Environment Waikato Technical Report 2005/27

Regional Estuary Monitoring Programme: Sediment Monitoring

April 2001 to April 2003

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1 Introduction

In April 2001 Environment Waikato initiated the Regional Estuary Monitoring Programme (REMP) at permanent monitoring sites in the southern Firth of Thames and Whaingaroa (Raglan) Harbour. The programme focuses on intertidal sediments and their benthic macrofauna communities[1] as "indicators" of the health of the Region's estuaries. The objective is to determine the current status of, and monitor the temporal changes in benthic macrofauna communities that may occur as a direct or indirect consequence of catchment activity and/or estuary development. Details of the rationale and design of the programme are provided in full in Turner (2000 and 2001).

The key variables measured in the REMP are:

1 A suite of 26 "indicator" species or taxa[2] characteristic of intertidal sand-flat benthic macrofauna communities (see Hewitt *et al.* 2001).
2 A suite of physical, chemical and biological sediment characteristics:
   - Sediment grain-size;
   - Organic matter content (total organic C, total N);
   - Benthic microalgal biomass (chlorophyll-*a* and phaeophytin concentration);
   - Sediment surface elevation.

The five sites situated in the southern Firth of Thames and Whaingaroa Harbour are monitored at 3- or 6-monthly intervals to determine seasonal, annual and spatial patterns of variability in the intertidal sand-flat benthic communities and sediment characteristics. The justification and design of the programme are provided in full in Turner (2000 and 2001). The monitoring programme is designed to provide relevant information for policy development and to assist with the sustainable management of estuaries in the Waikato Region. The programme has been designed on the premise that monitoring will continue for a minimum of 10 years, with a review after 3-5 years to ensure statistical integrity and cost effectiveness.

In April 2001, a pilot study was undertaken to establish a baseline for detecting changes in the benthic macrofauna communities and sediment characteristics over time (Turner *et al.*, 2002).

This report presents the results for the sediment-monitoring component of the REMP between the commencement in April 2001 and April 2003. Detailed results for the ecological component are available in Turner & Carter (2004).

Sufficient data have not yet been collected to enable detailed trend or time-series analysis, nor is it appropriate at this early stage in the monitoring programme to ascribe great significance to any apparent trends in the sediment characteristics. This report therefore only presents observations of the temporal variation sediment characteristics and does not attempt to determine driving forces for these changes.

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[1] "Benthic macrofauna communities" include the variety of organisms (e.g., shellfish, crabs, polychaetes [marine worms], crustaceans) that live in or on the bottom sediments. The "macrofauna" comprises those animals which are retained by a 500 µm mesh sieve.

[2] Note that the term "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 species groups monitored may include more than one species.

2 Methods

2.1 Field Sites

Five sites are monitored in both the southern Firth of Thames (Figure 1) and Whaingaroa Harbour (Figure 2). These sites are distributed throughout the main area of each estuary at approximately mid-tide level. Although accessibility was necessarily considered in the selection of sites, they are considered to be representative of the intertidal sand-flats in each estuary.

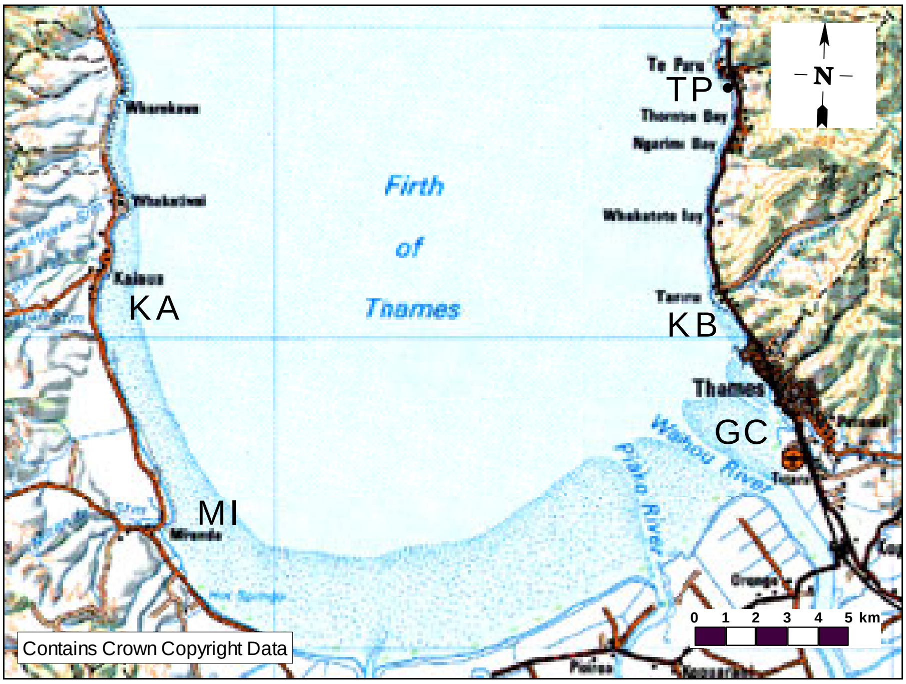


Figure 1: Location of permanent monitoring sites in the southern Firth of Thames.

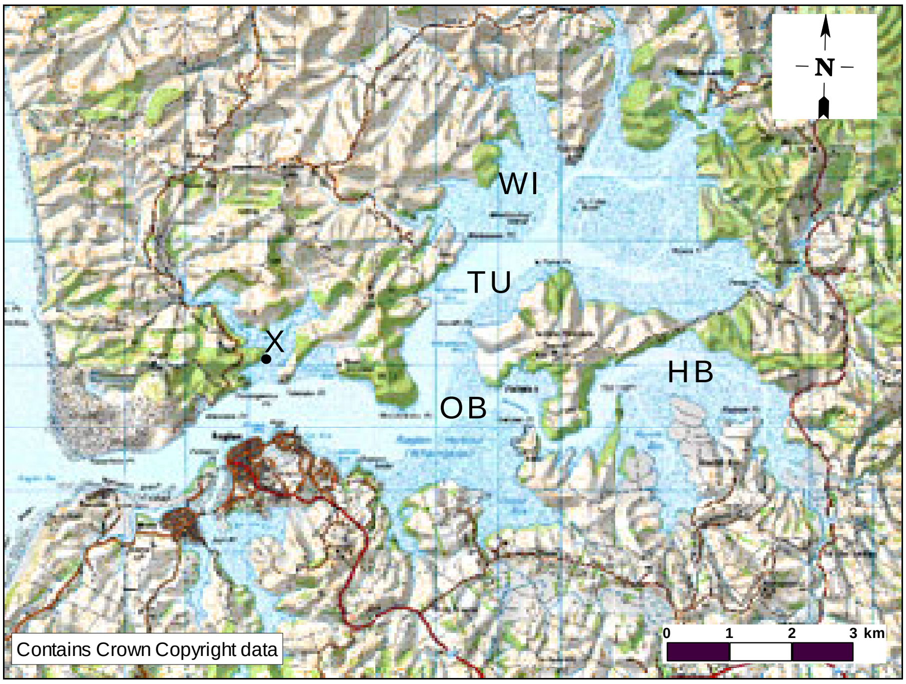


Figure 2: Location of permanent monitoring sites in Whaingaroa Harbour.

2.2 Sample Collection and Processing

The following samples are collected from each site.

2.2.1 Surficial Sediment Grain-Size

At each site, surface sediment samples (5 cm diameter, 1-2 cm deep core) are collected from the vicinity of the benthic core samples and bulked for analysis. Five composite samples (each containing five surface samples) are collected from each monitoring plot for grain-size analysis. A portion of each of these samples is archived (frozen).

Samples for grain-size analysis are pre-treated with 10% hydrogen peroxide to remove organic material and 1*M* HCl to remove carbonate material. During the first 12 months of the project (up to and including April 2002), Calgon was added as a dispersant and samples were placed in an ultrasonic bath for 10 minutes to aid disaggregation. Problems were experienced with the July 2002 samples, with some carbonate material not successfully digesting. In order to ensure complete carbonate digestion, the concentration of the HCl was increased to 2*M*. Subsequent Calgon treatment in the presence of the stronger acid generated a significant precipitate, so Calgon is not longer used as part of the treatment.

A Galai laser sediment analyser is used to obtain sediment grain size information. Data output from the Galai provides percentage (expressed as volume, number of particles and surface area) composition in specified grain-size ranges. The results of these analyses are presented as percentage composition (volume) of gravel, coarse sand, medium sand, fine sand, very fine sand, coarse silt, medium silt and clay.

The EW DOCs numbers for the complete data sets are listed in Table 1:

Table 1: DOCS References for full data sets for sediment grain size composition.

Site		DOCS #
Firth of Thames	Miranda (MI)	716892
	Kaiaua (KA)	716887
	Gun Club (GC)	716885
	Kurunui Bay (KB)	716888
	Te Puru (TP)	716896
Whaingaroa	Okete Bay (OB)	716900
	Whatitirinui Island (WI)	716906
	Haroto Bay (HB)	716897
	Te Puna Point (TU)	716903
	Ponganui Creek (X)	841441

2.2.2 Sediment Organic Matter Content

Each of the surficial sediment samples is sub-sampled for analysis of total organic carbon[3] and total nitrogen[4] content using an automated CHN analyser. The samples are dried and finely ground before analysis. Sediment for total organic carbon analysis is treated prior to analysis with acid to remove carbonate material.

2.2.3 Rates of Sediment Deposition and Erosion

Over geological time-scales, estuaries slowly fill up with sediments. Coring studies undertaken in estuaries on the Coromandel Peninsula have consistently shown sedimentation rates of 0.1-0.2 mm/yr prior to human settlement and associated land

[3] Total organic carbon was analysed with an elementar combustion analyser after acid pre-treatment.
[4] Total nitrogen was analysed with a thermal conductivity analyser (elementar analyser) following catalytic combustion and separation.

clearance (Hume and Dahm, 1992; Swales and Hume, 1994; Sheffield *et al.*, 1995; Swales and Hume, 1995).

These studies have shown that major catchment impacts following human settlement such as deforestation, gold mining activities, and subsequent reforestation into commercial crops, resulted in sedimentation rates of up to 10 mm/yr in Coromandel estuaries. Current knowledge of estuarine sedimentation in the Waikato Region is summarised in Turner and Riddle (2001).

Historical changes in land-use have also generated increased sedimentation rates in estuaries on the West Coast of the Waikato Region, although available data is much less detailed than from the Coromandel Peninsula.

Initial attempts to measure changes in sediment level as part of the Waikato Estuary Monitoring Programme used wooden pegs (Figure 3). This method provided useful information about the extent of fluctuation in bed level, but a number of problems were associated with this method, as described in Turner *et al.* (2002). This method was therefore abandoned and replaced by a trial using buried plates, as described in the Section 2.2.4.

Figure 3: Wooden post placed to mark the monitoring plot and to measure sediment levels. Localised scour around the posts has created problems with sediment level measurements.

2.2.4 Sediment Level: Buried Plate Measurements

Buried plates were trailed at four of the REMP sites in the Firth of Thames to investigate a method for measuring small fluctuations in sediment level. The aim of the trial was to establish a method for accurately measuring sediment levels as part of the routine monitoring of REMP sites. The problems of disturbance and scouring was eliminated by measuring sediment depth over a buried surface. The trial is summarised below, and detailed methods and results are available in Collins (2003).

Square concrete tiles (30 x 30 cm) were buried in the sediment at a level depth of approximately 20 cm. Plates were buried adjacent to each existing peg in the cross-shore transect, with the exception of the peg in the centre of the benthic sampling plot (to avoid unnecessary disturbance of the benthic sample plot). Three additional wooden pegs were placed equidistantly around the buried plates, as shown in Figure 4. These pegs could be used to accurately and quickly locate the buried plate at monitoring date.

The plate transects were buried in February 2003, and left for several weeks to allow the substrate to settle after the disturbance. In March 2003, a full cross-shore transect was surveyed using an EDM, from shore to the most seaward plate in each transect. This survey provided data on the cross-shore shape of the intertidal area at each site, as well as an accurate survey of the location and elevation of each plate and the sediment surface above each plate. Details of this survey can be found in Collins (2003). The sites will be re-surveyed using the same methods in 12-24 months to determine if there has been any movement or settling in the soft substrate.

Since the initial survey, until mid-June, the sediment depth over the plates was resurveyed every two weeks. These measurements will be continued monthly until the data has been collected for at least 12 months. Analysis will then be undertaken to further assess the number of plates necessary and the frequency of ongoing surveying required.

Repeated surveys are undertaken by measuring the depth of sediment over each plate using metal needles. Where shell material in the sediment was abundant, problems were experienced with successfully identifying the plate surface. Ten needles of the same length were therefore inserted at the same time. Any irregularities associated with the needles hitting shell soon became apparent using this approach (Figure 5). This also insured that measurements were well distributed around the plate surface. This method is repeated to give two samples with 10 replicates in each.

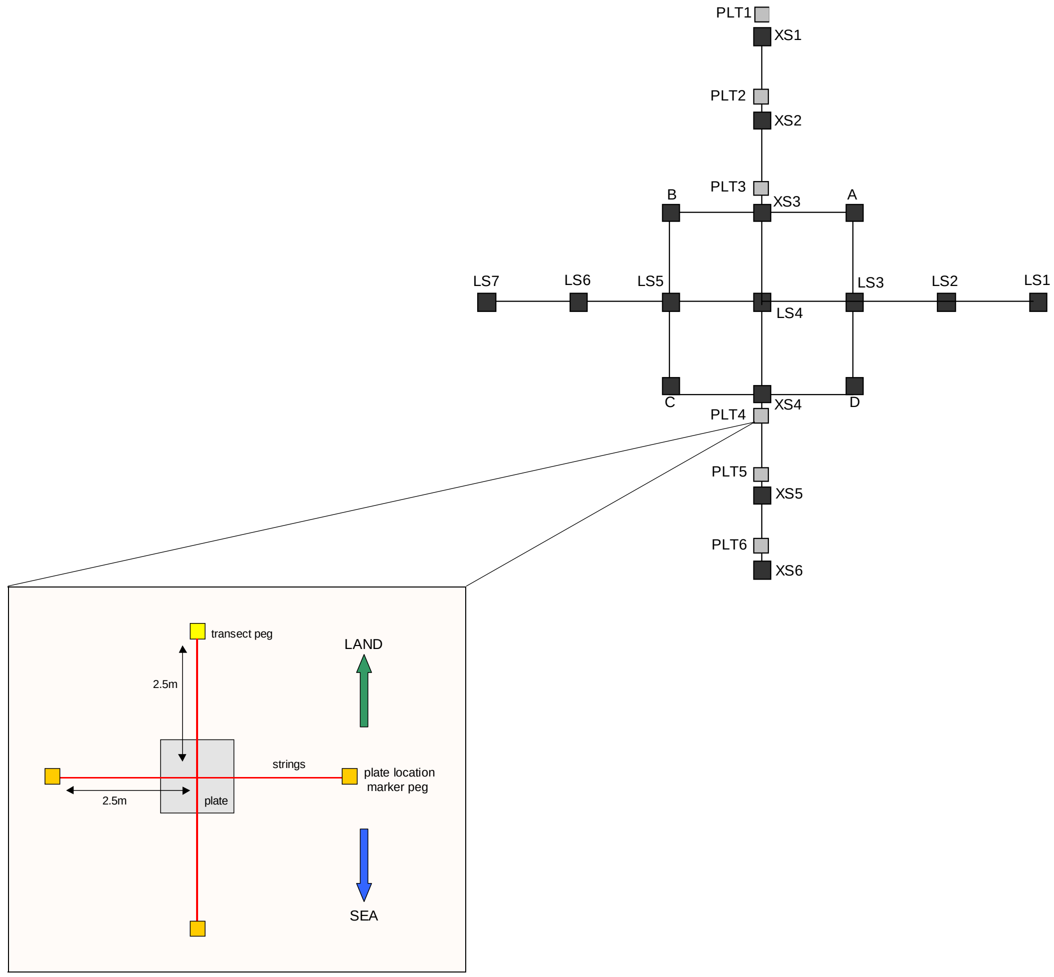


Figure 4: Diagram illustrating buried plate and locator peg positions.

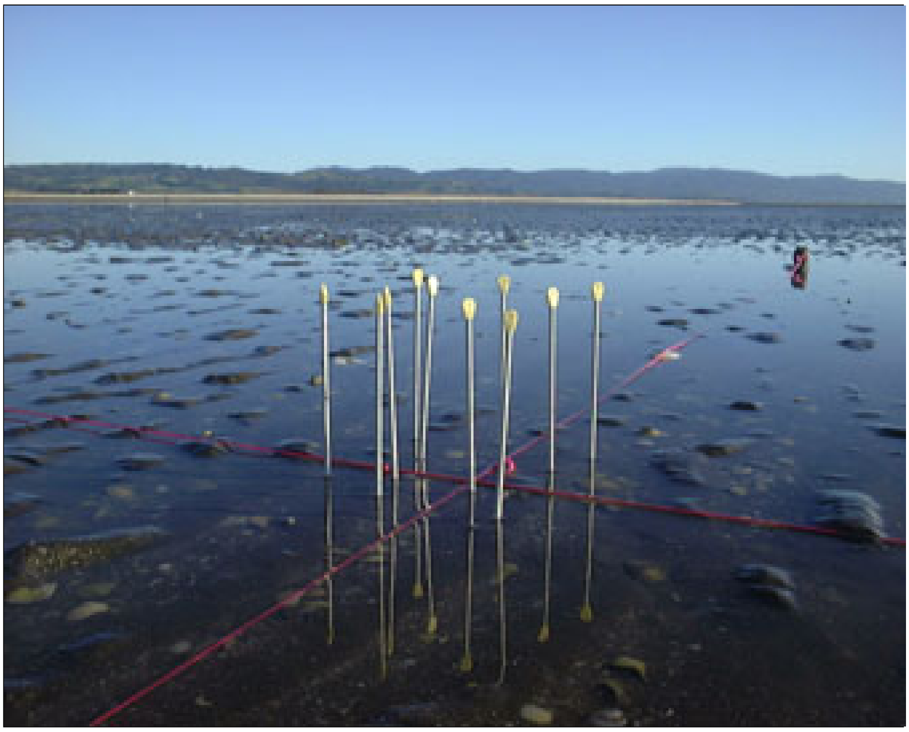


Figure 5: Knitting needles were used to measure the depth of sediment over each of the plates at each sampling run. One of the four locator pegs can be seen in the background, and the strings (pink) can be seen in the foreground, crossing over the plate.

3 Results and Discussion

3.1 Surficial Sediment Grain-Size

An important potential effect of catchment activities on estuarine and coastal areas is a change in the sediment regime in these areas as a result of sediment eroded from the catchment. Any increases in sediment run-off from a catchment can result in an increase in the rate of sedimentation and changes in the textural character of the surface sediments[5] in an estuary. Increased run-off is also likely to result in higher levels of ambient turbidity. Previous studies have established that in the past, catchment activities have had considerable impacts on the sediments (large increases in the rates of sedimentation and changes in the character of the sediments) in estuaries in the Waikato Region (see Turner and Riddle, 2001 for a review). Changes in the sediments in the southern Firth of Thames and Whaingaroa Harbour are being monitored as changes in the particle-size composition of the surface sediments and rates of sediment deposition.

Changes in turbidity, sedimentation rates and/or in the nature of sediments will often be accompanied by ecological changes, as many species have strict sediment particle size preferences and others are susceptible to small changes in the rate of sediment accumulation and the level of turbidity. For example: suspended fine material may result in the smothering or clogging of feeding and respiratory organs of some species; changes in the particle-size composition of the sediment may affect the ability of some species to feed or construct burrows, or may lead to alterations in the amount of oxygen present in the sediment which may have affects on species intolerant of anoxic conditions (Morrisey *et al.*, 1994). Increased turbidity also reduces primary production

[5] For example, changes from sandy sediments to silt/mud/clays.

in the water-column and on the bed of the estuary, potentially resulting in reduced food availability for some species (Morrisey *et al.*, 1994).

While the species composition of benthic communities is determined to a large degree by the nature of the sediment, the animals themselves can exert an influence on sediment characteristics. For example, burrowing and tube-building activities re-work the sediment, burying surface material and bringing deeper sediment to the surface; construction of dense mats of tubes can increase the stability of the sediment, reducing its tendency to erode. Suspension feeding species also ingest material suspended in the water column and the defecation of this material enhances the organic content of the sediment (Morrisey *et al.*, 1994).

3.1.1 Southern Firth of Thames

Kaiaua and Miranda sites are located on the western side of the southern Firth (Figure 1), and have similar sediment grain-size distributions. Gravel present (23.15% at Kaiaua and 15.6% at Miranda) in April 2001 has almost completely disappeared from the sediment at all the dates since. Kaiaua is consistently the muddiest of the Firth of Thames monitoring sites, with the highest percent of clay, silt and fine sand (Figure 6, Table 2).

The sediments are dominated at both sites by fine and very fine sand, with moderate medium and coarse sand content (usually 10-30%). The mud content in the sediments is consistently low at Miranda (1.5% - 2.3%), but highly variable at Kaiaua, with results from the sediment analysis varying between 0.8 % and over 17%. The sediment is poorly sorted and had a polymodal[6] sediment particle size distribution at both of these sites. At Kaiaua a layer of semi-fluid flocculent material (up to 20 cm deep) is often present between the shore and the monitoring plot. This layer overlies a firm sandy sediment surface, which is occasionally exposed. This layer is not usually present within the monitoring plot.

The composition of sediments from the Kaiaua site is variable. This is particularly evident in the gravel and coarse sand content, as well as the relative content of mud. Sediments collected in October 2001 had considerably higher mud content than at any other date, suggesting a recent influx of fine material. The percent composition of fine and medium sand in these sediments is relatively consistent.

The composition of sediments at Miranda is more consistent over time. Small changes occurred between April 2001 and April 2003, but no clear patterns are evident. At the last two sampling dates (January 2003 and April 2003), the content of very fine sand and mud was higher than at earlier dates, however it is unlikely that this represents a long term increase in the fine component of the sediment.

Sediment at the Kuranui Bay and Te Puru sites, located on the eastern side of the southern Firth (Figure 1) also have very similar grain-size distributions. As with sites on the western side of the Firth of Thames (Kaiaua and Miranda), gravel present at the first sampling date in April 2001 was not apparent at later dates. Sediment at both sites is poorly sorted with a polymodal distribution. The grain size distribution at both sites shows three peaks, one a sharp high peak at 250-350 microns (medium sand), with this narrow band accounting consistently for 15-20% of the sediment by volume. Sediment at these two sites is also about one third fine sand, with another peak in the distribution between 130 and 250 microns. Only relatively low levels of clay, silt and gravel (Figure 6, Table 2) are present in these sediments.

At Te Puru, sediment composition is very consistent within the site and throughout the study period. Sediment at this site is composed almost completely of fine, medium and coarse sand, with less than one percent mud, except for in October 2002, when the

[6] Refers to the mode of the sediment grain-size distribution, i.e. the most frequently occurring particle size, or the highest point on a frequency curve. A sample can be unimodal (have one peak), bimodal (have two peaks) or polymodal (have many peaks in the distribution).

mud content increased to 2.2%. Similarly, the percentage of gravel sized particles in Te Puru sediments was only 1-3%.

At Kuranui Bay, the sediment composition is also relatively consistent, though with an apparent steady increase in fine material. The mud content varied between 0.6% and 2.9%. To date there seems to be a steady increase in the content of fine and very fine sand, accompanied by a steady decrease in the medium and coarse sand percentage. There is no apparent increase in the relative mud content.

Sediment at the Gun Club site, located adjacent to the Waihou River in the south-eastern Firth (Figure 1), is the coarsest of the Firth of Thames monitoring sites. The sediment results indicated predominantly medium and coarse sand and gravel, and a very low percent of clay and silt (0.1-1.7% mud), (Figure 6, Table 2). Sediment at the Gun Club site is better sorted than at other sites in the southern Firth, mostly due to a much smaller component of fine material. This site also recorded the greatest weight of shell-hash. This sediment composition and the large apparently mobile bedforms evident at the site indicate a higher energy physical environment than other monitoring sites in the Firth of Thames.

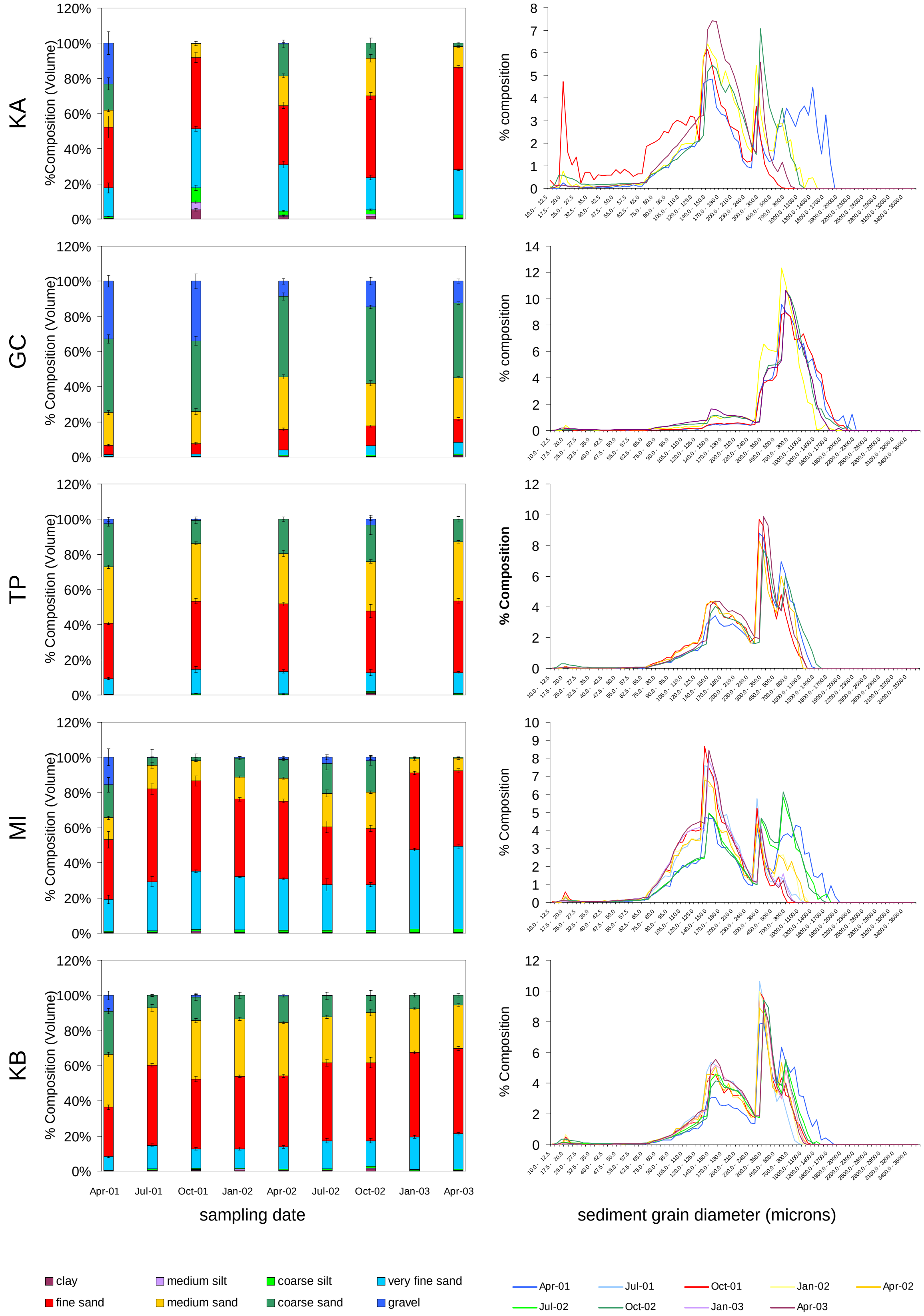


Figure 6: Sediment grain-size distribution for the five monitoring sites in the southern Firth of Thames.

Table 2: Results (mean ± standard error, n = 5) of grain-size analysis of surficial sediment collected from the five monitoring sites in the southern Firth of Thames from April 2001 to April 2002.

		Apr-01	Jul-01	Oct-01	Jan-02	Apr-02	Jul-02	Oct-02	Jan-03	Apr-03
Miranda MI	clay	0.29 (+/- 0.16)	0.41 (+/- 0.18)	0.69 (+/- 0.12)	0.46 (+/- 0.04)	0.35 (+/- 0.07)	0.36 (+/- 0.03)	0.39 (+/- 0.01)	0.27 (+/- 0.02)	0.35 (+/- 0.03)
	medium silt	0.23 (+/- 0.12)	0.25 (+/- 0.11)	0.4 (+/- 0.07)	0.29 (+/- 0.02)	0.24 (+/- 0.03)	0.22 (+/- 0.01)	0.2 (+/- 0.01)	0.17 (+/- 0)	0.21 (+/- 0.01)
	coarse silt	0.68 (+/- 0.28)	0.85 (+/- 0.08)	1.15 (+/- 0.12)	1.27 (+/- 0.02)	1.2 (+/- 0.05)	1.21 (+/- 0.12)	1.08 (+/- 0.05)	1.86 (+/- 0.05)	1.76 (+/- 0.09)
	very fine sand	18.08 (+/- 5.28)	27.83 (+/- 2.79)	33.1 (+/- 0.76)	30.1 (+/- 0.38)	29.25 (+/- 0.4)	25.78 (+/- 3.47)	25.88 (+/- 1.21)	45.17 (+/- 0.77)	47.01 (+/- 1.42)
	fine sand	33.89 (+/- 10.56)	52.76 (+/- 3.02)	51.4 (+/- 2.92)	44.14 (+/- 1.07)	44.21 (+/- 1.08)	32.88 (+/- 3.32)	31.98 (+/- 1.65)	43.62 (+/- 0.85)	43.05 (+/- 1.17)
	medium sand	12.54 (+/- 1.89)	13.43 (+/- 1.56)	11.6 (+/- 0.52)	12.58 (+/- 0.6)	12.96 (+/- 0.69)	19.05 (+/- 2.04)	20.64 (+/- 0.7)	7.98 (+/- 0.64)	7.13 (+/- 0.52)
	coarse sand	18.65 (+/- 9.19)	4.45 (+/- 4.52)	1.86 (+/- 1.91)	10.75 (+/- 0.97)	10.65 (+/- 0.72)	17.02 (+/- 3.74)	17.88 (+/- 2.51)	0.91 (+/- 0.43)	0.5 (+/- 0.22)
	gravel	15.63 (+/- 10.77)	0.12 (+/- 0.27)	0 (+/- 0)	0.44 (+/- 0.44)	1.17 (+/- 0.59)	3.5 (+/- 1.4)	1.93 (+/- 1.13)	0 (+/- 0)	0 (+/- 0)
Kurunui Bay KB	clay	0.17 (+/- 0.02)	0.53 (+/- 0.12)	0.57 (+/- 0.11)	0.75 (+/- 0.23)	0.4 (+/- 0.13)	0.49 (+/- 0.08)	1.25 (+/- 0.27)	0.21 (+/- 0.01)	0.34 (+/- 0.04)
	medium silt	0.11 (+/- 0.02)	0.31 (+/- 0.06)	0.36 (+/- 0.1)	0.43 (+/- 0.14)	0.22 (+/- 0.07)	0.23 (+/- 0.04)	0.52 (+/- 0.1)	0.1 (+/- 0.01)	0.15 (+/- 0.01)
	coarse silt	0.27 (+/- 0.01)	0.51 (+/- 0.07)	0.65 (+/- 0.1)	0.59 (+/- 0.09)	0.54 (+/- 0.04)	0.75 (+/- 0.07)	1.17 (+/- 0.15)	0.59 (+/- 0.03)	0.69 (+/- 0.03)
	very fine sand	7.72 (+/- 0.45)	13.39 (+/- 0.9)	11.19 (+/- 0.75)	11.05 (+/- 0.89)	12.67 (+/- 0.76)	15.9 (+/- 1.23)	14.35 (+/- 1.31)	18.62 (+/- 0.88)	20.12 (+/- 0.7)
	fine sand	28.11 (+/- 1.36)	45.53 (+/- 0.95)	39.77 (+/- 1.66)	41.27 (+/- 0.82)	40.49 (+/- 0.96)	44.2 (+/- 1.73)	44.4 (+/- 3)	48.11 (+/- 0.81)	48.52 (+/- 1.24)
	medium sand	30.02 (+/- 1.34)	32.78 (+/- 1.95)	33.33 (+/- 1.23)	32.75 (+/- 0.93)	30.48 (+/- 0.69)	26.22 (+/- 0.93)	28.43 (+/- 1.84)	24.79 (+/- 0.36)	24.72 (+/- 0.9)
	coarse sand	24.65 (+/- 1.53)	7.13 (+/- 0.59)	13.57 (+/- 2.03)	13.31 (+/- 1.67)	14.96 (+/- 0.63)	11.89 (+/- 2.03)	9.59 (+/- 2.86)	7.56 (+/- 0.93)	5.42 (+/- 0.95)
	gravel	8.94 (+/- 2.58)	0 (+/- 0)	0.78 (+/- 0.48)	0 (+/- 0)	0.32 (+/- 0.32)	0.28 (+/- 0.17)	0.15 (+/- 0.14)	0 (+/- 0)	0 (+/- 0)
Thames Gun Club GC	clay	0.2 (+/- 0.05)		0.25 (+/- 0.02)		0.43 (+/- 0.06)		0.32 (+/- 0.05)		0.55 (+/- 0.11)
	medium silt	0.13 (+/- 0.03)		0.14 (+/- 0.02)		0.26 (+/- 0.03)		0.21 (+/- 0.04)		0.37 (+/- 0.09)
	coarse silt	0.15 (+/- 0.03)		0.18 (+/- 0.02)		0.52 (+/- 0.08)		0.64 (+/- 0.04)		0.75 (+/- 0.12)
	very fine sand	0.96 (+/- 0.13)		1.23 (+/- 0.17)		2.96 (+/- 0.34)		5.23 (+/- 0.29)		6.64 (+/- 0.73)
	fine sand	5.31 (+/- 0.49)		5.91 (+/- 0.74)		11.57 (+/- 0.93)		11.29 (+/- 0.63)		13.26 (+/- 0.89)
	medium sand	18.59 (+/- 1.18)		18.16 (+/- 1.64)		29.96 (+/- 1.21)		24.34 (+/- 1.44)		23.61 (+/- 0.73)
	coarse sand	41.87 (+/- 2.38)		40.25 (+/- 2.5)		45.71 (+/- 2.01)		43.38 (+/- 0.89)		42.31 (+/- 0.71)
	gravel	32.82 (+/- 3.27)		33.93 (+/- 4.16)		8.64 (+/- 1.57)		14.6 (+/- 2.14)		12.51 (+/- 1.23)
Kaiaua KA	clay	0.28 (+/- 0.03)		5.35 (+/- 0.66)		1.37 (+/- 0.26)		1.76 (+/- 0.36)		0.41 (+/- 0.04)
	medium silt	0.21 (+/- 0.02)		4.2 (+/- 0.81)		0.77 (+/- 0.14)		1.16 (+/- 0.21)		0.29 (+/- 0.01)
	coarse silt	0.85 (+/- 0.12)		8.3 (+/- 1.49)		2.32 (+/- 0.28)		2.42 (+/- 0.35)		1.68 (+/- 0.06)
	very fine sand	16.47 (+/- 2.82)		33.71 (+/- 1.48)		26.5 (+/- 2.02)		18.22 (+/- 1.36)		25.68 (+/- 0.47)
	fine sand	34.48 (+/- 6.17)		40.66 (+/- 2.73)		33.7 (+/- 1.75)		46.38 (+/- 2.01)		58.36 (+/- 1)
	medium sand	9.65 (+/- 0.74)		8.05 (+/- 1.29)		16.79 (+/- 1.05)		21.46 (+/- 2.11)		11.8 (+/- 0.51)
	coarse sand	14.94 (+/- 3.43)		0.18 (+/- 0.18)		18.12 (+/- 2.2)		8.55 (+/- 2.86)		1.79 (+/- 0.5)
	gravel	23.15 (+/- 6.52)		0 (+/- 0)		0.47 (+/- 0.33)		0 (+/- 0)		0 (+/- 0)
Te Puru TP	clay	0.09 (+/- 0.01)		0.16 (+/- 0.03)		0.12 (+/- 0.01)		0.9 (+/- 0.72)		0.19 (+/- 0.04)
	medium silt	0.07 (+/- 0)		0.1 (+/- 0.01)		0.08 (+/- 0.01)		0.47 (+/- 0.34)		0.11 (+/- 0.02)
	coarse silt	0.3 (+/- 0.04)		0.52 (+/- 0.09)		0.43 (+/- 0.04)		0.84 (+/- 0.43)		0.54 (+/- 0.05)
	very fine sand	8.96 (+/- 0.56)		13.79 (+/- 1.7)		12.72 (+/- 0.95)		10.49 (+/- 1.73)		11.88 (+/- 0.72)
	fine sand	31.41 (+/- 0.79)		38.8 (+/- 1.52)		38.39 (+/- 1.17)		35.08 (+/- 3.94)		40.92 (+/- 1.31)
	medium sand	32.19 (+/- 0.92)		32.92 (+/- 0.83)		28.61 (+/- 1.66)		28.17 (+/- 1.05)		33.42 (+/- 0.76)
	coarse sand	24.4 (+/- 1.37)		13.1 (+/- 1.96)		19.67 (+/- 1.27)		20.7 (+/- 5.48)		12.95 (+/- 1.52)
	gravel	2.6 (+/- 1)		0.63 (+/- 0.46)		0.02 (+/- 0.01)		3.34 (+/- 0.92)		0 (+/- 0)

3.1.2 Whaingaroa Harbour

In April 2001 (see Turner *et al.,* 2002), the sediment at all five monitoring sites in Whaingaroa Harbour showed similar particle size distributions, being predominantly sandy with a high percent of coarse sand and gravel (Table 3, Figure 7). Sediment taken at subsequent sampling dates has had a much lower content of gravel and coarse sand. Sediment at all the sites is very poorly sorted with polymodal sediment particle size distributions.

The poor sorting of these sediments in Whaingaroa Harbour is reflected in both a slightly higher content of both mud and of coarse material (coarse sand and gravel) than at sites in the southern Firth of Thames (except for the Gun Club site).

Sediments at Haroto Bay (up the Waitetuna River arm of the harbour, through the “narrows”, Figure 2) have the highest percent of clay and silt (up to 20% mud). This probably reflects the location of this site, which is closer to the sheltered upper reaches of the estuary than any of the other sites. Here sediments are exposed to less energetic wave reworking. This site is also closest to sources of fine sediment washed from the catchment. Whatitirinui Island had a higher mud content than the other sites in the initial survey in April 2001 (Turner *et al.* 2002), but two more years of data has shown that the content of mud at Whatitirinui Island (5-10%) is similar to at other sites in the harbour. Over the two years reported here, there appears to be a possible gradual decrease in the content of coarse sand and gravel at Haroto Bay, coinciding with a relative increase in coarse silt and very fine sand. It is too early to determine whether this is a genuine trend or simply fluctuations in the sediment characteristics. The composition of the sediment at Whatitirinui Island varied during the study period but there was no apparent trend for progressive change.

Sediments at Te Puna Point are dominated by very fine sand and fine sand, with a mud content of up to 8.6% (though usually 1.5-4.5%). The gravel content is quite variable, ranging from almost none (0.3%) to over 20%. There is no apparent trend for change in the sediments over the study period.

The sediment at Okete Bay is consistently dominated by fine and very fine sand, except for the first sampling time in April 2001, when a large gravel and coarse sand content was present. Sediment composition has been relatively constant since July 2001, though there was an apparent trend back towards a coarser composition until October 2002. After October 2002, the content of very fine sand increased again, and the percent composition of medium sand or coarser material almost completely disappeared. As with most of the other sites, the sediment composition has not yet returned to that observed in April 2001, though there is no apparent long term trend for change.

Site X (Ponganui Creek) has been monitored since October 2001. The percentage of mud is the lowest of all the Raglan sites, at consistently around 4-5%, with the sediment composition dominated by fine and very fine sand. There is no clear change in sediment composition from October 2001 to April 2003.

As observed at monitoring sites in the Firth of Thames, all five sites have three distinct peaks or “modes” in the sediment grain size composition. Sediment analysis results at all five sites show a small peak in the sediment distribution at 17.5-20.0 microns, this is a small peak of several percent above adjacent size classes. A second peak in the distribution is at 130-140 microns, again consistently present at all sites and all dates. Similarly a peak is consistently present in all samples between 500 and 1000 microns (coarse sand fraction). These three peaks in the sediment size distribution make the Raglan sediments distinctly different from those taken from the Firth of Thames.

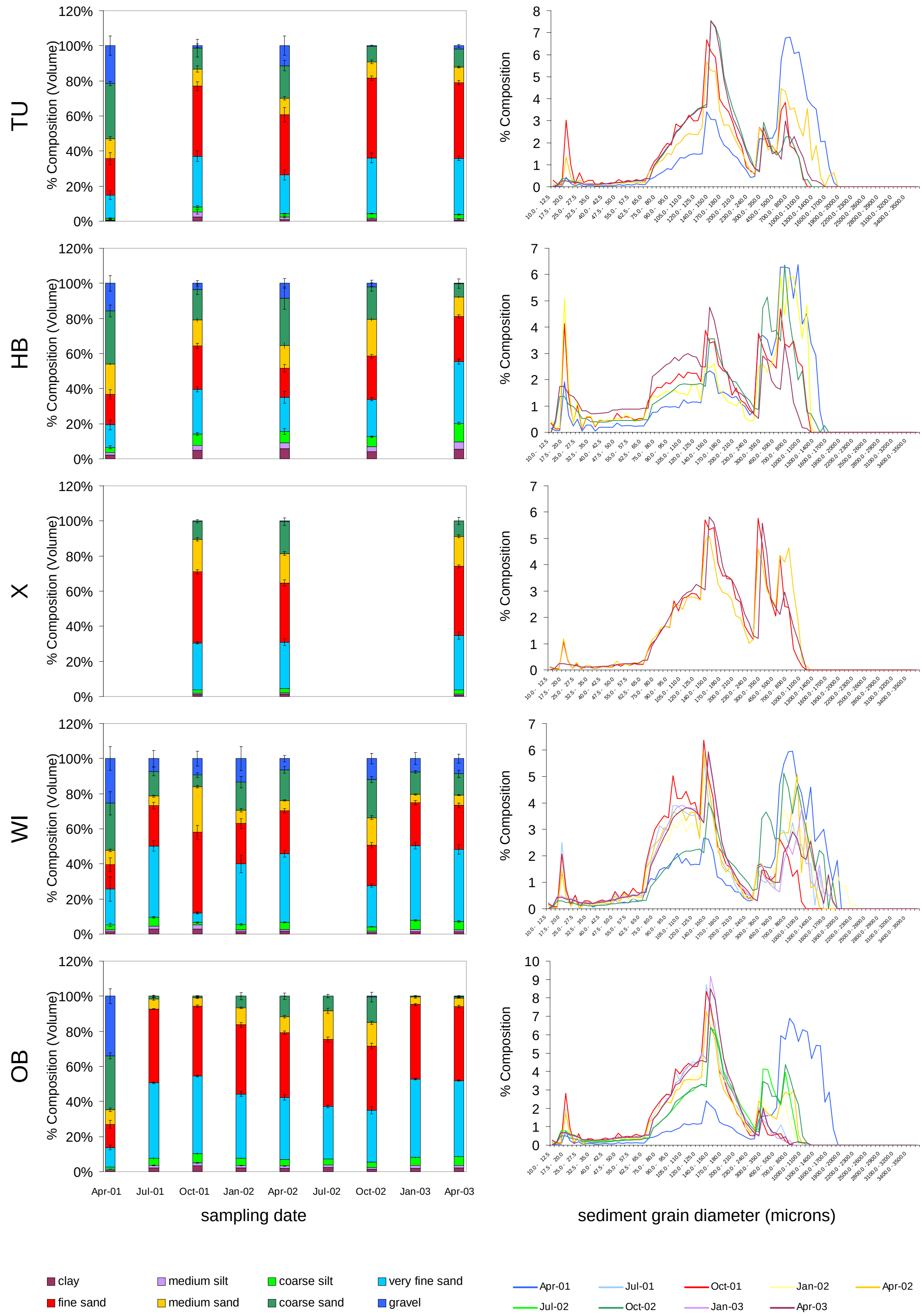


Figure 7: Sediment grain-size distribution for the five monitoring sites in the Whaingaroa Harbour.

Table 3: Results (mean ± standard error, n = 5) of grain-size analysis of sediment collected from the five monitoring sites in Whaingaroa Harbour in April 2001.

		Apr-01	Jul-01	Oct-01	Jan-02	Apr-02	Jul-02	Oct-02	Jan-03	Apr-03
Okete Bay OB	clay	0.83 (+/- 0.09)	2.27 (+/- 0.39)	3.31 (+/- 0.59)	2.15 (+/- 0.18)	2.01 (+/- 0.16)	2.35 (+/- 0.16)	1.38 (+/- 0.22)	2.01 (+/- 0.14)	2.12 (+/- 0.09)
	medium silt	0.57 (+/- 0.06)	1.26 (+/- 0.21)	1.72 (+/- 0.28)	1.42 (+/- 0.12)	1.25 (+/- 0.06)	1.51 (+/- 0.07)	1.08 (+/- 0.07)	1.5 (+/- 0.09)	1.55 (+/- 0.05)
	coarse silt	1.27 (+/- 0.12)	4.14 (+/- 0.4)	5.29 (+/- 0.44)	4.09 (+/- 0.24)	3.71 (+/- 0.09)	3.44 (+/- 0.08)	2.99 (+/- 0.18)	4.75 (+/- 0.23)	4.97 (+/- 0.18)
	very fine sand	11.14 (+/- 1.41)	43.07 (+/- 0.5)	44.22 (+/- 0.55)	36.69 (+/- 1.31)	35.43 (+/- 1.53)	29.96 (+/- 0.74)	29.46 (+/- 1.96)	44.56 (+/- 0.49)	43.25 (+/- 0.33)
	fine sand	13.2 (+/- 2.3)	41.93 (+/- 0.31)	39.91 (+/- 0.67)	39.53 (+/- 1.34)	37 (+/- 0.97)	38.08 (+/- 1.49)	36.56 (+/- 1.76)	42.28 (+/- 0.58)	42.16 (+/- 0.71)
	medium sand	8.28 (+/- 0.91)	5.79 (+/- 0.78)	4.8 (+/- 0.36)	9.67 (+/- 0.47)	9.12 (+/- 0.7)	16.22 (+/- 1.49)	13.37 (+/- 0.82)	4.38 (+/- 0.65)	4.84 (+/- 0.08)
	coarse sand	30.78 (+/- 1.62)	1.62 (+/- 0.54)	0.92 (+/- 0.42)	6.71 (+/- 2.05)	11.59 (+/- 1.77)	8.34 (+/- 0.92)	14.67 (+/- 2.75)	0.45 (+/- 0.28)	0.93 (+/- 0.54)
	gravel	34.02 (+/- 4.24)	0 (+/- 0)	0 (+/- 0)	0 (+/- 0)	0 (+/- 0)	0 (+/- 0)	0.41 (+/- 0.3)	0 (+/- 0)	0.12 (+/- 0.12)
Whatitirinui Island WI	clay	1.48 (+/- 0.58)	2.9 (+/- 1.25)	3 (+/- 0.71)	1.42 (+/- 0.31)	1.64 (+/- 0.15)		0.92 (+/- 0.06)	1.5 (+/- 0.13)	1.36 (+/- 0.09)
	medium silt	0.96 (+/- 0.4)	1.66 (+/- 0.72)	2.4 (+/- 0.57)	0.88 (+/- 0.21)	0.93 (+/- 0.04)		0.7 (+/- 0.06)	1.21 (+/- 0.09)	1.1 (+/- 0.08)
	coarse silt	2.83 (+/- 1.03)	5.05 (+/- 0.44)	1.44 (+/- 0.31)	3.24 (+/- 0.58)	4.1 (+/- 0.27)		2.54 (+/- 0.12)	5.1 (+/- 0.35)	4.76 (+/- 0.39)
	very fine sand	20.47 (+/- 6.93)	40.79 (+/- 3.02)	5.57 (+/- 0.66)	34.55 (+/- 4.97)	39.14 (+/- 1.97)		23.41 (+/- 0.9)	42.56 (+/- 1.94)	41.05 (+/- 2.66)
	fine sand	13.85 (+/- 3.94)	23 (+/- 1.88)	47.2 (+/- 4.05)	23.06 (+/- 2.81)	24.61 (+/- 1.16)		23.06 (+/- 1.5)	24.4 (+/- 1.17)	25.03 (+/- 1.25)
	medium sand	8.24 (+/- 0.67)	5.5 (+/- 0.67)	26.72 (+/- 0.75)	7.66 (+/- 0.96)	5.76 (+/- 0.41)		15.69 (+/- 1.01)	4.83 (+/- 0.35)	5.95 (+/- 0.28)
	coarse sand	26.84 (+/- 6.6)	14.07 (+/- 2.46)	6.83 (+/- 1.36)	15.93 (+/- 3.17)	17.5 (+/- 1.92)		21.73 (+/- 1.62)	12.78 (+/- 0.79)	12.08 (+/- 2.03)
	gravel	25.39 (+/- 6.73)	7.4 (+/- 4.57)	9.64 (+/- 4.25)	13.49 (+/- 6.8)	6.36 (+/- 1.76)		11.95 (+/- 2.93)	7.55 (+/- 3.33)	8.63 (+/- 2.55)
Te Puna Point TU	clay	0.5 (+/- 0.07)		2.34 (+/- 1.1)		1.08 (+/- 0.38)		0.98 (+/- 0.13)		0.73 (+/- 0.08)
	medium silt	0.31 (+/- 0.04)		3.07 (+/- 1.32)		1.39 (+/- 0.55)		0.73 (+/- 0.06)		0.63 (+/- 0.07)
	coarse silt	0.85 (+/- 0.15)		2.88 (+/- 0.6)		1.89 (+/- 0.26)		2.52 (+/- 0.25)		2.5 (+/- 0.16)
	very fine sand	13.25 (+/- 2.35)		28.92 (+/- 3.01)		22.13 (+/- 2.85)		31.85 (+/- 2.83)		31.92 (+/- 1.29)
	fine sand	20.78 (+/- 3.55)		40.23 (+/- 2.5)		34.35 (+/- 4.15)		45.4 (+/- 1.34)		43.17 (+/- 1.28)
	medium sand	11.4 (+/- 1.11)		9.82 (+/- 1.79)		9.5 (+/- 0.97)		9.33 (+/- 1.05)		8.85 (+/- 0.51)
	coarse sand	31.48 (+/- 1.15)		11.92 (+/- 5.07)		18.51 (+/- 2.98)		8.86 (+/- 1.3)		10.25 (+/- 1.57)
	gravel	21.47 (+/- 5.53)		1.41 (+/- 1.16)		11.38 (+/- 5.56)		0.32 (+/- 0.32)		1.91 (+/- 0.78)
Harato Bay HB	clay	2.2 (+/- 0.59)		4.75 (+/- 0.77)		5.85 (+/- 2.18)		4.15 (+/- 0.3)		5.42 (+/- 0.5)
	medium silt	1.43 (+/- 0.37)		2.92 (+/- 0.44)		3.42 (+/- 1.03)		2.82 (+/- 0.14)		4.13 (+/- 0.29)
	coarse silt	2.96 (+/- 0.75)		6.57 (+/- 0.66)		6.49 (+/- 1.67)		5.61 (+/- 0.24)		10.65 (+/- 0.62)
	very fine sand	12.78 (+/- 2.84)		25.36 (+/- 1.41)		19.54 (+/- 3.42)		21.27 (+/- 0.89)		35.09 (+/- 1.5)
	fine sand	17.5 (+/- 2.64)		24.85 (+/- 1.54)		16.59 (+/- 2.19)		24.5 (+/- 1.13)		25.67 (+/- 1.02)
	medium sand	17.35 (+/- 0.66)		14.88 (+/- 1.11)		13.03 (+/- 1.66)		21.04 (+/- 0.94)		10.95 (+/- 0.46)
	coarse sand	30.28 (+/- 3.33)		17.43 (+/- 3.07)		27.05 (+/- 6.41)		18.34 (+/- 2.37)		7.7 (+/- 2.65)
	gravel	15.72 (+/- 4.48)		3.43 (+/- 1.55)		8.56 (+/- 2.82)		2.08 (+/- 1.79)		0.14 (+/- 0.14)
Ponganui Creek X	clay	0.29 (+/- 0.07)		1.26 (+/- 0.32)		1.37 (+/- 0.26)				0.75 (+/- 0.08)
	medium silt	0.23 (+/- 0.05)		0.71 (+/- 0.2)		0.77 (+/- 0.14)				0.61 (+/- 0.06)
	coarse silt	0.68 (+/- 0.13)		1.96 (+/- 0.17)		2.32 (+/- 0.28)				2.61 (+/- 0.19)
	very fine sand	18.08 (+/- 2.36)		26.69 (+/- 0.7)		26.5 (+/- 2.02)				30.77 (+/- 2.01)
	fine sand	33.89 (+/- 4.72)		40.6 (+/- 1.19)		33.7 (+/- 1.75)				39.38 (+/- 0.84)
	medium sand	12.54 (+/- 0.84)		18.42 (+/- 0.99)		16.79 (+/- 1.05)				17.18 (+/- 0.85)
	coarse sand	18.65 (+/- 4.11)		10.36 (+/- 0.97)		18.12 (+/- 2.2)				8.71 (+/- 1.99)
	gravel	15.63 (+/- 4.81)		0.13 (+/- 0.08)		0.47 (+/- 0.33)				0 (+/- 0)

3.2 Sediment Total Organic Carbon and Total Nitrogen

In estuarine systems, organic matter is derived from freshwater inputs of terrestrial material; *in situ* primary production by phytoplankton, as well as mangroves, sea-grasses, macrophytes and photosynthetic bacteria; and as localised inputs, for example from marine farms, sewage treatment plants, storm-water drains (CSIRO, 2000).[7] The organic matter from these diverse sources can have different compositions and degrade at different rates. The organic matter content of sediment is determined by the sum of the various sources and the rates at which these are degraded by biological and chemical processes (CSIRO, 2000). Physical processes such as re-suspension and deposition also affect the amount of organic matter in the sediment. Surface sediments provide an integrated measure of organic matter inputs into an estuary over time periods varying between years to decades depending on sedimentation rates (CSIRO, 2000).

Organic matter represents an important energy source for microbial decomposer organisms in the sediment and for benthic animals that feed on detritus and the associated microbes (e.g. Pearson and Rosenberg, 1978).

Carbon:Nitrogen (C:N) ratios can be useful indicators of the terrestrial or marine sources of organic matter in an estuary – although the effects of degradation can markedly change these ratios (CSIRO, 2000). Values in the range 6-9 are typically reported for marine-derived organic matter, whereas values greater than 12 are usually found in terrestrially derived organic matter (e.g., Bordovskiy, 1965 cited in CSIRO, 2000).

3.2.1 Southern Firth of Thames

The mean total organic carbon concentrations varied from 0.20% (dry weight) at the Te Puru site to 0.48% (dry weight) at the Gun Club site.

Organic C levels between April 2001 and April 2003 were lowest at Miranda and Te Puru, with levels consistently around 0.15-0.3% except for the last sampling date in April 2003 when levels were considerably higher at 0.64% and 0.33% for Miranda and Te Puru respectively. In April 2003, organic C levels were much more variable than at other dates. In both cases, the raised average level is due to one of the five samples taken having a very high organic C content, raising both the resulting average and the standard error. There is no evidence for a long-term change in the organic C levels at these two sites.

The mean total nitrogen concentrations at the Te Puru site are consistently low, but apparently slowly increasing, from non-detectable in April 2001, to 0.1% in April 2003. The C:N ratio remains very consistent around 3-4. Similarly N content at Gun Club is consistently around 0.1%, with a C:N of approximately 5. At Miranda, N concentrations are consistently below 0.1% except for in July 2002 and April 2003 when levels are approximately 0.15%. C:N ratios are all low at 2-5.

At the Gun Club site, levels of organic C have remained very stable, at just under 0.5%. At Kaiaua, organic C levels were between 0.3% and 0.5% at three sampling dates (Apr 01, Oct 02 & Apr 03), but in October 2001 and April 2002, organic C levels were close to 1.5%, resulting in an increase in C:N from <5 to 7-8. The sediment composition over time is the most variable at Kaiaua (see section 3.1.1). Total N varied only slightly, from <0.1% to 0.21%, with no apparent trend.

[7] Note, however, that the sediment monitoring was designed to provide an overall picture of each estuary, rather than to investigate specific sources in detail.

At Kuranui Bay, north of Thames Township, the organic C content was also variable, peaking in October 2002 at 0.63%. At the other sampling dates, organic C levels at Kuranui Bay are between 0.3% and 0.5%. Total N levels are the highest and most variable at KB, peaking at 0.63% in July 2003. C:N ratios vary between 2 and 5.

In many estuaries there is a correlation between the organic matter content in the sediment and the proportion of clay and silts (the mud fraction with grain-sizes less than 63 µm), with low concentrations associated with sands and higher concentrations associated with muds. Quite clearly in this case the highest levels of organic C occur at the site with the highest (and most variable) mud content (KA). However, all the other sites have typically low mud contents (<3%) and correspondingly lower organic C, and there is no apparent consistent relationship between organic content and the clay and silt content of the sediment.

Higher than expected organic matter contents can be caused by a recent input of organic matter, for example from a phytoplankton bloom, high contents of terrestrially-derived organic matter, or due to the association of organic matter with non-clay particles such as wood fibre (CSIRO, 2000). The GC and KB sites are adjacent to Thames and potential sources of organic matter (e.g., storm-water drains, the discharge for treated wastewater from the oxidation pond system). Without further information (e.g., analysis of stable isotope signatures), it is not possible to identify and apportion the sources of organic matter at any of the sites.

The results are presented in full in Appendix 2.

3.2.2 Whaingaroa Harbour

The highest content of organic carbon is found at the site with the muddiest sediment (Haroto Bay), with concentrations of 0.63% (April 2003) - 0.89% (October 2002). Total N at Haroto Bay is consistently at 0.1%, except for a peak in October 2002 at 0.2%.

In Okete Bay, total C levels steadily dropped from April 2001 (0.65%) to April 2003 (0.5%). Total N at Okete Bay is below 0.1% except for October 2002 (0.2%).

At Whatitirinui Island, organic C is between 0.4 – 0.7%, highest in April 2003. Total N is approximately 0.1%, with some variability as explained further below.

A similar pattern was observed at the Te Puna Point site, total organic C remained consistent at approximately 0.45% until April 2003, when it dropped to 0.31%. Total N at Te Puna Point was below 0.1% except for October 2002 (0.13%).

Sediments at Ponganui Creek have the lowest level of organic C[8]. Organic C levels at this site were between 0.3-0.4%. Total N was also low, consistently below 0.1%.

Sediments at Ponganui Creek and Te Puna Point have the lowest mud content of the five monitoring sites at 3.9-4.5% and 1.7-8.3% respectively.

At Whatitirinui Island, Te Puna Point and Haroto Bay sites, a peak is seen in total N content of the sediments in October 2002. Levels at these three sites were at or around 0.1% from April 2001 until April 2002. Results from the October 2002 survey indicate raised total N levels, from a slight increase to 0.12% at Whatitirinui Island, to a distinct peak at Haroto Bay (0.22% from 0.11%) and Te Puna Point (0.13% from 0.07%). At Okete Bay, a distinct peak (0.18%) occurred in July 2002 (when levels at WI were also slightly raised). These are the only two sites monitored in July, so it is not possible to detect the same pattern at the other sites. It is possible there was a nutrient influx event of some sort between the April 2002 and July 2002 sampling dates that remained in the sediment until October 2002. There is no clear consistent relationship

[8] Site X has been monitored since October 2001.

between the percentage of fine (clays and silts) sediments and the total level of organic material in the sediments.

The C:N ratios varied between 3 and 8 at all sites. Results are presented in full in Appendix 2.

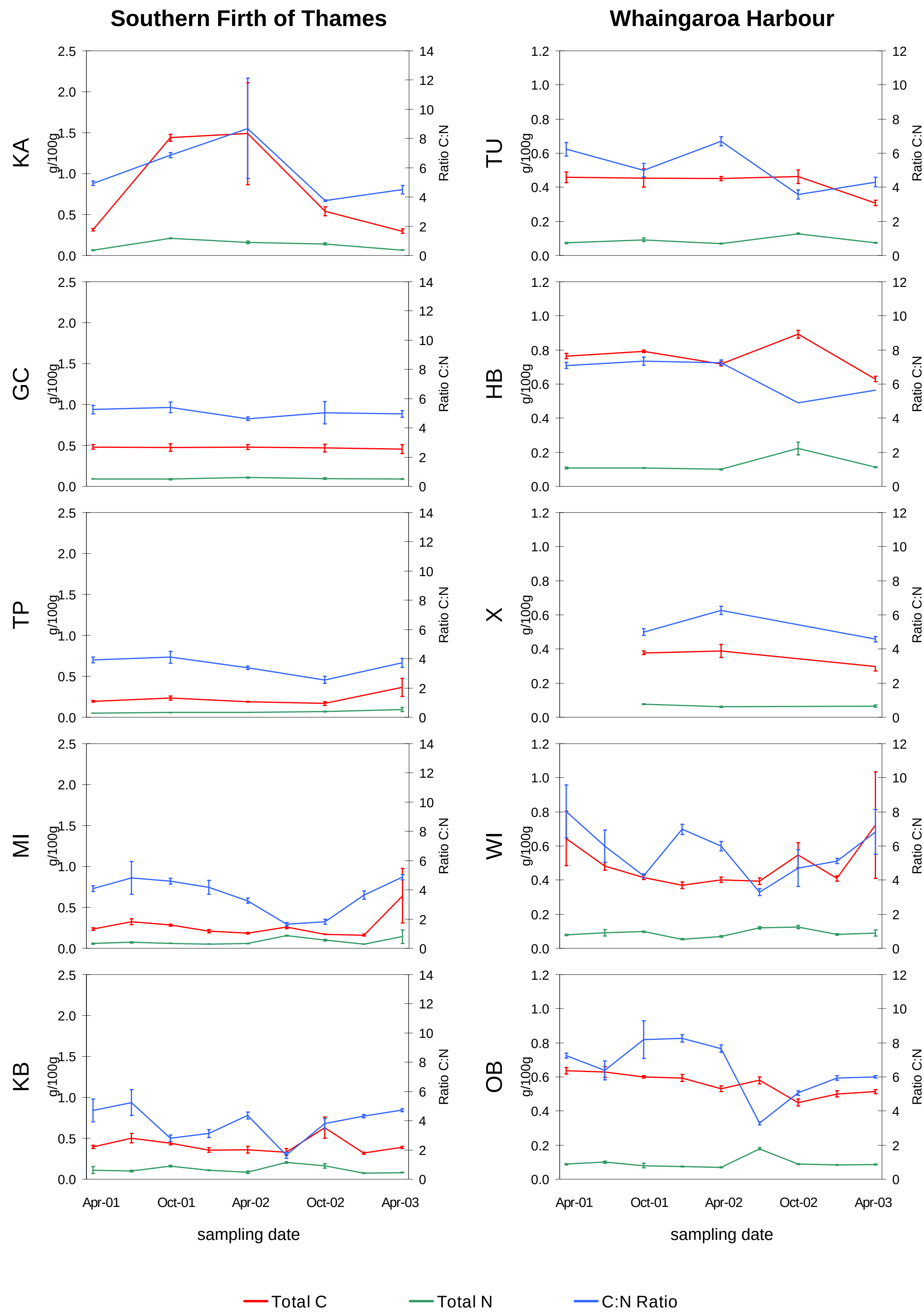


Figure 8: Total organic carbon and total nitrogen content and mean Carbon:Nitrogen ratio (mean ± standard error, n = 5) of surficial sediment collected from five monitoring sites in the southern Firth of Thames and Whaingaroa Harbour between April 2001 and April 2003.

3.3 Sediment Level: Buried Plate Measurements

As part of a pilot study (Collins, 2003), across-shore surveys were undertaken at four of the monitoring sites in the Firth of Thames (Miranda, Kaiaua, Gun Club and Kuranui Bay). Survey information is show in Appendix 3. Results are presented in full in Collins (2003). Elevation change results from the Pilot study are shown in Appendix 4.

The average measured range in sediment elevation for the Gun Club, Kaiaua and Kuranui Bay sites were very similar, at 22-24 mm. Sediment elevation at Miranda appears to be less dynamic than the other sites, with a range of 13 mm. Future reporting of this data (after a longer period of data collection) should further assess the adequacy of these four sites to represent variability in sediment elevation in the whole Firth of Thames.

The short period of data collection at this time makes it impossible to determine any trends for long term accretion or erosion, and has not picked up the full range of variability possibly associated with seasonal changes.

4 Recommendations

The estuary sediment monitoring programme should continue as described. There are a number of issues that need addressing in terms of the sediment monitoring programme to ensure it is providing sufficient information.

The plate surveying technique needs to be assessed further based on the first 12 months of data from March 2003 to March 2004. A resurvey is recommended after 12-24 months to determine if there has been any settlement or movement of the plates. The data collected from the plate pilot study also needs to be examined to determine the adequacy and power of this method to detect change in the level of the sediments at the monitoring sites. An early analysis of this was undertaken in Collins (2003), but with limited data.

It is recommended that the impact of periodic rainfall-event driven sedimentation is investigated further. Monitoring at an event scale would help to better understand changes in the physical properties of the sediment associated with periodic influxes of material from the catchment and subsequent processes of recovery.

The current report provides a summary of the first two years of the Regional Monitoring Programme. The length of record is not yet sufficient to identify progressive trends for change within the natural variation present. It is therefore recommended that the current monitoring regime be continued. A summary of the field measurements to be taken over the next 12 months are given below. The programme should be reviewed after 3-5 years of data have been collected to determine whether and changes in the frequency or nature of sampling should be implemented.

Table 4: Recommended 3- and 6-monthly sampling schedule at the five permanent monitoring sites in the southern Firth of Thames.

	KA	MI	GC	KB	TP
2001	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2002	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2003	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2004	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2005	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct

Table 5: Recommended 3- and 6-monthly sampling schedule at the five permanent monitoring sites in Whaingaroa Harbour.

	KA	MI	GC	KB	TP
2001	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2002	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2003	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2004	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct
2005	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct	Jan/Apr/Jly/Oct	Apr/Oct

Literature Cited

Collins, K. 2003: Pilot Study: Measuring Sedimentation Rates in the Firth of Thames using Buried Plates. Report for Department of Applied Science, Auckland University of Technology.

CSIRO Huon Estuary Study Team 2000: *Huon estuary Study, - Environmental research for Integrated Catchment Management and Aquaculture*. CSIRO, Tasmania, Project No. 96/284.

Hewitt, J.E.; Funnell, G.A.; Cummings, V.J. and Hatton, S. 2001: *Guide to Macrobenthic Invertebrate Taxa Monitored by Environment Waikato*. NIWA Client Report EVW01225/2.

Hume, T.M. and Dahm, J. 1992: *An investigation of the effects of Polynesian and European land use on sedimentation in Coromandel estuaries.* Water Quality Centre, DSIR, Consultancy Report No. 6104.

Morrisey, D.J., Hume, T.M. and Thrush, S.F. 1994: *Ecological Monitoring for Potential Effects of Forestry Activity on the Intertidal Habitats of Whangapoua Harbour.* NIWA Consultancy Report No. ERN002/3, prepared for Ernslaw One Ltd.

Pearson, T.H. and Rosenberg, R. 1978: Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: An Annual Review* 16:229-311.

Sheffield, A.T., Healy, T.R. and McGlone, M.S. 1995: Infilling rates of a steepland catchment estuary, Whangamata, New Zealand. *Journal of Coastal Research*, Vol. 4(1), p1294-1308.

Swales, A. and Hume, T.M. 1994: *Sedimentation history and potential future impacts of production forestry on the Whangamata estuary, Coromandel Peninsula.* NIWA, Consultancy Report CHH003.

Swales, A. and Hume, T.M. 1995: *Sedimentation history and potential future impacts of production forestry on the Wharekawa estuary – Coromandel Peninsula.* NIWA, Consultancy Report CHH004.

Turner, S. 2000: *Proposed Coastal Ecological Monitoring Programme for Environment Waikato*. Environment Waikato Internal Series 2000/08.

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

Turner, S. and Riddle, B. 2001: *Estuarine Sedimentation and Vegetation – Management Issues and Monitoring Priorities*. Environment Waikato Internal Series 2001/05.

Turner, S.; Gibberd, B. and Crozier, J. 2002: *Regional Estuary Monitoring Programme – Pilot Study*. Environment Waikato Internal Series 2002/02.

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.

Appendix 1 – NZMG GPS Positions

Southern Firth of Thames

	KA		MI		GC		KB		TP	
Peg	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
XS1	2714684	6450980	2716988	6444283	2735797	6446175	2734798	6450774	No peg - rock	
XS2	No peg		2717038	6444306	2735756	6446175	No co-ordinate		2734756	6458011
XS3	2714755	6450998	2717086	6444319	2735713	6446172	No co-ordinate		2734699	6458008
XS4	2714838	6451026	2717189	6444354	2735646	6446156	2734673	6450687	No co-ordinate	
XS5	2714874	6451036	2717226	6444367	2735613	6446149	2734643	6450664	2734699	6458008
XS6	2714911	6451047	2717275	6444384	2735574	6446146	2734606	6450640	No co-ordinate	
LS1	2714762	6451112	2717050	6444470	2735696	6446051	2734777	6450589	2734705	6457892
LS2	2714773	6451077	2717078	6444424	2735693	6446088	2734753	6450632	2734686	6457932
LS3	2714784	6451046	2717106	6444381	2735690	6446123	2734731	6450675	2734675	6457964
LS4	2714798	6451008	2717134	6444339	2735680	6446167	2734709	6450707	2734655	6458003
LS5	2714808	6450970	2717160	6444297	2735675	6446200	2734689	6450741	2734646	6458034
LS6	2714818	6450936	2717189	6444254	2735662	6446236	2734670	6450776	2734629	6458082
LS7	2714836	6450901	2717218	6444211	2735658	6446277	2734647	6450814	2734607	6458131
A	2714746	6451032	2717063	6444367	2735725	6446130	2734763	6450697	2734713	6457972
B	2714763	6450955	2717115	6444280	2735714	6446207	2734720	6450764	2734684	6458043
C inside	2714848	6450980	2717206	6444314	2735637	6446198	2734655	6450723	2734607	6458036
C outside	2714848	6450980	2717206	6444314	2735637	6446198	2734655	6450723	2734607	6458036
D	2714826	6451056	2717146	6444396	2735654	6446117	2734693	6450650	2734635	6457963

Whaingaroa Harbour

	WI		TU		HB		OB		X	
Peg	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
XS1	2679258	6380596	2678964	6378897	2681563	6377786	2679202	6377317	2675260	6378187
XS2	2679271	6380570	2678938	6378930	2681540	6377824	2679171	6377327	2675273	6378133
XS3	2679291	6380534	2678913	6378959	2681528	6377864	2679134	6377338	2675292	6378096
XS4	2679323	6380471	2678866	6379022	2681499	6377933	2679063	6377358	2675336	6378029
XS5	2679341	6380436	2678843	6379054	2681487	6377964	2679023	6377362	2675356	6377991
XS6	No peg		2678813	6379094	2681472	6377999	2678990	6377377	2675378	6377948
LS1	2679405	6380550	2678806	6378910	2681401	6377863	2679098	6377222	No peg	
LS2	2679378	6380538	2678834	6378935	2681437	6377874	2679098	6377268	No peg	
LS3	2679342	6380533	2678861	6378961	2681473	6377886	2679093	6377315	2675353	6378080
LS4	2679307	6380510	2678891	6378988	2681515	6377897	2679095	6377346	2675315	6378062
LS5	2679265	6380489	2678921	6379019	2681550	6377917	2679097	6377387	2675275	6378045
LS6	2679229	6380473	2678944	6379040	2681588	6377919	2679099	6377423	2675241	6378031
LS7	2679193	6380459	2678978	6379070	2681631	6377932	2679093	6377458	2675203	6378014
A	2679321	6380546	2678885	6378928	2681454	6377924	2679132	6377301	2675327	6378108
B	2679254	6380514	2678945	6378984	2681565	6377873	2679134	6377377	2675257	6378082
C inside	2679281	6380455	2678897	6379042	2681540	6377942	2679064	6377399	2675297	6378001
C outside	2679281	6380455	2678897	6379042	2681540	6377942	2679064	6377399	2675297	6378001
D	2679358	6380484	2678834	6378993	2681457	6377923	2679058	6377335	2675374	6378042

Appendix 2 – Total Organic Carbon and Total Nitrogen Content Results

Southern Firth of Thames

April 2001

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
KA	0.35	67.6	0.07
	0.27	69.5	0.05
	0.34	65.8	0.07
	0.31	65.6	0.07
	0.30	66.8	0.06
GC	0.42	64.7	0.10
	0.53	57.1	0.10
	0.42	60.0	0.08
	0.50	58.9	0.09
	0.54	58.1	0.09
TP	0.18	67.6	0.05
	0.20	68.4	0.05
	0.22	66.7	0.05
	0.21	69.9	0.05
	0.17	67.4	0.05
MI	0.19	71.0	0.05
	0.22	70.9	0.05
	0.23	70.2	0.05
	0.25	71.4	0.06
	0.28	71.9	0.08
KB	0.43	65.7	0.28
	0.38	65.5	0.07
	0.33	68.8	0.06
	0.38	65.0	0.07
	0.45	64.3	0.08

July 2001

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
MI	0.46	77.1	0.08
	0.29	68.2	0.09
	0.29	71.6	0.09
	0.30	74.3	0.10
	0.28	75.7	0.14
KB	0.68	66.7	0.05
	0.48	58.8	0.08
	0.33	70.0	0.09
	0.51	65.3	0.09
	0.51	72.4	0.06

Whaingaroa Harbour

April 2001

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
TU	0.42	68.4	0.06
	0.38	72.1	0.08
	0.53	67.3	0.08
	0.43	68.7	0.07
	0.53	66.6	0.08
HB	0.80	58.2	0.11
	0.73	60.6	0.10
	0.79	62.5	0.12
	0.78	60.5	0.11
	0.72	57.5	0.10
X	no sample	no sample	no sample
	no sample	no sample	no sample
	no sample	no sample	no sample
	no sample	no sample	no sample
	no sample	no sample	no sample
WI	0.53	67.7	0.08
	0.47	70.3	0.07
	0.46	68.5	0.07
	1.28	72.2	0.09
	0.48	68.5	0.08
OB	0.68	60.3	0.10
	0.68	60.8	0.09
	0.60	62.5	0.08
	0.63	61.9	0.09
	0.59	61.9	0.08

July 2001

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
WI	0.44	66.9	0.17
	0.43	67.4	0.08
	0.47	64.5	0.07
	0.52	62.3	0.07
	0.55	60.7	0.07
OB	0.70	55.6	0.10
	0.67	56.6	0.09
	0.66	56.5	0.09
	0.57	60.9	0.12
	0.54	61.6	0.10

October 2001

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
KA	1.43	31.2	0.21
	1.55	29.4	0.21
	1.47	27.5	0.21
	1.29	30.5	0.19
	1.45	26.4	0.23
GC	0.31	65.3	0.07
	0.47	63.9	0.08
	0.51	68.3	0.08
	0.51	62.8	0.11
	0.57	60.1	0.10
TP	0.21	66.1	0.05
	0.33	67.2	0.06
	0.21	62.8	0.06
	0.22	67.9	0.07
	0.21	64.7	0.05
MI	0.25	72.7	0.06
	0.31	70.6	0.07
	0.27	69.5	0.06
	0.27	72.5	0.06
	0.32	73.2	0.06
KB	0.50	60.1	0.14
	0.42	61.3	0.14
	0.42	62.6	0.16
	0.40	66.0	0.17
	0.46	63.9	0.19

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
TU	0.38	71.1	0.07
	0.47	68.2	0.09
	0.43	69.3	0.12
	0.65	65.6	0.11
	0.34	74.4	0.07
HB	0.79	58.1	0.10
	0.82	55.3	0.11
	0.79	57.3	0.11
	0.79	57.3	0.11
	0.77	54.9	0.11
X	0.42	70.9	0.08
	0.35	73.0	0.08
	0.37	74.9	0.07
	0.38	73.5	0.08
	0.37	74.4	0.07
WI	0.43	67.2	0.11
	0.41	66.7	0.10
	0.45	67.7	0.10
	0.41	68.2	0.09
	0.38	67.3	0.09
OB	0.61	61.9	0.10
	0.60	62.0	0.12
	0.57	59.2	0.06
	0.61	57.8	0.06
	0.61	59.9	0.06

Southern Firth of Thames

January 2002

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
MI	0.19	69.3	0.05
	0.19	70.2	0.06
	0.28	68.2	0.05
	0.19	73.1	0.05
	0.20	71.7	0.05
KB	0.30	68.6	0.12
	0.28	64.9	0.10
	0.39	63.1	0.12
	0.39	60.9	0.10
	0.42	59.3	0.12

Whaingaroa Harbour

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
WI	0.44	69.3	0.06
	0.33	69.1	0.06
	0.37	70.5	0.05
	0.35	68.4	0.05
	0.36	71.8	0.05
OB	0.66	65.3	0.08
	0.58	62.5	0.07
	0.53	64.0	0.07
	0.59	63.8	0.07
	0.61	64.6	0.08

April 2002

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
KA	0.48	56.7	0.13
	2.73	56.4	0.20
	0.43	62.2	0.13
	0.53	57.6	0.18
	3.27	56.7	0.16
GC	0.58	61.5	0.14
	0.39	63.5	0.09
	0.49	55.1	0.11
	0.45	62.0	0.10
	0.49	61.4	0.10
TP	0.19	64.9	0.06
	0.20	70.6	0.06
	0.18	68.4	0.06
	0.17	66.7	0.06
	0.21	63.6	0.06
MI	0.21	71.6	0.06
	0.17	73.7	0.05
	0.17	72.6	0.06
	0.17	73.7	0.06
	0.20	72.5	0.06
KB	0.33	65.4	0.07
	0.31	64.4	0.07
	0.51	60.2	0.14
	0.36	64.7	0.08
	0.29	66.8	0.07

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
TU	0.49	69.8	0.08
	0.47	68.6	0.07
	0.44	72.1	0.07
	0.43	74.4	0.06
	0.43	72.6	0.07
HB	0.73	56.7	0.11
	0.71	58.2	0.10
	0.75	60.6	0.09
	0.67	54.4	0.10
	0.73	56.0	0.10
X	0.48	70.6	0.06
	0.32	71.0	0.05
	0.28	68.0	0.06
	0.40	69.1	0.07
	0.46	69.0	0.07
WI	0.34	69.4	0.06
	0.41	64.7	0.07
	0.41	65.8	0.07
	0.41	72.9	0.06
	0.44	63.6	0.09
OB	0.51	65.0	0.06
	0.52	64.9	0.07
	0.49	65.7	0.07
	0.54	64.4	0.07
	0.59	63.9	0.08

July 2002

	Total Organic Carbon g/100g dry wt	**Dry Matter g/100g as rcvd**	**Total Nitrogen g/100g dry wt**
MI	0.23	71.4	0.17
	0.21	72.4	0.15
	0.32	70.3	0.16
	0.27	72.8	0.15
	0.26	69.9	0.15
KB	0.48	63	0.2
	0.37	65.3	0.23
	0.27	71.4	0.18
	0.26	66	0.23
	0.28	68.1	0.19

	Total Organic Carbon g/100g dry wt	**Dry Matter g/100g as rcvd**	**Total Nitrogen g/100g dry wt**
WI	0.34	69.1	0.12
	0.42	67.2	0.13
	0.39	70.8	0.13
	0.37	66.7	0.09
	0.45	68.9	0.13
OB	0.59	61.1	0.09
	0.57	61.4	0.09
	0.49	67.9	0.08
	0.95	61.7	0.11
	0.63	60.6	0.11

October 2002

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
KA	0.51	51	0.14
	0.68	48.9	0.17
	0.41	60.5	0.12
	0.44	57.3	0.11
	0.65	53.6	0.17
GC	0.49	61.4	0.1
	0.39	62.1	0.08
	0.64	56.3	0.08
	0.41	64.9	0.08
	0.41	66.3	0.13
TP	0.15	61.9	0.08
	0.12	66.9	< 0.05
	0.21	63.7	0.07
	0.24	60.9	0.08
	0.12	64.4	0.05
MI	0.16	68.7	0.13
	0.18	72.8	0.1
	0.17	66.7	0.11
	0.17	70.1	0.08
	0.18	67.7	0.08
KB	0.87	44.1	0.17
	0.34	64.7	0.11
	0.41	59.8	0.11
	0.99	50.2	0.26
	0.54	57.5	0.17

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
TU	0.45	69.1	0.14
	0.45	70.3	0.13
	0.4	71.8	0.12
	0.4	74.2	0.12
	0.61	69.7	0.13
HB	0.82	61.5	0.2
	0.86	59.8	0.24
	0.9	55.5	0.28
	0.94	57.1	0.3
	0.94	55.7	0.09
X	0.36	74	0.07
	0.36	76.4	0.06
	0.62	69.5	0.11
	0.43	70.5	0.09
	0.36	74.3	0.07
WI	0.47	64.4	0.13
	0.47	67.7	0.12
	0.83	66.2	0.09
	0.54	64.8	0.13
	0.42	67.1	0.15
OB	0.47	63.4	0.09
	0.41	70.8	0.08
	0.4	68.5	0.09
	0.47	68.9	0.09
	0.5	69.5	0.09

January 2003

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
MI	0.15	72	< 0.05
	0.12	75.1	< 0.05
	0.17	69.3	< 0.05
	0.18	66.7	0.05
	0.19	68.1	< 0.05
KB	0.3	66.5	0.06
	0.3	65.1	0.07
	0.32	66.5	0.08
	0.3	61.1	0.07
	0.37	60.7	0.09

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
WI	0.42	67.8	0.08
	0.36	70.5	0.07
	0.45	65.3	0.1
	0.43	66.2	0.08
	0.39	65.9	0.08
OB	0.53	67.3	0.08
	0.47	65.6	0.08
	0.5	66.4	0.09
	0.45	68.3	0.08
	0.55	63.5	0.09

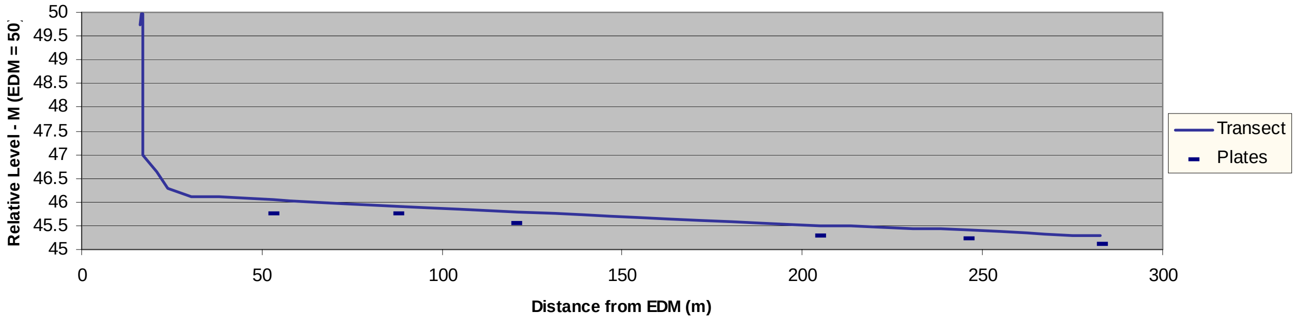
April 2003

	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
KA	0.26	62.1	0.06
	0.23	69.2	0.06
	0.35	64.5	0.07
	0.37	63	0.07
	0.27	68.8	0.07
GC	0.64	56.1	0.11
	0.49	57.2	0.09
	0.33	63.4	0.07
	0.44	58.4	0.1
	0.37	66.5	0.08
TP	0.3	60.5	0.06
	0.63	60.9	0.17
	0.14	64.7	< 0.05
	0.14	63.3	< 0.05
	0.61	65.5	0.15
MI	0.38	58.4	0.07
	1.97	71	0.47
	0.26	67.1	0.05
	0.31	63.9	0.07
	0.29	66.1	0.06
KB	0.42	60.9	0.08
	0.42	60.9	0.09
	0.37	62.9	0.08
	0.37	61.8	0.08
	0.36	63	0.08

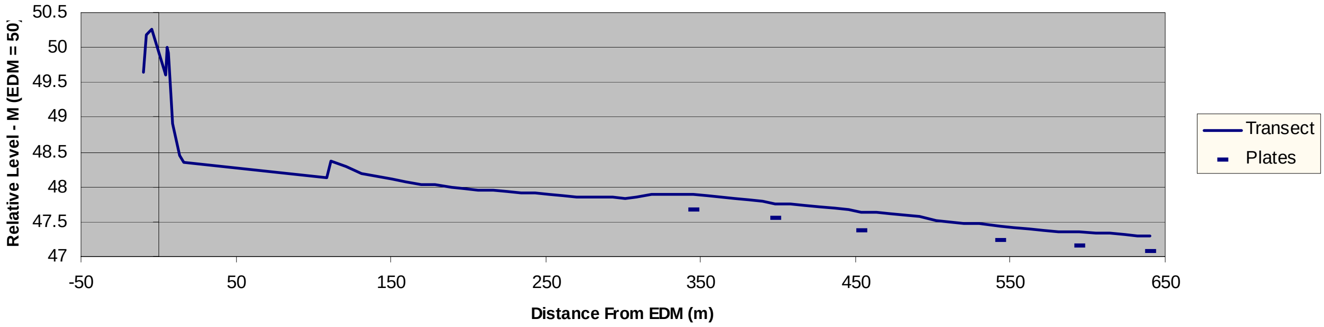
	Total Organic Carbon g/100g dry wt	Dry Matter g/100g as rcvd	Total Nitrogen g/100g dry wt
TU	0.34	71.4	0.07
	0.26	71.6	0.07
	0.34	70.8	0.07
	0.28	73.2	0.08
	0.32	72.3	0.08
HB	0.66	56.1	0.11
	0.59	57.1	0.11
	0.65	55.2	0.12
	0.66	56.1	0.11
	0.59	55.7	0.11
X	0.26	73.3	0.06
	0.35	71.6	0.07
	0.25	73.9	0.06
	0.25	75.1	0.05
	0.38	70.6	0.09
WI	0.35	63	0.07
	0.46	60.3	0.08
	0.45	68.9	0.07
	1.97	61.4	0.16
	0.38	70.5	0.07
OB	0.48	60.5	0.08
	0.52	62.6	0.09
	0.54	61.9	0.09
	0.49	60.7	0.08
	0.54	57.9	0.09

Appendix 3 – Cross-shore Surveys

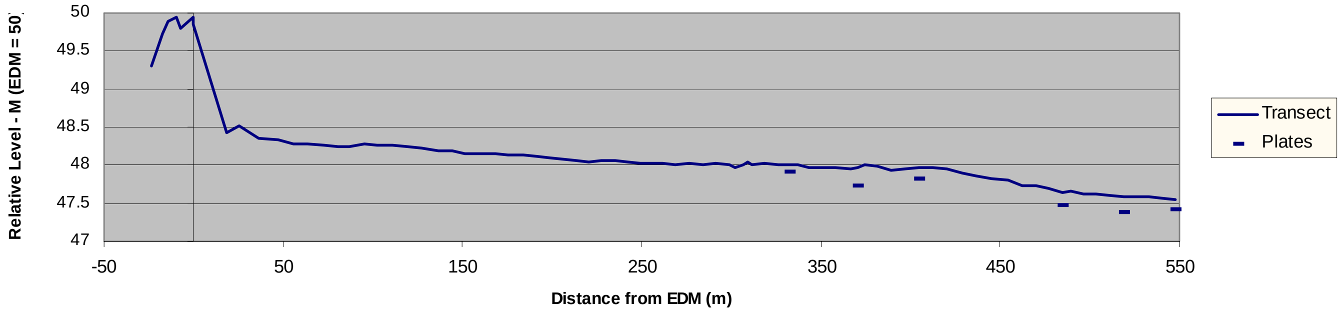
Cross Shore Survey: Kuranui Bay (06/03/2003)



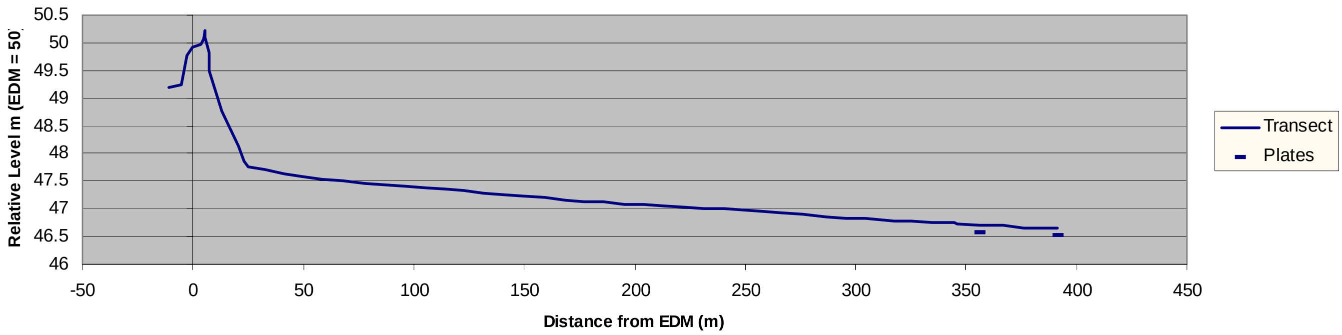
Cross Shore Survey: Miranda (05/03/2003)



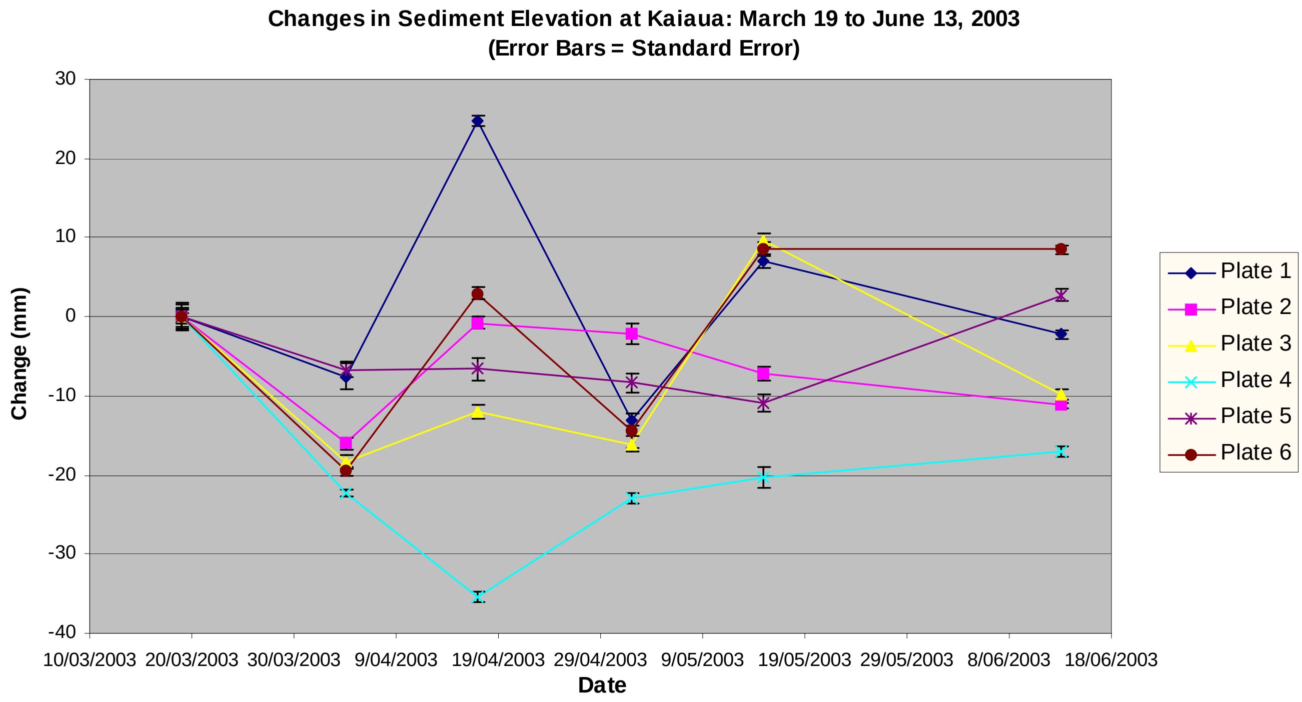
Cross Shore Survey: Gun Club (06/03/2003)

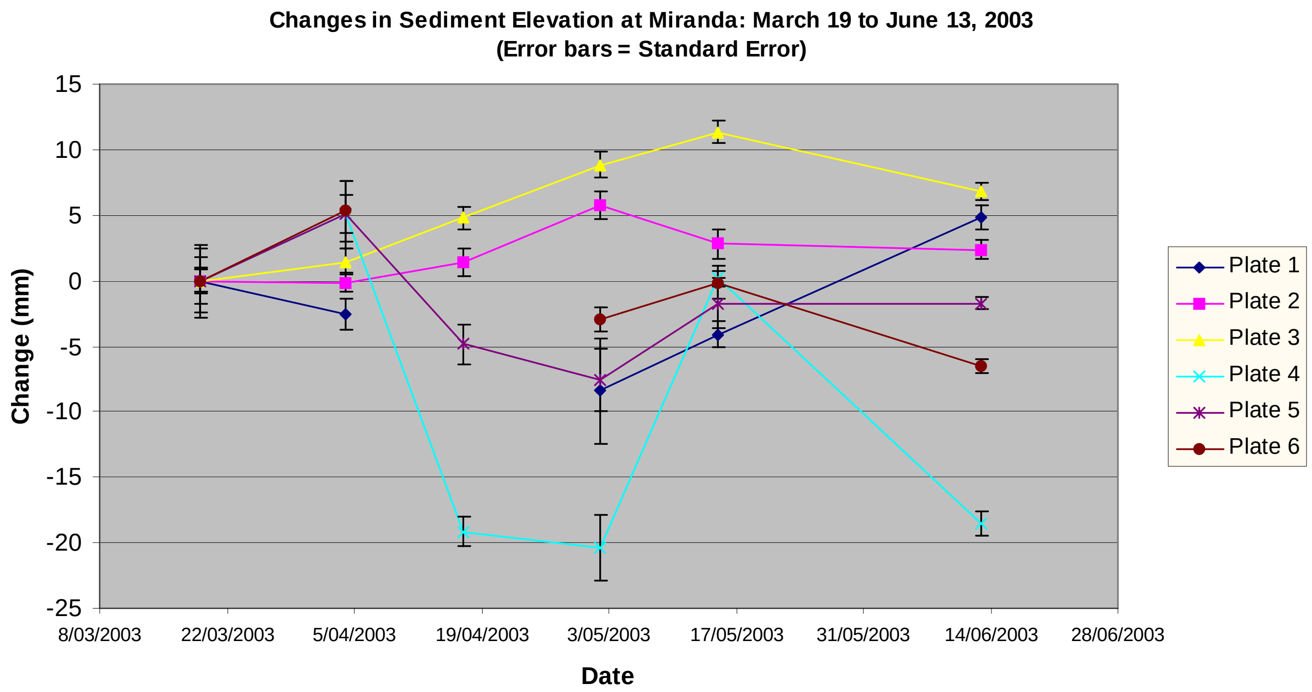


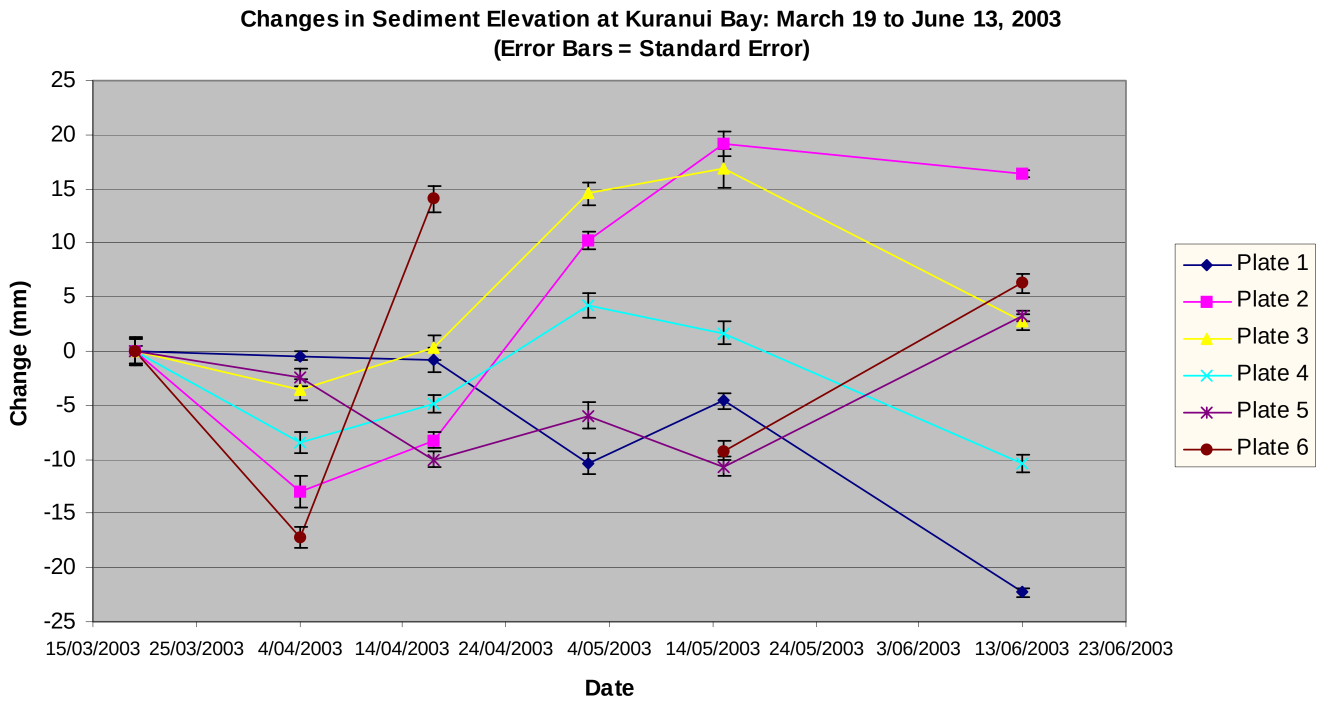
Cross Shore Survey: Kaiaua (06/03/2003)

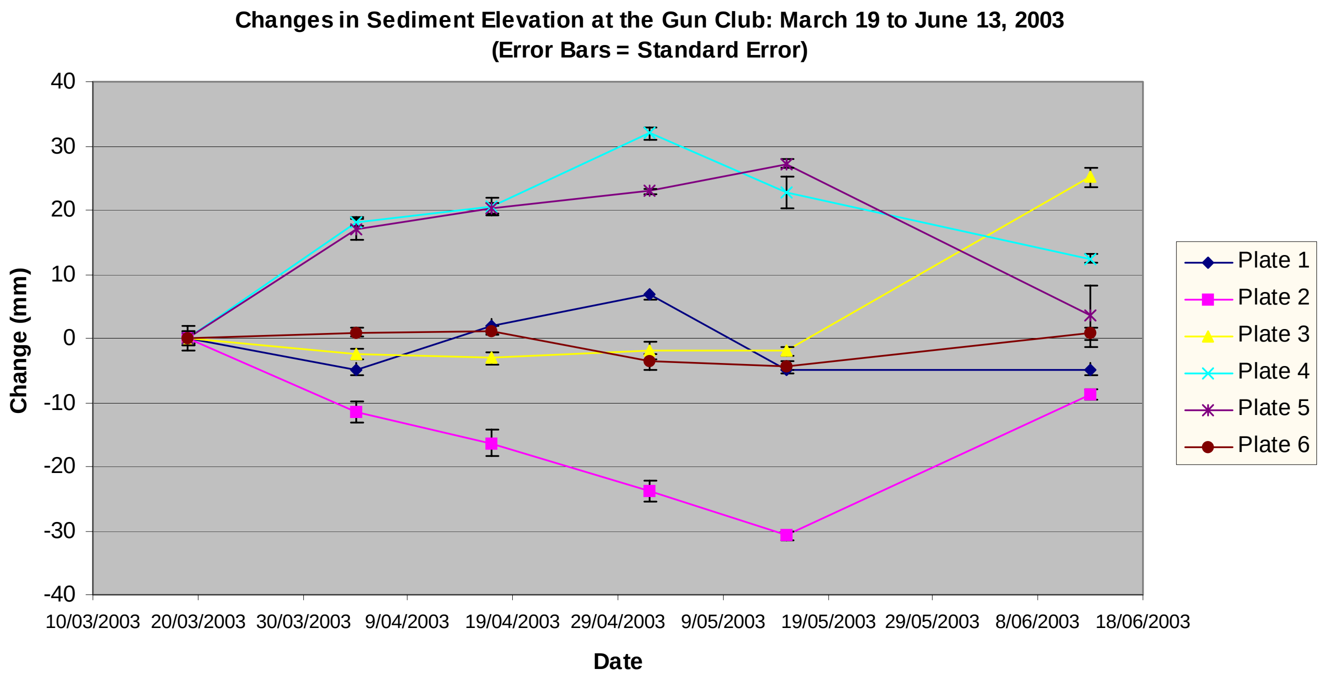


Appendix 4 – Changes in Sediment Elevation






Changes in Sediment Elevation at Kuranui Bay: March 19 to June 13, 2003
(Error Bars = Standard Error)
Change (mm)
Date
15/03/2003 25/03/2003 4/04/2003 14/04/2003 24/04/2003 4/05/2003 14/05/2003 24/05/2003 3/06/2003 13/06/2003 23/06/2003
25 20 15 10 5 0 -5 -10 -15 -20 -25
Plate 1
Plate 2
Plate 3
Plate 4
Plate 5
Plate 6


Changes in Sediment Elevation at the Gun Club: March 19 to June 13, 2003
(Error Bars = Standard Error)
Change (mm)
Date
10/03/2003 20/03/2003 30/03/2003 9/04/2003 19/04/2003 29/04/2003 9/05/2003 19/05/2003 29/05/2003 8/06/2003 18/06/2003
40 30 20 10 0 -10 -20 -30 -40
Plate 1
Plate 2
Plate 3
Plate 4
Plate 5
Plate 6