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Manukau Harbour Ecological Monitoring Programme: Report on data collected up until February 2007

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Manukau Harbour Ecological Monitoring Programme: Report on data collected up until February 2007

Judi E. Hewitt
Sarah F. Hailes

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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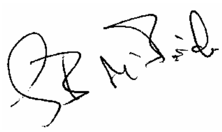

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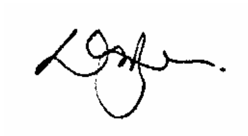

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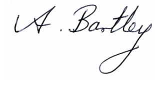


1 Executive Summary

This report updates the results of the Manukau Harbour Ecological Monitoring Programme, established in October 1987 as an initative of the Auckland Regional Council. 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. The programme is a temporally nested design with two sites permanently monitored (Auckland Airport and Clarks Beach). Elletts Beach, Karaka Point and Puhinui Stream alternate monitored with unmonitored years on a cycle of five years off, two years on. Cape Horn initially followed that cycle, but has been continuously monitored since removal of the waste water treatment ponds at Mangere. At present all six of the sites are being monitored; this began in August 2006 and should continue until April 2008.

The most significant changes that have been observed, over the monitored period, have occurred at the Cape Horn site. Most of these changes occurred between 1995 and 2000 and then again between 2000 and 2003. However, it appears that a new stable community structure has now been achieved. Changes observed between 2001 and 2005 at the Cape Horn site were largely those predicted to occur with improved waste water treatment. That is, a reduction of suspension feeders, reduced silt levels and reduced chlorophyll *a* concentrations. However, at least some of the changes at this site appear to have been influenced by the strong El Niño Southern Oscillation (ENSO) event that New Zealand has been having for the last six years.

Although no changes in sediment characteristics are apparent at the three sites that were not monitored between 2001 to 2006, the community composition observed in October 2006 at the Karaka Point and Puhunui Stream sites differs from the community compositions previously observed. The changes, however, are not large and may simply be a result of natural variability. With less than a year of new data, it has not been possible to investigate any long-term changes in populations relative to previous cyclic patterns, or to determine whether changes observed at the Karaka Point and Puhinui Stream sites are also ENSO related. We recommend that all six sites should continue to be monitored as planned (until June 2008), when any changes in the benthic communities at the sites can be effectively determined.

Importantly, 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. Many of the changes in the abundance of taxa at the monitored sites are now obviously long-term cycles. Thus, the current management initatives being implemented by the Auckland Regional Council to minimise effects of changing anthropogenic practises are effectively maintaining the health of Manukau Harbour. Moreover, the ability to predict at least some of the variability in temporal dynamics of taxa in the Manukau by ENSO patterns suggests that this monitoring programme (and others in the Mahurangi and Central Waitemata harbours) will be of tremendous use if the Auckland Regional Council wishes to investigate the potential for climate change effects.

2 Introduction

In October 1987 the Water Quality Centre (now NIWA) was commissioned to design and implement a biological monitoring programme for the Manukau Harbour. This was initiated in light of concerns for the Harbour, due to changing land developments and potential impacts that anthropogenic catchment practises 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. For cost effectiveness it was based on the abundance of 21 taxa. These taxa were selected for their likely importance to the rest of the community, or as they would provide a range of responses to different anthropogenic impacts, thus increasing the ability of the monitoring programme to detect important changes.

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 two years, up until April 2001. After April 2001, the monitoring programme was again reduced; this time to the continuously monitored sites at Auckland Airport and Clarks Beach and the Cape Horn site. The Cape Horn site was included as the Auckland Regional Council (ARC), wished to investigate whether improvements in water treatment discharging into the Manukau at Mangere had any effects on health of the benthic macrofauna. In August 2006, monitoring began again at Elletts Beach, Karaka Point and Puhinui Stream.

This report presents the results of data collected from the first monitoring in October 1987 until February 2007. The report focuses on trends in abundance of the monitored taxa and sediment data at the Auckland Airport, Clarks Beach and Cape Horn sites. Some initial analyses of whether there have been changes at the Elletts Beach, Karaka Point and Puhinui Stream sites will be discussed, but a full analysis and report on these sites will be contained in the 2009 report.

3 Methods

3.1 Sample collection and identification

The sites at Auckland Airport and Clarks Beach (Figure 3.1) have been sampled every two months between October 1987 and December 2006. Two sampling occasions were missed (October and December 1988) due to lack of continuity of funding. The sites at Cape Horn, Elletts Beach, Karaka Point and Puhinui Stream have been sampled for the ARC from October 1987 to February 1993, and again from August 1999 to April 2001. Sampling continued at Cape Horn from April 2001 to monitor effects of improvements in water quality discharging from Mangere. 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. The sites at Elletts Beach, Karaka Point and Puhinui Stream commenced again in June 2006 on the recommendation of Funnell et al. (2001).

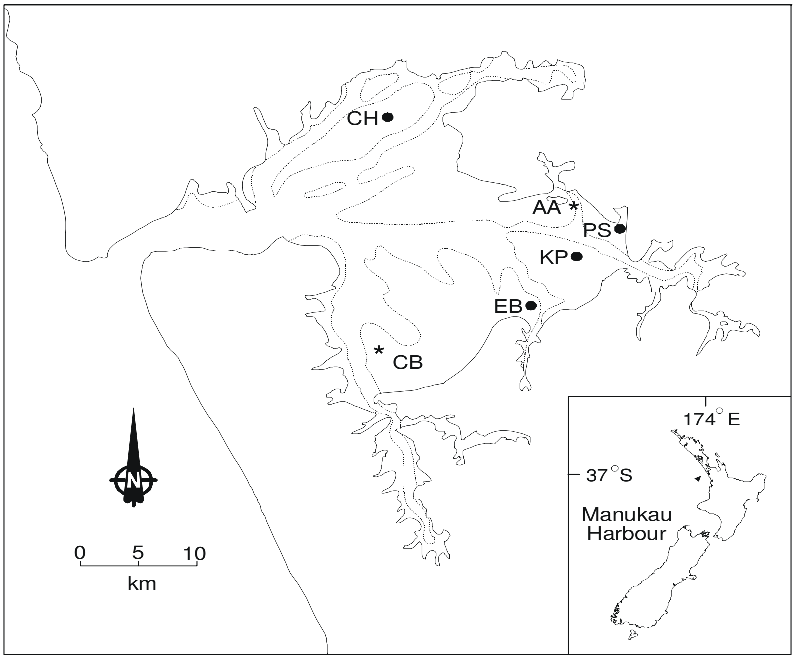
Samples are collected and processed as follows. Each site (9000 m^2) is divided into 12 equal sectors and one core sample (13 cm diameter, 15 cm depth) is taken from a random location within each sector. To limit the influence of spatial autocorrelation (see Thrush et al. 1989) and preclude any localised modification of populations by previous sampling events, core samples are not positioned within a 5 m 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 (500 µm mesh), preserved with 70% isopropyl alcohol in seawater and stained with rose bengal. The macrofauna are then sorted, and the 21 monitored taxa are identified, counted and stored in 50% isopropyl alcohol. Appendix 1 gives details of the mointored species and the reasons behind their selction.

3.2 Bivalve size class analysis

After identification, all monitored bivalve species are measured. Bivalves less than 10 mm (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., ≤1 mm, >1-2 mm, >2-4 mm, >4-8 mm, >11-16 mm, >16-22 mm and >22 mm).

Figure 3.1.

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).



3.3 Site characteristics

During each 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, homogenised and a subsample taken. 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 >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 site in October 1987, although only the gravel, snd and mud fractions were determined. 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 hours at 400°C. Also, on each sampling occasion, 6 core samples (adjacent to every second macrofauna core, 2.5 cm diameter and 2 cm 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 versus time are drawn and temporal autocorrelation analyses are caried out.
2. The time series of each population is tested to determine whether the variation in the temporal series contains a cyclic component (Chatfield, 1980).
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. The basal period is a time when peaks in recruitment are not affecting estimates of abundance, i.e., consistent periods of the year when the population is relatively constant. As such the basal population can contain both adults and juveniles as some species recruit through out the year, while still exhbiting definite times when recruitment is at a maximum.
    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 statistically significant temporal autocorrelation, adjustments are made to the calculation of standard errors and significant values
5. For all macrofaunal 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. This year, the strong concurrence of trends in the abundance of a few taxa across the three long-term monitored sites suggested that long-term cyclic variation may be affecting populations in the Manukau. The Southern Oscillation Index (SOI) is generally used to encapsulate ENSO (El Niño Southern Oscillation) events

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

(McBride and Nicholls, 1983). Lately the pressure difference between Auckland and Christchurch (Z1) has been proposed as encapsulating the effect of climate on westerly wind patterns across New Zealand (Salinger and Mullan 1999). As a first step in determining the relationship between variations in abundance and these two large-scale environmental factors, a two year moving average for each variable was constructed. Cross-correlation analysis was conducted to determine the lag period between SOL and Z1 and their effect (if any) on the population abundances of taxa exhibiting trends in abundance at each site (Auckland Airport, Clarks Beach and Cape Horn). Regression analysis was used to determine the significance of any relationship and to derive predicted time series for those populations exhibiting similarity in patterns of abundance across sites.

7. To help determine whether ENSO or changes in waste water treatment were the main drivers of change in taxa abundances at the Cape Horn site, data collected from 2000 – 2007 was combined with information on water column nutrients (nitrate – nitrogen, ammoniacal – nitrogen, total and soluble phosphorus), dissolved oxygen concentrations and total suspended sediments from a nearby ARC water quality monitoring site. Cross-correlation analysis was conducted to determine the lag period between these water quality variables and sediment chlorophyll content on the population abundances of taxa exhibiting trends in abundance at Cape Horn. Regression analysis was used to determine the variables important in predicting the trends in abundance since 2000.

8. Ordinations of all taxa observed at each site in every October were conducted using Multidimensional Scaling Analysis (MDS; Primer; Clarke and Gorley, 2006). October sampling times are the least likely to be affected by the recruitment peaks that occur for some of the monitored species. The change from DCA (used in all previous reports) was made as MDS is a better technique for displaying relational patterns in 2-dimensions. Before making the change, both techniques were compared using data from the last report, to determine that the technique used did not affect what was said. The degree to which observed changes related to changes in species or changes in relative abundances was determined by comparing results of the MDS based on raw data with one based on presence absence data.

4 Present status of the benthic communities of the Manukau Harbour

The Manukau Harbour monitoring programme was designed to answer the following questions over a long term time scale:

1. Are populations 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?

These questions are extremely broad and in order to answer them, 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?

Site characteristics such as appearance and sediment characteristics provide a background against which to describe changes in macrofauna. Changes to site characteristics such as expansion of sea grass beds into the monitored site, disturbance by rays, may help explain natural variability. 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. For this reason, a brief description of site appearance and sediment characteristics is given here, although they are not the focus of the monitoring programme.

4.1.1 General site descriptions[2]

Auckland Airport – The visual appearance of this site is largely unchanged since monitoring began in 1987 and is consistent with that described by Funnell and Hewitt (2005). The sediment surface is usually covered with sand ripples with a period of between 4 to 8 cm . The surface topography of this site is largely determined by the presence of ray pits which are typically seen in high frequency in the summer months (December – April) with associated shell hash surrounding them. Small sparse patches of seagrass were reported in June and August of 2005, but have not been recorded since. Diatom mats, such as that which covered half of the site in August 2006, are common in late winter – early summer, as is the presence of *Enteromorpha*. In October 2006, it was noted that a high density of stringy-type algae, *Ulva lactuca* and *Enteromorpha* was scattered across the site and also around the site. This algal detritus was not attached and it is likely that it was washed up due to a storm event.

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

Clarks Beach – The surface topography of this site is much the same as was recorded in 2005. The presence of surficial mud and/or a diatom mat is still consistent throughout the year, as is the presence of shell hash, worm tubes and gastropods (including *Zeacumantus* sp. and *Cominella* sp.). The presence of ray pits was not recorded in either the 2001 and 2005 reports, however, before 1997 they were a common feature between October – April. Since August 2006 they have again become common. In addition, seagrass was recorded to be present in large patches around the site at all sampling occasions since June 2005. This is consistent with the seagrass observed in 2001.

Cape Horn – The appearance of the Cape Horn site does not appear to have changed significantly in the past two years and a similar surface topography has been recorded on every sampling occasion since June 2005. While numerous polychaete tubes have been consistently observed, the tubes are now much larger and thought to be *Macroclymenella stewartensis*, compared to the once abundant *Boccardia syrtis*. Muddy sediment is associated with the dense tube mats created by *Boccardia syrtis* and this has also not been observed in the past two years, rather, sand ripples have become a dominant feature at this site. Ray pits (usually low frequency) have been observed during the warmer months with associated shell hash. In addition, a large amount of scallop shells amongst the shell hash was observed in April 2006.

Elletts Beach – This site generally has few surface features other than sand ripples. In August 2006 and February 2007 the surrounding area (especially the first 100 m from shore) was noted as being very muddy compared to inside the site. Whole shells, shell hash and gastropods on the sediment surface are dominant from August 2006 sampling to present which is consistent with the description reported in 2001 (Funnell et al. 2001). Ray pits and associated shell hash are common at this site during the warmer months, especially during December 2006 when there was a high frequency observed.

Karaka Point –Consistent with previous descriptions (Funnell et al. 2001), sand ripples, shell hash, whole shells and common gastropods (i.e., *Zeacumantus lutulentus*.) have been observed on each sampling occasion since August 2006. Similar to other sites, ray pits (low density) were observed over the summer months. *Ulva lactuca* was in abundance during December 2006 and is often associated with high levels of anthropogenic nutrients and pollution. Further monitoring will determine whether the presence of *Ulva lactuca* is becoming a common feature at this site.

Puhinui Stream – From the surface this sites seems largely unchanged since it was last sampled in 2001. The surface topography of this site is largely muddy during the winter (August to October) and throughout the summer months a surficial diatom mat occurrs. Sediments are sandy and rippled (with a period between 10-15 cm); shell hash, whole shells and common gastropods including *Zeacumantus* sp. and *Cominella* sp. are common all sampling occasions. Ray pits have been observed on every samping occasion at low frequency since the recommencement of the monitoring at this site in August 2006.

4.1.2 Sediment characteristics

A full record of sediment grain size, chlorophyll *a* and percentage orgaincs from each sampling site and time is located in Appendices 2-4.

4.1.2.1 Grain Size

The percentage mud levels at the Auckland Airport site are generally low and over the past two years the levels are still less than what they were at the start of the monitoring programme in 1987 (Figure 4.1, Table 4.1, Appendix 2). The variation in percentage mud at Auckland Airport is minimal, except for August 2002 where there was a higher than usual level of mud (16.5%). During that month, sites at Clarks Beach and Cape Horn also exhibited high mud levels (14.7%).

At Clarks Beach the percentage of mud in the sediment is generally greater than that recorded at the Auckland Airport and Cape Horn sites (although it appears similar to that observed at Elletts Beach and Karaka Point). Some seasonality is observed with high values generally occuring in and around October (Figure 4.1).

The decrease in percentage mud content of the sediments observed in previous years at Cape Horn has continued and levels are as low as at the Auckland Airport site. Lower percentage mud in the sediments of Cape Horn may be due to the decrease in abundance of the polychaete worm *Boccardia syrtis* that creates dense mats which traps fine silty particles.

The levels of percentage mud at Elletts Beach, Karaka Point and Puhinui Stream were first recorded in 1987 and were then sampled between the periods of August 1999 to June 2001 and then again from August 2006 until present. The percentage mud levels at Elletts Beach were variable during the 1999-2001 sampling period and since August 2006 until present, but levels are similar to those found when the site was first sampled in 1987. Karaka Point and Puhinui Stream were also variable during the 1999-2001 sampling period, however, since sampling recommenced in August 2006 they have been generally low and stable. Compared to when the monitoring programme started in 1987, levels of percentage mud are slightly lower (2.0%) at Karaka Point but similar at Puhinui Stream.

4.1.2.2 Chlorophyll *a*

Chlorophyll *a* concentrations in the sediments exhibit both seasonal and multi-year variations (Figure 4.2, Appendix 3). Funnell and Hewitt (2005), reported that chlorophyll *a* at Auckland Airport and Clarks Beach while variable have not changed significantly over time and this continues to be true. In contrast , the chlorophyll *a* levels at Cape Horn continue to exhibit a decreasing trend. Chlorophyll *a* concentrations at the Elletts Beach, Karaka Point and Puhinui Stream sites were similar to concentrations previously observed at these sites, and within the range observed at the Auckland Airport, Clarks Beach and Cape Horn sites.

Figure 4.1.

Sediment mud content (as percentage weight) from Auckland Airport (AA), Clarks Beach (CB), Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS) sites from 1987 – 2007.

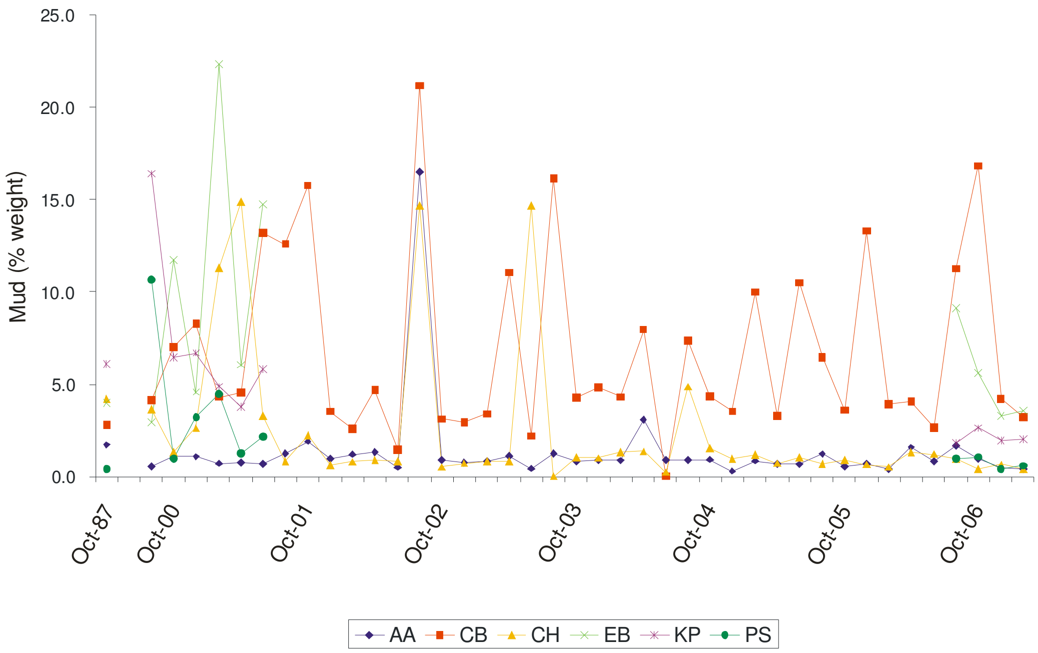
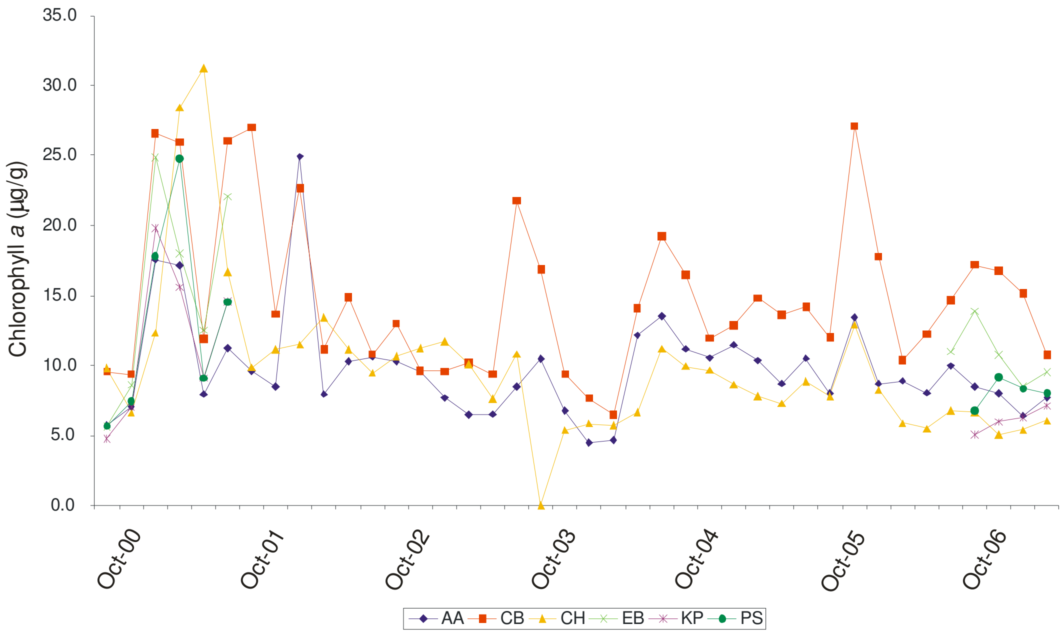


Figure 4.2.

Chlorophyll a levels of the sediment collected from each site Auckland Airport (AA), Clarks Beach (CB), Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS) from 1987 until 2007.



4.1.2.3 Organics

At all sites, the percentage organic content was relatively low and only varied slightly throughout the years (Figure 4.3, Appendix 4).

Figure 4.3.
Percentage composition of organic content of the sediments from Auckland Airport (AA), Clarks Beach (CB), Cape Horn (CH), Elletts Beach (EB), Karaka Point (KP) and Puhinui Stream (PS) sites between 1987 and 2007

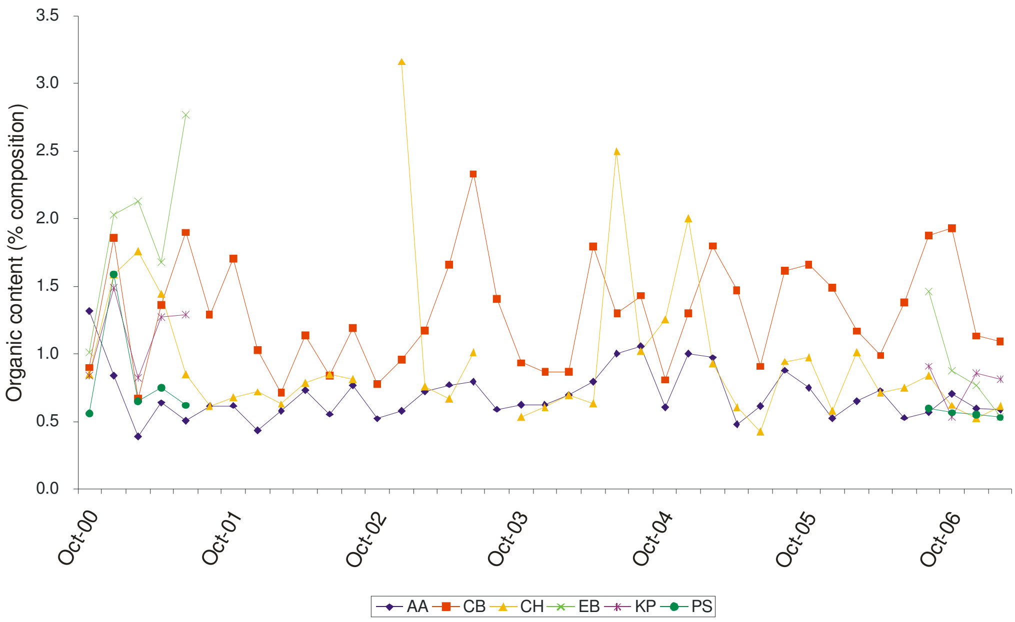


Table 4.1.

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 >2 mm, sand particles 63 µm-2 mm, mud particles <63 µm.

		Oct-87	Oct-95	Oct-96	Oct-97	Oct-98	Oct-99	Oct-00	Oct-01	Oct-02	Oct-03	Oct-04	Oct-05	Oct-06
Auckland	% gravel	1.6	0.6	0.4	0.02	0.33	1.3	0.0	0.0	0.1	1.0	0.0	0.2	0.0
Airport	% sand	96.7	99.1	99.3	99.5	96.7	98.5	98.9	98.1	99.0	98.2	99.1	99.2	99.0
(AA)	% mud	1.7	0.3	0.3	0.51	2.96	1.2	1.1	1.9	0.9	0.8	0.9	0.5	1.0
Clarks	% gravel	6.1	4.3	3.9	5.15	1.31	0.5	2.1	1.5	5.2	7.6	1.8	2.9	2.5
Beach	% sand	91.1	93.2	94.3	84.2	90.3	56.9	90.9	82.7	91.7	88.2	93.9	93.5	80.7
(CB)	% mud	2.8	2.5	1.8	10.68	8.41	42.5	7.0	15.8	3.1	4.3	4.3	3.6	16.8
Cape	% gravel	2.5					0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Horn	% sand	93.3					95.6	98.7	97.8	99.5	98.9	98.5	99.1	99.6
(CH)	% mud	4.2					4.3	1.3	2.2	0.5	1.0	1.5	0.9	0.4
Elletts	% gravel	0.1					2.1	0.2						0.8
Beach	% sand	95.9					85	88.1						93.6
(EB)	% mud	4.0					12.9	11.7						5.6
Karaka	% gravel	5.8					3.3	2.1						3.8
Point	% sand	88.1					81.7	91.4						93.6
(KP)	% mud	6.1					15	6.5						2.6
Puhinui	% gravel	0.6					0.1	0.0						0.1
Stream	% sand	99.0					97.1	99.0						98.9
(PS)	% mud	0.4					2.8	1.0						1.1

4.2 Are cyclic patterns in abundance being maintained?

Hewitt and Thrush (2007) report populations in the Manukau exhibiting cyclic patterns from as short as 2 – 3 years (15-26% of taxa at a site), 4 - 5 years (6-10% of taxa at a site), up to 7 – 9 years (2-28% of taxa at a site).

With 19 years of valuable uninterrupted data for the Auckland Airport and Clarks Beach sites, it has become possible to determine that some of the multi-year cycles observed are related to the long-term weather variations resulting from the El Niño Southern Oscillation (ENSO) (Table 4.2). For example, *Hiatula siliqua* (Figure 4.4) exhibits peaks and declines in abundance over a 7-9 year period that are largely explained by ENSO variations. Over the past two years the abundance of *Magelona ?dakini* has increased, not only at Clarks Beach, but also at the Auckland Airport and Cape Horn sites (Figure 4.5), presumably associated with ENSO (Figure 4.6).

Table 4.2.

Species exhibiting long-term cyclic patterns in abundance at the three sites with the longest monitoring records, where ENSO variables are useful predictors. A blank space indicates no relationship with ENSO variables. A = spec ies abundance at that site is too low for analysis.

Taxa	*Auckland Airport*	*Clarks Beach*	*Cape Horn*
Aglaophamus macroura	A		Y
Austrovenus stutchburyi	Y	Y	Y
Boccardia syrtis	A	Y	Y
Glycinde dorsalis[3]			Y
Hiatula siliqua	Y	Y	
Macomona liliana	Y	Y	
Magelona ?dakini	Y	Y	Y
Nucula hartvigiana	Y	Y	Y
Owenia fusiformis	A		Y
Waitangi brevirostris	Y	A	Y

This analysis has also been conducted for the Cape Horn site. Although the time series from this site is not continuous, the similarities in patterns between this site and the other two give us confidence in the analysis.

[3] Note that with the recent revision of the Goniada, *Goniada emerita* is now considered a variant of *Glycinde dorsalis*

Figure 4.4.
Abundance of *Hiatula siliqua* over time at Auckland Airport

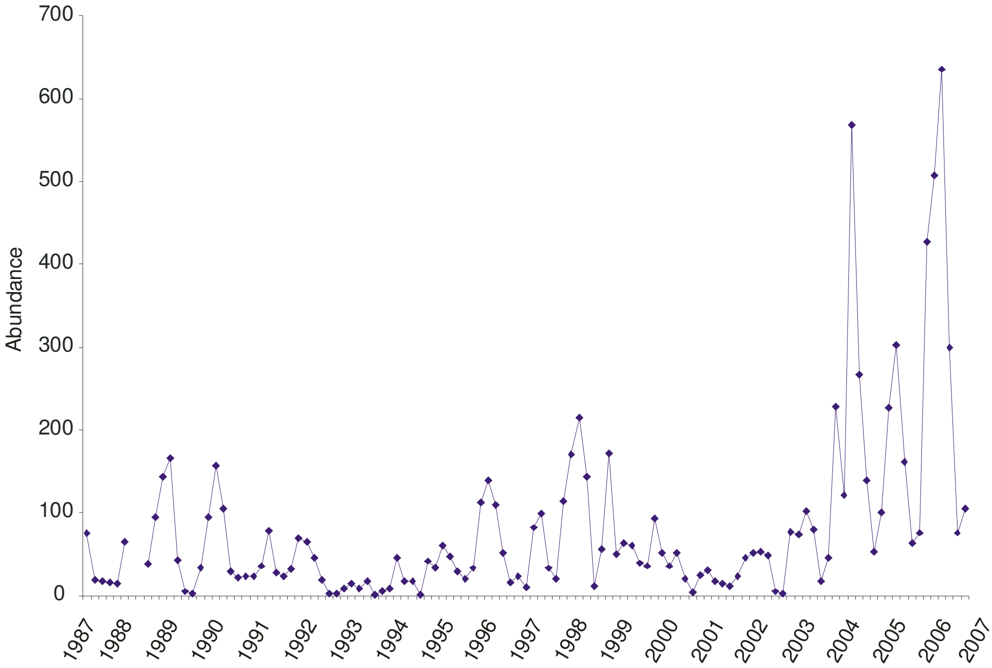


Figure 4.5.
Greater than annual cycles in abundance are evident for some monitored species, for example the abundance of *Magelona ?dakini* at Auckland Airport, Clarks Beach and Cape Horn.

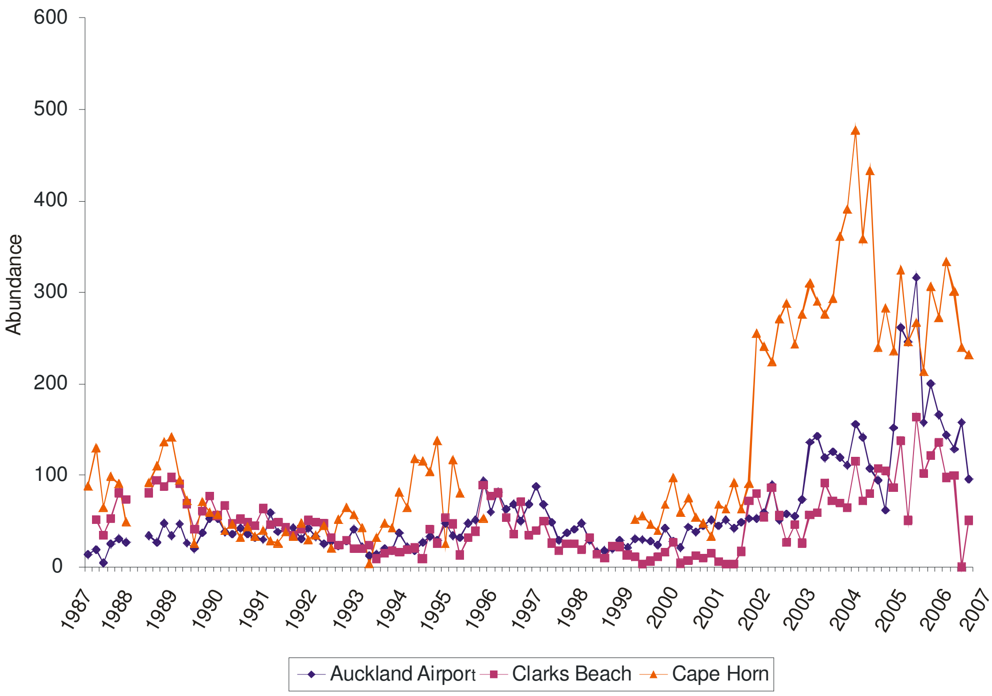
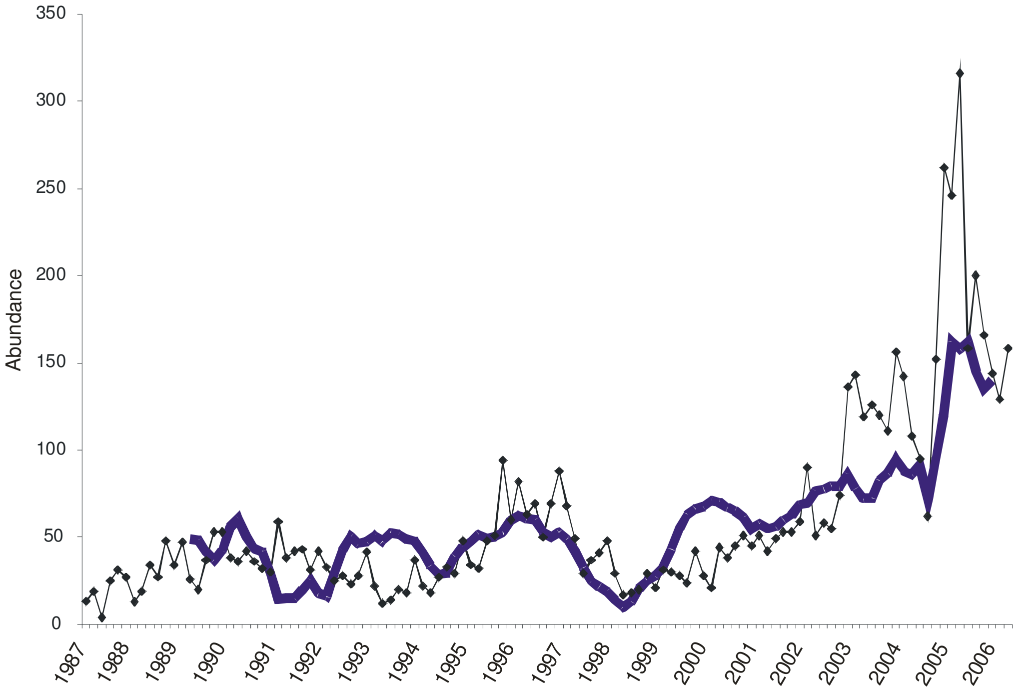


Figure 4.6:

The observed (black line) and predicted from ENSO variables (thick blue line) abundance of *Magelona ?dakini* at the Auckland Airport site over time.



However, there are a number of multi-year cyclic patterns in abundance that we have not been able to explain by ENSO. At Auckland Airport, *Trochodota dendyi and Aonides oxycephala* exhibit long-term cyclic patterns in abundances (Figure 4.7, 4.8), although the pattern could not be predicted by ENSO.

At Clarks Beach, *Notoacmea helmsi*, *Trochodota dendyi*, *Boccardia syrtis, Glycinde dorsalis* and *Prionospio aucklandica* (Figure 4.9) all exhibit multi-year cycles. *Boccardia syrtis* in particular is very temporally variable and recruitment is often high and exhibits long-term cycles of 5 – 7 years. Abundances of *Glycinde dorsalis* at this site shows short multi-year cycles of 2 – 3 years interspersed with longer ones of 6 – 7 years (Figure 4.10).

Finally at Cape Horn, both *Trochodota dendyi* and *Hiatula siliqua* exhibit multi-year cycles in peak abundance.

Figure 4.7.

Abundance of *Trochodota dendyi* over time at Auckland Airport.

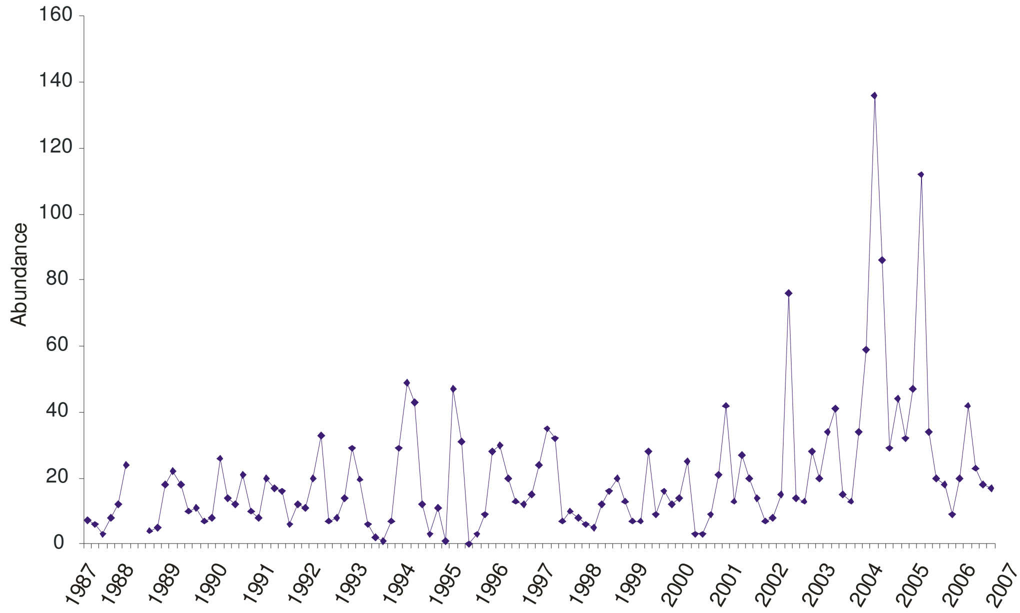


Figure 4.8.

Abundance of *Aonides oxycephala* over time at Auckland Airport.

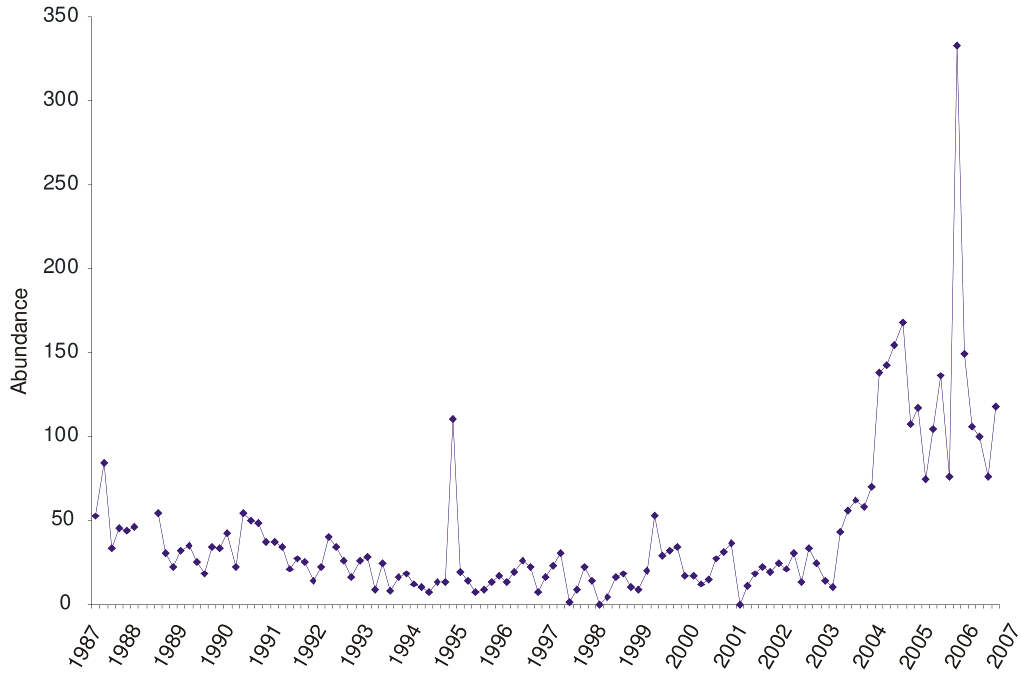


Figure 4.9.

Abundance of *Prionospio aucklandica* over time at Clarks Beach.

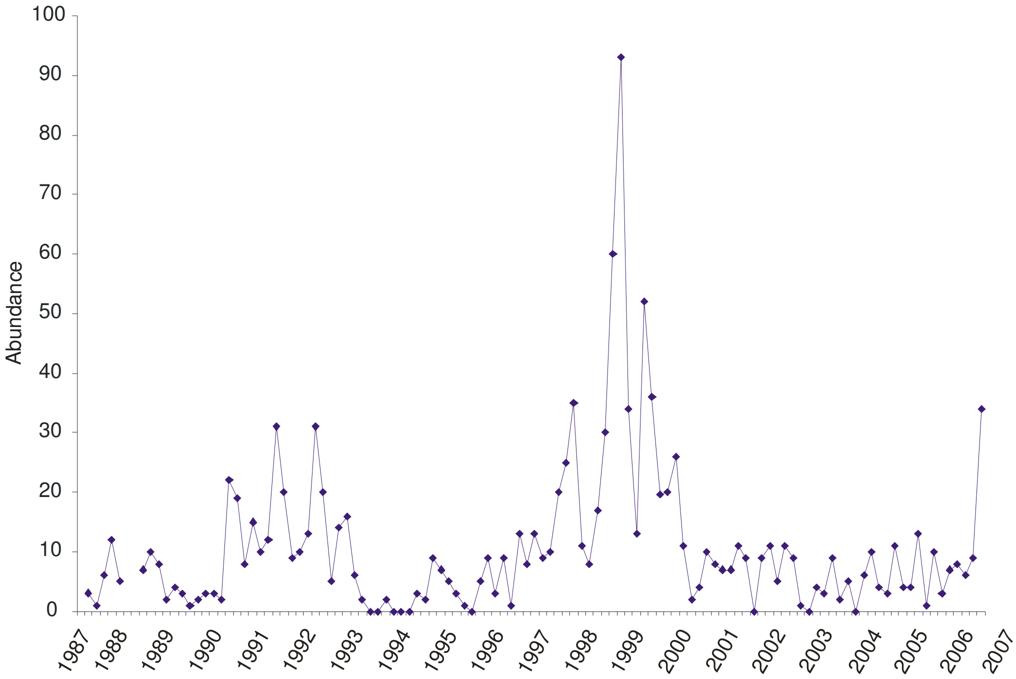
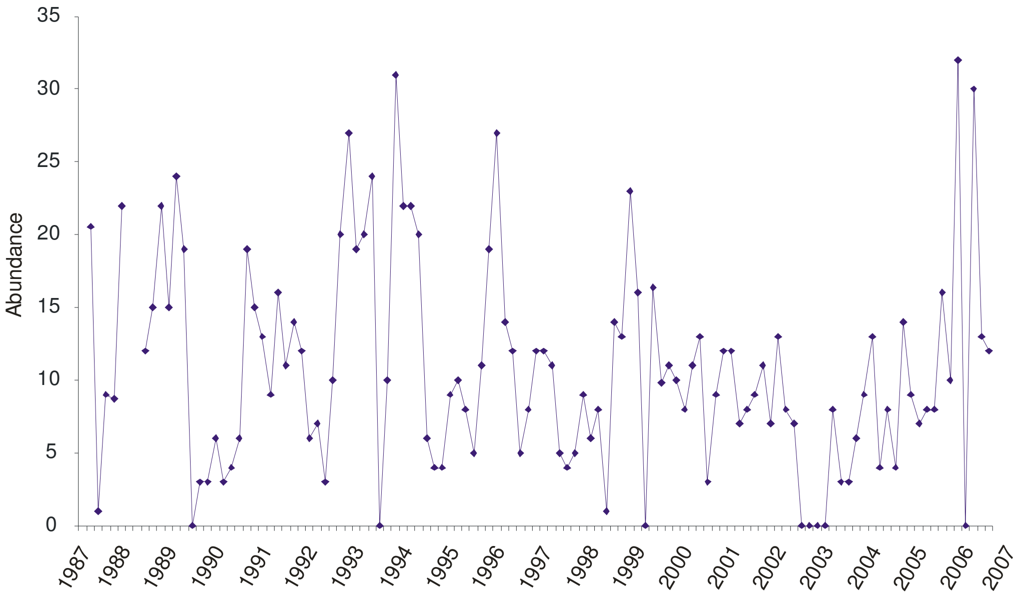


Figure 4.10.

Abundance of *Glycinde dorsalis* over time at Clarks Beach.



4.3 Are trends in abundance being maintained?

When long-term datasets are analysed by regression, it is easy for cyclic patterns to be identified as trends, even when autocorrelation is accounted for. Examination of the pattern of residuals can help separate cyclic patterns from trends, as can using covariables that are expected to show multi-year cycles that are not influenced by within-harbour anthropogenic activities. For this reason, for species included in Table 4.2, the trend analyses reported on in this section had ENSO variables included as covariables in the regression analysis. As a result of this change in the analysis, together with the addition of two more years of data, very few of the 24 trends in abundance observed at the Auckland Airport, Clarks Beach and Cape Horn sites in 2005 (Funnell and Hewitt, 2005) were still observed. Only 5 of the previously reported trends are still occuring; all of these occur at the Cape Horn site.

4.3.1 Auckland Airport

For the first time, no trends in abundance were detected for monitored taxa at this site (Table 4.3). However, it is important to note that *Notoacmea helmsii* found at low abundance at this site after the first three sampling occasions, had not been observed since October 2004.

The trends previously identified for *Hiatula siliqua* (Figure 4.4) and *Magelona ?dakini* (Figure 4.5,Table 4.3) appear to be multi-year cycles driven by the strong ENSO event in existance at present. The positive trend in abundance for *Trochodota dendyi,* identified in 2005 (Table 4.3), was also part of a cyclic pattern (Figure 4.7), although the pattern could not be predicted by ENSO.

Table 4.3:

Monitored species for which statistically significant trends in abundance were detected at Auckland Airport, from data collected between 1987 – 1999, 1987 – 2005 or 1987 - 2007. 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. Blank spaces indicate no statistically significant trend observed.

Taxa	October 1987 to February 1999	October 1987 to February 2005	October 1987 to February 2007
Hiatula siliqua		+61.0	
Magelona ?dakini		+60.0	
Trochodota dendyi		+7.8	

4.3.2 Clarks Beach

Table 4.4.

Monitored species for which statistically significant trends in abundance were detected at Clarks Beach, from data collected between 1987 – 1999, 1987 – 2005 or 1987 - 2007. Direction (increase '+' or decrease '-') and magnitude of the trend are indicated by slope estimates and presented as the difference in number of individuals in 12 cores, compared to initial sampling in 1987. Blank spaces indicate no statistically significant trend observed.

Taxa	October 1987 to February 1999	October 1987 to February 2005	October 1987 to February 2007
Aonides oxycephala	-7.2	-5.1	
Aglaophamus macroura			-1.2
Boccardia syrtis		-35	
Glycinde dorsalis		-7.1	
Hiatula siliqua	-9.52	-6.8	
Orbinia papillosa	-1.3	-0.8	

Of the five trends in abundance observed in the data to 2005, none are still present (Table 4.4). One (decline in abundance of *Hiatula siliqua* from 1987 to 2003) was a multi-year cycle related to ENSO; and three others (*Aonides oxycephala, Boccardia syrtis and Glycinde dorsalis*) were driven by long-term cycles in recruitment (see previous section). *Orbinia papillosa* has shown a negative trend up to 2005 as a result of a decrease in basal abundance pre 1999. Since 2005, the species has been more frequently found.

One previously unobserved trend in abundance was detected. A significant negative trend in the abundance of *Aglaophamus macroura* was detected, however, there is a small multi-year cyclical pattern occurring and it is likely that with another 2-4 years of data a peak in the numbers of *Aglaophamus macroura* will occur.

4.3.3 Cape Horn

A large number of trends in abundance (12) were reported for the Cape Horn site in 2005 (Table 4.5). Most of these (7) are no longer detectable. For *Austrovenus stutchburyi*, *Boccardia syrtis* (Figure 4.11), *Orbinia papillosa*, *Prionopsio aucklandica* and *Macomona liliana*, the trends have not been reversed; rather the new low densities are being maintained. For both *Trochodota dendyi* and *Hiatula siliqua*, the previous positive trends in abundance were driven by changes in peak abundance; changes were not occurring to the basal populations.

Table 4.5.

Monitored species for which statistically significant trends in abundance were detected at Cape Horn, from data collected between 1987 – 1999, 1987 – 2005 or 1987 - 2007. Direction (increase '+' or decrease '-') and magnitude of the trend are indicated by slope estimates and presented as the difference in number of individuals in 12 cores, compared to initial sampling in 1987. Blank spaces indicate no statistically significant trend observed.

Taxa	October 1987 to February 1999	October 1987 to February 2005	October 1987 to February 2007
Aglaophamus macroura		+0.9	+7.0
Austrovenus stutchburyi		-0.7	
Boccardia syrtis		-881.6	
Glycinde dorsalis		-8.6	-48.0
Hiatula siliqua		+3.4	
Magelona ?dakini		+51.2	+205.4
Orbinia papillosa		-1.2	
Owenia fusiformis		-9.4	-9.0
Prionospio aucklandica		-0.7	
Macomona liliana		-6.3	
Trochodota dendyi		+0.4	
Waitangi brevirostris		+10.6	+30.5

Five of the previously detected trends are still continuing; *Aglaophamus macroura, Magelona ?dakini* (Table 4.5, Figure 4.5) and *Waitangi brevirostris* have increased in abundance, while *Owenia fusiformis* and *Glycinde dorsalis* (Figure 4.12) have only rarely been observed at this site since 2003.

Figure 4.11.

Abundance of *Boccardia syrtis* over time at Cape Horn.

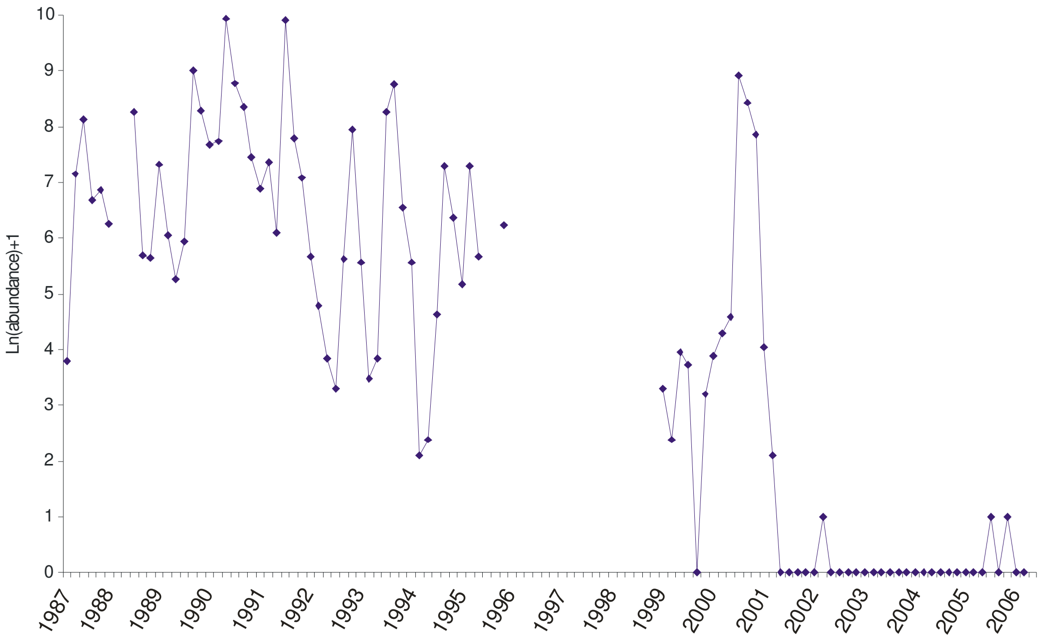
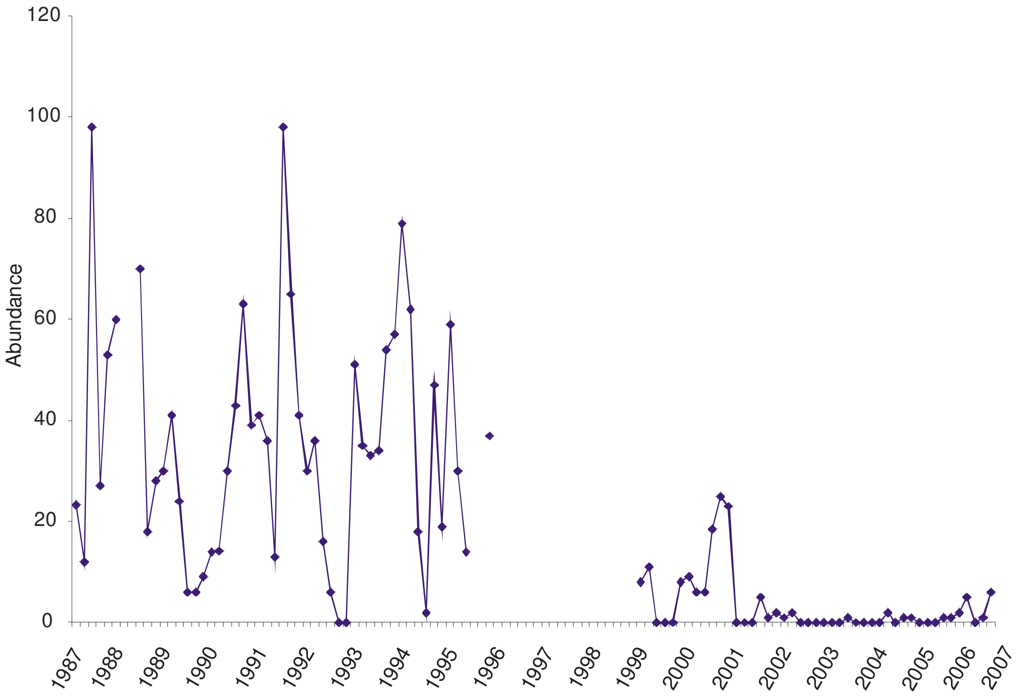


Figure 4.12.

Abundance of *Glycinde dorsalis* over time at Cape Horn.



4.4 Do any of the sites exhibit differences in community composition over time?

Variation in the community composition observed at all sites each October gives an indication of whether communities are changing over time, as well as how similar the sites are to each other (Table 4.6). Most of the general differences among sites commented on by Thrush et al. (1988) has been maintained over time. That is, the Auckland Airport site is least like the others and the Elletts Beach, Karaka Point and Puhunui Stream sites are the most similar (Figure 4.13).

The community at the Auckland Airport site exhibits least temporal variability (also stated in Funnell and Hewitt (2005)) and *Macomona liliana* has consistently been the dominant species throughout the monitoring (Table 4.6). The Clarks Beach site exhibits high temporal variablity (also observed after the initial 5 year period by Turner et al. 1996), however, no trend over time is exhibited.

Conversely, the community at Cape Horn has changed markedly over time (largely related to changes in abundance of taxa), and exhibits two distinct phases of change (Figure 4.13). The first period of change occurs sometime during the non-monitored period of 1996 – 1998 and was commented on by Funnell et al. (2001) and Funnell et al. (2003). The second period of change occurred between October 2000 and 2001; Funnell et al. (2003) suggested this may be related to the change in waste treatment at Mangere. Since October 2001, community composition at this site has remained relatively stable with the dominant species being *Magelona ?dakini* (dominant since 2000/2001) compared to the initially dominant species *Boccardia syrtis* (dominant between 1988 to 1992/1993) (Table 4.6).

In Figure 4.13, the latest October sampling at the Elletts Beach, Karaka Point and Puhunui Stream sites are shown. For the Elletts Beach site, the community composition observed in October 2006 is within the range of community compositions previously observed at this site. However, for the other two sites this is not the case. With only the one sample point it is hard to determine whether this reflects an increase in variability or a real change in community composition; this will be determined after the full two years of sampling these sites has finished.

A similar ordination plot based on taxa presence/absence, rather than abundances, was conducted, to determine whether it was actual taxa that were changing or only relative abundances. This ordination revealed that the taxa were not changing at Puhinui Stream. However, for the community at Karaka Point, the ordination revealed that not only were relative abundance of taxa changing but there were also changes in the taxa present at these sites. Regardless, the changes at Karaka Point are relatively minor compared with the changes observed at the Cape Horn site.

Table 4.6.

The three most abundant species found in October each year at the monitored sites a) Auckland Airport, b) Clarks Beach and c) Cape Horn.[4]

a) Auckland Airport

Year			
1989	*Macomona liliana*	*Austrovenus stutchburyi*	*Magelona ?dakini*
1990	*Macomona liliana*	*Hiatula siliqua*	*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*	*Hiatula siliqua*
1996	*Macomona liliana*	*Hiatula siliqua*	*Magelona ?dakini*
1997	*Macomona liliana*	*Hiatula siliqua*	*Austrovenus stutchburyi*
1998	*Macomona liliana*	*Hiatula siliqua*	*Austrovenus stutchburyi*
1999	*Macomona liliana*	*Orbinia papillosa*	*Hiatula siliqua*
2000	*Macomona liliana*	*Hiatula siliqua*	*Orbinia papillosa*
2001	*Macomona liliana*	*Magelona ?dakini*	*Trochodota dendyi*
2002	*Macomona liliana*	*Magelona ?dakini*	*Trochodota dendyi*
2003	*Macomona liliana*	*Magelona ?dakini*	*Nucula hartvigiana*
2004	*Macomona liliana*	*Hiatula siliqua*	*Aonides oxycephala*
2005	*Macomona liliana*	*Magelona ?dakini*	*Hiatula siliqua*
2006	*Macomona liliana*	*Hiatula siliqua*	*Colurostylis lemurum*

b) Clarks Beach

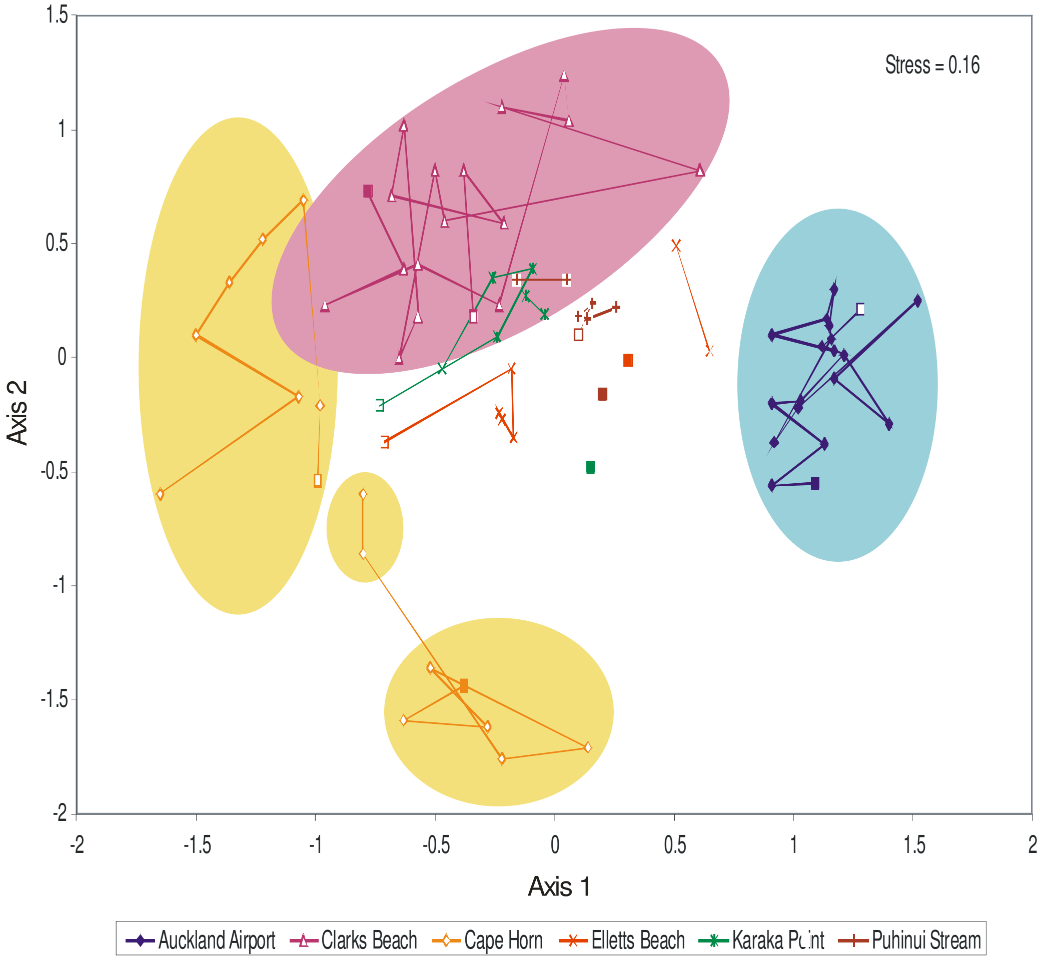
Year			
1989	*Macroclymenella*	*Macomona liliana*	*Torridoharpinia hurleyi*
1990	*Nucula hartvigiana*	*Boccardia syrtis*	*Macroclymenella*
1991	*Nucula hartvigiana*	*Macomona liliana*	*Macroclymenella*
1992	*Macroclymenella*	*Macomona liliana*	*Torridoharpinia hurleyi*
1993	*Macroclymenella*	*Boccardia syrtis*	*Nucula hartvigiana*
1994	*Macomona liliana*	*Macroclymenella*	*Torridoharpinia hurleyi*
1995	*Nucula hartvigiana*	*Magelona ?dakini*	*Macroclymenella*
1996	*Nucula hartvigiana*	*Boccardia syrtis*	*Torridoharpinia hurleyi*
1997	*Nucula hartvigiana*	*Boccardia syrtis*	*Macomona liliana*
1998	*Nucula hartvigiana*	*Macomona liliana*	*Torridoharpinia hurleyi*
1999	*Macroclymenella*	*Nucula hartvigiana*	*Macomona liliana*
2000	*Nucula hartvigiana*	*Macomona liliana*	*Macroclymenella*
2001	*Macomona liliana*	*Nucula hartvigiana*	*Macroclymenella*
2002	*Nucula hartvigiana*	*Macomona liliana*	*Magelona ?dakini*
2003	*Macroclymenella*	*Nucula hartvigiana*	*Macomona liliana*
2004	*Macroclymenella*	*Magelona ?dakini*	*Macomona liliana*
2005	*Macroclymenella*	*Nucula hartvigiana*	*Torridoharpinia hurleyi*
2006	*Nucula hartvigiana*	*Macroclymenella*	*Macomona liliana*

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

c) Cape Horn

Year			
1989	*Boccardia syrtis*	*Magelona ?dakini*	*Macroclymenella*
1990	*Boccardia syrtis*	*Macomona liliana*	*Macroclymenella*
1991	*Boccardia syrtis*	*Macroclymenella*	*Macomona liliana*
1992	*Macroclymenella*	*Colurostylis lemurum*	*Torridoharpinia hurleyi*
1993	*Macroclymenella*	*Torridoharpinia hurleyi*	*Magelona ?dakini*
1994	*Macroclymenella*	*Magelona ?dakini*	*Glycinde dorsalis*
1995	*Boccardia syrtis*	*Magelona ?dakini*	*Glycinde dorsalis*
:			
1999	*Torridoharpinia hurleyi*	*Macroclymenella*	*Magelona ?dakini*
2000	*Magelona ?dakini*	*Boccardia syrtis*	*Colurostylis lemurum*
2001	*Magelona ?dakini*	*Macroclymenella*	*Colurostylis lemurum*
2002	*Magelona ?dakini*	*Colurostylis lemurum*	*Hiatula siliqua*
2003	*Magelona ?dakini*	*Macroclymenella*	*Colurostylis lemurum*
2004	*Magelona ?dakini*	*Macroclymenella*	*Colurostylis lemurum*
2005	*Magelona ?dakini*	*Macroclymenella*	*Waitangi brevirostris*
2006	*Magelona ?dakini*	*Macroclymenella*	*Hiatula siliqua*

Figure 4.13.
Multi-dimensional Scaling (MDS) plot (stress = 0.16; indicates that the high-dimensional relationships among samples should be interpreted with caution) displaying the dissimilarity in communities across sites and over time (1987-2006) for each October. The earliest sampling occasion is marked by open squares and the most recent sampling time marked by closed squares. Coloured ovals represent the total area of community movement over time at Auckland Airport (blue), Clarks Beach (pink) and Cape Horn (gold). The further away the points are from each other in the ordination space, the more dissimilar the community composition is. Thus, the more tightly clustered the points from one site are, the more similar the community composition is over time.



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

In the previous report, Funnell and Hewitt (2005) related changes in the abundance of seven monitored taxa at the Cape Horn site to the breaching of the waste water ponds at Mangere begun in May 2001. Some of these taxa, however, are exhibiting changes in abundance at more than the Cape Horn site and the changes are at least partly explainable by ENSO (Table 4.2).

The degree to which changes are related to ENSO or the changes in waste water treatment will become more easily determined with another two years of data, as the strength of the ENSO event is slackening, and changes relating to it should show reversals. However, at this point in time, some information can be gathered using information on water column nutrients, oxygen content (as a surrogate for production) and total suspended sediments from the ARC water quality monitoring site nearby, and sediment chlorophyll content collected at the site. Unfortunately sediment chlorophyll content monitoring only began in 2000, thus there is not enough data to determine whether there is a strong change associated with the change in waste water tratment and water column monitoring of chlorophyll has an even shorter record. However, if the change in waste water treatment, rather than ENSO, is behind the observed changes in population abundances then we would expect that, for data from 2000, correlation with ENSO factors will be reduced and/or variables such as water column nutrients, oxygen content and total suspended sediments and sediment chlorophyll content will help predict variability in abundance.

As a preliminary to this analysis, the effect of the change in waster water treatment on the water column variables was assessed graphically. Ammonical and nitrate nitrogen and soluble phosphorus displayed a clear change in temporal patterns post May 2001 and the change in ammonical and nitrate nitrogen has been documented in Macaskill and Martin (2004). There were indications of a decreasing trend in total phosphorus concetrations prior to May 2001, and there were no clear changes for total suspended sediments and dissolved oxygen. Decreases in sediment chlorophyll content were already known to occur (section 4.1). Therefore, only the presence of ammoniacal and nitrate nitrogen, soluble phosphorus and sediment chlorophyll content as predictors of abundance were considered to be indicators of change related to the removal of the waste water tratment ponds. Note that none of these variables were well correlated with ENSO variables (Pearsons $R < 0.5$).

Analysis of the data from 2000 suggests that for 9 taxa at the Cape Horn site changes in abundance are related to environmental variables that would be expected to change as a result of the changes in waste water treatment (Table 4.7). Sediment chlorophyll content was important for *Glycinde*, *Macomona*, *Boccardia* and *Agalophamus*; water oxygen content was important for *Aglaophamus*, *Orbinia* and *Waitangi*; water column ammonium was important for *Glycinde*, *Magelona*, *Austrovenus*, *Owenia*,*Orbinia* and *Waitangi*; water column nitrate was important for *Austrovenus* and *Boccardia*; water column soluble phosphorus was important for *Austrovenus*, *Orbinia* and *Waitangi*; total phospohorus was important for *Waitangi*; and total suspended sediment was important for *Owenia*. For four of the taxa, *Boccardia*, *Magelona, Owenia* and *Waitangi*, ENSO was also important- even within this short time period.

Table 4.7.

Species exhibiting trends in abundance at CH (T) and those for which a significant effect of ENSO was observed over the full time series. Results of a new analysis on data from 2000 – 2007 to determine whether only ENSO variables, variables expected to change with waste water treatment (WWT) or both are important are shown, together with the increased invariability explained by the regression containing WWT variables as opposed to that just containing ENSO. The column 'trends' includes those for which a trend was detected in 2005 and which in 2007 look as if they have reached a new baseline in abundance (B). Variables important in predicting changes in abundance likely to be associated with a change in waste water treatment are also given (Schla = sediment chlorophyll a, Wam = water column ammonical nitrogen, Wnt = water column nitrate nitrogen, Wsp = water column soluble phosphorus).

Taxa	*Trend*	*ENSO*	*Variables*		*Increase in variability*
Aglaophamus macroura	T	Y	WWT	Schla,	0.26
Austrovenus stutchburyi	B	Y	WWT	Wam, Wnt, Wsp	0.30
Boccardia syrtis	B	Y	ENSO, WWT	Schla,Wnt	0.11
Glycinde dorsalis	T	Y	WWT	Schla	0.35
Macomona liliana	B		WWT	Schla	0.31
Magelona ?dakini	T	Y	ENSO, WWT	Wam	0.29
Nucula hartvigiana		Y	ENSO		
Owenia fusiformis	T	Y	ENSO, WWT	Wam	0.34
Orbinia papillosa	B		WWT	Wam, Wsp	0.37
Prionospio aucklandica	B				
Waitangi brevirostris	T	Y	ENSO, WWT	Wam, Wsp	0.11

5 Conclusions

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

Cyclic patterns of abundance are occurring at each of the monitored sites. 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?

Many of the changes in the abundance of taxa at the monitored sites are now obviously long-term cycles. Hewitt and Thrush (2007) report populations in the Manukau exhibiting cyclic patterns from as short as 2 – 3 years (15-26% of taxa at a site), to 4 - 5 years (6-10% of taxa at a site), up to 7 – 9 years (2-28% of taxa at a site). Much of the variability that occurs in the longer-term cycles is likely to be driven by climatic variation. While previously these changes would have been considered natural variability, human-induced climate change is likely to result in changes to the natural variability that will be difficult to distinguish for many years. However, the ability to predict at least some of the variability in temporal dynamics of taxa in the Manukau does suggest that this monitoring programme (and others in the Mahurangi and Central Waitemata harbours) will be of tremendous use if the ARC wishes to investigate the potential for climate change effects.

The most significant changes that have been observed, over the monitored period, have occurred at the Cape Horn site. Most of these changes occurred between 1996 - 1998 and then again between October 2000 and 2001. The changes observed between 2000 and 2005 at the Cape Horn site were largely those predicted to occur with improved waste water treatment. That is, a reduction of suspension feeding polychaetes, reduced silt levels and reduced chlorophyll *a* concentrations. It would be expected that with the improvements of the water quality there would be a subsequent decrease in nutrients, phytoplankton and suspended organic matter. This would have the greatest effect on suspension feeders, for example *Austrovenus stutchburyi*, *Boccardia syrtis*, *Prionospio aucklandica* and *Owenia fusiformis*. Negative trends were recorded for all of these species in 2005 (Table 4.5, Figure 4.9). These trends are not continuing, but the new low densities have been maintained. For all but *Prionospio aucklandica* the observed changes are correlated to changes in water column nutrients.

Effects on these species can be passed on to other components of the system. For example, polychaete mats, such as those formed by dense aggregations of *Boccardia syrtis* or *Owenia fusiformis*, are well known to bind fine particles together creating muddy hummocks as seen at Cape Horn in the 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* or *Owenia fusiformis* due to reduced food supply, it could be expected that less silt would be trapped on the sandflat and hence a reduction in chlorophyll *a* 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*.

While some of the changes at this site appear to have been influenced by the strong ENSO event that New Zealand has been having recently, our analysis suggests that this factor alone can not explain the all the changes in abundance observed. (1) Changes in abundance of only some of the taxa are correlated to ENSO. (2) The changes relate well to those predicted to occur with an improvement in water quality. More over, for 9 taxa, including water column nutrients in the analysis of changes in abundance post 2000, increased predictive ability above that obtained by ENSO variables alone. (3) Changes in overall community composition suggest 2 periods of change; the latter of which corresponds with the breaching of the ponds in 2001 rather than the onset of ENSO in 2003. Thus, it remains likely that change related to the breaching of the waste water ponds has occurred at this site.

Importantly, there is no evidence to suggest any detrimental effects on ecosystem health within the extensive intertidal flats that make up the main body of the Manukau Harbour. Thus, the current management initatives being implemented by the Auckland Regional Council to minimise effects of changing anthropogenic practises are effectively maintaining the health of Manukau Harbour.

6 Recommendations

At present, it is unclear whether changes observed in the macrofaunal communities at Karaka Point and Puhinui Stream are due to natural variability. With only 4 data points it has not been possible to investigate any long-term changes in populations relative to previous cyclic patterns, or to determine whether changes observed at the Karaka Point and Puhunui Stream sites are also ENSO related. We recommend that all six sites should continue to be monitored as planned (until April 2008), when any changes in the benthic communities at the sites can be effectively determined.

The data gained from the long term and uninterrupted monitoring of Auckland Airport and Clarks Beach sites provide an invaluable resource for determing inter- and intra-annual cycles in the abundance of several taxa. Such cycles have in the past frequently been blamed for the inability of monitoring programmes to detect changes. However, with a long-term dataset this type of temporal variability becomes an asset, rather than a problem, allowing changes in recruitment patterns and variability (often suggested as a first response to chronic low level stress) to be detected. Moreover, the ability to predict at least some of the variability in temporal dynamics of taxa in the Manukau using ENSO-related variables suggests that this monitoring programme (and the other monitoring programmes in the Mahurangi and Central Waitemata harbours) will be of tremendous use if the Auckland Regional Council wishes to investigate the potential for climate change effects.

The data and information gained from such a strong data set can be, and has been, applied and used as a comparison for other studies carried out on behalf of the Auckland Regional Council. These studies include the Mahurangi monitoring programme, the Waitemata monitoring programmes, the Whitford urban development project and the Benthic Health model. The information gained from this data set has vastly improved our understanding of estuarine ecosystem habitats and enabled us to extend our ability to assess the health of estuarine ecosystems.

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8 References

Chatfield C. (1980). *The analysis of time series: an introduction*. Chapman and Hall, London, United Kingdom.

Clarke, K.R. & Gorley, R.N. (2006). PRIMER v6: user manual/tutorial. PRIMER-E Ltd., Plymouth, United Kingdom. 190pp.

Funnell, G.A. & Hewitt, J.E. (2005). *Ecological monitoring programme for Manukau Harbour: Report on data collected up to February 2005*. Unpublished report for Auckland Regional Council. ARC Technical Publication 293.

Funnell, G.A.; Hewitt, J.E. & Thrush, S.T. (2003). *Ecological monitoring programme for Manukau Harbour: Report on data collected up to April 2003*. Unpublished report for Auckland Regional Council. ARC Technical Publication 264.

Funnell, G.A.; Ellis, J.I.; Hewitt, J.E. & Thrush, S.T. (2001). *Ecological monitoring programme for Manukau Harbour: Report on data collected up to April 2001*. Unpublished report for Auckland Regional Council. ARC Technical Publication 110.

Gibbs, M. & Hewitt, J.E. (2004). *Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC*. Unpublished report for Auckland Regional Council. ARC Technical Publication 264.

Hewitt J. E. and S. F. Thrush, 2006: Effective long-term ecological monitoring using spatially and temporally nested sampling. *Environmental Monitoring and Assessment*. In Press

Hewitt, J.E.; Thrush, S.F.; Pridmore, R.D. & Cummings, V.J. (1994). *Ecological monitoring programme for Manukau Harbour: analysis and interpretation of data collected October 1987 to February 1993.* Unpublished report for the Environment and Planning Division, Auckland Regional Council. NIWA-Ecosystems Consultancy Report No. ARC120/6.

Macaskill, J.B. & Martin, M.L. (2004). *Baseline water quality survey of the Auckland region annual report January-December 2003*. Unpublished report for the Auckland Regional Council. Technical publication 234.

McBride, J.L. & Nicholls, N. (1983). Seasonal relationships between Australian rainfall and the Southern Oscillation. *Monthly Weather Review* 111: 1998-2004.

Salinger, M.J. & Mullan, A.B. (1999). New Zealand climate: temperature and precipitation variations and their links with atmospheric circulation 1930-1994. *International Journal of Climatology* 19: 1049-1071.

Sartory, D.P. (1982). Spectrophometric analysis of chlorophyll *a* in freshwater phytoplankton. *Hydrol Res. Inst Rep TR* 115, Pretoria, South Africa.

Thrush, S.F.; Pridmore, R.D.; Hewitt, J.E. & Roper, D.S. 1988. *Design of an ecological monitoring prograame for the Manukau Harbour.* Unpublished report for Auckland Regional Water Board, Auckland Regional Authority by Water Quality Centre, D.S.I.R Consultancy Report No 7099.

Thrush, S.F.; Hewitt, J.E. & Pridmore, R.D. (1989). Patterns in the spatial arrangement of polychaetes and bivalves in Intertidal sandflats. *Marine Biology* 102: 529-535.

Turner, S.J.; Thrush, S.F.; Pridmore, R.D.; Hewitt, J.E.; Cummings, V.J. & Maskery, M. (1995). Are soft-sediment communities stable? An example from a windy harbour. *Marine Ecology Progress Series 120*: 219-230.

9 Appendices

9.1 Appendix 1: Monitored selected species

This section is section 4 from Thrush et al. 1988; the report documenting the set up of the monitoring programme in 1987- 1988. Note that one further species, the polychaete tube worm *Boccardia syrtis* was added to the species list in 1994. Changes have been made to the text where species names have changed over the course of the monitoring programme.

Choice of Species as potential monitors of environmental change.

Two aspects need to be considered when choosing species to monitor; their ecology and the practicality of sampling. The spatial distribution study provides information on the practicality of sampling and identifies numerically dominant species. However, species should also be chosen so that changes in their abundance are likely to reflect important changes within the ecosystem. The key issue here is the involvement of species in ecological processes. Very little work has been done in N.Z. which indicates species living in soft-sediments with important ecological roles. The published studies on the Manukau do not identify such organisms (see previous section). Process orientated studies have been conducted overseas and where possible this information has been utilized. Such comparisons coming from potentially very different environments need to be considered with some scepticism. Here only those studies considered at least partially comparable are utilized and fortunately at least some of the species common in the Manukau intertidal sandflats are cosmopolitan in distribution and thus represented in the overseas literature.

Generally species were chosen on the basis of potentially important aspects of their ecology. This is considered vital in the selection of species as it is the basis of our understanding of ecology that changes in population structure must be considered, their importance interpreted and possible causes inferred. A number of important aspects of the ecology of species are outlined below.

Potential keystone species

These are species with a greater influence on community structure and function than their abundance alone would indicate. Changes in the abundance of such species results in a cascade effect considerably modifying community structure and function. Examples of such species are predators which prevent competitive monopolization of resources, or tube building or burrow dwelling animals which affects sediment physico-chemical conditions, alter boundary layer hydrodynamics and influence patterns of larval settlement.

Sampling of different niches

As a variety of different species will be collected during sampling, species which occupy different niches should be counted. For example, filter feeding shellfish may be exposed to different contaminants and concentration levels than surface deposit feeding shellfish. Similarly animals regularly found at greater depths within the sediment may directly or indirectly be influenced by changes in sediment redox potential chemistry to a greater degree than those living close to the surface of the sediment.

Prey species

Animals which are known or inferred to be important in the diet of humans, fish and birds should also be considered for monitoring. Thus changes in these populations indicate loss of food resources.

Response to disturbance and pollution stress

Species which respond in a characteristic manner to particular types of disturbance or are sensitive to particular pollutants should also be considered for monitoring. Generally in estuarine and harbour habitats tolerant species are found. Specific lists of the toxicity of pollutants to marine organisms based on laboratory studies are available in the scientific literature (e.g. see Reish et al 1988), but of more importance are the results of studies of toxicity in natural situations. However, responses to disturbances, e.g. increased sedimentation, by specific organisms may also be identifiable.

Choice in relation to environmental gradients

Generally species are found over only a portion of the range of environmental conditions present. Along a gradient of enrichment certain species may be most abundant at a specific level of enrichment. Pearson and Rosenberg (1978) have extensively reviewed the use of indicator species in relation to organic enrichment in the marine environment. Their general conclusion was that in the most polluted areas characteristic species were those typical of the first stages of success.

Practical aspects

Collecting enough samples and accounting for spatial and temporal variation are of less importance than ecological issues because if it is desirable to sample a specific organism appropriate sampling programmes can be designed. Ideally, however, species chosen for monitoring should be able to be collected, identified and counted at minimal cost. Some macrobenthic species are frequently difficult to identify. Choosing species with reasonably straight-forward taxonomy, which are comparatively simple to identify, will obviously simplify monitoring. Moreover, some species are of dubious taxonomic status and this may confound the identification of trends.

Selected species

Based on these considerations the following species have been chosen as potentially suitable to monitor and were further analysed for changes over a one year period. Species are listed and their potential importance highlighted. All species were abundant at least at one site and are comparatively easy to identify and count. Sites where species are most common are indicated. Further detail may be obtained from Section 3 and Appendix 2 *(in Thrush et al. 1988).* Commonness is ascribed arbitrarily on the basis of the size of the animal under consideration and the range of abundances obtained in the spatial survey.

Coelenterata

Anthopleura aureoradiata. A predatory sea anemone. Intolerant of high turbidity and requires salinities higher than 20 p.p.t. (Jones 1983). Some species of Coelenterata have been found to be excluded from areas severely affected by sewage pollution (Smyth 1968). Common at Karaka Point (184 individuals collected in 36 core samples) and also found at Clarks Beach, Puhinui Creek and Airport.

Polychaetes

Macroclymenella stewartensis. A maldanid polychaete. This worm potentially has a key role in sediment turnover and reworking. Individuals of a related species *Axiothella rubrocinta* have been demonstrated to rework about 5 g dry sediment day-1 in Tomales Bay, California (USA) (Rhoads, 1967). Another maldanid *Clymenella torquata* has recorded sediment turnover rates at various sites in the USA of 274, 246, 96 [ml wet mud individual-1] (Mangum, 1964). *Macroclymenella stewartensis* density in the Manukau ranged from about 100 – 500 m-2. The movement of sediment and the associated pumping of water into subsurface layers will potentially modify sediment conditions in such a way as to provide suitable living conditions for other species. Common at Elletts Beach and Clarks Beach (213 and 195 individuals collected in 36 core samples respectively) and reasonably abundant at all the other sites.

Magelona ?dakini. A magelonid polychaete. Highly abundant at all sites. Very little is known about the ecology of these subsurface deposit feeders. The animal was one of the most common collected in this study. The related species *Magelona papillicornis* recorded a production rate of 0.69 g m-2 y-1 and lived for a maximum of three years in a Cornish estuary (cited in Warwick, 1980).

Aglaophamus macroura. A large predatory nephtyid polychaete. Common at Elletts Beach and Cape Horn (22 and 12 individuals collected respectively) rare at the other sites. One N.Z. species *Aglaophamus verrilli*, studied in Tasman Bay by Escourt (1975), was slow growing, recorded irregular recruitment and lived for at least 5 years. Recent overseas studies have shown that related species have a significant effect on infaunal communities. Ambrose (1984) demonstrated that the presence of *Nephyts caeca*, and other predators, adversely affected the abundance of infauna, and resulted in predator avoidance behaviour through prey emigration. On the tidal flats of the North Sea experimental additions of *Nephtys hombergii* and analysis of the gut content of the worms demonstrated significant predation on other polychaetes (*Scoloplos armiger* related to *Orbinia papillosa*) and *Heteromastus filiformis*). Total prey consumption by Nephtys hombergii was about 1/10th of the consumption by fish and birds. This was taken to indicate the importance of this worm as an intermediate predator by Schubert & Reise (1986). Davey & George (1986) demonstrate that in the Tamar estuary *Nereis diversicolor* [another infaunal predatory worm] was less capable of colonizing new habitat than *Nephtys hombergii*; juvenile Nereisi were also predated upon by Nephtys. The related species *Nephtys insisa* recorded production of 9.34 g m-2 y-1 and also lived for 3 years (cited in Warwick 1980).

*Glycinde dorsalis (*originally *Goniada emerita).* Although smaller than *Aglaophamus macroura*, this is also a predatory polychaete and may also play a key role in determining community structure and function. Members of this family of polychaetes are frequently found at intermediate positions on gradients of organic enrichment (Pearson and Rosenberg 1978). This worm is common at many of the sites studied.

Orbinia papillosa. A large deposit-feeding orbiniid polychaete. Widespread and reasonably abundant. Little is known of its ecology.

Owenia fusiformis. A cosmopolitan species frequently abundant in sandflats. Common at Karaka Point and Clarks Beach (61 and 34 individuals collected in 36 core samples respectively). The worm builds large tubes from heavy sand grains. Tube structures may influence larval settlement and provide refuges from epibenthic predator. Owenia fusiformis 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 & Rosenberg (1978).

Prionospio (originally *Aquilaspio) aucklandica*. This species was moderately abundant in the mudflats at the Airport and Big Muddy Creek sampling sites studied within the Manukau by Roper et al, 1988. Although rare in sandflats, changes in the abundance of this species may be indicative of increases in sediment mud content. Moderately abundant at Karaka Point.

Travisia olens. Another orbinidd polychaete. A large deposit feeding worm, very little is known of its ecology. Common only at airport.

Aonidies oxycephala. A small spionid polychaete, of cosmopolitan distribution. Very little is known of its ecology, it is possibly more common in muddier sediments.

Crustacea

Torridoharpinia (originally *Proharpinia) hurleyi*. An amphipod. Very common at Elletts Beach (111 individuals collected) and moderately abundant at all other sites. Probably feeds on detritus and microscopic organism. Burrows into the sediment and may significantly contribute to sediment turnover. Amphipods are generally important pretty for fish and birds. Amphipods of this family (Phoxocephalidae) have been shown to be sensitive to toxic contamination of sediments (e.g. Swartz et al 1982) and there is evidence that *Proharpinia hurleyi* may also be sensitive to pollution (Roper et el 1988; Fox et al 1988).

Exosphaeroma spp. (?*falcatum* and *chilensis*) An isopod. Very little ecological information is available, but isopods are typically important pretty for fish and birds. Abundant at Puhinui Creek, and moderate to rare at other sites.

Methalimedon sp. An amphipod. Like *Proharpinia hurleyi* they probably feed on detritus and microscopic organism. Moderately abundant at Elletts Beach and Puhinui Creek (23 and 31 individuals collected respectively in 36 core samples).

Waitangi brevirostris. Probably plays an important role in sediment reworking. Like other amphipods, probably an important prey item for fish and birds. Abundant at Airport.

Colurostylis lemurum. Feed on detritus and small organisms. Moderately abundant at Airport, Cape Horn, Elletts Beach and Puhinui Creek (34, 17, 15 and 15 individuals collected respectively). Typically important prey for fish and birds. Cumacea appear to be sensitive to various forms of pollution (Agg et al 1978), although Roper et al (in press) reported an increase in abundance of Diastylopsis crassior near sewage outfalls. This may represent stimulation resulting from slight increases in organic content of the sediment.

Gastropods

Notoacmea helmsi. A limpet. Found associated with gravel and cockle shells. A grazer. Some limpets have been shown to be sensitive to sewage pollution (Smyth 1968). Abundant at Karaka Point and airport (102 and 96 individuals collected respectively in 36 core samples).

Bivalves

Macomona (originally *Tellina) liliana*. This is a reasonably large and mobile deposit feeder which lives well below the sediment surface. It is one of the most dominant species in terms of biomass in the Manukau sandflats and consequently is probably an important food resource for birds and fish. Common at all sites but Cape Horn. Barnett and Wilson (1986) have monitored changes in the population of the related species *Tellina tenuis* in the first of Clyde, Scotland. They demonstrated that recruitment was greater in a thermally enriched area (adjacent to a nuclear power station), although recruitment did reach high levels in 'natural' areas in warm years. Shellfish did not grow as large in the thermally enriched area. The related species *Tellina martinicensis* (Biscayne Bay, Florida) recorded a production rate of 0.23 g m-2 y-1, life span about 2 years (cited in Warwick 1980).

Hiatula (originally *Soletellina) siliqua*. another large deposit feeder, very little is known of its ecology. Common at airport, Puhinui Creek and moderately common at Clarks Beach (225, 142 and 52 individuals collected respectively in 36 core samples).

Nucula hartvigiana. This is a small deposit feeding bivalve which lives near the sediment surface. Common at all sites but Cape Horn and Elletts Beach. This is a highly mobile species, probably capable of rapid small scale recolonisation. Morton and Miller (1973) indicate that this species and Chione stutchburyi are found in the Manukau in sediments too silty for *Tellina liliana*. This is not corroborated by this study or that of Roper et al (1988). Bivalves in this family are frequently found in the 'undisturbed' zones of an organic pollution gradient (Pearson and Rosenberg 1978).

Austrovenus (originally *Chione) stutchburyi*. This is a surface living suspension feeder. Very common at Airport. The bivalve is quite mobile and adults are capable of moving up through silt layers (Grange 1977). Oystercatchers have been shown to heavily predate on Cockles in the Avon-Heathcote estuary (Baker 1969) with between 29 and 41 cockles consumed per hour and an annual predation by a population of 4000 birds of about 4.5 million cockles. As with the other large bivalves *Tellina liliana* and *Soletellina siliqua* it is likely that different predators will exploit these prey species at different stages in their life cycle. For example, newly settled individuals will be exploited by polychaete predators, shrimps and juvenile fish whereas adults will be exploited by birds and larger fish such as stingrays. The related species *Chione cancellata* in Biscayne Bay recorded production rate of 8.9 g m-2 y-1 and lived for 7 years (cited in Warwick 1980).

Echinoderms

Trochodota dendyi. A small sea-cucumber. Common at Puhinui Creek and moderately common at Clarks Beach and Elletts Beach. A detrital feeder. Echinoderms are generally very sensitive to any form of pollution (Agg et al 1978) and those New Zealand holothurian species which have been studied certainly fit into this pattern (Roper et al, in press). *Trochodota dendyi* is fairly common and like other holothurians is likely to be responsible for considerable sediment turnover.

9.2 Appendix 2: Sediment grain size (% weight)

Gravel (>2 mm), sand (63 µm-2 mm), silt/clay (<63 µm).

	Auckland Airport			Clarks Beach			Cape Horn			Elletts Beach			Karaka Point			Puhinui Stream		
	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay
Oct-87	1.6	96.7	1.7	6.1	91.1	2.8	2.5	93.3	4.2	0.1	95.9	4.0	5.8	88.1	6.1	0.6	99.0	0.4
Aug-99	0.8	98.3	0.9	1.2	74.1	24.7	0.0	91.8	8.2	0.07	97.8	1.5	1.8	86.1	12.1	0.1	97.0	2.9
Oct-99	1.3	98.5	1.2	0.5	56.9	42.5	0.1	95.6	4.3	2.1	85.0	12.9	3.3	81.7	15.0	0.1	97.1	2.8
Dec-99	0.0	98.5	0.5	0.5	84.4	15.2	0.0	98.7	1.3	0.2	92.8	7.1	4.4	91.1	4.5	2.3	95.9	1.8
Feb-00	0.6	98.6	0.8	5.3	92.7	2.1	0.1	99.0	1.0	0.1	90.9	9.0	7.6	88.6	3.7	0.1	98.6	1.3
Apr-00	0.3	98.1	1.6	0.3	90.8	8.9	0.0	98.1	1.9	0.0	93.0	7.0	2.8	84.8	12.4	0.0	98.2	1.8
Jun-00	0.1	99.5	0.4	0.8	97.34	1.9	0.1	98.8	1.2	0.1	92.4	7.5	1.6	85.8	12.6	0.0	98.5	1.5
Aug-00	0.0	99.5	0.6	1.6	94.2	4.1	0.1	96.3	3.6	0.2	96.9	2.9	1.3	82.3	16.4	0.0	89.4	10.6
Oct-00	0.0	98.9	1.1	2.1	90.9	7.0	0.0	98.7	1.3	0.2	88.1	11.7	2.1	91.4	6.5	0.0	99.0	1.0
Dec-00	0.1	98.9	1.1	0.5	91.2	8.3	0.0	97.4	2.6	0.1	95.4	4.6	3.7	89.6	6.7	0.3	96.5	3.2
Feb-01	0.3	99.0	0.7	1.5	94.2	4.3	0.0	88.7	11.3	0.0	77.7	22.3	4.1	91.1	4.9	0.2	95.3	4.5
Apr-01	1.5	97.8	0.8	3.0	92.5	4.5	0.0	85.1	14.9	0.2	93.8	6.1	4.2	92.1	3.8	0.3	98.4	1.3
Jun-01	0.1	99.3	0.7	0.6	86.2	13.2	0.1	96.6	3.3	0.0	85.3	14.7	5.1	89.1	5.8	0.1	97.7	2.2
Aug-01	0.3	98.4	1.2	2.6	84.8	12.6	0.0	99.2	0.8	-	-	-	-	-	-	-	-	-
Oct-01	0.0	98.1	1.9	1.5	82.7	15.8	0.0	97.8	2.2	-	-	-	-	-	-	-	-	-
Dec-01	1.6	97.4	0.9	0.5	96.0	3.5	0.0	99.4	0.6	-	-	-	-	-	-	-	-	-
Feb-02	0.1	98.7	1.2	1.5	95.9	2.6	0.0	99.2	0.8	-	-	-	-	-	-	-	-	-
Apr-02	0.0	98.7	1.3	0.8	94.6	4.7	0.0	99.1	0.9	-	-	-	-	-	-	-	-	-
Jun-02	0.2	99.4	0.5	2.2	96.3	1.4	0.0	99.2	0.8	-	-	-	-	-	-	-	-	-
Aug-02	0.2	83.4	16.5	0.2	78.6	21.2	0.7	84.6	14.7	-	-	-	-	-	-	-	-	-
Oct-02	0.1	99.0	0.9	5.2	91.7	3.1	0.0	99.5	0.5	-	-	-	-	-	-	-	-	-
Dec-02	0.0	99.2	0.8	2.9	94.1	2.9	0.9	98.4	0.7	-	-	-	-	-	-	-	-	-
Feb-03	0.4	98.7	0.8	2.3	94.3	3.4	0.0	99.2	0.8	-	-	-	-	-	-	-	-	-

	Auckland Airport			Clarks Beach			Cape Horn			Elletts Beach			Karaka Point			Puhinui Stream		
	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay	gravel	sand	Silt/clay
Apr-03	0.6	98.3	1.1	0.9	88.1	11.1	0.0	99.1	0.8	-	-	-	-	-	-	-	-	-
Jun-03	0.1	99.4	0.4	0.0	97.7	2.2	2.1	83.2	14.7	-	-	-	-	-	-	-	-	-
Aug-03	0.6	98.1	1.3	0.2	83.7	16.2	-	-	-	-	-	-	-	-	-	-	-	-
Oct-03	1.0	98.2	0.8	7.6	88.2	4.3	0.0	98.9	1.0	-	-	-	-	-	-	-	-	-
Dec-03	0.2	98.9	0.9	1.2	93.9	4.8	0.0	99.1	1.0	-	-	-	-	-	-	-	-	-
Feb-04	0.1	99.0	0.9	5.6	90.1	4.3	0.0	99.0	1.3	-	-	-	-	-	-	-	-	-
Apr-04	0.1	96.8	3.1	0.0	92.1	7.9	0.0	98.6	1.4	-	-	-	-	-	-	-	-	-
Jun-04	0.0	99.1	0.9	0.0	94.1	0.0	0.2	99.6	0.2	-	-	-	-	-	-	-	-	-
Aug-04	0.1	99.0	0.9	2.0	90.7	7.4	0.0	95.1	4.9	-	-	-	-	-	-	-	-	-
Oct-04	0.0	99.1	0.9	1.8	93.9	4.3	0.0	98.5	1.5	-	-	-	-	-	-	-	-	-
Dec-04	0.3	99.5	0.3	0.0	96.5	3.5	0.9	98.1	0.9	-	-	-	-	-	-	-	-	-
Feb-05	0.0	99.2	0.8	0.7	89.3	10.0	0.0	98.8	1.2	-	-	-	-	-	-	-	-	-
Apr-05	0.0	99.3	0.7	1.3	95.5	3.3	0.0	99.3	0.7	-	-	-	-	-	-	-	-	-
Jun-05	0.0	99.4	0.6	1.3	88.2	10.5	0.0	99.0	1.0	-	-	-	-	-	-	-	-	-
Aug-05	0.0	99.1	1.2	6.0	87.5	6.4	0.0	99.3	0.7	-	-	-	-	-	-	-	-	-
Oct-05	0.2	99.2	0.5	2.9	93.5	3.6	0.0	99.1	0.9	-	-	-	-	-	-	-	-	-
Dec-05	0.0	99.3	0.7	0.1	86.6	13.3	0.0	99.4	0.6	-	-	-	-	-	-	-	-	-
Feb-06	0.0	99.6	0.4	13.3	82.8	3.9	0.7	98.8	0.5	-	-	-	-	-	-	-	-	-
Apr-06	0.0	98.4	1.6	0.0	95.9	4.1	0.0	98.7	1.3	-	-	-	-	-	-	-	-	-
Jun-06	0.0	99.2	0.8	0.7	93.0	2.6	0.0	98.5	1.2	-	-	-	-	-	-	-	-	-
Aug-06	0.3	98.1	1.7	0.3	88.5	11.3	0.0	99.0	1.0	0.3	90.6	9.1	3.1	95.1	1.8	0.0	99.0	1.0
Oct-06	0.0	99.0	1.0	2.5	80.7	16.8	0.0	99.6	0.4	0.8	93.6	5.6	3.8	93.6	2.6	0.1	98.9	1.1
Dec-06	0.1	99.4	0.4	2.0	93.8	4.2	0.0	99.4	0.6	0.5	96.3	3.3	1.4	96.6	2.0	0.2	99.4	0.4
Feb-07	0.1	99.5	0.4	2.8	94.0	3.2	0.0	99.6	0.4	0.3	96.2	3.6	1.4	96.6	2.0	0.6	98.8	0.6

9.3 Appendix 3: Sediment chlorophyll *a* levels (µg/g sediment)

	Auckland Airport	Clarks Beach	Cape Horn	Elletts Beach	Karaka Point	Puhinui Stream
Aug-00	5.7	9.56	9.82	5.64	4.77	5.67
Oct-00	7.05	9.39	6.62	8.62	7.02	7.44
Dec-00	17.57	26.59	12.34	24.85	19.81	17.79
Feb-01	17.14	25.95	28.41	18.02	15.58	24.78
Apr-01	7.95	11.92	31.22	12.52	9.12	9.1
Jun-01	11.23	26.07	16.66	22.06	14.60	14.55
Aug-01	9.61	27.01	9.84	-	-	-
Oct-01	8.48	13.69	11.13	-	-	-
Dec-01	24.91	22.67	11.49	-	-	-
Feb-02	7.95	11.16	13.42	-	-	-
Apr-02	10.27	14.89	11.13	-	-	-
Jun-02	10.60	10.80	9.47	-	-	-
Aug-02	10.25	12.99	10.66	-	-	-
Oct-02	9.56	9.64	11.26	-	-	-
Dec-02	7.68	9.59	11.73	-	-	-
Feb-03	6.48	10.21	10.10	-	-	-
Apr-03	6.52	9.38	7.65	-	-	-
Jun-03	8.47	21.75	10.82	-	-	-
Aug-03	10.48	16.88	-	-	-	-
Oct-03	6.75	9.39	5.37	-	-	-
Dec-03	4.47	7.66	5.84	-	-	-
Feb-04	4.69	6.47	5.73	-	-	-
Apr-04	12.16	14.10	6.68	-	-	-
Jun-04	13.52	19.27	11.22	-	-	-
Aug-04	11.19	16.46	9.94	-	-	-
Oct-04	10.55	11.96	9.67	-	-	-
Dec-04	11.47	12.87	8.64	-	-	-
Feb-05	10.36	14.84	7.80	-	-	-
Apr-05	8.71	13.63	7.28	-	-	-
Jun-05	10.51	14.20	8.87	-	-	-
Aug-05	8.00	12.02	7.80	-	-	-
Oct-05	13.41	27.10	12.90	-	-	-
Dec-05	8.70	17.77	8.25	-	-	-
Feb-06	8.89	10.40	5.87	-	-	-
Apr-06	8.03	12.25	5.50	-	-	-
Jun-06	9.97	14.67	6.75	-	-	-
Aug-06	8.48	17.19	6.65	13.86	5.04	6.76
Oct-06	8.03	16.74	5.05	10.77	5.96	9.17
Dec-06	6.42	15.14	5.39	8.49	6.30	8.37
Feb-07	7.68	10.78	6.08	9.51	7.11	8.02

9.4 Appendix 4: Sediment organic content (%).

	Auckland Airport	Clarks Beach	Cape Horn	Elletts Beach	Karaka Point	Puhinui Stream
Oct-00	1.32	0.90	0.85	1.01	0.84	0.56
Dec-00	0.84	1.86	1.59	2.03	1.49	1.59
Feb-01	0.39	0.67	1.76	2.13	0.82	0.65
Apr-01	0.64	1.36	1.45	1.68	1.27	0.75
Jun-01	0.51	1.90	0.85	2.77	1.29	0.62
Aug-01	0.62	1.29	0.62	-	-	-
Oct-01	0.62	1.71	0.68	-	-	-
Dec-01	0.43	1.03	0.72	-	-	-
Feb-02	0.58	0.71	0.63	-	-	-
Apr-02	0.73	1.14	0.79	-	-	-
Jun-02	0.56	0.84	0.85	-	-	-
Aug-02	0.77	1.19	0.82	-	-	-
Oct-02	0.52	0.78	-	-	-	-
Dec-02	0.58	0.96	3.16	-	-	-
Feb-03	0.72	1.17	0.76	-	-	-
Apr-03	0.77	1.66	0.67	-	-	-
Jun-03	0.80	2.33	1.01	-	-	-
Aug-03	0.59	1.41	-	-	-	-
Oct-03	0.63	0.94	0.53	-	-	-
Dec-03	0.63	0.86	0.61	-	-	-
Feb-04	0.70	0.87	0.70	-	-	-
Apr-04	0.79	1.80	0.64	-	-	-
Jun-04	1.00	1.30	2.50	-	-	-
Aug-04	1.06	1.43	1.02	-	-	-
Oct-04	0.61	0.81	1.25	-	-	-
Dec-04	1.00	1.30	2.00	-	-	-
Feb-05	0.97	1.80	0.93	-	-	-
Apr-05	0.48	1.47	0.61	-	-	-
Jun-05	0.62	0.91	0.43	-	-	-
Aug-05	0.88	1.62	0.94	-	-	-
Oct-05	0.75	1.66	0.98	-	-	-
Dec-05	0.52	1.49	0.58	-	-	-
Feb-06	0.65	1.17	1.01	-	-	-
Apr-06	0.73	0.99	0.71	-	-	-
Jun-06	0.53	1.38	0.75	-	-	-
Aug-06	0.57	1.88	0.84	1.46	0.91	0.60
Oct-06	0.71	1.93	0.62	0.88	0.53	0.57
Dec-06	0.60	1.13	0.52	0.77	0.86	0.55
Feb-07	0.59	1.10	0.62	0.54	0.81	0.53