Ministry for the Environment
Manatū Mō Te Taiao

Sustainable Management Fund

Feasibility study to investigate the replenishment/reinstatement of seagrass beds in Whangarei Harbour – Phase 2

NIWA Client Report: AKL2005
10 February 2005

NIWA Project: NRC05101

Feasibility study to investigate the replenishment/reinstatement of seagrass beds in Whangarei Harbour – Phase 2

J. Reed
A. Schwarz
M. Morrison

Prepared for

Northland Regional Council

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National Institute of Water & Atmospheric Research Ltd
269 Khyber Pass Road, Newmarket, Auckland
P O Box 109695, Auckland, New Zealand
Phone +64-9-375 2050, Fax +64-9-375 2051
www.niwa.co.nz

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Contents

Reviewed by: *Approved for release by:*

Fleur Matheson Andrew Jeffs

Formatting checked

A. Bartley

Executive Summary

This report has been prepared for the Northland Regional Council and is Phase 2 of a larger project which aims to assess the feasibility of restoring seagrass beds in Whangarei Harbour and determine the best practicable option and method/s for doing so. The purpose of this report is to quantify the environmental conditions (i.e. water clarity and sediment quality) that are likely to influence current seagrass growth and health in the harbour and to identify the potential of sites for consideration for restoration.

To achieve this goal, existing Northland Regional Council data was analysed and additional sampling was conducted in November 2004 at three sites within the harbour. The sites were (1) where seagrass exists as stable beds, (2) where seagrass grows as patches (or transitional beds) and (3) where seagrass no longer exists but was present in the mid-1940s. At each of these sites, sampling was conducted at low tide along a 50 m transect. Each transect was located between the high and low tide level (i.e. shore to sea) and at regular intervals sediment cores were collected for analysis of particle size, total organic carbon (TOC) and metal concentrations (total zinc, copper and lead). Where it was present, seagrass was sampled to determine percent cover and above and below ground biomass. In addition, sampling of the water column was conducted at high tide at each of the study sites plus two additional sites where seagrasses have historically been reported. Measurements of water clarity (using a secchi disk) and attenuation of photosynthetically available radiation (using an underwater light meter) were made. Water samples were taken for analysis of nutrients (nitrogen and phosphorus) and total suspended sediment load.

At the sites where seagrasses currently grow, both water and sediment quality were within published ranges for seagrass growth although plant nutrient concentrations and organic carbon contents were both at the lower end of those ranges. Metal concentrations in sediments were below ANZECC–low guideline. Water clarity was, however, variable and given the importance of water clarity to seagrass growth we recommend regular monitoring. Sediments were mostly a combination of fine sand and coarse silt, except at site 3 (One Tree Point East), where sediments had a higher proportion of coarse sand. At site 3, the absence of seagrass was consistent with the sandiest substrate and lowest organic content of all three sites. The vicinity of two sites where seagrasses currently grow will be considered further (Task 3 to 5 of SMF project 2209) for implementing seagrass restoration trials.

1. Introduction

This report is the second phase of a feasibility study to investigate the replenishment of seagrass beds in Whangarei Harbour. The aim of this phase is to quantify environmental conditions (i.e. water clarity and sediment quality) that are likely to influence current seagrass growth and health in the harbour.

Previously, in phase 1 of this study, the availability of light, total suspended sediments in the water column and changes to estuarine sediments (i.e. texture) were identified as likely factors influencing past growth and survival of seagrass in Whangarei Harbour (Reed et al. 2004). Nutrients and contaminants in runoff from urban areas were also identified as possible factors (Webster et al. 2000, Reed et al. 2004).

This report outlines the findings from phase 2 of this project which had the following objectives:

1. To assess environmental conditions from data collected in Whangarei Harbour between 1994 and 2003 using existing data (Northland Regional Council).

2. To measure water clarity, sediment texture and quality, seagrass biomass and % cover at selected sites in Whangarei Harbour in 2004. As part of the water clarity measurements we undertook to provide a comparison between secchi disc readings and light measurements for ease of future monitoring and data interpretation by estuary managers.

3. To relate seagrass cover and biomass to sediment and water quality measurements thereby enhancing our ability to identify conditions suitable for seagrass growth in Whangarei Harbour.

2. Methods

2.1 Objective 1-Whangarei Harbour water and sediment quality, 1994 - 2003

Some water and sediment quality data in Whangarei Harbour have been collected by Northland Regional Council on various occasions between 1992 and 2003. In this analysis we compare data collected during 1994 and 2003 as these were the years in which the most comprehensive and comparative sampling was conducted. Data include faecal coliform concentrations, salinity, temperature and dissolved oxygen (DO). In addition a suite of samples for metal concentrations in sediment were collected from 15 sites in September 2002.

Sample numbers ranged from 3 to 24 at each site depending on the number of times they were sampled in a year. For the purposes of this analysis average concentrations and standard deviations for all available data in each year were calculated for sites located between Hatea River and Marsden Point.

2.2 Objectives 2 and 3-Field sampling 2004

2.2.1 Site selection

In phase 1 of this project, aerial photographs, reports and local knowledge established the location of extensive seagrass beds in Whangarei Harbour in mid-1900s and documented their loss during the 1960s – 1970s (Reed et al. 2004). Factors likely to be responsible for the loss of the seagrass beds were also reported. Using the digital (Geographic Information Systems - GIS) maps from this report and other historical information of the locations of seagrass beds, six sites were identified as potentially suitable for sampling seagrass in phase 2 (One Tree Point (west and east), Parua Bay, Munro Bay, Takahiwai and Skull Creek). A site visit was undertaken to choose the most suitable sites for this project. Figure 1 shows the location of the three sites chosen for sampling: (1) One Tree Point-west: where seagrass exists as stable beds, (2) Takahiwai: where seagrass grows as patches (or have been transitional over many years) and (3) One Tree Point- east (Marsden Point): where seagrass no longer exists but was present in the mid-1940s.

The different seagrass characteristics of these sites provided an opportunity to assess the range of environmental conditions that were supporting extant seagrass beds in

FIGURE REMOVED

Figure 1: Location of sampling sites in Whangarei Harbour, 2004.

Whangarei Harbour. Lack of accessibility and absence of seagrass at Munro Bay, Parua Bay and Skull Creek were reasons for not selecting these sites.

2.2.2 Sediment characteristics

At each of sites 1 to 3, sampling was conducted at low tide along a 50 m transect. Each transect was laid through the seagrass bed (or equivalent tidal range at One Tree Point East) from the high (0 m) to low (50 m) tide level (i.e. shore to sea). At distances of 5, 10, 20 and 40 m along the transect, three, 10 cm deep, 1.54 cm^2 cores were collected for particle size analysis. Each core was divided into three sections: 0-2 cm; 2-6 cm and 6-10 cm (Figure 2). Each section was then combined from three cores before being sub-sampled for analysis.

Samples were analysed for particle size, total organic carbon and metals (total zinc, copper and lead). For particle size analysis samples were dispersed in hydrogen peroxide solution to destroy organic matter then analysed on a Galai laser analyser in the 0-300 µm and 2-600 µm mode. Total organic carbon (TOC) content of samples was determined using an Elementor Combustion Analyser. Metal concentrations (total zinc, copper and lead) were analysed using an acid extraction followed by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS).

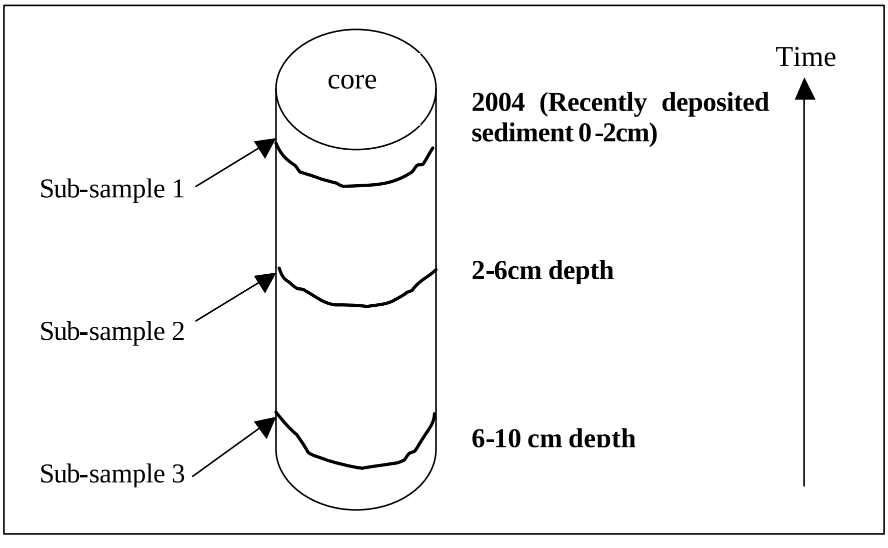

Figure 2: Cross section of sediment core.

2.2.3 Seagrass biomass and cover

At sites 1 and 2, seagrass samples (area of 30 cm x 30 cm) were collected to determine the above (shoots) and below (roots and rhizome) ground biomass. An estimate of percentage cover of seagrass was also recorded at sites 1 and 2 at every 5 m along the transect.

2.2.4 Water clarity and quality

Sediment deposition and re-suspension have been identified as an environmental issue for Whangarei Harbour (Reed et al. 2004) and it was predicted that suspended sediments in this harbour had the potential to markedly influence water clarity. For this reason we investigated the relationship between water clarity and suspended sediments in the water column. The rate at which light, and specifically photosynthetically available radiation (PAR), that enters the water surface is attenuated with increasing depth is expressed as an attenuation coefficient (K_d). This is a critical parameter to quantify as it enables us to estimate how much light is available over different parts of the tide, for plants such as seagrasses that grow on the estuary floor.

On the 30 November 2004, water clarity was measured at high tide at each of the study sites plus Parua Bay and Snake Bank (Figure 1). At each site a secchi depth was obtained and PAR was measured using a LiCor underwater 2pi sensor attached to a surface Li1000 logger. Measurements were made at depth intervals of 0.5 to 1 m to a maximum depth of 6 m (depending on water depth). At the same sites, surface water samples were taken for nutrient analysis (nitrogen and phosphorus) and calculation of total suspended sediment concentration.

K_d is often estimated from secchi depth (SD) as a rough overall correlation does exist. However the general relationship can differ from estuary to estuary (Davies-Colley et al. 1993). We used the measurements of PAR (which requires more specialised equipment) and secchi depth (which is relatively easy to measure) to approximate a relationship between the two variables in Whangarei Harbour.

4. Results and Discussion

4.1 Objective 1-Whangarei Harbour water and sediment quality, 1994-2003

Average concentrations for dissolved oxygen (DO), salinity, temperature and faecal matter (e.g. coliform bacteria) measured by Northland Regional Council in 1994 and 2003 are shown in Figures 3-6.

Average concentrations of zinc, copper, lead, cadmium, chromium and nickel from 15 sites in 2002 are shown in Figures 7-12.

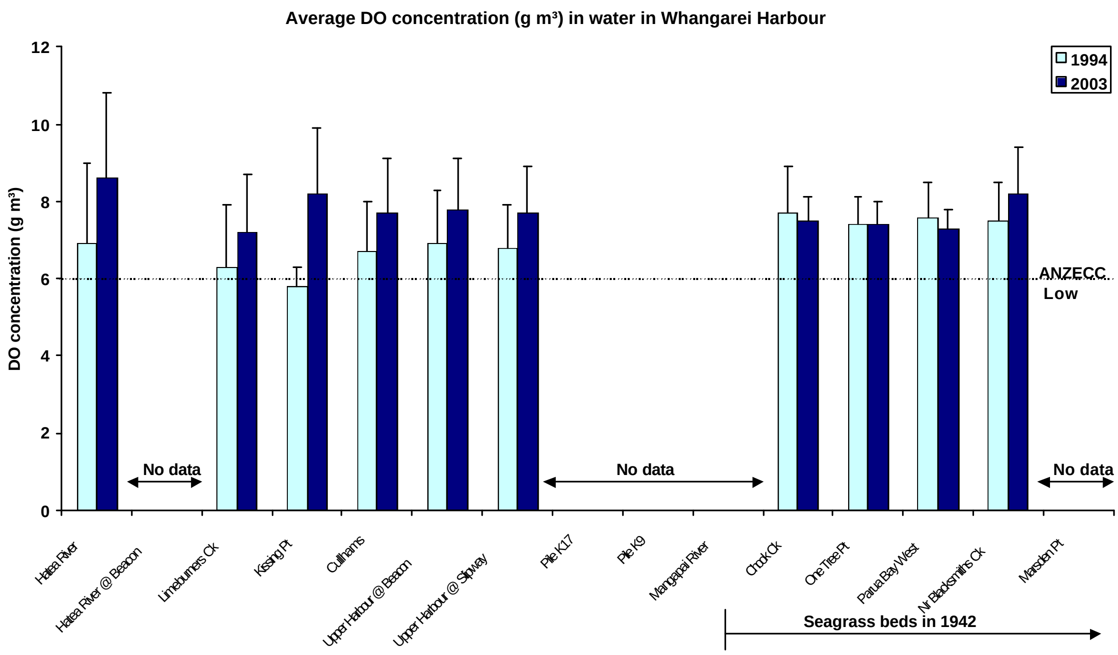

Figure 3: Concentration of dissolved oxygen at sites in Whangarei Harbour in 1994 and 2003 compared with water quality guidelines ANZECC-low. Values are average ± 1 SD.

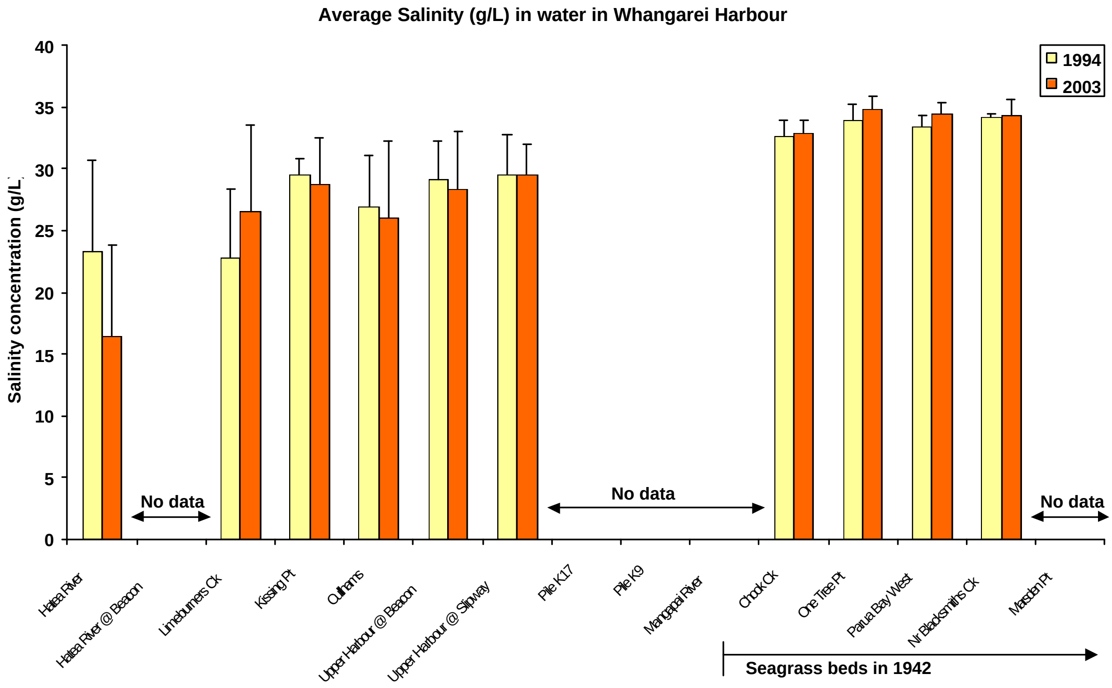

Figure 4: Salinity concentration at sites in Whangarei Harbour in 1994 and 2003. Values are average ± 1 SD.

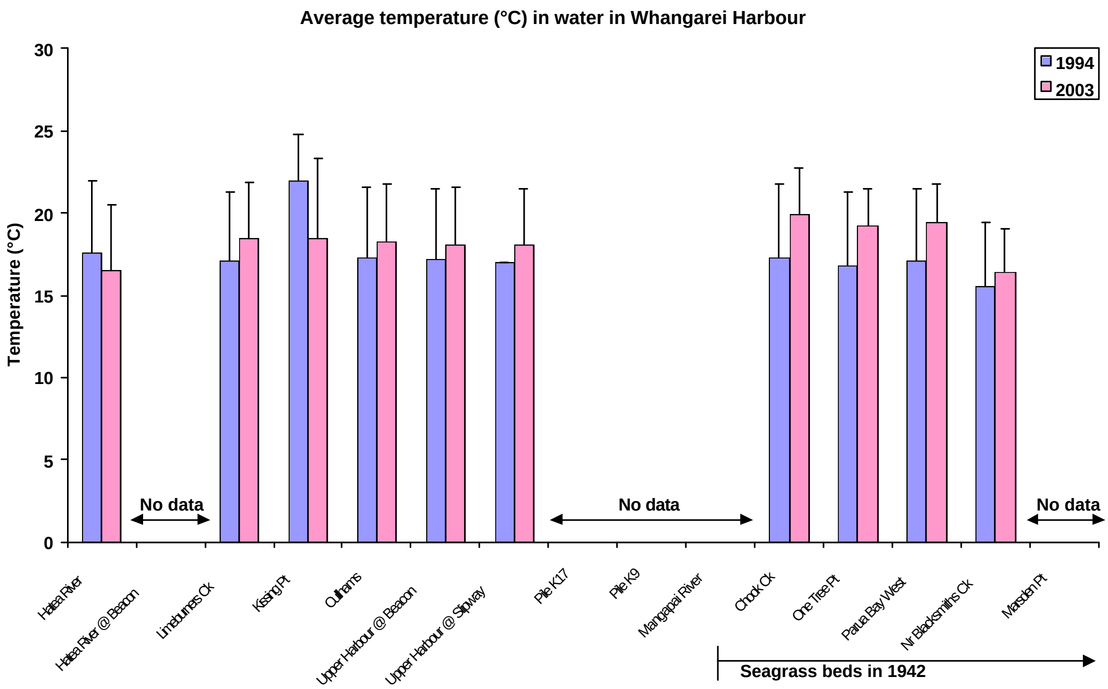

Figure 5: Temperature (°C) at sites in Whangarei Harbour in 1994 and 2003. Values are average ± 1 SD.

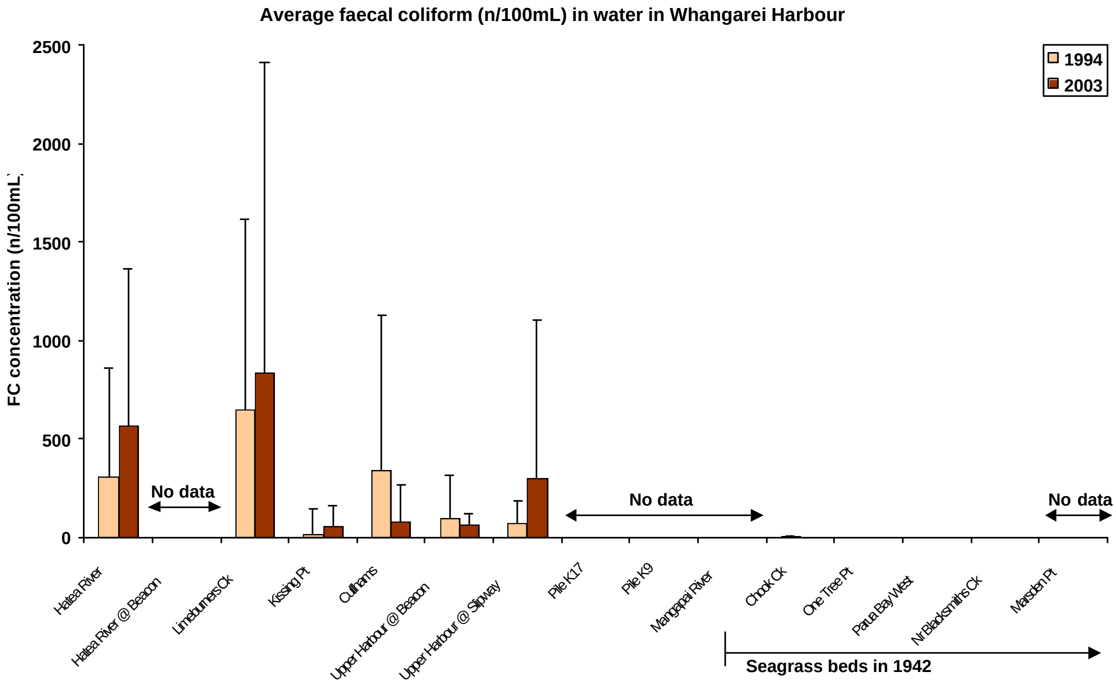

Figure 6: Concentration of faecal coliform at sites in Whangarei Harbour in 1994 and 2003, including sites where seagrass was present in 1942. Values are average ± 1 SD.

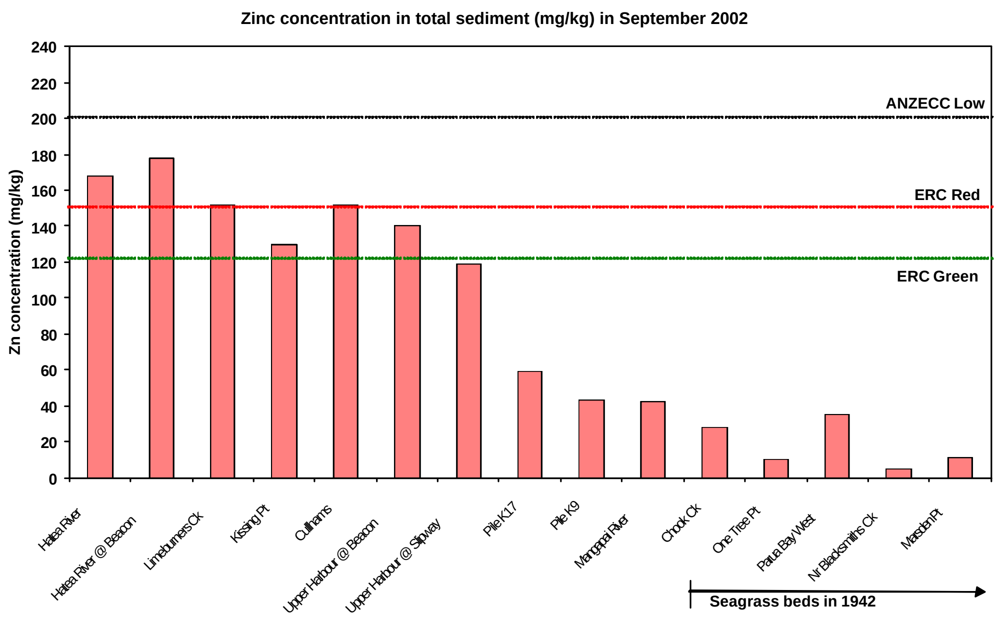

Figure 7: Concentration of zinc at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value and ERC values (Environmental Response Criteria used by ARC to trigger further action).

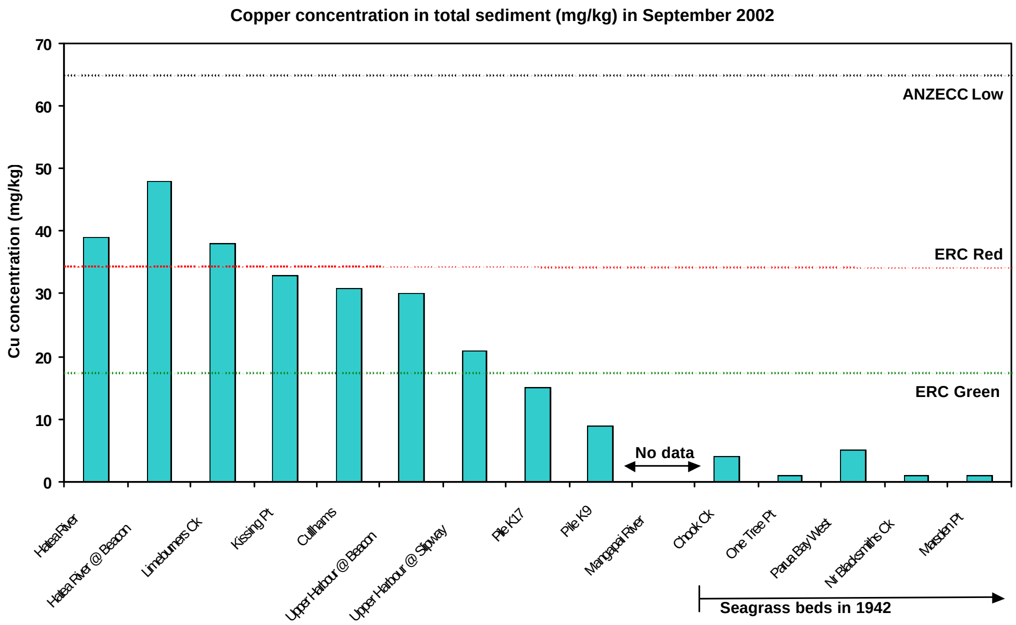

Figure 8: Concentrations of copper at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value and ERC values (Environmental Response Criteria used by ARC to trigger further action).

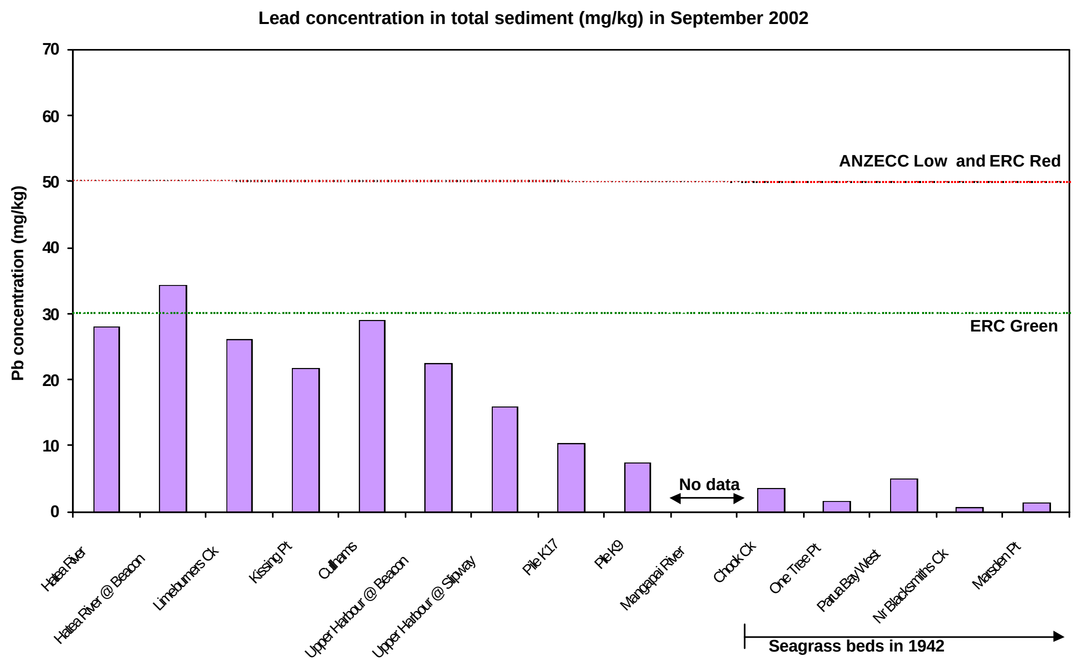

Figure 9: Concentrations of lead at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value and ERC values (Environmental Response Criteria used by ARC to trigger further action).

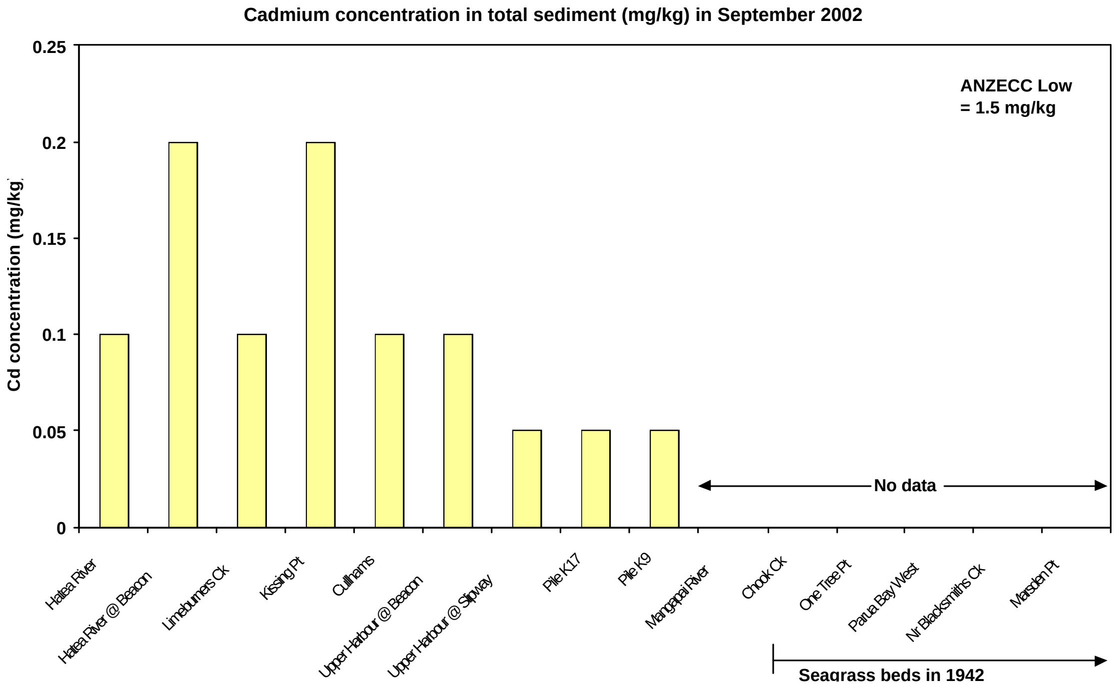

Figure 10: Concentrations of cadmium at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value.

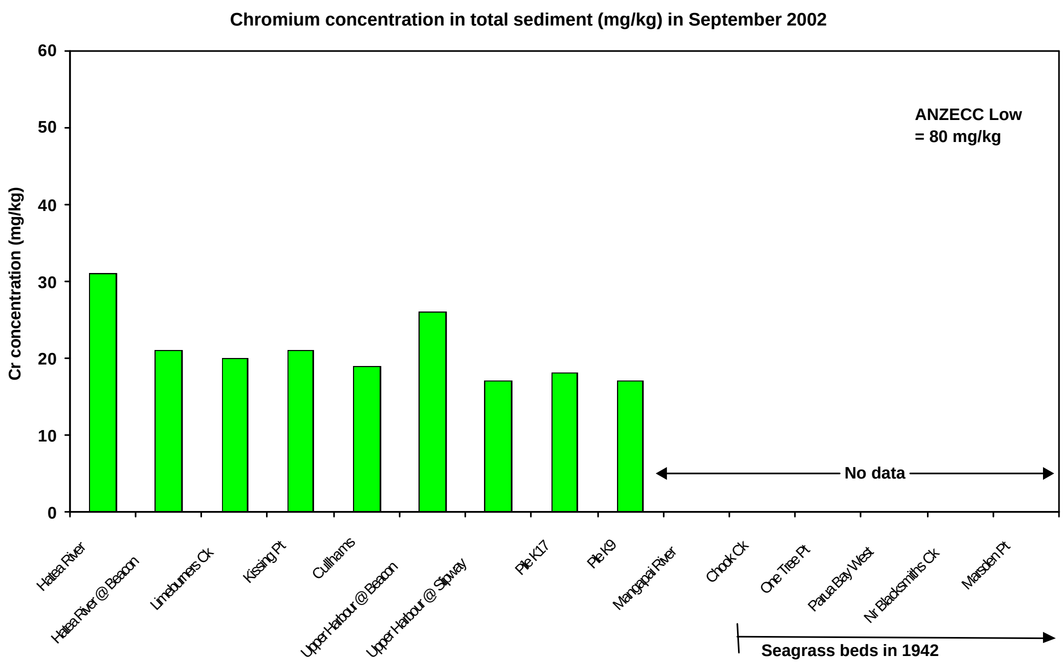

Figure 11: Concentrations of chromium at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value

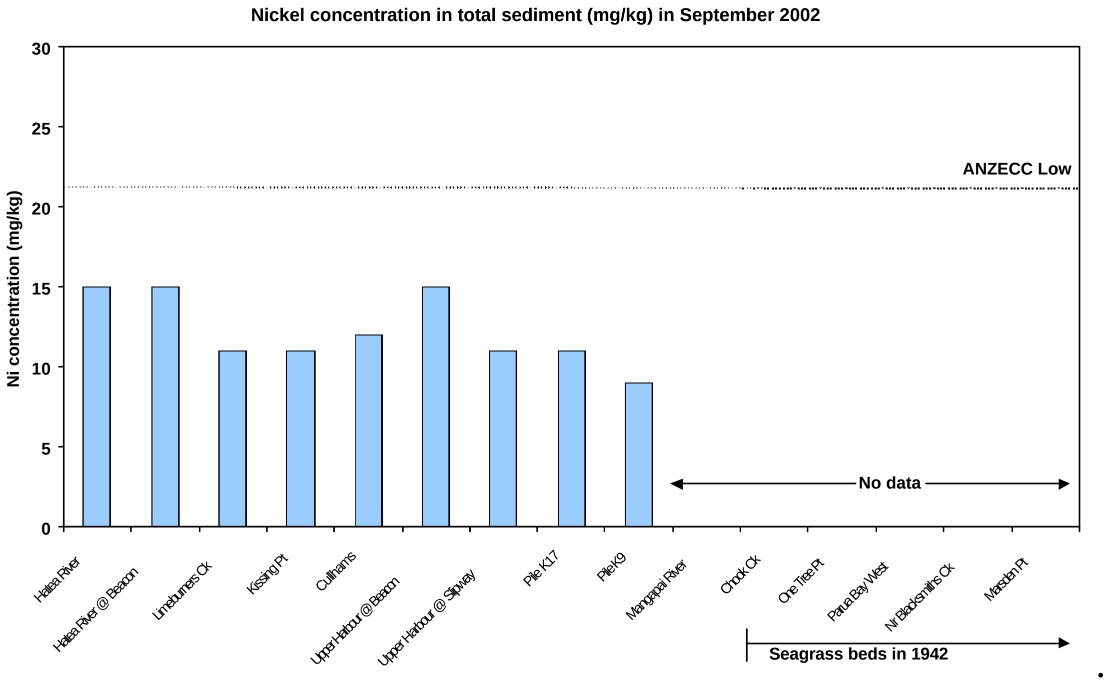

Figure 12: Concentrations of nickel at sites in Whangarei Harbour in 2002 compared with sediment quality guidelines ANZECC-low value.

The ANZECC guidelines provide maximum and minimum allowable levels of a range of parameters. ‘ANZECC-Low’ guideline values are used to protect most aquaculture species (ANZECC, 2000). Dissolved oxygen levels throughout the estuary were greater than minimum allowable ANZECC-Low levels in 1994 and 2003. Concentrations of faecal coliform (FC) in Whangarei Harbour are presented as one indicator of water quality. The highest concentrations of faecal coliforms were measured in the upper estuary close to Whangarei city. At the sites where seagrass currently exists or has grown in the past, concentrations of FC were low or undetectable. Although concentrations of FC do not affect seagrasses directly, this suggests that water quality might be expected to be higher at these sites than close to the city. The remaining parameters are more directly relevant to habitat suitability for seagrass growth.

Seagrasses tolerate a wide range of salinity usually ranging from 10 to 45 ppt. Average salinity levels in Whangarei Harbour were well within this range: 31- 35 g/L (ppt) in the outer harbour and > 15 g/L at the inner harbour site at the mouth of the Hatea River.

Seawater temperature ranged from 12-22°C. Seagrasses are tolerant of a wide range of water temperatures and this range is unlikely to be detrimental to growth at any time of year while plants are submerged. During summer, however, intertidal seagrass beds can experience very high temperatures when exposed to the air at low tide and the impact on seagrass health, growth and/or survival will depend on the intensity, duration and frequency of these high temperatures. Of particular significance is desiccation on hot, dry days. Exposure to desiccation can limit the amount of the intertidal that is suitable for sustaining long-term seagrass growth; i.e. the upper intertidal where sediments are exposed for the longest period during low tide are more susceptible to drying out and hence, from the perspective of desiccation, are likely to be less suitable for seagrass growth than further down slope.

Concentrations of metals in sediments sampled in 2002 were below the ANZECC-Low guidelines. These concentrations are regarded as background levels and according to research elsewhere (J. Reed et al., unpublished data) should not cause an impact on seagrass growth or survival. Metal concentrations were also below the ARC's trigger guideline –Environmental Response Criteria- green at historic seagrass sites.

4.2 Objectives 2 and 3

4.2.1 Nutrient concentrations

Common forms of nitrogen (N) available for plant growth in water are inorganic forms such as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+). Phosphorus (P) is often adsorbed to suspended particulate matter such as clays and detritus or bound up in organic compounds such as proteins (ANZECC, 2000). Phosphorus is also present in the dissolved form originating from certain phosphates or organic colloids (a collection of small particles). Nutrients are essential for plant growth and seagrass plants can acquire nutrients from both the sediment through their roots or from overlying water through their leaves. On a global scale, nutrient levels in the water column above seagrasses are typically relatively low. Sediment porewater concentrations can be present in much higher concentrations.

Nutrients such as nitrogen and phosphorus need to be present in sufficient quantities to ensure growth is not limited. Conversely excessive nutrients can result in the growth of epiphytes on seagrass leaves, thereby reducing the amount of light the seagrasses can obtain. In addition, at high concentrations some nutrient forms can become toxic to seagrass growth. Ammonium, for example, is a common form of nitrogen present in soil and water, but it has been shown to produce toxicity symptoms in the seagrass *Zostera marina* plants at water column concentrations of 25 µM or higher (van Katwijk et al. 1997).

Water column nutrient concentrations in estuaries can vary markedly over spatial, seasonal and tidal time scales hence this one off sampling in Whangarei Harbour merely provides a snapshot for assessing the suitability of conditions for seagrass growth. The highest nutrient concentrations were measured at Snake Bank and One Tree Point East and the lowest at Parua Bay (Table 1). Concentrations of NO_3-N in surface waters ranged from 6 ug l^{-1} at Parua Bay to 57 ug l^{-1} at Snake Bank (0.4 – 4 µM) (Table 1) and NH_4-N ranged from 8 ug l^{-1} at Parua Bay 37 ug l^{-1} at One Tree Point East (0.6 – 2.6 µM). For comparison and context we use Tauranga Harbour where extensive extant seagrass beds occur and where there has been an intensive water column nutrient monitoring programme for a number of years (Environment Bay of Plenty monitoring of Tauranga Harbour, Environment B.O.P., 1994). We also compare and contrast with results from an extensive study on environmental conditions and seagrass distribution in Moreton Bay, Queensland, Australia (Dennison and Abal 1999). Both nitrate (NO_3-N) and ammonium (NH_4-N) concentrations are within the ranges recorded in Tauranga Harbour. They also span the range measured in open water and in the vicinity of river inflows in Moreton Bay. With the exception of the low levels in Parua Bay on this occasion, concentrations were consistent with average water column ammonium and nitrate concentrations measured over seagrass beds globally (~3 µM) (Hemminga and Duarte 2000).

DRP levels were at the high end of the range of values measured in Tauranga Harbour monitoring but were at the lowest end of the range measured in Moreton Bay. In general, water column nutrients on the day of sampling appear to be sufficient for seagrass growth in Whangarei Harbour although not excessive, and with ammonium concentrations equating to levels of <3 µM, are well below levels considered toxic for seagrass growth.

Table 1: Results of water sampling in Whangarei Harbour (30 November, 2004).

Location	Takahiwai	One Tree Point-west	Marsden Point–One Tree Point East	Parua Bay	Snake Bank
Total suspended sediments (g l^{-1})	0.004	0.003	0.001	0.011	0.001
Attenuation coefficient (K_d (m^{-1}))	0.57	0.39	0.33	1.38	0.19
Secchi (m)	3.05	2.85	5.25	0.9	6.76
Water column nutrients (µg l^{-1})					
DRP (n=2)	18	14	16	18	15
NO_3-N (n=1)	24	17	32	6	57
NH_4-N (n=1)	11	9	37	8	23

4.2.2 Water clarity

TSS concentrations were highest in Parua Bay (0.011 g l^{1}) and lowest at One Tree Point East and Snake Bank (0.001 g l^{-1}) (Table 1). On the 30th November 2004, suspended sediments in the water column had a marked effect on the attenuation of PAR. K_d was linearly related to suspended sediments over the range of concentrations measured (Figure 13). Secchi depth also showed a clear relationship with suspended solids. Secchi depths of greater than 5 coincided with suspended sediment concentrations of 0.001 g l^{1} (Table 1, Figure 14).

Secchi depth is a simple and rapid technique which can, if collected regularly over long time periods, provide an indication of average trends in water clarity. However it is K_d (measured using underwater light meters) that provides a quantitative estimation of the amount of light available for benthic plant photosynthesis. From the data presented here, the relationship between secchi depth and K_d in this study was, K_d = 1.42/Secchi Depth (Figure 15). This investigation provides a data-based rationale for using secchi depth to estimate the irradiance available for plant photosynthesis in Whangarei Harbour. If secchi depth is monitored regularly the data can be used later to calculate irradiance conditions for plants if required. This would be an important component of a restoration trial and monitoring programme. It is important to recognise that water clarity can vary markedly in estuaries over different time scales and so long term data sets from regular monitoring are necessary to obtain an estimation of average water clarity.

In the reporting for tasks 3 and 4 of SMF project 2209 we assess the suitability of water clarity ranges measured in Whangarei Harbour, for seagrass growth.

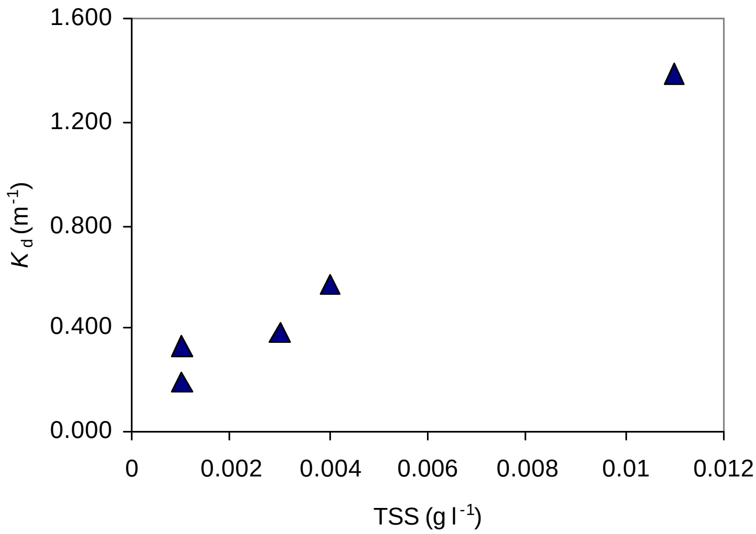

Figure 13: Relationship between light attenuation (Kd) and total suspended sediments (TSS) in seawater at 5 sites in Whangarei Harbour on 30 November 2004. Higher values of K_d = higher attenuation of light and so, lower water clarity.

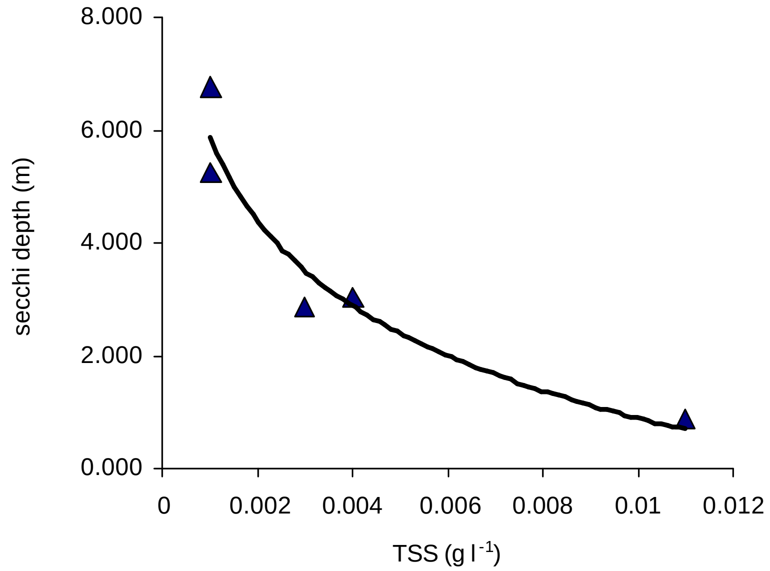

Figure 14: Relationship between secchi depth and total suspended sediments in seawater at 5 sites in Whangarei Harbour on 30 November 2004. Higher values of secchi depth = higher water clarity.

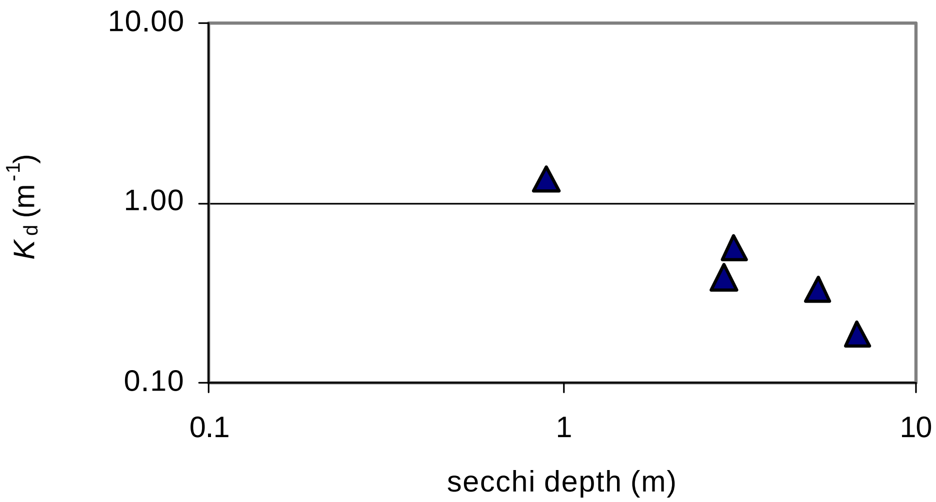

Figure 15: Relationship between the measurements of PAR and secchi depth at 5 sites in Whangarei Harbour on 30 November 2004.

4.2.3 Metal concentrations in sediments

Concentrations of metals in sediment cores taken by NIWA in 2004 at Takahiwai, One Tree Point West and One Tree Point East are shown in Table 2 and Figure 16. Typical concentrations of zinc and copper were ~8 mg kg^{-1} throughout the core at both Takahiwai and One Tree Point West. At One Tree Point East, average zinc concentrations were ~6 mg kg^{-1} and copper was ~1 mg kg^{-1}. Lead concentrations were consistently low (~1 mg kg^{-1}) at all three sites.

Metal concentrations at all sites were below the ANZECC-low guidelines and were considered to be representative of background levels.

4.2.4 Sediment texture and quality

Sediment particle size was analysed at the particle size range of 2-600 µm (see Appendix 1). At One Tree Point East, sediment was typically sandy with double the amount of medium sand as the other sites, and a small percentage of coarse sand. At Takahiwai and One Tree Point West, sediments were mostly very fine sand and coarse silt (see Figure 17).

The total organic carbon in sediments ranged from 0.12 to 0.29 %. Organic content of seagrass sediments ranges between 0.5 and 16.5 % globally (Koch 2001) but usually the values are less than 5%. The TOC values reported here equate to less than 1% organic matter at all sites which is at the lowest end of the typical ranges for seagrass growth. In addition, in the top 2cm of cores from One Tree Point East TOC contents were equivalent to an organic matter content of 0.45%, less than that considered suitable to support seagrass growth.

The *Zostera* species found in New Zealand have been found to grow better in coarse sediments (Larkum et al. 1984), and generally prefer soft-sediment environments consisting of sand and organic material. However, at sites where sediments become sandier with a decrease in fine sediments, a stressful sedimentary environment may be created as coarser sediments are generally lower in nutrient and organic matter (McKenzie, 1994). This is consistent with the absence of seagrass at One Tree Point East where sediments have a relatively high proportion of sand and less organic carbon than the other sites (Table 2, Figures 17 and 18).

Table 2: Results of sediment and seagrass sampling in Whangarei Harbour (29-30 November, 2004). Arrows indicate increasing depth of sediment. Values are average ± S.D.

Location	Takahiwai	One Tree Point-West	Marsden Point–One Tree Point East
Seagrass cover (%)	Range = 0 - 90 Average = 16 ± 26	Range = 3 - 80 Average = 50 ± 29	Not present
Seagrass biomass Above ground (AG) (g m^{-2}) Below Ground (BG) (g m^{-2}) Ratio AG:BG	 10.69±6.07 106.87±63.15 0.18±0.12	 25.59±4.87 150.01±21.75 0.17±0.03	 Not present
Average Particle size (%) Volume* Sand Silt clay	 97.07 ± 0.36 2.93 ± 0.37 0.01 ± 0.01	 97.33 ± 0.34 2.67 ± 0.34 0	 98.11 ± 0.17 1.90 ± 0.17 0
Total organic carbon (g/100g dw) @ 0-2cm surface ↓ 2-6cm depth >6cm depth	 0.23±0.06 0.16±0.05 0.16±0.06	 0.21±0.01 0.22±0.01 0.20±0.04	 0.13±0.01 0.11±0.02 0.10±0.03
Zinc (mg/kg dw) @ 0-2cm surface ↓ 2-6cm depth >6cm depth	 8.75±0.49 7.40±0.57 7.70±0.28	 8.10±0.28 7.65±0.35 7.70±0.28	 6.25±1.34 6.40±0.99 6.65±0.35
Copper (mg/kg dw) @ 0-2cm surface ↓ 2-6cm depth >6cm depth	 0.75±0.0 0.75±0.0 0.75±0.0	 0.70±0.0 0.65±0.07 0.65±0.07	 0.45±0.07 0.50±0.0 0.50±0.0
Lead (mg/kg dw) @ 0-2cm surface ↓ 2-6cm depth >6cm depth	 1.36±0.10 1.12±0.01 1.08±0.08	 1.12±0.02 1.01±0.01 1.06±0.0	 1.01±0.20 1.04±0.09 1.18±0.11

*volume is proportional to the mass and weight of the sediment fractions.

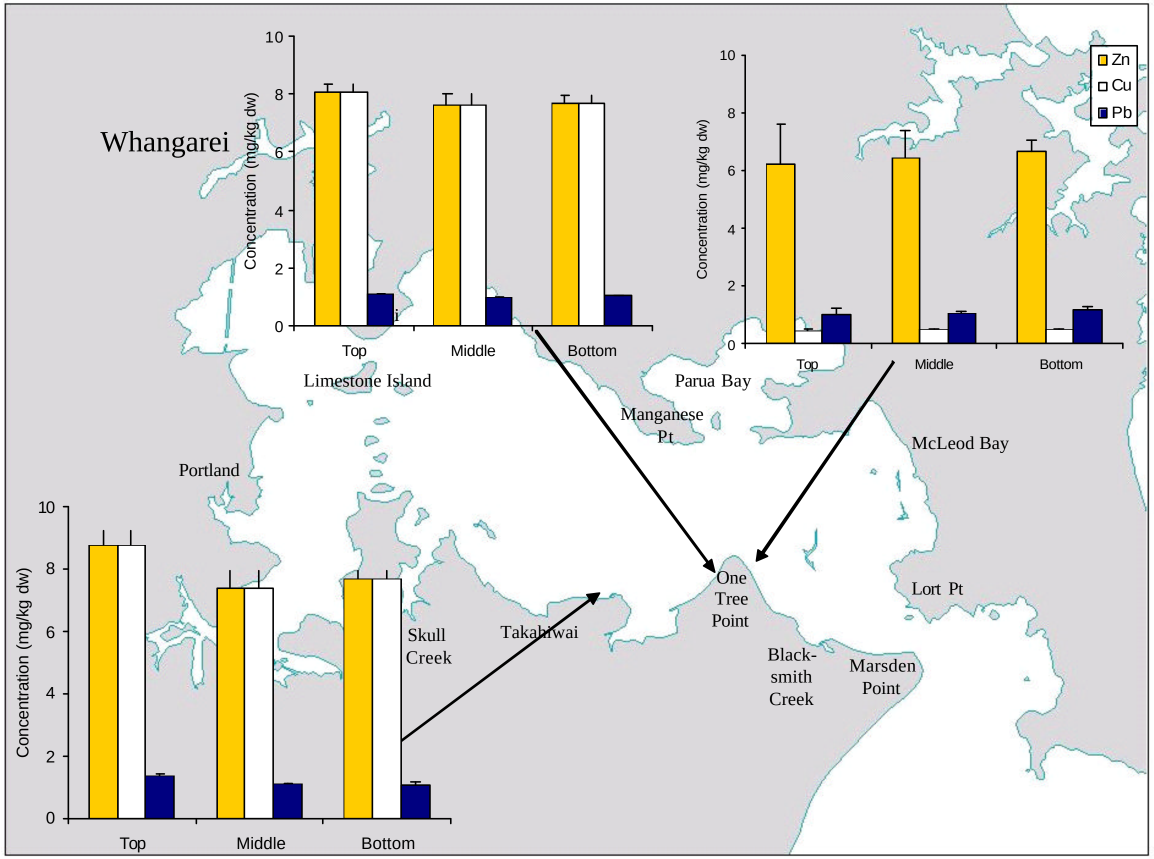

Figure 16: Concentrations of metals (mg/kg dw) in sediment cores (top = 0-2cm; middle = 2-6cm; bottom = 6-9cm) at 3 sites in Whangarei Harbour on 30 November 2004.

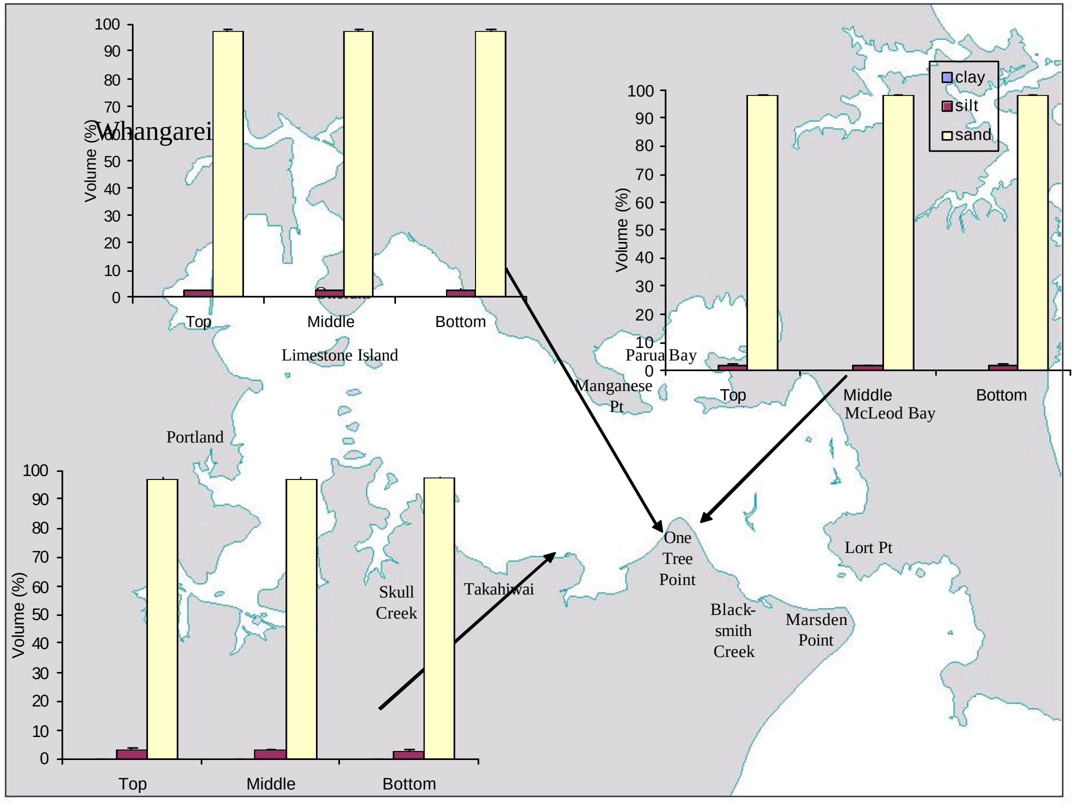

Figure 17: Percent sand, silt and clay in sediment cores (top = 0-2cm; middle = 2-6cm; bottom = 6-9cm) at 3 sites in Whangarei Harbour (30 November 2004).

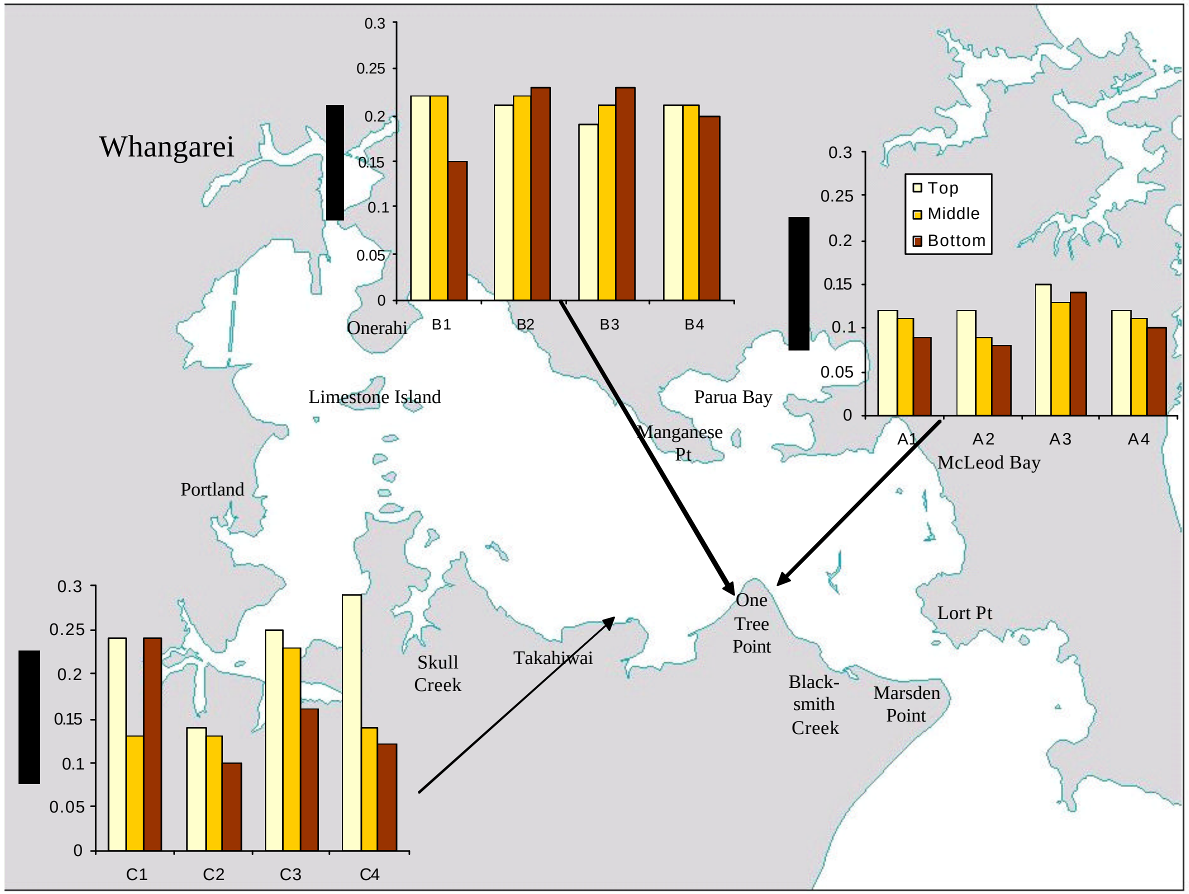

Figure 18: Concentrations of Total organic carbon (g/100g dw) in sediment cores (top = 0-2cm; middle = 2-6cm; bottom = 6-9cm) at 3 sites in Whangarei Harbour on 30 November 2004. A1, B1 and C1 represent the landward end of each transect and A4, B4 and C4, the seaward end.

4.2.5 Seagrass cover and biomass

Percent cover of seagrass was low at Takahiwai (average 16%) compared to One Tree Point West (average 50%) and this was consistent with a lower above and below ground biomass at Takahiwai (Table 2). Takahiwai consisted of seagrass patches rather than extensive beds like those at One Tree Point West.

Although there was a difference between total biomass at the two sites (see Figure 19), there was no difference in average above ground biomass:below ground biomass (AG:BG) ratio. It has been suggested that nutrient limitation affects AG:BG biomass ratio (Hemminga and Duarte 2000), resulting in a larger allocation of biomass to roots than shoots, which enhances nutrient acquisition from the sediment. The similarity in AG:BG biomass ratio between sites suggests there is no difference in nutrient availability between the two sites.

The highest values of TOC tended to occur where seagrasses were growing and over all samples on each transect total seagrass biomass (above plus below ground) was significantly positively correlated ($P < 0.05$, $r^2 = 0.60$) with organic content in sediments (see Figure 20).

The majority of all seagrasses require a minimum of 11% of surface irradiance in order to grow. Some taxa, including New Zealand's *Zostera*, however, have much higher light requirements. From the limited amount of information available, it appears that *Zostera* may require up to 30 to 40 % of incident irradiance on average over a year (Schwarz, unpublished data). For intertidal species, this annual average is made up of times when plants experience 100% irradiance while exposed at low tide and considerably less than 30 – 40% depending on water clarity and water depth when plants are submerged at high tide. As an example of how measurements can help us predict suitable water clarity conditions for seagrass growth, in order to achieve 40% of incident irradiance on seagrasses growing at a depth of 2 m at high tide an attenuation coefficient of 0.46 (or less, i.e. a higher clarity) is required. According to the relationship established in this study that equates to a secchi depth of 3.04 m or better (higher). Such values of K_d or secchi were found at four of the five water quality sampling sites (Takahiwai, One Tree Point West, One Tree Point East and Snake Bank) investigated on 30 November 2004. Note that the secchi depth at One Tree Point West falls slightly below the target value despite the K_d being sufficiently clear to meet the requirement. This illustrates that the accuracy of the two methods is not always comparable.

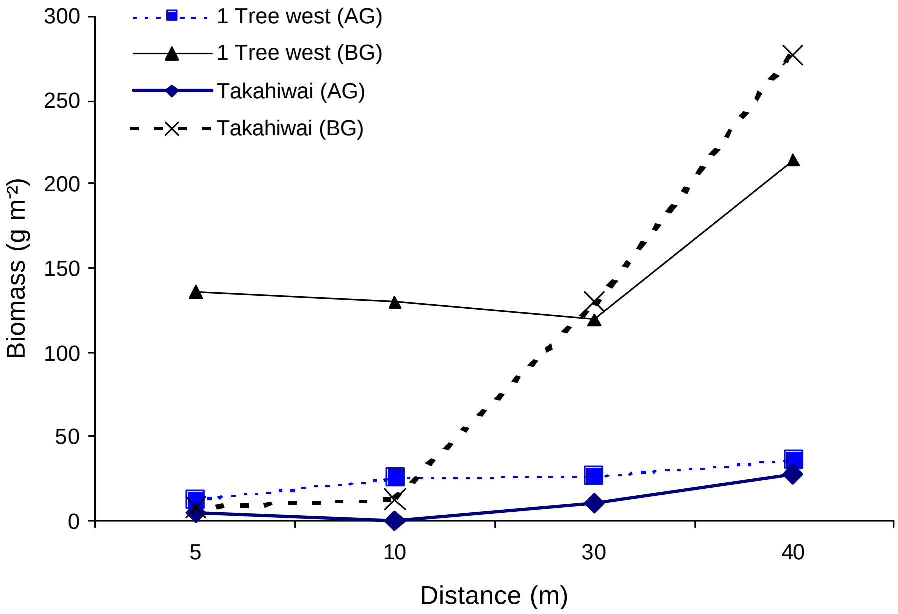

Figure 19: Seagrass biomass (above ground (AG) and below ground (BG)) at Takahiwai and One Tree Pont West in Whangarei Harbour on 30 November 2004.

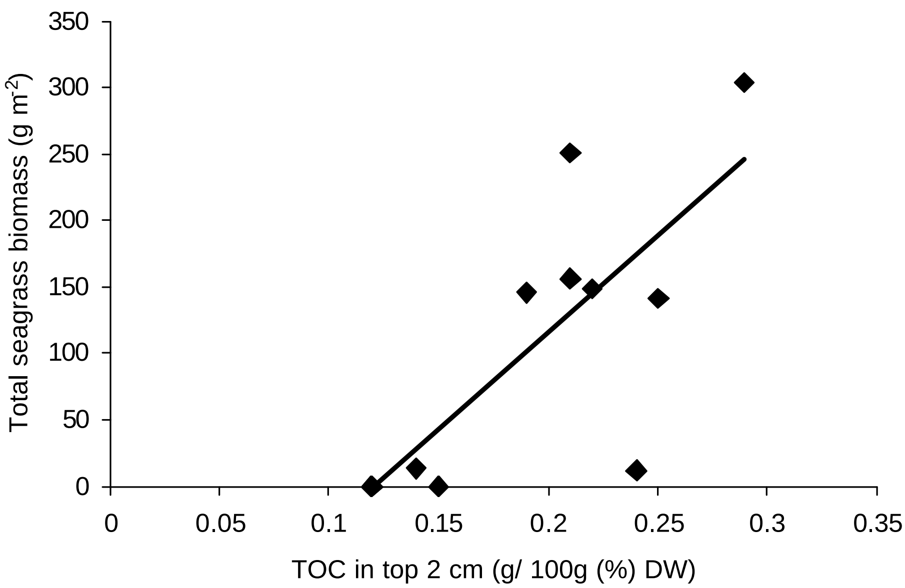

Figure 20: Relationship between total seagrass biomass (above and below ground) and TOC (g/100g dw) at Takahiwai, One Tree Point West and One Tree Point East on 30 November 2004. The variables are significantly correlated ($P < 0.05$, $r^2=0.6$).

5. Conclusions and recommendations

This investigation of environmental conditions including water clarity, nutrients chemical contaminants, sediment texture and organic carbon content in Whangarei Harbour supports the supposition (phase 1) that water clarity and sediment characteristics play an important role in determining where seagrasses grow in Whangarei Harbour. The results show that in the vicinity of existing seagrass beds, water and sediment quality were within suitable ranges for seagrass growth. At One Tree Point East however, where no seagrasses occur, some of these conditions are not currently met.

Water clarity clearly varies from site to site and given the relationship to suspended sediments is likely to vary markedly over different time scales depending on factors such as weather conditions. A combination of low water clarity at times, which may detrimentally affect plants growing at the lower part of the intertidal, and of the potential for desiccation to detrimentally affect plants in the upper intertidal, may work together to "squeeze" the available suitable intertidal habitat for seagrass growth in Whangarei Harbour.

We recommend regular water clarity monitoring (as secchi depth) at selected sites in Whangarei Harbour, especially in areas where seagrasses remain. In the next phase of this SMF project contract 2209, tasks 3 to 5 (to be reported on separately), will recommend target secchi depths for promoting healthy seagrass beds and will continue to address the following objectives:

1. To identify case studies elsewhere in the world where transplanting seagrasses has been successful; and highlight problems and/or limiting factors that should be considered prior to transplanting.

2. To identify suitable sites for transplanting seagrasses (including donor and replenishment sites) in Whangarei Harbour and to provide site specific advice on catchment and environmental initiatives that might be needed prior to transplanting being undertaken.

3. To provide advice on the techniques necessary for monitoring the success of restored and replenished trial areas.

The future aim of this project is to design a scientifically-robust approach to a restoration trial and in the long-term actively restore plants at chosen sites.

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7. Appendix 1: Particle Size Results: Volume Distribution

Tables 3 and 4 show the summary of particles size distributions in the samples in terms of surface area and volume, respectively. Surface area is relevant to the surface adsorption capacity of the sediments for chemical contaminants whereas volume is proportional to the mass and weight of the sediment fractions.

Table 3: Percentage contributions to surface area based on Udden-Wentworth particle size fractions. Values (%) are means.

		clay	very fine silt	fine silt	medium silt	coarse silt	very fine sand	fine sand	medium sand	coarse sand
Site name	Core depth (cm)	0µm-	3.9-	7.8-	15.6-	31.3-	62.5-	125-	250-500	500-600
A1	0-2	0.13	0.47	0.9	1.51	5.67	18.9	61.51	10.86	0.04
A1	2-6	0.17	0.47	0.8	1.19	5.79	19.45	61.68	10.44	0.01
A1	6-9	0.16	0.43	0.81	1.32	5.82	20.08	60.74	10.6	0.03
A2	0-2	0.15	0.51	0.93	1.6	5.48	20.18	60.19	10.9	0.07
A2	2-6	0.16	0.46	0.85	1.29	5.46	19.43	61.57	10.76	0.02
A2	6-9	0.16	0.52	1.24	1.82	5.91	20.57	58.28	11.4	0.11
A3	0-2	0.15	0.41	0.75	1.15	5.97	18.46	60.72	12.38	0
A3	2-6	0.19	0.46	0.88	1.53	5.42	17.46	60.02	14.04	0
A3	6-9	0.21	0.47	0.94	1.35	5.05	17.87	62.56	11.55	0
A4	0-2	0.14	0.39	0.67	1.1	4.79	16.41	63.26	13.25	0
A4	2-6	0.2	0.53	1.01	1.35	4.85	17.43	63.56	11.07	0
A4	6-9	0.19	0.46	0.93	1.09	5.21	16.86	61.43	13.83	0
B1	0-2	0.21	0.54	0.8	1.45	5.64	28.39	58.42	4.56	0
B1	2-6	0.24	0.58	0.88	1.22	5.52	25.44	59.73	6.39	0
B1	6-9	0.24	0.58	0.76	1.44	5.92	27.93	58.96	4.17	0
B2	0-2	0.17	0.5	0.88	1.79	6.47	31.59	54.67	3.93	0
B2	2-6	0.15	0.47	0.94	1.73	6.19	30.08	55.31	5.14	0
B2	6-9	0.2	0.6	1	1.64	6.51	28.19	56.61	5.26	0
B3	0-2	0.16	0.5	0.9	1.59	6.84	31.34	55.13	3.54	0
B3	2-6	0.17	0.51	0.91	1.66	6.93	31.15	55.15	3.52	0
B3	6-9	0.15	0.55	0.97	1.81	7.47	31.26	53.56	4.24	0
B4	0-2	0.16	0.47	0.77	1.37	6.36	32.44	55.44	3.02	0
B4	2-6	0.17	0.46	0.99	1.65	6.23	31.15	56.58	2.77	0
B4	6-9	0.17	0.49	0.96	1.75	7.65	32.28	53.95	2.75	0
C1	0-2	0.22	0.63	1	1.74	6.7	31.04	56.08	2.58	0
C1	2-6	0.2	0.47	0.91	1.31	6.44	31.2	57.14	2.32	0
C1	6-9	0.22	0.73	1.48	2.09	7.22	31	54.62	2.64	0
C2	0-2	0.17	0.48	0.8	1.34	6.02	31.14	57.42	2.64	0
C2	2-6	0.14	0.42	0.78	1.38	6.03	32.03	56.77	2.46	0
C2	6-9	0.15	0.48	0.7	1.28	6.13	28.67	59.5	3.1	0
C3	0-2	0.28	0.76	1.25	2.17	7.64	35.52	50.88	1.5	0
C3	2-6	0.28	0.62	1.27	1.84	6.81	31.64	55.59	1.96	0
C3	6-9	0.2	0.6	1	1.73	6.93	33.77	53.45	2.32	0
C4	0-2	0.17	0.59	1.23	1.86	6.98	33.58	53.22	2.39	0
C4	2-6	0.18	0.61	1.03	1.92	7.39	35.83	51.72	1.31	0
C4	6-9	0.16	0.53	0.92	1.61	6.6	32.21	55.56	2.41	0

Table 4: Percentage contributions to sediment volume based on Udden-Wentworth particle size fractions. Values (%) are means.

		clay	very fine silt	fine silt	medium silt	coarse silt	very fine sand	fine sand	medium sand	coarse sand
Site name	**Core depth (cm)**	**0µm-**	**3.9-**	**7.8-**	**15.6-**	**31.3-**	**62.5-**	**125-**	**250-500**	**500-600**
A1	0-2	0	0.02	0.06	0.21	1.72	11.06	67.07	19.74	0.13
A1	2-6	0	0.02	0.06	0.17	1.79	11.39	67.69	18.86	0.03
A1	6-9	0	0.02	0.06	0.19	1.78	11.94	66.69	19.23	0.1
A2	0-2	0	0.02	0.07	0.22	1.66	11.89	66.19	19.75	0.21
A2	2-6	0	0.02	0.06	0.18	1.64	11.51	67	19.52	0.07
A2	6-9	0	0.02	0.09	0.25	1.79	12.18	64.32	21	0.35
A3	0-2	0	0.01	0.05	0.16	1.79	10.52	66.01	21.45	0
A3	2-6	0	0.02	0.06	0.21	1.56	9.87	64.24	24.04	0
A3	6-9	0	0.02	0.07	0.18	1.49	10.42	67.77	20.05	0
A4	0-2	0	0.01	0.05	0.14	1.37	9.07	67.21	22.15	0
A4	2-6	0	0.02	0.07	0.19	1.45	10.1	69.02	19.15	0
A4	6-9	0	0.02	0.06	0.14	1.5	9.36	65.74	23.17	0
B1	0-2	0.01	0.02	0.06	0.23	1.94	19.35	69.33	9.05	0
B1	2-6	0.01	0.02	0.07	0.19	1.82	16.54	69.16	12.2	0
B1	6-9	0.01	0.02	0.06	0.23	2.02	19	70.44	8.22	0
B2	0-2	0	0.02	0.08	0.3	2.36	22.43	66.48	8.34	0
B2	2-6	0	0.02	0.08	0.28	2.15	20.41	66.67	10.4	0
B2	6-9	0	0.02	0.08	0.26	2.25	19.19	67.6	10.6	0
B3	0-2	0	0.02	0.08	0.27	2.48	22.42	67.34	7.4	0
B3	2-6	0	0.02	0.08	0.27	2.53	22.1	67.51	7.48	0
B3	6-9	0	0.02	0.08	0.31	2.73	22.22	65.69	8.95	0
B4	0-2	0	0.02	0.07	0.23	2.32	23.52	67.59	6.24	0
B4	2-6	0	0.02	0.08	0.28	2.26	22.56	69.05	5.75	0
B4	6-9	0	0.02	0.08	0.3	2.86	23.7	67.14	5.9	0
C1	0-2	0.01	0.03	0.09	0.29	2.47	22.59	69.08	5.45	0
C1	2-6	0.01	0.02	0.08	0.22	2.38	22.64	69.8	4.85	0
C1	6-9	0.01	0.03	0.13	0.35	2.69	22.6	68.41	5.78	0
C2	0-2	0	0.02	0.07	0.22	2.19	22.48	69.54	5.47	0
C2	2-6	0	0.02	0.07	0.23	2.18	23.25	69.12	5.14	0
C2	6-9	0	0.02	0.06	0.21	2.16	20.12	71.1	6.32	0
C3	0-2	0.01	0.04	0.12	0.39	3.04	27.57	65.5	3.35	0
C3	2-6	0.01	0.03	0.11	0.32	2.54	23.61	69.22	4.16	0
C3	6-9	0.01	0.03	0.09	0.3	2.61	25.12	66.85	5	0
C4	0-2	0	0.03	0.11	0.33	2.64	25.24	66.53	5.14	0
C4	2-6	0.01	0.03	0.1	0.35	2.94	27.79	65.91	2.89	0
C4	6-9	0	0.02	0.08	0.28	2.43	23.48	68.67	5.04	0