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Regional Estuary Monitoring Programme 10 year trend report: April 2001 to April 2011

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Disclaimer

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Executive summary

Waikato Regional Council's Regional Estuary Monitoring Programme (REMP) was initiated in April 2001 to determine the current status and monitor the temporal changes in the state of selected estuaries in the region. The monitoring programme samples sediments and sediment-dwelling organism communities on intertidal mud- and sand-flats in two estuaries: the Firth of Thames and Raglan (Whaingaroa) Harbour. This report presents the first 10 years of monitoring data (April 2001 to April 2011). It provides analyses of trends over this period of time and investigates patterns and features in results that indicate the ecological health of the monitored estuaries.

The variables measured in the REMP include 26 "indicator" taxa (sediment-dwelling organisms selected to represent a variety of taxonomic groups, range of life-histories and susceptibilities to fine sediments and organic enrichment), as well as sediment properties, such as grain size, organic carbon and nitrogen content, and microalgal biomass. There are five sampling sites in each of the two estuaries and these have been sampled twice or four times per year. The sampling sites in the Firth of Thames are Kaiaua, Miranda, Thames Gun Club, Kuranui Bay and Te Puru, and in Raglan (Whaingaroa) Harbour are Ponganui Creek, Whatitirinui Island, Te Puna Point, Haroto Bay and Okete Bay.

Estuaries are dynamic environments and natural variation in the community structure of sediment-dwelling organisms occurs in response to factors such as food availability, water temperature, and recruitment. In order to identify these patterns and tease them apart from those that might indicate a decline in the health of the environment we have to collect data over a long period of time. We have analysed the long-term (10 year) dataset generated by the REMP using a number of statistical techniques in order to help us identify trends that might reflect the impact of land-use change in the catchment or other anthropogenic impacts on the health of these estuaries.

At an estuary wide scale, both the Firth of Thames and Raglan (Whaingaroa) Harbour have shown little evidence of any ecologically significant changes to sediment characteristics or indicator taxa over the past 10 years of monitoring. This indicates that, overall, the health of these estuaries has not changed significantly in recent years. However, within each estuary there are site-specific trends occurring that do not appear to be related to natural seasonal and cyclical events.

Firth of Thames

Two sites (Miranda and Te Puru) out of five in the Firth of Thames showed changes in their community composition over time. However, these shifts have not occurred similarly in each of the two sites, indicating that the drivers of change are not necessarily the same. Miranda showed the greatest number of temporal trends in taxa abundance and sediment characteristics in the Firth of Thames once seasonal and cyclical events had been factored out. Four taxa, *Anthopleura aureoradiata* (small brown anemone), *Aonides trifida*, Capitellidae and Nerididae (all polychaete worms), responded as would be expected given an increase in sediment mud content and indeed, a positive trend with mud was observed with a concurrent decrease in coarse sand. There was also a significant increase in sediment chlorophyll-*a*, although this was also observed at an estuary-wide scale, and as such is more likely to be linked to climatic or system level factors. There is an active Chenier plain at Miranda, consisting of shell and sand banks which are constantly sculpted by wave action, and which are likely to influence sediment characteristics and sediment-dwelling organism community structure. Therefore although trends and responses in indicator taxa appear most acute at this site, the source of these changes may be of less cause for concern than data initially suggests. Continuation of monitoring is important at this ecologically important location.

Te Puru has consistently been one of the least muddy, sand-dominated sites of the five REMP monitoring locations in the Firth of Thames. However, we have found significant decreases in abundance for the mud intolerant bivalves *Linucula hartvigiana* (nutshells) and *Paphies australis* (pipi), and an increase in abundance of the mainly mud tolerant Capitellidae (polychaete worm). It is not clear from measured sediment characteristics what may be driving these trends; for example, we detected no significant change in sediment mud content over the monitored period. For pipi, it is possible that overharvesting may be affecting adult numbers, or that larger organisms are migrating further down shore into the sub-tidal environment.

Raglan (Whaingaroa) Harbour

Unlike the Firth of Thames, no single site in Raglan (Whaingaroa) Harbour displayed any obvious transitions in sediment-dwelling organism community composition, although there were some trends in indicator taxa and sediment properties detected at some sites. There was a statistically significant increase in sediment mud content (for the period 2001 – 2007) for Haroto Bay and Okete Bay. Despite the increasing 'muddiness' of Haroto Bay, no temporal trends in indicator taxa were observed. This is a sheltered site in the upper section of the south-eastern arm of the harbour and is likely influenced by the Waitetuna River. Thus, the sediment-dwelling organism community may be well adjusted to periodic changes in environmental conditions, and thus may not be highly sensitive to increased muddiness. In contrast, at Okete Bay we detected increasing trends in abundance for four taxa that prefer habitats that are moderately or very muddy (*Prionospio aucklandica*, Paraonidae, Capitellidae and Nereididae, all polychaete worms). We also detected a trend of decreasing shell hash for Okete Bay that may be influencing the sediment-dwelling organism community as it is known to provide a biogenic habitat structure favoured by certain organisms.

Comparison between estuaries

In both the Firth of Thames and Raglan four of the 10 sampling sites showed a positive trend in Capitellidae abundance over time, possibly related to climatic signals such as the El Niño Southern Oscillation (ENSO). An increasing trend in sediment chlorophyll-*a* content was also evident at all of the Firth of Thames sites, potentially also a response to climatic factors (although only one site in Raglan Harbour showed a similar trend). Continued monitoring is required if we are to robustly identify the influence of long-term climatic change on these indicator taxa and sediment properties, due to the time scales over which climate oscillations occur.

We have also recognised that greater taxonomic resolution is required to improve our understanding of how susceptible sediment-dwelling organism communities are to changes in environmental conditions. For example, differing species within the Capitellidae complex respond differently to organic enrichment, contamination and sediment mud content, confounding our ability to link changes in Capitellidae abundance with changes in sediment properties. Since 2007, the taxonomic resolution of non-monitored taxa identifications was increased, with full identifications being conducted on an annual basis (October). As well as strengthening the REMP dataset, this should enable comparisons with Auckland Council's estuary monitoring program, and allow us to develop a clearer picture of the health of estuaries across the Hauraki Gulf Marine Park.

By identifying organisms to the lowest taxonomic level possible we have been able to trial a new tool developed by NIWA, a Traits Based Index (TBI), on REMP data. The TBI is based on the species richness of the macrofaunal taxa community, and provides a way to compare functional redundancy between sites within an estuary, and between estuaries. When used in the context of a long-term monitoring program, this may increase our ability to track any changes in functional redundancy through time. Preliminary analysis on the REMP dataset from 2007 - 2011 indicates that some sites may display low or reducing functional redundancy (e.g. Haroto Bay, Raglan and Kaiaua, Firth of Thames). These sites are therefore likely to be more susceptible to environmental change, and future monitoring is therefore important.

Key recommendations

Although neither the Firth of Thames nor Raglan (Whaingaora) Harbour has shown any major shifts in community structure or sediment characteristics over the 10 year monitoring period, this does not imply that monitoring is no longer necessary, as some site-specific changes in each estuary were observed. Furthermore, preliminary application of a Traits Based Index (TBI) to the REMP dataset has shown that some sites have low or reducing functional redundancy. It is recommended that the TBI is further developed for the Waikato region as it condenses complex ecological information into an easily-interpretable measure of the ecological health of an estuary. Along with continued monitoring in the Firth of Thames and Raglan Harbour, this will require continued efforts to improve taxonomic resolution, and development of location specific thresholds that classify sites as having good, intermediate and poor functional redundancy.

Tairua Harbour has recently been included in REMP (sampling commenced in August 2013), but there are about 25 estuaries in the Waikato region, covering a range of different types, containing a wide variety of habitats, and exposed to a wide range of pressures. Expansion of REMP may be able to be resourced by implementation of a nested monitoring design at estuaries currently monitored. A nested approach would see two sites monitored in each estuary for a period of five years, followed by monitoring at all sites for the next two years. Expansion of REMP further to other estuaries in the region would greatly improve our understanding of the health of these important ecosystems and the impacts of human influences on their state and functioning.

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1 Introduction

Estuaries are dynamic and productive ecosystems that provide important habitats for many fish, shellfish and bird species as well as other marine organisms and plants. They act as a natural buffer between land and sea, filtering run-off from the surrounding catchment and reducing the impacts of coastal erosion and storm damage on the land. Estuaries are also highly valued by people culturally, commercially and recreationally.

An estuary's location at the receiving end of the terrestrial catchment makes it a vulnerable environment. Estuaries are at risk of stress-related ecological and physical change driven by catchment activities such as land clearance and increased urbanisation. Estuaries receive and accumulate sediment, nutrients and contaminants from the surrounding catchment. What happens on land can directly or indirectly affect the health of an estuary.

As a consequence of their high value and vulnerability, estuaries need to be carefully managed. Regional councils play a key role in the management of New Zealand's estuaries due to their statutory obligations under the Resource Management Act 1991 to protect natural resources of the coastal environment and control the use of land for the purpose of maintaining and enhancing coastal ecosystems. A critical aspect of managing the region's estuaries is monitoring their state. Monitoring allows early detection of adverse environmental changes, and as such provides an opportunity to initiate effective changes to management practices on land or in the coastal environment.

Intertidal sand- and mud-flats comprise a large area in most estuaries within the Waikato region. Below the surface of these intertidal expanses a whole host of sediment-dwelling organisms[1] perform many important ecological processes such as nutrient recycling, sediment mixing and water filtration. Sediment-dwelling organisms are widely used as indicators of estuary health in environmental monitoring programmes globally because certain species respond predictably to many common natural and man-made stressors. Changes in species community composition or abundance may indicate impacts from local-scale pressures, such as point-source pollution, or catchment scale pressure, such as increased sediment loading or nutrient input.

Waikato Regional Council's Regional Estuary Monitoring Programme (REMP) was initiated in April 2001 to determine the current status and monitor the temporal changes in the state of selected estuaries in the region. Until recently the monitoring programme analysed sediments and sediment-dwelling organisms in two estuaries: the Firth of Thames, and Raglan (Whaingaroa) Harbour. In 2013 Tairua Harbour was added as a third estuary to the programme.

Results from the monitoring have been published in six data reports (Turner & Carter, 2004; Felsing et al., 2006; Singleton & Pickett, 2006; Singleton, 2007; Singleton 2010a, Singleton 2010b). Findings from the sediment sampling up to April 2003 were also reported in Gibberd and Carter (2005). The first 'trend report' (Felsing and Singleton, 2008) brought together data from the first five years of monitoring (from April 2001 to April 2006) and analysed trends over this period of time. A layman's report summarising this information is also available (Singleton, 2009) and information on the monitoring programme is available on the council's website (Box 1).

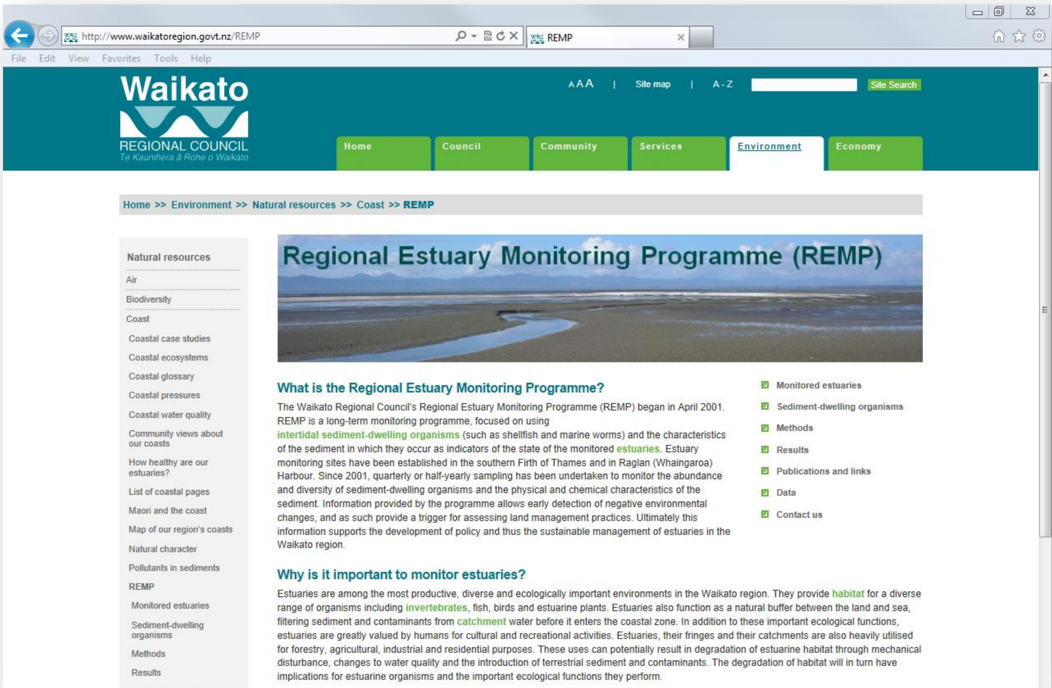
[1] Sediment-dwelling organisms are animals that live in or on the seabed. More specifically for this monitoring programme, we monitor macrobenthic invertebrates. These are animals with no backbone (invertebrates) living in or on the seabed (benthic) that will not pass through a 0.5 mm mesh (macro). Examples are worms or shellfish.

This report presents the first 10 years of monitoring data (April 2001 to April 2011). It provides analyses of trends over this period of time and investigates pattern and features in results that indicate the ecological health of the monitored estuaries.

Box 1. REMP website

Our Regional Estuary Monitoring Programme (REMP) has its own website:

http://www.waikatoregion.govt.nz/REMP*



Visit our REMP website for:

- general information on the programme,
- information on the sediment-dwelling organisms we monitor,
- results of past and recent monitoring,
- links to reports, and
- data to download.

* This link takes you to the REMP homepage. Once you start browsing through the website you will be directed to the full URL of the REMP website, which is http://www.waikatoregion.govt.nz/Environment/Natural-resources/coast/Regional-Estuary-Monitoring-Programme/

2 Methods

2.1 General programme design

The Regional Estuary Monitoring Programme is a long-term monitoring programme. It focuses on monitoring sediment-dwelling organisms and sediment characteristics in intertidal mud- and sand-flats of estuaries in the Waikato region. Initially two estuaries were selected for the programme: the Southern Firth of Thames and Raglan (Whaingaroa) Harbour. Within each estuary, five monitoring sites were selected. At each site sampling was carried out twice or four times per year.

The key variables measured in the Regional Estuary Monitoring Programme are:

1) Twenty-six “indicator” taxa[2] characteristic of intertidal mud- and sand-flat benthic macrofauna communities, selected to represent a variety of taxonomic groups and a range of life-histories, ecological niches, feeding methods and susceptibilities to fine sediments and organic enrichment (see Hewitt et al. 2001 and http://www.waikatoregion.govt.nz/Environment/Natural-resources/coast/Regional-Estuary-Monitoring-Programme/Organisms/).

2) Sediment properties that characterise habitats and influence the distribution and abundance of benthic macrofauna:
   - grain-size,
   - total organic carbon and total nitrogen, and
   - benthic microalgal biomass (quantified by chlorophyll-*a* and phaeophytin concentration).

Rates of sediment deposition and erosion are also monitored. These will be described in a separate report.

Result are analysed using various methods to examine:
- differences among sites within each estuary,
- differences between estuaries, and
- changes over time.

For all changes we detect we investigate if they were caused by natural variability (for example by factors that change with seasons such as food availability, water temperature or recruitment) or if they indicate environmental change that might represent a decline in estuary health.

2.1.1 Monitoring locations and sampling protocol

The background to the selection of the permanent monitoring sites is described in Turner (2000 and 2001). The locations of the five permanent monitoring sites in the Firth of Thames and Raglan (Whaingaroa) Harbour are shown in Figure 1. At each site a permanent monitoring plot (approximately 100 m × 100 m) has been established. Monitoring plots are located at approximately the mid-intertidal level.

Sampling times are provided in Table 1. Modifications made to the sampling protocol over time are explained in Table 1 and Box 2. In August 2013 Tairua Harbour was added to the programme and future reports will present results from all three monitored estuaries.

[2] 'Taxa' is used here to indicate that some sediment-dwelling organisms cannot reliably be identified to species level and that therefore some of the monitored 'taxa' may include more than one species.

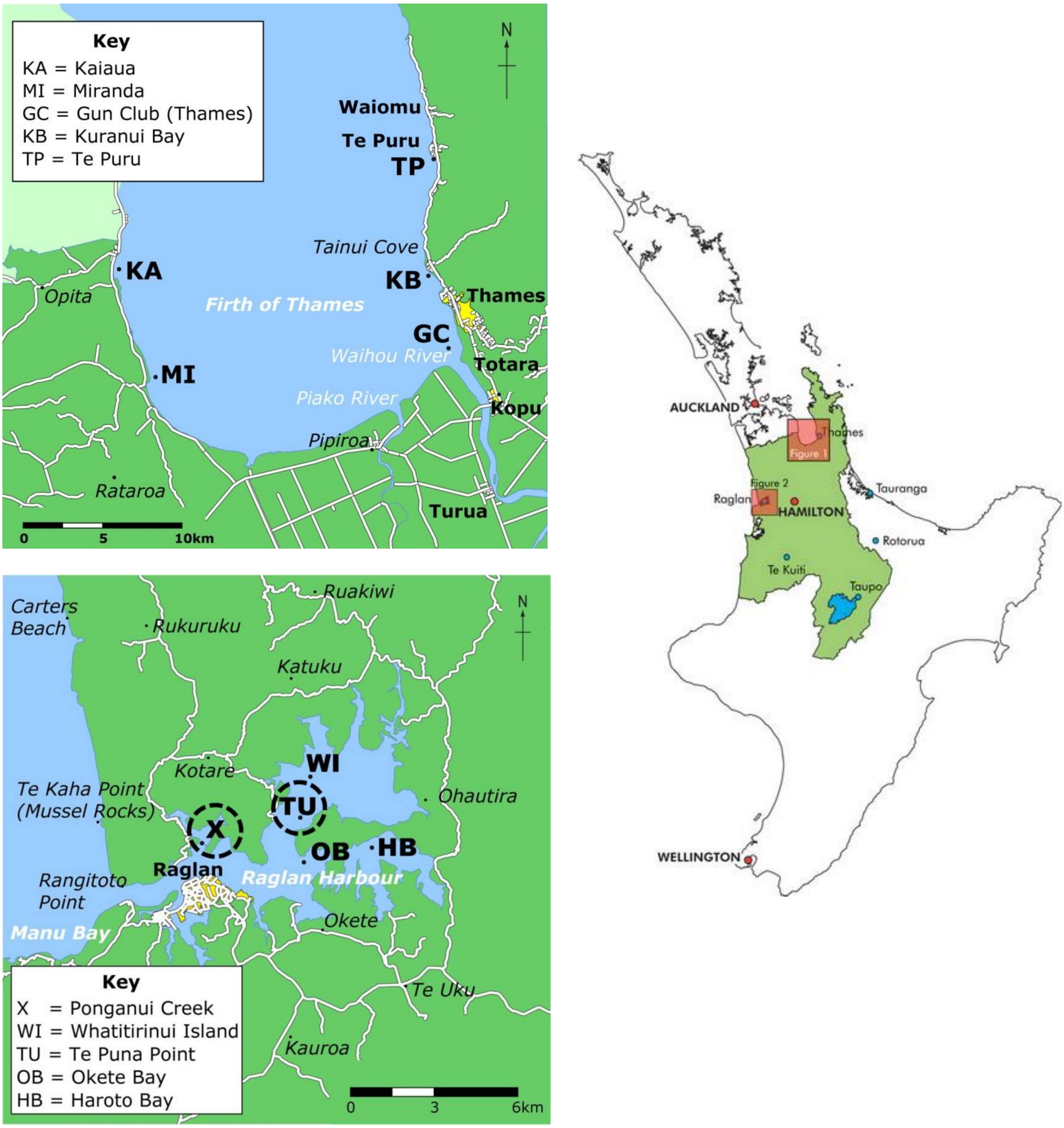


Figure 1: Location of monitoring sites in the southern Firth of Thames and Raglan (Whaingaroa) Harbour. Circled sites in Raglan (Whaingaroa) Harbour indicate sites that are no longer monitored (see Table 1 for more details).

Table 1: REMP monitoring sites in the southern Firth of Thames and Raglan (Whaingaroa) Harbour. Also shown are sampling times and modifications made to the sampling protocol between 2001 and 2011.

Site	Site Code	Sampling Times	Modifications*
Firth of Thames			
Kaiaua	KA	April, October	Relocated October 2001
Miranda	MI	Initial: January, July, October, April From 2009: April, October From 2012: January, July, October, April	
Thames (Gun Club)	GC	April, October	
Kuranui Bay	KB	Initial: January, July, October, April From 2009: April, October From 2012: January, July, October, April	
Te Puru	TP	April, October	Relocated 2007
Raglan (Whaingaroa) Harbour			
Whatitirinui Island	WI	Initial: January, July, October, April From 2009: April, October From 2012: January, July, October, April	
Te Puna Point	TU	April, October	Discontinued, last sampling October 2008
Okete Bay	OB	Initial: January, July, October, April From 2009: April, October From 2012: January, July, October, April	
Haroto Bay	HB	April, October	
Ponganui Creek	X	April, October	Established October 2001 Discontinued, last sampling April 2011

* see Box 2 for details of modifications made

Box 2. Modifications to REMP sampling protocols

Since the beginning of the REMP, some modifications to sampling protocol and analysis techniques have been made based on the findings of previous programme reports (e.g. Felsing and Singleton 2008), critical assessment of the programme (e.g. Compton et al., 2011), cost effectiveness and logistical constraints.

Site relocations and discontinuation of sampling

In October 2001 the Kaiaua site in the Firth of Thames was relocated 200 m upshore due to access difficulties. Similarly, in April 2007 the Te Puru site was shifted approximately 70 m along shore and 30 m up-shore due to access issues. In Raglan (Whaingaroa) Harbour, the fifth monitoring site, Ponganui Creek, was added in October 2001.

After analyses of the programme's effectiveness, sites at Te Puna Point and Ponganui Creek in Raglan (Whaingaroa) Harbour were discontinued in October 2008 and April 2011, respectively, to free up resources for more frequent sampling at the remaining monitoring sites.

Changes in methodology

Sediment grain size samples were analysed with a GALAI laser sediment particle sizer until October 2007. From then on, a new laboratory was used to analyse sediment samples using a Malvern Mastersizer 2000 laser particle sizer.

From 2007 all sediment-dwelling organisms were identified to the lowest taxonomic level possible to enable more comprehensive descriptions of the community structure.

2.2 Sample collection and processing

2.2.1 Sediment-dwelling organisms

On each sampling occasion 12 core samples[3] (13 cm diameter, 15 cm deep) were collected from within each monitoring plot. Each plot was divided into 12 equal-sized sectors and one core sample taken randomly (using randomly derived Cartesian co-ordinates) from within each sector following the methodology of Thrush et al. (1988). To minimise sample interdependence, samples were not positioned within a 5 m radius of each other. To avoid effects from previous sampling occasions, samples were not taken within 5 m of previous sampling positions over any 6-month period.

Sediment-dwelling organisms were separated from the sediment by sieving (500 µm mesh), preserved with 70% isopropyl alcohol in tap water and stained with 0.1% Rose Bengal. In the laboratory, the sediment-dwelling organisms were sorted, identified and counted (see Figure 2 for a typical view through the microscope). A number of sediment-dwelling organisms have been selected as 'indicator taxa'. These organisms are known to either be tolerant or intolerant to high mud, organic enrichment and/or sediment pollution levels. In general, they respond to changes in environmental conditions by either increasing or decreasing in numbers, depending on their tolerance levels. By observing the changes in abundance of indicator taxa over time, we can draw conclusions on likely changes that have taken place in the environmental. Indicator taxa are identified to the lowest possible taxonomic level. A list of indicator taxa is shown in Table 2 and detailed information about them is provided in Appendix 1.

Indicator bivalve species were also measured (shell width) and abundances were recorded for these different size-classes:

- *Arthritica bifurca*: < 2 mm; > 2 mm;
- *Austrovenus stutchburyi* (cockle): < 5 mm, > 5 mm;
- *Macomona liliana* (wedge shell): < 5 mm, 5-15 mm, > 15 mm;
- *Nucula hartvigiana* (nut-shell): < 2 mm, > 2 mm;
- *Paphies australis* (pipi): < 5 mm, 5-15 mm, > 15 mm;
- *Theora lubrica*: < 5 mm, > 5 mm.

Non-indicator taxa were identified to the lowest taxonomic level practicable. The remaining non-living material (shell material, pebbles and sand) was dried at 70°C for 48 hrs and weighed to determine the dry weight of each sample. In all samples shell material dominated the non-living material (typically much more than 90%) so we refer to this material as shell hash.

[3] See Hewitt et al. (2001) and Turner (2000) for justification.

Table 2: Sediment-dwelling organism indicator taxa monitored. Code refers to the abbreviation used for the taxa. For more information on these taxa see Appendix 1.

Phylum	Class	Order	Family	Genus	Species	Code	Common name
Crustaceans							
Amphipods (sea fleas and sand hoppers)							
Arthropoda	Malacostraca	Amphipoda	Corophiidae			ACOR	
Arthropoda	Malacostraca	Amphipoda	Phoxocephalidae			APHOX	
Cumaceans (hooded shrimp or comman shrimp)							
Arthropoda	Malacostraca	Cumacea	Diastylidae	Colurostylis	*lemurum*	CCL	Cumacean shrimp or hooded shrimp
Bivalves (molluscs that have a shell consisting of two hinged valves)							
Mollusca	Bivalvia	Venerida	Lasaeidae	Arthritica	bifurca	BAB	
Mollusca	Bivalvia	Venerida	Veneridae	Austrovenus	stutchburyi	BAS	New Zealand cockle, tuangi
Mollusca	Bivalvia	Venerida	Tellinidae	*Macomona*	*liliana*	BML	Wedge shell
Mollusca	Bivalvia	Nuculida	Nuculidae	*Linucula*	*hartvigiana*	BNH	Nut shell
Mollusca	Bivalvia	Venerida	Mesodesmatidae	*Paphies*	*australis*	BPA	Pipi
Mollusca	Bivalvia	Venerida	Semelidae	*Theora*	*lubrica*	BTHL	Asian semele
Gastropods (snails and slugs)							
Mollusca	Gastropoda	Neogastropoda	Buccinulidae	*Cominella*	*adspersa*	GCA	Speckled whelk
Mollusca	Gastropoda	Patellogastropoda	Lottiidae	*Notoacmea*	spp.	GNHE	Limpet
Polychaetes (segmented marine worms)							
Annelida	Polychaeta	Spionida	Spionidae	*Prionospio*	*aucklandica*	PAA	
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Aglaophamus*	spp.	PAGL	
Annelida	Polychaeta	Spionida	Spionidae	*Aonides*	*trifida*	PAO	
Annelida	Polychaeta	Scolecida	Paraonidae	*Aricidea*	spp.	PAR	
Annelida	Polychaeta	Spionida	Spionidae	*Pseudopolydora*	*complex*	PBOC	
Annelida	Polychaeta	Scolecida	Cossuridae	*Cossura*	*consimilis*	PCOS	
Annelida	Polychaeta	Sabellida	Sabellidae	*Euchone*	spp.	PEUC	Fan or feather-duster worms
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniada*	spp.	PGE	
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera*	spp.	PGLY	Blood worms
Annelida	Polychaeta	Scolecida	"Capitellidae"			PHF	
Annelida	Polychaeta	Spionida	Magelonidae	*Magelona*	*cf. dakini*	PMD	
Annelida	Polychaeta	Phyllodocida	Nereididae			PNIC	Ragworms
Annelida	Polychaeta	Scolecida	Orbiniidae	*Orbinia*	*papillosa*	POP	
Annelida	Polychaeta	Scolecida	Paraonidae			PPAR	
Other							
Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Anthopleura*	*aureoradiata*	OAN	Mud anemone, small brown anemone

Figure 2: A typical view through the microscope of sorted and stained (with Rose Bengal) sediment-dwelling organisms (Photo: Barry O'Brien, University of Waikato).

2.2.2 Sediment sampling

Two samples (5 cm diameter, 2 cm deep core) of surface sediment were collected from the vicinity of each of the 12 core samples collected from each monitoring plot. Samples from each monitoring plot were combined into five composite samples. Samples were stored frozen, then sub-sampled and analysed for grain-size, organic carbon and nitrogen as described below. Five surface sediment scrapes were also collected at each monitoring plot for analysis of chlorophyll-*a* and phaeophytin. Samples were taken at the four corners and the centre of each plot. They were stored in black containers and frozen until analysis.

Sediment grain-size: Sediments were pre-treated with 10% hydrogen peroxide to remove organic material and 1M hydrochloric acid to remove carbonate material. Calgon™ was added as a dispersant and samples were placed in an ultrasonic bath for 10 minutes to aid disaggregation. Up to October 2007 samples were analysed using a GALAI (CIS-100) stream-scanning laser particle sizer. From October 2007 onwards, samples were analysed using a Malvern Mastersizer 2000. Since the Malvern Mastersizer has a lower detection limit than the GALAI, sediment grain size results are not directly comparable between these two periods of time. This is discussed in detail in the Section 3.4 and Box 7. Grain size data were grouped into the following grain size categories: mud (<63 µm); very fine sand (63-125 µm); fine sand (125-250 µm); medium sand (250-500 µm); coarse sand (500-1000 µm) and gravel (>1000 um) (following the Wentworth sediment classification).

Sediment organic carbon and nitrogen content: Sediments were dried and finely ground, then analysed for total organic carbon and total nitrogen content using an automated CHN analyser. Samples for total organic carbon analysis were pre-treated with acid to remove carbonate material prior to analysis.

Sediment microalgal biomass: Chlorophyll-*a* (chl-*a*), was extracted from the sediment by boiling in 95% ethanol and the extract analysed using a spectrophotometer. Acidification was used to separate plant degradation products (phaeophytin) from chlorophyll-*a*.

2.3 Data analysis

2.3.1 Overview of data analysis techniques

Estuaries are dynamic environments. Natural variation (for example cyclical patterns that can be short term, seasonal, annual or inter-annual or natural differences between locations) in the community structure of sediment-dwelling organisms occur in response to factors such as food availability, water temperature, and recruitment. It is important to identify these patterns and tease them apart from patterns that might indicate a decline in health of the environment. In order to do this it is important to collect data over long periods of time. Without long-term data, short-term patterns in community composition could be misinterpreted. This could result in erroneous warnings of declining environmental health or in failures to detect actual environmental degradation, particularly slow degradation caused by cumulative adverse effects.

Separating natural variation from changes potentially indicating environmental degradation is not trivial. We have used a number of different data analysis techniques to ensure optimal interpretation of our data and to help us recognise potential problems in our estuaries. The rationale for these techniques and brief descriptions are outlined below.

2.3.2 Abundance and dominance of sediment-dwelling organisms

Changes in the numerical dominance of sediment-dwelling organisms at a site can indicate shifts in community composition over time. The three most abundant indicator taxa in each monitoring year were collated to examine such changes.

2.3.3 Trend analysis

Trend analysis is the statistical tool used to formally identify patterns in both biotic (sediment-dwelling organism) and abiotic (sediment) variables. Using this regression-based tool, we have the ability to separate naturally occurring cyclical patterns (e.g. seasonal or multi-year events) from other potential drivers of change that might indicate changes in ecological health of the estuary. Trend analysis was used at each site to determine if significant changes in sediment-dwelling organism abundances or sediment characteristics had occurred. Since the primary concern related to grain size changes in coastal ecosystems is an increase in fine sediments, especially mud, trend analysis results of grain size data are only reported for the mud fraction.

Trends were also compared among sites to identify if sediment-dwelling organisms or sediment characteristics showed similar trends throughout the estuary or if changes only occur locally. Trends in sediment-dwelling organisms were also compared to trends in sediment characteristics to assess if they were driven by environmental change.

Trends in indicator bivalve abundances were also analysed by size classes to obtain information on recruitment events and their influence on subsequent abundance dynamics.

More information on trend analysis is provided in Appendix 2.

2.3.4 Changes in community composition over time

Identifying shifts in community composition enables a more holistic assessment of change. This analysis enables us to detect if sites within an estuary (or even estuaries as a whole) are becoming more or less similar to one another. Sites undergoing the greatest changes in community structure over the 10 year monitoring period are also evaluated. This analysis does not, however, indicate what the drivers of any observed changes may be.

More information on how we assessed changes in community composition over time is provided in Appendix 2.

2.3.5 Relationships between community composition and sediment characteristics

This analysis allows us to establish if the sediment-dwelling organism communities at the monitoring sites are influenced by sediment characteristics. It also enables us to identify which sediment characteristics are most influential and the degree of these influences.

These relationships are explored using statistical models called DISTLM (distance-based linear models) to discover which sediment characteristics (predictors) are playing the greatest role in structuring communities (response) at an estuary wide scale over time. To do this a process called backwards elimination is used. It begins with a full model of all predictor variables and then sequentially removes those variables that do not improve the ability of the model to explain the sediment-dwelling organism community structure.

Due to changes in the monitoring sites and the grain size analysis method (Table 1, Box 2) relationships between sediment-dwelling organisms and sediment characteristics were conducted on the first three Octobers (2001 to 2003) and then again on data from October 2008 to October 2011. This allows us to examine the key relationships between sediment-dwelling organism community composition and sediment characteristics for each estuary. We can then determine if the influences of sediment characteristics have changed over time.

More information on how we assessed relationships between community composition and sediment characteristics is provided in Appendix 2.

3 Results

3.1 Abundance and dominance of sediment-dwelling organisms

For each site, the three most abundant indicator taxa in each monitoring year were collated to look for shifts in dominance over time (Table 3). Such shifts can have important consequences on the nature of the sediment-dwelling organism community composition and potentially indicate changes in the wider ecosystem.

Firth of Thames

The Kaiaua monitoring site is dominated by nut shells (*Linucula hartvigiana*) and capitellid polychaetes (Capitellidae). Between 2001-2002 and 2005-2006, and then again in 2010-2011, cockles (*Austrovenus stutchburyi*) were also among the most dominant species. At Miranda, eight different species have featured among the three most abundant since monitoring began. The polychaete *Aonides trifida* has been one of the most abundant species every year and Capitellidae has appeared in the top three since 2005-2006. Little change has occurred in the three most abundant species at Gun Club. *Aonides trifida* has maintained its position as the most abundant species, reaching 27 times greater in number than the second most abundant species. Capitellidae have been the second most abundant organisms since 2005-2006, indicating a potential cyclical pattern. Pipi (*Paphies australis*) has also featured in the top three in all but two years. Kuranui Bay has maintained a fairly constant dominant fauna over time. Capitellidae feature in the top three abundant taxa in all but one year (frequently as the most numerically dominant) and *Austrovenus stutchburyi* were always either the first or second-most abundant species at this site. At Te Puru, *Paphies australis* and *Linucula hartvigiana* were among the three most abundant species every year since the beginning of monitoring in 2001. *Austrovenus stutchburyi* were dominant until 2006-2007 but from then onwards *Aonides trifida* and Capitellidae began to appear in high abundances. During the more recent monitoring period (2009-2010), *Aonides trifida* were recorded at more than twice the abundance of any other organism at Te Puru. *Linucula hartvigiana* and *Paphies australis* were recorded at their lowest numbers since monitoring began, but were still the second and third most abundant species.

Raglan (Whaingaroa) Harbour

Haroto Bay has four indicator taxa that occur in the top three most abundant species throughout the 10 years of monitoring. Capitellidae appears as the primary or secondary dominant species, interchanging with the bivalve *Arthritica bifurca.* The other two species to occur in the top three were *Austrovenus stutchburyi* and the ragworms Nereididae. At Whatitirinui Island, *Austrovenus stutchburyi* were the most abundant organisms in all but two years of monitoring. Capitellidae were also found in large numbers in every year of monitoring. The only other two species featuring in the top three over the monitoring period were nut shells (*Linucula hartvigiana*) and wedge shells (*Macomona liliana*). Interestingly, of the three years that *Macomona liliana* appeared in the top three, two were in more recent years (2008-2010) however *Linucula hartvigiana* replaced this again in 2010-2011. Te Puna Point is also dominated by *Austrovenus stutchburyi* and *Linucula hartvigiana*. Other abundant species at this site were limpets (*Notoacmea* spp.) and the polychaete *Prionospio aucklandica*. In 2008-09 Capitellidae appeared on the list of the three most abundant species for the first time. Okete Bay is dominated by polychaetes, specifically Capitellidae (most abundant organism in all but two years), *Cossura consimilis* and *Prionospio aucklandica*. In fact, these three species have been in the top three for the past eight years. In the first two years of monitoring, phoxocephalid amphipods were the third most abundant species but their numbers were much lower than the second most abundant species. At Ponganui Creek, *Austrovenus stutchburyi* and *Linucula hartvigiana* have been the two most abundant species in all years of monitoring. In most years the polychaete *Prionospio aucklandica* followed as third most abundant species, except for 2004-05 when this was *Macomona liliana*. In 2009-2010 Capitellidae were among the three most abundant species for the first time.

Key Findings

Dominant taxa differed amongst sites, but in both estuaries were often bivalves (e.g. *Linucula hartvigiana*, *Austrovenus stutchburyi*, or *Macomona liliana*) and polychaetes (e.g. Capitellids, *Aonides trifida*, or *Prionospio aucklandica*).

No estuary wide shifts in species abundance were observed in the Firth of Thames or Raglan (Whaingaroa) Harbour. However, at several sites in both estuaries Capitellidae tended to became dominant during the later years of the monitoring period (i.e. from 2005-2006 to 2010-2011).

Table 3: The three most abundant taxa in each site of both estuaries over the 10 year monitoring period. Yearly mean abundances (per m^2) given in parentheses are averaged from July sampling to April sampling of the following year.

Firth of Thames	Kaiaua	Miranda	Gun Club	Kuranui Bay	Te Puru
2001-2002	*Linucula hartvigiana* (2950)	*Aonides trifida* (3605)	*Aonides trifida* (6771)	*Austrovenus stutchburyi* (1357)	*Linucula hartvigiana* (9307)
	Austrovenus stutchburyi (1406)	*Macomona liliana* (221)	*Paphies australis* (1046)	Capitellidae (1100)	*Austrovenus stutchburyi* (2857)
	Theora lubrica (705)	*Austrovenus stutchburyi* (215)	Nereididae (552)	Corophiidae (314)	*Paphies australis* (1860)
2002-2003	*Linucula hartvigiana* (2806)	*Aonides trifida* (4934)	*Aonides trifida* (7100)	Capitellidae (1356)	*Linucula hartvigiana* (5192)
	Austrovenus stutchburyi (1271)	*Macomona liliana* (324)	*Austrovenus stutchburyi* (674)	*Austrovenus stutchburyi* (770)	*Paphies australis* (1566)
	Capitellidae (1227)	*Austrovenus stutchburyi* (278)	*Macomona liliana* (301)	*Aonides trifida* (447)	*Austrovenus stutchburyi* (257)
2003-2004	*Linucula hartvigiana* (3732)	*Aonides trifida* (2818)	*Aonides trifida* (1249)	*Austrovenus stutchburyi* (1196)	*Linucula hartvigiana* (3719)
	*Austrovenus stutchbury*i (596)	*Macomona liliana* (588)	*Paphies australis* (1070)	Corophiidae (783)	*Paphies australis* (1334)
	Capitellidae (335)	*Austrovenus stutchburyi* (359)	*Macomona liliana* (251)	*Arthritica bifurca* (411)	*Austrovenus stutchburyi* (128)
2004-2005	*Linucula hartvigiana* (5571)	*Aonides trifida* (1445)	*Aonides trifida* (12851)	*Austrovenus stutchburyi* (1433)	*Linucula hartvigiana* (3270)
	*Austrovenus stutchbury*i (2373)	*Austrovenus stutchburyi* (624)	*Paphies australis* (1293)	Capitellidae (1367)	*Paphies australis* (2853)
	Capitellidae (1497)	Nereididae (232)	*Austrovenus stutchburyi* (260)	*Aonides trifida* (871)	*Austrovenus stutchburyi* (386)
2005-2006	*Linucula hartvigiana* (5349)	*Aonides trifida* (714)	*Aonides trifida* (16461)	Capitellidae (3531)	*Linucula hartvigiana* (1745)
	Capitellidae (646)	Capitellidae (626)	Capitellidae (1076)	*Austrovenus stutchburyi* (984)	*Paphies australis* (1519)
	Austrovenus stutchburyi (514)	*Orbinia papillosa* (508)	*Paphies australis* (753)	*Magelona cf. dakini* (557)	Capitellidae (232)

(Table 3 continued)

Firth of Thames	Kaiaua	Miranda	Gun Club	Kuranui Bay	Te Puru
2006-2007	*Linucula hartvigiana* (4021)	*Aonides trifida* (874)	*Aonides trifida* (15184)	Capitellidae (4222)	*Paphies australis* (1337)
	Capitellidae (577)	*Arthritica bifurca* (536)	*Paphies australis* (988)	*Austrovenus stutchburyi* (549)	*Austrovenus stutchburyi* (1279)
	Arthritica bifurca (273)	*Prionospio aucklandica* (533)	*Austrovenus stutchburyi* (819)	*Magelona cf. dakini* (371)	*Linucula hartvigiana* (1073)
2007-2008	*Linucula hartvigiana* (3572)	*Aonides trifida* (1087)	*Aonides trifida* (17023)	Capitellidae (2043)	*Linucula hartvigiana* (2586)
	Capitellidae (853)	*Prionospio aucklandica* (565)	Capitellidae (630)	*Austrovenus stutchburyi* (554)	*Paphies australis* (703)
	Phoxocephalidae (182)	*Orbinia papillosa* (439)	*Austrovenus stutchbury*i (307)	*Arthritica bifurca* (359)	Capitellidae (386)
2008-2009	*Linucula hartvigiana* (10007)	Capitellidae (1577)	*Aonides trifida* (14462)	Capitellidae (1433)	*Linucula hartvigiana* (822)
	Capitellidae (5437)	*Aonides trifida* (1467)	*Colurostylis lemurum* (835)	*Austrovenus stutchburyi* (502)	*Paphies australis* (342)
	Pseudopolydora complex (326)	*Prionospio aucklandica* (636)	*Paphies australis* (681)	*Arthritica bifurca* (217)	Capitellidae (172)
2009-2010	*Linucula hartvigiana* (10277)	Capitellidae (1010)	*Aonides trifida* (13448)	Capitellidae (3952)	Capitellidae (806)
	Capitellidae (1415)	Nereididae (580)	Capitellidae (621)	*Austrovenus stutchburyi* (665)	*Linucula hartvigiana* (505)
	Pseudopolydora complex (191)	*Aonides trifida* (342)	*Paphies australis* (539)	Nereididae (188)	*Paphies australis* (288)
2010-2011	*Linucula hartvigiana* (7964)	Capitellidae (1478)	*Aonides trifida* (11464)	Capitellidae (5942)	*Aonides trifida* (1208)
	Capitellidae (872)	Nereididae (495)	Capitellidae (913)	*Austrovenus stutchburyi* (1104)	Capitellidae (379)
	Austrovenus stutchburyi (304)	*Austrovenus stutchburyi* (458)	*Austrovenus stutchburyi* (787)	*Arthritica bifurca* (379)	Pseudopolydora complex (254)

(Table 3 continued)

Raglan Harbour	Haroto Bay	Whititirinui Island	Te Puna Point	Okete Bay	Ponganui Creek
2001-2002	Capitellidae (1268)	*Austrovenus stutchburyi* (1988)	*Austrovenus stutchburyi* (3071)	*Cossura consimilis* (1855)	*Austrovenus stutchburyi* (2071)
	Austrovenus stutchburyi (693)	Capitellidae (1647)	*Prionospio aucklandica* (1682)	Capitellidae (734)	*Linucula hartvigiana* (1735)
	Nereididae (376)	*Macomona liliana* (805)	*Linucula hartvigiana* (1623)	Phoxocephalidae (241)	*Prionospio aucklandica* (1054)
2002-2003	Capitellidae (2043)	*Austrovenus stutchburyi* (3260)	*Austrovenus stutchburyi* (4746)	Capitellidae (1783)	*Linucula hartvigiana* (2181)
	Austrovenus stutchburyi (1368)	Capitellidae (2954)	*Linucula hartvigiana* (2542)	*Cossura consimilis* (1525)	*Austrovenus stutchburyi* (1943)
	Arthritica bifurca (1101)	*Linucula hartvigiana* (1956)	*Prionospio aucklandica* (1368)	Phoxocephalidae (273)	*Prionospio aucklandica* (1083)
2003-2004	*Arthritica bifurca* (1243)	*Austrovenus stutchburyi* (3010)	*Austrovenus stutchbury*i (3776)	Capitellidae (1396)	*Austrovenus stutchburyi* (2435)
	Capitellidae (863)	*Linucula hartvigiana* (2382)	*Linucula hartvigiana* (2539)	*Cossura consimilis* (1126)	*Linucula hartvigiana* (1739)
	Nereididae (853)	Capitellidae (1852)	*Notomacea* spp. (973)	*Prionospio aucklandica* (296)	*Prionospio aucklandica* (709)
2004-2005	Capitellidae (718)	*Austrovenus stutchburyi* (3195)	*Austrovenus stutchburyi* (4419)	*Cossura consimilis* (1698)	*Austrovenus stutchburyi* (3051)
	Arthritica bifurca (417)	*Linucula hartvigiana* (2588)	*Linucula hartvigiana* (2831)	Capitellidae (1622)	*Linucula hartvigiana* (1657)
	Austrovenus stutchburyi (395)	Capitellidae (2156)	*Notomacea* spp. (1032)	*Prionospio aucklandica* (646)	*Macomona liliana* (809)
2005-2006	Capitellidae (897)	*Austrovenus stutchburyi* (2042)	*Austrovenus stutchburyi* (3983)	Capitellidae (1795)	*Austrovenus stutchburyi* (2357)
	Austrovenus stutchburyi (502)	*Linucula hartvigiana* (1878)	*Linucula hartvigiana* (2721)	*Cossura consimilis* (1404)	*Linucula hartvigiana* (1930)
	Arthritica bifurca (495)	Capitellidae (1855)	*Notomacea* spp. (809)	*Prionospio aucklandica* (428)	*Prionospio aucklandica* (988)

(Table 3 continued)

Raglan Harbour	Haroto Bay	Whititirinui Island	Te Puna Point	Okete Bay	Ponganui Creek
2006-2007	*Arthritica bifurca* (1425)	*Linucula hartvigiana* (2693)	*Austrovenus stutchburyi* (3939)	Capitellidae (2096)	*Austrovenus stutchburyi* (2335)
	Capitellidae (1117)	*Austrovenus stutchburyi* (2166)	*Linucula hartvigiana* (3164)	*Cossura consimilis* (1285)	*Linucula hartvigiana* (1946)
	Nereididae (932)	Capitellidae (2020)	*Notomacea* spp. (856)	*Prionospio aucklandica* (455)	*Prionospio aucklandica* (1010)
2007-2008	Capitellidae (1494)	*Linucula hartvigiana* (2490)	*Austrovenus stutchburyi* (3132)	Capitellidae (2290)	*Austrovenus stutchburyi* (3079)
	Arthritica bifurca (976)	Capitellidae (1948)	*Linucula hartvigiana* (2417)	*Cossura consimilis* (831)	*Linucula hartvigiana* (1921)
	Nereididae (831)	*Austrovenus stutchburyi* (1657)	Prio*nospio aucklandica* (847)	*Prionospio aucklandica* (632)	*Prionospio aucklandica* (1500)
2008-2009	Capitellidae (1447)	*Austrovenus stutchburyi* (2488)	*Linucula hartvigiana* (2115)	Capitellidae (2101)	*Austrovenus stutchburyi* (2536)
	Arthritica bifurca (725)	Capitellidae (1929)	*Austrovenus stutchburyi* (2078)	*Cossura consimilis* (740)	*Linucula hartvigiana* (1600)
	Nereididae (291)	*Macomona liliana* (1132)	Capitellidae (652)	*Prionospio aucklandica* (688)	*Prionospio aucklandica* (1346)
2009-2010	Capitellidae (1830)	*Austrovenus stutchburyi* (4554)	N/A	Capitellidae (1826)	*Austrovenus stutchburyi* (3776)
	Arthritica bifurca (809)	Capitellidae (2366)	N/A	*Cossura consimilis* (759)	*Linucula hartvigiana* (1437)
	Austrovenus stutchburyi (693)	*Macomona liliana* (1236)	N/A	*Prionospio aucklandica* (514)	Capitellidae (1312)
2010-2011	Capitellidae (1814)	*Austrovenus stutchburyi* (4316)	N/A	Capitellidae (2354)	*Austrovenus stutchburyi* (2969)
	Nereididae (769)	Capitellidae (2448)	N/A	*Cossura consimilis* (1089)	*Linucula hartvigiana* (1936)
	Arthritica bifurca (747)	*Linucula hartvigiana* (1619)	N/A	*Prionospio aucklandica* (709)	*Prionospio aucklandica* (1541)

3.2 Trends in indicator taxa

Trend analysis identifies natural seasonal and multi-year cycles in taxa abundance. These trends are explained in Boxes 3 to 5. Trend analysis also helps separate such natural cyclic trends from other non-cyclic trends (for example increases or decreases over time) that might be attributable to changing environmental conditions. These non-cyclic trends are of particular interest to the REMP as they give an indication of individual taxa that may be in decline or becoming more abundant.

Many of the indicator taxa displayed trends in abundance (Table 4). Seasonal and multi-year cycles made up the majority of trends in both the Firth of Thames and Raglan (Whaingaroa) Harbour. For example, Phoxocephalidae, *Arthritica bifurca, Austrovenus stutchburyi, Macomona liliana* and Capitellidae displayed seasonal or multi-year trends in seven or more of the 10 monitoring sites. These natural trends are not discussed in any detail in this report as they constitute naturally occurring dynamics.

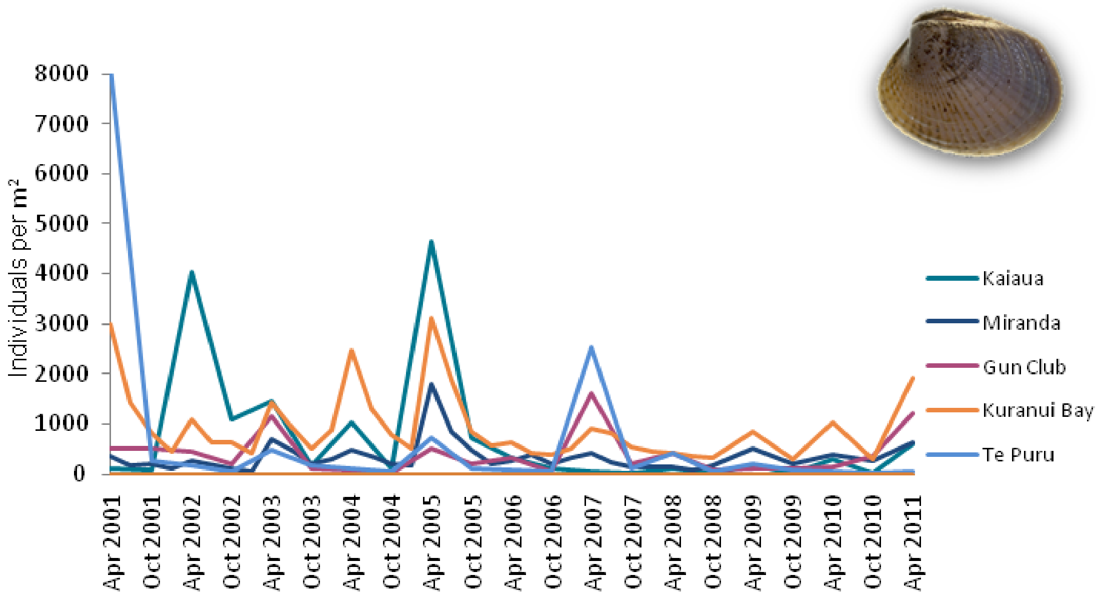
Table 4: Trends and cycles detected for indicator taxa over the 10 year period. Black symbols denote natural seasonal and multi-year cycles or indicate taxa with low or highly variable abundances, i.e. Z = absent greater than 75% of the time, L = average fewer than 2 individuals per core greater than 75% of the time, S = seasonal patterns, M = multi-year cycles, and H = highly variable. Red symbols denote non-cyclic trends that may be attributed to environmental change, i.e. T+ = increasing trend, and T- = decreasing trend.

	Sampling frequency per year									
	4		2			4		2		
	Firth of Thames					Raglan				
Taxa	Kuranui Bay	Miranda	Kaiaua	Te Puru	Gun Club	Okete Bay	Whatitirinui Island	Haroto Bay	Ponganui Creek	Te Puna Point
Corophiidae	H	M	L	L	L	LS	LS	Z	Z	Z
Phoxocephalidae	S	S	SM	L	L	S	S	S	S	L
Arthritica bifurca	S	M	SM	L	SM	SM	SM	H	L	H
Austrovenus stutchburyi	SM	SM	SM	H	SM	L	S	S	SM	SM
Macomona liliana	M	M	M	Z	M	LM	H	M	T+	SM
Linucula hartvigiana	L	Z	MT+	HT-	Z	L	S/M	Z	S	H
Paphies australis	Z	Z	Z	MT-	M	Z	Z	Z	Z	Z
Theora lubrica	L	L	SM	Z	Z	H	LS	L	L	Z
Colurostylis lemurum	M	SMT+	L	L	H	S	LS	Z	H	L
Cominella adspersa	L	L	L	L	L	Z	Z	Z	Z	Z
Notoacmea sp.	L	L/S	Z	LS	LM	Z	S/M	Z	M	H
Anthopleura aureoradiata	L	T-	Z	Z	L	Z	T+	Z	L	T-
Prionospio aucklandica	SM	SM	L	Z	Z	T+	MT+	H	SM	ST-
Agloaophamus sp.	L	Z	L	L	Z	Z	Z	Z	Z	Z
Aonides trifida	M	MT-	Z	Z	H	L	LS	Z	L	H
Aricidea sp.	Z	Z	LM	Z	Z	M	MT+	L	L	L
Cossura sp.	Z	Z	L	Z	Z	MT-	L	L	Z	Z
Euchone sp.	Z	Z	Z	Z	Z	H	Z	Z	Z	Z
Goniada sp.	L	Z	L	Z	Z	L	L	Z	Z	Z
Magelona cf. *dakini*	M	M	SM	L	L	L	L	Z	Z	Z
Orbinia papillosa	L	SM	Z	Z	Z	Z	Z	Z	Z	Z
Paraonidae	Z	Z	Z	Z	Z	T+	H	Z	L	L
Pseudopolydora complex	M	H	H	M	M	L	L	L	L	L
Capitellidae	M	MT+	H	SMT+	M	T+	H	M	T+	M
Glycera sp.	L	L	L	L	L	L	L	L	L	L
Nereididae	M	MT+	M	L	H	SMT+	H	S	M	H

Box 3. What is a seasonal trend?

These trends describe a cyclical rise and fall in species abundance consistent with seasonal changes in environmental conditions such as changes in air and sea temperatures, daylight hours (photoperiod) and food availability. Although the actual number of individual sediment-dwelling organisms may change over time (annual variability), the pattern should still be detectable over the majority of the monitoring period.

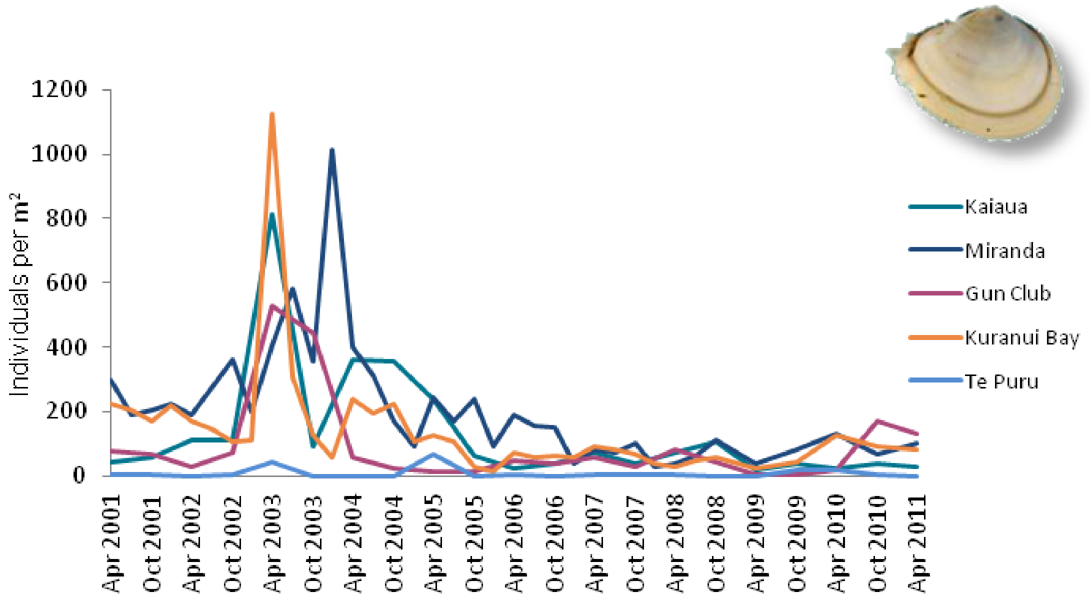
The graph below demonstrates that although the actual number of cockles (*Austrovenus stutchburyi*) present in each site in the Firth of Thames may differ, the peaks and troughs occur at the same time of year in many instances (i.e., they align well on the graph). This indicates a seasonal trend.



Example: *Austrovenus stutchburyi* patterns of abundance in the Firth of Thames show a strong seasonal signal. Seasonal peaks in abundances occur in April of each year. These differ in magnitude depending on both the site and the year.

Box 4. What is a multi-year trend?

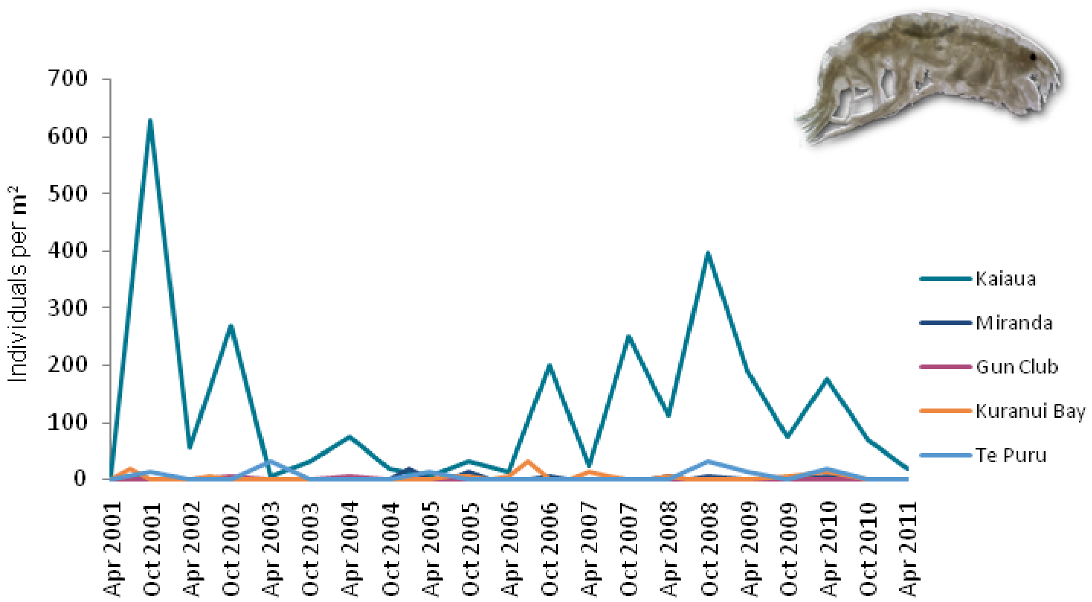
As the name suggests, multi-year trends are those peaks or troughs in abundance that span a greater length of time than a seasonal trend. Peaks in abundance may last for several years in a row and can occur in response to local (site) or regional level (estuary) changes in the environment that the organism can exploit.



Example: *Macomona liliana* displayed multi-year cycles in four of the five monitored sites in The Firth of Thames. Te Puru is the only site where abundance of this sediment-dwelling organism was too low to detect any apparent pattern. Peaks in abundance at all other sites occurred between mid-2002 and mid-2005. In this case, the pattern is driven by an increase in the number of *Macomona* < 5mm long (see Section 3.3). In other words high larval recruitment and settlement preceded this increase in abundance.

Box 5. How can you have a seasonal and multiyear cycle?

This is a trend which has components of both seasonal and multi-year cycles. For example, at the Kaiaua site in the Firth of Thames the Phoxocephilidae amphipods show peaks in abundance primarily in October (seasonal trend). Although the seasonal peak occurs, there is another longer term pattern developing. The number of individuals at each peak reduced year on year between 2001 and 2003. This was followed by a period of low abundances before the number of Phoxocephilidae once again increased from October 2006 – 2008. This cycle of abundance is our multi-year trend. 2009 – 2010 abundances indicate a lowering abundance demonstrating this cycle has begun again.



Example: Phoxocephalidae amphipods show a clear seasonal and multi-year cycle at Kaiaua in the Firth of Thames. At the start of the monitoring period there are peaks in abundance in October of each year; however for the next few years abundances decrease before increasing once again in the latter part of the monitoring period. This cycle occurs approximately every 3 years at this site.

Table 5: Trends likely associated with changes in environmental conditions over the 10 year monitoring period, i.e. T+ = increasing trend and T- = decreasing trend. N.B. T± (b) indicates that there is no trend overall for Capitellidae at Whatitirinui Island but baseline values are changing.

	Sampling frequency per year									
	4		2			4		2		
	Firth of Thames					Raglan				
Taxa	Kuranui Bay	Miranda	Kaiaua	Te Puru	Gun Club	Okete Bay	Whatitirinui Island	Haroto Bay	Ponganui Creek	Te Puna Point
Arthritica bifurca										
Macomona liliana									**T+**	
Linucula hartivigiana			**T+**	**T-**						
Paphies australis				**T-**						
Colurostylis lemurum		**T+**								
Anthopleura aureoradiata		**T-**					**T+**			**T-**
Prionospio aucklandica						**T+**	**T+**			**T-**
Aonides trifida		**T-**								
Aricidea sp.							**T+**			
Cossura sp.						**T-**				
Paraonidae						**T+**				
Capitellidae		**T+**		**T+**		**T+**	**T±(b)**		**T+**	
Nereididae		**T+**				**T+**				

The remainder of this section focuses on non-cyclic trends that indicate changes in taxa abundance which may be attributed to environmental change.

Firth of Thames

In the Firth of Thames, three of the five monitoring sites showed non-cyclic trends in indicator taxa abundances (Table 5). Miranda showed most change, exhibiting five taxa with temporal abundance trends (Figure 3). The relatively mud intolerant small brown anemone (*Anthopleura aureoradiata*) and the polychaete *Aonides trifida* have become less abundant over time, while the more mud tolerant Capitellidae and Nerididae have become more abundant. The crustacean *Colourstylis lemurum,* showed a positive trend in abundance, and although this species tolerates sediment mud content of up to 60%, its preferred habitat is sandy, with an optimum sediment mud content of 0-5%. Therefore four of the five taxa behaved as would be expected with increased mud inputs.

At Te Puru, three long term trends in abundance were observed for indicator taxa (Figure 4; Table 5). Decreases in abundance were noted for the mud intolerant bivalves *Linucula hartvigiana* and *Paphies australis*. An increase in the mainly mud tolerant Capitellidae was also observed. Capitellidae have species-specific responses to sediment changes, but generally become more abundant in response to mud content increase up to about 40% mud content.

Kaiaua showed a positive trend in *Linucula hartvigiana* abundance, a species which prefers sandy habitats (Figure 5; Table 5). This was the only significant trend observed at this site. Kuranui Bay and Gun Club displayed no detectable trends in abundance in indicator taxa once multi-year cycles and seasonal patterns were factored out (Table 5).

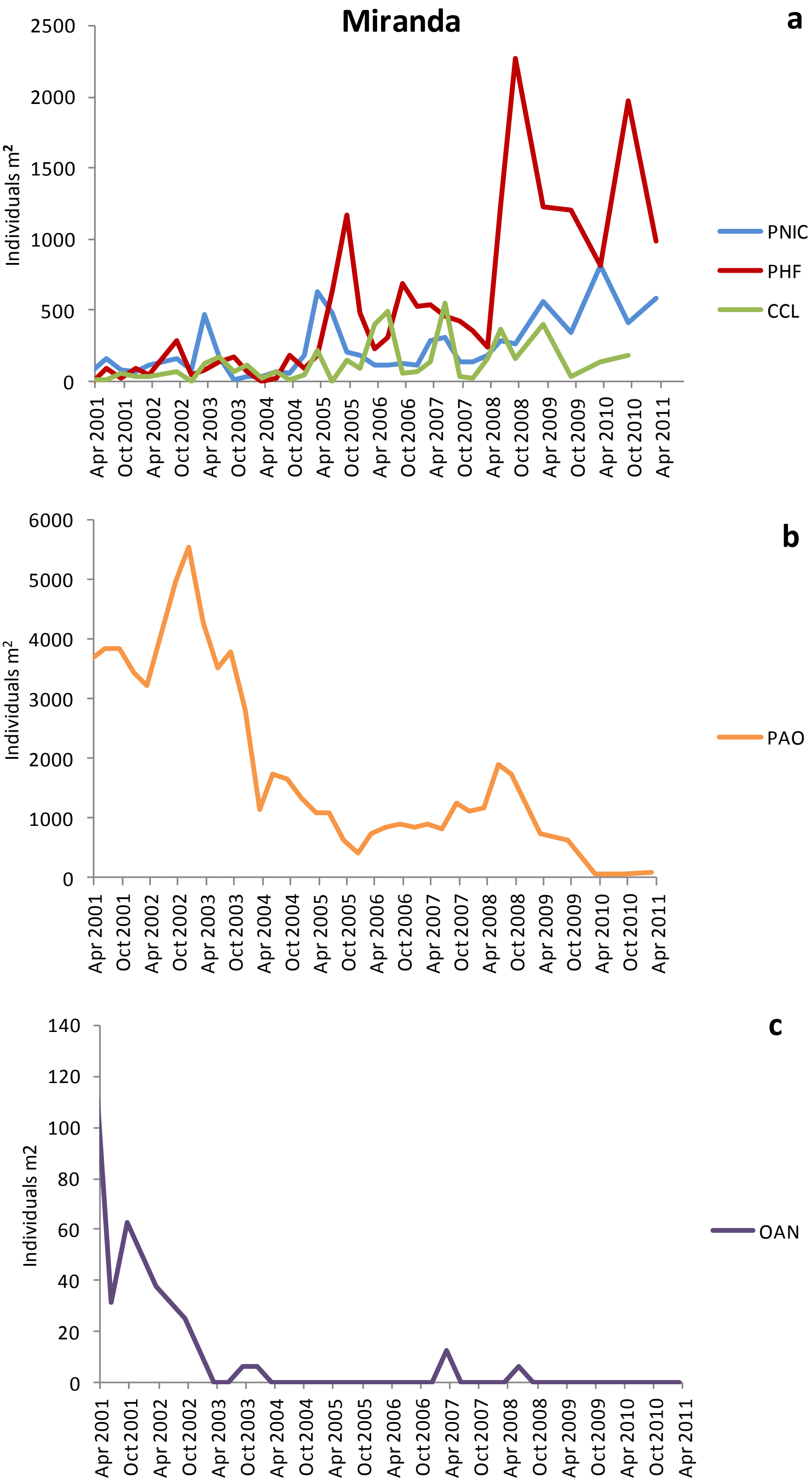


Figure 3: **Trends in indicator taxa abundances at Miranda, Firth of Thames: (a) positive trends in Nereididae (PNIC), Capitellidae (PHF) and *Colurostlyis lemurum* (CCL) abundances, (b) negative trend in *Aonides trifida* (PAO) abundances, and (c) negative trend in *Anthopleura aureoradiata* (OAN).**

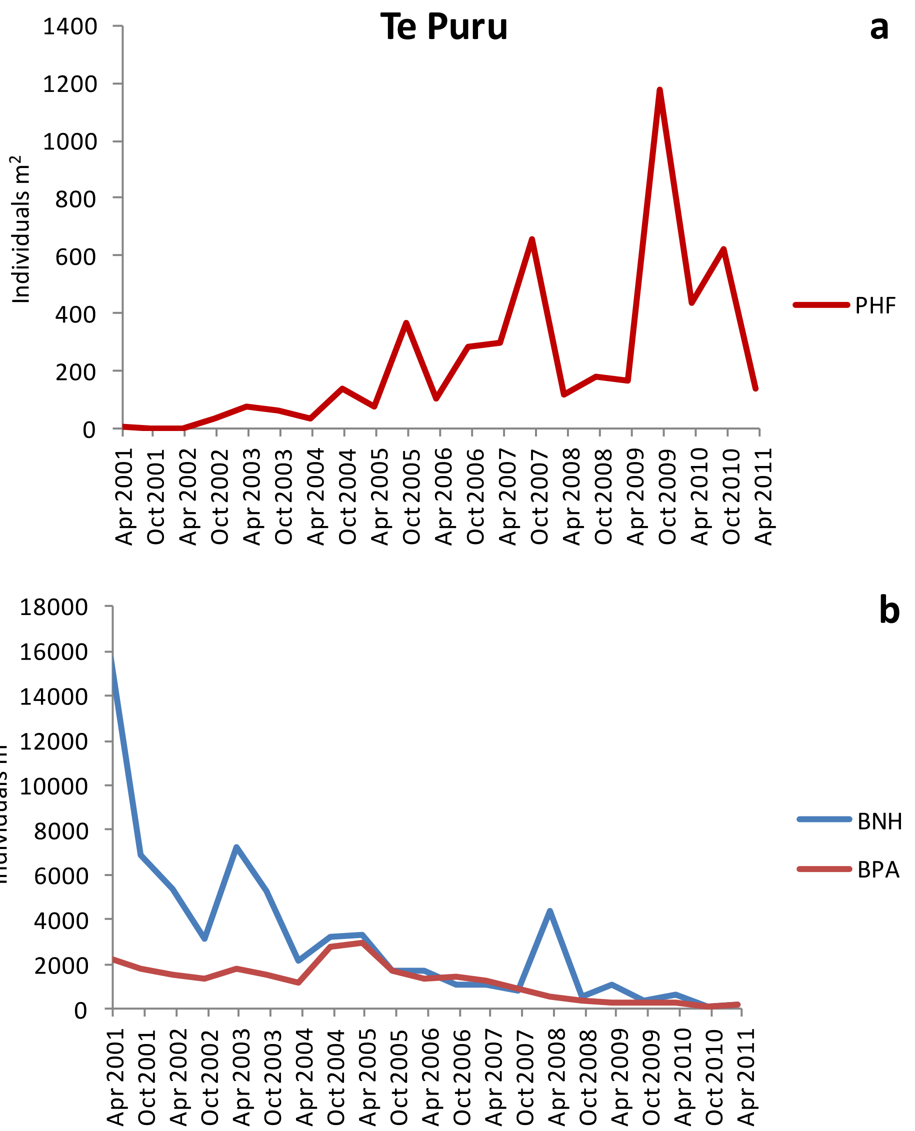


Figure 4: **Trends in indicator taxa abundances at Te Puru, Firth of Thames: (a) positive trend in Capitellidae (PHF) abundance, and (b) negative trends in *Linucula hartvigiana* (BNH) and *Paphies australis* (BPA).**

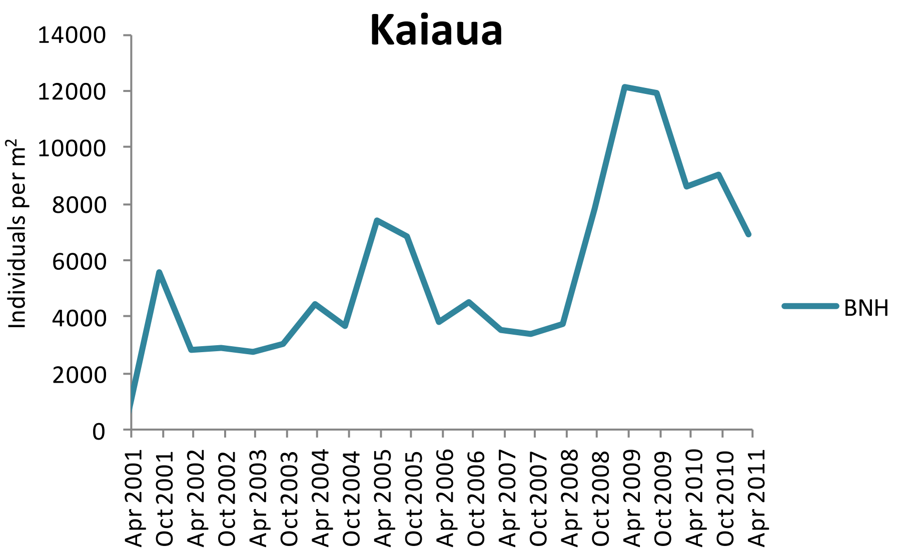


Figure 5: **Positive trend in *Linucula hartvigiana* (BNH) abundances at Kaiaua, Firth of Thames.**

Raglan (Whaingaroa) Harbour
In Raglan, four of the five monitoring sites showed detectable trends in taxa abundances likely associated with environmental change (Table 5). Haroto Bay was the only site to show no consistent trends with time once seasonal and multi-year cycles were factored out. *Prionospio aucklandica* exhibited similar trends at Okete Bay and Whatitirinui Island and Capitellidae displayed the same positive trends at Okete Bay and Ponganui Creek.

Okete Bay displayed trends in five of the indicator taxa (Figure 6; Table 5). Polychaetes *Prionospio aucklandica,* Paraonidae, Capitellidae and Nereididae all showed increasing trends in abundance, and all four taxa prefer habitats that are moderately or very muddy. A decrease in the abundance of *Cossura consimilis* was also seen; a species which tends to prefer habitats that are slightly muddy.

At Whatitirinui Island, three trends in indicator taxa were detected (Figure 7; Table 5). *Anthopleura aureoradiata, Prionospio aucklandica,* and *Aricidea* sp. displayed increases in abundance, with two being consistent with increased mud content (*Prionospio aucklandica* and *Aricidea* sp.). *Anthopleura aureoradiata* is mud intolerant and would be expected to reduce when mud content increases, so the increasing trend in abundance for this species is inconsistent with trends observed for the other taxa. It should also be noted that the baseline values for Capitellidae appear to be changing at this site, making it difficult to ascertain whether or not there is a trend, and so continued monitoring is required to confirm whether there is an increasing or decreasing trend for this taxa at this site.

The now discontinued Ponganui Creek monitoring site showed a positive trend in *Macomona liliana and* Captellidae abundances (Figure 8; Table 5). Both taxa tend to prefer habitats with some mud; the optimal mud content range for *Macomona* is 0-30% mud content, and for Capitellidae it is slightly higher (10-40%).

Te Puna Point displayed negative trends in both *Prionospio aucklandica* and *Anthopleura aureoradiata* abundances (Figure 9; Table 5). *Prionospio* prefers moderately to very muddy habitats whereas *Anthopleura* prefers sandy habitats so the trends detected are somewhat inconsistent with one another.

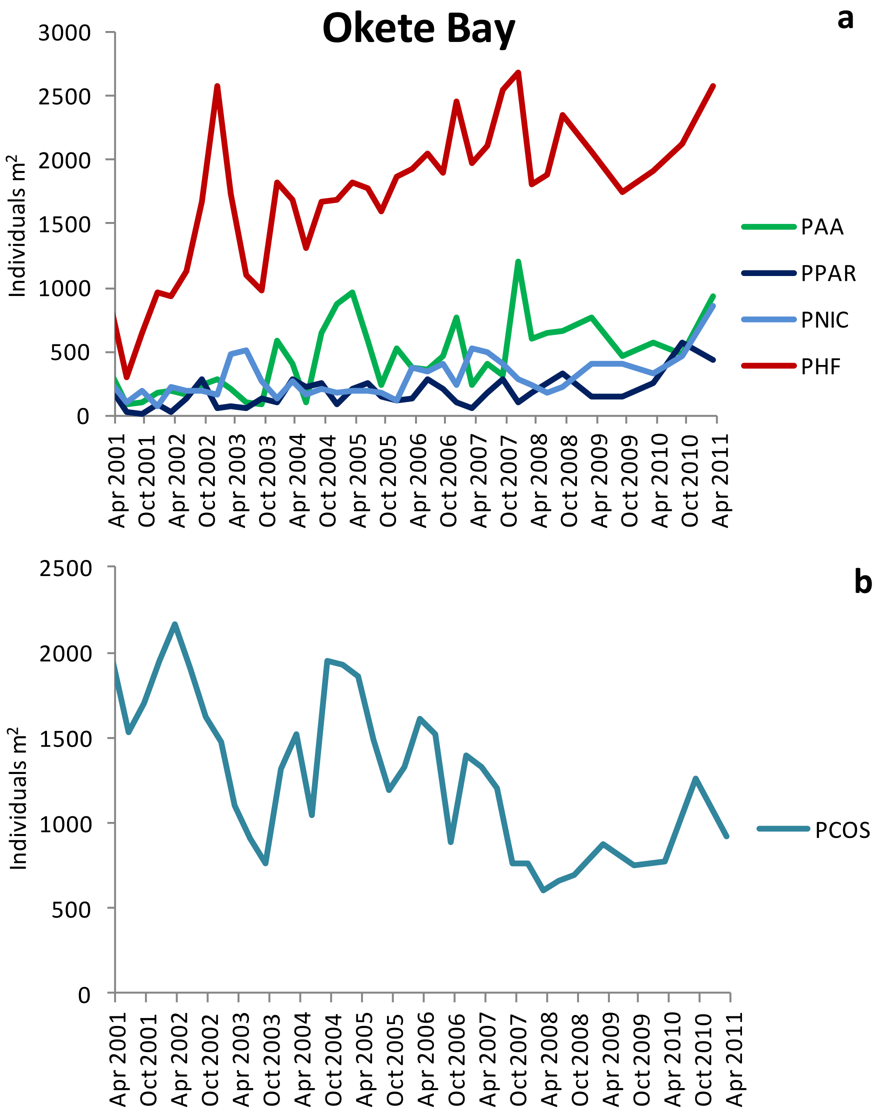


Figure 6: **Trends in indicator taxa abundances at Okete Bay, Raglan (Whaingaroa) Harbour: (a) positive trends were observed in *Prionospio aucklandica* (PAA), Paraonidae (PPAR), Nereididae (PNIC) and Capitellidae (PHF) abundances, and (b) a negative trend was observed in *Cossura consimilis* (PCOS).**

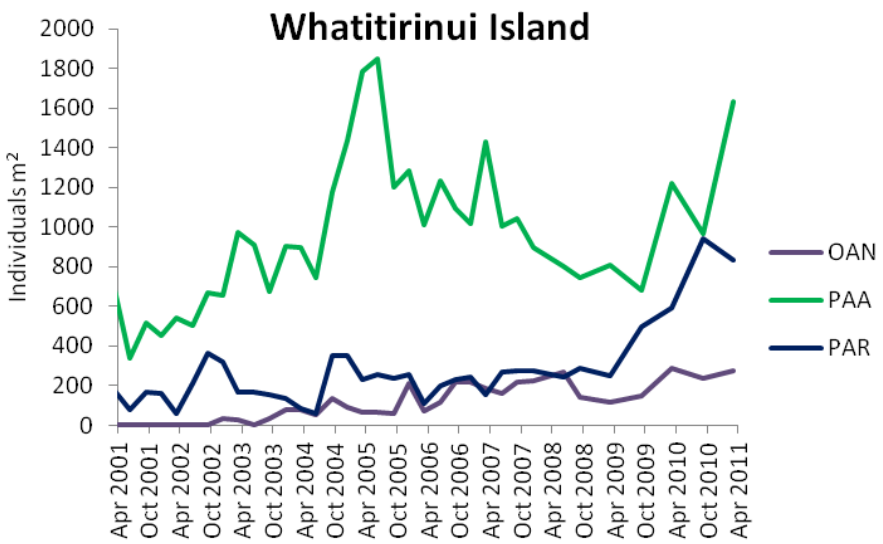


Figure 7: **Trends in indicator taxa abundances at Whatitirinui Island, Raglan (Whaingaroa) Harbour. Positive trends were observed in *Prionospio aucklandica* (PAA), *Anthopleura aureoradiata* (OAN) and *Aricidea* sp (PAR) abundances.**

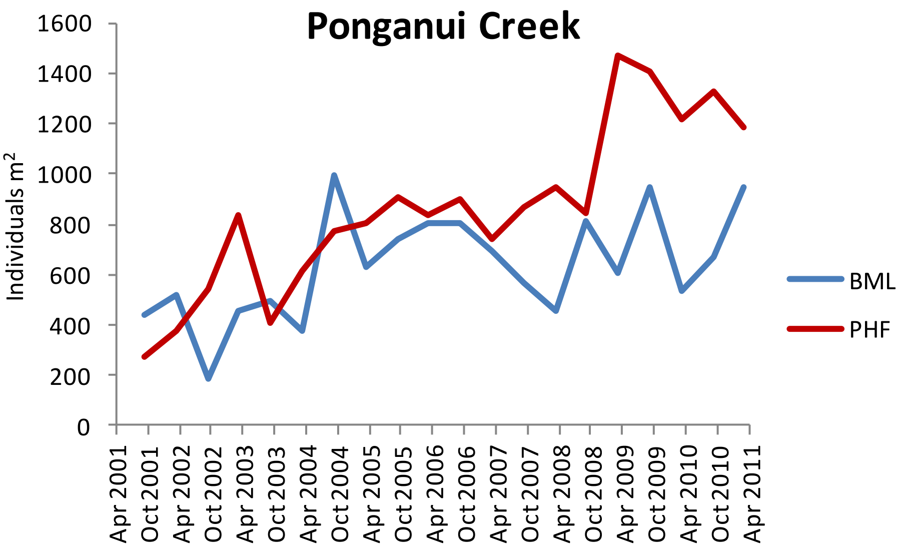


Figure 8: **Trends in indicator taxa abundances at Ponganui Creek, Raglan (Whaingaroa) Harbour. Positive trends in *Macomona liliana* (BML) and Capitellidae (PHF) abundances were observed.**

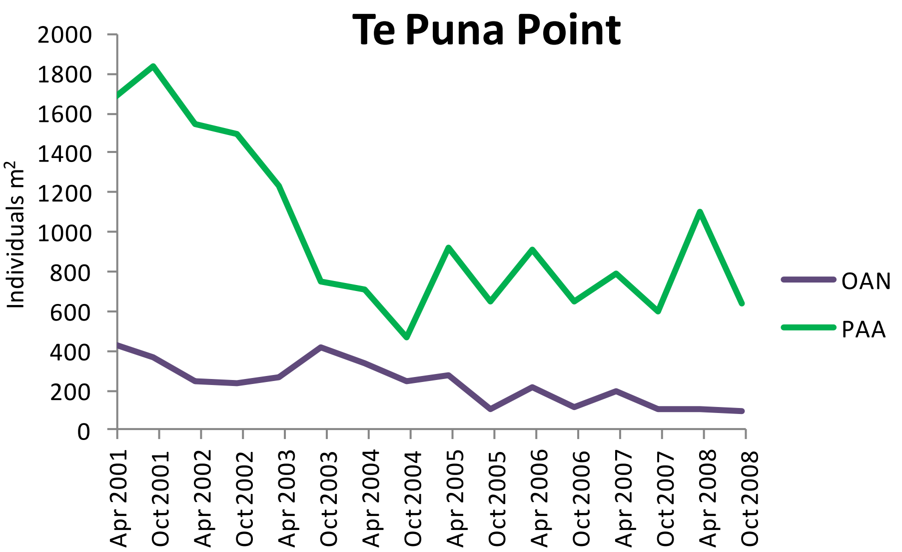


Figure 9: **Trends in indicator taxa abundances at Te Puna Point, Raglan (Whaingaroa) Harbour. Negative trends in *Anthopleura aureoradiata* (OAN) and *Prionospio aucklandica* (PAA) abundances were observed.**

Key Findings

In both estuaries, sites close to each other did not show strong trends in the same taxa indicating that many of the observed changes are spatially limited.

Overall, relatively few taxa exhibited trends in abundance in each site (≤ 5) once seasonal and cyclical shifts had been accounted for. Only two sites in each estuary exhibited temporal trends in more than two taxa. These sites were Miranda and Te Puru in the Firth of Thames and Okete Bay and Whatitirinui Island in Raglan (Whaingaroa) Harbour. The trends observed at Miranda, Te Puru and Okete Bay were consistent with increasing mud content. However, very few taxa demonstrated trends in the same direction at more than one site within each of the two estuaries, indicating responses were spatially limited.

3.3 Trends in bivalve size classes

Data on the size of monitored bivalve species provide information on recruitment events (see Box 6) and their influence on species abundances in the larger size classes in subsequent months and years. These periods of influx often heavily influence the seasonal and multi-year trends seen in the total abundances in the previous section (Table 4).

Firth of Thames

Trends in the abundance of *Linucula hartvigiana* were observed in three of the five sites in the Firth of Thames (Figure 10). At Kuranui Bay both size classes (< 2 mm and > 2 mm) of this bivalve displayed a negative trend (r^2 = 0.33, p < 0.001 for individuals sized < 2 mm; r^2 = 0.47, p = 0.036 for individuals sized > 2 mm, Figure 10a); however, there were fewer than two individuals per core 75 % of the time, meaning this trend should be treated with caution. At nearby Te Puru, abundances of individuals > 2 mm also decreased over time (r^2 = 0.67, p = 0.003, Figure 10b). This was despite peaks in abundances of animals < 2 mm (i.e. recruitment events) between April 2003 and 2005, and in April 2008. In contrast, at Kaiaua, on the opposing eastern side of the Firth of Thames, abundance of individuals > 2 mm increased over time (r^2 = 0.57 p = 0.017, Figure 10c). *Linucula hartvigiana* was absent more than 75% of the time at Miranda and Gun Club, and so trends were not assessed at these sites.

Only one trend was seen in the Firth of Thames for *Paphies australis*. This was a decrease of individuals sized > 15 mm at Te Puru (r^2 = 0.91, p < 0.0001, Figure 11). Although two peaks in recruitment were observed over the 10 years of sampling, these events do not appear to have buffered the overall decline in animals >15 mm at this site.

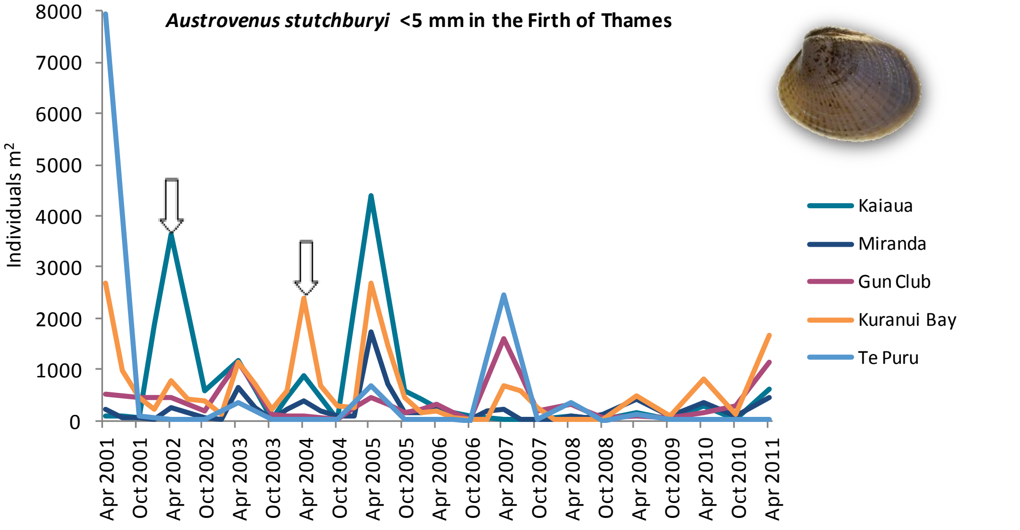
Macomona liliana did not display any consistent size-class specific trends over the 10 year monitoring period at Firth of Thames sites beyond natural variability among locations and times (Figure 12). The smaller size class (< 5 mm) showed a strong multi-year cycle in recruitment in all sites except for Te Puru (Figure 12a). This drove the multi-year cycles observed in total abundance shown in Table 4. Kuranui Bay and Miranda did, however, have higher numbers of individuals > 15 mm prior to 2004 than have been observed thereafter (Figure 12b). Since 2004 numbers have been relatively low but stable.

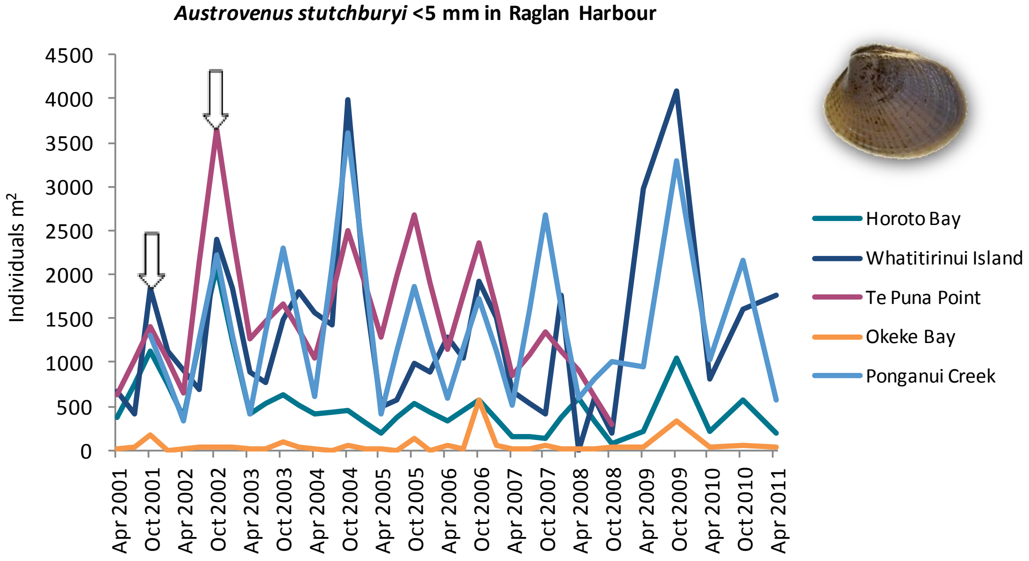
Box 6. Recruitment trends

Many bivalves reproduce by releasing their gametes (sperm and eggs) in to the water column where they develop in to larvae. Reproduction events in most species are driven by seasonal triggers such as changes in water temperature. During the larval phase bivalves disperse in water currents before settling back to the sea bed where they develop and grow (this is called "recruitment"). The distance larvae may travel is often linked to the shape of the estuary or harbour and the strength of currents and tides and can therefore differ greatly from location to location.

What does a recruitment trend look like?

In trend analysis (Section 3.2), strong seasonal signals were seen in the abundance of the common cockle (*Austrovenus stutchburyi*). As can be seen from the graphs below, this was driven by mainly seasonal recruitment events visible in both estuaries.





Interestingly, in Raglan (Whaingaroa) Harbour, the peak of recruitment occurs in October each year, whereas in the Firth of Thames the peak is often seen in April. The number of these smaller cockles is also generally lower in the Firth of Thames than in Raglan. Recruitment and growth rates are known to vary greatly between locations and can be dependent on organism density, current speed and water temperatures (Michael et al. 2008). Natural mortality can also be as high as 17-37% per annum (Michael et al. 2008).

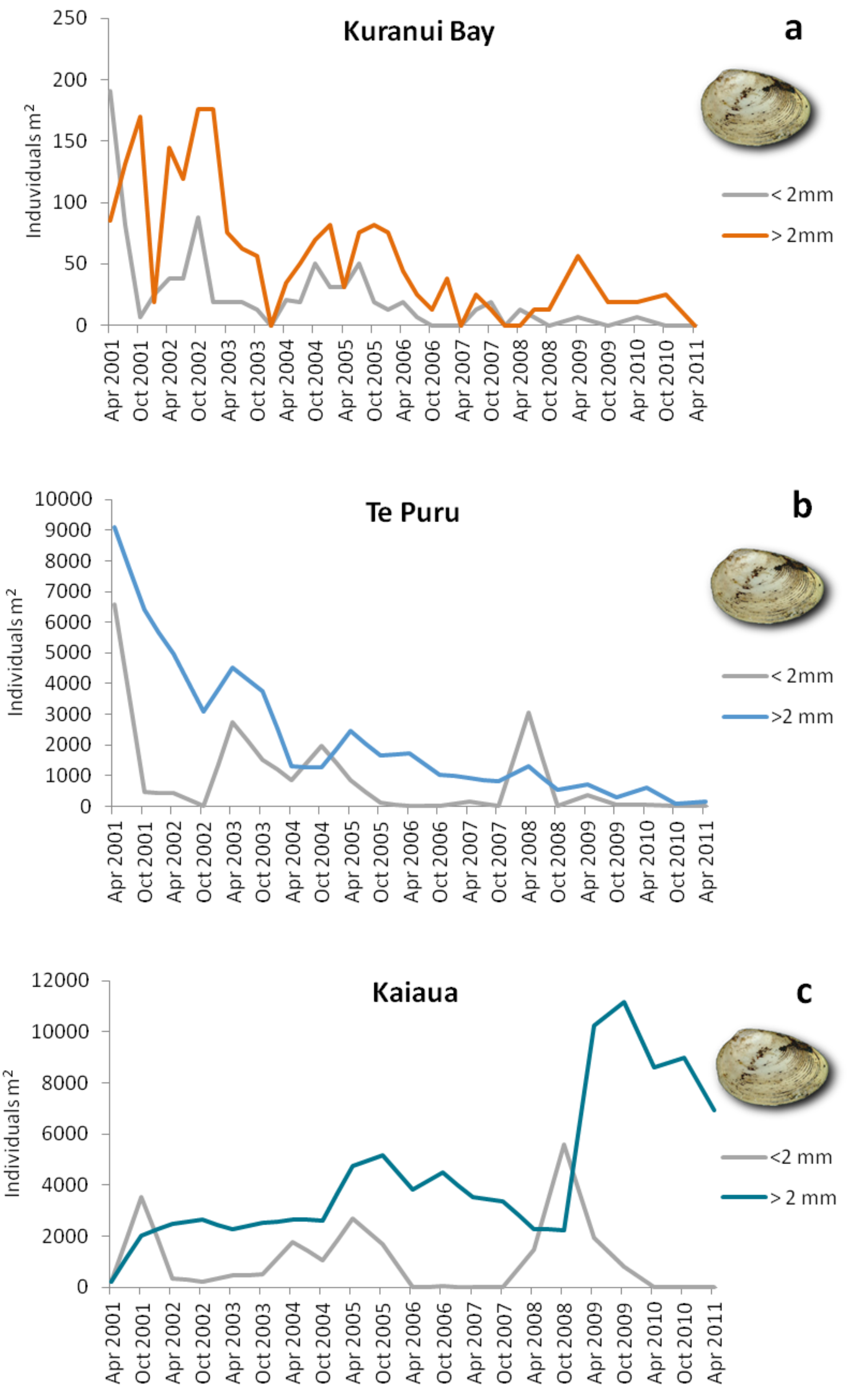


Figure 10: Both size classes of *Linucula hartvigiana* show a downward trend at Kuranui Bay in the Firth of Thames (a). However the actual numbers of individuals per core were low and therefore this trend should be treated cautiously. A decreasing trend in *Linucula hartvigiana* > 2 mm was seen in Te Puru in the Firth of Thames despite periodic peaks in recruitment to the area (b). An increasing trend in *Linucula hartvigiana* > 2 mm was seen in Kaiaua in the Firth of Thames (c). Periodic recruitment events are noticeable in the < 2mm size class data.

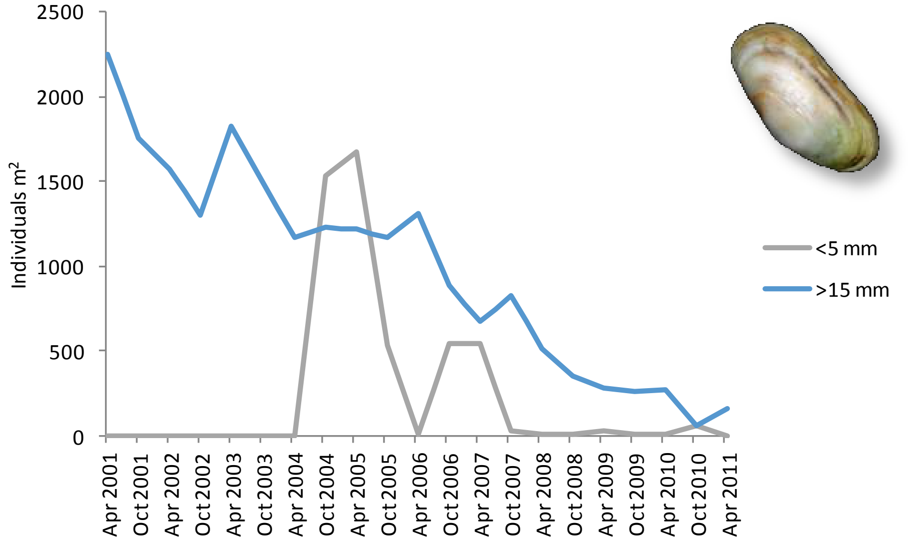


Figure 11: Despite two peaks in recruitment, a continuous decline in *Paphies australis* >15 mm is apparent at Te Puru in the Firth of Thames.

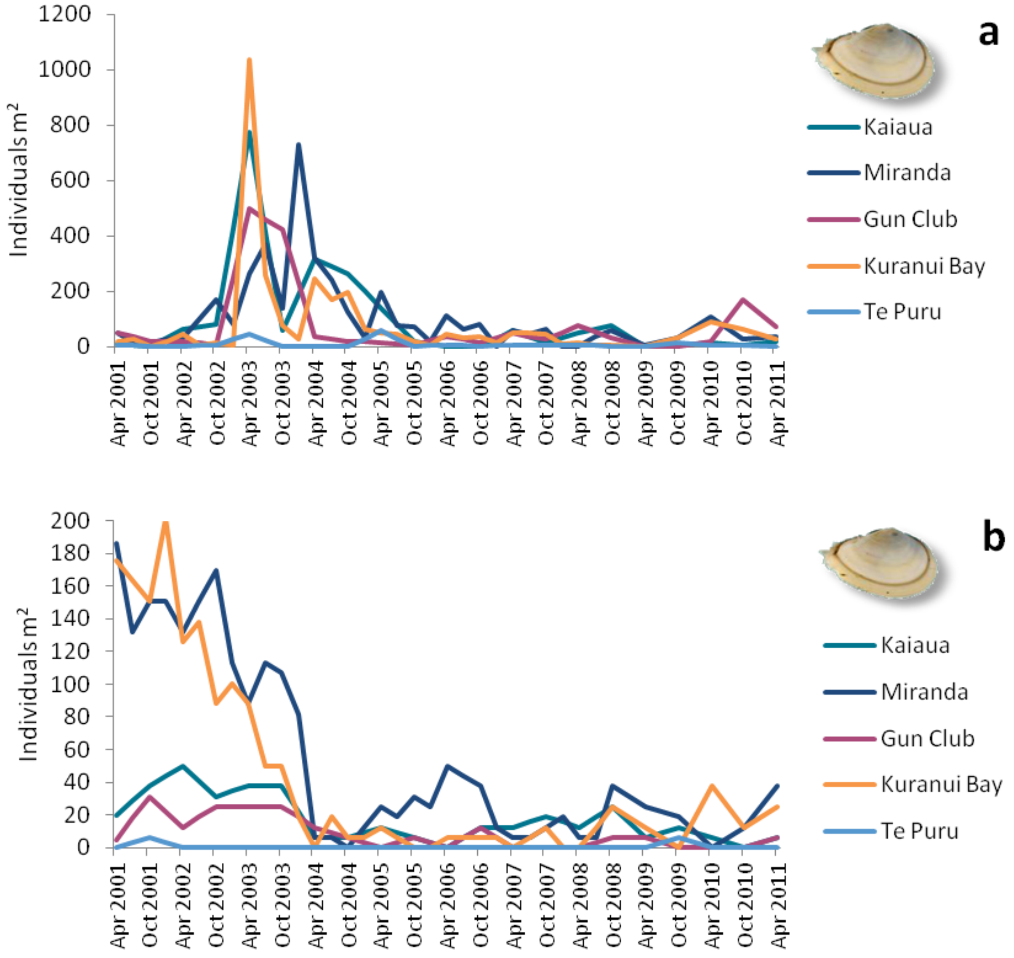


Figure 12: *Macomona liliana* juveniles (< 5 mm) in the Firth of Thames display multi-year cycles in all sites excluding Te Puru where they are infrequently found (a). *Macomona liliana* > 15 mm displayed a significant reduction in abundance between 2001 and 2004 at Kuranui Bay and Miranda (b). Some indication of recovery is apparent.

Raglan (Whaingaroa) Harbour

Periodic recruitment events in the smaller size classes of *Linucula hartvigiana, Macomona liliana, Austrovenus stuchburyi and Arthritica bifurca* were observed across sites in Raglan (Whaingaroa) Harbour (Figure 13). However, no consistent increasing or decreasing patterns in abundances in any size classes for any of the monitored bivalves were detected over the 10 year monitoring period. Note that an increasing trend in *Macomona liliana* (the total abundance across all size classes) had been detected at Pongonui Creek (Section 3.2) but there were no significant trends detected for the individual size classes (i.e. individuals < 5 mm, individuals 5 – 15 mm, and individuals > 15 mm length).

Irrespective of estuary *Theora lubrica* size classes mimicked each other closely, with sites either displaying no individuals or sporadic recruitment events (Figure 14). Therefore no trends, irrespective of size class, could be detected over the 10 year monitoring period for this species.

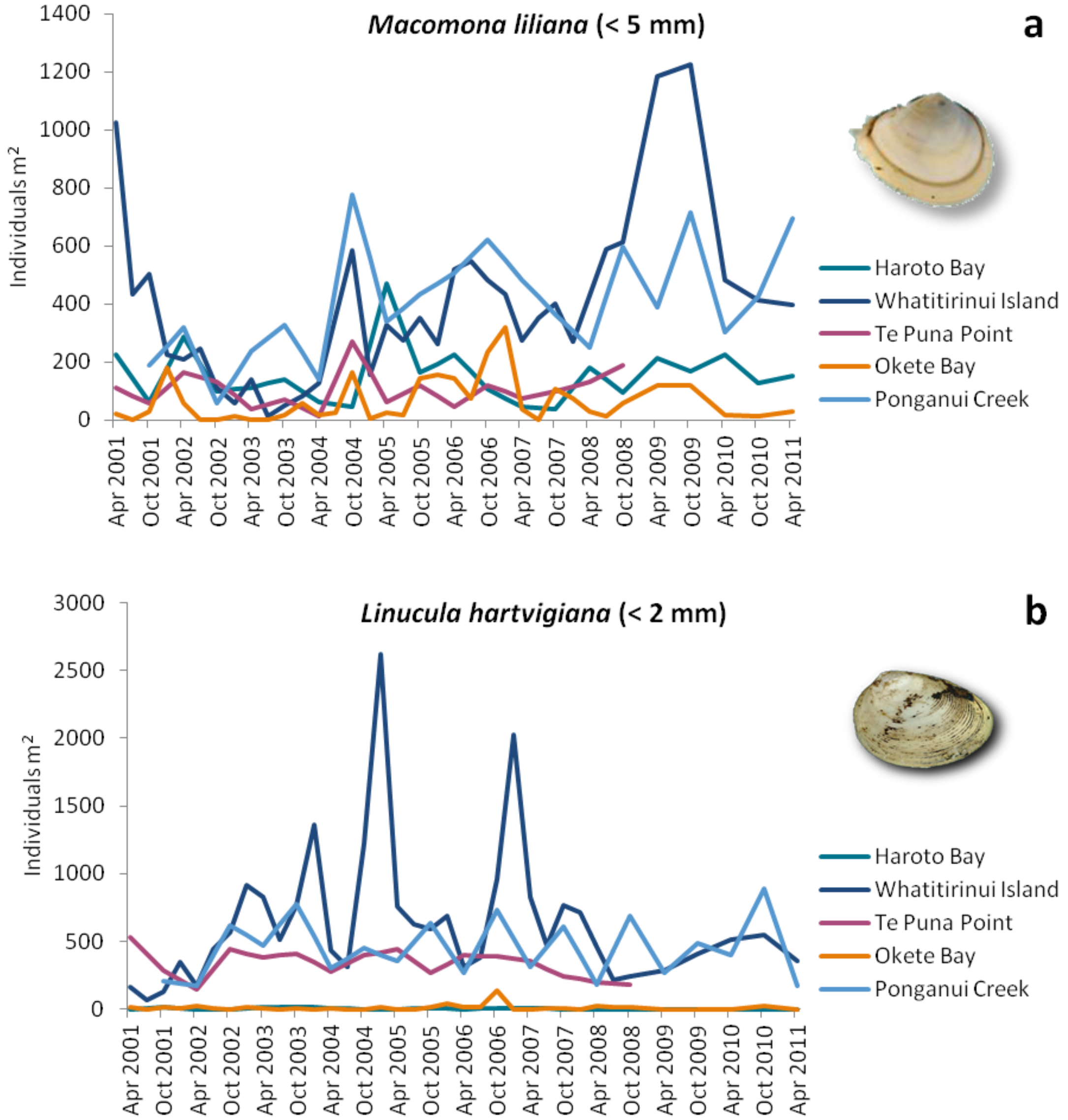


Figure 13: Abundance of *Macomona liliana* juveniles (a), and *Linucula hartvigiana* juveniles at all sites in Raglan (Whaingaroa) Harbour, (b), showing periodic recruitment events.

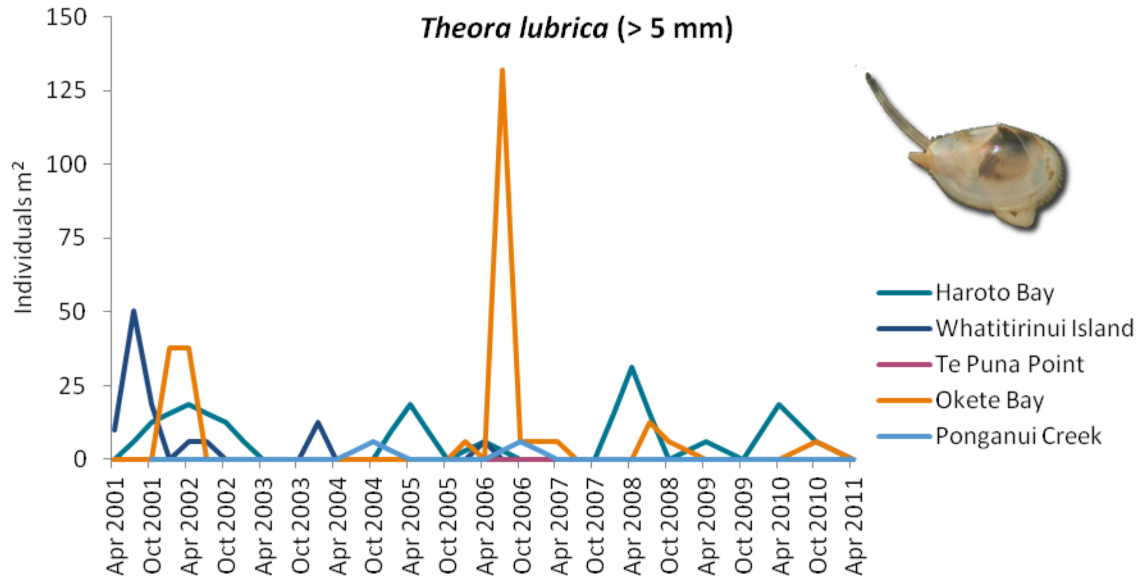


Figure 14: ***Theora lubrica*** **(> 5 mm) at all sites in Raglan (Whaingaroa) Harbour, showing low abundance at some sites (e.g. Ponganui Creek, Te Puna Point) and sporadic peaks in abundance at other sites.**

Key Findings

Trends in the abundance of *Linucula hartvigiana* individuals > 2 mm were observed in three of the five sites in the Firth of Thames. However the direction of change was not consistent between sites. Te Puru showed a negative trend in the larger size classes of two important bivalves, *Paphies australis* (pipi) and *Linucula hartvigiana* (nutshell) despite pulses of recruitment.

In Raglan (Whaingaroa) Harbour periodic recruitment events were observed for *Linucula hartvigiana, Macomona liliana, Austrovenus stuchburyi and Arthritica bifurca*, but consistent increasing or decreasing trends in abundance were not seen for any bivalve size class.

3.4 Trends in sediment characteristics

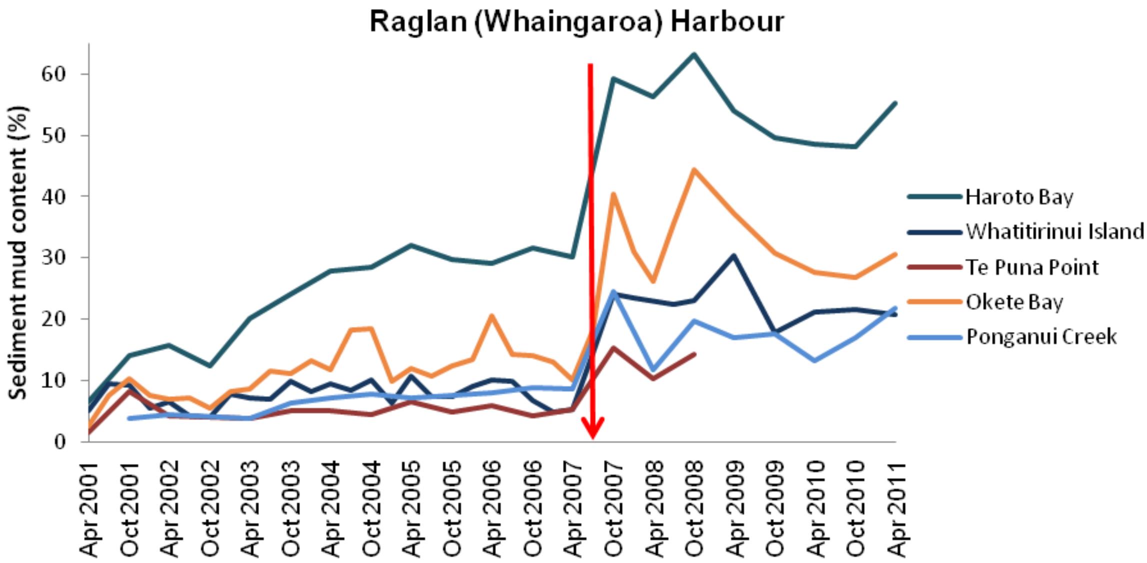
Trend analysis can also help detect changes to sediment characteristics that may have occurred over the 10 year monitoring period. Comparing trends in sediment characteristics to those observed for sediment-dwelling organisms can help explain why organism abundances and community compositions have changed over time. We will go into these comparisons in the discussion section of this report.

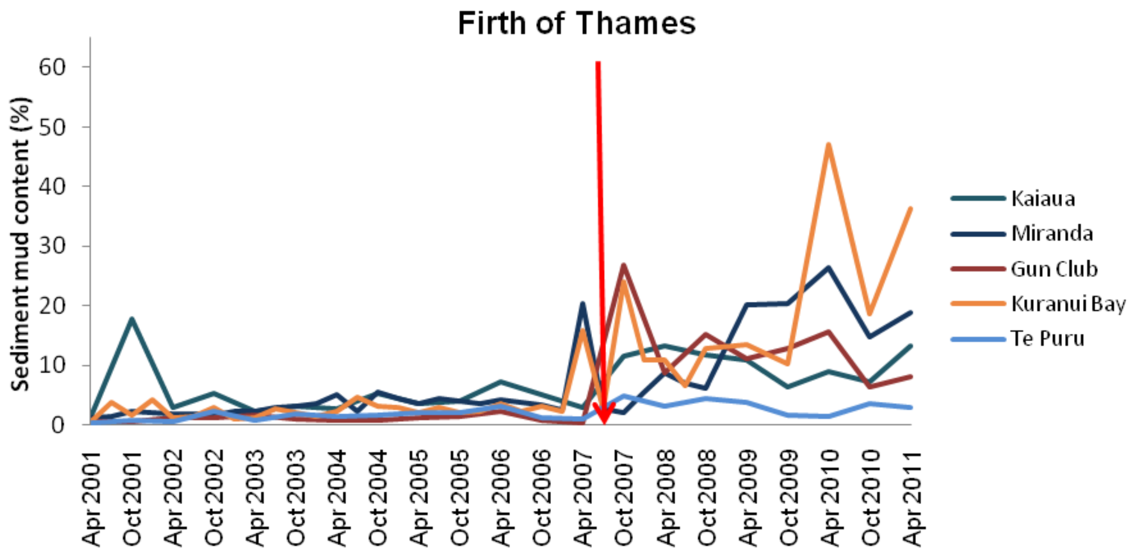
A change in the way in we have measured sediment grain size during the monitoring program has necessitated the use of certain statistical analysis techniques that are detailed in Box 7.

Box 7. Dealing with the changes in sediment analysis techniques

A change in particle size analysis methodology has had a clear effect on the observed pattern of results. The instrument used since 2007 (Malvern Mastersizer) has a lower detection limit (i.e. can detect smaller sediment particles). Therefore the relative proportion of mud (sediment particles <63 μm) is greater compared to that obtained from the instrument used up until 2007 (the Galai laser particle sizer). To account for this systemic change grain size data were analysed in a compartmental way.

The two graphs below show the mud content at each of the sites in the two estuaries. At first glance, it looks like the mud content has increased in nearly all locations since monitoring began. However, this is always not the case. Instead, our statistical analysis showed that the increase in mud content was often due to the change in methodology (indicated with a red arrow).





How does our analysis work?

To tease apart legitimate trends from those caused by our change in methodology, trends in grain sizes were partitioned in to two subsets for statistical analysis. 'Method' was used as a categorical factor (i.e., Galai vs. Malvern analysis) and time was introduced as a continuous variable (days since sampling began). We then tested if there were significant effects of 'days' once the influence of 'method' had been removed (see Appendix 2 for more detail on this statistical analysis).

Firth of Thames

In the Firth of Thames, a significant trend for increasing sediment chlorophyll-*a* content was detected at all five sites indicating an estuary wide shift over time (Table 6, Figure 15a). A statistically significant trend in phaeophytin, a degradation product of chlorophyll-*a*, was also detected at two sites: Kuranui Bay and Miranda (Table 6, Figure 15b). No trends were detected at any sites in the Firth of Thames for nitrogen and only a single declining trend was observed for organic matter content (Te Puru, Table 6, Figure 16) and shell hash (Gun Club, Table 6, Figure 17). Sediment mud content showed positive trends at Miranda and, to a lesser degree, Kuranui Bay (Table 6, Figure 18). Overall, Miranda showed the most change over time with increases in chlorophyll-*a*, phaeophytin and mud content but Kuranui Bay showed almost identical trends.

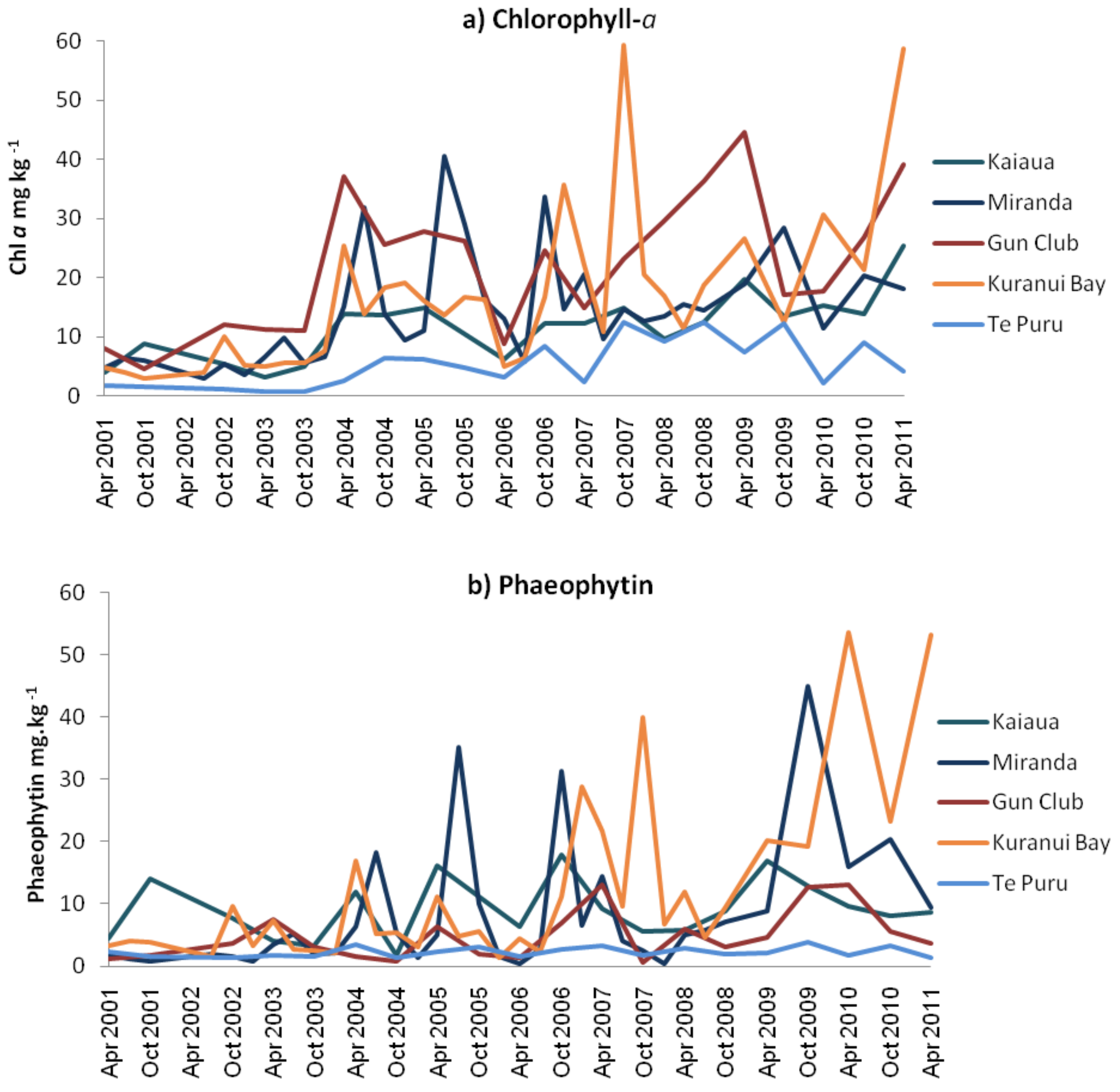


Figure 15: Changes in sediment chlorophyll-*a* concentration (a), and phaeophytin concentration over the 10 year monitoring period in the Firth of Thames (b). A positive trend was detected for chlorophyll-*a* across all monitoring sites, but differed in magnitude between sites.

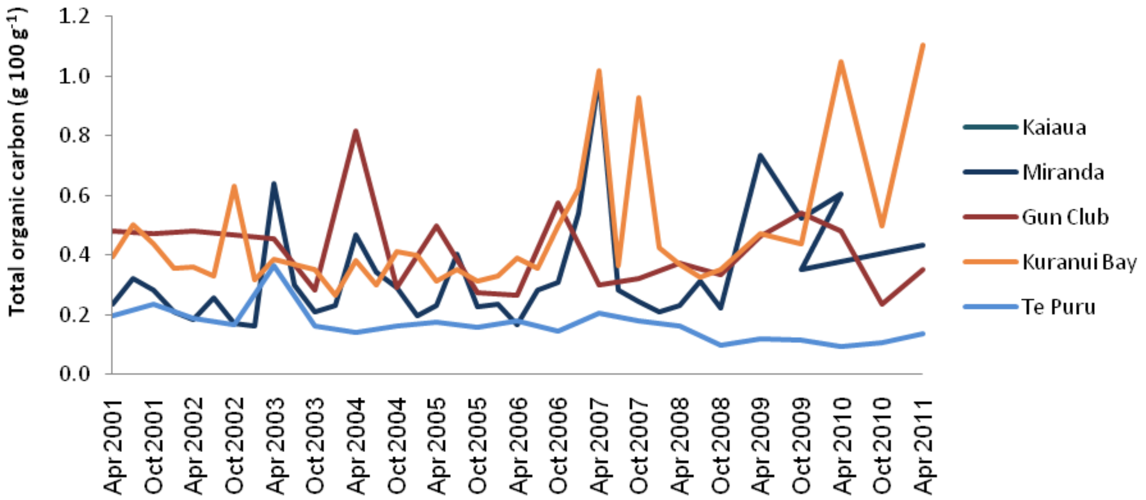


Figure 16: **Changes in sediment total organic carbon content over the 10 year monitoring period in the Firth of Thames. A negative trend was detected at Te Puru.**

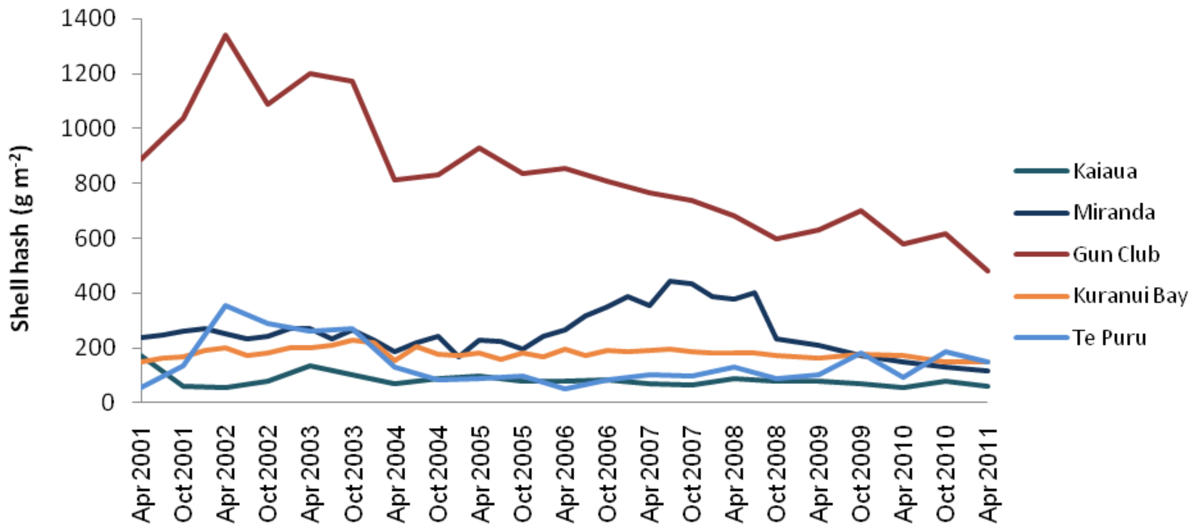


Figure 17: **Changes in shell hash content over the 10 year monitoring period in the Firth of Thames. A negative trend was detected at Gun Club.**

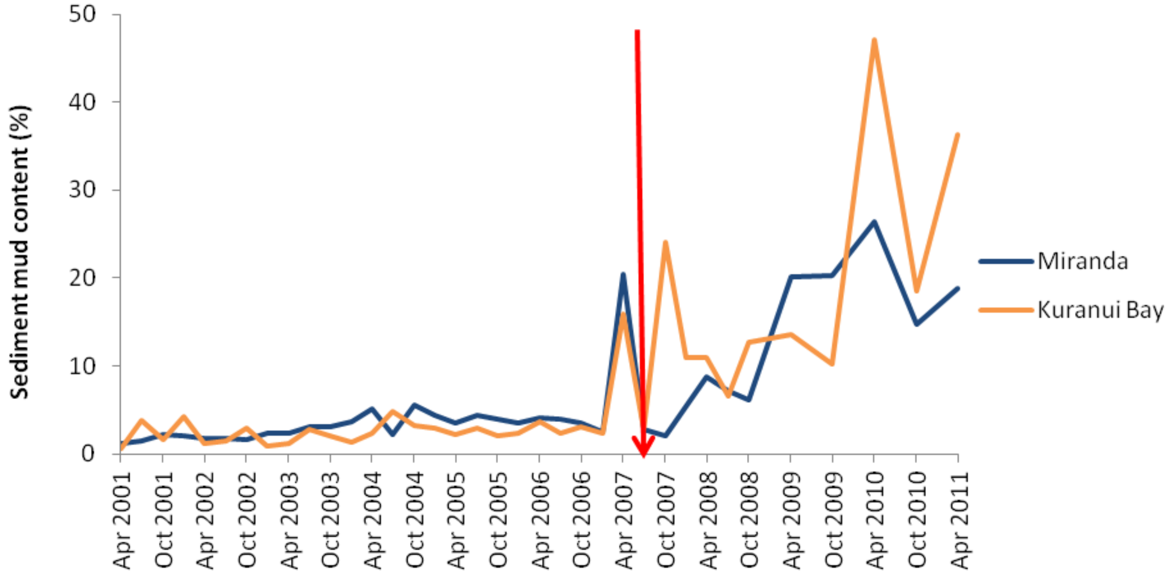


Figure 18: **Changes in sediment mud content at Miranda and Kuranui Bay over the duration of monitoring. The red line denotes the change in analysis technique. Data were split at this point to test the statistical significance of the overall trend.**

Table 6: **Trends in sediment characteristics at each monitoring site of the Firth of Thames. Symbols indicated indicates the direction of the trend (+ = increase, - = decrease).**

Sediment characteristic	Kuranui Bay	Miranda	Kaiaua	Te Puru	Gun Club
Chl-*a*	+	+	+	+	+
Phaeo	+	+			
TOC				-	
Nitrogen					
Shell hash					-
Mud	near +	+			

Raglan (Whaingaroa) Harbour

Only one significant, positive trend in chlorophyll-*a* content was observed in this estuary, occurring in Haroto Bay, where an almost significant increasing trend in phaeophytin concentration was also detected (Table 7, Figure 19). A significant decreasing trend in organic carbon was revealed at Te Puna Point, which was accompanied by a nearly statistically significant negative trend in nitrogen (Figure 20). Statistical analysis indicated a significant increase in mud content at Okete Bay and Haroto Bay over the 10 year period. However, from Figure 21 it is apparent that this was likely driven by changes during the early years of monitoring (2001-2007). Since 2007 mud content does not appear to have increased at these sites.

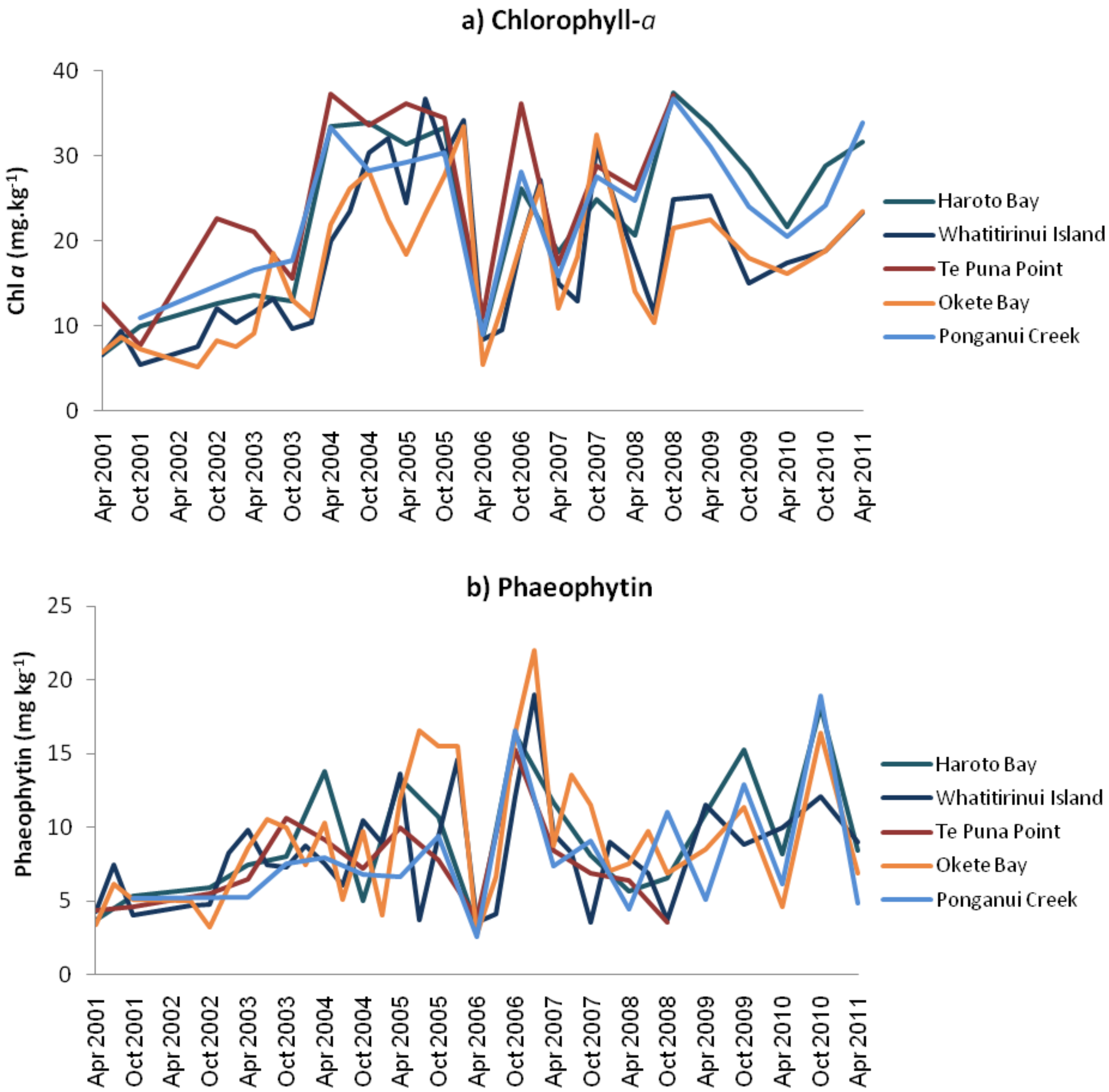


Figure 19: (a) Changes in sediment chlorophyll-*a* concentration and, (b) phaeophytin concentration, over the 10 year monitoring period in Raglan (Whaingaroa) Harbour. A positive trend was detected for chlorophyll-*a* at Haroto Bay.

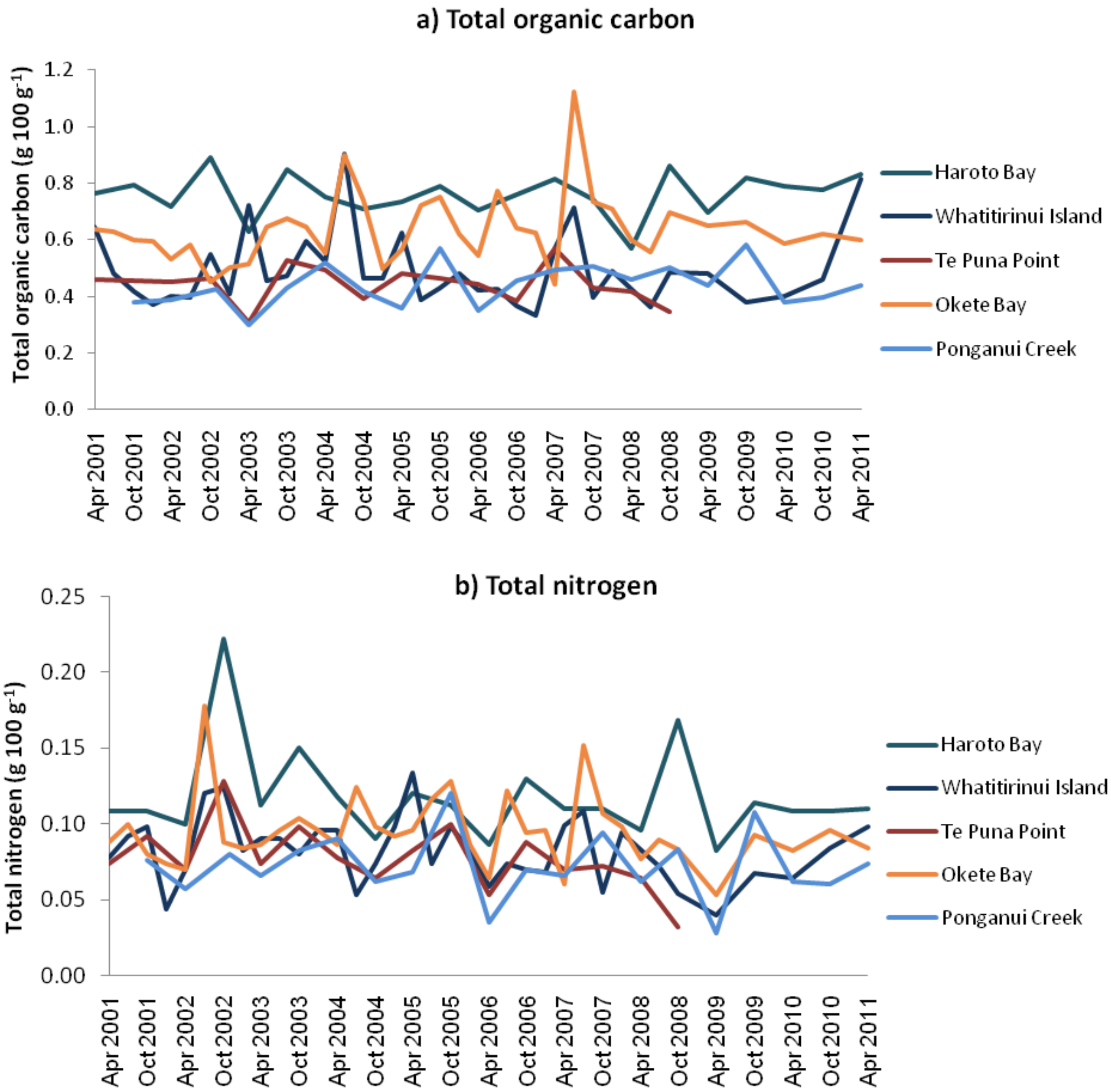


Figure 20: (a) Changes in sediment organic carbon and, (b) total nitrogen content in Raglan (Whaingaroa) Harbour. A negative trend was detected for organic carbon and nitrogen at Te Puna Point.

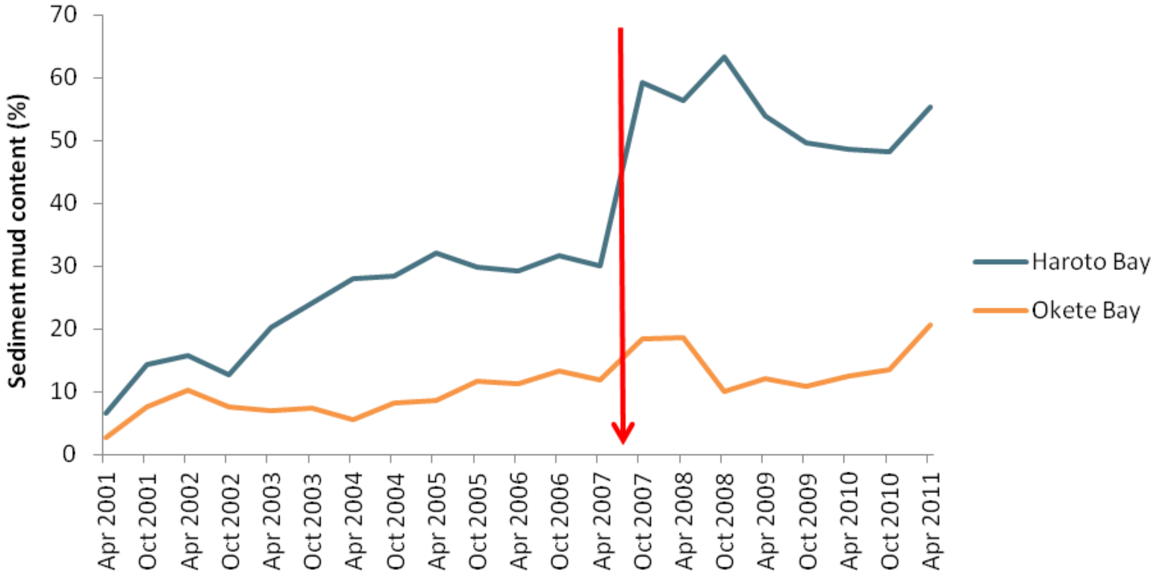


Figure 21: **Changes in sediment mud content at Haroto Bay and Okete Bay over the duration of monitoring. The red line denotes the change in analysis technique. Data were split at this point to test the statistical significance of the overall trend.**

Table 7: **Trends in sediment characteristics in each monitoring site of Raglan (Whaingaroa) Harbour. Symbols indicated indicates the direction of the trend: + = increase, - = decrease.**

Sediment characteristic	Okete Bay	Whatitirinui Island	Haroto Bay	Ponganui Creek	Te Puna Point
Chl-*a*			+		
Phaeo			near +		
TOC					-
Nitrogen					near -
Shell hash	-	-			
Mud	+*		+*		

* Trend is for the period 2001-2007

Key Findings

In the Firth of Thames, an estuary wide increase in sediment chlorophyll-*a* content was observed. Miranda and, to a slightly lesser extent, Kuranui Bay, showed the most change over time with increases in chlorophyll-*a*, phaeophytin and mud.

In Raglan (Whaingaroa) Harbour, no estuary wide trends in sediment characteristics were observed. Haroto Bay experienced an increase in chlorophyll-*a*, shell hash decreased at Okete Bay and Whatitirinui Island, and Te Puna Point showed a reduction in organic carbon and nitrogen. Mud content increased at Okete Bay and Haroto Bay during the period 2001-2007.

3.5 Changes in community composition over time

By observing shifts in indicator taxa community composition we can identify sites in an estuary that are undergoing the greatest change and assess if sites within the estuary are becoming more similar or more different to one another. We can also compare community changes occurring in the Firth of Thames with those occurring in Raglan (Whaingaroa) Harbour. To do these analyses we used multidimensional scaling (MDS) which provides visualisation of a complex dataset as a two dimensional plot (see Box 8 for further explanation), and canonical analysis of principal co-ordinates (CAP) to determine whether the changes were correlated with time. (CAP produces a correlation coefficient that indicates the degree of correlation between two variables).

When considering community composition of all indicator taxa, a clear separation between the two estuaries was revealed (Figure 22). This indicates that each estuary has a discrete community structure, which is expected considering the distance between the estuaries and their location on opposite coasts of the Waikato region. Overall, greater variability over time (average distance between markers for each site) and among sites (distance between markers of different sites) in community composition was observed for the Firth of Thames. In Raglan (Whaingaroa) Harbour the sediment-dwelling organism communities at each site generally changed less over time (small distance between markers of each site) and were more similar to each other (small distance between markers of different sites). When comparing all sites across both estuaries, only a weak correlation between changes in community composition and time was observed (canonical correlation coefficient = 0.65).

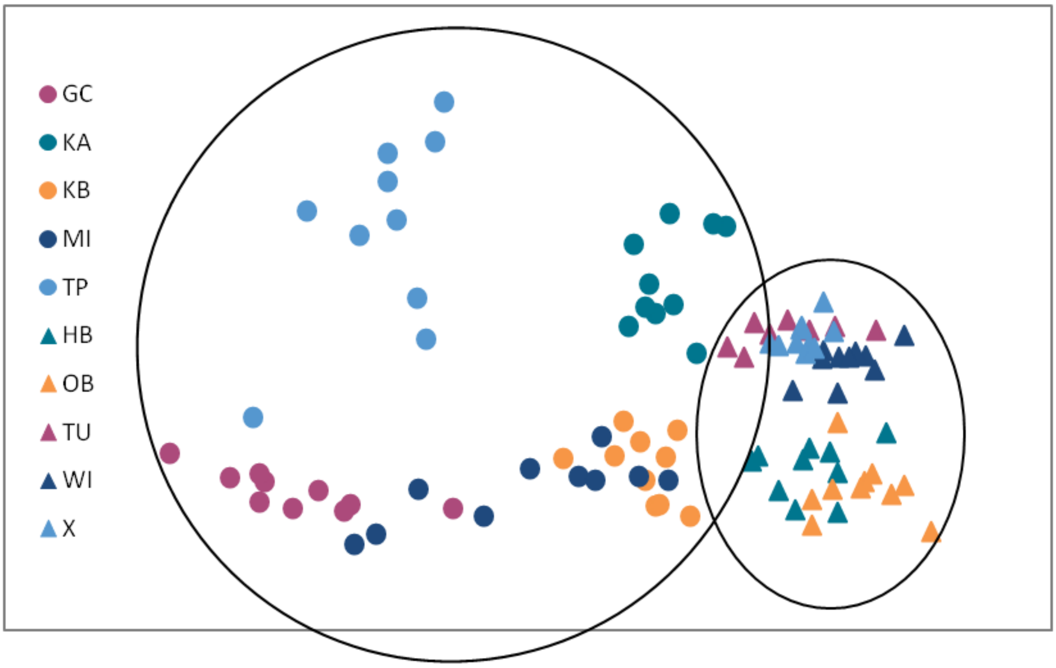


Figure 22: A comparison of the changes in community structure in both the Firth of Thames and Raglan (Whaingaroa) Harbour. Firth of Thames sites are depicted as circles and Raglan (Whaingaroa) Harbour sites are depicted as triangles. The ovals show the two major groupings are that of the two separate estuaries. Stress value = 0.14.

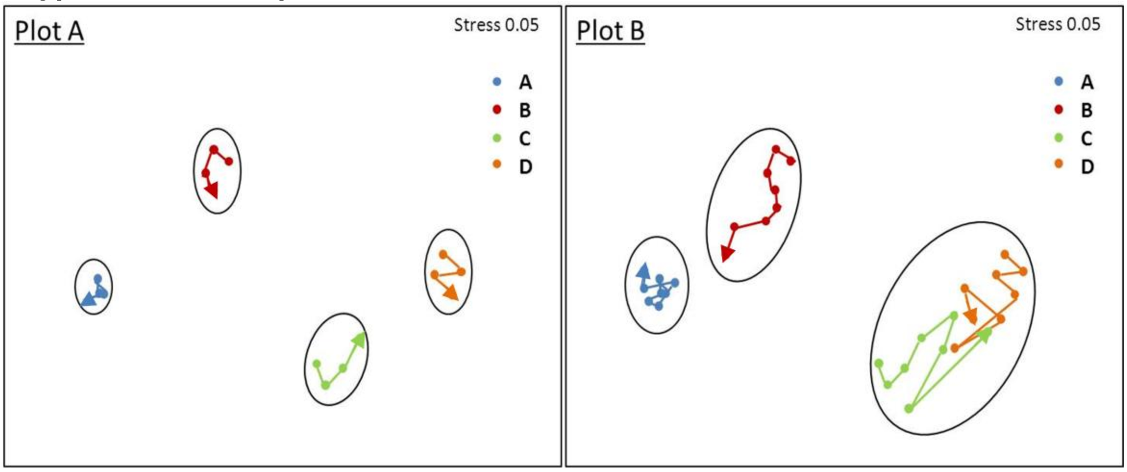
Box 8. Interpreting MDS plots

Multidimensional scaling (MDS) provides a visualisation of a complex dataset, usually in a two-dimensional MDS plot. MDS plots of community compositions show patterns and changes in community structure through time. Each point on the plot represents one sampling event at one site. Sites are colour-coded so that MDS plots can be used to compare community composition between different estuaries or between sites within an estuary.

A line can be drawn between sampling points from the same site, joining them sequentially through time. An arrow drawn at the most recent sampling point indicates the direction of recent change. When two sampling points are positioned close together the sediment-dwelling organism communities observed at these two monitoring events (if they are connected by a line) or monitoring locations (if they are two points on differently coloured lines) are similar, both in the type of species present and their abundance. Where points are more distant the degree of similarity is lower. Thus the length of line between consecutive sampling points indicates the degree of change in community composition at a location between two monitoring events. Lines that are long and well-spaced indicate greater changes in sediment-dwelling community structure through time than those that are close together or are looping back to initial sampling times (see example below).

Technically, MDS plots represent a configuration of many points in a two-dimensional space. However, the best possible configuration in two dimensions may be a very poor, distorted, representation of the data. The reliability of data representation is indicated by a stress value. If data is represented poorly the stress value is high (generally above 0.15). The lower the stress value the better the configuration and the more confidence one can have in the patterns displayed. Stress values below 0.1 are considered excellent.

A hypothetical example



Plot A shows four sites (A, B, C and D) with different community structures that are relatively stable over time. Plot B shows the same sites after more sampling events, and now a shift in community structure is taking place at three sites (B, C and D). Although still discrete, site B is becoming more similar to site A. Sites C and D have become more similar to each other, indicating they now have more species in common. Site C shows the highest natural variability over time, shown by the pronounced zigzag pattern of the green line.

Note: In Figures 23 and 24 of this report, the data points themselves are no longer displayed but you can recognise them as changes in the direction of the line.

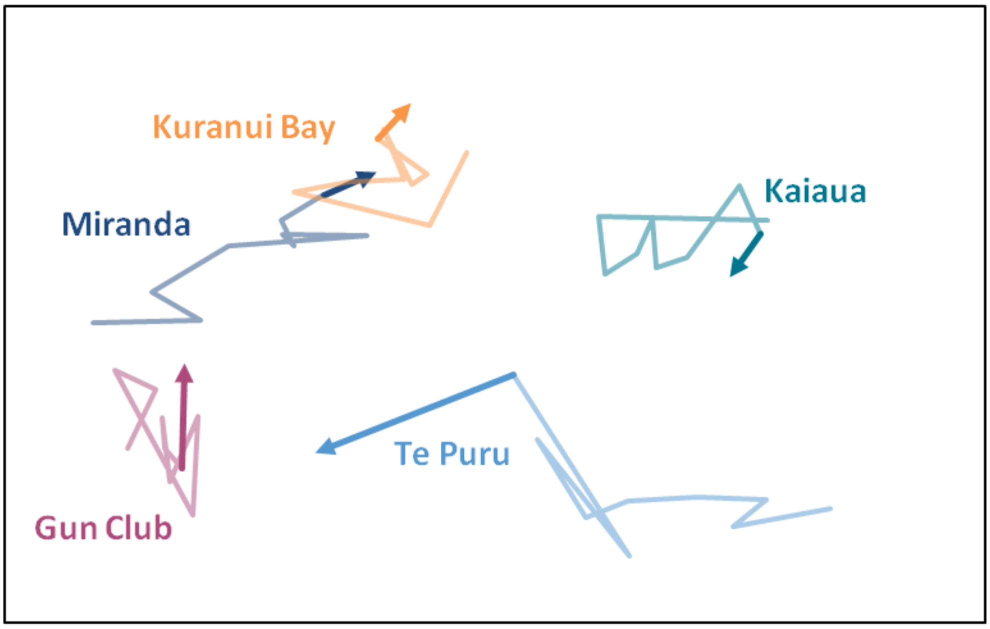


Figure 23: An MDS plot representing the changes in community composition in the Firth of Thames over the 10 year monitoring period. The lines connecting monitoring events from the most recent sampling period are displayed in bold with an arrow indicating the MDS result from most recent sampling date. Stress value = 0.11.

Firth of Thames

The MDS plot of all sampling events at the Firth of Thames monitoring sites during the 10 years of monitoring shows different patterns for the five monitoring sites (Figure 23). At Gun Club, Kuranui Bay and Kaiaua some changes over time are visible; however, the changes indicate mainly within-site variability as the lines criss-cross and do not follow a clear direction. We can therefore conclude that the sediment-dwelling organism communities at these three sites have been relatively stable since the commencement of monitoring in 2001. These three sites are also far apart from each other, indicating different community structures.

In contrast, obvious shifts in community structure over time can be seen at Te Puru and Miranda. Although some variability exits from year to year, the connecting line demonstrates a trend away from the community composition at the beginning of REMP monitoring in 2001. Specifically, the Miranda sediment-dwelling organism community has transitioned from being more similar to the community observed at Gun Club to being more similar to the Kuranui Bay community. The community structure at Te Puru was initially quite different to all other monitoring locations. However, this site is becoming more similar to the more southern monitoring locations, particularly Gun Club. Therefore, despite Te Puru and Miranda both showing a consistent change with time, this is not in the same direction.

It is interesting to note that the level of similarity of communities does not necessarily reflect the geographical proximity of monitoring sites. For example, Gun Club and Kuranui Bay are geographically, the closest monitoring sites but community compositions are very different, and each is more similar to the community composition at Miranda. However, the northernmost monitoring locations at the east and west coast of the Firth of Thames, Te Puru and Kaiaua, are distinctly different from each other and from the communities at the three more southern locations, which is consistent with their geographical location.

Canonical analysis of principal coordinates showed that across all sites in the Firth of Thames community composition was highly correlated with time (canonical correlation coefficient = 0.87), likely driven by the shift in community composition observed at two of the sites (Miranda and Te Puru) over the 10 years of monitoring.

Raglan (Whaingaroa) Harbour

In Raglan (Whaingaroa) Harbour, the MDS analysis revealed that the sediment-dwelling organism communities at Okete Bay and Haroto Bay are distinct from each other as well as from the other three monitoring sites (Figure 24). This is illustrated by their isolated positioning on the MDS plot. At both of these monitoring sites some changes occurred over time. However, these did not follow a consistent direction and indicate natural variability. Okete Bay and Haroto Bay are somewhat geographically separated from the other sites, being located in and just outside of the south-eastern arm of Raglan (Whaingaroa) Harbour. For this reason it is not unexpected that these sites have distinctive sediment-dwelling organism communities.

The sediment-dwelling organism communities at Whatitirinui Island, Ponganui Creek and the discontinued monitoring site Te Puna Point are relatively similar to each other; demonstrated by the close proximity of sampling points on the MDS plot. These monitoring sites are located in the northern and north-western part of the harbour. Very little change over time has occurred at these three sites, with some variability from year to year though not consistently in one direction. This indicates stable communities in all three locations. Overall, a very weak relationship between changes in community composition and time was observed across all sites in Raglan (canonical correlation coefficient = 0.36), which indicates that communities in Raglan have typically been quite stable throughout the 10 years of monitoring.

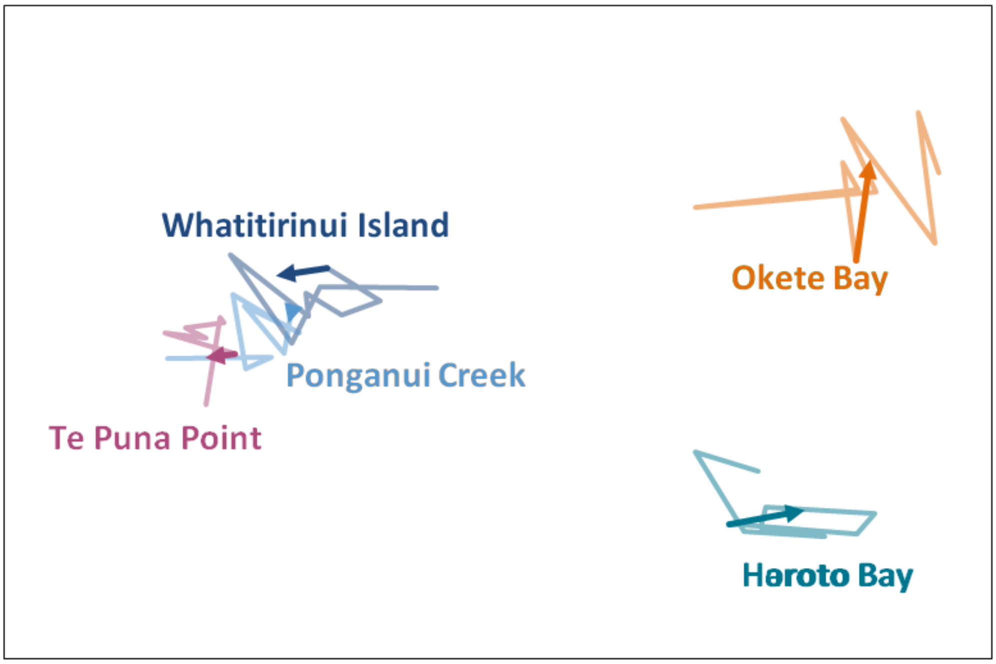


Figure 24: An MDS plot representing the changes in community composition in Raglan (Whaingaroa) Harbour over the 10 year monitoring period. The lines connecting monitoring events from the most recent sampling period are displayed in bold with an arrow indicating the MDS result from most recent sampling date. Stress value = 0.08.

Key Findings

In the Firth of Thames, the sediment-dwelling organism communities at Miranda and Te Puru showed some shifts in community structure through time. The community structure at Te Puru is becoming more similar to that of Gun Club. Sediment-dwelling community structure at Miranda was most like that of Gun Club at the start of monitoring, but over time has become more like that of Kuranui Bay.

Overall there was little change in sediment-dwelling communities over time in Raglan (Whaingaroa) Harbour. Okete Bay and Haroto Bay had distinctively different sediment-dwelling organism community structures compared to each other and the remaining sites. Communities at Whatitirinui Island, Te Puna Point and Ponganui Creek were very similar.

3.6 Relationships between community composition and sediment characteristics

The relationships between sediment-dwelling organism communities and sediment characteristics was analysed using a statistical model (DISTLM) that can help determine to what extent sediment characteristics (the predictors) influence sediment-dwelling organism communities (the response). These models also show which sediment characteristics play the greatest role in structuring the community compositions. We have visualised the model results using distance-based redundancy analysis (dbRDA) plots, which are explained in Box 9.

The data were split into two periods due to differences in the sites monitored and grain size analysis techniques used during the 10 year monitoring period. Therefore there are two dbRDA plots for each estuary: one displaying results for the first three years of monitoring (2001-2003) and one for the last three years in the 10 year monitoring period (2008-2010). Data were grouped into 12 month periods, representing one year of monitoring each. In the dbRDA plots the sites are represented by differently coloured symbols. As each plot displays three years of sampling there are three points for each monitoring site per plot.

Firth of Thames

Overall, sediment characteristics explained 94% of the variance in community composition in the Firth of Thames in the periods 2001-2003 (r^2 =0.94) and 2008-2010 (r^2 = 0.94). The sediment characteristics most strongly related to changes in community composition were the same in both periods, suggesting little change at an estuary wide scale. Shelf hash, total nitrogen, fine sand, mud and coarse sand explained 66% and 73% of the total variability in 2001-2003 and 2008-2010, respectively (Figure 25) .

Raglan (Whaingaroa) Harbour

Sediment characteristics explained 96% of the variance in sediment-dwelling organisms in Raglan (Whaingaroa) Harbour over the first three years of monitoring (2001-2003, r^2 = 0.96) and 97% in the most recent three years (2008-2010, r^2 = 0.97). Mud, chlorophyll-*a*, very fine sand, fine sand and coarse sand collectively accounted for 52% of the total variability in community structure between 2001-2003 (Figure 26a). For 2008-2010, shell hash, fine sand, very fine sand, gravel and chlorophyll-*a* explained 82% of the variability in community structure; shell hash and fine sand had a large effect and these two predictors explained 66% of that variability (Figure 26b). Forcing the inclusion of sediment mud content did not improve the model indicating this was not a key variable in structuring the community at an estuary wide scale.

Key Findings

In the Firth of Thames shell hash was the most important sediment characteristic in structuring communities at an estuary wide scale. Little change was seen over time.

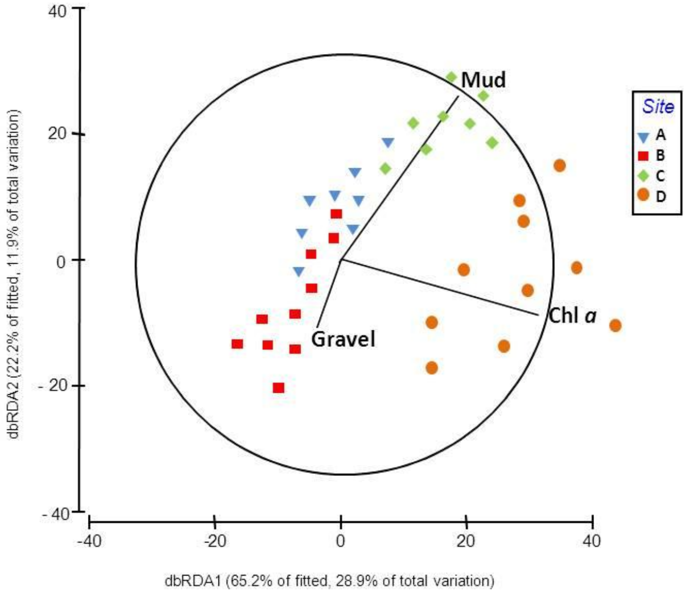
In Raglan (Whaingaroa) Harbour, some changes in the sediment characteristics influencing community structure were seen over time. Between 2001-03 mud, chlorophyll-*a*, very fine sand, fine sand and coarse sand were the most influential characteristics accounting for over half of the variability observed. However between 2008-10 shell hash and fine sand had a greater effect than the previous four characteristics collectively.

Box 9. Interpreting dbRDA plots

Results of the statistical models assessing relationships between community structure and sediment characteristics can be visualised using distance-based redundancy analysis (dbRDA) plots (see example below). The data points represent sediment-dwelling organism communities. The lines (vectors) radiating from the centre of the circle represent the sediment characteristics that have a statistically significant influence (effect) on community structure. The further the vector extends from the centre, the larger the effect of this sediment characteristic on community composition.

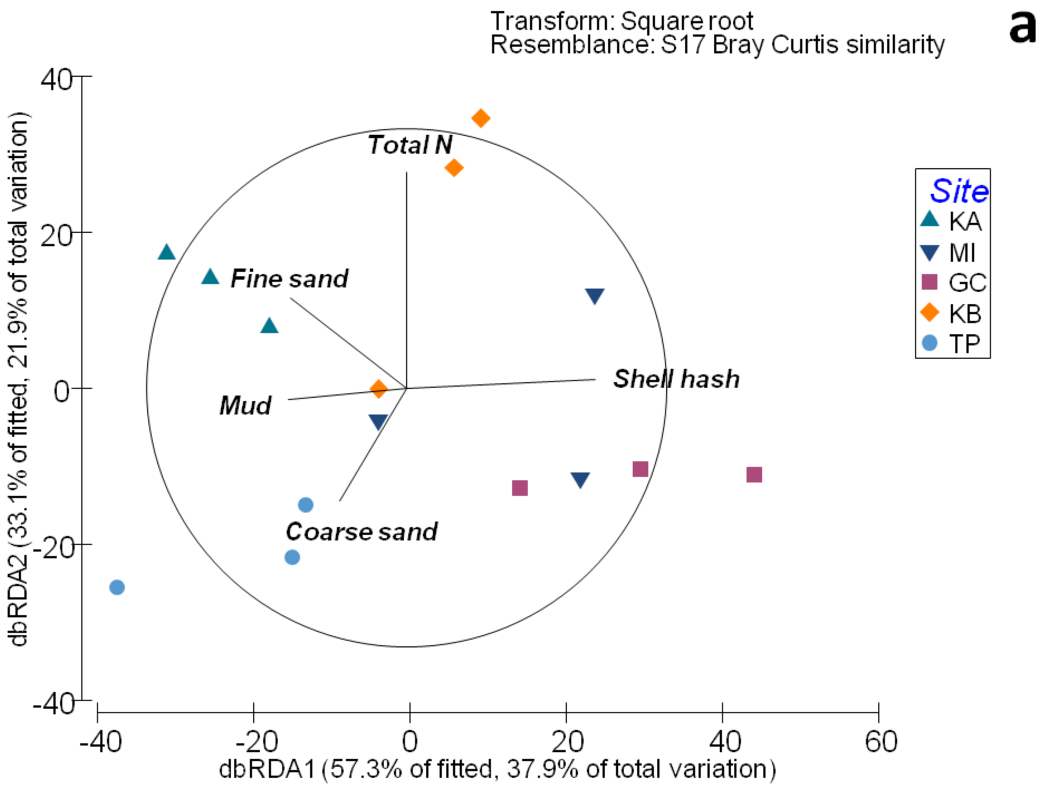
The position of a point reflects which and to what degree the sediment-dwelling organism community is influenced by the sediment characteristics. If a point is located very close to the outer end of a vector, the corresponding sediment characteristic has a strong influence on the community. If a point is located near the centre of the plot it is not much influenced by any sediment characteristic. If it is located between two vectors, it is influenced by the corresponding two sediment characteristics. This is illustrated in the example below.

A hypothetical example



This example shows four sites (A-D). There are three significant sediment characteristics: mud, gravel and chlorophyll-*a*. The community composition at site C is strongly influenced by mud with most data points from this site clustering near the outer end of the mud vector. At site A the influence of mud is less pronounced and some results are close to the centre of the plot, indicating weak influences of sediment characteristics. Site B is generally more influenced by gravel. Gravel and mud are pointing into opposite directions, indicating that communities typically favour one or the other. The mud vector is longer than the gravel vector, indicating that overall, mud has a greater influence on the community structure in the estuary.

Mud and gravel also affect site D (indicated by the spread of orange points parallel to the mud/gravel gradients); however, this site is primarily separated from all other sites by a greater influence of chlorophyll-*a* on the community. Higher within site variability is denoted by the larger spaces between points for site D. The number of points scattered between the distal ends of the mud and chlorophyll-*a* vectors indicate that these two characteristics are correlated. The relative position of points to each other indicates their similarity (as on the MDS plot).



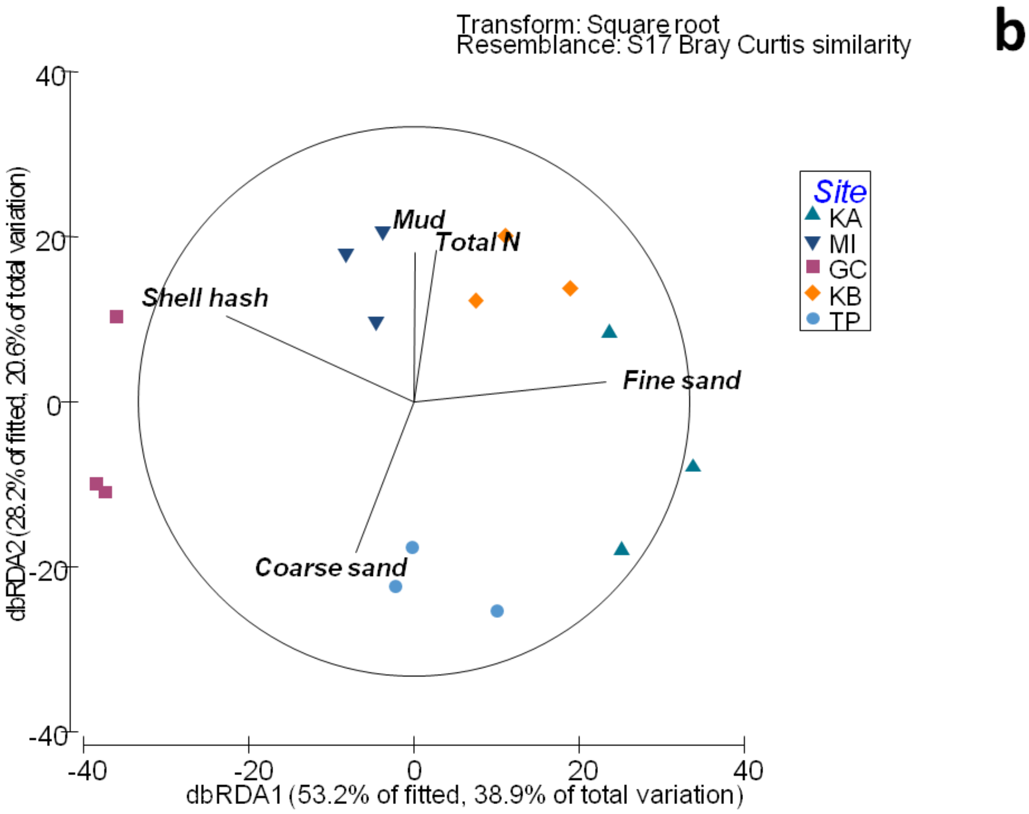


Figure 25: dbRDA plots of the key sediment characteristics influencing community structure in The Firth of Thames from 2001-2003 (a). dbRDA plots of the key sediment characteristics influencing community structure in The Firth of Thames from 2008-2010 (b).

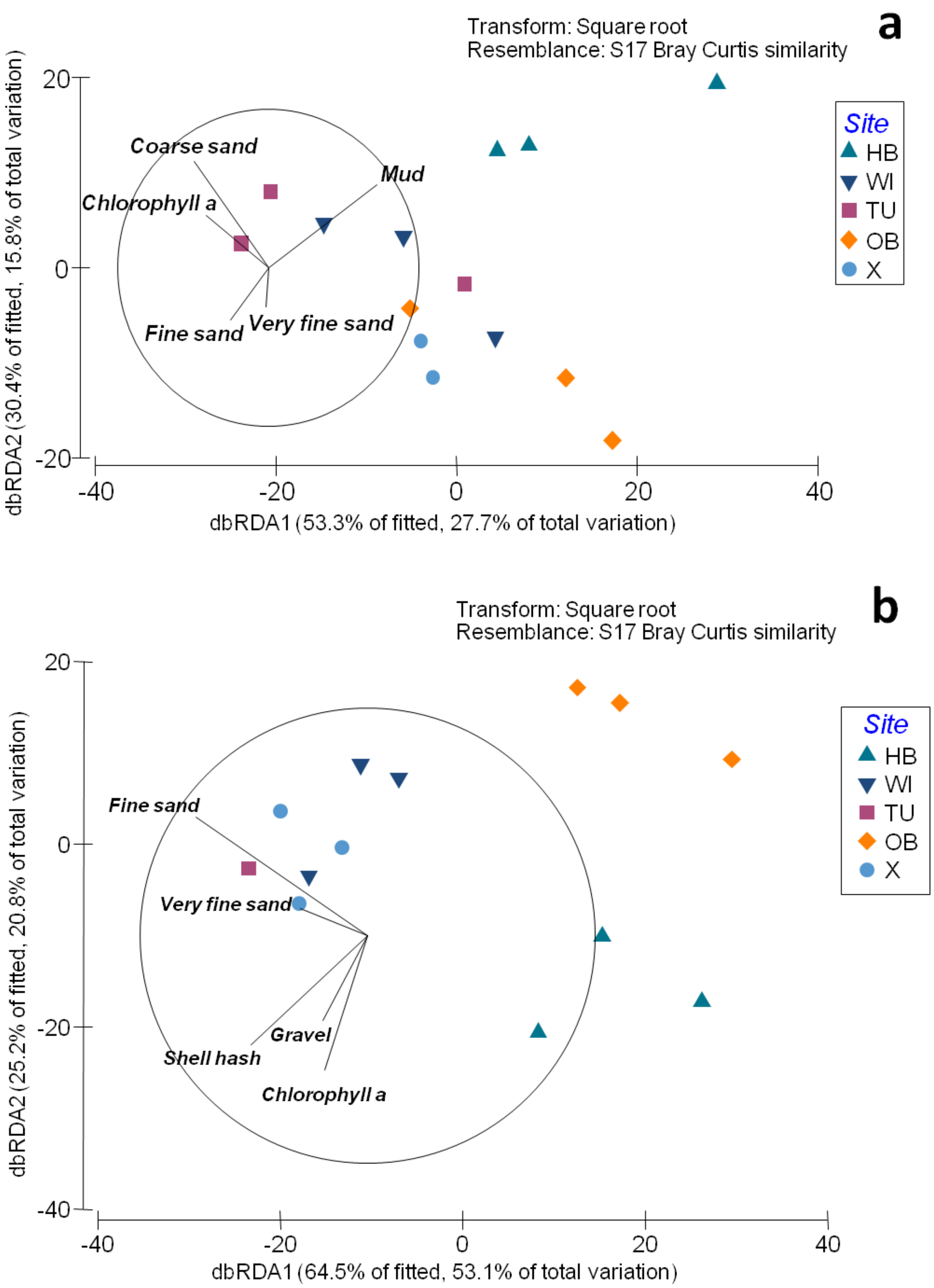


Figure 26: dbRDA plots of the key sediment characteristics influencing community structure in Raglan (Whaingaroa) Harbour from 2001-2003 (a). dbRDA plots of the key sediment characteristics influencing community structure in Raglan (Whaingaroa) Harbour from 2008-2010 (b).

4 Discussion

4.1 REMP: April 2001 to April 2011

The REMP was designed to determine the current status and monitor the temporal changes in the state of selected estuaries in the region. During the first 10 years of the monitoring programme, five sites in the southern Firth of Thames and five sites in Raglan (Whaingaroa) Harbour were sampled two to four times per year. Sediment-dwelling organisms and a range of sediment characteristics have been measured and the results of these 10 year datasets presented in Section 3 of this report. By using a range of statistical methodologies to analyse the datasets we have been able to tease apart patterns in the data related to natural variability (e.g. recruitment events, seasonal change) from those potentially caused by a changing environment. The latter patterns are of particular interest for resource managers as they can reflect the impact of land-use change in the catchment or other anthropogenic impacts on intertidal sand- and mud-flats in estuaries.

At an estuary wide scale, both the Firth of Thames and Raglan (Whaingaroa) Harbour have shown little evidence of any ecologically significant changes to either their sediment characteristics or the indicator taxa over the past 10 years of monitoring. This indicates that, overall, the health of these estuaries has not changed significantly in recent years. However, within each estuary there are site-specific trends occurring aside from seasonal and cyclical events which merit further discussion.

Although appropriate statistical analyses have been used to test for changes in grain size over time, step trends associated with both actual shifts in grain size composition and the flow on effect from changes in analysis technique have made it inappropriate to compare differences in the average sediment mud content (or any other grain size category) before and after 2007. To do so would likely give a false impression of increased muddiness of these estuaries. Therefore our discussion focuses on the trends over time rather than percentage shifts in grain size categories as previously reported in Felsing and Singleton (2008). Similarly, comparisons of broad sediment classifications based on the median grain size (e.g., sand, muddy-sand, mud) before and after 2007 have been avoided.

It is also important to highlight that linking patterns in the benthic macrofaunal assemblages to changes in sediment characteristics only provides an indication of which sediment characteristics are likely to play a role in the shifts in community structure. Causality can only be demonstrated through well designed field or laboratory experiments (Clarke and Warwick, 2001), which is beyond the scope of the REMP.

Firth of Thames
Overall, changes in community composition were strongly associated with time in the Firth of Thames. This was primarily driven by two sites: Miranda and Te Puru, where community structure (of indicator taxa) transitioned away from their initial composition over time. However, these shifts have not occurred similarly in each of the two sites, indicating that the drivers of change are not necessarily the same at these two sites. Miranda and Te Puru showed eight of the nine trends in indicator taxa abundances seen in the Firth of Thames, once seasonal and multi-year cycles had been removed, but differed in the species affected in all but one case; the Capitellidae.

In recent years, shell hash was highlighted as one of the most influential sediment characteristics on community structure in the Firth of Thames; a continuation of the pattern detected in the five year trend report (Felsing and Singleton, 2008). Combined with coarse sand, the presence of shell hash aids in explaining why Gun Club and Miranda's community structures appear distinct from the three other Firth of Thames monitoring sites. Gun Club has consistently had greater shell hash content than any other monitoring site in this estuary and although a significant negative trend in shell hash was observed in Gun Club over the 10 year period, there is currently no evidence of an associated response in indicator taxa abundance to this change. The Gun Club monitoring site is close to the mouth of the Waihou River. This river is the largest in the Southern Firth of Thames and sediment-dwelling organisms that live there are likely subject to associated factors such as periodic increases in turbidity, freshwater input and flow rates. Hence this community are likely to be well adapted to fluctuating environmental conditions.

Miranda showed the greatest number of temporal trends in taxa abundance and sediment characteristics in the Firth of Thames once seasonal and cyclical events had been factored out. Four of the five taxa responded as would be expected given an increase in sediment mud content and indeed, a positive trend with mud was observed with a concurrent decrease in coarse sand. These trends were also detected after the first five years of monitoring, showing a gradual but consistent change over time for these sediment characteristics (Felsing and Singleton, 2008). However decreasing trends in shell hash, indicated in the five year trend report, were no longer detected after a further five years of sampling. Furthermore, the trend in medium sand has reversed direction, displaying an increase of this particle size after the effects of changes in analysis techniques were factored out. Increases in fine particles can influence not only the benthic community structure and species abundances but can also affect other sediment characteristics. For instance, sediment chlorophyll-*a* reflects the amount of benthic microalgae (key in the role of benthic primary production and a food source for many species) present in the system, which is positively influenced by the presence of fine, muddy sediments. However, the increase in sediment chlorophyll-*a* seen in Miranda was also observed at an estuary-wide scale, making this observed change more likely to be linked to climatic or system level factors.

Miranda is a particularly interesting and dynamic system due to the presence of an active Chenier plain (Figure 27). These globally important shell and sand banks are formed as sand and cockle bars which are pushed landwards by wave action. Successions of 13 shell ridges are recognised at Miranda. This constant sculpting and shaping of the coast is likely to influence sediment characteristics and recruitment, and consequently sediment-dwelling organism community structure. Therefore although trends and responses in indicator taxa appear most acute at this site, the source of these changes may be of less cause for concern than data initially suggests. i.e. these changes may be driven by natural variation of sediment structure at this site as opposed to a reduction in ecological health *per se*. Continuation of monitoring is important at this ecologically important location.

Kuranui Bay showed an increase in mud content over the 10 year monitoring period which was almost statistically significant. However, despite this, no temporal trends for indicator taxa were observed once seasonal and multi-year cycles had been eliminated. Responses to an increase in mud content may be gradual; therefore continuation of monitoring is important for this location. Kuranui Bay suffered losses of larger sized *Macomona liliana* (> 15 mm) between 2001 and 2004. This species is relatively intolerant to increased mud content, with an optimum range of between 0 and 30% mud content. However, as some recovery in density of larger sized *Macomona liliana* has been observed post 2004, factors other than sediment mud content are likely to have contributed to this reduction.

Te Puru has consistently been one of the least muddy, sand-dominated sites of the five REMP monitoring locations in the Firth of Thames. The five year report observed increasing trends in sediment chlorophyll-*a*, fine sand and mud content alongside concurrent decreases in coarse sand and organic carbon levels (Felsing and Singleton, 2008). After a further five years of data collection, the relationships with chlorophyll-*a* and total organic carbon still apply. Declines in *Linucula hartvigiana* and *Austrovenus stuchburyi* were detected after five years of monitoring with increases in pseudopolydorid and capitellid polychaetes. Several of these trends have now proven to be multi-year, seasonally dependent or highly variable. However, patterns in

Linucula hartvigiana and Capitellidae remained after a further five years of monitoring. Capitellidae often respond positively to increased organic content, but the significant negative trend in organic carbon after 10 years of monitoring indicates this was not the driver of this trend. The perceived decline in *Linucula hartvigiana* was caused by an initial high abundance of juveniles (April 2001); a period of recruitment that has not been repeated in this location. A recruitment phase of *Paphies australis* was observed between April 2004 and October 2005, and to a lesser degree between July 2006 and July 2007; however larger specimens have been declining, which has resulted in an overall negative trend in abundance. It is not evident from measured sediment characteristics what may be driving this decline as despite a negative trend in total organic carbon, the increase in chlorophyll-*a* concentration indicates that overall nutrient supply and food resources are unlikely to be a limiting factor. As pipi (*Paphies australis*) are often collected as a food source, it is possible that overharvesting may be affecting adult numbers. Alternatively, adult *Paphies australis* are known to migrate to sub-tidal environments, and therefore the observed reduction may merely indicate that those larger organisms are migrating further down shore. Both *Paphies australis* and *Linucula hartvigiana* display a negative response to metal pollution (zinc and copper respectively), which may justify an exploration in to potential contaminants at this location. Many other metal sensitive indicator taxa (particularly some of the polychaete worms) are found too infrequently at this site to assist in this assessment, although analysis of full community structure (indicator and non-indicator species) may prove useful. Despite a reduction in adult shellfish at this site, a simultaneous increase in shell hash was not observed.

Figure 27: Chenier plain development and movement at Miranda from 2003 (a), 2007 (b), 2008 (c) and 2010 (d). Images courtesy of Google Earth.

Raglan (Whaingaroa) Harbour

Unlike the Firth of Thames, no single site in Raglan displayed any obvious transitions in sediment-dwelling organism community composition, resulting in an overall weak correlation between changes in community composition with time across the estuary.

Mud content was one of the significant predictor variables of community composition in the first three years of monitoring. However in the five year trend report, shell hash was considered the single sediment characteristic that best explained estuary wide differences in community structure (Felsing and Singleton, 2008). Shell hash (along with fine sand) was still one of the most influential sediment characteristics at an estuary wide scale after a further five years. Okete Bay has had comparatively low shell hash sediments since monitoring began and that is likely linked to its distinct community structure. Haroto Bay has also been subject to some decreases in shell hash (though not significantly so), but is also separated from other sites' community composition due to its lower fine sand content, when compared to other monitoring sites in this estuary.

Haroto Bay has consistently had a greater proportion of mud than other sites in Raglan (Whaingaroa) Harbour throughout the monitoring period, likely due to its sheltered location in the upper section of the south-eastern arm of the harbour. Haroto Bay has also showed the greatest change in sediment traits over time. A reduction in medium and coarse sand with concurrent increases in mud was observed. Sediment pigment content also showed positive trends with time, a factor often linked to increased fine sediment fractions. Despite the increasing 'muddiness' of this site, no temporal trends in indicator taxa were observed. Similar to Gun Club in the Firth of Thames, this site is likely influenced by riverine input, in this case the Waitetuna River, which enters Raglan (Whaingaroa) Harbour close to Haroto Bay. The sediment-dwelling organism community at this site may therefore be well adjusted to periodic changes in environmental conditions, and thus may not be highly sensitive to increased muddiness.

Haroto Bay has always had the lowest abundance of indicator taxa of the Raglan sites. As many of the indicator taxa have never been present at this site or are absent greater than 75% of the time, it is not possible to detect trends over time or gain insight in to whether this absence is due to increasing unsuitability of sediments or is constrained by other factors such as low recruitment. Those species that do show seasonal or multi-year cycles generally appear to be those species with a high tolerance to mud. For example, Nereididae have a preference for mud concentrations between 10-40% but can tolerate up to 100%, *Austrovenus stutchburyi* has a preferential range of 0-10% but can tolerate 85%, *Macomona liliana* have a preferential range of 0-30% but can tolerate 95% mud content. Sediment analysis issues aside, Haroto Bay has been measured as having 63% mud content at its highest point (October 2009), which is well within the limits of these organisms. Any future changes in the cyclical or multi-year patterns observed, or the increasing presence of mud tolerant organisms would be cause for concern, however.

Also situated in the south eastern arm of Raglan (Whaingaroa) Harbour is Okete Bay, where the greatest number of changes in organism abundances was detected over the decade of monitoring. After the first five years, increasing trends in *Prionospio aucklandica* and Capitellidae were observed (Felsing and Singleton, 2008). After a further five years of monitoring these increasing trends are still present. *Aricidea* sp. and Nereididae also show increasing trends at this site. All of these polychaete species are highly mud tolerant with their optimum ranges being between 20 and 100%. Therefore their increasing presence at this site is likely to be directly linked to the observed increase in sediment mud content detected for this site using trend analysis. *Cossura cosimilis* displayed a negative trend in abundance at this site, possibly due to sediment mud content exceeding its optimum range, despite being well within the known tolerance (0-65%). Decreasing shell hash in Okete Bay may also be influencing the structure and functioning of the macrofaunal community as it is known to provide a biogenic habitat structure favoured by certain organisms. Future analysis of full community structure data may help to resolve these trends.

After five years monitoring at Whatitirinui Island it was reported that there were increases in fine sand and mud content with concurrent reductions in coarse sand

(Felsing and Singleton, 2008). Five years on from this, some of these changes are no longer statistically significant. Only a decrease in shell hash was detected over time. However, trends in indicator taxa abundance and the increase in *Prionospio aucklandica* and *Aricidea* sp. indicate that changes in sediment composition may be occurring to some degree. Further monitoring should enable detection of further shifts in both sediment characteristics and community structure to be assessed.

Te Puna Point is located in the same embayment of the estuary as Whatititrinui Island, but has consistently had the lowest sediment mud content in all of the Raglan (Whaingaroa) Harbour sites. None of the trends associated with either the measured sediment characteristics or indicator taxa were present at both sites, indicating that any observed changes were spatially limited. This was the only location in Raglan (Whaingaroa) Harbour where decreases in total organic carbon and to some degree, nitrogen content were observed. Reduction in food sources may therefore account for the decline in *Arthritica bifurca* and *Anthopleura aureoradiata;* two species that have opposing mud tolerances. Monitoring at Te Puru was discontinued at the end of 2008 to free up resources.

Comparison between estuaries
In both the Firth of Thames and Raglan four of the 10 sampling sites showed a positive trend in Capitellidae abundance over time. This similarity among sites indicates a likely response to climatic signals. Previous studies (Hewitt and Hailes, 2007) have shown strong relationships between macrofaunal abundances and the strong El Niño Southern Oscillation (ENSO) event that began in New Zealand in 2003. This event is now slackening, and therefore response to this climatic factor would be confirmed by reversals or declines in Capitellidae abundance in future monitoring data. However, differing species within the Capitellidae complex respond differently to disturbance, organic enrichment, contamination (increased *Capitella capitata*) and sediment mud content (increased *Heteromastus filiformis*). Therefore greater taxonomic resolution is required to more accurately interpret this observed response. A consistent positive trend in sediment chlorophyll-*a* content was also evident at all of the Firth of Thames sites, indicating an estuary wide increase in the intertidal microphytobenthic population. This increase may also be in response to climatic signals, however the localised nature of this shift (with only one site in Raglan (Whaingaroa) Harbour showing a similar trend), may indicate a response to other local factors. Further monitoring is important in revealing if this is a natural phenomenon or potentially an anthropogenically-induced change.

4.2 Future perspectives and initiatives

In 2011, WRC commissioned NIWA to conduct a critical assessment of the Regional Estuary Monitoring Programme in order to establish the cost-effectiveness of sampling procedures, and the suitability of indicator taxa and measured sediment characteristics (Compton et al., 2011). This was with the vision that if after 10 years of monitoring the baseline dataset was robust enough to reduce sampling frequency, the diversion of funds would enable monitoring in other estuaries, widening the scope of the study across the region.

A reduction from quarterly to six-monthly sampling at all sites has already begun as although more patterns were detected in those areas that were monitored quarterly, patterns were still detectable in sites sampled every six months. Pragmatically this approach is relatively robust and cost effective, but by further reducing the number of sites monitored in each estuary, the ability to detect the spatial extent of any change will reduce. However, as there are no large changes in community composition currently being detected Compton et al. (2011) suggested a spatially and temporarily nested approach could be implemented whereby two sites are monitored in each estuary for a period of five years then all are monitored for the next two. This has proven an effective and robust method for the Auckland Council in the Manukau estuary (Hewitt and Thrush 2007).

Since 2007, the taxonomic resolution of non-monitored taxa identifications was increased, with full identifications being conducted on an annual basis (October). This aligns with Auckland Council's estuary monitoring program, which would aid our collective ability to develop a clearer picture of the health of estuaries across the Hauraki Gulf Marine Park. Furthermore, collecting comprehensive community composition data at a high taxonomic level will strengthen the REMP dataset by providing a wider understanding of shifts in community structure over time in the future. Indicator species have typically been used to monitor specific stressors, with the primary focus having been sediment mud content. Therefore integrating information on the wider species pool will enable a greater understanding of how susceptible the communities are to changes in environmental conditions. Such information will also aid in predicting where shifts in ecosystem function may occur.

Figure 28: Aerial image of the intertidal area of Tairua Harbour (WRAPS, 2007)

4.2.1 Development of new REMP sites

REMP has recently been expanded to include an east coast estuary. Tairua Harbour (Figure 28) was selected as it is recognised as an Area of Significant Conservation Value in the Waikato Regional Coastal Plan (2005).The estuary is also a significant site to Hauraki iwi, and is known to support important ecological communities and shellfish beds. Furthermore, Tairua Harbour provides habitat for rare and threatened wading and coastal bird species, and important whitebait spawning habitat (Felsing and Giles 2011). This estuary covers 605 ha, has a catchment area of 28,044 ha, and the intertidal area supports large areas of vegetation including mangroves, seagrass, and saltmarsh (Graeme, 2008).

A preliminary survey of eight sites in Tairua Harbour was conducted in 2012 and all taxa were identified to the lowest taxonomic level. Monitoring has been conducted at five sites, at quarterly intervals, from August 2013, with results to be reported on in the future.

4.2.2 Trait based indices

An ongoing collaboration between NIWA and Auckland Council was set up to find and develop easily understandable and scientifically defensible indicators of the ecological integrity of estuarine and coastal areas. Through this partnership, the NIWACOOBII index was developed based on the functional traits of sediment-dwelling benthic macrofauna (van Houte-Howes and Lohrer 2010). After successful trials of this trait based index (hereafter referred to as TBI) on Auckland Council's State of the Environment reporting (Lohrer and Rodil, 2011), WRC gained advice on the suitability of the TBI for application to the REMP data set. The first steps towards integrating this approach in to future regional estuarine monitoring, through a series of trials based on existing data, are detailed below.

Box 10. Trait based indices - key terms

Species richness
This term refers to the actual number of differing species present within an ecological community. It does not take in to account the abundance of the species. This is different to species diversity, which accounts for both species richness and the relative abundance of species within a community.

Biological traits
Biological traits are the characteristics, both physical and behavioural, used to define a species, e.g., body size, mobility, physical structure (hard or soft bodies) and habitat (within sediment, in the water column etc.). Traits such as these enable species to be defined in terms of their ecological role, i.e., how they interact with their habitat and surrounding species.

Functional or trait groups
Functional or trait groups are a way of categorising several organisms with similar biological traits. These groups can be broad to encompass many species or nested to be more specific. For example, first we may classify our sediment-dwelling organisms by mobility. Secondly we may be interested in grouping by body size and then furthermore by feeding behaviour. As this information becomes more honed, so too does the number of organisms that fit within each group.

Although often used interchangeably, a trait group refers to groupings based on common physical or behavioural characteristics whereas the term functional group is often used when referring to how trait groups influence their environment and subsequent functioning of the ecosystem.

How does the TBI work?
The TBI is based on the species richness of the macrofaunal taxa community after categorising taxa by seven individual biological trait groups covering a broad cross-section of macrofaunal functional types (van Houte-Howes and Lohrer et al., 2010). Box 10 provides a glossary for some key terms, i.e. species richness, biological traits and functional types. For each taxa, one functional group is selected from within the seven broader trait categories. These categories, which have 32 individual trait groups among them, were assigned to taxa using expert in-house knowledge (NIWA) and the best available information from published literature.

The functional groups used to categorise taxa were based on attributes such as feeding behaviour, position in the sediment column, degree of mobility, type of topographic feature created (pits, tubes, mounds), body size, body shape and other such factors. Therefore the proportion that one taxa contributes to the TBI is dependent on how many trait groups it contributes to. The index value is calculated based on the taxonomic richness in each of the seven trait groups and standardised to fall within the range of zero to one (with values near zero indicating highly degraded sites, and values near one indicating more pristine environments). Detailed explanations of how the indicator is calculated are available in van Houte-Howes and Lohrer (2010) and Lohrer and Rodil (2011).

Declines in the TBI scores in association with increased sediment mud content are interpreted as losses of functional redundancy. Functional redundancy is based on the observation that some species perform similar roles in communities and ecosystems to others. High functional redundancy means there are many species that perform the same functional role within a community, so can in theory substitute for each other if losses occur, with little impact on ecosystem processes (Lawton and Brown 1993). High numbers of taxa are also likely to equate to a greater range of activity types within a single functional group. Habitats with high functional redundancy will have a higher number of indicator taxa present in each functional trait group, which is used to infer higher inherent resistance and resilience to environmental change.

Trialling the TBI method on REMP data

To calculate TBI scores effectively, full datasets including both indicator taxa and all other species present are required. In 2007, WRC followed recommendations from NIWA to identify all sediment-dwelling organisms to the lowest taxonomic level possible to provide a comprehensive description of the overall community structure. Therefore the index was trialled on REMP data collected from October 2007 to April 2011 (inclusive), which provided sufficient detail to calculate a reasonably robust TBI score. However, it should be noted that thresholds for determining what constitutes good, intermediate and poor functional redundancy will need to be developed over time for this data set as it is currently too short to do so. Direct comparison between current TBI scores and the thresholds devised for Auckland Council datasets is not yet advisable as consistency between taxonomic resolution has not yet been met.

Preliminary Results

TBI scores (averaged over 2007 – 2011) were higher (indicating greater functional redundancy) in Raglan (Whaingaroa) Harbour, in all but one instance, when compared to the Firth of Thames (Figure 29). Three sites in Raglan averaged a TBI score of ≥0.44 (Whatitirinui Island, Okete Bay, Ponganui Creek). Note that sampling at site Te Puna Point was discontinued in 2008, so was averaged over fewer data points. Raglan also contained the site with the lowest TBI score over both estuaries with Haroto Bay averaging a score of 0.24. This suggests that the macrofaunal community at Haroto Bay has low functional redundancy and is likely to be influenced by sediment mud content. This is of particular concern given that trend analysis showed a significant increase in sediment mud content at this location.

All sites in the Firth of Thames had TBI values below 0.33 with the lowest value at site Te Puru (0.26). This value suggests a lower functional redundancy comparative to the other sites in this estuary inferring that the community is therefore more vulnerable to increases in sediment mud content. Despite Kaiaua having the highest average TBI score, this was the only site in either estuary to exhibit an overall negative trend in the TBI score through time ($r^2 = 0.42$) which is particularly evident post October 2008 (0.4 in Oct 2008 to 0.25 in October 2010, Figure 30). This loss of functional redundancy indicates potential cause for concern at this site, which should be monitored closely to establish if further decline occurs.

Figure 29: Average TBI scores for the 10 REMP sites based on post 2007 data

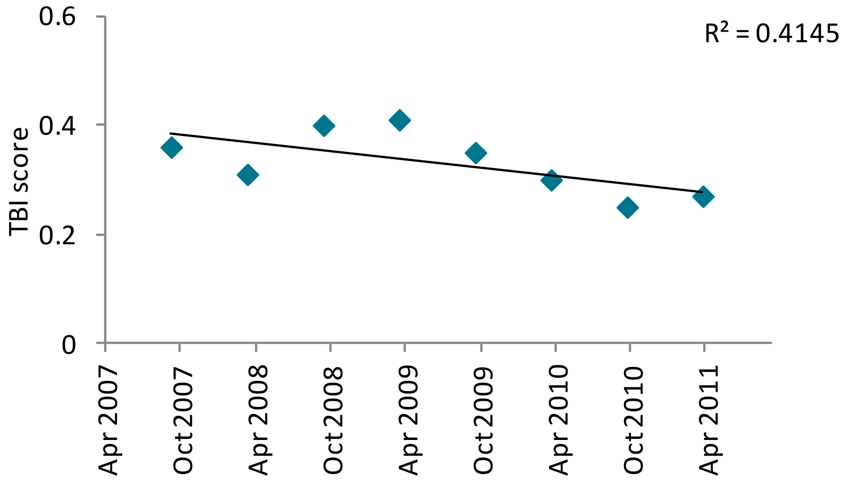


Figure 30: TBI trends over time in Kaiaua, Firth of Thames. This is the only site in the Firth of Thames or Raglan Harbour to display a strong negative trend with time.

Ways to increase the power of TBI for future application to REMP data

When comparing between times of year, October TBI scores tended to be more temporally stable than those in April and also tended to be slightly higher (with the exception of Miranda and Kuranui Bay in the Firth of Thames and Haroto Bay in Raglan). This is likely due to peaks in recruitment increasing variability in the warmer months. Because of this, it is recommended that annual collection of total macrofaunal community structure (begun in 2007) be conducted in October. These samples should be identified to the lowest taxonomic level practicable. This also aligns with Auckland Council's TBI sampling strategy and will enable future comparisons across the Auckland and Waikato regions for State of the Environment monitoring programmes.

Although the TBI provides a good indication of what is occurring in our two monitored estuaries, in reality the current values generated in this preliminary analysis are likely to be underestimates. Increasing the taxonomic resolution of particular taxa categories is essential for increasing the power of the TBI. Furthermore, differentiation of some taxa will also enable us to better track ecological changes as much is known about sensitivities of particular common species in these groups. Those particular groups highlighted as currently requiring greater taxonomic resolution are the polydorids, Maldanidae, other polychaetes and some amphipods. Steps are already being made to split apart family level taxonomy (e.g. Neridideae) in to genera or species (e.g., *Neanthes, Ceratonereis, Perinereis vallate, Nicon aestuariensis*). Consistency in the level of taxonomic differentiation is also important to maintain. To ensure this, communal training and communication between those who identify the samples across regional councils will help ensure comparability and quality assurance. As taxonomic resolution increases, it is anticipated that TBI scores will also elevate. Because of this we can anticipate TBI scores to increase over time. Comparisons between pre-and post taxonomic resolution increases can be done (if required), by recombining species/genus data into broader taxonomic groups.

In summary, the TBI indicates where site-specific shifts in functional redundancy are occurring and whether specific functional traits are being affected. This makes it highly complementary to benthic health models currently under development in New Zealand (Andersen et al., 2003, 2006, Hewitt and Ellis 2010) and relevant to WRC's regional estuarine monitoring programme. The TBI is relatively easy to calculate, although accuracy will depend on the level of taxonomic resolution used. A great asset of this approach is that the TBI can be validly calculated in places with different regional species pools as it only requires the presence of specific functional traits to be noted. This will facilitate future comparisons between regional councils to compare ecological health of estuaries across regional boundaries. WRC must first implement the TBI effectively through the development of thresholds, whereby classifications of good, intermediate or poor scores need to be established over time. This should be done in conjunction with increased taxonomic resolution.

4.2.3 Summary of recommendations for future monitoring

- **Continue expansion of REMP to other estuaries in the region**
  Whilst the recent inclusion of an east coast estuary (Tairua Harbour) in REMP increases the coverage of this monitoring program there are c. 25 estuaries in the Waikato region. These estuaries cover a range of different types, contain a wide variety of habitats, and are exposed to a wide range of pressures and anthropogenic influences. Expansion of REMP further to improve regional coverage will greatly aid our ability to manage the coastal environment across the entire region.

  Expansion of REMP may be able to be resourced by implementation of a nested monitoring design at estuaries currently monitored, as previously suggested by Compton et al. (2011). A nested approach would see two sites monitored in each estuary for a period of five years, followed by monitoring at all sites for the next two years.

- **Continue with efforts to increase taxonomic resolution in identification of sediment-dwelling organisms and to ensure consistency in identifications with other agencies**
  There are a number of benefits associated with increased taxonomic resolution of sediment-dwelling organisms. Firstly, greater taxonomic resolution is required to more accurately interpret changes in community structure, particularly for some groups such as Capitellidae (the members of which show different responses to changes in sediment characteristics such as mud content). Also, consistency with the taxonomic resolution achieved at other regional councils (e.g. Auckland Council) will allow comparisons to be made across regional boundaries, which is particularly important for projects such as the Hauraki Gulf Marine Spatial Plan. Finally, increased taxonomic resolution is required for calculation of indices such as the Trait Based Index (see below).

- **Further development of the trait based index (TBI) for REMP**
  Calculation of the TBI for REMP condenses complex ecological information into an easily-interpretable measure of the ecological health of an estuary. The index provides a way to compare functional redundancy between sites within an estuary, and between estuaries, and when used in the context of a long-term

monitoring program, to track any changes in functional redundancy that may be occurring through time. It is therefore important that the TBI is developed further for REMP by improving taxonomic resolution and development of thresholds that classify sites as having good, intermediate and poor functional redundancy.

5 Conclusions

Both the Firth of Thames and Raglan (Whaingaroa) Harbour have distinct indicator taxa community composition. Neither estuary has shown any major shifts in community structure or sediment characteristics over the 10 year monitoring period. This indicates that in general, the health of both estuaries has not declined significantly over this period. This does not however imply that monitoring is no longer necessary, as some site-specific changes in each estuary were observed. Preliminary analysis using the Trait Based Index also indicates that some sites may display low or reducing functional redundancy. These sites are therefore more susceptible to environmental change, and future monitoring is therefore important.

The primary asset of long-term data sets such as the REMP is that continuous monitoring over multiple years enables us to determine inter- and intra-annual cycles in abundance of certain taxa, as has been demonstrated in this report. Natural cycles in abundance often confound our ability to detect genuine changes to community structure in shorter term data sets. Long-term datasets enable such patterns to be seen as a help rather than a hindrance when teasing apart temporal dynamics from legitimate response to environmental changes. Furthermore, insight into local estuarine dynamics and the response of taxa to broad scale climatic factors such as ENSO is a great asset to WRC in terms of ability to manage coastal environments. Long-term collection of data is also necessary should future investigations into natural versus human-induced climatic variation be deemed necessary (Hewitt and Hailes, 2007).

Incorporation of the Trait Based Index into REMP will aid in condensing complex ecological information into an indicator that can track changes in the functional redundancy of sediment-dwelling organism communities and therefore the likely resilience of a site to environmental change. It will also enable regional councils to compare information on estuarine health irrespective of differences in community structure. Preliminary analyses have shown that accuracy and comparability of TBI calculated for WRC's REMP to Auckland Council data is reliant on first increasing the extent of our total community structure data and the taxonomic resolution to which organisms are identified, both of which are currently being implemented. This will allow robust thresholds to be developed (describing functional resilience) for REMP sites.

The recent integration of an east coast estuary (i.e. Tairua Harbour) into REMP will strengthen the capacity of WRC to assess estuarine health at a regional scale. It also assists in addressing more site-specific issues in an area of significant conservation value that is currently seeing significant development in both the catchment and coastal area. Expansion of REMP further to other estuaries in the region would greatly improve our understanding of the health of these important ecosystems and the impacts of human influences on their state and functioning.

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Appendix 1: Indicator taxa

This appendix contains detailed information about indicator taxa monitored in the Regional Estuary Monitoring Programme. Information sources are provided in a reference list at the end.

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Amphipods			
Corophiidae	Normally found in muddy intertidal habitats. They can tolerate low salinity and can also be found in fresh water. They are common in intertidal areas of North Island estuaries.	Corophiid amphipods are tiny shrimp-like crustaceans, which burrow into the sediment and emerge at high tide to scavenge or deposit feed. They have noticeably enlarged second antennae. There are around 6000 amphipod species worldwide. Corophiid amphipods tolerate a sediment mud content of 40-100%, with an optimum range of 95-100%. Therefore, they are usually found in very muddy habitats. Corophiid amphipods can also tolerate organic enrichment and pollution. Where the sediment mud content increases (exceeding 40-50%) and/or becomes polluted or organically enriched, the abundance of corophiids is likely to increase.	 (Photo courtesy of Stephen Moore, Landcare Research)
Phoxocephalidae	Occur from intertidal (shallow) to deeper environments (50 m depth). Burrow into the sediment. Prefer muddy sand habitats and are sensitive to pollution. They are found New Zealand wide.	Phoxocephalidae are small amphipods which are surface deposit feeders and bioturbators. At least five species of phoxocephalid species are found in the Waikato estuaries we sample. They are prey for fish and birds. The preferred mud content is unknown for most phoxocephalids; however, phoxocephalid amphipods are known to be intolerant to very high mud content. They are usually found in muddy sands. One species (*Waitangi chelatus*) is known to prefer a very low mud content of 0-5%. Phoxocephalid amphipods cannot tolerate pollution. For example, one species (*Waitangi brevirostris*) has been shown to be sensitive to lead contamination. If the sediment becomes muddier and/or polluted the abundance of phoxocephalids is likely to decline.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Bivalves *Arthritica bifurca*	Muddy-sandy habitats, occurs in intertidal and subtidal zones to a depth of 110 m. They are found New Zealand wide.	*Arthritica bifurca* is a small deposit feeding bivalve (<6 mm shell length) that is dull-white or pale greyish in colour. Its shell is quadrate-ovate in shape and moderately inflated with a smooth surface. *Arthritica bifurca* tolerates a sediment mud content of up to 75% with an optimum range of 20-60%. Therefore, it prefers moderately muddy habitats. Where estuarine sediments change from a sandy to muddier type habitat the abundance of *Arthritica bifurca* is expected to increase. However, where the sediment mud content exceeds its optimum range (>60%), *Arthritica bifurca* is expected to decrease in abundance.	
Austrovenus stutchburyi (New Zealand cockle, tuangi)	Cockles are very common on tidal mud and sand flats, from mid-tidal zone to depths of 5 m. Larvae settle near the high tide mark and migrate down the beach as they grow. Individuals burrow just below the surface (2-4 cm). Cockles are endemic to New Zealand.	Cockles are one of the most common intertidal bivalves. In North Island estuaries individuals are considered large at 35 mm in length, whereas South Island individuals can grow to about 60 mm. Densities can exceed 4500 per m^2 (for example in Otahu Estuary, Coromandel Peninsula). Maturity occurs at 18-20 mm. The shell is white-grey in colour, solid, inflated and has strong radial ribs crossed by concentric bands. Cockles are highly mobile surface suspension feeders. They are often found with algae, worm tubes, anemones or barnacles attached to the outer shell. Cockles provide a valuable food source for birds and fish, such as oystercatchers and eagle rays, and cockle beds may filter many thousands of litres of water per tidal cycle. In some regions reductions in abundance and size have been attributed to pollution and over harvesting. Cockles tolerate mud content up to 85% with an optimum range of 0-10%. They are sensitive to long term exposure to high levels of mud. Therefore, they prefer sandy habitats with a small amount of mud. Cockles are also sensitive to copper contamination. Where the sediment mud content increases (exceeding their optimum range) and/or sediments become polluted (particularly with copper) the abundance of cockles is likely to decline.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Bivalves (cont.)			
Macomona liliana (Wedge shell)	Intertidal and shallow subtidal sand and mud flats in estuaries and sheltered harbours. Prefers sandy to muddy sand habitats. Individuals burrow in the sediment to depths of 5-15 cm. Adults live at around 10 cm sediment depth. They are found New Zealand wide.	*Macomona liliana* is a large surface deposit feeder with an ivory white ovate shell that is roughly triangular in shape and slightly inflated. Individuals can grow up to 70 mm in length (more common around 40 mm) and mature around 20-22 mm. Adults can have a strong effect on many of the other sediment-dwelling organisms living nearby. *Macomona* are an important food resource for fish and birds. *Macomona liliana* tolerates mud content up to 75%, with an optimum range of 0-30%. Therefore it prefers sandy habitats with some mud. *Macomona liliana* is also sensitive to copper contamination. Where sediment mud content increases (exceeding its optimum range) and/or sediments become polluted (particularly with copper), the abundance of *Macomona liliana* is likely to decline.	 **(Photo courtesy of Barry O'Brien, University of Waikato)**
Linucula hartvigiana (Nut shell)	Muddy sand to sandy mud habitats (intertidal and subtidal to a depth of 20 m) in unpolluted environments. They are found New Zealand wide.	*Linucula hartvigiana* is a small to moderately large shellfish (6-8 mm in length) with an ovate inflated shape. The shell is olive/bronze to light brown coloured with small concentric ridges. *Linucula hartvigiana* is a highly mobile deposit feeder. It has evolved from an ancient lineage that began about 250 million years ago. *Linucula hartvigiana* tolerates a sediment mud content up to 60%, with an optimum range of 0-5%. Therefore it prefers more sandy habitats. *Linucula hartvigiana* is also sensitive to organic enrichment and copper contamination. Where the sediment mud content increases (exceeding its optimum range) and/or becomes organically enriched or polluted with copper, the abundance of *Linucula hartvigiana* is likely to decline.	 **(Photo courtesy of Barry O'Brien, University of Waikato)**

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Bivalves (cont.)			
Paphies australis (Pipi)	Pipi are often most abundant near subtidal channels where they burrow to 2-3 cm below the sediment surface. Juveniles are often found in fine sandy habitats while adults prefer coarser sediment and fast currents. Juveniles are usually more abundant than adults on upper intertidal flats. As they mature, juveniles migrate down the shore to lower intertidal areas. They are found New Zealand wide.	Pipi are large surface suspension-feeding bivalves which can grow up to approximately 80 mm shell length. Maturity is reached around 40 mm shell length. They frequently occur in very dense aggregations (for example exceeding 7000 per m^2 in Tairua Harbour, Coromandel Peninsula). Pipi have a solid white to light brown/orange elongated shell, which is often covered with a thin yellowish periostratum (thin organic coating or 'skin'). They are highly mobile both as adults and juveniles and are the largest of the bivalves we monitor. Pipi are an important food source for birds and humans. Pipi only tolerate a maximum sediment mud content of 5% and are very sensitive to high turbidity. Therefore, they are usually found in sandy habitats. Pipi are also sensitive to zinc contamination. Where sediment becomes muddier (>5% mud) and/or more polluted (particularly with zinc) the abundance of pipi is likely to decline.	 **(Photo courtesy of Barry O'Brien, University of Waikato)**
Theora lubrica (Asian semele)	*Theora lubrica* occurs subtidally and on lower intertidal flats where it burrows to 50 mm below the sediment surface. They are found on the North and South Islands of New Zealand.	*Theora lubrica* is a selective deposit feeder. Its shell is very thin and almost transparent, smooth and elongated in shape (7-15 mm in length). *Theora lubrica* is an invasive species that arrived in North Island harbours about 1972, probably in ballast water from its home in Japan. It has since spread to most other ports in the country and rapidly colonises disturbed and muddy habitats. *Theora lubrica* is very mud tolerant. It can tolerate a mud content of up to 65% with an optimum range of 45-50%. Therefore *Theora lubrica* has a preference for muddy habitats with some sand. Where estuarine sediments change from a sandy to muddier type habitat the abundance of *Theora lubrica* is expected to increase. However, where sediment mud content exceeds their optimum range (>50%) *Theora lubrica* is expected to decrease in abundance. *Theora lubrica* is also tolerant of pollution and organic enrichment. Consequently, it is often found in organically enriched or polluted sediments.	 **(Photo courtesy of Peter J. Bryant, University of California)**

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Cumaceans			
Colurostylis lemurum (Cumacean shrimp or hooded shrimp)	Intertidal zone of estuaries where they burrow into the soft sediment surface. Prefer fine to muddy sand and are sensitive to pollution. They are found in the North Island (common in Auckland and Waikato regions) and in the South Island.	Generally small, transparent and non-descript crustaceans. They are burrowers, reworking or bioturbating the sediment surface. *Colurostylis lemurum* tolerates a sediment mud content of up to 60%, with an optimum range of 0-5%. Therefore they are usually found in sandy habitats. *Colurostylis lemurum* is also sensitive to lead contamination and other pollution. Where the sediment mud content increases (exceeding its optimum range) and/or becomes more polluted the abundance of *Colurostylis lemurum* is likely to decline.	
Gastropods			
Cominella adspersa (Speckled whelk)	Sheltered to semi-exposed shores, intertidal and shallow subtidal sand and mud habitats as well as rocky platforms. They are found in the North Island, northern South Island and the Chatham Islands.	*Cominella adspersa* is a large marine snail (up to 70 mm in height) with a shell that is yellowish-brown and often patterned with reddish brown dots. The shell interior-opening is orange-yellow. Speckled whelks are highly mobile predators of shellfish as well as being scavengers. *Cominella adspersa* is found in muddy sediments (the optimum range is unknown). Where estuarine sediments change from a sandy to muddier type habitat the abundance of *Cominella adspersa* is expected to increase.	 (Photo courtesy of Barry O'Brien, University of Waikato)
Notoacmea spp. (Limpet)	Attach to shells, stones and seagrass blades on intertidal sand flats. They are found New Zealand wide.	*Notoacmea* are the most common soft-sediment limpets found in the North Island. They are variable in shape and colour and are large surface grazers. *Notoacmea* are highly sensitive to sediment mud content, with an optimum range of 0-5% and distribution range of 0-10%. Therefore, they are usually found in sandy habitats. *Notoacmea* can also be sensitive to pollution (particularly zinc). Where the sediment mud content increases (exceeding their optimum range) and/or becomes polluted, the abundance of *Notoacmea* is likely to decline.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes			
Prionospio aucklandica	Prefers living in muddy sands and is common in the lower intertidal regions of estuaries and harbours, living within the sediment and burrowing to a depth of about 10 cm. They are found New Zealand wide.	*Prionospio aucklandica* is a spionid worm, which is slightly larger than the related spionid species *Aonides trifida*. *Prionospio aucklandica* has two pairs of eyes with a rounded head, and three pairs of feather-like gills. It is a surface deposit-feeder. *Prionospio aucklandica* tolerates a sediment mud content of up to 95%, with an optimum range of 20-70%. It is usually found in moderately to very muddy habitats, but is less abundant in extremely muddy areas (>70% mud). *Prionospio aucklandica* is also sensitive to copper contamination. Where estuarine sediments change from a sandy to muddier type habitat, the abundance of *Prionospio aucklandica* is expected to increase. However, where the sediment mud content exceeds its optimum range (>70%) or becomes more polluted (particularly with copper), the abundance of *Prionospio aucklandica* is likely to decline.	
Aglaophamus spp.	*Aglaophamus macroura* is mainly found on the intertidal sand flats in harbours, whereas *Aglaophamus verrilli* is found in the subtidal region in fine to muddy sands. They are found New Zealand wide.	*Aglaophamus* spp. are large (up to 170 mm in length) muscular, vigorous, free-burrowing nephtyid worms. They are usually white or cream in colour. Nephtyids are important secondary predators in sediment-dwelling organism communities and a food source for birds and fish. There are two common species found in New Zealand, *Aglaophamus macroura* and *Aglaophamus verrilli*. We currently list both species combined as *Aglaophamus* spp. At present little is known about the biology of *Aglaophamus* spp. or their sensitivity to sediment mud content. However, they generally prefer sandy habitats over muddy ones. Accordingly, increases in sediment mud content are likely to result in a decline in *Aglaophamus* spp. abundance.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes (cont.)			
Aonides trifida	Prefers living in fine sands (low mud content) to 10 cm sediment depth, and is found New Zealand wide.	*Aonides trifida* is a small thin active spionid worm (smaller than a related spionid species, *Prionospio aucklandica*), with a pointed head and two pairs of eyes. It is a surface deposit feeder and bioturbator and a prey for fish and birds. *Aonides trifida* grows up to 100 mm in length. *Aonides trifida* tolerates a sediment mud content up to 80%, but has an optimum range of 0-5%. Accordingly, *Aonides trifida* is most abundant in sandy habitats. *Aonides trifida* is also sensitive to copper contamination. Where the sediment becomes muddier (exceeding its optimum range) and/or polluted (particularly with copper), the abundance of *Aonides trifida* is likely to decline.	
Aricidea spp.	Prefer muddy sands and are sensitive to changes in mud content. Burrow to a depth of about 15cm. They are found New Zealand wide.	*Aricidea* spp. are small paraonid worms, which are sub-surface deposit feeders and bioturbators. *Aricidea* spp. can be distinguished from other paraonids by a small thread-like antennae protruding from the top of the head. *Aricidea* spp. tolerate a sediment mud content up to 70%, with an optimum range of 35-40%. Therefore, they are usually found in habitats that have a slightly greater proportion of sand than mud (e.g. muddy sands). *Aricidea* spp. have also shown sensitivity to lead and zinc contamination. Where estuarine sediments change from a sandy to muddier type habitat the abundance of *Aricidea* spp. is expected to increase. However, where sediments become more polluted (particularly with lead or zinc) and/or where sediment mud content exceeds their optimum range (35-40%), *Aricidea* spp. are expected to decrease in abundance.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes (cont.) *Pseudopolydora complex*	They live in a wide range of habitats from fine sand to sandy mud, and are found New Zealand wide.	Polydorids are tube-dwelling worms, with tubes that are made of fine grains and are flexible. They are surface deposit-feeders, which can switch to suspension feeding. They can form dense mats which help stabilise the sediment surface, and therefore play an important role in maintaining community structure. Some species specialise in boring into shells. Most polydorids live in sediments ranging from fine sand to sandy mud, while some are tolerant of muddier sediment (15-30%). Polydorids have also shown sensitivity to lead contamination. Where estuarine sediments becomes muddier and/or polluted (particularly with lead), the abundance of polydorids is likely to decline.	 (Photo courtesy of Barry O'Brien, University of Waikato)
Cossura consimilis	They live in muddy sand in depths ranging from shallow intertidal harbours and estuaries to the inner continental shelf and out to the continental slope (0-2000 m, and are found New Zealand wide.	*Cossura consimilis* is a slender thread-like worm with a blunt head. It is a small deposit feeder, growing up to 20 mm in length. *Cossura consimilis* tolerates a sediment mud content of 5 to 65%, with an optimum range of 20-25%. Therefore, it is usually found in habitats which are more sandy than muddy (e.g. muddy sand). *Cossura consimilis* has also shown sensitivity to copper contamination. Where estuarine sediments become muddier (exceeding their optimum range) and/or polluted (particularly with copper), the abundance of *Cossura consimilis* is likely to decline.	 (Photo courtesy of Barry O'Brien, University of Waikato)
Euchone spp. (Fan or feather-duster worms)	Found in soft sediment habitats New Zealand wide.	*Euchone* spp. are small (<20 mm length) sabellid or fan worms (named for fan-like feeding appendages). They are suspension-feeders and are often found encased in a sandy tube, protruding above the sediment surface with the fan-like tentacles exposed. At present, the tolerance of *Euchone* spp. to sediment mud content is unknown. *Euchone* spp. are known to be sensitive to copper and zinc contamination, however.	 (Photo courtesy of Barry O'Brien, University of Waikato)

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes (cont.)			
Goniada spp.	Found New Zealand wide in intertidal, subtidal and offshore (continental shelf) soft sediments.	Goniadids are highly mobile, burrowing predators, scavengers and bioturbators. They can grow up to 260 mm in length (although usually less than 50 mm). Goniadids are often smaller and more slender than *Glycera* spp. They have an eversible proboscis with one pair of large chitinous jaws (compared to four found in *Glycera* spp.). Goniadids tolerate a sediment mud content up to 60%, with an optimum range of 50-55%. Therefore, they are usually found in more muddy habitats with some sand. Goniadids have also shown sensitivity to copper contamination. Where estuarine sediments change from a sandy to muddier type habitat the abundance of goniadids is expected to increase. However, where sediment mud content exceeds their optimum range (50-55%) or sediments become polluted (particularly with copper), goniadids are expected to decrease in abundance.	
Glycera spp. (Blood worms)	Prefer sands and sandy mud habitats from intertidal to the deep sea. They are found New Zealand wide.	The glycerids are large, very muscular, active, burrowing ambush predators and scavengers/bioturbators. Adults can grow up to 350-400 mm long and 15 mm in diameter. They have a long muscular foregut region called a pharynx, which includes a proboscis. There are four large chitinous jaws at the tip of the proboscis which are made of tough semitransparent chitin. The whole pharynx can be expelled (everted) forcefully through the mouth to grasp or capture prey (and also to burrow). At the base of the jaws are poison glands filled with a neurotoxin used to kill prey. A bite from a large glycerid, although not lethal, can be painful even to humans. Glycerids tolerate a sediment mud content up to 95%, with an optimum range of 10-15%. Therefore, they are usually most abundant in sandy habitats with some mud content. Glycerids are sensitive to low levels of oxygen, which can occur in organically enriched estuarine sediments. Where estuarine sediments become muddier (exceeding their optimum range) and/or organically enriched, the abundance of glycerids is likely to decline.	 (Photos courtesy of Barry O'Brien, University of Waikato)

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes (cont.)			
"Capitellidae"	Capitellids prefer a muddy sand habitat in estuaries and harbours where they can burrow deeply into the sediment (to about 10 cm). They are one of the few worms which can be found in very high numbers around organic effluent discharges.	Capitellid worms are long, thin and fragile worms. They have no head appendages or other distinguishable characteristics. Adults can grow up to 50mm long. Capitellids are subsurface deposit feeders and bioturbators. They are prey for fish and birds. Capitellids tolerate a sediment mud content of up to 95%, with an optimum range of 10-40%. Therefore they are usually found in moderately muddy habitats. Capitellid abundance is often high in organically enriched estuarine sediments. Where estuarine sediments change from a sandy to muddier type habitat and/or become organically enriched, the abundance of capitellids is expected to increase. However, where sediment mud content exceeds their optimum range (>40%), capitellids are expected to decrease in abundance.	
Magelona cf. dakini	Magelonids build meandering burrows in medium to fine sands. They are found New Zealand wide over a range of depths from mid-intertidal and subtidal to the continental slope.	*Magelona cf. dakini* is a small, thin and shovel-nosed (shield like head) burrower and subsurface deposit feeder. Adults grow up to 70 mm long. These worms are visible to the naked eye as pinkish threads when sediment clumps are broken apart by hand. At present the tolerance of magelonids to sediment mud content is unknown. However, they are usually most abundant in sandy habitats. Magelonids are highly sensitive to lead contamination. Where estuarine sediments become polluted (particularly with lead) and/or very muddy, the abundance of magelonids is expected to decline.	
Orbinia papillosa	Found New Zealand wide and prefers sandy habitats.	*Orbinia papillosa* is a large sub-surface deposit feeder and bioturbator. It has a small pointed head without eyes. Adults can grow in size to more than 100mm long but are less than 2 mm in width. *Orbinia papillosa* is prey for fish and birds. *Orbinia papillosa* tolerates a sediment mud content up to 40%, with an optimum range of 5-10%, so is usually found in sandy habitats. *Orbinia papillosa* has been shown to be slightly sensitive to zinc contamination.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Polychaetes (cont.) Nereididae (Ragworms)	They are found New Zealand wide and prefer muddy sand to mud habitats in areas of reduced salinity.	Nereidids are large thick worms, usually green or brown in colour, with two pairs of large eyes. They are active omnivores. Adults can grow to more than 300 mm long and 20 mm thick, although most adult nereidids are about 50-100mm in length, and some are much smaller. Nereidids tolerate a sediment mud content of up to 100%, with an optimum range of 35-60%. Therefore, they are usually most abundant in moderately to very muddy habitats. Where estuarine sediments change from a sandy to muddier type habitat the abundance of nereidids is expected to increase. However, where sediment mud content exceeds their optimum range (>60%), nereidids are expected to decrease in abundance. Nereidids are not sensitive to copper, lead and zinc contamination and can be found in high densities in relatively contaminated sediments. Their abundance often increases in contaminated sediments. It is not known if this represents a preference for contaminated sediments or results from a contamination intolerance of their competitor species.	 (Photos courtesy of Barry O'Brien, University of Waikato)
Paraonidae	Found New Zealand wide, typically in muddy sands over a range of habitats from intertidal flats in estuaries and harbours to the deep sea.	Paraonidae is a family of thin slender burrowing worms. Paraonids are mainly subsurface deposit feeders. Adults can grow in size to 4 mm in length and a width of 1 mm but are usually much smaller. At present the tolerance to sediment mud content and optimum range for paraonids is unknown. However, they generally prefer habitats with some mud (muddy sands) and some paraonids (*Aricidea* spp.) are known to tolerate mud content up to 70% with an optimum range of 35-40%. Therefore, where estuarine sediments change from a sandy to muddier type habitat the abundance of paraonids is expected to increase. However, where the sediment mud content becomes very high, paraonids are expected to decrease in abundance.	

Scientific name (common name)	Habitat	Description and relevance as indicator taxa	Photo
Anthozoans			
Anthopleura aureoradiata (Mud anemone, small brown anemone)	*Anthopleura aureoradiata* is found New Zealand wide in tide pools and on mudflats in estuaries, often attached to shells (for example cockles), stones or wood. It is intolerant of low salinity.	*Anthopleura aureoradiata* is a small brown predatory tube-dwelling anemone (up to 10 mm in diameter) with a cylindrical body which is wider towards the tentacles. It uses the tentacles for food capture, manipulation, ingestion and defence. The tissues of the anemone support colonies of green plant cells called zooxanthellae. *Anthopleura aureoradiata* tolerates a sediment mud content of up to 40%, with an optimum range of 0-10%. It is intolerant of high turbidity. Therefore *Anthopleura aureoradiata* is usually found in more sandy habitats. This species is also very sensitive to copper contamination. Where estuarine sediments become muddier (exceeding its optimum range) and/or polluted (with copper in particular), the abundance of *Anthopleura aureoradiata* is likely to decrease.	 (Photo courtesy of Michela Mitchell, www.taxonomyservicesaustralia.com)

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Appendix 2: Statistics

1. Trend analysis

Trend analysis was undertaken using averaged data from each sampling event for each type of monitoring data collected, i.e., monitored taxa abundance, sediment characteristics and sediment grain size fractions. For sites where samples were collected quarterly, variables were investigated for positive-autocorrelation of residual data using the Durbin-Watson statistic. This displays relationships between values separated from each other by a given time lag. In other words, we can address whether any of the patterns we see are seasonal, multi-year cycles or step trends. Where positive autocorrelations were observed, increasing or decreasing trends were investigated by adjusting parameters and significance levels using the AUTOREG procedure in SAS (version 9.1.3).

Where trends in abundance were detected, the fit of the trend to the observed data was examined by analysis of the residuals. Patterns of high variability of species data can hinder the detection of trends using this procedure, therefore trend analysis was only conducted for monitored taxa with average abundances ≥ 2 individuals per core at least 25% of the time. Where necessary, non-linearities were incorporated by log transformations or by using the Kruskal-Wallis test (for step trends). Trends were tested to a significance level of $p=0.05$.

2. Changes in community composition over time

Multivariate analysis techniques (PRIMER E Ltd.; Clarke and Gorley, 2006), were used to visualise patterns in community structure over the monitoring period at differing spatial scales. Patterns within sites, between sites and between estuaries were identified using non-metric multidimensional scaling ordination (MDS) plots. Data from October of each year were used for this analysis so that patterns were not masked by the between season 'noise' (known as autocorrelation). October sampling times were selected as this month showed fewer recruitment peaks in abundance in indicator taxa than other times of year. Data were square root transformed to reduce the influence of numerically dominant taxa, then analysed using Bray-Curtis similarities based on mean abundance values from each replicate on each sampling date.

Due to the long-term nature of our data series, we moved away from the ANOSIM type approach used in the 5 year trend report (Felsing and Singleton, 2008). The regressive approach used now is more appropriate for establishing statistically significant changes in community composition associated with time. To constrain the MDS ordination to find the variation most closely associated with time regression analysis was conducted using canonical ordination of principle co-ordinates (CAP) based on Bray-Curtis similarities. The analyses were conducted using mean abundance values from each replicate on each sampling date that were square root transformed to reduce the influence of numerically dominant taxa. The software PERMANOVA+ for PRIMER v6 was used for these analyses (Anderson et al., 2008).

3. Relationships between community composition and sediment characteristics

Relationships between monitored taxa and the collected sediment characteristics were investigated using a distance-based redundancy analysis based on Bray-Curtis similarities of square root transformed abundances and normalised sediment characteristics. Backwards selection using Akaike's Information Criteria (AIC) was used to determine the most significant sediment predictor characteristics on the composition of monitored taxa using the DISTLM routine in PERMANOVA+ for PRIMER v6 (Anderson et al., 2008).

4. Identifying true trends in sediment grain size data – eliminating the effect of the change in methodology

Due to the change in analysis technique in 2007, sediment data had to be partitioned prior to analysis to enable us to look at legitimate changes over time since sampling began, eliminating any false effect driven by our change in sediment grain size analysis technique (Galai vs. Malvern). To do this, we used a general linear model to look at the significance of patterns. For each site, data was ordered into columns of the categorical variable under investigation (in this case change in method) and the continuous variable of interest (days since sampling began). Change in method was entered in the model first and a type 1 mean squares test was used to identify if there is a significant (significance level of p=0.05) effect of 'day' once the change in 'method' has been removed.

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