Environment Waikato Technical Report 2008/48

Regional Estuary Monitoring Programme: April 2001 to April 2006

Southern Firth of Thames and Raglan (Whaingaroa) Harbour

www.ew.govt.nz
ISSN 1172-4005 (Print)
ISSN 1172-9284 (Online

Environment Waikato
REGIONAL COUNCIL

Prepared by:
Malene Felsing & Nathan Singleton

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

26 July 2007

Document #: 1204995

Acknowledgement

Throughout the years, many people have assisted with fieldwork on this programme, and the authors would like to particularly thank Bevan Jenkins, Bronwen Gibberd, Vernon Pickett, Erin Petuha, Dan Borman, Glen Cooper, Hannah Jones, Mark Williams, Nick Carter, Nicola Foran, Paul Smith, Rebecca Ireland, Stephanie Turner, and many more. Thanks also go to Lisa Tomlinson, Hannah Jones and Shari Conn, for help with sorting of sediment samples.

Peer reviewed by:
Debra Stokes Date October 2008

Approved for release by:
Peter Singleton Date October 2008

Table of Contents

List of Figures

List of Tables

Executive Summary

Environment Waikato's Regional Estuary Monitoring Programme was initiated in April 2001, to determine the current status and monitor the temporal changes in the state of the Region’s estuaries. The monitoring programme samples sediments and associated macro-invertebrate communities at five permanent sites in each of two estuaries: the Firth of Thames, and Raglan (Whaingaroa) Harbour. In this report, the data collected from April 2001 to April 2006, was analysed to assess the current status and temporal changes in the health of the estuaries during this time.

The variables measured in the Regional Estuary Monitoring Programme include 26 macrobenthic indicator taxa, as well as sediment grain size, organic matter content, and microalgal biomass. The sampling sites in the Firth of Thames are Kaiaua, Miranda, the Thames Gun Club, Kuranui Bay and Te Puru, and in Raglan Harbour Ponganui Creek, Whatitirinui Island, Te Puna Point, Haroto Bay and Okete Bay. Sampling was undertaken quarterly at two sites in each estuary, and twice a year at three sites.

Inner Firth of Thames

The data from the inner Firth of Thames show the sediments of sites along the east coast (Te Puru, Kuranui Bay and the Gun Club) to classify as sandy (maximum mud content 5%), and those on the west coast (Kaiaua and Miranda) to classify as slightly muddy sands (mud content 5-25%). Between 2001 and 2006 statistically significant increases in sediment fine sands and mud occurred at all sites apart from Kaiaua. At Kaiaua a great influx of mud occurred in the spring of 2001, most likely connected to a weatherbomb, the effects of which took about a year to dissipate fully. At all sites apart from Kaiaua, concurrent with an increase in fine sediments was a decrease in coarse sands. No increasing trends in sediment organic carbon or total nitrogen were found at any of the sites, and few clear trends were found in sediment pigment levels over time.

Analyses showed sediment shellhash and coarse sand content, chlorophyll-*a* concentration and total organic carbon to be important parameters accounting for the differences in macrobenthic assemblages between the monitoring sites.

In addition to the sediment trends, a number of trends were found for indicator taxa between 2001 and 2006. Most of these trends were increases in abundance, but a few declining trends were noted. Because sediment mud content is a major factor known to structure macrofaunal communities, the faunal trends were assessed in terms of possible relation to trends in sediment mud content.

At Kaiaua, only the invasive bivalve Theora declined in abundance, and at this site the only sediment parameter to show a clear trend was an increase in fine sand over time.

At the Thames Gun Club, mud levels increased from 0.5% to 2.2%, and no declining trends in abundance of indicator species were found.

At Te Puru mud content increased from 0.5% to 3.1% and two taxa of macrofauna (the bivalves *Nucula* and *Austrovenus*) declined over time. The declines were caused by lack of recruitment of these species after 2001. The slight increase in sediment mud content is unlikely to have adversely affected abundance of these species, as mud levels at the site were lower than the optimum for *Austrovenus*, and within the optimal range for *Nucula.* Recruitment of the pipi *Paphies australis* occurred at this site after 2001, and it is possible that the lack of recruitment of *Nucula* and *Austrovenus* was caused by competition from *Paphies* juveniles.

At Miranda mud increased from 1.2% to 5.6%. At this site only one declining trend was found for macrofauna (for the polychaete *Aonides*). It is considered unlikely that the declining trend of *Aonides* is related to the increase in sediment mud content, as the optimal range of this species is sediment with a mud content of <5%, and the average mud content at Miranda only just exceeded 5%.

At Kuranui Bay mud increased from 0.6% to 4.8%. Here the only declining trends were slight declines in the abundance of the wedgeshell *Macomona* and the polychaete *Aquilaspio*. *Macomona* is known to be relatively intolerant to high sediment mud contents, but only once it exceeds at least 5%, and *Aquilaspio* is known to prefer sediments with a mud content of at least 20%. The declines in these species are therefore not considered related to the increase in sediment mud content.

Overall, although clear trends of increasing fine sediments and decreasing coarse sand were observed at most sites, the trends in macrofaunal assemblages were not dominantly towards a decline in species sensitive to increased fine sediments. The differences between macrofaunal assemblages at the different sites within the Firth of Thames related most clearly to sediment shellhash content – a parameter which showed few clear increasing or decreasing trends over time.

The presence of diverse macrofaunal communities at the five permanent monitoring sites, including many species intolerant of higher levels of fine sediments (and other pollutants), indicate that the inner Firth of Thames is in good health. Although the sediment mud level in the southern Firth of Thames has increased, it is still low, and not at a level where it affects sensitive species. Thus, based on the invertebrate communities present, no changes in the health of the monitored sites were observed over the five years monitored.

Raglan (Whaingaroa) Harbour

Sediment fine sand and mud content increased over time at all the permanent monitoring sites in Raglan Harbour. The sediments at all sites apart from Haroto Bay can be classified as slightly muddy sands, but with sediment mud contents of up to 32% at Haroto Bay, sediments there have become muddy sands. As sediment mud contents increased, sediment coarser sand fractions decreased at all sites. No trends were found for the sediment shellhash, nutrient or pigment content over time.

Analyses showed that the between-site differences in macrofaunal assemblages correlated highly with the amount of sediment shellhash, mud and total organic carbon.

Te Puna Point sediment mud content increased from 1.7% to 8.3% between 2001 and 2006. Two declining trends were noted for macrofauna (the polychaete *Aquilaspio* and the anemone *Anthopleura*). *Anthopleura* is known to be intolerant of high turbidity, and the decline in this species is possibly related to the increase in sediment mud content, however, sediment mud levels were too low to adversely affect *Aquilaspio.*

Haroto Bay saw a marked increase in sediment mud content, from 6.6% to 32.1%. Here, a decline in capitellid polychaetes was noted. This family of polychaetes is known to prefer sediments with a mud content of up to 40%, and it is unlikely that the decrease in capitellids at this site is related to the increase in fine sediments. The total number of taxa and individuals found at Haroto Bay were the lowest of the sites in Raglan Harbour, indicating that the high sediment mud content may have lead to the absence of some taxa.

Sediment mud content increased from 3.9% to 8.1% at Ponganui Creek, but no declining trends of macrofaunal abundance were found at this site.

Similarly, at Whatitirinui Island, sediment mud content increased from 4.2% to 10.7%, and only increasing trends of macrofaunal abundance were found.

At Okete Bay, sediment mud content increased from 2.7% to 18.5%. The proportion of mud in sediments at this site was the second highest in Raglan Harbour, although on average still only half those of Haroto Bay. Again, only increasing trends in macrofaunal abundance were noted at this site. The total number of individuals found at Okete Bay was low and similar to that of Haroto Bay, indicating that the sediment mud content negatively impacted on macrofaunal abundance at these sites.

Overall, clear trends of increasing fine sediments and decreasing coarse sands were found for all the monitoring sites in Raglan Harbour, however macrofaunal trends were not easily linked to the changes in sediment parameters. At all sites in the Harbour some indicator species were present which are known to be intolerant to higher levels of fine sediments, and no clear declining trends in sensitive species were observed over time. However, the diversity (abundance of taxa) was lowest at the muddiest site (Haroto Bay), and the two muddiest sites (Haroto Bay and Okete Bay) also showed the lowest abundances of individuals. This indicates that at the muddiest sites, macrobenthic diversity and abundance may be influenced by the sediment mud content. Based on the monitoring data, Raglan Harbour is still moderately healthy, but there are signs of compromised health at the muddiest sites (Haroto Bay and Okete Bay).

Comparison of the Firth of Thames and Raglan (Whaingaroa) Harbour

The sediments at the sampling sites in Raglan Harbour sediments were much muddier than those at the sampling sites in the Firth of Thames, and sediment mud content increased much more markedly in Raglan Harbour than in the Firth. Total nutrient and chlorophyll-*a* levels were somewhat higher in Raglan than in the Firth, which is probably related to the high sediment mud content.

In general, there were higher numbers of bivalves in Raglan Harbour than in the Firth of Thames. Species such as *Austrovenus*, *Arthritica* and *Macomona* were more abundant in Raglan Harbour than in the Firth of Thames, whereas *Paphies* and *Theora* were more abundant in the southern Firth of Thames. Recruitment of bivalve species occurred within both estuaries: in the Firth of Thames, *Austrovenus* recruitment was detected in April, whereas in Raglan Harbour it was detected in October. Other species showed mixed seasonality of recruitment at different sites.

Factors other than the sediment parameters measured in this study may influence the abundance and diversity of macrofauna, such as the black sands of Raglan Harbour, hydrodynamic conditions, freshwater runoff, predation, recruitment and anthropogenic influences.

Recommendations

The clear trend detected of increasing sediment mud content, and decreasing sediment coarse sand content, at all sites monitored apart from Kaiaua in the Firth of Thames, is cause for concern. Although the changes in sediment have not affected the health of the invertebrate communities over the five years monitored, should the trend of increasing fine sediments continue, it is very likely that the health of the monitoring sites will decline. Given the clear changes observed over a relatively short timeframe, it is strongly recommended that the monitoring programme be continued, as extending the period of monitoring is likely to help separate natural cycles in sediment composition and macrofaunal abundances from potential longer term trends. If the increase in sediment mud content continues in the future, it is likely that adverse effects on macrobenthic communities will ensue, with potential knock-on effects on e.g. fish and birds.

To enable enumeration of species diversity, it is recommended that all taxa rather than only indicator taxa be enumerated from now on. To increase our understanding of the monitored sites, it is recommended that the feasibility of measuring tidal exposure, air and water temperature, and salinity at the monitoring sites be evaluated.

In order to free up resources to enable the expansion of the estuarine monitoring programme, it is recommended that sampling be carried out at half-yearly intervals at all sites from now on. In Raglan, Whatitirinui Island, Te Puna Point and Ponganui Creek were found to be very similar in terms of macrofaunal assemblages and sediment trends, and to free up resources, it is recommended that monitoring at Te Puna Point be discontinued. The resources that will be freed up by the recommended changes should be used to monitor and map benthic resources (such as shellfish beds and substrate type) in other estuaries in the Waikato Region.

1 Introduction

Environment Waikato is responsible (with other agencies) for managing about 1150 km of open coast and estuarine shoreline, extending 12 nautical miles seawards of mean high water springs. Estuaries have been identified in the Waikato State of the Environment Report as one of the coastal areas within the Waikato Region most at risk from human activities (Environment Waikato, 1999). They are important areas for people culturally, commercially and recreationally; and are highly productive ecosystems that provide important habitats for many fish, shellfish and bird species. 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. Monitoring will allow early detection of any adverse environmental changes, and as such provide a trigger for assessing land management practices.

Environment Waikato's Regional Estuary Monitoring Programme was initiated in April 2001, to determine the current status and monitor the temporal changes in the state of the Region's estuaries. The monitoring programme samples sediments and associated macro-invertebrate communities at five permanent sites in each of two estuaries: the Firth of Thames, and Raglan (Whaingaroa) Harbour. Sampling is undertaken quarterly at two sites in each estuary, and twice a year at three sites.

The findings from a pilot study undertaken in April 2001 were presented in Turner et al. (2002). Results from the monitoring have been published in three data reports to date (Turner & Carter, 2004; Felsing et al., 2006; Singleton & Pickett, 2006). These report presented the findings from one or two years, including the species present and the sediment characteristics at the different sites in each estuary. The current report aims to bring together the data for the five years of monitoring from April 2001 to April 2006, to assess:

- the current status of health of the estuaries, based on invertebrate community and sediment characteristics; and
- temporal changes in the health of the estuaries over the duration of the monitoring to date.

The report also recommends where changes should be made to the estuary monitoring programme.

2 Methods

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

1. Twenty-six "indicator" taxa[1] characteristic of intertidal mud / sand-flat benthic macrofauna communities, selected to represent a variety of taxonomic groups and a range of life-histories, ecological niches and feeding methods (see Hewitt et al. 2001).
2. Sediment physical, chemical and biological characteristics:
    - Grain-size;
    - Organic matter content;
    - Benthic microalgal biomass (quantified by chlorophyll-*a* and phaeophytin concentration);

Rates of sediment deposition and erosion are also monitored, and these will be reported on in a separate report.

[1] 'Taxa' is used here to indicate that some benthic macrofauna can not reliably be identified to species level and that therefore some of the 'taxa' or monitored may include more than one species.

2.1 Field sites and sampling regime

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.

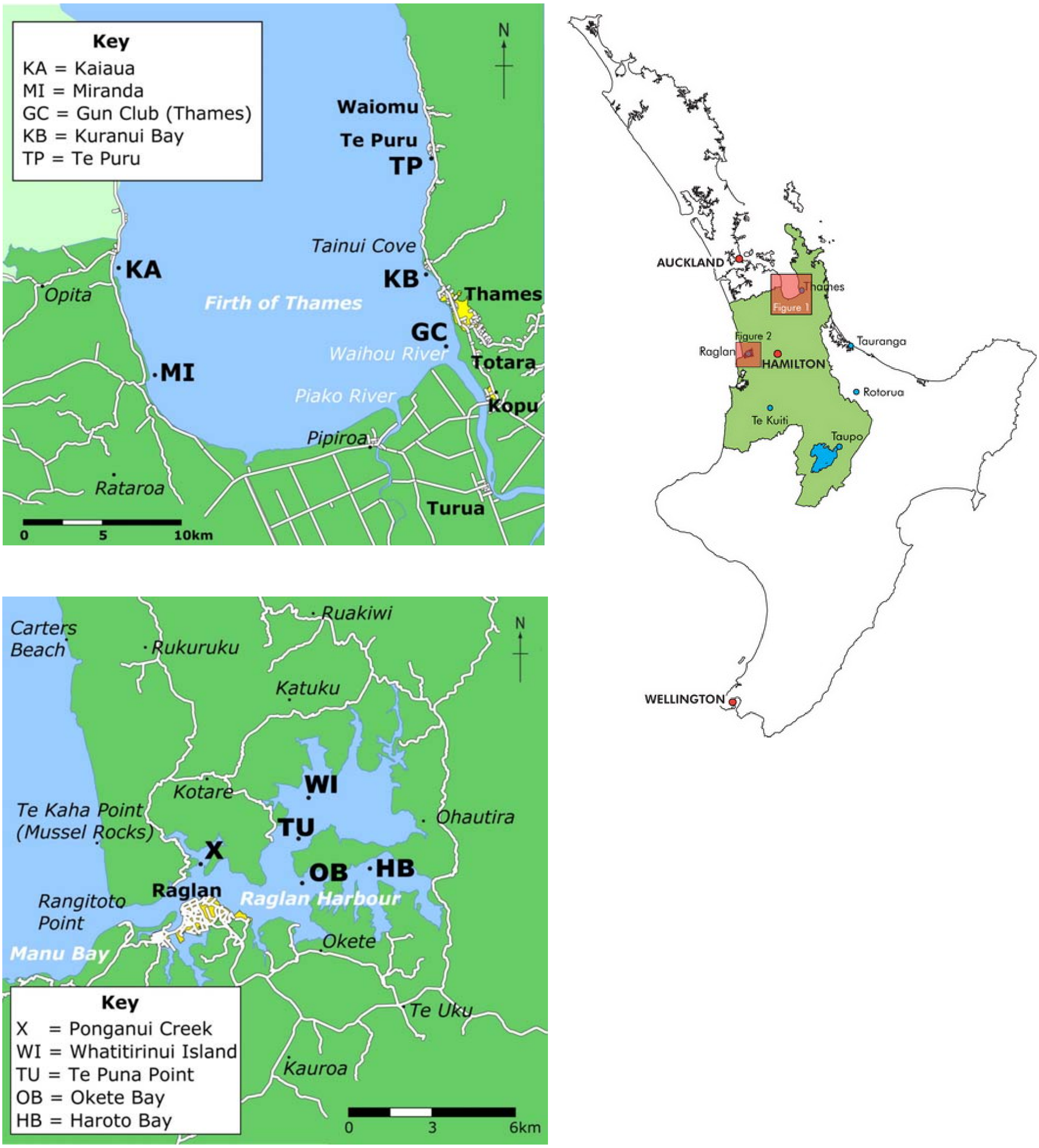


Figure 1: Location of permanent monitoring sites in the southern Firth of Thames and Raglan.

Details of the sites, and the frequency of sampling, are provided in Table 1.

Table 1: Details of permanent monitoring sites and sampling regime in southern Firth of Thames and Raglan Harbour.

Estuary	Site Name	Site Code	Sampled
Firth of Thames	Kaiaua	KA	April, October
	Miranda	MI	January, April, July, October
	Gun Club (Thames)	GC	April, October
	Kuranui Bay	KB	January, April, July, October
	Te Puru	TP	April, October
Raglan	Whatitirinui Island	WI	January, April, July, October
	Te Puna Point	TU	April, October
	Okete Bay	OB	January, April, July, October
	Haroto Bay	HB	April, October
	Ponganui Creek	X	April, October

At each site, a permanent monitoring plot (approximately 10,000 m² in size - 100 m x 100 m), located at approximately the mid-intertidal level, is sampled.

2.2 Sample collection and processing

2.2.1 Benthic macrofauna

On each sampling occasion 12[2] core samples (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.

Macrofauna 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 macrofauna were sorted, and indicator taxa (see Table 2) identified and counted. Wherever possible, non indicator taxa were identified to the lowest taxonomic level possible. Indicator bivalve species were measured (shell width) and recorded into 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.

Fauna were stored in 50% isopropyl alcohol.

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

Table 2: Macrofauna indicator species / taxa monitored in the Regional Estuary Monitoring Programme. Comment information from Hewitt et al. (2001) and Gibbs & Hewitt (2004) and references mentioned therein.

Taxa	Comments	Tolerance to mud
Amphipods		
Corophiidae	Burrowing scavenger / deposit feeder. Tolerates low salinity and organic enrichment.	Optimum range 95-100% mud,* distribution range 40-100%*.
Phoxocephalidae	Small surface deposit feeder. Bioturbator. Prey for fish and birds. Sensitive to pollution of sediments	Optimum and distribution range for *Waitangi? Chelatus* is 0-5% mud*.
Bivalves		
Arthritica bifurca	Small deposit feeder. Sensitive to changes in sediment composition.	Optimum range 55-60%* or 20-40%**, distribution range 0-75%**.
Austrovenus stutchburyi	Large highly mobile surface suspension feeder. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects.	Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).
Macomona liliana	Large surface deposit feeder. Sedentary adults live at about 10 cm sediment depth. Highly mobile juveniles. High densities of adult *Macomona* affect other species and sediment chemistry. Important prey for fish and birds.	Optimum range 0-5% mud* or 0-30% mud**, distribution range 0-75%**.
Nucula hartvigiana	Deposit feeder. Highly mobile.	Optimum range 0-5% mud**, distribution range 0-60%**.
Paphies australis	Large surface-dwelling suspension-feeder. Highly mobile. Important food source for birds and humans. Sensitive to turbidity.	Juveniles found in fine sand and sandy mud habitats, but optimum and distribution range for adults 0-5% mud*.
Theora lubrica	Invasive species, selective deposit-feeder. Indicator of organic enrichment overseas. Sensitive to changes in sediment composition.	Prefers some mud (small %).
Cumaceans		
Colurostylis lemurum	Semi-pelagic, surface and subsurface detritivore. Bioturbator. Prey for fish and birds. Sensitive to pollution.	Optimum range 0-5% mud*, distribution range 0-60%*.
Gastropods		
Cominella adspera	Large, surface dweller, highly mobile predator, scavenger.	Found in muddy sediments.
Notoacmea sp.	Large soft sediment surface grazer. Attaches to shells and seagrass blades.	Optimum range 0-5% mud*, distribution range 0-10%*. Highly sensitive to fine sediments.
Polychaetes		
Aquilaspio aucklandica	Surface deposit-feeder. Occurs down to 10 cm sediment depth.	Optimum range 65-70% mud* or 20-50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.
Aglaophamus sp.	Predator.	
Aonides oxycephala	Surface deposit feeder, occurs to 10 cm sediment depth. Bioturbator. Prey for fish and birds.	Optimum range 0-5% mud*, distribution range 0-80%**. Sensitive to changes in sediment mud content.
Aricidea sp.	Small sub-surface deposit feeder. Occurs to 15 cm sediment depth. Bioturbator.	Optimum range 35-40% mud*, distribution range 0-70%*. Sensitive to changes in mud content of sediments.
Pseudopolydora	Tube-dwelling surface deposit-feeder, can switch to suspension feeding. Can form dense mats which stabilise sediment surface.	Live in wide range of habitats, from fine sands to sandy muds.
Cossura sp.	Small deposit feeder.	Optimum range 20-25% mud*, distribution range 5-65%*.
Euchone sp.	Tube dwelling suspension-feeder	
Goniada sp.	Highly mobile predator, scavenger. Bioturbator. Prey for fish and birds.	Optimum range 50-55% mud*, distribution range 0-60%*.
Glycera sp.	Highly mobile predator, scavenger. Bioturbator.	Optimum range 10-15% mud*, distribution range 0-95%*.
Capitellidae	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.	*Heteromastus filiformis* optimum range 10-15%* or 20-40% mud**, distribution range 0-95%**.

Taxa	Comments	Tolerance to mud
Magelona dakini	Subsurface deposit feeder.	
Nereidae	Surface deposit feeder, scavenger, predator. Prefers reduced salinities.	Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.
Orbinia papillosa	Large sub-surface deposit feeder. Bioturbator, prey for fish and birds.	Optimum range 5-10% mud*, distribution range 0-40%*. Sensitive to changes in sedimentation rate.
Paraonidae		Optimum range 10-15%* or 15-35% mud**, distribution range 0-50%*. Sensitive to changes in mud content of sediment.
Anemone		
Anthopleura aureoradiata	Predator. Requires hard substrate (e.g. shell, wood) intolerant of high turbidity, and of low salinity.	Optimum range 5-10%* or 0-5% mud**, distribution range 0-40%**.

* Preferred and distribution ranges based on findings from the Whitford Embayment in the Auckland Region (Norkko et al., 2001).

** Preferred and distribution ranges based on findings from 19 North Island estuaries (Thrush et al., 2004).

After sorting, the remaining non-living material (e.g. broken shells – 'shellhash') was dried at 70°C for 48 hours and dry weight was established.

2.2.2 Sediment characteristics

At each site, sediment samples were collected from within the monitoring plot for the analysis of physical and chemical sediment characteristics that may influence the distribution and abundance of benthic macrofauna.

2.2.2.1 Sediment grain-size

At each site, two samples (5 cm diameter, 2 cm deep core) of surface sediment were collected from the vicinity of the benthic core samples. Samples were bulked into five composite samples (each containing four to five core samples) for grain-size analysis. Samples were stored frozen. Prior to analyses, samples were pre-treated with 10% hydrogen peroxide to remove organic material and 1*M* HCl to remove carbonate material. Calgon was added as a dispersant and samples were placed in an ultrasonic bath for 10 minutes to aid disaggregation. Samples were then analysed using a Galai laser sediment analyser.

2.2.2.2 Sediment organic matter content

A sub-sample from each bulked sediment sample was dried and finely ground, then analysed for total organic carbon and total nitrogen content using an automated CHN analyser. Sediment for total organic carbon analysis was pre-treated with acid to remove carbonate material prior to analysis.

2.2.2.3 Sediment photosynthetic pigment concentration

Five replicate surface sediment scrapes were collected from each monitoring plot on each sampling occasion. Samples were stored in black containers and frozen until analysis. Sediments were analysed for chlorophyll-*a* and phaeophytin content. Chlorophyll-*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 Statistical analysis

2.3.1 Sediments

Temporal trends in sediment variables were investigated using Kendall rank correlation of abundance versus time. To adjust for Type 1 error rates, significance levels of multiple comparisons were adjusted using the Benjamini-Hochberg False Discovery Rate (FDR) (McBride, 2005). No adjustments were made for temporal autocorrelation, as the trend analyses in this report are restricted to the period for which data is available, and no attempts are made to predict relationships outside the timeframe of observations (McBride, 2005).

Principal component analyses (PCAs), based on normalised Euclidean distances, were used to assess trends over time in overall sediment characteristics (using PCA in MVSP). Following an examination of the analyses for seasonal trends, for clarity only data from April of each year were used in the figures presented in Section 3.3.

2.3.2 Macrofauna

Multivariate analysis techniques were used to examine the changes in indicator taxa abundances over time at the permanent monitoring sites. The statistical programs PRIMER (v.6, PRIMER-E Ltd, UK, 2005) and MVSP (v. 3.13, Kovach Computing Services, UK, 2003) were used for the analyses.

Multivariate patterns of community change over time were explored using non-metric multidimensional scaling (MDS) ordinations based on Bray-Curtis similarities of taxa abundance data.

Differences in macrofaunal assemblages were investigated using one-way analysis of similarities randomisation tests based on rank similarities of the samples (PRIMER ANOSIM (analysis of similarities) routine). The ANOSIM global test was used to indicate whether there were significant differences between macrofaunal communities at different sites within an estuary, or between the sampling dates within a site. ANOSIM pairwise comparison tests were used to indicate which sites were significantly different from each other within an estuary, and the extent of any differences.[3]

Macrobenthic abundance data were square-root transformed to reduce the influence that dominant species/taxa have on the results. Because only a sub-set of the species/taxa in the communities have been monitored, the dominance of taxa in the sub-set does not necessarily reflect their true dominance in the whole community, so it is appropriate to reduce their influence on the analysis (Morrisey et al., 1999). MDS ordinations were based on the mean abundance values for each indicator taxa from all the samples at each site on each sampling date. ANOSIM analyses used the indicator species/taxa data from each replicate sample collected at each site on each sampling date. The number of individuals of each indicator bivalve species in all the size-classes combined was used in all analyses.

Similar to the analysis of sediment variables, temporal trends in abundant[4] and total macrofaunal and taxa abundance data were detected using Kendall rank correlation of abundance versus time. To adjust for Type 1 error rates, significance levels of multiple comparisons were adjusted using the Benjamini-Hochberg False Discovery Rate (FDR) (McBride, 2005). No adjustments were made for temporal autocorrelation, as the trend analyses in this report are restricted to the period for which data is available, and no attempts are made to predict relationships outside the timeframe of observations (McBride, 2005). Slope estimates of trends were calculated from linear regression of taxa abundance over time, and to limit the reporting of significant trends to those of potential ecological importance, only trends with slopes exceeding 0.1 were included (equivalent to a net change in mean abundance of 2 individuals over the five years monitored). For the sites monitored quarterly, macrofaunal trend analysis was performed on the full dataset, as well as on data from half yearly monitoring, to detect whether a potential future reduction in sampling would alter the inference.

The BIO-ENV routine in PRIMER (using Spearman rank correlation, ρ_s) was used to explore the relationship between multivariate assemblage composition and sediment variables. For sediment photosynthetic pigment concentrations, samples were not

[3] The important message from the ANOSIM pair-wise tests is usually not so much the significance level, but the pair-wise *R* values, since this gives an absolute measure of how separated the groups are (Clarke & Gorley, 2006).

[4] The analysis was carried out only for abundant species, defined as those with a mean abundance of ≥ 1 at each site over all sampling dates.

available for all dates, and the PRIMER 'missing tool' application was used to estimate missing values[5]

In the BIO-ENV analysis, mean abundance values for each indicator taxa from all the samples at each site on each sampling date and the mean values for sediment variables were used. To reduce skewness, sediment variables were log transformed. Further information on the link between macrobenthic assemblage composition and sediment variables was obtained from Canonical Correspondence Analysis (CCA in MVSP) of the macrobenthic and sediment data.

It is important to note that linking patterns in the benthic macrofauna assemblages to those of sediment variables provides only an indication of which sediment characteristics may be important in contributing to the biological pattern, they do not actually prove cause-and-effect. Causality can only be demonstrated by manipulative field or laboratory experiments (Clarke and Warwick, 2001).

[5] This estimates missing values by applying an expectation maximum likelihood algorithm, which assumes a multi-normal distribution model for the data.

3 Results

3.1 Benthic macrofauna community structure

3.1.1 Southern Firth of Thames

Table 3 shows the presence of indicator species at the Firth of Thames monitoring sites. All indicator taxa apart from the polychaete genus *Euchone* were present in the Firth of Thames.

Table 3: Indicator species present at each of the permanent monitoring sites in the southern Firth of Thames.

Taxa	Kaiaua	Gun Club	Te Puru	Miranda	Kuranui Bay
Amphipods					
Corophiidae	✓	✓	✓	✓	✓
Phoxocephalidae	✓	✓	✓	✓	✓
Bivalves					
Arthritica bifurca	✓	✓	✓	✓	✓
Austrovenus stutchburyi	✓	✓	✓	✓	✓
Macomona liliana	✓	✓	✓	✓	✓
Nucula hartvigiana	✓	✓	✓	✓	✓
Paphies australis	✓	✓	✓	✓	✓
Theora lubrica	✓			✓	✓
Cumaceans					
Colurostylis lemurum	✓	✓	✓	✓	✓
Gastropods					
Cominella adspera	✓		✓	✓	✓
Notoacmea sp.		✓	✓	✓	✓
Polychaetes					
Aquilaspio aucklandica	✓	✓	✓	✓	✓
Aglaophamus sp.	✓	✓	✓	✓	✓
Aonides oxycephala	✓	✓	✓	✓	✓
Aricidea sp.	✓		✓	✓	✓
Pseudopolydora	✓	✓	✓	✓	✓
Cossura sp.	✓	✓		✓	✓
Euchone sp.					
Goniada sp.	✓			✓	✓
Glycera sp.	✓	✓	✓	✓	✓
Capitellidae	✓	✓	✓	✓	✓
Magelona dakini	✓	✓	✓	✓	✓
Nereidae	✓	✓	✓	✓	✓
Orbinia papillosa	✓	✓	✓	✓	✓
Paraonidae	✓			✓	
Anemone					
Anthopleura aureoradiata		✓		✓	✓

Figure 2 shows the major taxonomic groups found at the permanent sampling sites in the southern Firth of Thames for the years 2001 to 2006. Note that the data from 2006 is tentative, as it only includes data from April.

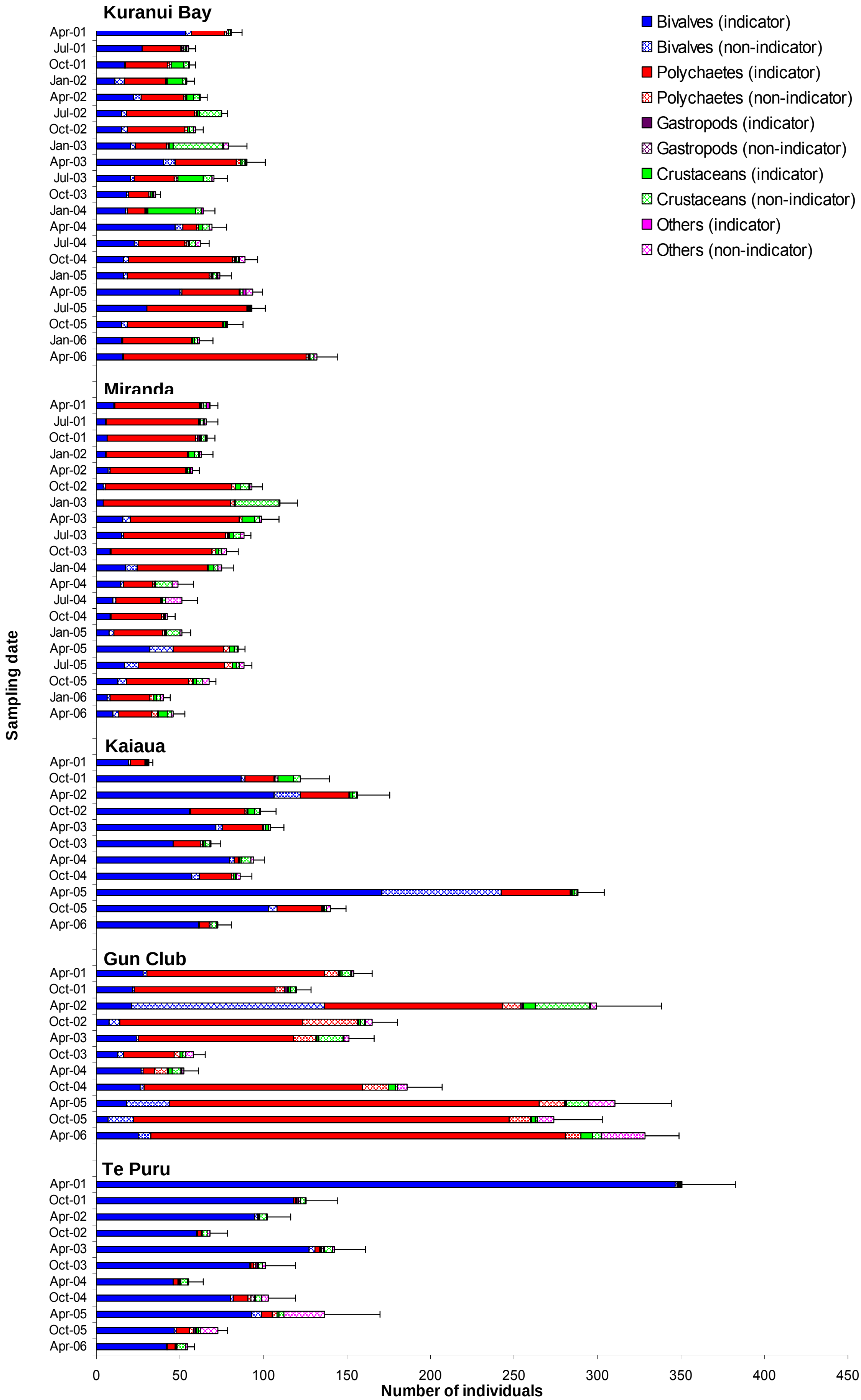


Figure 2: **Mean (± standard error) total number of individuals and major taxonomic group composition of intertidal benthic macrofauna communities (complete community – not just indicator species) at the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006.**

Figure 2 shows that macrofaunal abundance was highest at the Gun Club and lowest at Miranda. Bivalves dominated the benthic fauna at Te Puru and Kaiaua, whereas polychaetes dominated at the Gun Club and Miranda. The high proportion of non-indicator bivalves found at the Gun Club in April 2002, and at Kaiaua in April 2005 were the invasive Asian date mussel *Musculista senhousia.*

Some taxa were consistently abundant at many sites (e.g. the bivalves *Austrovenus*, *Nucula*, *Paphies Macomona*; and the polychaetes *Aonides* and Capitellidae). The three most common indicator taxa recorded at each site are shown in Appendix 1.

3.1.2 Raglan (Whaingaroa) Harbour

Table 4 shows the presence of indicator species at the Raglan (Whaingaroa) Harbour monitoring sites. All indicator species were present in Raglan Harbour, and most were found at all sites.

Table 4: Indicator species present at each of the permanent monitoring sites in Raglan (Whaingaroa) Harbour.

Taxa	Te Puna Point	Haroto Bay	Ponganui Creek	Whatitirinui Island	Okete Bay
Amphipods					
Corophiidae	✓	✓		✓	✓
Phoxocephalidae	✓	✓	✓	✓	✓
Bivalves					
Arthritica bifurca	✓	✓	✓	✓	✓
Austrovenus stutchburyi	✓	✓	✓	✓	✓
Macomona liliana	✓	✓	✓	✓	✓
Nucula hartvigiana	✓	✓	✓	✓	✓
Paphies australis	✓	✓	✓	✓	✓
Theora lubrica	✓	✓	✓	✓	✓
Cumaceans					
Colurostylis lemurum	✓	✓	✓	✓	✓
Gastropods					
Cominella adspera	✓		✓		✓
Notoacmea sp.	✓	✓	✓	✓	✓
Polychaetes					
Aquilaspio aucklandica	✓	✓	✓	✓	✓
Aglaophamus sp.	✓	✓	✓		✓
Aonides oxycephala	✓	✓	✓	✓	✓
Aricidea sp.	✓	✓	✓	✓	✓
Pseudopolydora	✓	✓	✓	✓	✓
Cossura sp.	✓	✓	✓	✓	✓
Euchone sp.				✓	✓
Goniada sp.	✓	✓	✓	✓	✓
Glycera sp.	✓	✓	✓	✓	✓
Capitellidae	✓	✓	✓	✓	✓
Magelona dakini	✓	✓		✓	✓
Nereidae	✓	✓	✓	✓	✓
Orbinia papillosa	✓			✓	✓
Paraonidae	✓	✓	✓	✓	✓
Cnidarian					
Anthopleura aureoradiata	✓	✓	✓	✓	✓

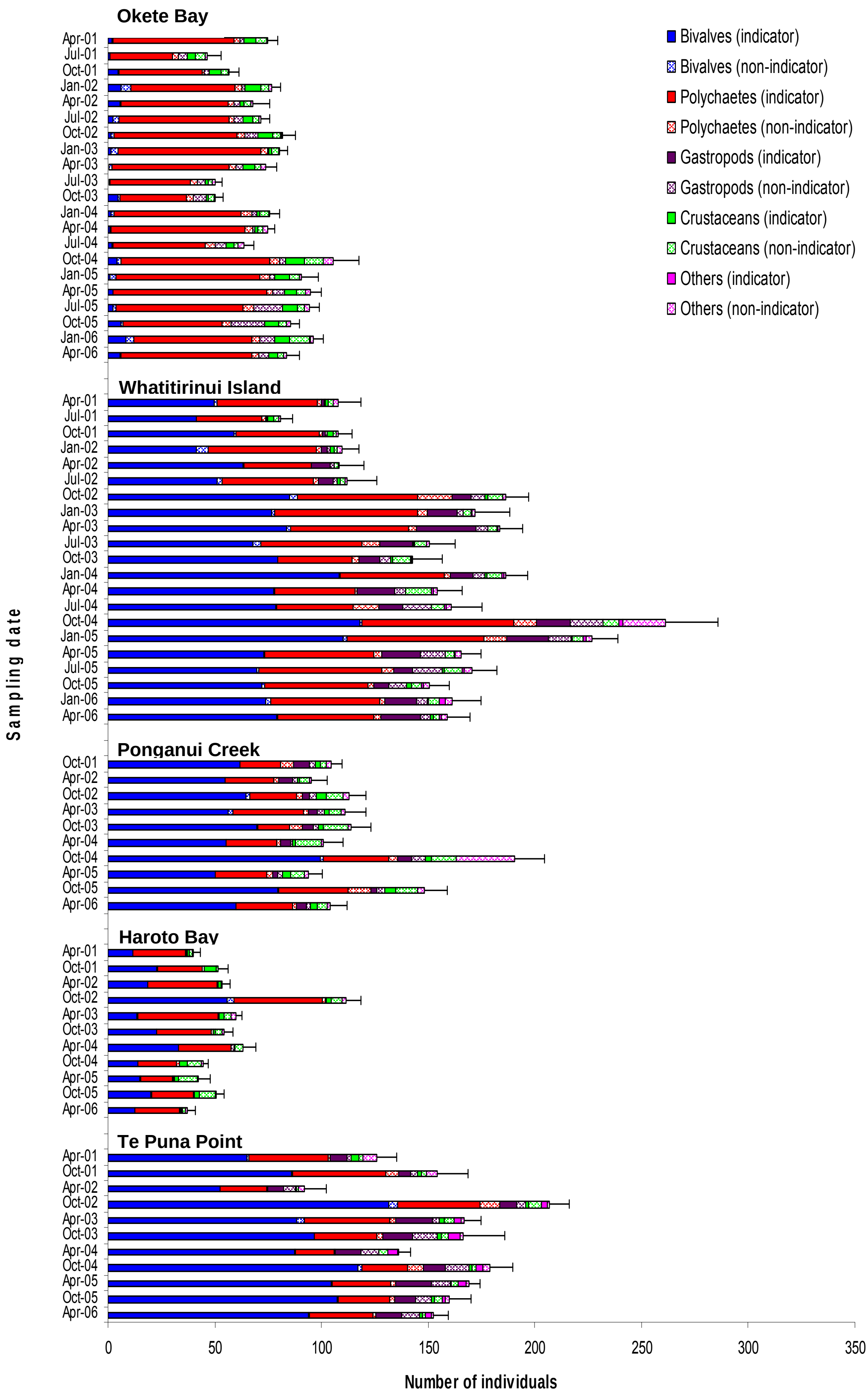


Figure 3: **Mean (± standard error) total number of individuals and major taxonomic group composition of intertidal benthic macrofauna communities (complete community – not just indicator species) at the permanent monitoring sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006.**

Figure 3 shows the major taxonomic groups found at the permanent sampling sites in Raglan Harbour. The highest abundance of individuals was found at Te Puna Point and Whatitirinui Island, and the lowest at Haroto Bay. At Whatitirinui Island, Ponganui Creek and Te Puna Point, bivalves were the most abundant taxonomic group, whereas at Okete Bay, polychaetes dominated numerically.

Consistently abundant species at the five sites in Raglan include the bivalves *Austrovenus* and *Nucula*, and the polychaetes Capitellidae and *Aquilaspio*. The three most common indicator species recorded at each site are shown in Appendix 1.

3.2 Macrofaunal changes over time

3.2.1 Southern Firth of Thames

The abundances at each sampling event for abundant indicator taxa and size frequency distribution for bivalve species are shown in Appendix 2.

The total number of taxa and the abundance of individuals found at each site are shown in Figure 4. The graphs show a great deal of fluctuation in diversity and abundance over time. The highest number of individuals was generally found at the Gun Club, and the lowest number at Miranda and Kuranui Bay. No consistent differences in the number of taxa were apparent between sites.

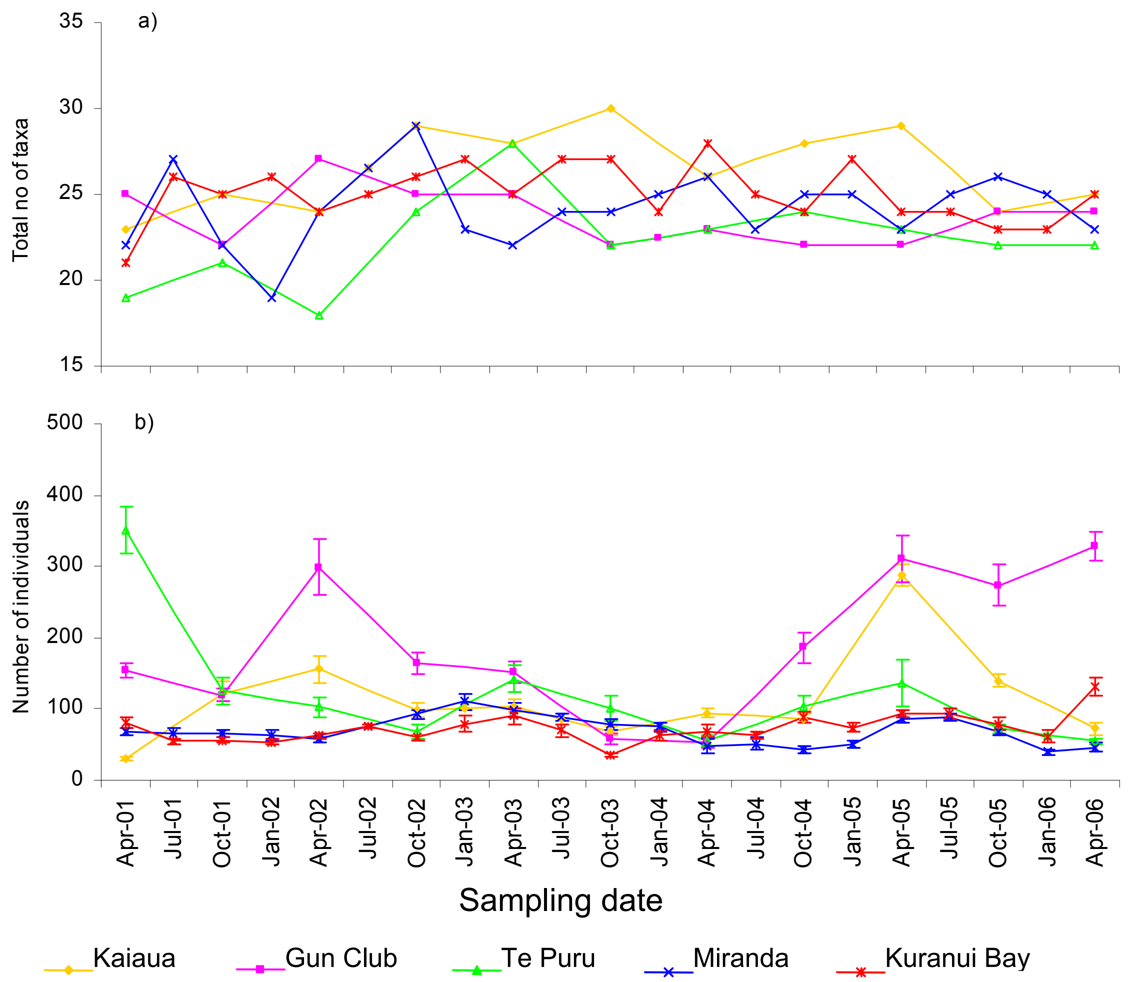


Figure 4: Total (a) number of taxa found and (b) abundance of invertebrates (mean (± standard error) total number of individuals) at each of the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006.

Trends in the abundance of individual species, total number of taxa and total number of individuals were explored using the Mann-Kendall test on abundance versus time. The statistically significant results from this analysis are shown in Table 5.

At Kaiaua, one declining trend was observed (*Theora*), and one strongly increasing trend (*Nucula*). At the Gun Club, two increasing trends were found (capitellid polychaetes and *Colurostylis*), and two possible increasing trends (*Aonides* and total abundance). At Te Puru, three strong declining trends were found (*Nucula*, *Austrovenus* and total abundance), and two weak increasing trends were found (capitellid and pseudopolydorid polychaetes). At Miranda, two declining trends were found (*Aonides* and total abundance), and four weak increasing trends (*Colurostylis*, Capitellidae, *Orbinia* and *Arthritica*). At Kuranui Bay, three increasing trends were found (capitellids, *Magelona* and total abundance).

The abundances of the different size classes of bivalves are shown in Appendix 2. The declining trend in *Theora* at Kaiaua was due to a decline in larger individuals (> 5 mm) as well as a smaller recruitment pulse in April 2005 following the initial big recruitment in 2001 and 2002, and no recruitment in April 2006. The increasing trend in *Nucula* at Kaiaua was caused by an increase in the number of larger individuals (> 2 mm), whereas the declining trend in *Nucula* at Te Puru was caused by a decrease in abundance of adults, as well as an unusually (compared to subsequent years) large recruitment pulse in April 2001. The large fluctuations in the abundance of *Macomona* at Kaiaua were caused by juvenile recruitment in April 2003 and 2004, and the decline in this species noted at Kuranui Bay was caused by a decrease in larger individuals (> 15 mm) over the monitoring period. The increase in *Arthritica* at Miranda was caused by an increase in juveniles (< 2 mm) over time. The declining trend in *Austrovenus* found at Te Puru was caused by a decline in recruitment following the initial high recruitment in April 2001, as well as a slight decline in adult *Austrovenus* over the monitoring period. At all other sites, the abundance of *Austrovenus* was cyclical, with recruitment pulses of different sizes noted in April. The number of pipi (*Paphies australis*) at the Gun Club and Te Puru fluctuated, mainly because of recruitment pulses.

For Miranda and Kuranui Bay, trend analysis of the reduced dataset of half-yearly monitoring, as opposed to the full dataset of quarterly monitoring, did not yield any change in the number of statistically significant trends detected.

Table 5: Significant ($p < 0.05$ when corrected using the Benjamini-Hochberg (1995) False Discovery Rate (FDR) procedure) results from Mann-Kendall tests on abundance versus time for fauna at each of the permanent monitoring sites in the southern Firth of Thames. Results are presented in descending order of statistical significance. Slope estimates are from linear regression analysis, and results are only reported where slope is higher than 0.1, equivalent to where there is a net change in average abundance of more than two individuals over the five years of monitoring. Trends are described as 'cyclic' when there is no clear increasing or declining trend. Only fauna with a mean abundance of ≥ 1 individual were included in the analysis.

Site	Species	Kendall tau correlation	p	Slope	Direction of trend
Kaiaua	*Nucula hartvigiana*	0.413	<0.001	2.496	Increase
	Theora lubrica	-0.469	<0.001	-0.467	Decline
	Macomona liliana	0.274	<0.001	0.121	Cyclic
	Phoxocephalidae	-0.232	<0.001	-0.161	Cyclic
	Total abundance	0.194	<0.001	3.164	Cyclic
	Capitellidae	0.155	<0.008	0.292	Cyclic
Gun Club	Capitellidae	0.425	<0.001	0.569	Increase
	Austrovenus stutchburyi	-0.223	<0.001	-0.213	Cyclic
	Aonides oxycephala	0.216	<0.001	6.488	Cyclic, possible increase
	Total abundance	0.211	<0.001	6.496	Cyclic, possible increase
	Colurostylis lemurum	0.182	<0.002	0.118	Increase
	Nereidae	-0.130	<0.025	-0.194	Cyclic
Te Puru	*Nucula hartvigiana*	-0.476	<0.001	-6.531	Decline
	Pseudopolydora	0.397	<0.001	0.160	Increase
	Capitellidae	0.381	<0.001	0.138	Increase
	Total abundance	-0.336	<0.001	-8.130	Decline
	Austrovenus stutchburyi	-0.288	<0.001	-2.784	Decline
Miranda	*Colurostylis lemurum*	0.316	<0.001	0.125	Increase
	Aonides oxycephala	-0.510	<0.001	2.696	Decline
	Capitellidae	0.353	<0.001	0.324	Increase
	Orbinia papillosa	0.348	<0.001	0.290	Increase
	Austrovenus stutchburyi	0.187	<0.001	0.270	Cyclic
	Arthritica bifurca	0.183	<0.001	0.107	Increase
	Nereidae	0.165	<0.001	0.112	Cyclic
	Total abundance	-0.140	<0.002	-0.882	Cyclic, decline
Kuranui Bay	*Magelona dakini*	0.344	<0.001	0.356	Increase
	Macomona liliana	-0.301	<0.001	-0.117	Decline
	Corophiidae	-0.295	<0.001	-0.172	Cyclic
	Capitellidae	0.184	<0.001	1.508	Increase
	Total abundance	0.183	<0.001	1.502	Increase
	Aquilaspio aucklandica	-0.177	<0.001	-0.105	Decline
	Aonides oxycephala	0.125	<0.003	0.338	Cyclic

Figure 5 shows the non-metric multi-dimensional scaling (MDS) ordination of the benthic macrofauna assemblage data at each of the five monitoring sites from April 2001 to April 2006.

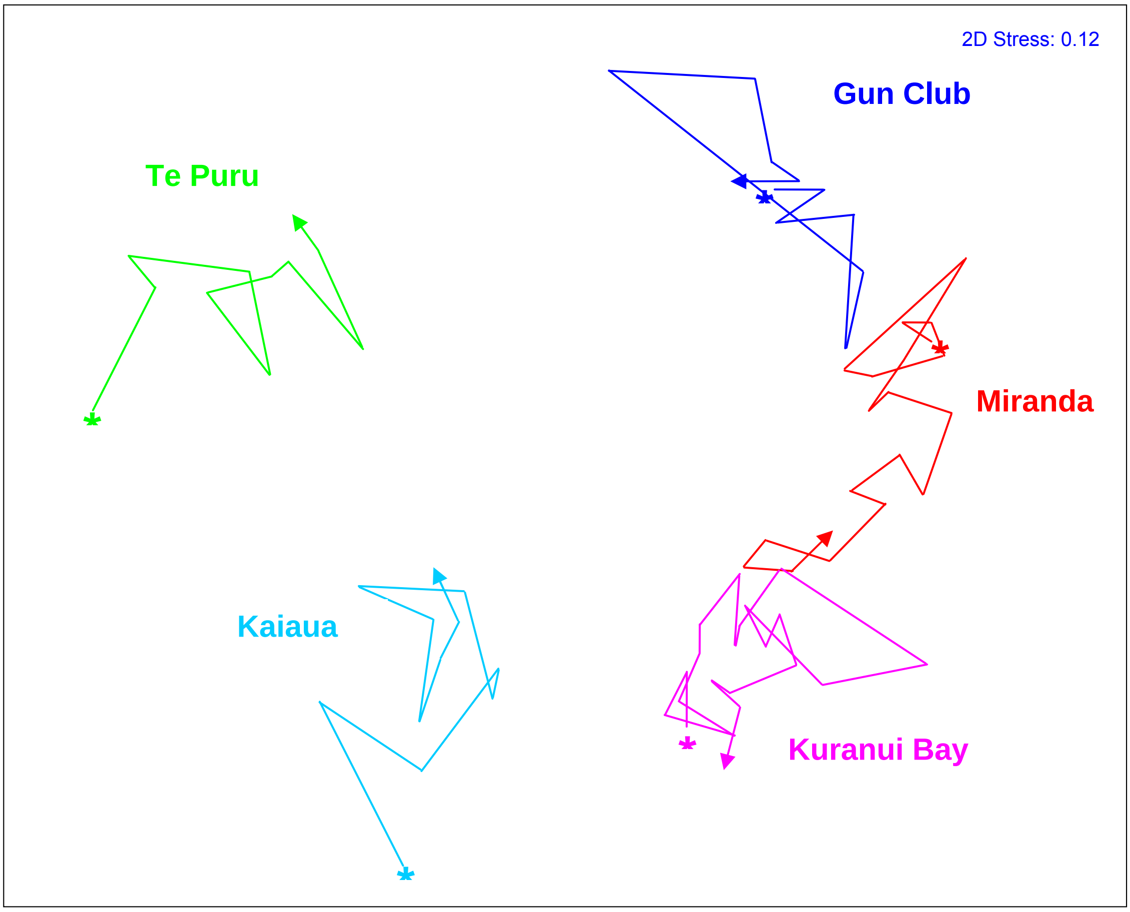


Figure 5: Non-metric multi-dimensional scaling (MDS) ordination of the square-root transformed southern Firth of Thames benthic macrofauna assemblage data based on mean abundance values for each indicator taxa from all the samples at each site on each sampling date. The first sampling date (April 2001) is shown as an asterisk, the last sampling date (April 2006) as an arrow.

Changes in macrofaunal community composition over time were evident at all sites. The five sites in the Firth of Thames show distinct differences in macrofaunal communities (Figure 5), although some overlap was apparent at times between Miranda and Kuranui Bay, and to a lesser extent Miranda and the Gun Club. The ANOSIM global test was used to indicate whether significant differences were present between the macrofaunal assemblages at the different sites (Table 6). Results indicate that sites generally separate out quite well (global *R*: 0.761[6]). As expected, the biggest differences were noted between the sites located furthest apart on the MDS plot, and the smallest differences between the sites that are located close to each other on the MDS plot.

[6] *R* values can be interpreted as follows; *R* > 0.75 = well separated, R > 0.5 = overlapping but clearly different, R < 0.25 barely separable (Clarke & Gorley, 2006).

Table 6: ANOSIM pairwise tests of the square-root transformed southern Firth of Thames benthic macrofauna assemblage data based on mean abundance values for each indicator species/taxa from all the samples at each site on each sampling date.

Pairwise comparison	*R*	p
Kaiaua, Gun Club	0.939	**
Kaiaua, Te Puru	0.670	**
Kaiaua, Miranda	0.895	**
Kaiaua, Kuranui Bay	0.633	**
Gun Club, Te Puru	0.920	**
Gun Club, Miranda	0.426	**
Gun Club, Kuranui Bay	0.844	**
Te Puru, Miranda	0.987	**
Te Puru, Kuranui Bay	0.952	**
Miranda, Kuranui Bay	0.592	**

**: p<0.01
*: p<0.05
ns: not significant

At the Gun Club and Kuranui Bay, the community in April 2006 was quite similar to that of April 2001. No clear trend over time was common for the five sites: over time, Te Puru and Kaiaua show similar changes, whereas Miranda moved in the opposite direction. ANOSIM analysis indicated that there were clear differences in assemblage composition between the sampling dates for all of the five sites. Intermediate global R values at Miranda (0.620), Kuranui Bay (0.589), Kaiaua (0.690) and the Gun Club (0.536) indicate separation of macrofaunal communities with a degree of overlap, and a lower R value at Te Puru (0.323) indicate a higher degree of overlap of community composition over time at this site.

3.2.2 Raglan (Whaingaroa) Harbour

The abundances at each sampling event for abundant indicator taxa, and size frequency distribution for bivalve species, are shown in Appendix 3.

The total number of taxa found at each site, and abundance of individuals, is shown in Figure 6. Considerable fluctuation over time in taxa richness and abundance of individuals is evident. The lowest number of taxa was consistently found at Haroto Bay, and the highest at Okete Bay, Ponganu Creek and Whatitirinui Island. The lowest number of individuals was consistently found at Haroto Bay and Okete Bay, and the highest at Te Puna Point and Whatitirinui Island.

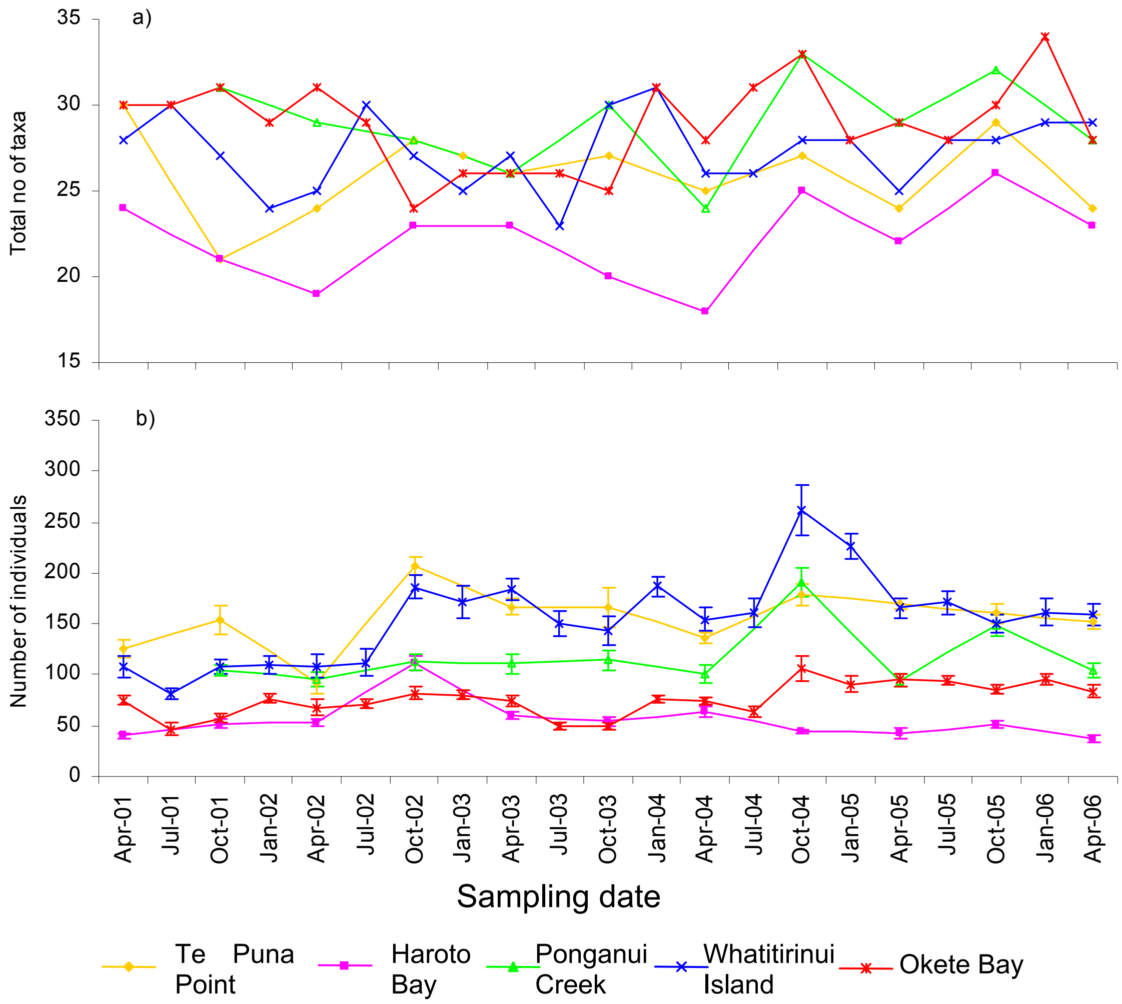


Figure 6: Total (a) number of taxa found and (b) abundance of invertebrates (mean (± standard error) total number of individuals) at each of the permanent monitoring sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006.

Trends in the abundance of individual species, total number of taxa and total number of individuals were explored using the Mann-Kendall test on abundance versus time. The statistically significant results from this analysis are shown in Table 7.

At Te Puna Point, declining trends over time were found for three taxa (*Aquilaspio*, nereidae and *Anthopleura*), and increasing trends were found for another three taxa (*Nucula*, *Austrovenus* and *Notoacmea*). At Haroto Bay, two declining trends were found (capitellid polychaetes and *Austrovenus*). At Ponganui Creek, only increasing trends were found (capitellid polychaetes and *Macomona*). At Whatitirinui Island, five increasing trends in abundance were found (*Arthritica*, *Nucula*, *Notoacmea*, *Aquilaspio* and total abundance), and one declining trend (nereid polychaetes). At Okete Bay, three increasing trends were found (*Aquilaspio*, capitellids and total abundance), and one cyclic trend for (*Cossura*).

The abundances of the different size classes of bivalves are shown in Appendix 3. The increasing trend in *Nucula* at Te Puna Point reflected an increase in larger individuals (> 2 mm) over time, whereas the increase in abundance of *Nucula* at Whatitirinui Island was caused by increases in both juveniles and adults over time. The increase in abundance of *Austrovenus* at Te Puna Point was due to an increase in recruitment of juveniles (< 5 mm) over time, whereas the decline in *Austrovenus* at Haroto Bay was caused by a decline in recruitment. At Ponganui Creek, *Macomona* increased in abundance over time, reflecting an increase in juveniles (< 5 mm). The increase in abundance of *Arthritica* at Whatitirinui Island also reflected an increase in recruitment over time.

Table 7: Significant ($p < 0.05$ when corrected using the Benjamini-Hochberg (1995) False Discovery Rate (FDR) procedure) results from Mann-Kendall tests on abundance versus time for fauna at each of the permanent monitoring sites in Raglan (Whaingaroa) Harbour. Results presented in descending order of statistical significance. Slope estimates are from linear regression analysis, and results are only reported where slope is higher than 0.1, equivalent to where there is a net change in average abundance of more than two individuals over the five years of monitoring. Trends are described as 'cyclic' where there is no clear increasing or declining trend. Only fauna with a mean abundance of ≥ 1 individual were included in the analysis.

Site	Species	Kendall tau correlation	p	Slope	Direction of trend
Te Puna Point	*Aquilaspio aucklandica*	-0.343	<0.001	-0.783	Decline
	Nucula hartvigiana	0.323	<0.001	0.923	Increase
	Anthopleura aureoradiata	-0.189	<0.001	-0.126	Decline
	Notoacmea sp.	0.166	<0.004	0.238	Increase
	Nereidae	-0.132	<0.024	-0.100	Cyclic
	Austrovenus stutchburyi	0.129	<0.027	0.519	Increase
Haroto Bay	Capitellidae	-0.256	<0.001	-0.534	Decline
	Austrovenus stutchburyi	-0.148	<0.011	-0.346	Cyclic
Ponganui Creek	Capitellidae	0.371	<0.001	0.409	Increase
	Macomona liliana	0.337	<0.001	0.348	Increase
	Total abundance	0.139	<0.03	1.519	Cyclic
Whatitirinui Island	*Arthritica bifurca*	0.367	<0.001	0.474	Increase
	Nucula hartvigiana	0.361	<0.001	1.317	Increase
	Notoacmea sp.	0.355	<0.001	0.661	Increase
	Aquilaspio aucklandica	0.364	<0.001	0.685	Increase
	Nereidae	-0.237	<0.001	-0.157	Decline
	Total abundance	0.327	<0.001	4.129	Increase
Okete Bay	*Aquilaspio aucklandica*	0.297	<0.001	0.313	Increase
	Capitellidae	0.372	<0.001	0.748	Increase
	Total abundance	0.274	<0.001	1.535	Increase
	Cossura sp.	-0.092	<0.029	-0.229	Cyclic

For Whatitirinui Island and Okete Bay, trend analysis of the reduced dataset of half-yearly monitoring, as opposed to the full dataset of quarterly monitoring, did not yield any change in the number of statistically significant trends detected.

Figure 7 shows the non-metric multi-dimensional scaling (MDS) ordination of the square-root transformed benthic macrofauna assemblage data from Raglan Harbour from April 2001 to April 2006.

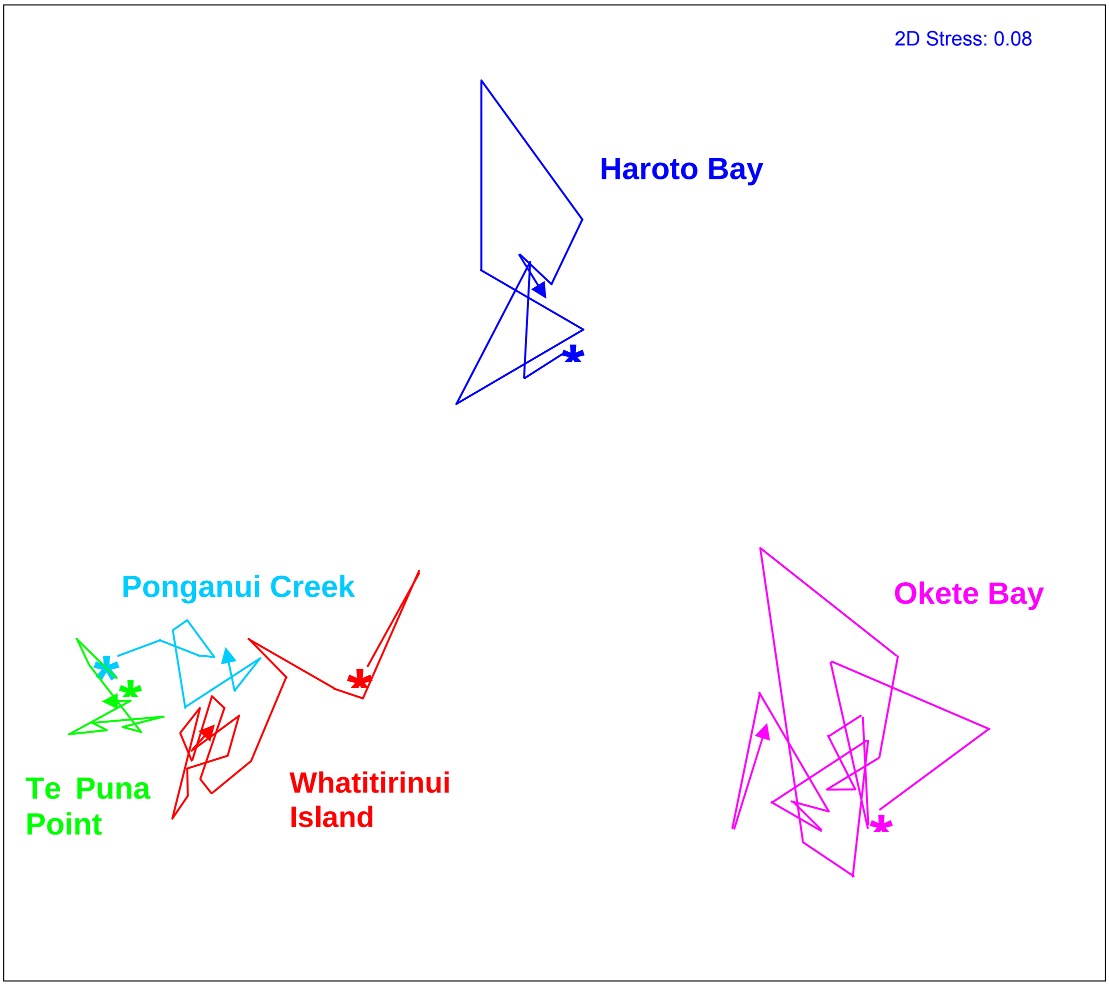


Figure 7: Non-metric multi-dimensional scaling (MDS) ordination of the square-root transformed Raglan Harbour benthic macrofauna assemblage data based on mean abundance values for each indicator taxa from all the samples at each site on each sampling date. The first sampling date (April 2001) is shown as an asterisk, the last sampling date (April 2006) as an arrow.

The MDS ordination shows the five monitoring sites to separate out quite well, although some overlap is apparent of Te Puna Point, Ponganui Creek and Whatitirinui Island. The ANOSIM global test was used to indicate whether significant differences were present between the macrofaunal assemblages at the different sites (Table 8). Results indicate that the macrobenthic community composition was overlapping somewhat but that individual sites were distinctive (global *R*: 0.705), however only small differences in macrofaunal assemblages were found between Te Puna Point, Ponganui Creek and Whatitirinui Island[7].

At Te Puna Point, the community in April 2001 was very similar to that in April 2006. Larger changes over time occurred at the other sites, although changes over time were not unidirectional at any of the sites. At Okete Bay and Haroto Bay the MDS plot show similar changes over time, whereas at Ponganui Creek changes in the opposite direction occurred[8]. ANOSIM carried out on the data on each site shows little difference in community assemblage between sampling dates at all sites. Relatively low global *R* values at Haroto Bay (0.398), Whatitirinui Island (0.393) and Okete Bay (0.439) indicate high degree of overlap in community composition over time at these sites. Low global R values at Ponganui Creek (0.184) and Te Puna Point (0.195) show that the community changes over time were barely detectable at these sites.

[7] *R* values can be interpreted as follows; *R* > 0.75 = well separated, R > 0.5 = overlapping but clearly different, R < 0.25 barely separable (Clarke & Gorley, 2006).

[8] Note that for Ponganui Creek, the first sampling event was in October 2001, rather than April 2001 as for the other sites.

Table 8: ANOSIM pairwise tests of the square-root transformed Raglan (Whaingaroa) Harbour benthic macrofauna assemblage data based on mean abundance values for each indicator species/taxa from all the samples at each site on each sampling date.

Pairwise comparison	*R*	p
Te Puna Point, Haroto Bay	0.926	**
Te Puna Point, Ponganui Creek	0.419	**
Te Puna Point, Whatitirinui Island	0.303	**
Te Puna Point, Okete Bay	0.964	**
Haroto Bay, Ponganui Creek	0.867	**
Haroto Bay, Whatitirinui Island	0.842	**
Haroto Bay, Okete Bay	0.847	**
Ponganui Creek, Whatitirinui Island	0.365	**
Ponganui Creek, Okete Bay	0.939	**
Whatitirinui Island, Okete Bay	0.943	**

**: p<0.01
*: p<0.05
ns: not significant

3.3 Sediment characteristics

3.3.1 Southern Firth of Thames

The sediment characteristics at the Firth of Thames monitoring sites are shown in Figures 8 and 10. Figure 9 provides an overview of the changes in the grain size of the sediments between April 2001 and April 2006.

The percentage mud fluctuated over time at the five sites (Figures 8a and 9), but the data shows an overall increase in the range of mud content at the five sites from 0.5-1.3% in April 2001 to 2.2-7.2% in April 2006. The highest percentage mud was found in October 2001 at Kaiaua, where sediment mud content increased from 1.3% in April 2001 to 17.9% in October 2001. This increase in mud content did not last, and in April 2002, the percentage mud at Kaiaua decreased to 4.5%. No other sites exhibited fluctuations in the percentage mud of this magnitude. At all sites, the trends towards increasing mud content of sediments were statistically significant (see Table 9).

At all sites apart from the Gun Club, fine sands (63-250 µm) made up the majority of the sediments. This size fraction increased significantly over time at all sites (Figures 8b and 9, Table 9) and was most pronounced at Miranda (from 52% to 91% of sediments) and Kaiaua (from 50 to 85% of sediments). At the Gun Club, fine sand content increased more than three-fold, from 6% to 22% of sediments, and at Kuranui Bay, it almost doubled, from 35% to 65%.

The proportion of medium sand (250-500 µm) fluctuated widely at Te Puru, Kuranui Bay and Kaiaua, increased over time at the Gun Club, and decreased significantly at Miranda (Figure 8c; Table 9).

Sediment coarse sand content (500-1000 µm) decreased at all sites over the monitored period (Figures 8d and 9). This decreasing trend was statistically significant at all sites (Table 9). The proportion of shellhash (Figure 8e) in the samples was consistently much higher at the Gun Club (~800 to 1200 g per core) than at the other sites (~60 to 300 g shellhash per core). The sediment shellhash content decreased significantly at Miranda, and possibly at the Gun Club (Table 9).

Reflecting the general increase in fine sand and mud, and the decrease in coarse sand, the median grain size decreased at all sites over the monitoring period (Figure 8f). This decrease was statistically significant at all sites (Table 9).

Sediment total organic carbon levels fluctuated over time (Figure 10a). At Kaiaua, organic carbon levels increased more than four-fold from April 2001 to October 2001.

Levels remained high in April 2002, but stabilised at a lower level by October 2002, and remained lower thereafter. This peak in sediment organic carbon coincided with the peak in sediment mud content reported for October 2001. No other sites showed fluctuations in organic carbon of the magnitude found at Kaiaua. The sudden increase in sediment mud and organic matter content suggests that a localised event occurred between April and October 2001, which caused a deposition of organically enriched fines at Kaiaua. Statistically significant decreases in sediment organic carbon content occurred at the Gun Club and Te Puru (Table 9).

Sediment total nitrogen levels fluctuated widely over time (Figure 10b). At Kaiaua, nitrogen levels increased in October 2001, and remained elevated until April 2004. This elevation coincided with the increase in sediment mud content and total organic carbon noted in October 2001. All statistically significant trends in sediment total nitrogen levels reflected cyclic trends (Table 9).

Sediment chlorophyll-*a* levels (Figure 10c) were uniformly low until April 2004, when increases in chlorophyll-*a* occurred at all sites. Levels remained high at most sites until and including October 2005, after which they declined to levels similar to those observed prior to April 2004. Sediment phaeophytin levels (Figure 10d) showed a trend similar to that observed for chlorophyll, with increases occurring at most sites in April 2004, and levels remaining high until and including October 2005, after which a decrease occurred. All statistically significant changes for sediment pigment levels reflected cyclic changes.

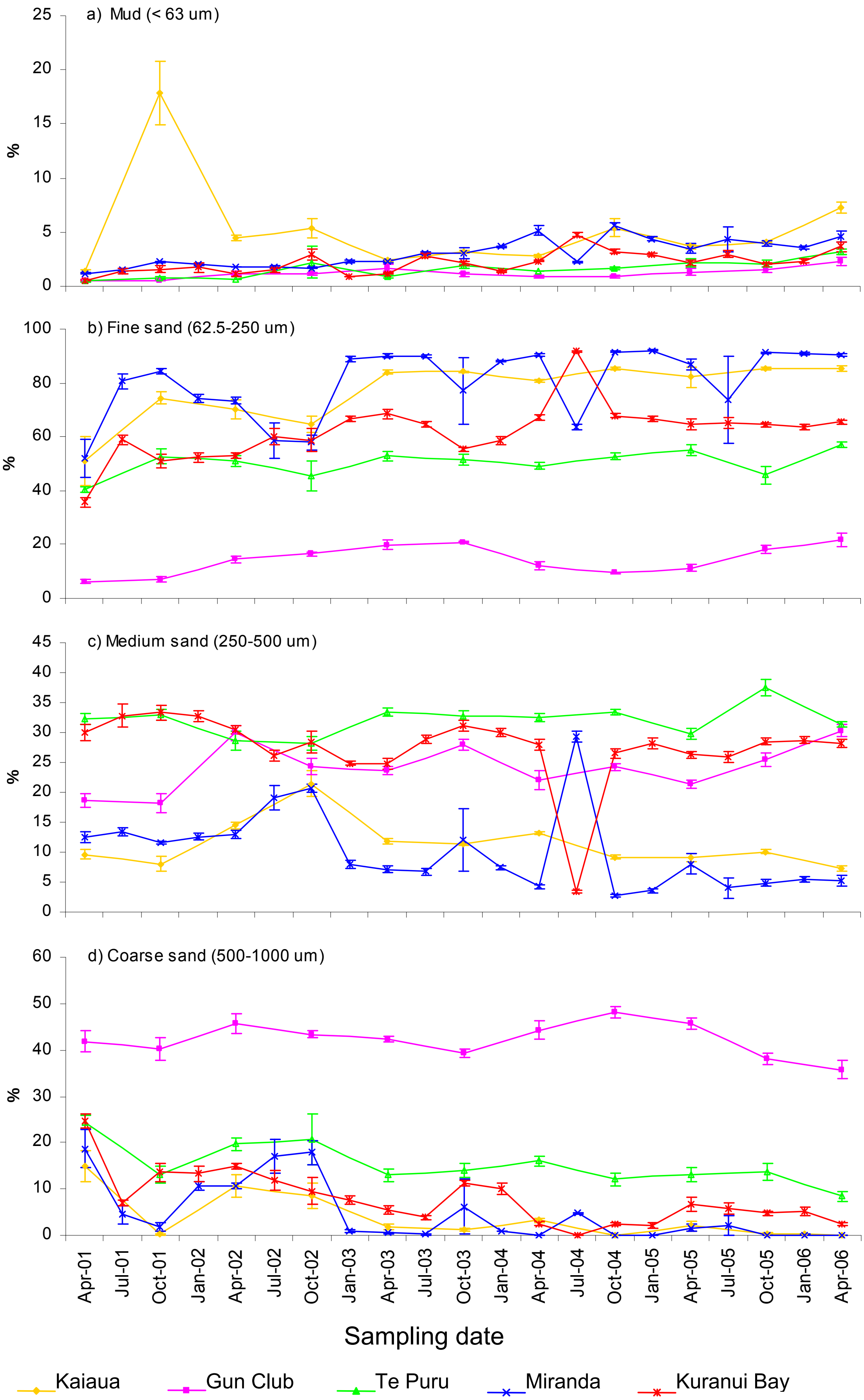


Figure 8: **Mean (± standard error, N=5) a) proportion of mud (< 63 µm); b) fine sand (62.5 – 250 µm); c) medium sand (250 – 500 µm); d) coarse sand (500 – 1000 µm); e) shellhash dry weight and f) median grain size at the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006. Note the different scales on the vertical axes.**

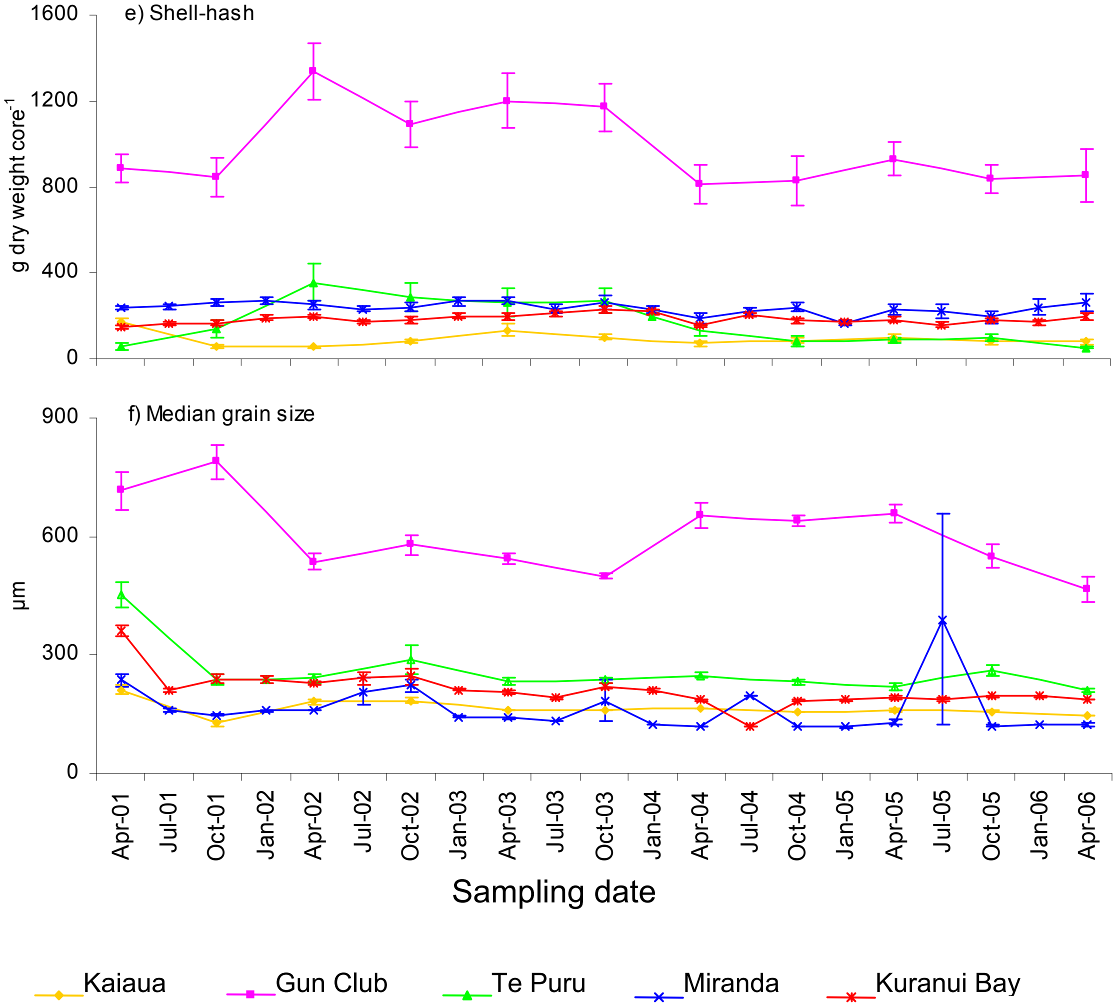


Figure 8 (cont.)

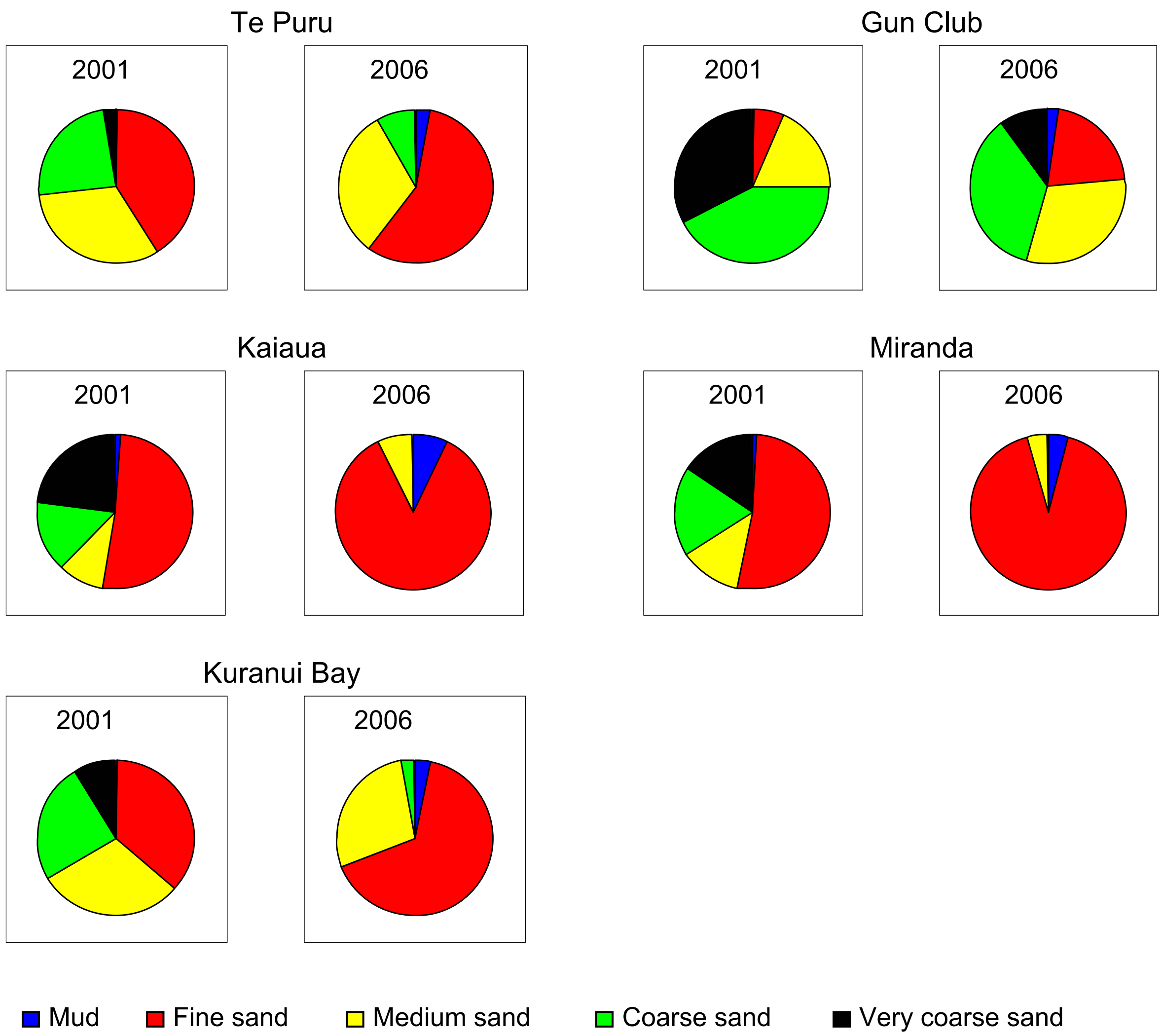


Figure 9: **Average grain size composition of the sediments at the permanent monitoring sites in the southern Firth of Thames in April 2001 and April 2006. Mud: % of <63 µm; Fine sand: 63-250 µm; Medium sand: 250-500 µm; Coarse sand: 500-1000 µm; Very coarse sand: >1000 µm.**

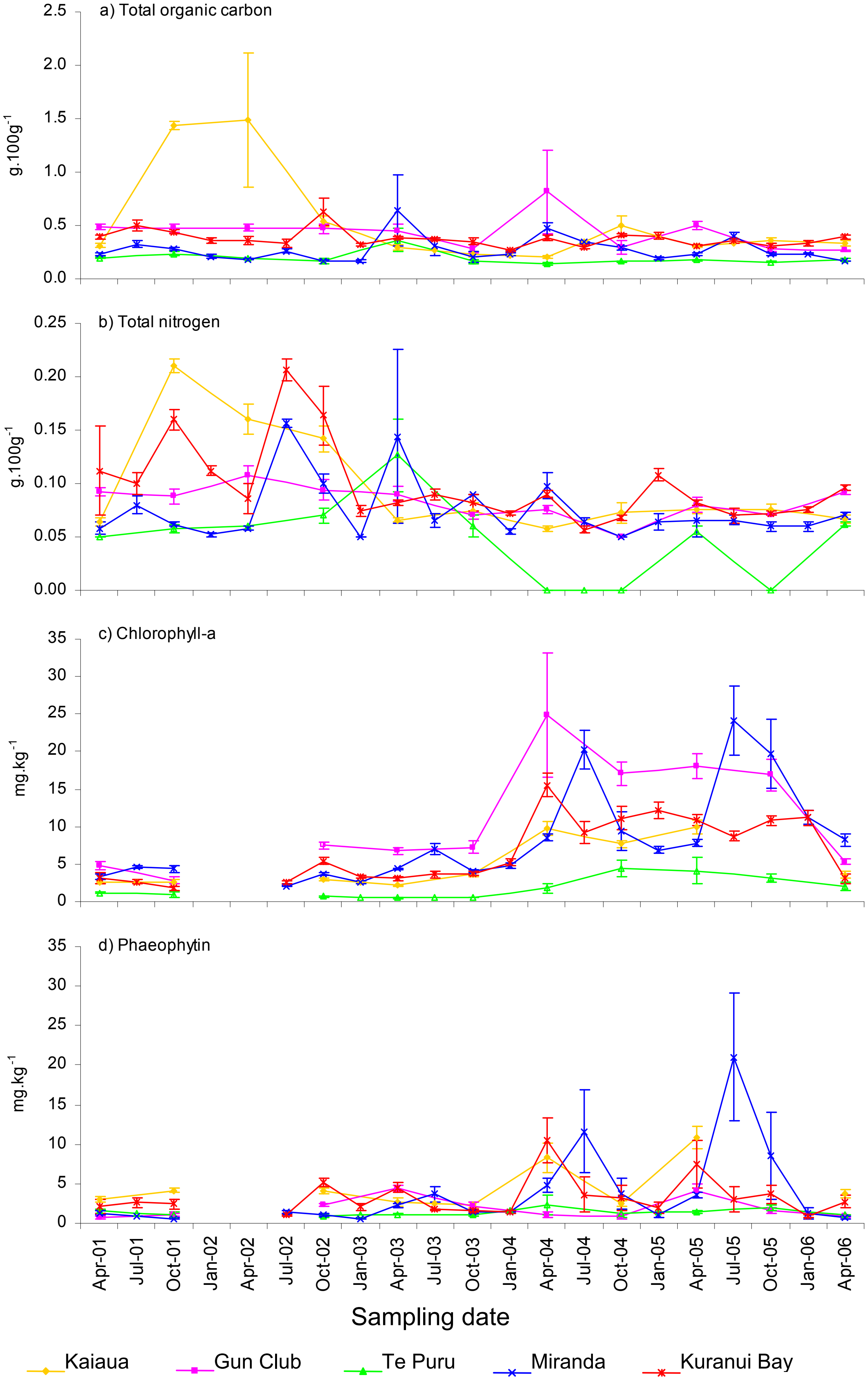


Figure 10: **Mean (± standard error, N=5) a) total organic carbon; b) total nitrogen; c) chlorophyll-a and d) phaeophytin concentration at the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006. Note the different scales on the vertical axes.**

Table 9: Results from Mann-Kendall correlation analysis of sediment characteristics versus time at each of the permanent monitoring sites in the southern Firth of Thames. Significant tests are those where p < 0.05 when corrected using the Benjamini-Hochberg (1995) False Discovery Rate (FDR) procedure. Trends are described as cyclic where no clear increasing or decreasing trend is apparent.

Parameter	Site	Kendall tau correlation	p	Direction of significant trends
Mud (% <63 µm)	Kaiaua	0.280	**	Cyclic
	Gun Club	0.363	**	Increase
	Te Puru	0.694	**	Increase
	Miranda	0.557	**	Increase
	Kuranui Bay	0.264	**	Increase
Fine sand (% 63-250 µm)	Kaiaua	0.536	**	Increase
	Gun Club	0.328	**	Increase
	Te Puru	0.255	**	Increase
	Miranda	0.433	**	Increase
	Kuranui Bay	0.375	**	Increase
Medium sand (% 250-500 µm)	Kaiaua	-0.288	**	Cyclic
	Gun Club	0.234	*	Cyclic, possible increase
	Te Puru	0.087	ns	-
	Miranda	-0.451	**	Decrease
	Kuranui Bay	-0.231	**	Cyclic
Coarse sand (% 500-1000 µm)	Kaiaua	-0.433	**	Cyclic
	Gun Club	-0.111	ns	Decrease
	Te Puru	-0.401	**	Decrease
	Miranda	-0.493	**	Decrease
	Kuranui Bay	-0.455	**	Decrease
Shellhash (g core^{-1})	Kaiaua	-0.096	ns	-
	Gun Club	-0.152	**	Cyclic, possible decrease
	Te Puru	-0.112	ns	-
	Miranda	-0.192	**	Decrease
	Kuranui Bay	0.040	ns	-
Median grain size (µm)	Kaiaua	-0.409	**	Cyclic
	Gun Club	-0.251	**	Decrease
	Te Puru	-0.325	**	Decrease
	Miranda	-0.504	**	Decrease
	Kuranui Bay	-0.532	**	Decrease
Total organic carbon (g 100 g^{-1})	Kaiaua	-0.213	*	Cyclic
	Gun Club	-0.365	**	Decrease
	Te Puru	-0.200	*	Decrease
	Miranda	-0.022	ns	-
	Kuranui Bay	-0.174	**	Cyclic
Total nitrogen (g 100 g^{-1})	Kaiaua	-0.354	**	Cyclic
	Gun Club	-0.351	**	Cyclic
	Te Puru	-0.218	*	Cyclic
	Miranda	-0.023	ns	-
	Kuranui Bay	-0.247	**	Cyclic
Chlorophyll-a (mg kg^{-1})	Kaiaua	0.445	**	Cyclic
	Gun Club	0.391	**	Cyclic
	Te Puru	0.324	**	Increase
	Miranda	0.569	**	Cyclic, possible increase
	Kuranui Bay	0.495	**	Cyclic
Phaeophytin (mg kg^{-1})	Kaiaua	0.118	ns	-
	Gun Club	-0.045	ns	-
	Te Puru	0.059	ns	-
	Miranda	0.135	ns	-
	Kuranui Bay	-0.001	ns	-

**: p<0.01
*: p<0.05
ns: not significant

No consistent seasonal fluctuations were apparent in the monitored sediment parameters.

Figure 11 shows the results from Principal Components Analysis of the sediment data from the Firth of Thames sampling sites in April of each year. The Figure shows a clear trend at all sites towards greater sediment mud and fine sand content, and less medium and coarse sand. The large influx of organically enriched muddy sediments at Kaiaua shows up clearly on the biplot.

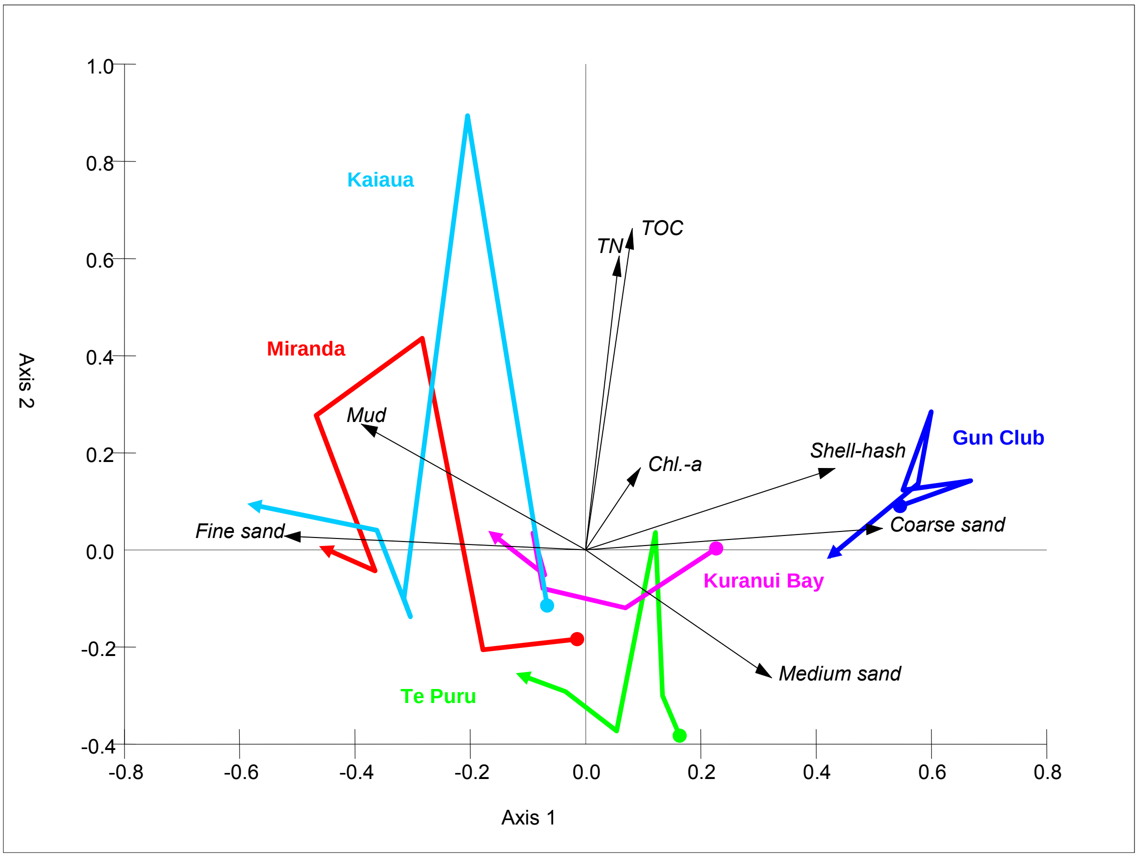


Figure 11: Biplot of Principal Components Analysis (PCA) of the sediment data, showing changes over time in the month of April in sediment characteristics at the five monitoring sites in the Firth of Thames. The first sampling date (April 2001) is shown as a circle, the last sampling date (April 2006) as an arrow. Superimposed on the plot are the vectors for the different sediment characteristics: TOC: total organic carbon; TN: total nitrogen; Mud: % of <63 µm; Fine sand: 63-250 µm; Medium sand: 250-500 µm; Coarse sand: 500-1000 µm.

3.3.2 Raglan (Whaingaroa) Harbour

Figures 12, 13 and 14 show the sediment characteristics at the sampling sites in Raglan Harbour, and Table 10 shows the results from trend analysis of the sediment data versus time. Monitoring at Ponganui Creek began in October 2001, therefore no data is available for this site prior to that time.

Sediment mud content increased at all sites over the period of monitoring (Figures 12a and 13). The most marked increased occurred at Haroto Bay, where mud content increased from an average of 6.6% to an average of 32%. Since the monitoring commenced, Haroto Bay has consistently been muddier than the other sites monitored in Raglan Harbour. The increase in mud between 2001 and 2006 was statistically significant at all sites (Table 10).

Fine sand (63-250 µm) constituted the majority of the sediments, and the proportion of fine sands increased dramatically over the monitoring period at all sites (Figures 12b and 13). The most drastic increase was at Okete Bay, where the proportion of fine sands in the sediments increased from 24% to 85% between April 2001 and July 2001, after which they remained high. At Te Puna Point, the proportion of fine sands more than doubled between April 2001 and April 2006 (from 34% to 77%), and at Whatitirinui Island it nearly doubled (from 34% to 67%). The increases were statistically significant at all sites apart from Okete Bay, where all values apart from those from April 2001 were consistently high (Table 10).

The proportion of medium sands (250-500 µm) decreased over time at all sites (Figures 12c and 13). The decreasing trends were statistically significant at all sites. Similarly, the sediment coarse sand (500-1000 µm) decreased significantly over time at all sites (Figures 12d and 13, and Table 10).

The sediment shellhash content fluctuated over the monitoring period, but no clear increasing or declining trends were apparent (Figure 12d). Sediment shellhash content was consistently lowest at Okete Bay, and highest at Ponganui Creek.

The median grain size decreased over the duration of the monitoring period (Figure 12e), reflecting the increase in sediment fine sands and mud, and the decrease in medium and coarse sand. The trend of decreasing median grain size was statistically significant at all sites (Table 10).

Sediment total organic carbon content showed fluctuations over time at all sites, but no clear increasing or decreasing trends were discernable (Figure 14a). Sediment total nitrogen levels also fluctuated over time, but again no clear increasing or decreasing trends were found (Figure 14b).

The sediment pigment (chlorophyll-*a* and phaeophytin) concentrations showed a great deal of variation over time (Figures 14c and 14d). Samples from January and April of 2002 were lost due to lab error and as a result there is a gap in the data. Chlorophyll-*a* levels were relatively low in 2001, and remained low at Whatitirinui Island, Okete Bay and Haroto Bay up until and including April 2003, after which concentrations increased. Chlorophyll-*a* concentrations remained elevated at most sites up until April 2006, when they decreased at all sites to levels similar to those found in 2001. Chlorophyll-*a* levels were generally highest at Te Puna Point, and lowest at Okete Bay. Sediment phaeophytin data showed a similar trend of increasing concentrations after October 2002, with levels remaining high and very variable at all sites until April 2006, where concentrations were uniformly low. Due to the great fluctuations over time, all statistically significant trends were deemed cyclic (Table 10).

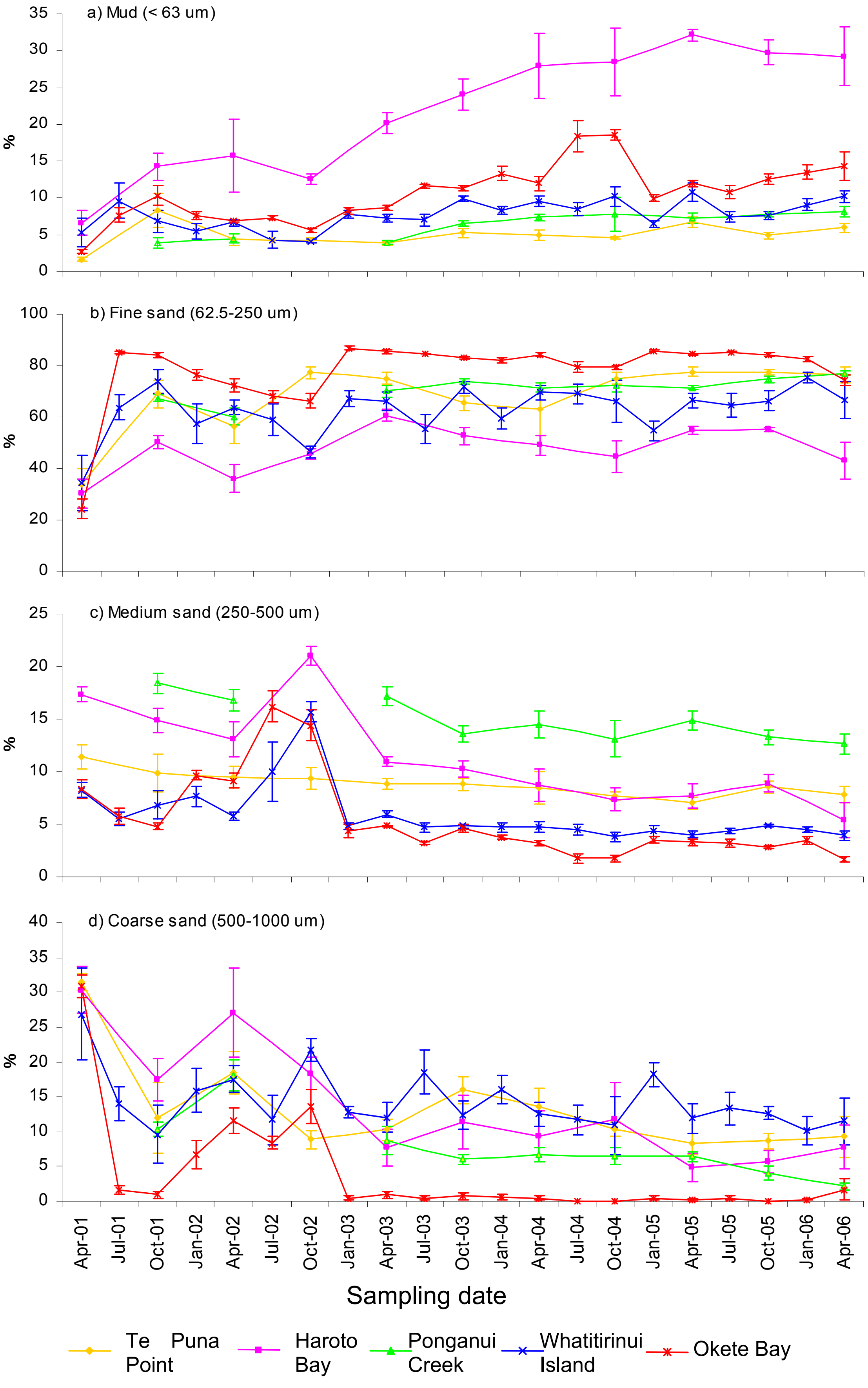


Figure 12: Mean (± standard error, N=5) a) proportion of mud (< 63 µm); b) fine sand (62.5 – 250 µm); c) medium sand (250 – 500 µm); d) coarse sand (500 – 1000 µm); e) shellhash dry weight and f) median grain size at the permanent monitoring sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006. Note the different scales on the vertical axes.

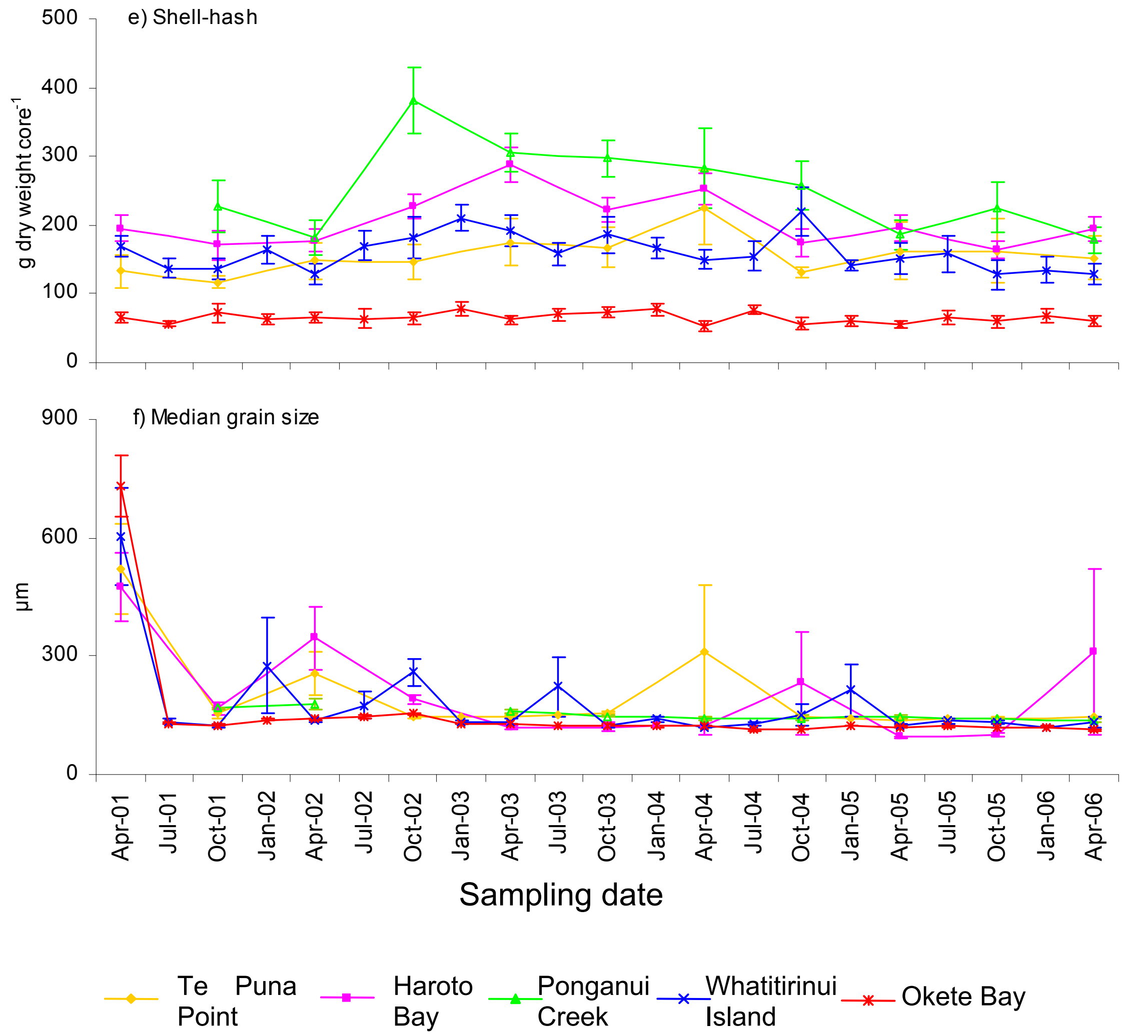


Figure 12 (cont.)

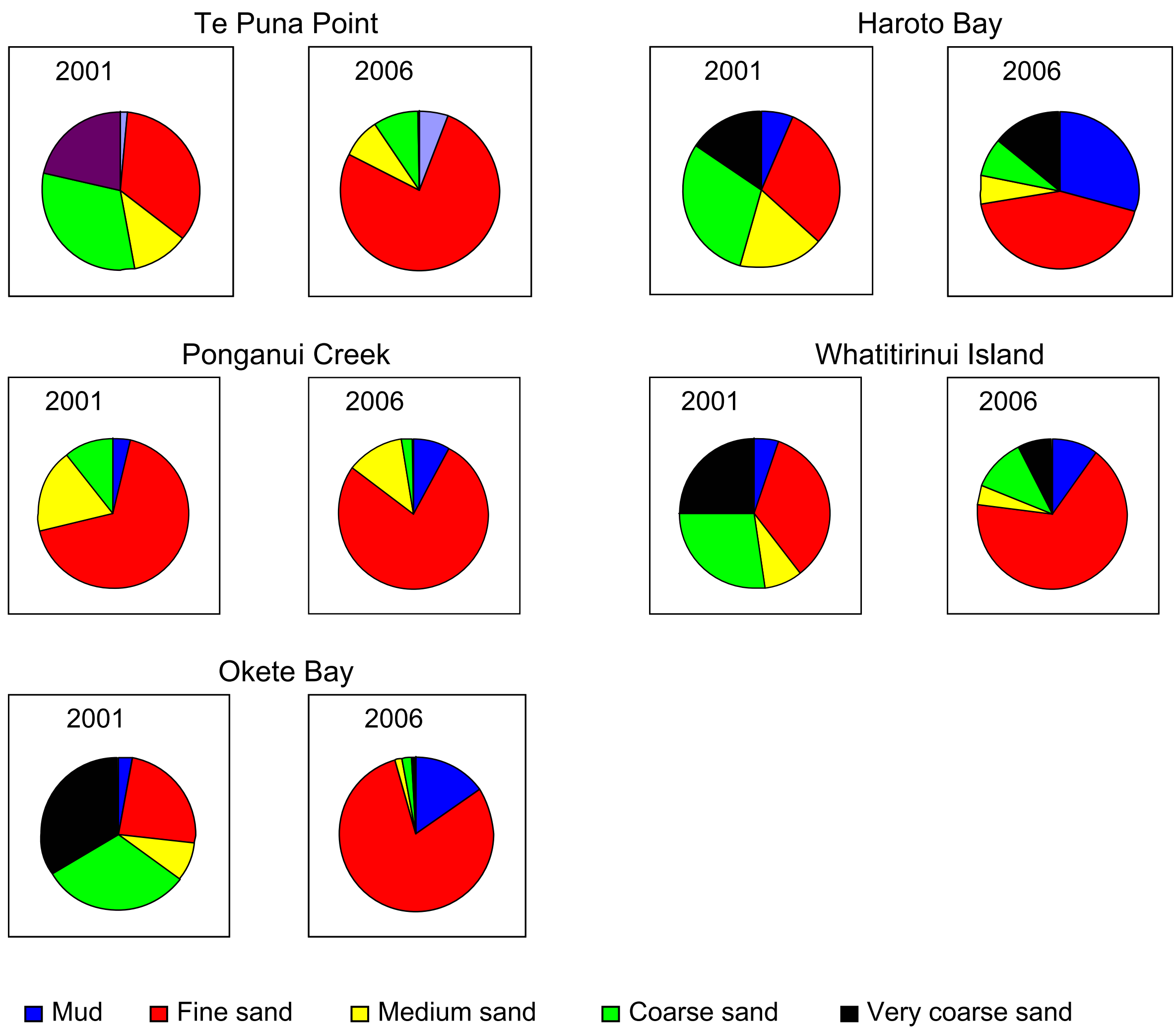


Figure 13: Average grain size composition of the sediments at the permanent monitoring sites in Raglan (Whaingaroa) Harbour in April 2001 and April 2006, apart from at Ponganui Creek, where October 2001 is shown because this site was not sampled in April 2001. Mud: % of <63 µm; Fine sand: 63-250 µm; Medium sand: 250-500 µm; Coarse sand: 500-1000 µm; Very coarse sand: >1000 µm.

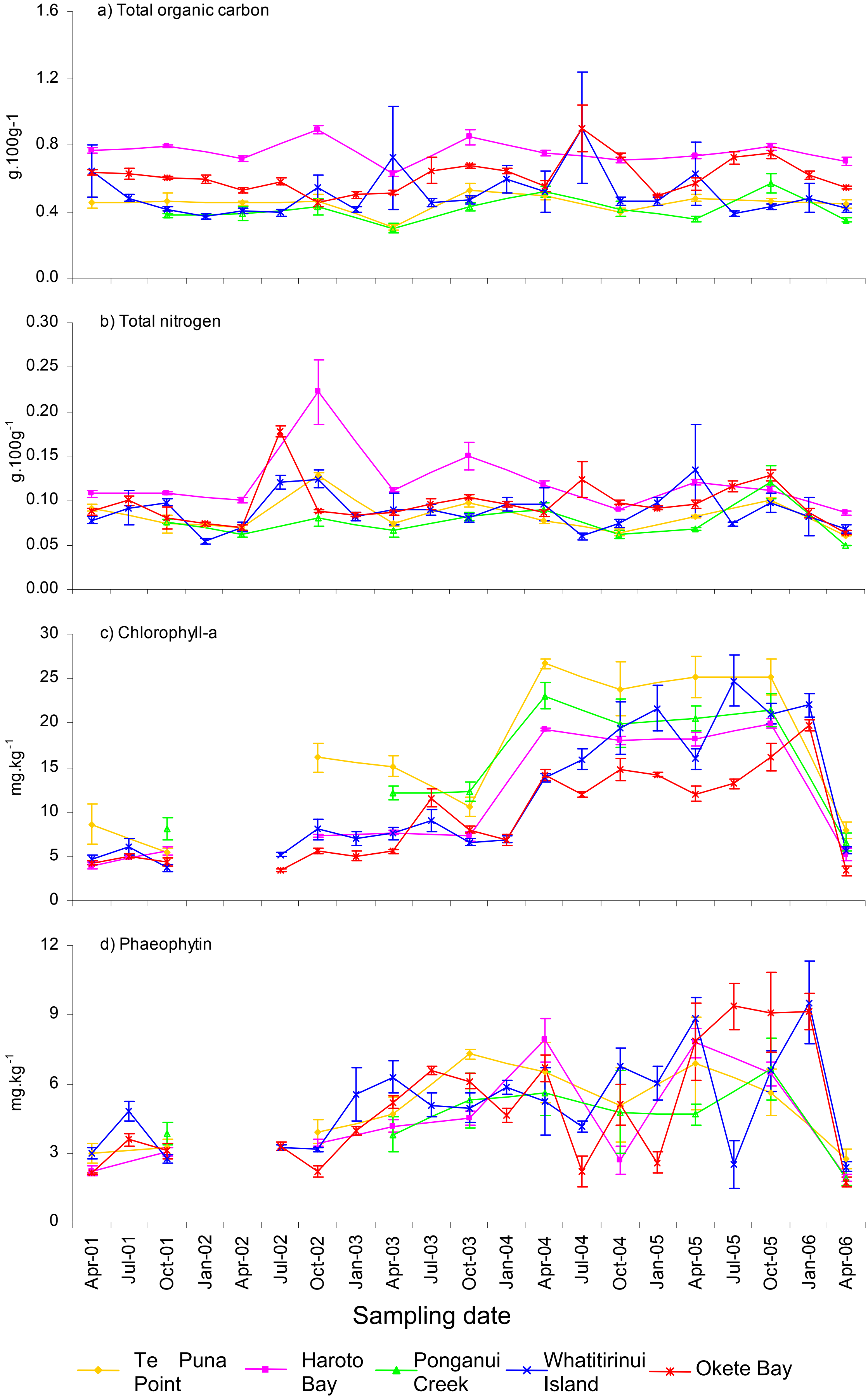


Figure 14: Mean (± standard error, N=5) a) total organic carbon; b) total nitrogen; c) chlorophyll-*a* and d) phaeophytin concentration at the permanent monitoring sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006. Note the different scales on the vertical axes.

Table 10: Results from Mann-Kendall correlation analysis of sediment characteristics versus time at each of the permanent monitoring sites in Raglan (Whaingaroa) Harbour. Significant tests are those where p < 0.05 when corrected using the Benjamini-Hochberg (1995) False Discovery Rate (FDR) procedure. Trends are described as cyclic where no clear increasing or decreasing trend is apparent.

Parameter	Site	Kendall tau correlation	p	Direction of significant trends
Mud (% <63 µm)	Te Puna Point	0.324	**	Increase
	Haroto Bay	0.584	**	Increase
	Ponganui Creek	0.537	**	Increase
	Whatitirinui Island	0.271	**	Increase
	Okete Bay	0.560	**	Increase
Fine sand (63-250 µm)	Te Puna Point	0.358	**	Increase
	Haroto Bay	0.230	*	Increase
	Ponganui Creek	0.460	**	Increase
	Whatitirinui Island	0.166	*	Increase
	Okete Bay	0.130	ns	-
Medium sand (%250-500 µm)	Te Puna Point	-0.274	**	Decrease
	Haroto Bay	-0.584	**	Decrease
	Ponganui Creek	-0.446	**	Decrease
	Whatitirinui Island	-0.386	**	Decrease
	Okete Bay	-0.521	**	Decrease
Coarse sand (% 500-1000 µm)	Te Puna Point	-0.320	**	Decrease
	Haroto Bay	-0.448	**	Decrease
	Ponganui Creek	-0.549	**	Decrease
	Whatitirinui Island	-0.174	**	Decrease
	Okete Bay	-0.460	**	Decrease
Shellhash (g core^{-1})	Te Puna Point	0.019	ns	-
	Haroto Bay	-0.038	ns	-
	Ponganui Creek	-0.105	ns	-
	Whatitirinui Island	-0.071	ns	-
	Okete Bay	-0.014	ns	-
Median grain size (µm)	Te Puna Point	-0.344	**	Decrease
	Haroto Bay	-0.491	**	Cyclic, possibly decrease
	Ponganui Creek	-0.581	**	Decrease
	Whatitirinui Island	-0.211	**	Decrease
	Okete Bay	-0.573	**	Decrease
Total organic carbon (g 100 g^{-1})	Te Puna Point	0.061	ns	-
	Haroto Bay	-0.148	ns	-
	Ponganui Creek	0.107	ns	-
	Whatitirinui Island	-0.012	ns	-
	Okete Bay	0.119	ns	-
Total nitrogen (g 100 g^{-1})	Te Puna Point	-0.107	ns	-
	Haroto Bay	-0.122	ns	-
	Ponganui Creek	-0.061	ns	-
	Whatitirinui Island	-0.080	ns	-
	Okete Bay	0.142	*	Cyclic
Chlorophyll-a (mg kg^{-1})	Te Puna Point	0.348	**	Cyclic
	Haroto Bay	0.444	**	Cyclic
	Ponganui Creek	1.992	ns	-
	Whatitirinui Island	0.569	**	Cyclic
	Okete Bay	0.526	**	Cyclic
Phaeophytin (mg kg^{-1})	Te Puna Point	0.169	ns	-
	Haroto Bay	0.270	**	Cyclic
	Ponganui Creek	-0.063	ns	-
	Whatitirinui Island	0.240	**	Cyclic
	Okete Bay	0.308	**	Cyclic

**: p<0.01
*: p<0.05
ns: not significant

No consistent seasonal patterns were discernible in the sediment characteristics.

Figure 15 shows the results from Principal Components Analysis of the sediment data from the Raglan (Whaingaroa) Harbour sampling sites in April of each year. The Figure shows clear trends towards less coarse sand at all sites, and the trends towards increased sediment mud content at Haroto Bay and Okete Bay are also apparent.

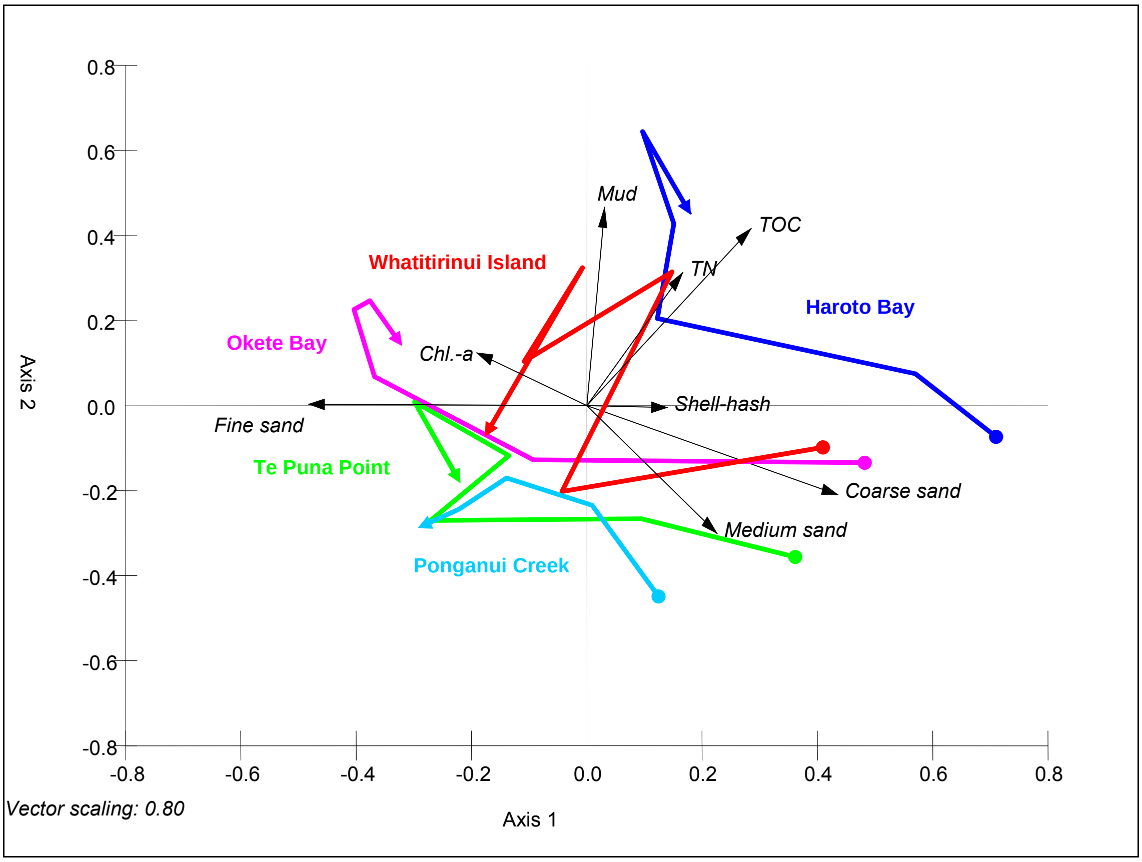


Figure 15: Principal Components Analysis (PCA) of the sediment data, plotted in two-dimensional space, showing changes over time in the month of April in sediment characteristics at the five monitoring sites in Raglan (Whaingaroa) Harbour. The first sampling date (April 2001) is shown as a circle, the last sampling date (April 2006) as an arrow, except for Ponganui Creek, where the first April sample was taken in 2002. Superimposed on the plot are the vectors for the different sediment characteristics: TOC: total organic carbon; TN: total nitrogen; Mud: % of <63 µm; Fine sand: 63-250 µm; Medium sand: 250-500 µm; Coarse sand: 500-1000 µm.

3.4 Linking assemblage composition to sediment characteristics

3.4.1 Southern Firth of Thames

Shellhash was found to be the single sediment variable which best explained the patterns of macrofauna assemblage composition (PRIMER BEST analysis, Spearman rank correlation coefficient ρ_s = 0.462). Shellhash and chlorophyll-*a* concentration were the best 2-sediment variables found (ρ_s = 0.528), and the best 3-sediment variable combination was shellhash, chlorophyll-*a* and total organic carbon concentrations (ρ_s = 0.540).

Results from canonical correspondence analysis of the macrofauna data for the Firth of Thames can be seen in Figure 16. The analysis shows the Gun Club and Kaiaua / Kuranui Bay to cluster at opposite ends of the spectrum of sediment shellhash and mud levels. The analysis also shows Te Puru to group separately correlating with the lower chlorophyll-*a* levels and higher medium sand content at this site, and Miranda, the Gun Club and Kuranui Bay to group in the direction towards higher sediment chlorophyll-*a* levels. Over time, there was no common direction of change between the different sites, and Miranda was the only site where changes over time correlated with increasing fine sand and mud content of sediment.

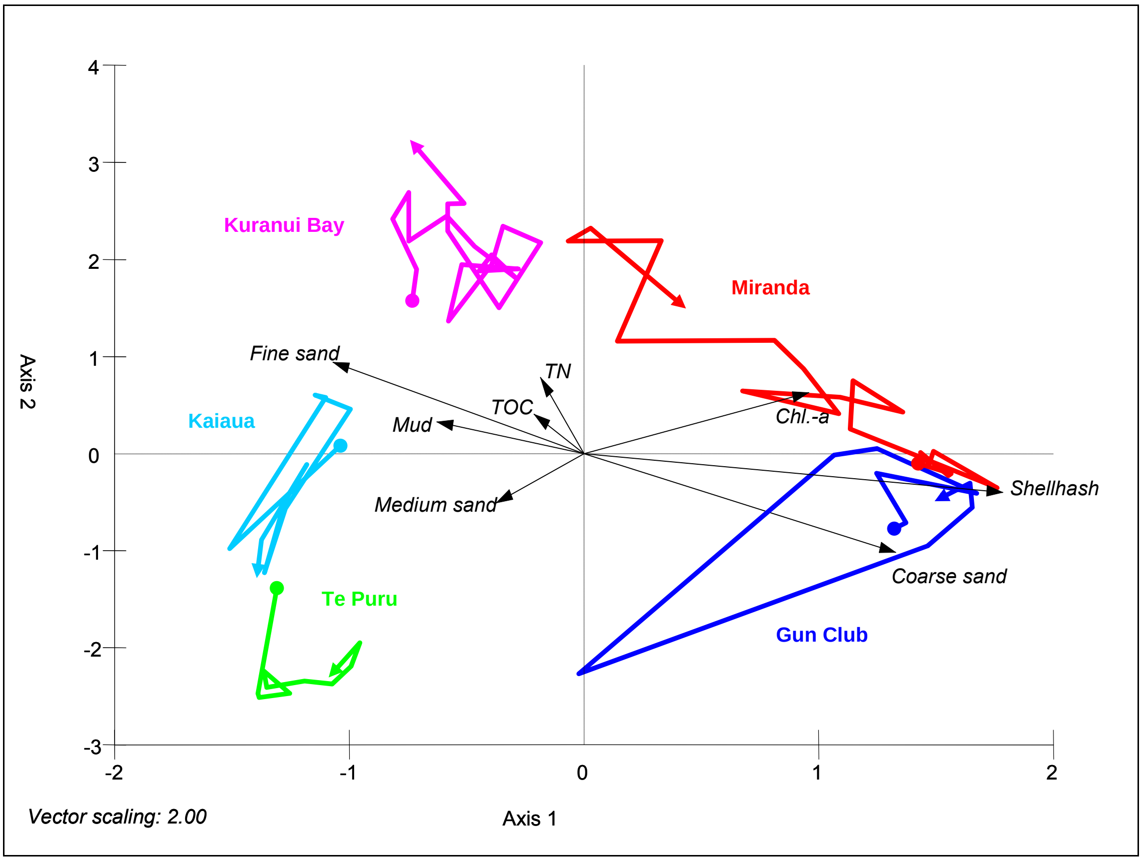


Figure 16: Biplot from canonical correspondence analysis of the macro-invertebrate data at each of the five sites in the southern Firth of Thames between April 2001 and April 2006. Closed circles indicate April 2001; arrows April 2006. Superimposed on the plot are the vectors for environmental variables: TOC: total organic carbon; TN: total nitrogen; Chl.-a: chlorophyll-*a*; Mud: sediments <63 µm; Fine sand: sediments 63-250 µm; Medium sand: sediments 250-500 µm; Coarse sand: sediments 500-1000 µm. Eigenvalues: axis 1: 0.472; axis 2: 0.206. Percentage of total variance explained: axis 1 = 21.1; axis 2 = 9.2.

3.4.2 Raglan (Whaingaroa) Harbour

Similar to the Firth of Thames, in Raglan (Whaingaroa) Harbour, sediment shellhash was found to be the single sediment variable which best explained the patterns of macrofauna assemblage composition (PRIMER BEST analysis, Spearman rank correlation coefficient ρ_s = 0.535). The best 2-sediment variable combination was shellhash and the proportion of mud (grain size < 63 µm), which was marginally better than the single sediment parameter (ρ_s = 0.539). The best 3-sediment variable combination included shellhash, the proportion of mud and coarse sands (the grain size fraction 500-1000 µm) (ρ_s = 0.542). This was the highest correlation found in the BEST analysis.

Results from canonical correspondence analysis of the macrofauna data for Raglan (Whaingaroa) Harbour can be seen in Figure 17. Okete Bay clustered separately from other sites towards the high end of Axis 1, correlating with low shellhash levels found at this site. A clear gradient of decreasing sediment mud and total organic carbon content could be found from Haroto Bay, towards Whatitirinui Island, Ponganui Creek and Te Puna Point. No consistent trends in assemblage composition linked with environmental parameters were evident across all sites over time: Ponganui Creek moved in the direction of increasing sediment mud content, whereas Whatitirinui Island moved in the opposite direction.

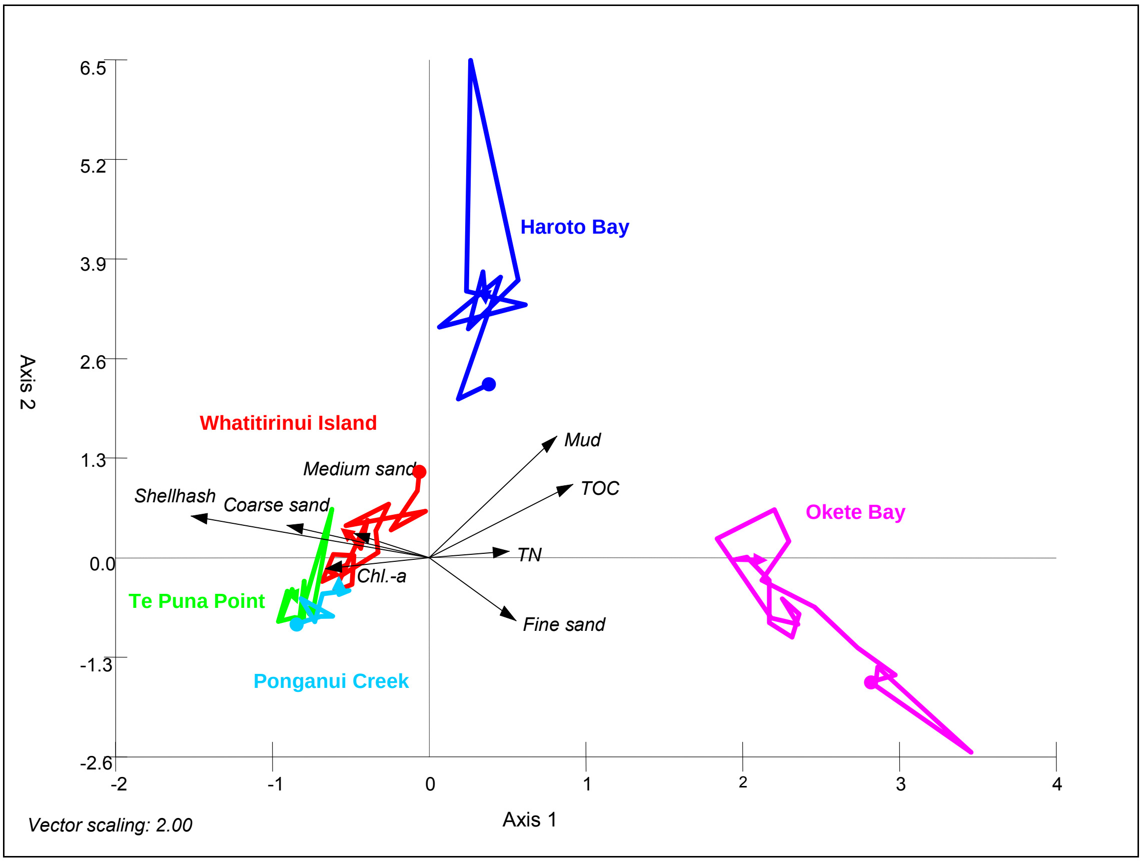


Figure 17: Biplot from canonical correspondence analysis of the macro-invertebrate data at each of the five sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006. Closed circles indicate April 2001; arrows April 2006. Superimposed on the plot are the vectors for environmental variables: TOC: total organic carbon; TN: total nitrogen; Chl.-a: chlorophyll-*a*; Mud: sediments <63 µm; Fine sand: sediments 63-250 µm; Medium sand: sediments 250-500 µm; Coarse sand: sediments 500-1000 µm. Eigenvalues: axis 1: 0.357; axis 2: 0.091. Percentage of total variance explained: axis 1 = 39.5; axis 2 = 10.1.

4 Discussion

This report investigates:

- The current status of health of the estuaries, based on invertebrate community and sediment characteristics; and
- Temporal changes in the health of the estuaries over the duration of the monitoring to date.

The report also aims to provide recommendations for future monitoring.

To address these questions, the discussion below aims to first characterise the sediment and macrofaunal environments of the two estuaries monitored, and next to look at changes in sediment parameters and macrofaunal assemblages over time. Finally, recommendations for future monitoring are provided.

Macrofaunal assemblages often show great variability over time, and a number of naturally varying parameters not measured in this study (such as predation, recruitment, temperature, insolation, wave exposure, salinity, tidal exposure) can influence the abundances of individual taxa, and cause cyclic changes in abundances. Such natural cyclical changes can last from a few months to many years. Changes in the sediment parameters measured (sediment grain size, organic matter, etc.) can also cause changes in macrofaunal abundances. Because trends in these parameters over time may reflect changes in land management and resultant terrestrial runoff, it is these changes that Environment Waikato is most interested in identifying. The following discussion therefore attempts to identify any patterns in macrofaunal assemblages that may be related to changes in the measured sediment variables.

4.1 Firth of Thames

4.1.1 Sediment characteristic

The increase in fine sands and mud over time at all sites apart from Kaiaua (where a great influx of mud occurred in October 2001 and subsequently dissipated) indicates that sediments in the Firth of Thames are getting finer, and more muddy.

Although the sediments at all the monitoring sites have become finer over the monitoring period, the level of mud is still relatively low (up to just over 5%), and the sediments at Te Puru, the Gun Club and Kuranui Bay can be classified as sandy, although at Miranda they have now moved into slightly muddy sands according to the sediment classification in Flemming (2000). With its mud content of up to about 20%, Kaiaua sediments are also classified as slightly muddy sands (Flemming, 2000). Concurrent with an increase in fine sediments was a decrease in the fraction of coarse sand. Overall, this likely reflects deposition of fine sediments at the monitoring sites. The source of the fine sediments is ultimately likely to be runoff from the catchment, but because the Firth is a dynamic system, it is not easy to determine whether the increase in fines reflects recent runoff events, or redistribution of fines deposited historically. A separate report is planned which will assess sediment level measurements and address this issue in more detail.

Increases in sediment mud content are often accompanied by increases in sediment organic matter. However, no increasing trends in sediment organic carbon or total nitrogen were found at the monitoring sites in the Firth of Thames.

The cyclic variation in sediment pigment levels likely reflects different levels of solar radiation throughout the monitoring period. Few clear trends were found in sediment pigment levels (limited to an increase in sediment chlorophyll-*a* levels over time at Te Puru, and a possible increase at Miranda).

The influx of mud noted at the Kaiaua site in October 2001 was most likely the result of runoff associated with a weatherbomb which struck the North Island in August 2001 (MetService, 2001).

4.1.2 Macrofaunal assemblages

All indicator species apart from the polychaete genus *Euchone* were present in the southern Firth of Thames. Most of these species are present also in harbours on the east side of the Coromandel (e.g. Halliday et al., 2006) and in the Auckland Region (e.g. Cummings et al., 2003, Gibbs & Hewitt, 2004).

The presence or absence of indicator species at individual monitoring sites in the southern Firth of Thames provides an indication of the health of the benthic environment. At the two permanent monitoring sites in the Firth of Thames with the consistently lowest sediment mud content (< 5%) and the highest coarse sand content (Gun Club and Te Puru), many of the indicator taxa were absent, including many that prefer some mud in sediments (the invasive bivalve *Theora*, the gastropod *Cominella*, the polychaetes *Aricidea* sp., *Cossura* sp. and paraonids). The Gun Club also had much higher sediment shellhash content, and the analysis indicates that shellhash is the major sediment factor structuring macrofaunal communities. At Kaiaua, which had the highest sediment mud content of the Firth of Thames sites over large parts of the monitoring period (up to ~20%), the limpet *Notoacmea* sp. which has a strong sand preference, was absent, as was the anemone *Anthopleura*, a species which is intolerant of high turbidity levels. However, *Anthopleura* was also absent from Te Puru, despite the low sediment mud content at this site.

Both the PRIMER BEST analysis and the canonical correspondence analysis showed sediment shellhash content to be an important parameter structuring macrobenthic communities. The canonical correspondence analysis also included coarse sand as an environmental variable correlating with changes in macrobenthic assemblages, and the analysis indicated that the differences in community composition between the Gun Club and other sites was caused by the higher levels of coarse sediments at this site.

Sediment pigment levels were also found to be important, causing the clear separation of the macrofaunal community at Te Puru in the canonical correspondence analysis. Sediment pigment concentrations can be related to water column and sediment nutrients, and the sediment nutrient levels at Te Puru were the lowest found at the sites in the Firth of Thames.

In the canonical correspondence analysis, Kaiaua separated out because of the high levels of sediment mud and fine sand found at this site at the October 2001 sampling event, most likely the result of a weatherbomb that struck central North Island in August 2001.

A number of indicator taxa showed significant trends in abundance over the five years of monitoring. Statistically significant trends were also found for a number of sediment parameters, and the following examines where trends in macrofaunal abundances may be linked to sediment changes over time.

Of all the sediment parameters monitored, Kaiaua showed only an increasing trend in fine sand over time. At this site, an increasing trend in abundance was noted for the bivalve *Nucula*, and a decreasing trend for the invasive bivalve *Theora*. The great deposition and subsequent dissipation of fine sediments at this site in October 2001 and the concurrent increase in sediment organic matter highlight how dynamic this site was over the monitoring period.

At the Gun Club, sediment fine sand and mud content increased (mud from 0.5% to 2.2%) over time, as did total organic carbon. The coarser sand fractions decreased and a potential decrease was found for shellhash. An increasing trend in abundance was noted for capitellid polychaetes and the cumacean *Colurostylis*, and possible increasing trends for the polychaete *Aonides* and for total abundance of individuals of all taxa. Of the species showing increasing trends in abundance, *Colurostylis* and *Aonides* are both known to prefer sandy substrates, and *Colurostylis* is sensitive to pollution in sediments (see Table 2). Although sediment mud content has increased, the sediments are still sandy, and mud content is on average less than half of the upper optimum range for these species. Capitellid polychaetes are known indicators of organic enrichment, but the increase in the abundance of capitellids coincided with a decline in sediment total organic carbon. Overall, there is thus little evidence of correlations between sediment parameters and changes in the macrobenthic community at the Gun Club.

At Te Puru, sediment chlorophyll-*a* concentration, fine sand and mud content increased (mud from 0.5% to 3.1%), and coarse sand levels decreased as did total organic carbon levels. The site saw a decline in the bivalves *Nucula* and *Austrovenus* over time, and an increase in pseudopolydorids and capitellid polychaetes. Total abundance of macrofauna declined over time. The decline in *Nucula* and *Austrovenus* were caused by initial high abundances of juveniles (in April 2001) which did not repeat in subsequent years. The lack of high recruitment of *Nucula* and *Austrovenus* at this site subsequent to April 2001 is unlikely to be linked to sediment characteristics, because recruitment of the pipi *Paphies australis* occurred at Te Puru between April 2004 and October 2005. If environmental factors limited the recruitment of *Nucula* and *Austrovenus*, it is likely that they would also limit recruitment of *Paphies*, but the latter appears unaffected. The sediment mud content is unlikely to have adversely affected fauna at Te Puru, as mud levels at the site were lower than the optimum for *Austrovenus*, and within the optimal range for *Nucula*, and the very slight decline in sediment organic matter levels is unlikely to have affected the abundance of the bivalves either. The slight increase in sediment chlorophyll-*a* levels indicate that microalgae within the sediment and in the water column above were not experiencing progressive nutrient limitation over the monitoring period, or limiting the abundance of the bivalves. It is possible that the lack of recruitment of *Nucula* and *Austrovenus* was caused by competition from *Paphies* juveniles, as these were not present at the site when the high recruitment of *Nucula* and *Austrovenus* occurred. Overall, the lack of recruitment of *Nucula* and *Austrovenus* at this site after April 2001 warrants concern, but no clear relationship between this and the monitored sediment parameters is apparent.

Sediment fine sand and mud content increased over time (mud from 1.2% to 5.6%), and the coarser sand fractions and shellhash content decreased at Miranda. A possible increasing trend of sediment chlorophyll-*a* concentration was also noted at this site. A number of macrofaunal trends were detected, most of which were increasing (*Colurostylis*, Capitellidae, *Orbinia* and *Arthritica*). A strong declining trend was noted for the polychaete *Aonides*, and as a result of this the total abundance of individuals also declined over time. It is unlikely that the strong declining trend of *Aonides* is related to the increase in sediment mud content, as the optimal range of this species is sediment with a mud content of <5%, and at the end of the monitoring period the average mud content at Miranda only just exceeded 5%.

At Kuranui Bay sediment fine sand and mud content also increased over time (mud from 0.6% to 4.8%), and coarser sand fractions decreased. Two increasing trend were found at this site (*Magelona* and Capitellidae), and two decreasing trends (*Macomona* and *Aquilaspio*). The declines of these species were only slight (on average a decrease of just over two individuals in five years). The decline in abundance of *Macomona* was attributable to a decline in large individuals. *Macomona* is relatively intolerant to high sediment mud contents, but only once it exceeds 5 – 30%, and it is unlikely that the decline in this species is caused by the increase in mud at this site, although should the trend of increasing mud continue, impacts may occur. *Aquilaspio* is known to prefer sediments with a mud content of at least 20%, and the decline in this species is therefore not related to the increase in sediment mud content either. The increase in total abundance was caused mainly by the increased abundance of capitellid polychaetes.

Overall, although clear trends of increasing fine sediments and decreasing coarse sand were observed at most sites, the trends in macrofaunal assemblages were not dominantly towards a decline in species sensitive to increased fine sediments. The differences between macrofaunal assemblages at the different sites within the Firth of Thames related most clearly to sediment shellhash content – a parameter which showed few clear increasing or decreasing trends over time. The presence of diverse macrofaunal communities at the five permanent monitoring sites, including many species intolerant of higher levels of fine sediments, indicate that although the sediment mud level in the southern Firth of Thames has increased, it is still low, and not at a level where it affects sensitive species.

4.2 Raglan (Whaingaroa) Harbour

4.2.1 Sediment characteristics

Sediment fine sand and mud content increased over time at all the permanent monitoring sites in Raglan Harbour, indicating that as a whole, the sediments of the Harbour are getting finer. The sediments at all sites apart from the muddiest (Haroto Bay) can be classified as slightly muddy sands, but with sediment mud contents of up to an average of 32% at Haroto Bay, sediments there have now moved into the muddy sands category (Flemming, 2000). As sediment mud contents increased, sediment coarser sand fractions decreased at all sites. The decrease in coarser materials was not reflected in sediment shellhash content, which remained constant over time at all sites.

No significant trends were found in sediment nutrient content over time, indicating that the increase in sediment fines did not result in higher levels of organic matter at any of the sites.

As for the Firth of Thames, it is likely that the cyclic variation in sediment pigment levels reflects different levels of solar radiation throughout the monitoring period.

4.2.2 Macrofaunal assemblages

Several indicator taxa were absent from Haroto Bay, the muddiest site. These species include the gastropod *Cominella*, and the polychaetes *Euchone* sp. and Paraonidae. Of these, *Cominella* and Paraonidae both prefer sediments with at least some (>10%) mud. Haroto Bay recorded the lowest number of taxa throughout the monitoring period. At Ponganui Creek, the site with the highest sediment shellhash content, and relatively low mud content (for Raglan – average of 3.9 – 8.1%), the amphipod Corophiidae, a family which prefers very muddy sediments, was absent.

The PRIMER BEST analysis and the canonical correspondence analysis showed that the differences in macrofaunal assemblages correlated highly with the amount of sediment shellhash, mud and total organic carbon. Okete Bay clustered separately on the canonical correspondence analysis, correlating with low amounts of sediment shellhash and high levels of fine sand found at this site. Generally, bivalves were most common at Whatitirinui Island, Ponganui Creek and Te Puna Point, and least common at Okete Bay, and the low occurrence of bivalves at Okete Bay may be related to the low amounts of coarser sediments at this site.

The proportion of mud was also found to correlate with changes in macrofaunal communities, and in the canonical correspondence analysis Haroto Bay showed clear separation from the other sites because of its higher sediment mud and organic carbon content.

Te Puna Point, Ponganui Creek and Whatitirinui Island separated out because of their higher sediment chlorophyll-*a* concentrations, with Te Puna Point having the highest chlorophyll-*a* levels, and Whatitirinui Island the lowest of the three.

Several indicator taxa showed significant trends in abundance over the five years of monitoring, and statistically significant trends over time were also found for a number of sediment parameters.

At Te Puna Point, sediments changed from sands to slightly muddy sands over time (from 1.7% to 8.3% average sediment mud content), and the fraction of coarser sand decreased. Two declining trends were noted for macrofauna (the polychaete *Aquilaspio* and the anemone *Anthopleura*), and three increasing trends (the bivalves *Nucula* and *Austrovenus*, and the limpet *Notoacmea*). *Anthopleura* is known to be intolerant of high turbidity, and the optimum upper sediment mud content for this species is 5 to 10%. It is possible that the decline in *Anthopleura* is related to the increase in sediment mud content. On the other hand, *Aquilaspio* is known to prefer sediments with at least 20% mud, and the decline of this species is not likely to be related to the increase in sediment fines. The sediment mud content at the site is within the optimal range for *Austrovenus*, but likely getting a bit high for *Nucula*, although the increase in abundance of the latter indicates that they are unaffected. The sediment mud content at Te Puna Point was the lowest of those found in Raglan Harbour, and consistent with the above, the canonical correspondence analysis did not show a correlation between the change over time in macrofaunal assemblages at Te Puna Point and increasing sediment mud content.

Haroto Bay experienced a marked increase in sediment fine sand and mud content, moving from slightly muddy sands to muddy sands (from 6.6% to 32.1% average sediment mud content). Fine sands increased as well, and the coarser sediment fractions decreased. At this site, a relatively strong decline in capitellid polychaetes was noted, but no other species showed trends in abundance over time. Capitellid polychaetes are known to prefer sediments with a mud content of up to 40%, and it is unlikely that the decrease in capitellids at this site is related to the increase in fine sediments. Some species that prefer sandy sediments were found at Haroto Bay (e.g. the pipi *Paphies australis*, the wedge shell *Macomona liliana*, the limpet *Notoacmea* sp., phoxocephalid amphipods, and the polychaete *Aonides oxycephala*). However, these species were all found in low numbers, particularly *Paphies* and *Notoacmea* (<10 individuals of these taxa were found over the five years). The polychaete *Orbinia papillosa*, which is known to prefer sediment mud contents of 5-10%, was absent from the site and the total number of taxa and individuals found at Haroto Bay were the lowest of the sites in the Harbour, indicating that although adverse effects from the high sediment mud content were not clearly detectable from the indicator taxa, it may have lead to the absence of other taxa. However, the sediment mud content at Haroto Bay increased from similar levels to the other sites in the Harbour (6%) to levels many times higher than the other sites, and it is interesting to note that no decline in the number of taxa or individuals occurred despite this drastic increase in sediment mud content. It is possible that the site is very dynamic, and that the organisms present are used to great fluctuations in sediment mud content over time.

Sediment fine sand and mud content also increased over time at Ponganui Creek (mud from 3.9% to 8.1%), accompanied by a decline in coarser sands. Only increasing trends of abundance were found at this site, for capitellid polychaetes, and for the wedgeshell *Macomona*. The increase in *Macomona* was attributed to increasing juvenile recruitment over the years. This species is known to prefer sediments with a mud content of up to 30%, and the increase in recruitment over time shows that the increase in sediment mud content at Ponganui Creek has not affected this species.

At Whatitirinui Island, sediment fine sand and mud content also increased (mud from 4.2% to 10.7%), and the coarse sand fraction decreased over time. At this site only increasing trends of abundance were found (for the bivalves *Arthritica* and *Nucula*, the limpet *Notoacmea* sp., and the polychaete *Aquilaspio*). The increase in *Arthritica* was caused by increasing recruitment of juveniles, and the increase in *Nucula* by increases in both juveniles and adults over time. Whereas the optimum range for *Arthritica* and *Aquilaspio* is relatively high sediment mud content (20 to 70%), *Nucula* and *Notoacmea* prefer sediments with less than 5% mud. The increase in abundances of *Nucula* and *Notoacmea* indicate that the level of mud in sediments has not reached levels leading to adverse effects on these species, but if the trend of increasing mud continues, they are likely to decline in abundance.

Okete Bay also experienced a drastic increase in sediment fine sand and mud content (mud from 2.7% to 18.5%) and a decrease in coarse sand content over time. The proportion of mud in sediments at this site was the second highest in Raglan Harbour, although on average still only half that of Haroto Bay. The sediment shellhash and coarse sand contents were the lowest of all the sites in the Harbour. Again, only increasing trends in macrofaunal abundance were noted (for the polychaetes *Aquilaspio aucklandica* and Capitellidae). Both *Aquilaspio* and capitellids are known to prefer sediments with a mud content of at least 10-20%, and their increase at this site could be related to the increase in sediment mud content over time. It is likely that the very low abundance of the limpet *Notoacmea* at Okete Bay is related to high sediment mud content – this species was also present in very low abundances at Haroto Bay. The fact that Haroto Bay and Okete Bay had the highest sediment mud levels and both had low overall invertebrate abundances compared to the other sites in Raglan Harbour, supports the notion that the sediment mud content influenced levels of total abundance.

Overall, the sediments in Raglan Harbour classified as slightly muddy to muddy sands, and mud levels increased markedly during the monitoring period. The muddiest site (Haroto Bay) reached more than 30% mud at the end of the monitoring period reported here, and at this site the abundance of taxa was the lowest of all the sites in the Harbour. The two muddiest sites (Haroto Bay and Okete Bay) also showed the lowest abundances of individuals. This indicates that at the muddiest sites, macrobenthic diversity and abundance may be influenced by the sediment mud content. This is further supported by the fact that the differences in macrobenthic assemblages between the monitoring sites correlated with sediment shellhash, mud and organic carbon content. At all monitoring sites in the Harbour, clear trends of increasing fine sediments and decreasing coarse sands were observed. Trends in macrofaunal abundances occurred at all sites, however these were not easily linked to the change in sediment parameters. At all sites in the Harbour some indicator species were present which are known to be intolerant to higher levels of fine sediments, and no clear declining trends in sensitive species were observed over time.

4.3 Comparison of the southern Firth of Thames and Raglan (Whaingaroa) Harbour

4.3.1 Sediment characteristics

The sediments at the sampling sites in Raglan Harbour were much muddier (8-32% average sediment mud content in April 2006) than those at the sampling sites in the Firth of Thames (2-6% average sediment mud content in April 2006 for all sites apart from Kaiaua, where mud content briefly reached about 18%). The sediment fine sand content was highest at Miranda and Kaiaua in the Firth of Thames where it reached more than 90%, but high average levels were also observed in RaglanHarbour. Sediment mud content increased over the five years of monitoring in both estuaries, although much more markedly in Raglan Harbour. Between 2001 and 2006, the sediments at the sites monitored in the Firth of Thames changed from sands to slightly muddy sands. In Raglan, the sediments at one site changed from slightly muddy sands to muddy sands, whereas at the other sites, they remained slightly muddy sands. The levels of coarse sand and shellhash in sediments were on average slightly higher at the monitoring sites in Raglan than in the Firth of Thames, with the exception of the Gun Club site in the Firth, which had the highest levels of shellhash and coarse sand of all the monitoring sites.

Total nutrient levels were somewhat higher in Raglan (Whaingaroa) Harbour (on average 0.2 g 100 g^{-1} for total organic carbon, and 0.05 g 100 g^{-1} for total nitrogen) than in the Firth of Thames, apart from between October 2001 and April 2002, where Kaiaua in the Firth of Thames showed a peak in sediment nutrients. The generally higher levels of organic matter in Raglan Harbour are not surprising given the normally strong relationship between sediment mud and organic matter content – the higher mud levels found in Raglan Harbour would be expected to lead to high concentrations of organic matter.

Sediment chlorophyll-*a* levels were generally higher in Raglan Harbour than in the Firth of Thames, and in the Firth, particularly low levels were found at Te Puru. In both estuaries, sediment pigment levels peaked from April 2004 to January 2006, which indicates that the variation in pigment levels were caused by climatic factors affecting both estuaries, such as temperature, rainfall (affecting clarity of water and salinity) or levels of solar radiation. It is possible that the relatively higher levels of sediment pigment found in Raglan Harbour reflect the higher sediment nutrient levels found there.

4.3.2 Macrofaunal assemblages

Generally, the number of taxa found in the southern Firth of Thames was slightly lower (18-30) than that found in Raglan (Whaingaroa) Harbour (18-34). This could indicate lower overall species diversity in the Firth of Thames. However, the monitoring programme presently does not enumerate all species, but rather a selection of indicator species, with other organisms found grouped into broad taxonomic groupings, and it is possible that higher resolution of identification within these broad taxonomic groupings would alter the findings.

Abundances of individuals were higher in the Firth of Thames than in Raglan Harbour, particularly at Te Puru, the Gun Club and Kaiaua. The high abundances at Kaiaua and Te Puru were caused by high levels of bivalve recruitment, whereas at the Gun Club, polychaetes dominated numerically. In general, however, there were higher numbers of bivalves in Raglan Harbour than in the Firth of Thames. Species such as *Austrovenus*, *Arthritica* and *Macomona* were more abundant in Raglan Harbour than in the Firth of Thames, whereas *Paphies* and *Theora* were more abundant in the southern Firth of Thames.

Recruitment of bivalve species occurred within both estuaries. In the Firth of Thames, peak abundance of small (< 5 mm) *Austrovenus* occurred in April, whereas in Raglan Harbour peak abundances of small *Austrovenus* occurred in October. Other species showed mixed seasonality of peak number of juveniles at different sites, with no clear difference between estuaries in the frequency of bivalve recruitment. The differences in abundances of juvenile bivalve species indicate that site specific information should be considered when planning monitoring of bivalves, as the time of year that monitoring is carried out can influence the abundance of bivalves dramatically.

The difference in abundance of bivalve species may reflect the overall more muddy conditions in Raglan Harbour – *Paphies* is known to strongly prefer sandy sediments, and *Theora* is thought to be sensitive to changes in sediment mud content. The polychaete *Orbinia papillosa*, which also prefers sandy sediments, was also more common in the Firth of Thames than in Raglan Harbour. However, some species that prefer sandy sediments were more abundant at the sampling sites in Raglan Harbour than in the Firth of Thames, including the phoxocephalid amphipods, the wedgeshell *Macomona*, the anemone *Anthopleura* and the limpet *Notoacmea*.

In Raglan Harbour the dissimilarity between some of the monitoring sites were quite low, indicating some overlap in macrofaunal assemblage between sites whereas in the Firth of Thames, the sites monitored generally had quite distinct macrobenthic communities.

Factors other than the sediment parameters measured here may influence the abundance and diversity of macrofauna. The sediment in Raglan Harbour contains black sands, and the dark colour of the intertidal sediments likely causes them to heat up more than those in the Firth of Thames. The hydrodynamic conditions differ in the two estuaries, with the Firth of Thames having a large fetch for wind-generated waves, compared to the more branching Raglan Harbour. Predation and natural sources of recruitment may also differ between the two estuaries. Anthropogenic and natural influences may also play a part, for example, Kim (2007) found higher concentrations of the heavy metals arsenic, cadmium, copper, mercury, lead and zinc in Firth of Thames sediments than in Raglan Harbour. Preliminary investigations suggest that the most likely sources of these metals are weathering and erosion following land clearance (arsenic and copper), disposal of mine tailings to the Ohinemuri River (zinc, cadmium, and lead) and agricultural inputs (zinc and cadmium).

Overall, although they have many species in common, clear differences in macrobenthic communities exist between the Firth of Thames and Raglan (Whaingaroa) Harbour. Some of the differences in assemblages may be related to the different sediment characteristics in the two estuaries, particularly the higher average sediment mud content in Raglan Harbour, but other factors not monitored here are also likely to play a part.

4.4 Recommendations for future monitoring

In the context of macrofaunal assemblage patterns, five years is not a long time, and it is quite possible that some of the trends detected are part of natural multi-year cyclic patterns of abundance.

4.4.1 Macrofauna and sediment characteristics

The clear trend detected of increasing sediment mud content, and decreasing sediment coarse sand content, at all sites monitored apart from Kaiaua in the Firth of Thames, is cause for concern. Given the clear changes observed over a relatively short timeframe, it is recommended that the monitoring programme be continued, as increasing the period of monitoring is likely to help separate natural cycles in sediment composition and macrofaunal abundances from potential longer term trends. If the increase in sediment mud content continues in the future, it is likely that adverse effects on macrobenthic communities will ensue, with potential knock-on effects on e.g. fish and birds that prey on benthic invertebrates.

After five years of monitoring, it has become clear that the current selection of indicator species does not always include the most abundant or important fauna at the monitoring sites. For example, the indicator species *Cominella adspersa* is not very common in the two estuaries, but *Cominella glandiformis* is more common in Firth of Thames. *Scoloplos cylindrifer* (a non-indicator orbinid) is also abundant at the Gun Club, Firth of Thames. Similarly, new or invasive species are not picked up when only indicator species are enumerated or reported upon. It is therefore recommended that the use of indicator species be discontinued, and that from now on all macroinvertebrate fauna be identified to the lowest taxonomic level possible, and that future reports include information on all taxa present in the two estuaries.

The temporally intensive monitoring over five years has shown some trends in the abundances of macrofaunal species. The quarterly monitoring carried out at some sites has provided valuable information about seasonal cycles in abundance of taxa, but no change in the number of trends detected occurred when the analysis was carried out on data from half-yearly sampling as opposed to quarterly sampling. To free up resources to enable the expansion of the monitoring programme to other locations, it is recommended that sampling be carried out at half-yearly intervals at all sites from now on.

Three of the five monitoring sites in Raglan (Te Puna Point, Whatitirinui Island and Ponganui Creek) showed some degree of overlap in macrofaunal community composition. All these three sites showed significant increases in sediment mud and fine sand content, but only Whatitirinui Island showed discernable change in macrofaunal assemblage composition over the duration of the monitoring. To free up resources, it is recommended that monitoring at Te Puna Point be discontinued – this site is within the same part of the estuary as Whatitirinui Island, and is likely to be subject to similar changes over time.

Many of the factors that are likely to structure macrobenthic communities in the two estuaries are not monitored as part of the programme. To increase our understanding of the monitored sites, it is recommended that the feasibility of measuring tidal exposure, air and water temperature, and salinity at the monitoring sites be evaluated as soon as possible.

The monitoring programme is only monitoring two of the 35 estuaries in the Region. It is recommended that the resources that will be freed up by reducing the monitoring intensity from quarterly to half yearly and discontinuing monitoring at Te Puna Point be used to monitor and map benthic resources (such as shellfish beds and substrate type) in other estuaries.

5 Conclusions

In the Firth of Thames, clear trends of increasing levels of fine sediments and decreasing coarse sand were observed at most sites. These changes are of concern, as increasing mud levels in estuaries are likely to reflect increasing catchment runoff of fine sediments. However, the lack of clear trends in the abundances of sensitive macrofaunal species indicate that the sediment mud content is not yet at a level where macrofaunal assemblages are adversely affected. Supporting this is the fact that many species intolerant of high sediment mud content were found in the Firth of Thames, indicating that although the muddiness of the southern Firth of Thames has increased, it is still at a level where sensitive species are present. However, given the rapid rate of increase in sediment mud content (clear trends detectable in only five years of monitoring) it is likely that if the trend continues, adverse effects on macrofaunal communities will ensue.

In Raglan (Whaingaroa) Harbour, sediment mud content was higher than in the Firth of Thames, and levels increased during the monitoring period at all sites. This clear trend of increasing mud indicates that catchment runoff is increasing, and is cause for concern. A very substantial increase in sediment mud content occurred at Haroto Bay, where mud content reached 30%, and at this site the abundance of taxa was the lowest of all the sites in the Harbour. The lowest abundances of individuals of all taxa were found at the two sites with the highest sediment mud content (Haroto Bay and Okete Bay), and the differences in macrobenthic assemblages between monitoring sites were found to correlate with sediment shellhash and mud content. However, at all sites in the Harbour some indicator species known to be intolerant to higher sediment mud content were found, and no clear declining trends in sensitive species were observed over time. Overall this indicates that at some sites in Raglan Harbour, macrobenthic diversity and abundance are likely adversely affected by the sediment mud content, but levels of fine sediment have not yet reached levels where all sites, or all sensitive species, are affected.

Clear differences in macrobenthic communities exist between the Firth of Thames and Raglan (Whaingaroa) Harbour. Some of the differences in assemblages may be related to the different sediment characteristics in the two estuaries, particularly the higher average mud levels in Raglan Harbour, but other environmental factors (such as temperature, salinity) are also likely to play a part.

Given the clear trends of increasing fine sediment observed in only five years of monitoring, it is essential that monitoring continues. The increases in sediment mud content have likely adversely affected the macrofaunal community at some sites in Raglan Harbour, and if the Harbour continues to become muddier, it is only a question of time before other sites become impacted. It is recommended that monitoring continues in both estuaries, but at reduced temporal intensity (monitoring every six months at all sites instead of every three months), and that monitoring at Te Puna Point in Raglan be discontinued. It is also recommended that the use of indicator species be abandoned, and that all taxa be identified to the lowest taxonomic level possible from now on. It is recommended that the resources that will be freed up by the reduction in the monitoring intensity be used to collect data on environmental parameters such as tidal exposure, temperature and salinity at the monitoring sites, and that the monitoring programme be expanded to other estuaries in the Region.

References

Benjamini, Y. and Hochberg, Y. 1995: Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)* 57(1):289-300.

Clarke, K.R. and Gorley, R.N. 2006: *PRIMER v6: User Manual / Tutorial.* PRIMER-E Ltd., Plymouth.

Clarke, K.R. and Warwick, R.M. 2001: *Change in Marine Communities : an Approach to Statistical Analysis and Interpretation*. PRIMER-E Ltd., Plymouth.

Cummings, V.; Nicholls, P. and Thrush, S. 2003: *Mahurangi Estuary Ecological Monitoring Programme : Report on Data Collected from July 1994 to January 2003.* NIWA Client Report: HAM2003-066. Prepared for Auckland Regional Council. National Institute of Water and Atmospheric Research, Hamilton.

Environment Waikato. 1999: *Waikato State of the Environment Report 1998*. Waikato Regional Council (Environment Waikato), Hamilton.

Felsing, M.; Singleton, N. and Gibberd, B. 2006: *Regional Estuary Monitoring Programme (REMP) Data Report: Benthic Macrofauna Communities and Sediments - July 2002 to April 2004 : Southern Firth of Thames and Whaingaroa (Raglan) Harbour.* Environment Waikato Technical Report 2006/27. Waikato Regional Council (Environment Waikato), Hamilton.

Flemming, B.W. 2000: A revised textural classification of gravel-free muddy sediments on the basis of ternary diagrams. *Continental Shelf Research* 20(10-11):1125-1137.

Gibbs, M. and Hewitt, J.E. 2004: *Effects of Sedimentation on Macrofaunal Communities : a Synthesis of Research Studies for ARC*. Auckland Regional Council Technical Publication 264. Auckland Regional Council, Auckland.

Halliday, J.; Thrush, S. and Hewitt, J. 2006: *Ecological Monitoring for Potential Effects of Forestry Activity on the Intertidal Habitats of Whangapoua Harbour. Long-Term Review 1993-2006. NIWA* Client Report: HAM2006-113. Prepared for Ernslaw One Ltd., National Institute of Water and Atmospheric Research, Hamilton

Hewitt, J.E.; Funnell, G.A.; Cummings V.J. and Hatton, S. 2001: *Guide to Macrobenthic Invertebrate Taxa Monitored by Environment Waikato*. Prepared for Environment Waikato. NIWA Client Report EVW01225/2. National Institute of Water and Atmospheric Research, Hamilton.

Kim, N. 2007: *Trace Metals in Sediments of the Eastern Coast of the Lower Firth of Thames*. Environment Waikato Technical Report 2007/08. Waikato Regional Council (Environment Waikato), Hamilton.

McBride, G.B. 2005: *Using Statistical Methods for Water Quality Managemen t: Issues, Problems and Solutions*. Wiley Series in Statistics in Practice. Wiley, New York.

MetService 2001: *Meteorological Service of New Zealand Ltd (MetService).* http://www.metservice.co.nz/default/index.php?alias=2001winter2194263 (1 Jun 2007)

Morrisey, D.J.; Burt, K.; Funnell, G.A.; Hume, T.M.; Kemp, C.L.S.; Ovenden, R.; Smith, R.K. and Swales, A. 1999: *Ecological Monitoring for Potential Effects of Forestry Activity on the Intertidal Habitats of Whangapoua Harbour. Annual Report 1998-1999 and Summary of Results 1993-1999.* NIWA Client Report ERN90202/1. Prepared for Ernslaw One Ltd., National Institute of Water and Atmospheric Research, Hamilton

Norkko, A.; Talman, S.; Ellis, J.; Nicholls, P. and Thrush, S. 2001: *Macrofaunal sensitivity to fine sediments in the Whitford Embayment.* Auckland Regional Council Technical Publication; no. 158. Auckland Regional Council, Auckland.

Singleton, N. and Pickett, V. 2006: *Regional Estuary Monitoring Programme (REMP) Data Report : Benthic Macrofauna Communities and Sediments - July 2004 to April 2005, Southern Firth of Thames and Whaingaroa (Raglan) Harbour.* Environment Waikato Technical Report 2006/44. Waikato Regional Council (Environment Waikato), Hamilton.

Thrush, S.F.; Pridmore, R.D.; Hewitt, J.E. and Roper, D.S. 1988: *Design of an Ecological Monitoring Programme for the Manukau Harbour*. Water Quality Consultancy Report No. 7099 / Auckland Regional Water Board Technical Publication; no. 79. Auckland Regional Water Board, Auckland

Thrush, S.F.; Lundquist, C.J.; and Hewitt, J.E. 2004: Spatial and temporal scales of disturbance to the seafloor: a generalised framework for active habitat management. In: Barnes, P.W. and Thomas, J.P. (Eds.) *AFS Symposium on Benthic Habitats and the Effects of Fishing*. American Fisheries Society, Bethesda, MD. September 2005.

Turner, S. and Carter, N. 2004: *Regional Estuary Monitoring Programme: Benthic Macrofauna Communities, April 2001 to April 2002: Southern Firth of Thames and Whaingaroa (Raglan) Harbour.* Environment Waikato Technical Report 2004/08. Waikato Regional Council (Environment Waikato), Hamilton.

Turner, S.; Gibberd, B. and Crozier, J. 2002: *Regional Estuary Monitoring Programme : Pilot study*. Environment Waikato Internal Series 2002/02. Waikato Regional Council (Environment Waikato), Hamilton.

Turner, S. 2000: *Proposed Coastal Ecological Monitoring Programme for Environment Waikato*. Environment Waikato Internal Series 2000/08. Waikato Regional Council (Environment Waikato), Hamilton.

Turner, S. 2001: *Monitoring the Region's Estuaries : Intertidal Sand-Flat Benthic Communities*. Environment Waikato Internal Series 2000/11. Waikato Regional Council (Environment Waikato), Hamilton.

Appendix 1: Most abundant indicator species

Table A1.a: The three most common indicator species/taxonomic groups (listed in descending order) on each sampling date for each permanent monitoring site in the southern Firth of Thames. The July 2002 samples from Miranda were lost.

	Kaiaua	Gun Club	Te Puru	Miranda	Kuranui Bay
Apr 01	*Theora* *Nucula* *Aricidea* sp.	*Aonides* *Paphies* *Austrovenus*	*Nucula* *Austrovenus* *Paphies*	*Aonides* *Austrovenus* *Macomona*	*Austrovenus* *Arthritica* Capitellidae
July 01				*Aonides* *Macomona* *Austrovenus*	*Austrovenus* Capitellidae *Aquilaspio*
Oct 01	*Nucula* Capitellidae Phoxocephalidae	*Aonides* *Paphies* *Austrovenus*	*Nucula* *Paphies* *Austrovenus*	*Aonides* *Macomona* *Austrovenus*	Capitellidae *Austrovenus* *Paracorophium*
Jan 02				*Aonides* *Paracorophium* *Macomona*	Capitellidae *Paracorophium* *Austrovenus*
Apr 02	*Austrovenus* *Nucula* *Magelona*	*Aonides* Nereidae *Paphies*	*Nucula* *Paphies* *Austrovenus*	*Aonides* *Austrovenus* *Macomona*	Capitellidae *Austrovenus* *Magelona*
Jul 02					Capitellidae *Austrovenus* *Magelona*
Oct 02	*Nucula* Capitellidae *Austrovenus*	*Aonides* Nereidae *Austrovenus*	*Nucula* *Paphies* *Austrovenus*	*Aonides* Capitellidae Nereidae	Capitellidae *Austrovenus* *Aonides*
Jan 03				*Aonides* *Macomona* Nereidae	*Arthritica* Capitellidae *Aonides*
Apr 03	*Nucula* *Austrovenus* Capitellidae	*Aonides* *Austrovenus* *Macomona*	*Nucula* *Paphies* *Austrovenus*	*Aonides* *Austrovenus* Nereidae	Capitellidae *Austrovenus* *Macomona*
Jul 03				*Aonides* *Orbinia* *Macomona*	*Paracorophium* *Austrovenus* Capitellidae
Oct 03	*Nucula* Capitellidae *Magelona*	*Aonides* *Macomona* *Paphies*	*Nucula* *Paphies* *Austrovenus*	*Aonides* *Orbinia* *Macomona*	*Arthritica* *Austrovenus* *Aonides*
Jan 04				*Aonides* *Macomona* *Austrovenus*	*Paracorophium* *Austrovenus* *Aonides*
Apr 04	*Nucula* *Austrovenus* *Macomona*	*Paphies* *Aonides* *Colurostylis*	*Nucula* *Paphies* *Austrovenus*	*Aonides* *Austrovenus* *Macomona*	*Austrovenus* *Arthritica* *Macomona*
Jul 04				*Aonides* *Austrovenus* *Macomona*	*Austrovenus* Capitellidae *Magelona*
Oct 04	*Nucula* Capitellidae *Macomona*	*Aonides* *Paphies* *Colurostylis*	*Nucula* *Paphies* *Pseudopolydora*	*Aonides* *Arthritica* *Orbinia*	Capitellidae *Aonides* *Austrovenus*
Jan 05				*Aonides* *Arthritica* *Orbinia*	Capitellidae *Aonides* *Magelona*
Apr 05	*Nucula* *Austrovenus* Capitellidae	*Aonides* *Paphies* *Austrovenus*	*Nucula* *Paphies* *Austrovenus*	*Austrovenus* *Aonides* Nereidae	*Austrovenus* *Aonides* Capitellidae
Jul 05				*Orbinia* *Aonides* *Austrovenus*	Capitellidae *Austrovenus* *Magelona*
Oct 05	*Nucula* Capitellidae *Austrovenus*	*Aonides* Capitellidae *Paphies*	*Nucula* *Paphies* Capitellidae	Capitellidae *Aonides* *Austrovenus*	Capitellidae *Austrovenus* *Magelona*
Jan 06				Capitellidae *Aonides* *Aquilaspio*	Capitellidae *Austrovenus* *Magelona*
Apr 06	*Nucula* *Macomona* *Austrovenus*	*Aonides* *Paphies* Capitellidae	*Nucula* *Paphies* *Pseudopolydora*	*Aonides* *Colurostylis* *Arthritica*	Capitellidae *Austrovenus* *Magelona*

Table A1.b: The three most common species/taxonomic groups (listed in descending order) on each sampling date for each permanent monitoring site in Raglan Harbour. At Ponganui Creek, sampling commenced in October 2001.

	Te Puna Point	Haroto Bay	Ponganui Creek	Whatitirinui Island	Okete Bay
Apr 01	*Austrovenus* *Aquilaspio* *Nucula*	Capitellidae *Austrovenus* *Macomona*		*Austrovenus* Capitellidae *Macomona*	*Cossura* sp. Capitellidae *Aquilaspio*
Jul 01				*Austrovenus* Capitellidae *Macomona*	*Cossura* sp. Capitellidae *Phoxocephalidae*
Oct 01	*Austrovenus* *Aquilaspio* *Nucula*	*Austrovenus* Capitellidae *Arthritica*	*Austrovenus* *Nucula* *Aquilaspio*	*Austrovenus* Capitellidae *Macomona*	*Cossura* sp. Capitellidae *Phoxocephalidae*
Jan 02				Capitellidae *Austrovenus* *Macomona*	*Cossura* sp. Capitellidae *Phoxocephalidae*
Apr 02	*Austrovenus* *Nucula* *Aquilaspio*	Capitellidae Nereidae *Arthritica*	*Nucula* *Austrovenus* *Aquilaspio*	*Austrovenus* Capitellidae *Nucula*	*Cossura* sp. Capitellidae Nereidae
Jul 02				Capitellidae *Austrovenus* *Nucula*	*Cossura* sp. Capitellidae *Aricidea* sp.
Oct 02	*Austrovenus* *Nucula* *Aquilaspio*	*Austrovenus* Capitellidae *Arthritica*	*Austrovenus* *Nucula* *Aquilaspio*	*Austrovenus* Capitellidae *Nucula*	Capitellidae *Cossura* sp. *Phoxocephalidae*
Jan 03				Capitellidae *Austrovenus* *Nucula*	Capitellidae *Cossura* sp. *Aquilaspio*
Apr 03	*Austrovenus* *Nucula* *Notoacmea* sp.	Capitellidae Nereidae *Austrovenus*	*Nucula* *Aquilaspio* *Austrovenus*	*Austrovenus* Capitellidae *Nucula*	Capitellidae *Cossura* sp. Nereidae
Jul 03				*Austrovenus* *Nucula* Capitellidae	Capitellidae *Cossura* sp. Nereidae
Oct 03	*Austrovenus* *Nucula* *Notoacmea* sp.	Capitellidae *Austrovenus* *Arthritica*	*Austrovenus* *Nucula* *Macomona*	*Austrovenus* *Nucula* Capitellidae	Capitellidae *Cossura* sp. Nereidae
Jan 04				*Austrovenus* *Nucula* Capitellidae	Capitellidae *Cossura* sp. *Aquilaspio*
Apr 04	*Austrovenus* *Nucula* *Notoacmea* sp.	*Arthritica* Nereidae *Austrovenus*	*Nucula* *Austrovenus* *Aquilaspio*	*Austrovenus* *Nucula* Capitellidae	Capitellidae *Cossura* sp. *Aquilaspio*
Jul 04				*Austrovenus* *Nucula* Capitellidae	Capitellidae *Cossura* sp. Paraonidae
Oct 04	*Austrovenus* *Nucula* *Notoacmea* sp.	Capitellidae *Austrovenus* *Arthritica*	*Austrovenus* *Nucula* *Macomona*	*Austrovenus* Capitellidae *Nucula*	*Cossura* sp. Capitellidae *Aquilaspio*
Jan 05				*Nucula* *Austrovenus* Capitellidae	*Cossura* sp. Capitellidae *Aquilaspio*
Apr 05	*Austrovenus* *Nucula* *Notoacmea* sp.	Capitellidae *Macomona* *Arthritica*	*Austrovenus* *Nucula* Capitellidae	*Nucula* *Aquilaspio* *Austrovenus*	*Cossura* sp. Capitellidae *Aquilaspio*
Jul 05				*Nucula* Capitellidae *Aquilaspio*	Capitellidae *Cossura* sp. *Aquilaspio*
Oct 05	*Austrovenus* *Nucula* *Notoacmea* sp.	Capitellidae *Arthritica* *Austrovenus*	*Austrovenus* *Nucula* *Aquilaspio*	*Nucula* Capitellidae *Austrovenus*	Capitellidae *Cossura* sp. *Phoxocephalidae*
Jan 06				*Austrovenus* Capitellidae *Nucula*	Capitellidae *Cossura* sp. *Aquilaspio*
Apr 06	*Austrovenus* *Nucula* *Aquilaspio*	Capitellidae Nereidae *Austrovenus*	*Nucula* *Austrovenus* *Aquilaspio*	*Austrovenus* Capitellidae *Nucula*	Capitellidae *Cossura* sp. *Aquilaspio*

Appendix 2: Abundance of indicator species Firth of Thames

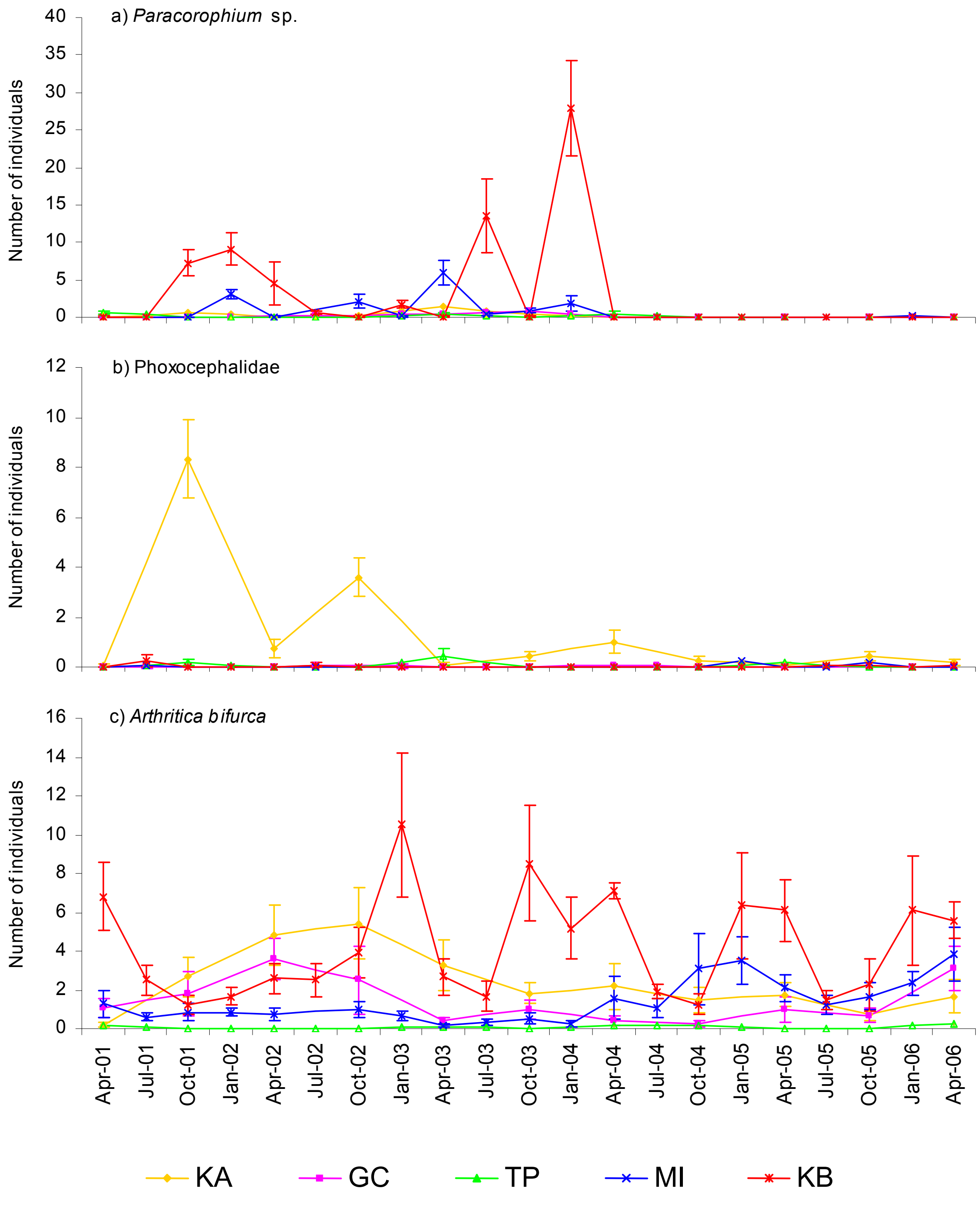


Figure A2.a: **Mean (± standard error, N=12) abundance of macrobenthic indicator species found at the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006. Note the different scales on the vertical axis**

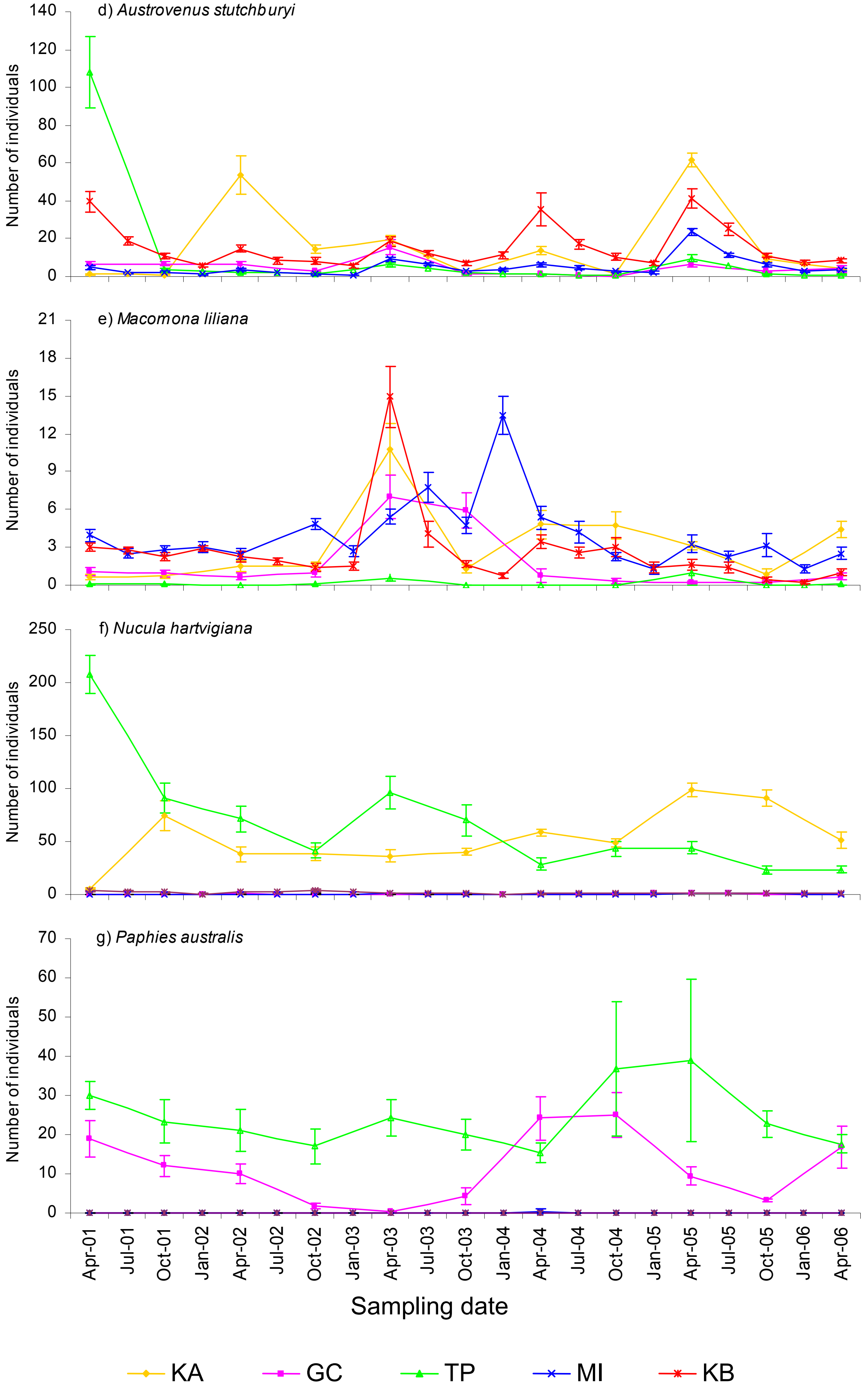


Figure A2.a (cont.)

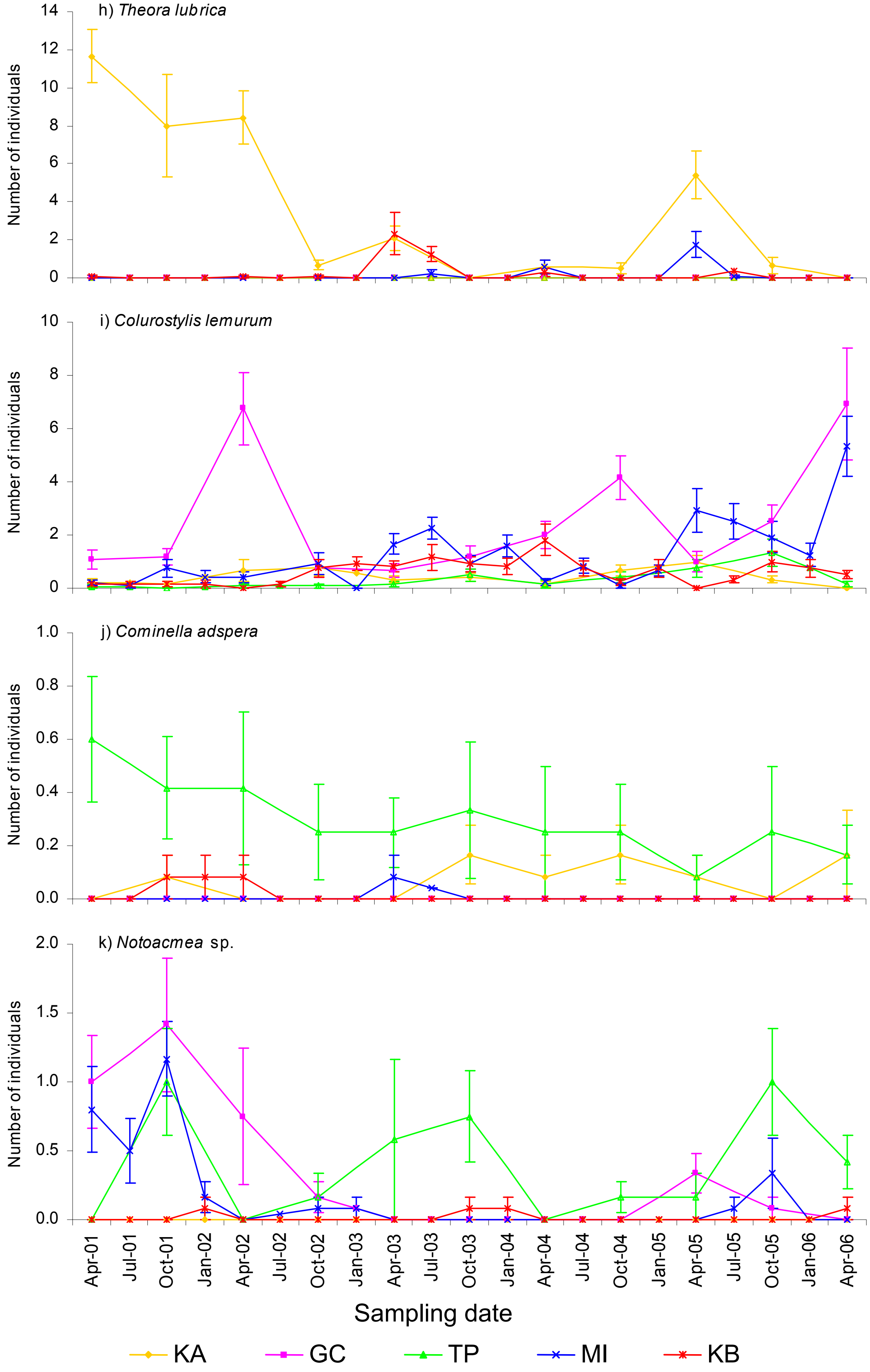


Figure A2.a (cont.)

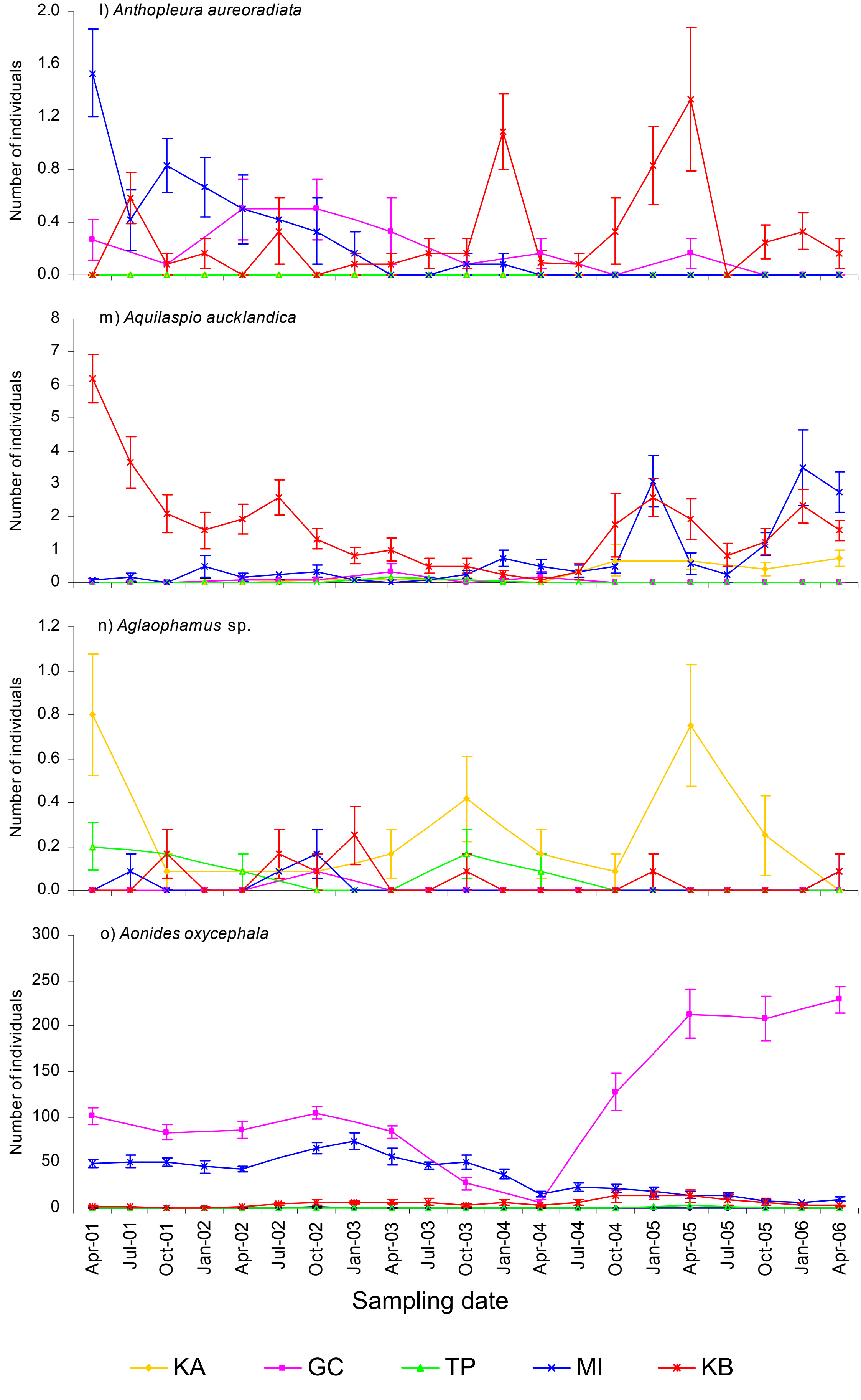


Figure A2.a (cont.)

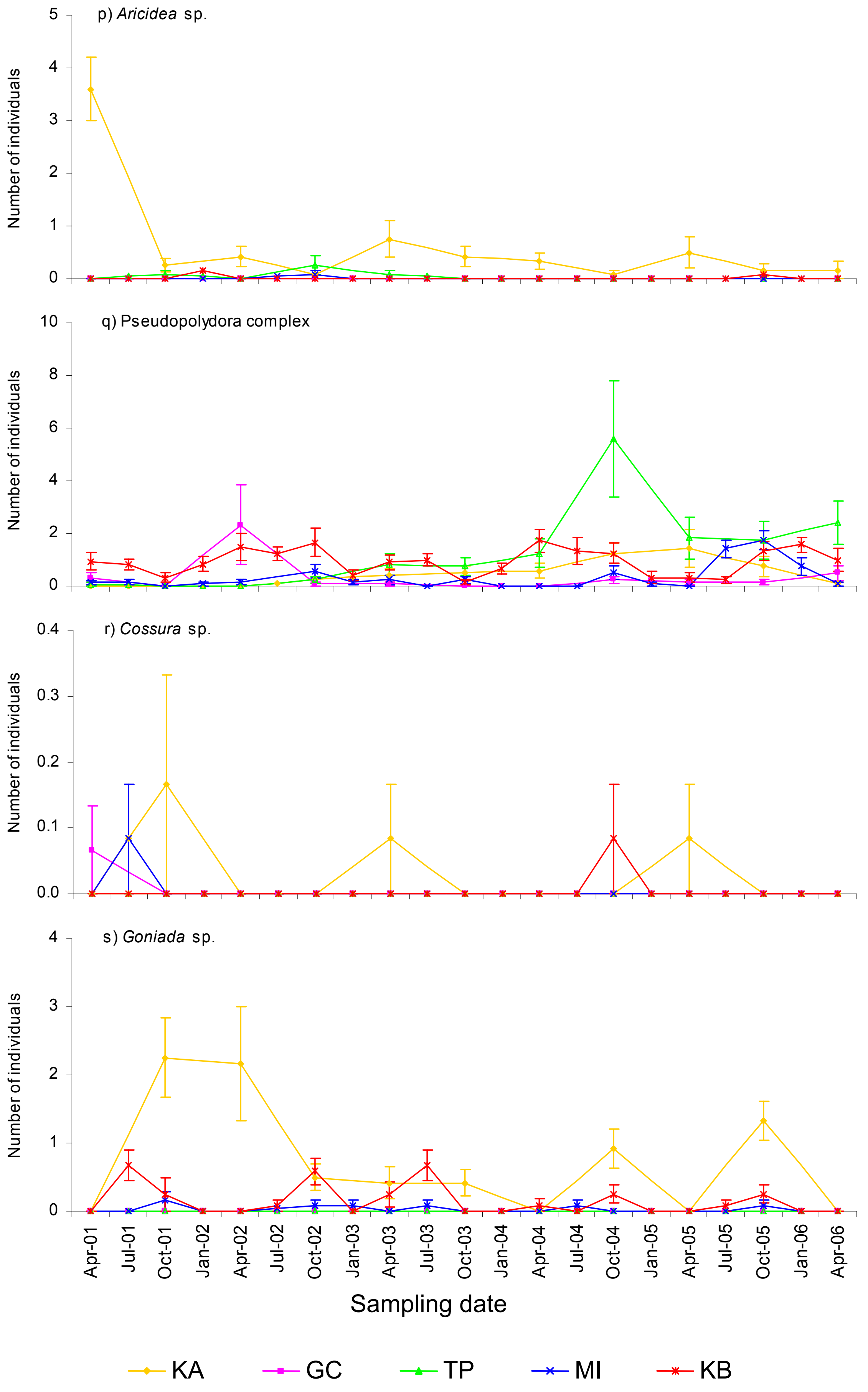


Figure A2.a (cont.)

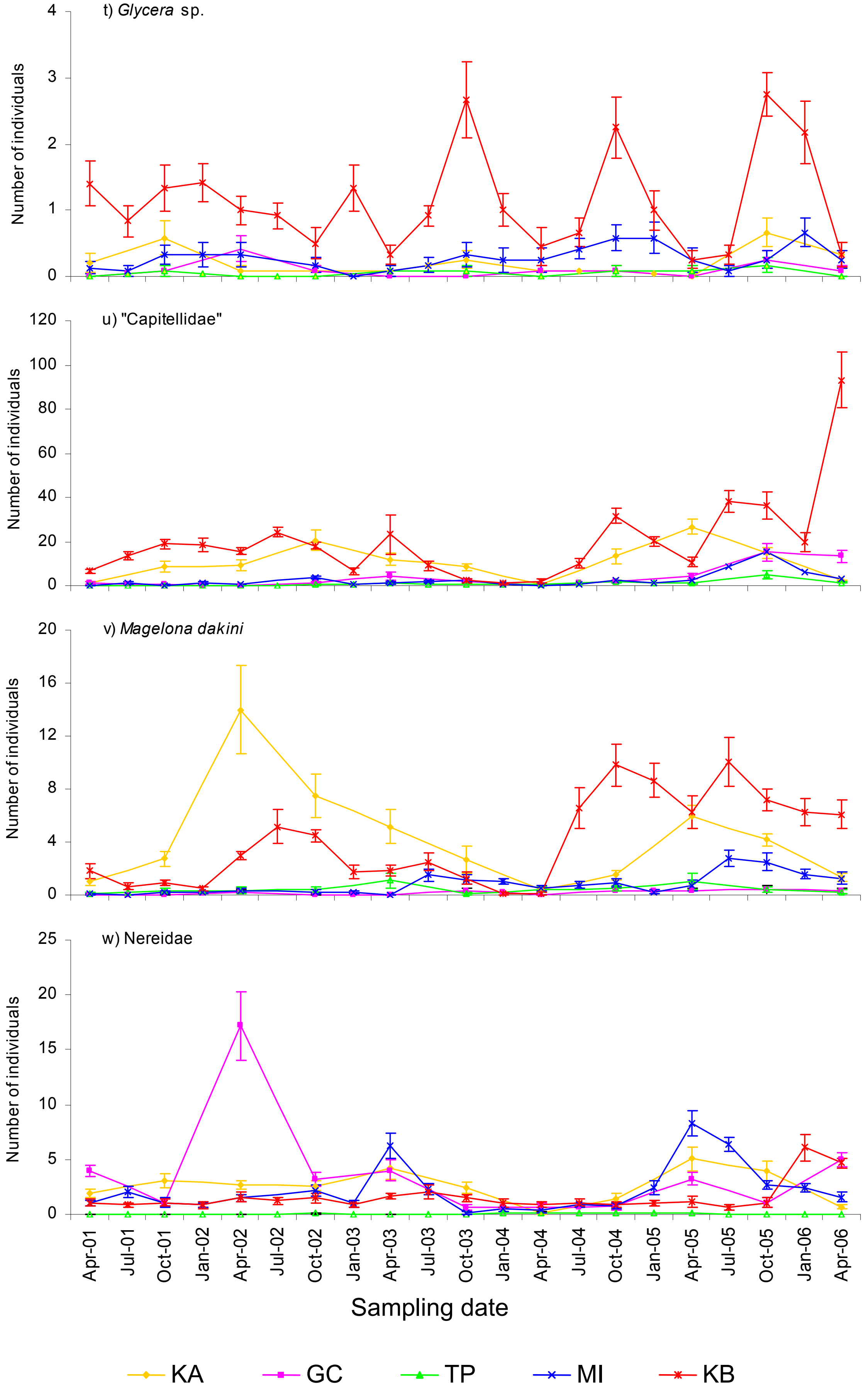


Figure A2.a (cont.)

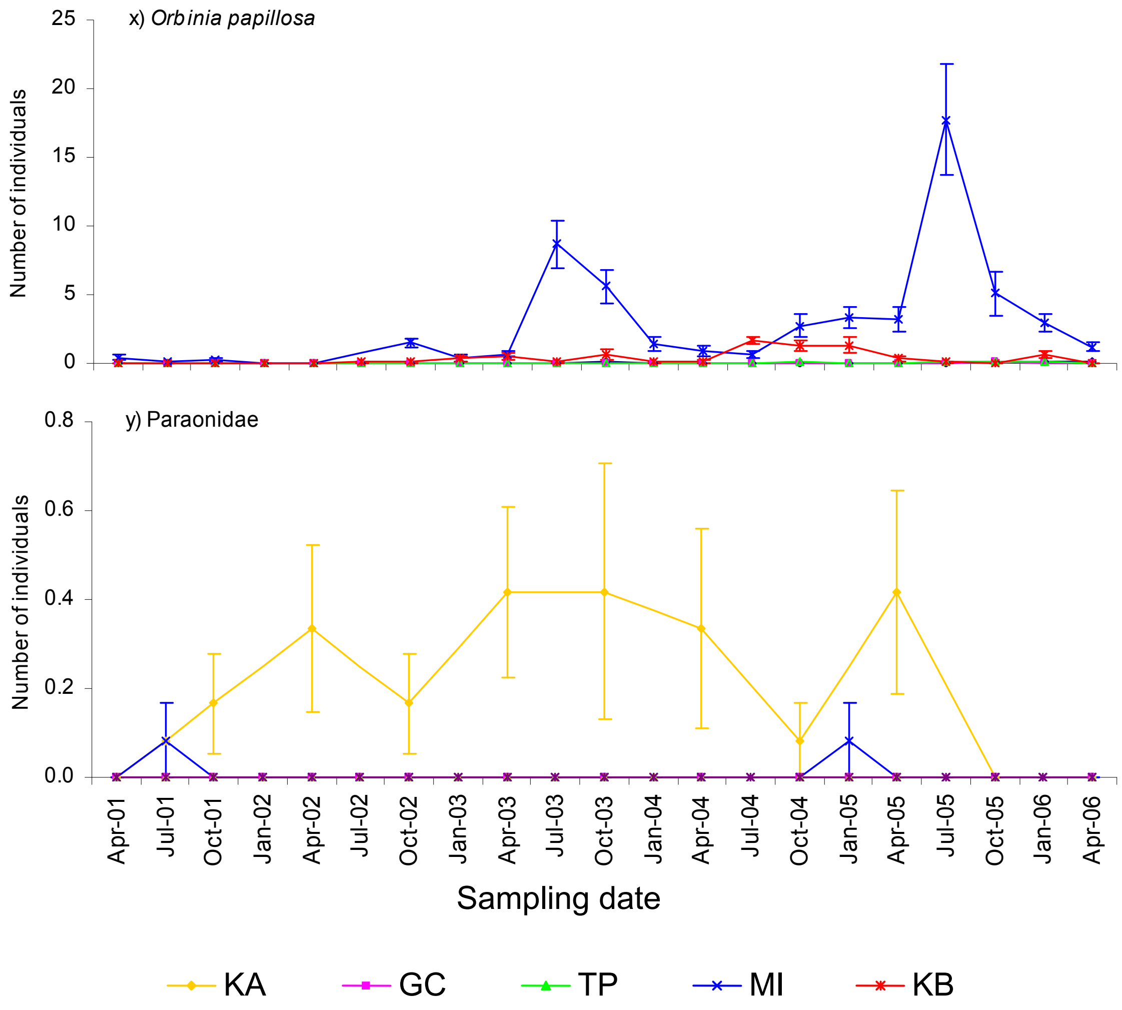


Figure A2.a (cont.)

Bivalve size class frequency Firth of Thames

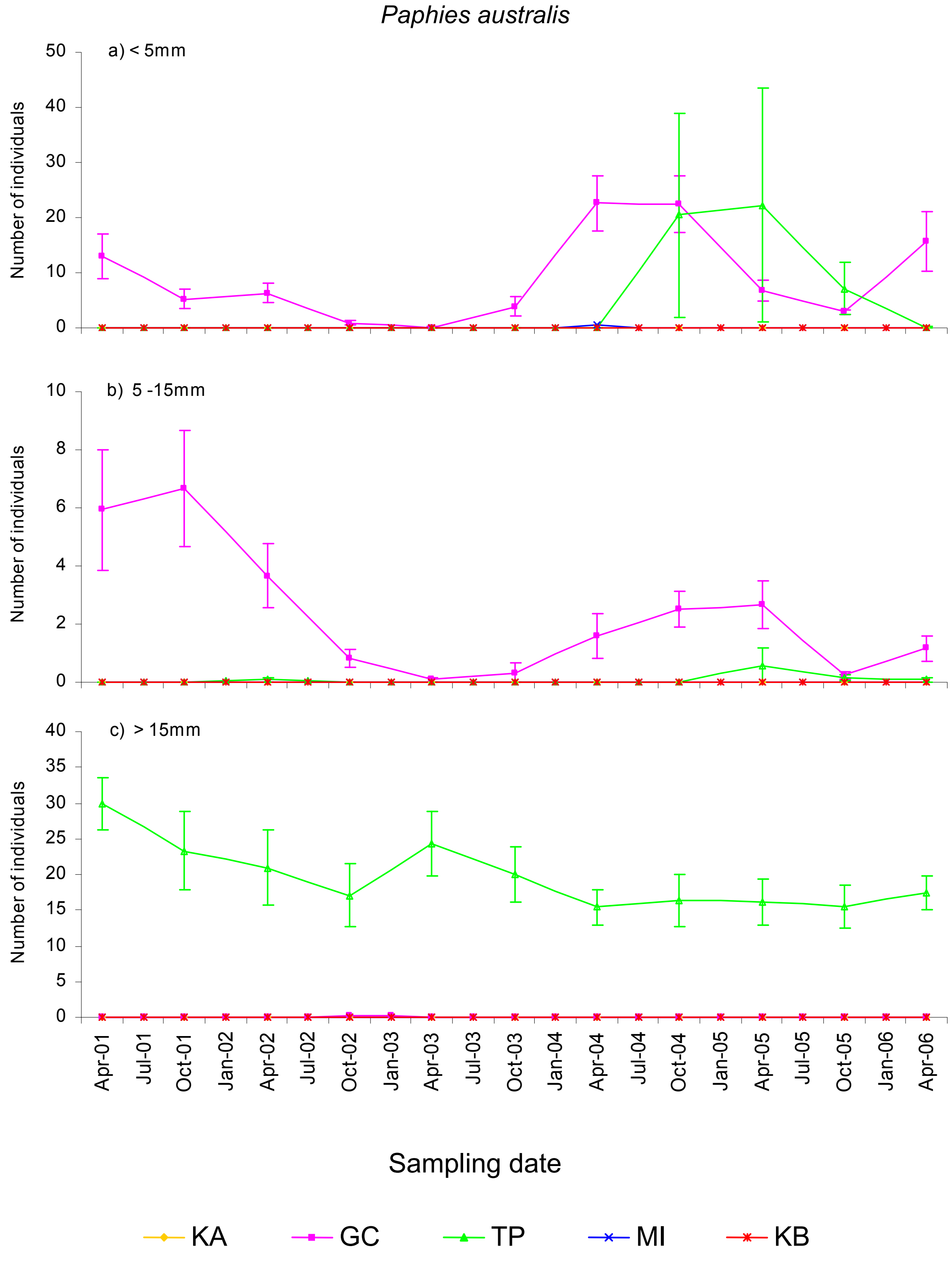


Figure A2.b: **Mean (± standard error, N=12) abundance of the different size classes of indicator bivalve species found at the permanent monitoring sites in the southern Firth of Thames between April 2001 and April 2006. Note the different scales on the vertical axis**

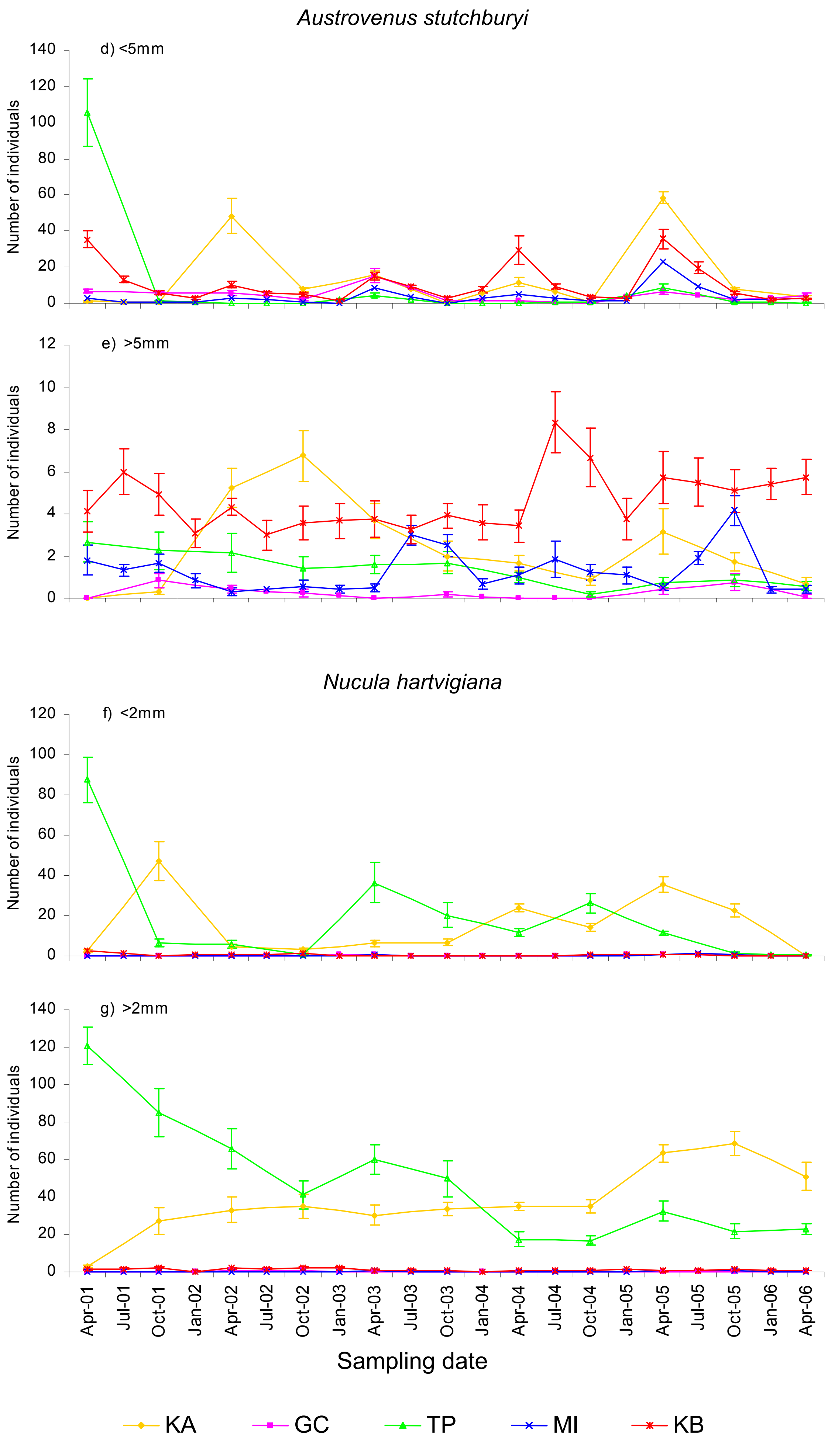


Figure A2.b (cont.)

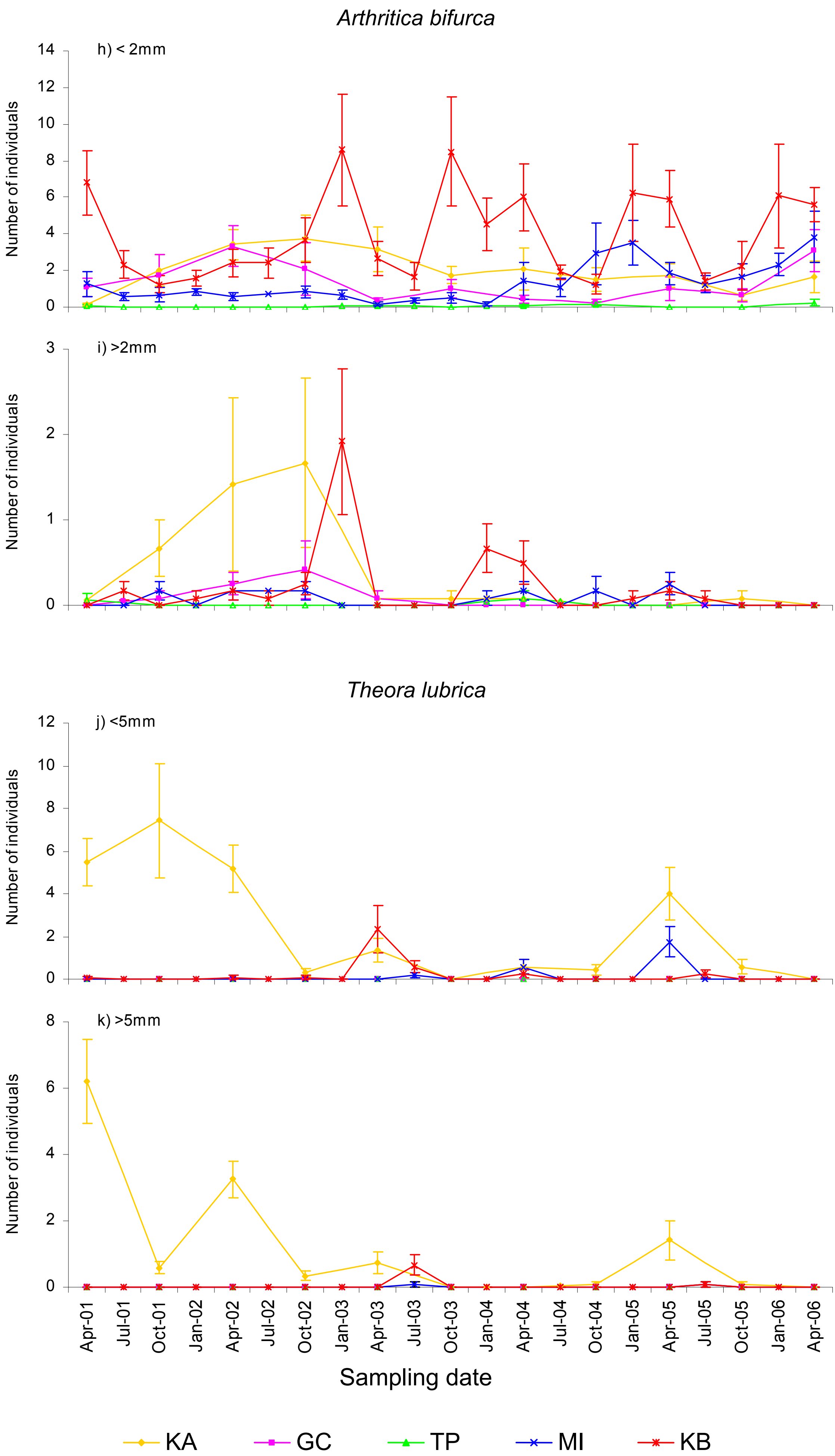


Figure A2.b (cont.)

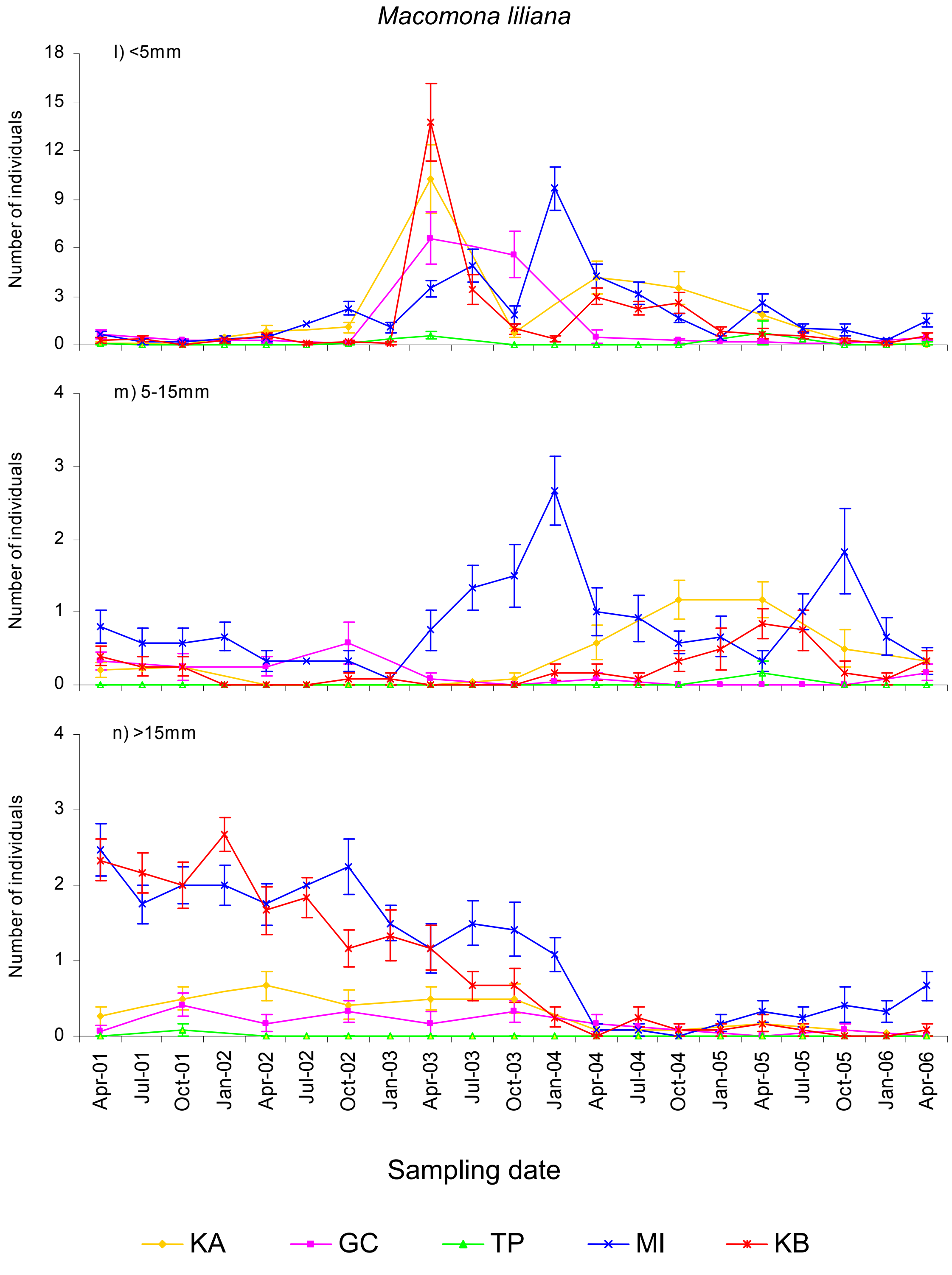


Figure A2.b (cont.)

Appendix 3: Abundance of indicator species Raglan (Whaingaroa) Harbour

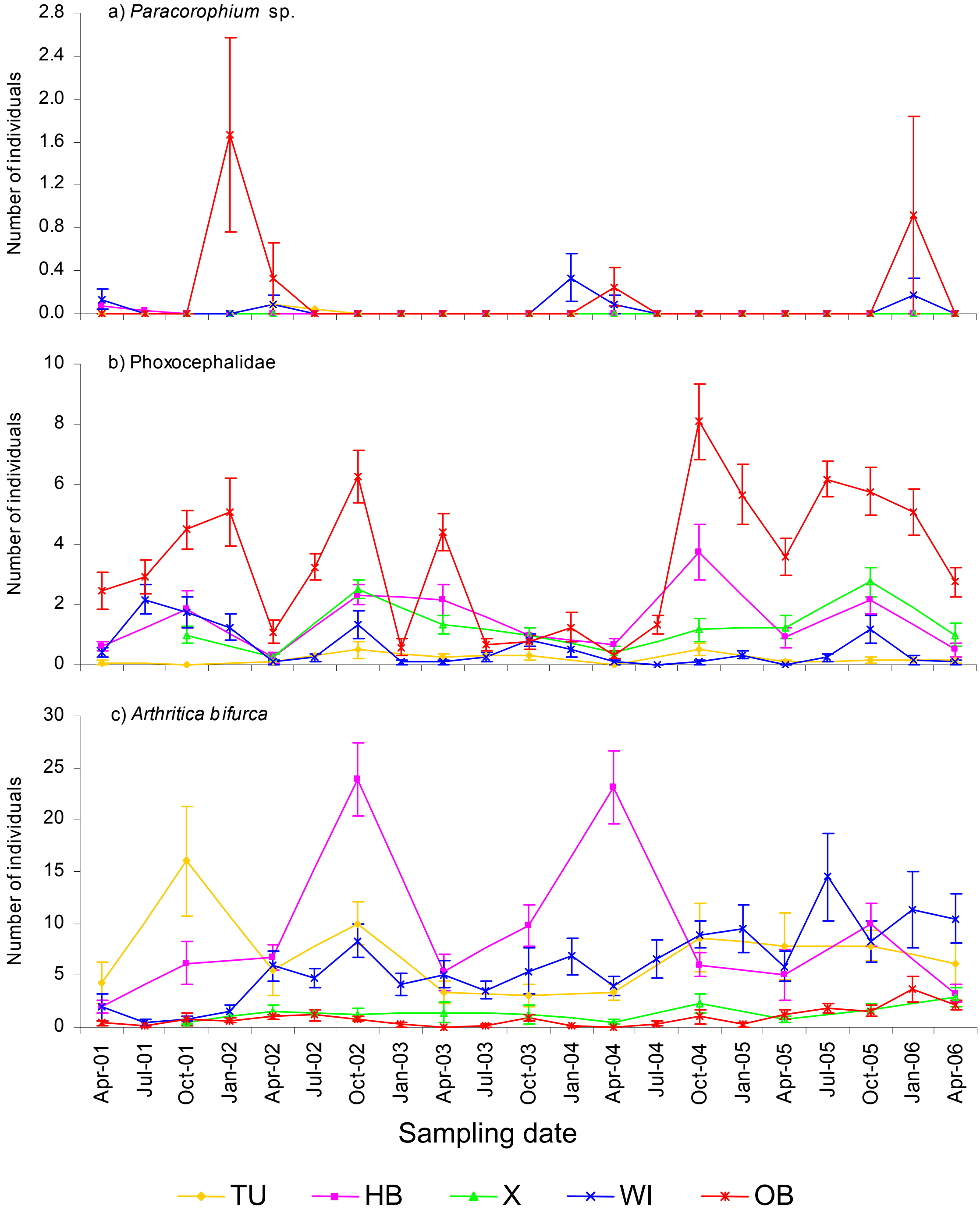


Figure A3.a: **Mean (± standard error, N=12) abundance of macrobenthic indicator species found at the permanent monitoring sites in Raglan (Whaingaroa) Harbour between April 2001 and April 2006. Note the different scales on the vertical axis.**

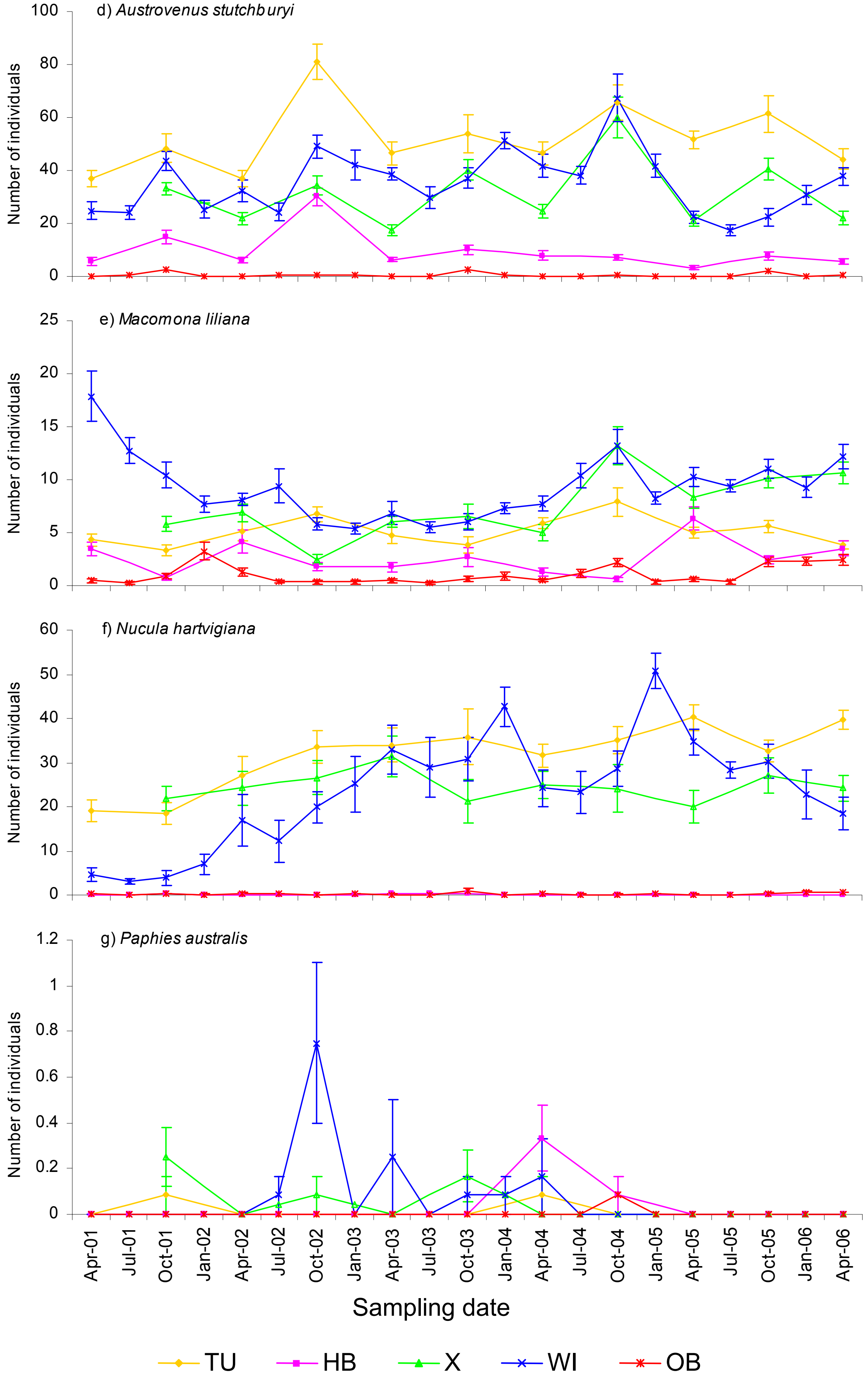


Figure A3.a (cont.)

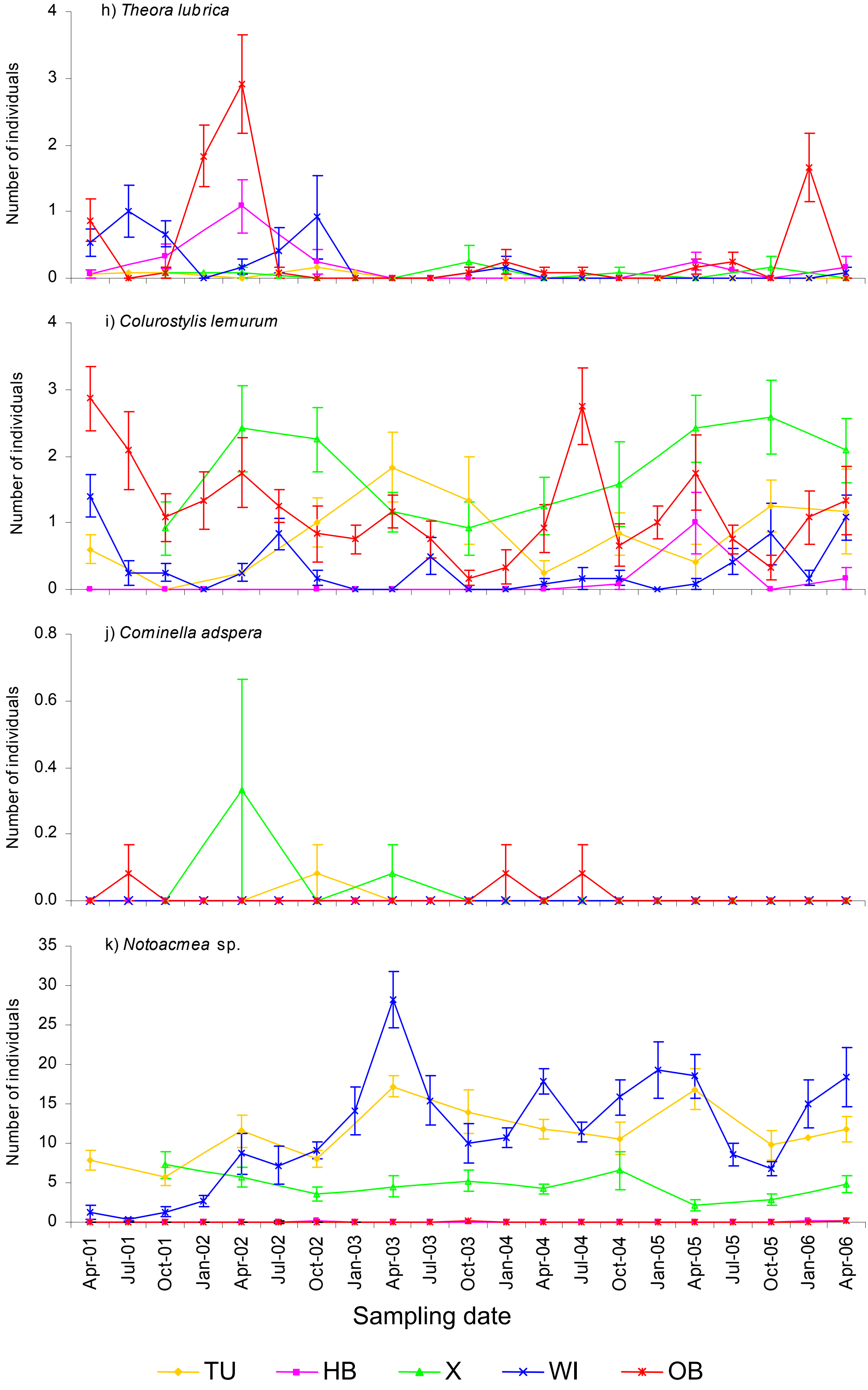


Figure A3.a (cont.)

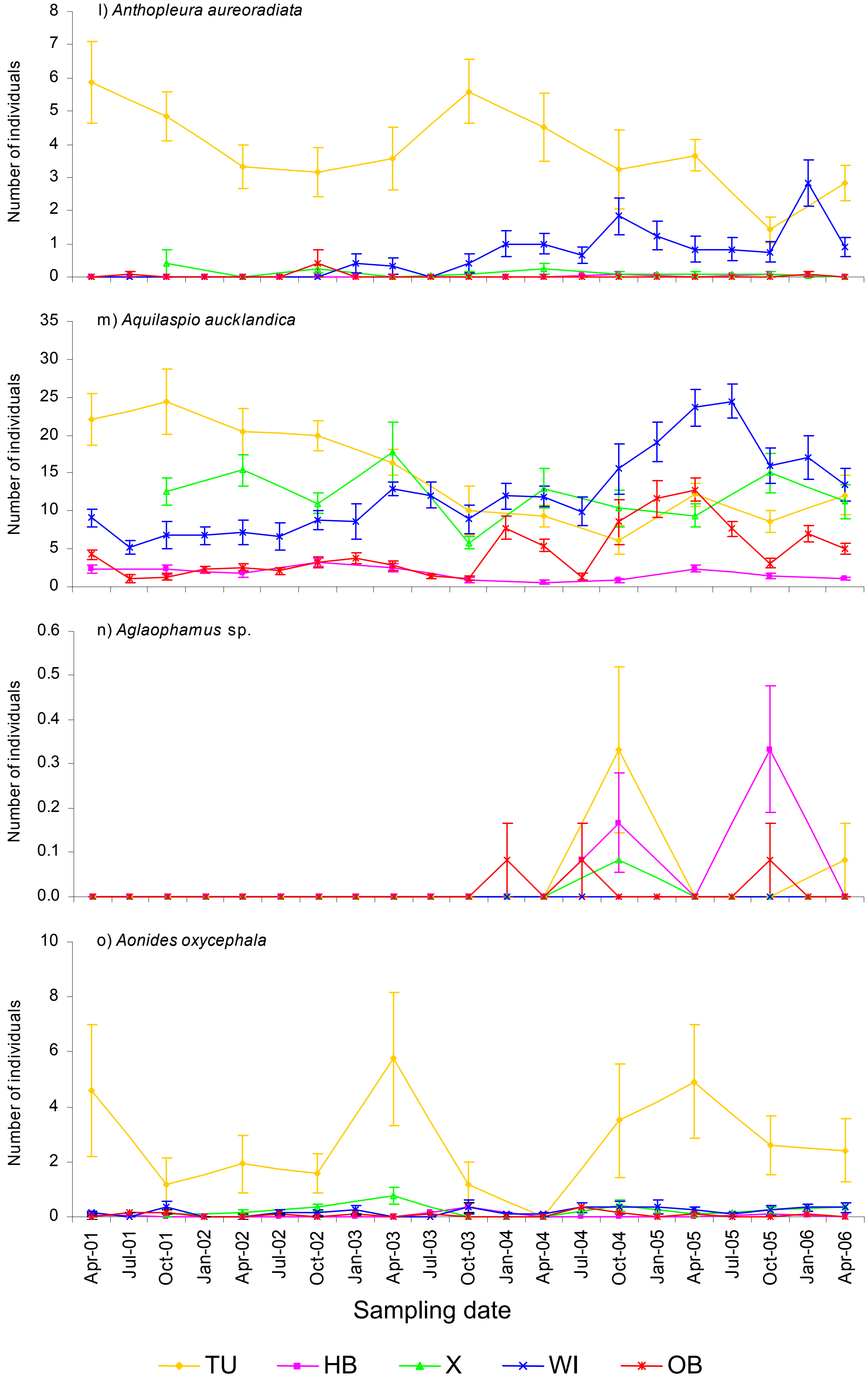


Figure A3.a (cont.)

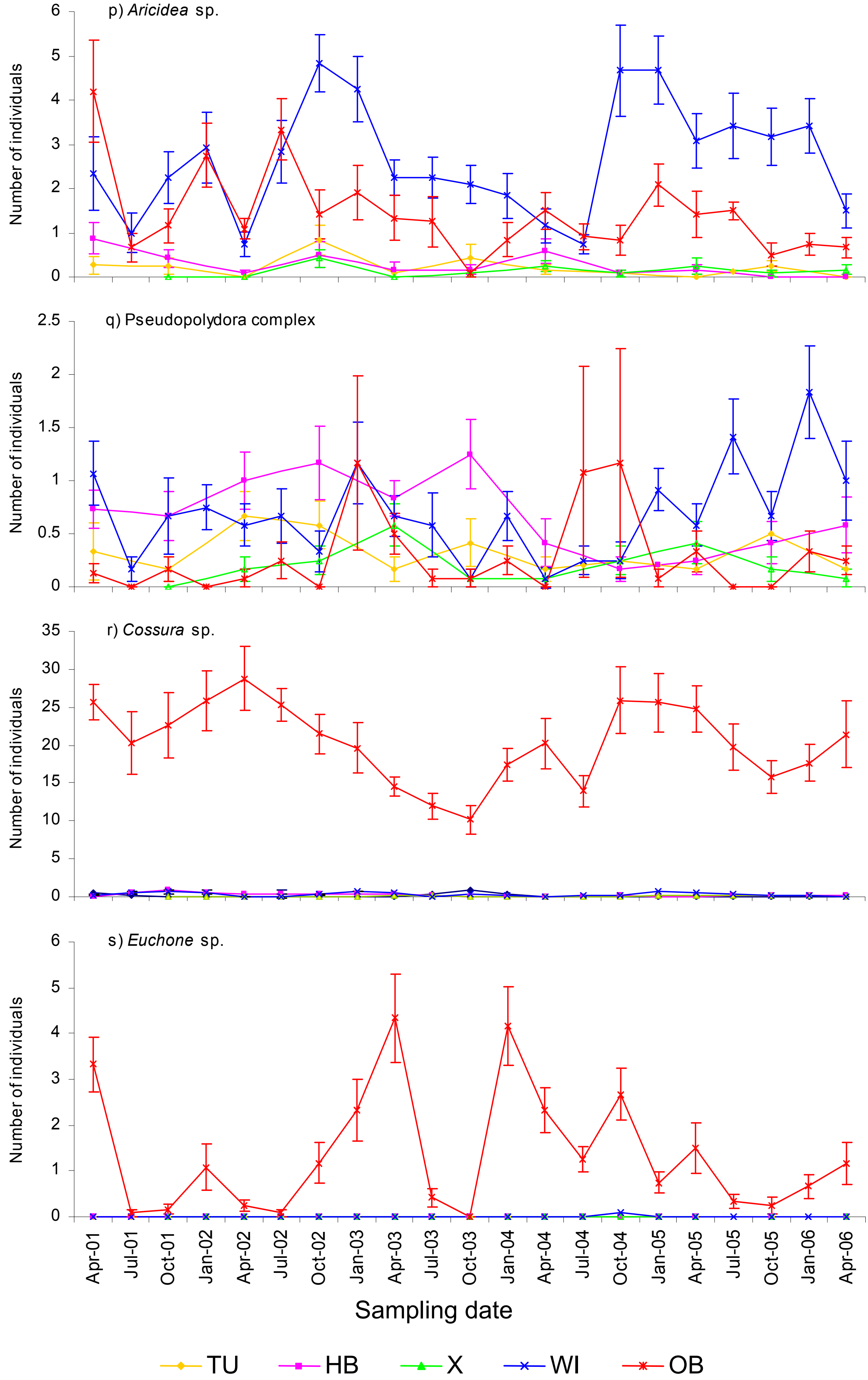


Figure A3.a (cont.)

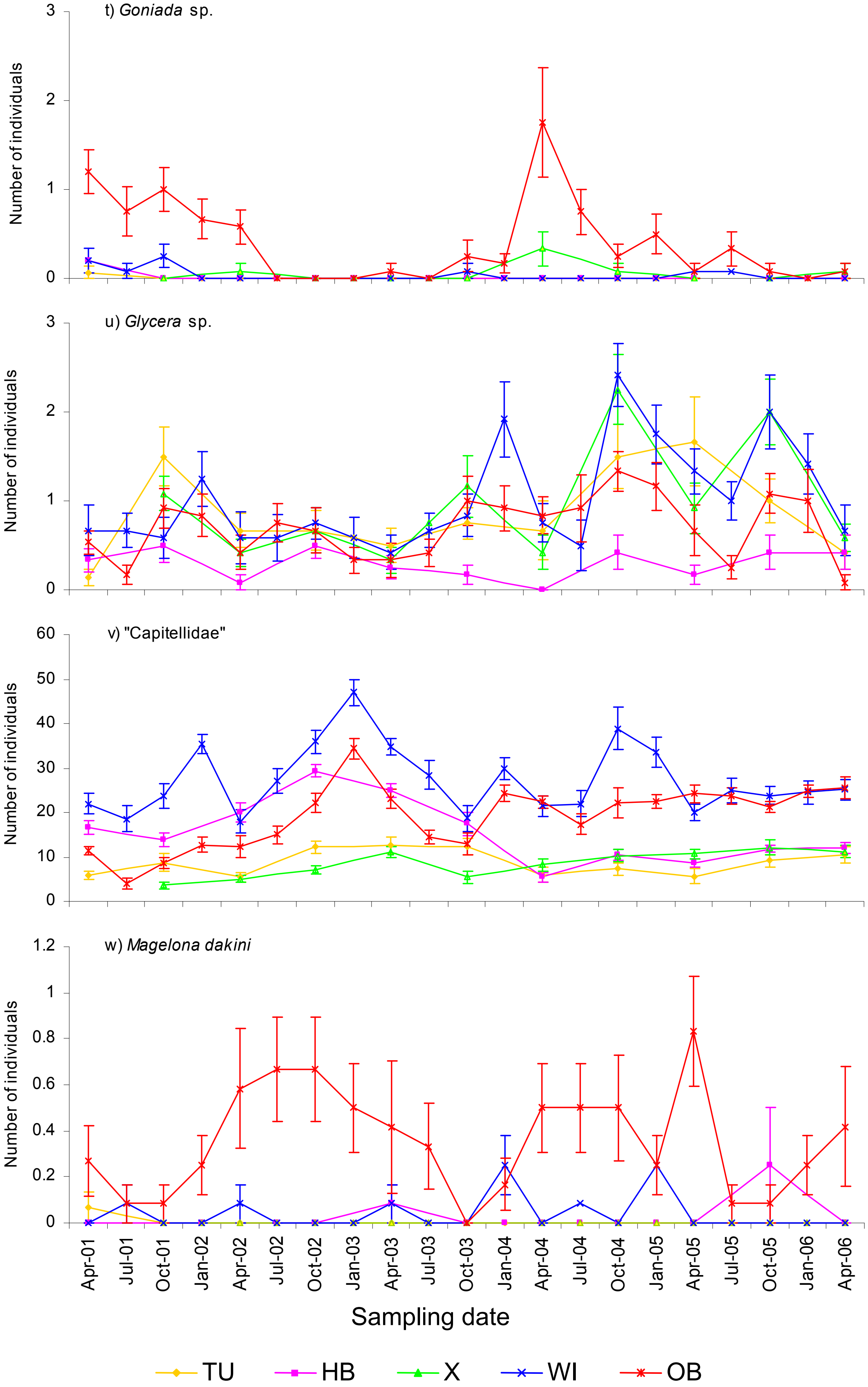


Figure A3.a (cont.)

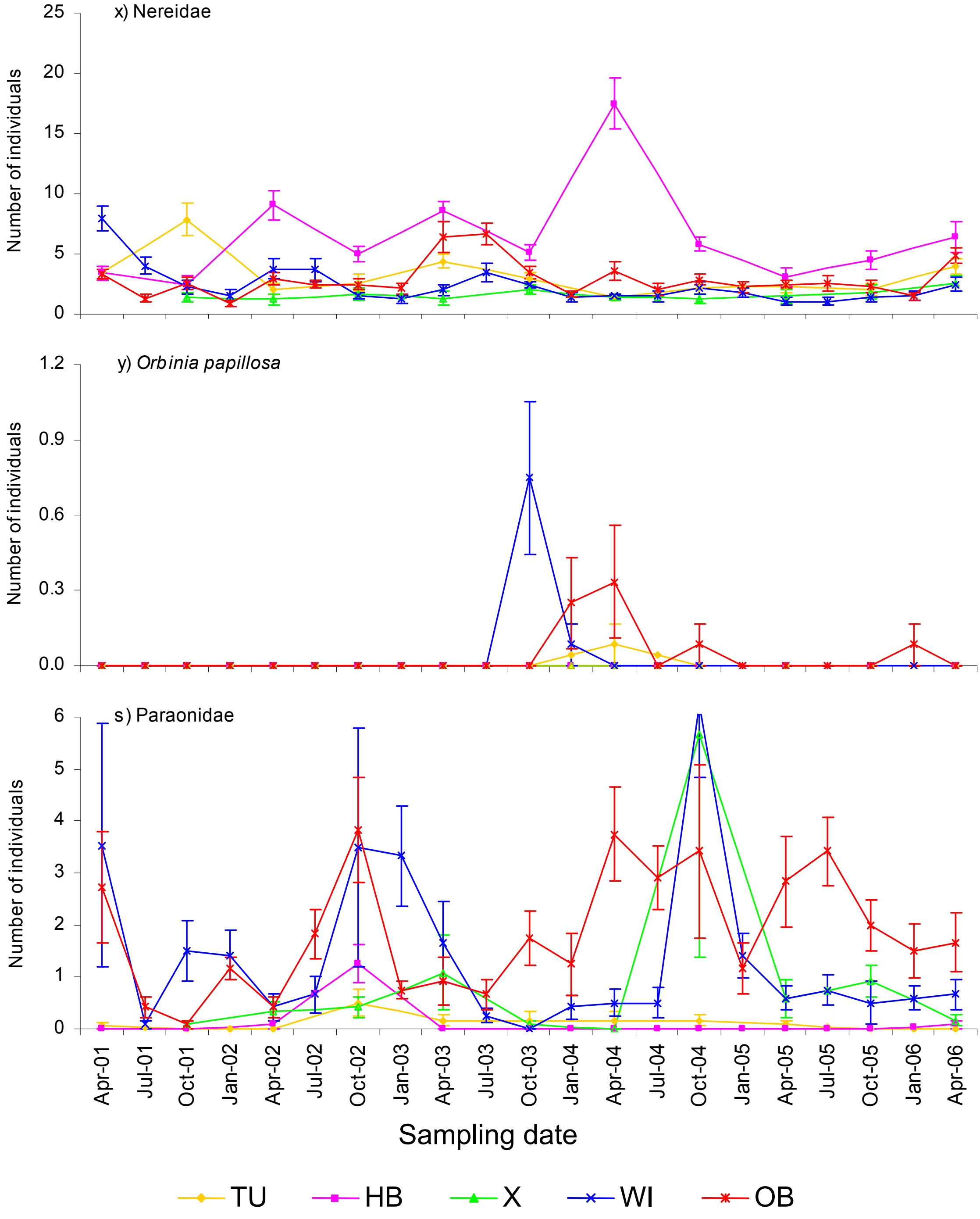


Figure A3.a (cont.)

Bivalve size class frequency Raglan (Whaingaroa) Harbour

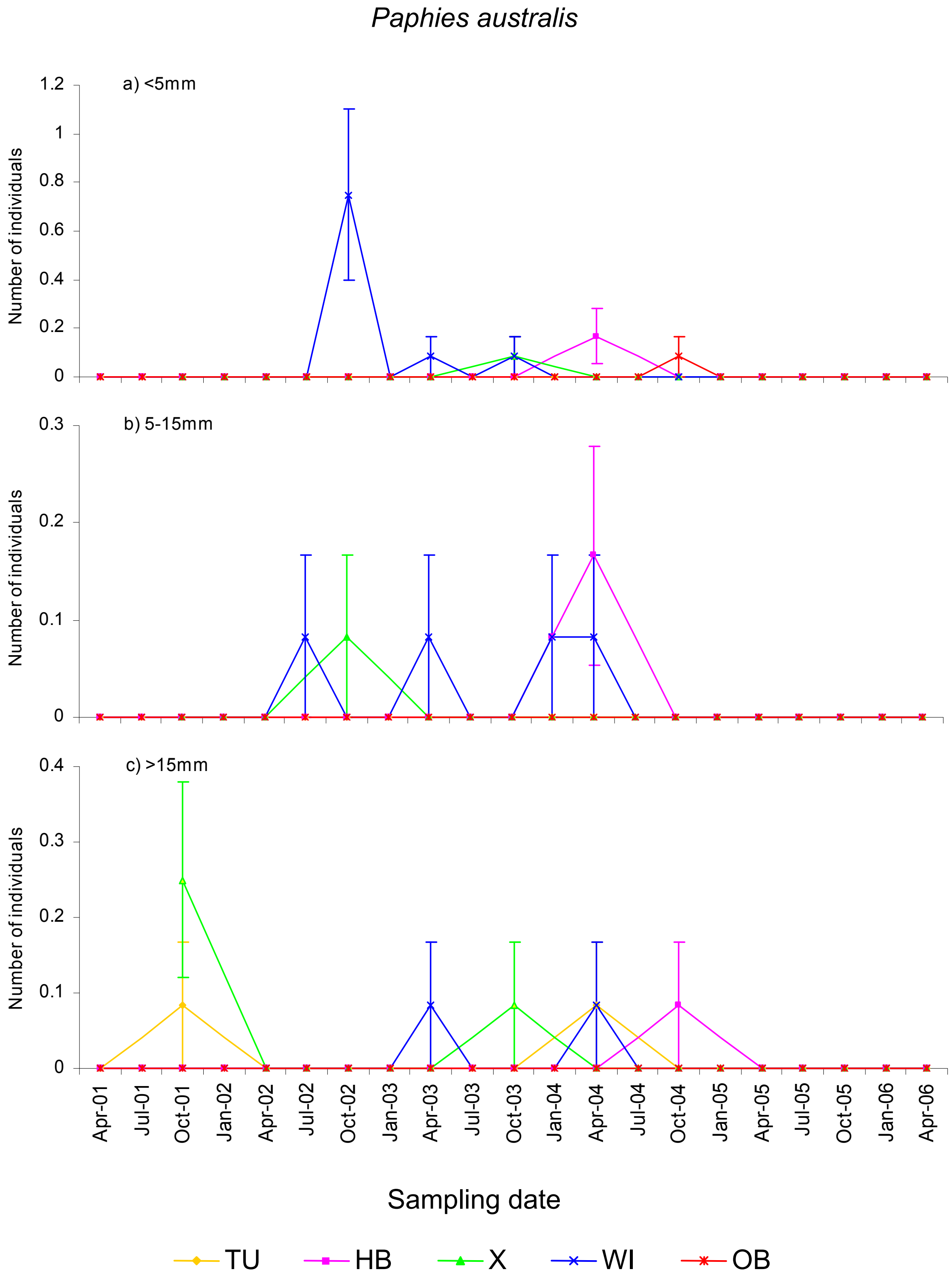
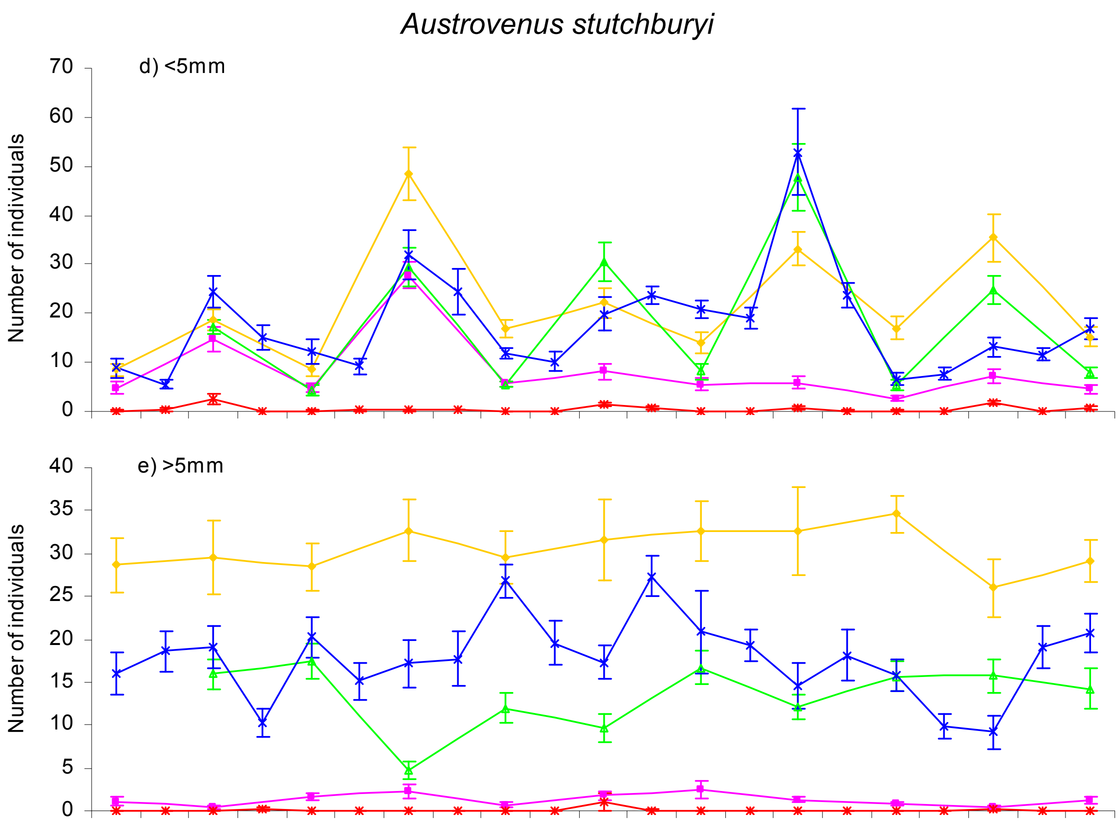


Figure A3.b: **Mean (± standard error, N=12) abundance of the different size classes of indicator bivalve species found at the permanent monitoring sites in the Raglan (Whaingaroa) Harbour between April 2001 and April 2006. Note the different scales on the vertical axis.**



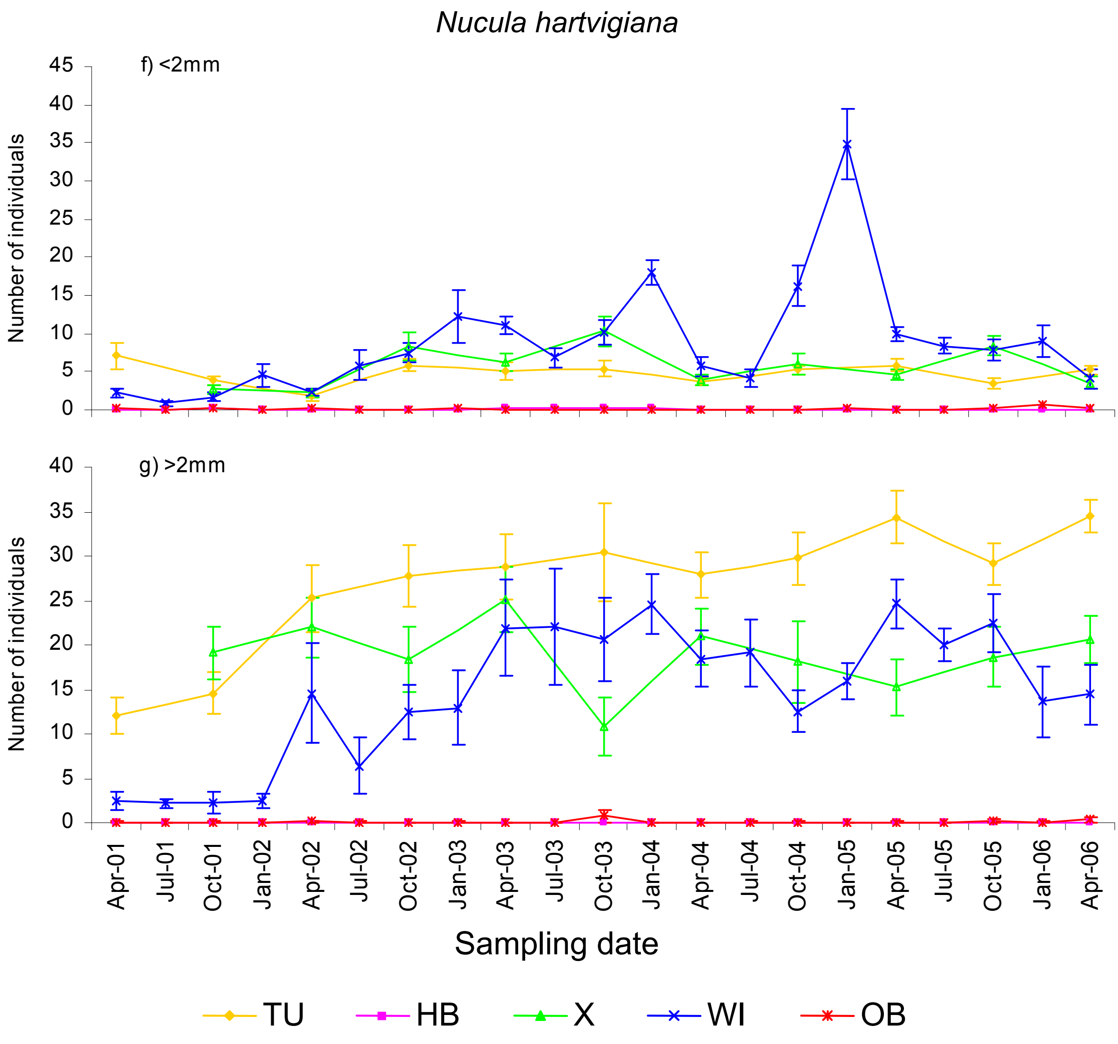


Figure A3.b (cont.)

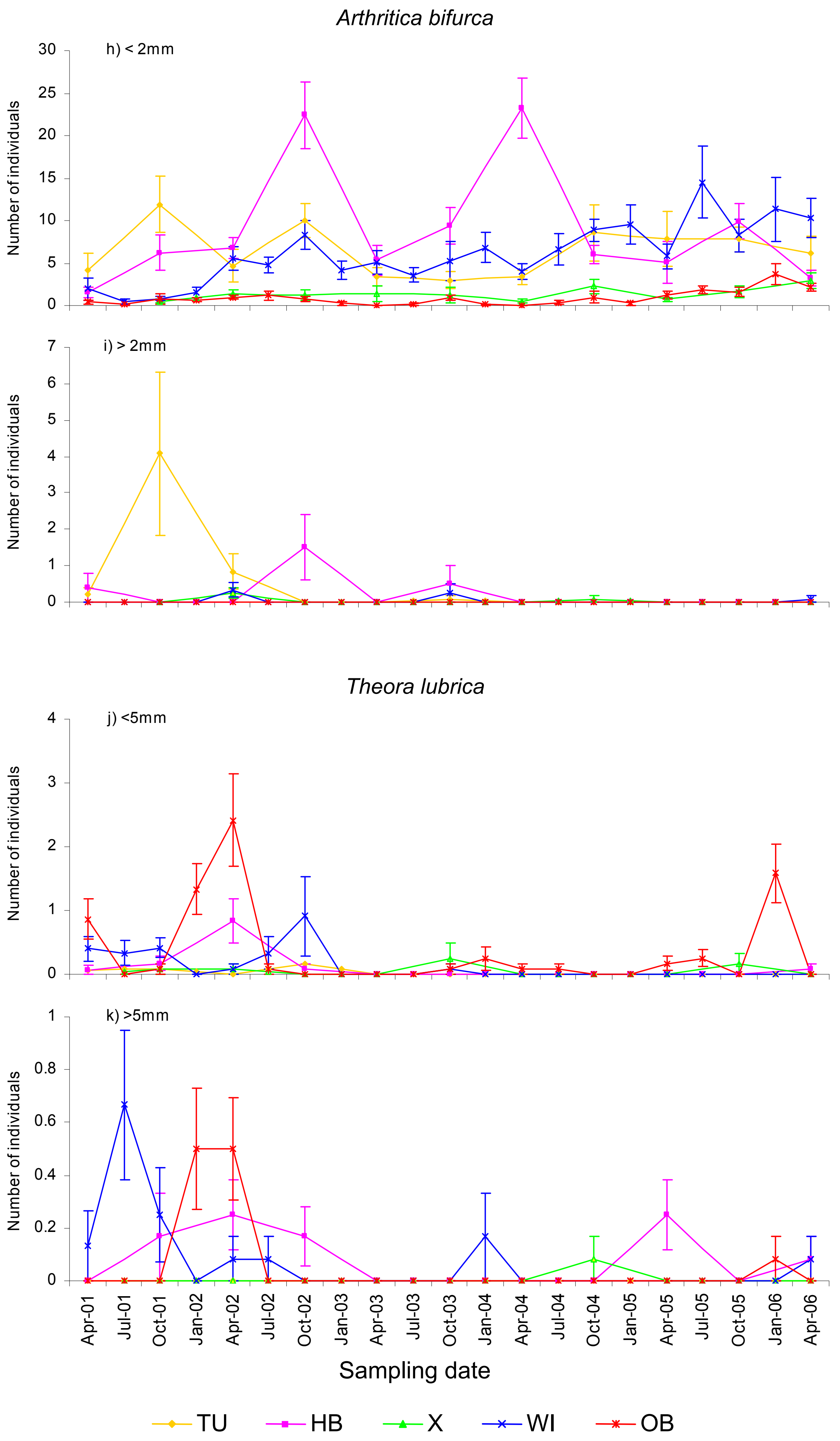


Figure A3.b (cont.)

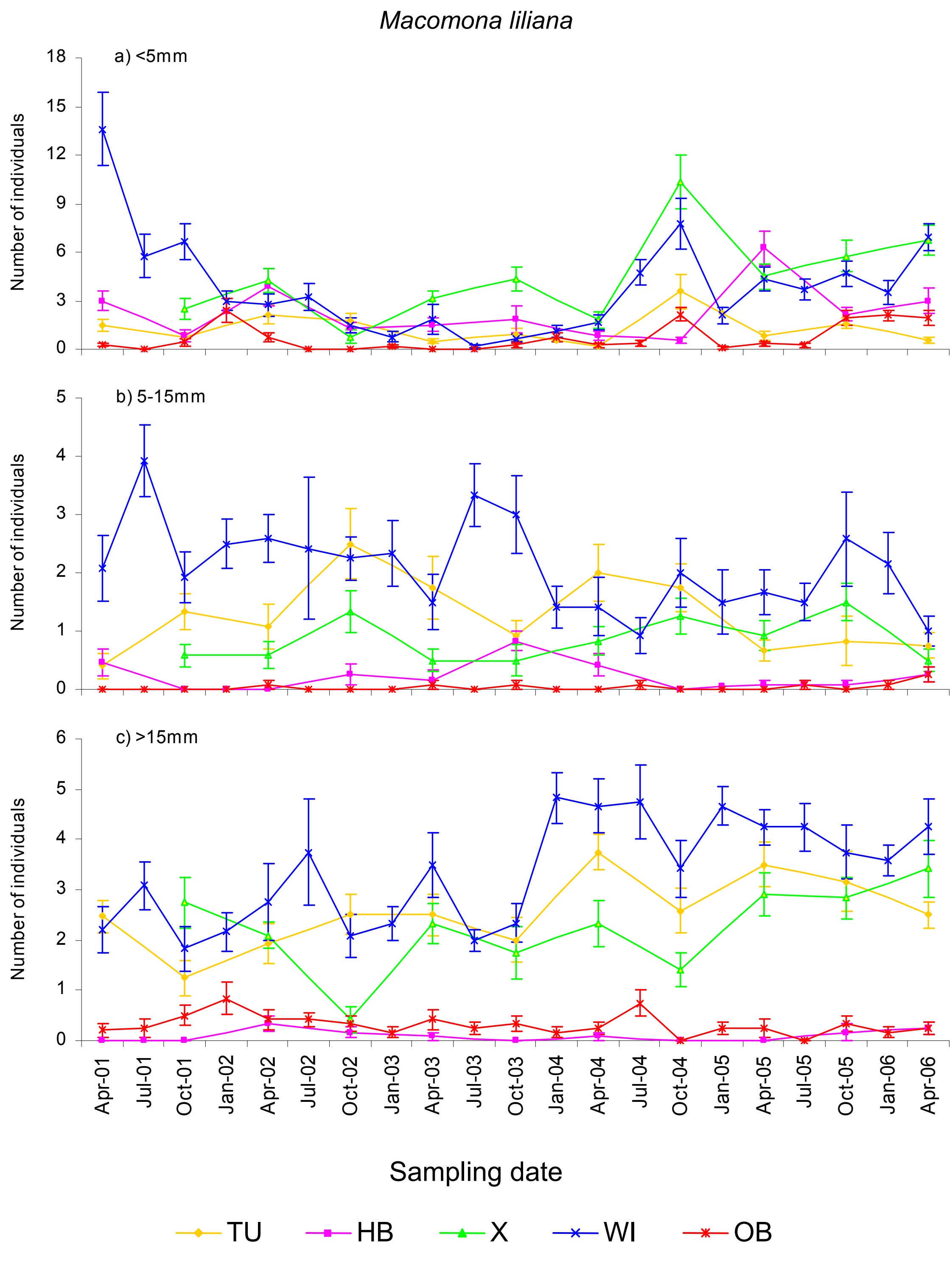


Figure A3.b (cont.)