	2	0.2	0	0.0	6	0.5
Methalimedon sp.	95	3	0.3	0	0.0	0	0.0
Methalimedon sp.	96	6	0.5	5	0.4	-	-
Methalimedon sp.	97	0	0.0	2	0.2	12	1.0
Methalimedon sp.	98	2	0.2	6	0.5	6	0.5
Methalimedon sp.	99	0	0.0	2	0.2	0	0.0
Methalimedon sp.	100	1	0.1	0	0.0	5	0.4
Methalimedon sp.	101	0	0.0	2	0.2	5	0.4
Methalimedon sp.	102	2	0.2	15	1.3	20	1.7
Methalimedon sp.	103	0	0.0	13	1.1	14	1.2
Methalimedon sp.	104	0	0.0	14	1.2	8	0.7
Methalimedon sp.	105	0	0.0	18	1.5	2	0.2
Notoacmea helmsi	94	3	0.3	1	0.1	0	0.0
Notoacmea helmsi	95	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	96	1	0.1	2	0.2	-	-
Notoacmea helmsi	97	0	0.0	1	0.1	0	0.0
Notoacmea helmsi	98	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	99	0	0.0	1	0.1	0	0.0
Notoacmea helmsi	100	2	0.2	0	0.0	0	0.0
Notoacmea helmsi	101	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	102	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	103	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	104	0	0.0	0	0.0	0	0.0
Notoacmea helmsi	105	0	0.0	0	0.0	0	0.0

Nucula hartvigiana	94	18	1.5	58	4.8	0	0.0
Nucula hartvigiana	95	3	0.3	84	7.0	0	0.0
Nucula hartvigiana	96	7	0.6	9	0.8	-	-
Nucula hartvigiana	97	122	10.2	126	10.5	5	0.4
Nucula hartvigiana	98	9	0.8	115	9.6	2	0.2
Nucula hartvigiana	99	23	1.9	44	3.7	4	0.3
Nucula hartvigiana	100	18	1.5	12	1.0	0	0.0
Nucula hartvigiana	101	39	3.3	34	2.8	0	0.0
Nucula hartvigiana	102	23	1.9	41	3.4	1	0.1
Nucula hartvigiana	103	38	3.2	47	3.9	3	0.3
Nucula hartvigiana	104	55	4.6	290	24.2	0	0.0
Nucula hartvigiana	105	33	2.8	60	5.0	1	0.1
Orbinia papillosa	94	99	8.3	2	0.2	1	0.1
Orbinia papillosa	95	124	10.3	0	0.0	0	0.0
Orbinia papillosa	96	153	12.8	0	0.0	-	-
Orbinia papillosa	97	105	8.8	0	0.0	0	0.0
Orbinia papillosa	98	41	3.4	0	0.0	3	0.3
Orbinia papillosa	99	6	0.5	0	0.0	0	0.0
Orbinia papillosa	100	60	5.0	0	0.0	3	0.3
Orbinia papillosa	101	17	1.4	2	0.2	1	0.1
Orbinia papillosa	102	15	1.3	0	0.0	2	0.2
Orbinia papillosa	103	13	1.1	0	0.0	2	0.2
Orbinia papillosa	104	3	0.3	3	0.3	1	0.1
Orbinia papillosa	105	4	0.3	0	0.0	0	0.0
Owenia fusiformis	94	0	0.0	7	0.6	0	0.0
Owenia fusiformis	95	0	0.0	4	0.3	0	0.0
Owenia fusiformis	96	0	0.0	14	1.2	-	-
Owenia fusiformis	97	1	0.1	16	1.3	0	0.0
Owenia fusiformis	98	1	0.1	13	1.1	0	0.0
Owenia fusiformis	99	0	0.0	9	0.8	0	0.0
Owenia fusiformis	100	0	0.0	11	0.9	0	0.0
Owenia fusiformis	101	0	0.0	12	1.0	0	0.0
Owenia fusiformis	102	0	0.0	14	1.2	0	0.0
Owenia fusiformis	103	0	0.0	6	0.5	0	0.0
Owenia fusiformis	104	0	0.0	7	0.6	0	0.0
Owenia fusiformis	105	0	0.0	10	0.8	0	0.0
Torridoharpinia hurleyi	94	1	0.1	37	3.1	0	0.0
Torridoharpinia hurleyi	95	0	0.0	2	0.2	0	0.0
Torridoharpinia hurleyi	96	4	0.3	25	2.1	-	-
Torridoharpinia hurleyi	97	12	1.0	38	3.2	3	0.3
Torridoharpinia hurleyi	98	6	0.5	10	0.8	1	0.1
Torridoharpinia hurleyi	99	4	0.3	1	0.1	0	0.0
Torridoharpinia hurleyi	100	7	0.6	11	0.9	0	0.0
Torridoharpinia hurleyi	101	3	0.3	29	2.4	0	0.0
Torridoharpinia hurleyi	102	7	0.6	75	6.3	0	0.0
Torridoharpinia hurleyi	103	15	1.3	52	4.3	0	0.0
Torridoharpinia hurleyi	104	21	1.8	70	5.8	0	0.0
Torridoharpinia hurleyi	105	8	0.7	13	1.1	0	0.0

Travisia olens	94	5	0.4	0	0.0	0	0.0
Travisia olens	95	3	0.3	0	0.0	0	0.0
Travisia olens	96	3	0.3	0	0.0	-	-
Travisia olens	97	12	1.0	0	0.0	0	0.0
Travisia olens	98	15	1.3	0	0.0	0	0.0
Travisia olens	99	14	1.2	0	0.0	0	0.0
Travisia olens	100	5	0.4	0	0.0	0	0.0
Travisia olens	101	2	0.2	0	0.0	0	0.0
Travisia olens	102	8	0.7	0	0.0	0	0.0
Travisia olens	103	15	1.3	0	0.0	0	0.0
Travisia olens	104	22	1.8	0	0.0	0	0.0
Travisia olens	105	17	1.4	0	0.0	0	0.0
Trochodota dendyi	94	28	2.3	4	0.3	0	0.0
Trochodota dendyi	95	20	1.7	1	0.1	0	0.0
Trochodota dendyi	96	34	2.8	4	0.3	-	-
Trochodota dendyi	97	41	3.4	1	0.1	1	0.1
Trochodota dendyi	98	15	1.3	2	0.2	2	0.2
Trochodota dendyi	99	13	1.1	6	0.5	0	0.0
Trochodota dendyi	100	34	2.8	1	0.1	1	0.1
Trochodota dendyi	101	59	4.9	5	0.4	1	0.1
Trochodota dendyi	102	136	11.3	2	0.2	2	0.2
Trochodota dendyi	103	86	7.2	1	0.1	0	0.0
Trochodota dendyi	104	29	2.4	1	0.1	0	0.0
Trochodota dendyi	105	44	3.7	2	0.2	1	0.1
Waitangi brevirostris	94	7	0.6	0	0.0	2	0.2
Waitangi brevirostris	95	8	0.7	0	0.0	1	0.1
Waitangi brevirostris	96	6	0.5	0	0.0	-	-
Waitangi brevirostris	97	1	0.1	0	0.0	8	0.7
Waitangi brevirostris	98	3	0.3	0	0.0	10	0.8
Waitangi brevirostris	99	5	0.4	0	0.0	12	1.0
Waitangi brevirostris	100	3	0.3	0	0.0	15	1.3
Waitangi brevirostris	101	5	0.4	0	0.0	32	2.7
Waitangi brevirostris	102	10	0.8	0	0.0	17	1.4
Waitangi brevirostris	103	20	1.7	0	0.0	18	1.5
Waitangi brevirostris	104	17	1.4	0	0.0	42	3.5
Waitangi brevirostris	105	4	0.3	0	0.0	55	4.6

9.2 Sediment grain size (% composition) on each sampling date since June 2001. Percent composition of initial samples (October 1987) are also given for comparison. Grain size fractions given are: Gravel (particles >2mm), Sand (particles 63μm-2mm), Silt/clay (particles <63μm).

	Auckland Airport			Clarks Beach			Cape Horn		
	gravel	sand	silt/clay	gravel	sand	silt/clay	gravel	sand	silt/clay
October 1987	1.6	96.7	1.7	6.1	91.1	2.8	2.5	93.3	4.2
June 2001	0.1	99.3	0.7	0.6	86.2	13.2	0.1	96.6	3.3
August 2001	0.3	98.4	1.2	2.7	84.8	12.6	0	99.2	0.8
October 2001	0	98.1	1.9	1.5	82.7	15.8	0	97.8	2.2
December 2001	1.6	97.4	1	0.5	96	3.5	0	99.4	0.6
February 2002	0.1	98.7	1.2	1.5	95.9	2.6	0	99.2	0.8
April 2002	0	98.7	1.3	0.8	94.5	4.7	0	99.1	0.9
June 2002	0.2	99.4	0.5	2.2	96.3	1.4	0	99.2	0.8
August 2002	0.2	83.4	16.5	0.2	78.6	21.2	0.7	84.6	14.7
October 2002	0.2	99	0.8	5.2	91.8	3	0	99.6	0.4
December 2002	0.1	99.1	0.8	2.9	94.2	2.9	0.9	98.4	0.7
February 2003	0.5	98.7	0.8	2.3	94.3	3.4	0	99.2	0.8
April 2003	0.6	98.3	1.1	0.9	88.1	11.1	0.0	99.1	0.8
June 2003	0.1	99.4	0.4	0.0	97.7	2.2	2.1	83.2	14.7
August 2003	0.6	98.1	1.3	0.2	83.7	16.2	.	.	.
October 2003	1.0	98.2	0.8	7.6	88.2	4.3	0.0	98.9	1.0
December 2003	0.2	98.9	0.9	1.2	93.9	4.8	0.0	99.1	1.0
February 2004	0.1	99.0	0.9	5.6	90.1	4.3	0.0	99.0	1.3
April 2004	0.1	96.8	3.1	0.0	92.1	7.9	0.0	98.6	1.4
June 2004	0.0	99.1	0.9	0.0	94.1	0.0	0.2	99.6	0.2
August 2004	0.1	99.0	0.9	2.0	90.7	7.4	0.0	95.1	4.9
October 2004	0.0	99.1	0.9	1.8	93.9	4.3	0.0	98.5	1.5
December 2004	0.3	99.5	0.3	0.0	96.5	3.5	0.9	98.1	0.9
February 2005	0.0	99.2	0.8	0.7	89.3	10.0	0.0	98.8	1.2

9.3 Sediment chlorophyll *a* levels (μg /g sediment) at each site for the period June 2001 to February 2005.

	Auckland Airport	Clarks Beach	Cape Horn
June 2001	11.2	26.1	16.7
August 2001	9.6	27.0	9.8
October 2001	8.5	13.7	11.1
December 2001	24.9	22.7	11.5
February 2002	7.9	11.2	13.4
April 2002	10.3	14.9	11.1
June 2002	10.6	10.8	9.5
August 2002	10.3	13.0	10.7
October 2002	9.6	9.6	11.3
December 2002	15.4	19.2	23.5
February 2003	13.0	20.4	20.2
April 2003	6.5	9.4	7.6
June 2003	8.5	21.7	10.8
August 2003	10.5	16.9	-
October 2003	6.8	9.4	5.4
December 2003	4.5	7.7	5.8
February 2004	4.7	6.5	5.7
April 2004	12.2	14.1	6.7
June 2004	13.5	19.3	11.2
August 2004	11.2	16.5	9.9
October 2004	10.5	12.0	9.7
December 2004	11.5	12.9	8.6
February 2005	10.4	14.8	7.8

9.4 Percent organic content at each site for the period June 2003 to February 2005.

Site	Auckland Airport	Clarks Beach	Cape Horn
April 2003	0.8	1.7	0.7
June 2003	0.8	2.3	1.0
August 2003	0.6	1.4	.
October 2003	0.6	0.9	0.5
December 2003	0.6	0.9	0.6
February 2004	0.7	0.9	0.7
April 2004	0.8	1.8	0.6
June 2004	1.0	1.3	2.5
August 2004	1.1	1.4	1.0
October 2004	0.6	0.8	1.3
December 2004	1.0	1.3	2.0
February 2005	1.0	1.8	0.9