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NORTHLAND REGIONAL COUNCIL

Kaipara Harbour Sediments

Information Review

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Kaipara Harbour sediments: information review

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Contents

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1 Executive Summary

Auckland Regional Council (ARC) and Northland Regional Council (NRC) contracted NIWA to review existing information relating to sedimentation and sediment composition in the Kaipara Harbour. The review includes recommendations on an appropriate suite of metals and organic compounds to measure for any future baseline surveys and/or state of the environment monitoring of harbour bed sediments.

Estuaries are susceptible to accelerated estuarine sedimentation associated with changing catchment land use and development activities. In North Island estuaries, these changes have included large-scale catchment deforestation from the mid-1800s, and subsequent conversion to pastoral agriculture, production forestry and urban development. These catchment landcover changes have been found to substantially increase loads of fine sediments delivered to estuaries. Evidence from the literature suggests that like many North Island estuaries there have been substantial catchment landcover changes in the Kaipara, particularly over the last 150 years. The resulting changes will have certainly resulted in increased rates of soil erosion and therefore sedimentation. As a consequence the Kaipara Harbour now is a predominantly rural catchment with some contaminant inputs from urban areas.

Although the bed sediments of the southern Kaipara Harbour have been comprehensively sampled by Hewitt & Funnell (2005) there is no detailed information on particle size distributions. There is a paucity of information on bed sediment characteristics in the northern Kaipara Harbour.

The literature review also shows that there is no quantitative information on sediment accumulation rates (SAR) in the Kaipara Harbour.

Radioisotope dating using lead-210 (^{210}Pb) and caesium-137 (^{137}Cs) have been successfully applied to accurately determine SAR in a number of North Island estuaries. These techniques also enable areas of preferentially fine-sediment accumulation to be identified. Such studies can now also be completed by compound-specific isotope techniques to identify the sources of catchment sediments deposited in estuaries.

Natural geology contributes a significant amount of the background concentration of heavy metals that can be detected in harbour sediments. Metals associated with the soils found surrounding the Kaipara Harbour include aluminium, iron, manganese and magnesium. If metal concentrations, or other chemicals that are not present in natural soils e.g., Dichloro-Diphenyl-Trichloroethane (DDT), are higher than local background concentrations, the implication is that the source is from anthropogenic activities such as the spraying of rural soils by horticultural/agricultural activities to enhance concentrations of copper (Cu), zinc (Zn), cadmium (Cd), for example, or enhanced Cu and Zn concentrations from nearby urban activities. The overall concern for the environment comes from the potential impacts that anthropogenic activities are having on the local environment.

- There is no quantitative information on sediment accumulation rates in the Kaipara Harbour.
- There is limited information on bed-sediment composition.
- Hewitt & Funnell, (2005) undertook a comprehensive sampling of bed sediments in the southern Kaipara. However, sediments were classified into size classes only, so that there is no detailed information on sediment particle size distributions.
- There is no data on contaminants in harbour-bed sediments, in particular anthropogenic concentrations of metals.
- Historical coring is recommended to determine historical sediment accumulation rates and to draw out linkages to changes in land-cover.
- Monitoring of bed sediment compostion and anthropogenic contaminants is recommended. The suite of metals and organics to be tested for should include Cd (is one of the primary concerns for rural run off) Zn, Hg and pathogens (the usual culprits when it comes to shellfish pollution issues).

2 Introduction

2.1 Background

Estuaries are susceptible to the effects of increased sedimentation associated with changing catchment land use and development. In North Island estuaries, these changes have included large-scale catchment deforestation from the mid-1800s and subsequent conversion to pastoral agriculture, production forestry and urbanisation. These catchment land cover changes have substantially increased fine sediment loads delivered to estuaries. Effects in estuaries have included accelerated sedimentation, shifts from sand to mud habitats, increased turbidity and changes in plant and animal communities (Swales et al. 1997; 2002a; 2007a; Thrush et al. 2004) as also observed in Australian estuaries (Roy et al. 2001). In addition, other contaminants such as heavy metals and organic compounds associated with stormwater discharged from rural and urban catchments can accumulate in estuarine sediments in high enough concentrations to have adverse ecological effects (Swales et al. 2002b).

Auckland Regional Council (ARC) and Northland Regional Council (NRC) have recognised that a potential lack of information on sediments in Kaipara Harbour may result in adverse environmental changes not being detected in a timely manner. To address this issue, ARC and NRC contracted NIWA to review existing information relating to sedimentation and sediment composition in the Kaipara Harbour.

This report represents the finding of a comprehensive information review of sedimentation and composition of bed sediments in the Kaipara Harbour. This review also includes recommendations for a suite of suitable metals and organic contaminants for any future baseline survey and/or state of the environment monitoring of harbour bed sediments.

2.2 Study Objectives

As stated in the study brief, the study objectives are to locate and briefly review existing information for the entire Kaipara Harbour on:

- recent sedimentation rates;
- composition of harbour bed sediments, preliminary detection of heavy metal concentrations and organic compounds; and
- identify a suitable suite of contaminants for a future baseline survey and/or monitoring.

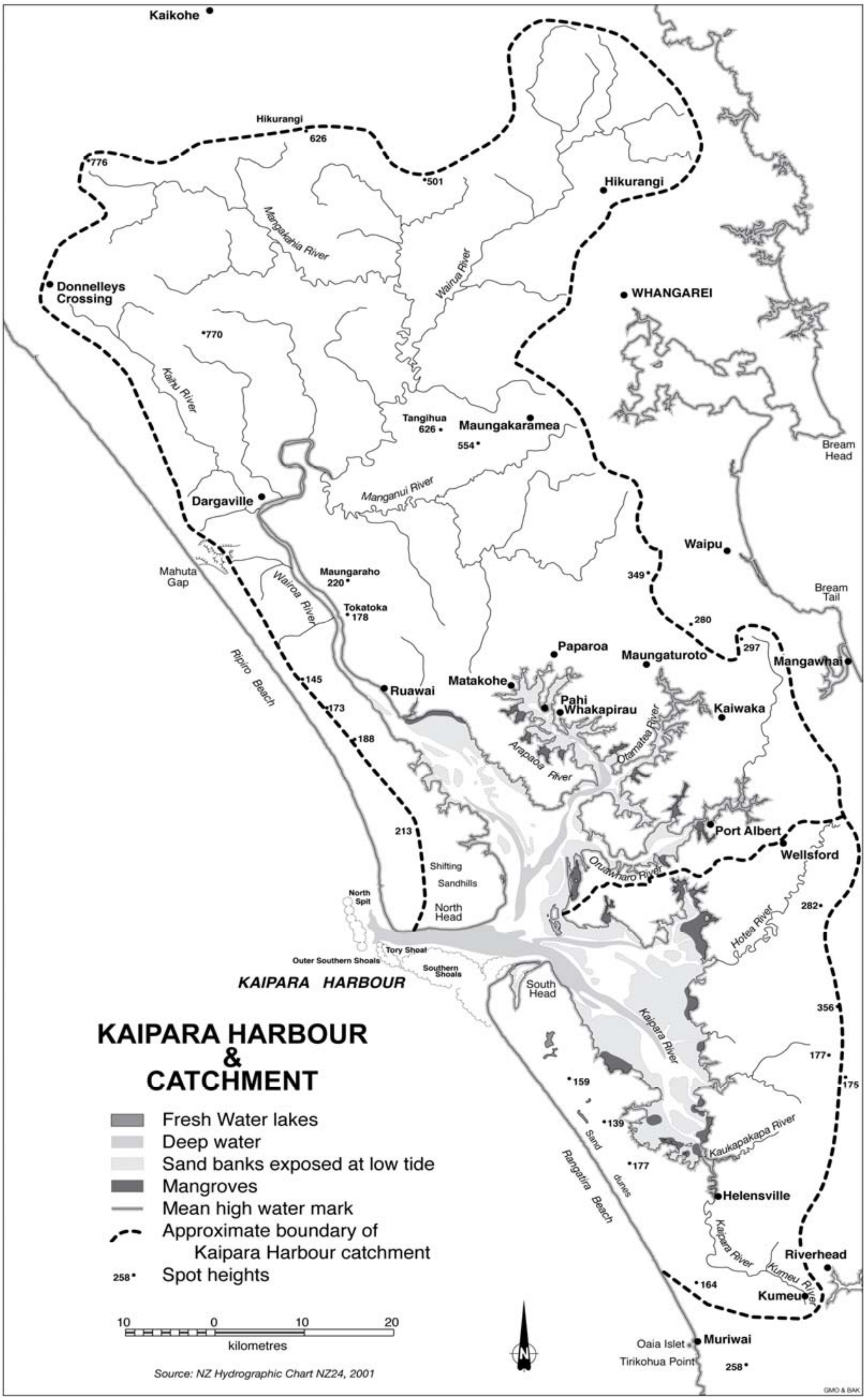
2.3 Study Area

The Kaipara Harbour is a drowned-valley and barrier enclosed type estuary located on the West Coast of the North Island, North of Auckland City (Fig. 1). The Harbour is the largest estuary in New Zealand and one of the largest in the Southern hemisphere (Brockbank, 1983; Bryne, 1986; Ryburn, 1999; Benson et al. 2003), with a high tide surface area of 950 km^2 and some 612 km of shoreline. The harbour inlet measures 7 km across and at one point the main channel is over 50 m deep (Hicks & Hume, 1996; Kirschberg, 2007). The 4,170 km^2 land area of the Kaipara Harbour catchment drains almost half of the Northland Peninsula (Fig. 1). Catchment geology is composed of a basement of Miocene interbedded sandstones and conglomerates, which are overlaid by quaternary surface deposits (Biddy & Webster-Brown, 2005).

The Northern Kaipara Harbour is dominanted by discharge from the 3,900 km^2 Wairoa catchment. Land use is predominatly pastoral farming on the low-lying alluvial flats that border the Wairoa Estuary (Hume & Male, 1985). The complex geology, deep soil profiles, high-intensity rainfall and agricultural land use practices are all factors that contribute to frequent and sometimes severe soil erosion, particularly in the Northern Kaipara (Northland Catchment Commission, 1980).

The largely rural catchments of the Southern Kaipara Harbour cover an area of 270 km^2 or only 7% of the Kaipara's total catchment area. Land use includes a mixture of agriculture, horticulture, forestry and small farm blocks (Biddy & Webster-Brown, 2005).

Figure 1.
Location of the Kaipara Harbour and catchment, Northland Peninsula.



2.4 Historical Changes

The value of the Kaipara Harbour resources was first recognised by Maori when they inhabited the Kauri Coast or Kaipara. The area was named Kaipara after a hangi Taramainuku (a grandson of the *Arawa* captain) hosted at Pouto in the 15th century, at which the para fern (*Marattia salicina*) was served (Bryne, 2002). Hence the name Kai - food, Para - fern root, which gives some insight into the nature of the catchment that was present before European settlement. Captain James Cook sailed past the Kaipara entrance in November 1769 and noted the large sand hills of the Kaipara beach, which he named "The Desert Coast" (Ferrar, 1934). However, the first European to see Kaipara Harbour from the land was Samual Marsden when he visited Kaipara in 1820 accompanied by timber surveyor Mr Ewels (Bryne, 1986; Ryburn, 1999). One of the purposes of their visit was to determine whether the entrance to the Harbour was navigable (Bryne, 1986; Ryburn, 1999).

Beever (1981) reconstructed Pre-European vegetation cover of the lower Northland area and southern Kaipara catchment. This work was largely based on early land surveys and the accounts of the land surveyors themselves. Pre-European land cover of the Southern Kaipara was originally dominated by dense kauri forest, with mangrove swamps fringing the harbour shore (Fig. 2).

Kauri gum extraction began as early as 1829 and the Kauri timber trade commenced in 1850 at Mangawhare, when Adkins and Marriner obtained spars for the British admiralty (Ryburn, 1999). Kauri timber was harvested for pit-sawn timber and spars for the British navy and several sawmills were established by 1865 (Ryburn, 1999). The harbour was first surveyed in 1852 by the H.M.S *Pandora* under Commander B. Drury, and was proclaimed a port of entry in 1854. As Kaipara developed and timber mills flourished, timber (both pit-sawn and logs) and kauri gum was transported by ship and intensive catchment deforestation occurred (Ferrar, 1934; Bryne, 1986; Ryburn, 1999).

Noticeable changes have occurred to the coastline of the Kaipara Harbour since the early 1900s (Figs. 3 & 4). At the northern most point of South Head the sand spit has changed its alignment considerably, recurving and moving eastward, and the large quantities of sand have accumulated between Poutu and the old signal station on North Head (Wright, 1969) (Fig. 3). There has also been substantial reclamation of mangrove areas on the tidal flats between Kaukapakapa and Tauhoa (Fig. 4) (Chapman, 1976; Beever, 1981).

Figure 2.

Historic map showing Pre-European catchment landcover of the southern Kaipara Harbour as reconstructed by Beever (1981).

Figure 3.

Geology and bathymetry of the Northern Kaipara Harbour based on a c. 1923 hydrographic chart. Also mapped is the approximate location of the present-day shoreline digitised from aerial photographs and the RNZN 1990 Kaipara Harbour Chart. The pre-1923 chart adapted from Ferrar (1934) has been georeferenced using ARC GIS to an existing hydrographic chart with a known coordinate system

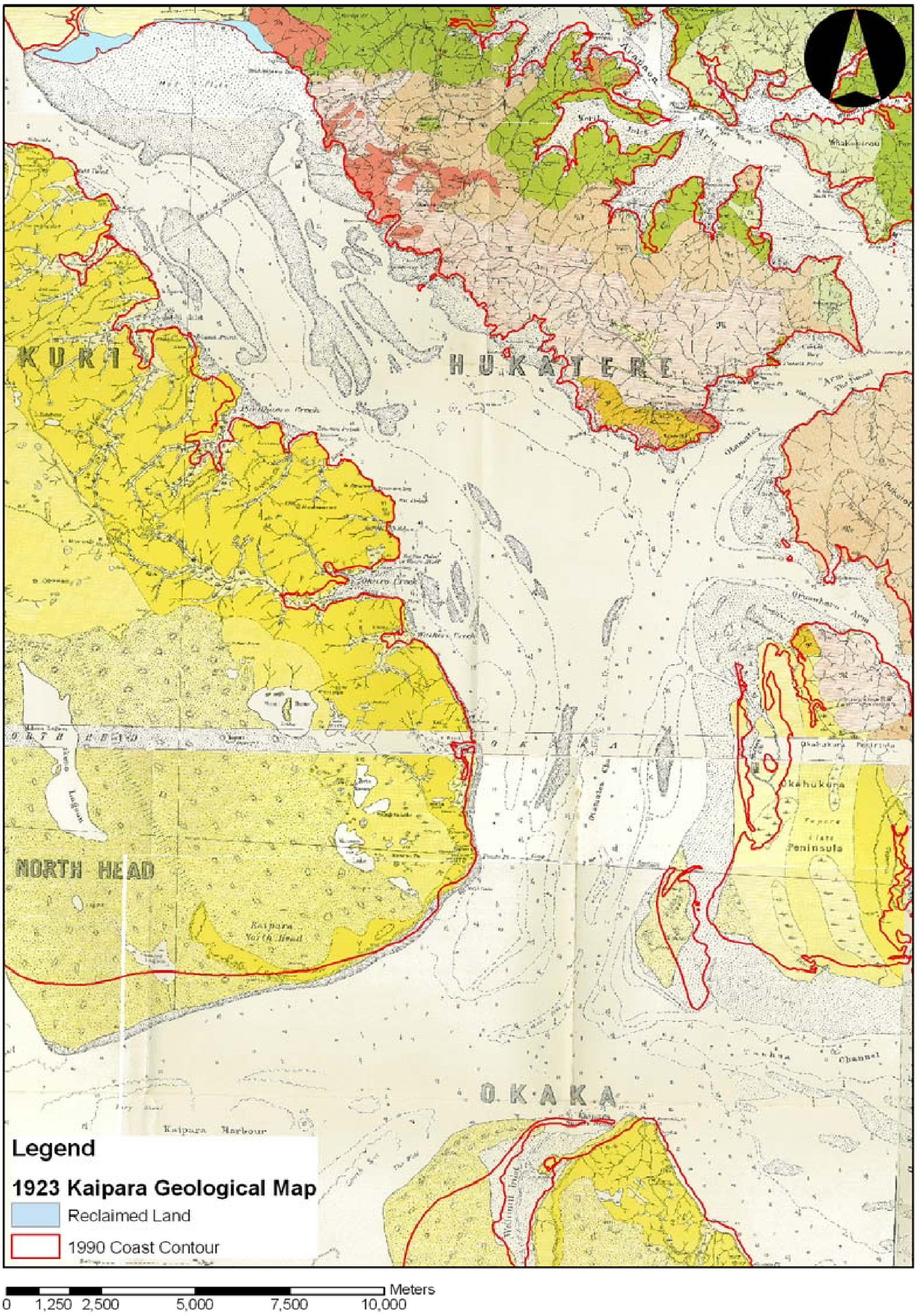
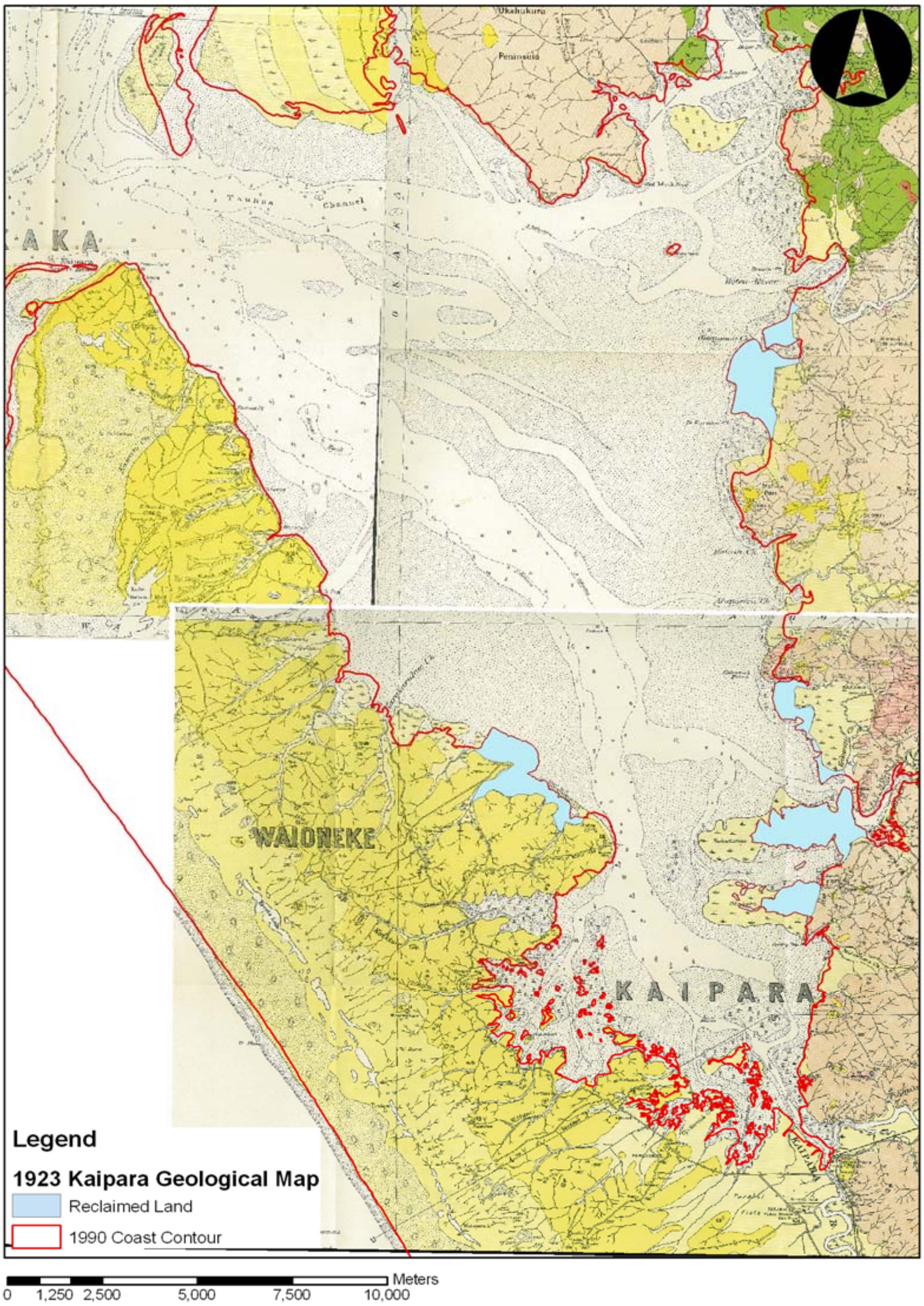


Figure 4.
Geology and bathymetry of the Southern Kaipara Harbour based on a c. 1923 hydrographic chart. Also mapped is the approximate location of the present-day shoreline digitised from aerial photographs and the RNZN 1990 Kaipara Harbour Chart. The pre-1923 chart adapted from Ferrar (1934) has been georeferenced using ARC GIS to an existing hydrographic chart with a known coordinate system.



3 Literature review

3.1 Harbour sedimentation

One of the primary objectives of this study is to determine whether there is any information relating to sediment accumulation rates (SAR) in the Kaipara Harbour. A comprehensive search and review of the literature contained on NIWA databases, library databases/catalogues and the articles outlined in the Kaipara Harbour information search undertaken by O'Shaughnessy (2007), shows that there is a lack of quantitative information on sedimentation in the harbour.

Although not specifically related to SAR measurements, the work undertaken by Hume (2000) and Hume et al. (2001, 2001a, 2001b, 2002, 2002a 2002b and 2003) is of interest. These studies investigated inlet dynamics of the Kaipara harbour and attempted to quantify the sand transport in the vicinity of the inlet and tidal deltas. Sediment cores were collected from North Kaipara Head, Tapora Island and South Kaipara Head. Eight cores were collected in total, with the main purpose to establish the history of natural shoreline change. Radiocarbon dating of the cores was undertaken and the historical evolution of the inlet and shoreline established. Four of the eight cores recovered, comprised material suitable for radiocarbon dating. Core Tau-1 collected from the southern reaches of the Tauhara Estuary yielded a carbon date from a peat sample collected from 1.35 m depth of 12,554±70 BP and a single cockle shell found buried at 1.32 m yielded a date of 3,956±114 BP. Core Tau-2 collected from the middle reaches of the Tauhara Estaury yielded a radiocarbon date for a single pipi shell of 4,223 ± 72 BP from a depth of 0.9 m. Core Tau-3 collected from the beach off Tauhara Spit, returned a radiocarbon date from a peat layer found 1.23 m down of 11,145 ± 150 BP. Core Wai-1 was collected from the upper (southern) reach of the inlet within the mangrove forests yielded a radiocarbon age from an articulated cockle buried at 1.96 m of 596 ± 87 BP. Results show that there has been rapid growth of Tauhara Spit. The spit had grown sufficiently to enclose Tauhara Estuary by 3,800 years BP (Hume et al. 2003). Formation of Waionui inlet as interpreted from core Wai-1 suggests the evolution of the Papakanui Spit that encloses the inlet began forming sometime between 1640 and 1860 AD. The evidence suggest rapid infilling and movement of sand has occurred and Waionui inlet has evolved rapidly to its present state. Although providing insights about the holocene evolution of the harbour, these studies do not provide information on the effects of human activities on catchment sediment inputs and harbour sedimentation over the last several hundered years.

Evidence of historic changes at the harbour inlet has been analysed by Parnell (1995), which indicates that there has been active sedimentation and erosion occurring in the inlet for many decades, related to changes in the alignment of sand banks and sub-tidal shoals (Parnell, 1995). Hume et al. (2003a) documented the movement of one submarine sand bank, was charted by the Royal New Zealand Navy in 1993. When depth soundings were undertaken in 2001, the sand bank was found to have moved 300 m.

The Kaipara Harbour has largely infilled with marine and catchment-derived sediment, and today about 40% of the high-tide surface area is occupied by intertidal flats (Hume et al. 2003a). The harbour has also become increasingly ebb-dominated as it has infilled (Hume et al. 2003). Consequently the main source of sediment accumulating in the harbour is derived from the land rather than the marine sands transported through the inlet.

Although there are no quantitative measurements of SAR for the northern and southern Kaipara Harbour, historical records suggest that there has been a substantial increase in SAR since the early 1900s following catchment deforestation. Hume et al. (2003) note that thick muds composed of eroded soils had accumulated in the tidal creeks. Further evidence supporting increased sedimentation is the colonisation of large tidal flat areas in the upper harbour by mangroves. By the 1920s intertidal surface elevations in the mangrove forests were at the spring high tide level (Ferrar, 1934). These observations indicate that the fringes of the harbour had substantially infilled by the early decades of the 20th Century following large-scale catchment deforestation.

Brockbank (1983) constructed a simple conceptual model of the harbour to determine sedimentation on a broad scale (Fig. 5). The estuary was divided into four areas: the inlet, North Harbour, South Harbour and the Eastern-Harbour tidal creeks. This includes the Eastern Otamatea and Oruawharo harbour arms (flooded valley complex). Assessments were made on whether these areas were actively accreting or eroding. Findings show that in the lower reaches of the harbour (around the inlet), fine quartzose sands enter the system from erosion of the inner shores of both the South and North Kaipara Barriers, and by transport from the ocean coast through the harbour mouth. In the high energy upper reaches of both the Northern and Southern Kaipara Harbour shoreline erosion increases during storm events, and contributes to harbour infilling. Accumulation of fine sediments occurs in the flooded valley complex in the north-east of the harbour, and around the low energy mangrove environments of the upper Northern and upper Southern Harbour. The Wairoa River is a major contributor of fine sediment input in the northern extent of the harbour. No actual measurements of SAR were made and conclusions regarding sedimentaion are qualitative.

The review of relevant literature indicates that there have been no quantitative studies of recent sedimentation (i.e., last 150 years) in the Kaipara Harbour as have been conducted in Aucklands east-coast estuaries (Swales, 1997, 2002a, 2002b).

3.2 Sediment composition

The Kaipara inlet has been the focus of several studies related to sand-extraction consents and monitoring (Grace 1995, 1996; Hume 2000; Hume et al. 2001, 2001a, 2001b, 2002a, 2002b 2003 and 2003a). Sampling of sediment undertaken for the Kaipara Sand Study shows that the inlet sands are mainly comprised of a fine sand component (Hume 2000; Hume et al. 2001, 2001a, 2001b, 2002a, 2002b, 2003 and 2003a). These results are consistent with studies undertaken by Grace (1995, 1996).

The range of sand measured in the inlet is 0.125 – 0.25 mm. However, some areas of 0.25 – 0.5 mm medium sand do exist.

The most comprehensive sampling of bed sediments has been conducted in the Southern Kaipara Harbour by Hewitt & Funnell (2005) as part of a baseline benthic-ecology study. Samples were collected at over 200 locations (113 intertidal sites and 117 subtidal sites) for the purpose of describing and categorising ecological communities (Fig. 6). Surficial sediments were collected and wet sieved through 2000 μm, 500 μm, 250 μm and 62.5 μm mesh sieves. Sediments were classified into one of several sediment types: percentage weight of gravel/shell hash (> 2000 μm), coarse sand (500 – 2000 μm), medium sand (250 – 500 μm), fine sand (62.5 – 500 μm) and mud (< 62.5 μm). Particle size distributions show that much of the intertidal area between Helensville and just to the south of sandy beach is predominantly muddy sediments. Seaward of this point, mud is still present near the mangrove fringes and small drainage channels, but much of the intertidal flat sediment are sand. In the more exposed areas of the southern harbour, firm packed rippled sand is common and in a few locations rocky outcrops occur. Although the Hewitt & Funnell (2005) study does not provide detailed information on sediment particle-size distributions, it does enable large-scale patterns in sediment type to be identified. A summary of the data are presented in Appendix One. Although this was a comprehensive sampling effort the results remain semi-quantitative, and no conclusions can be made on whether there has been a change in the quality and quantity of sediments in the Southern Kaipara Harbour. Particle sizing methods would prove a more quantitative assessment of surface sediment characteristics.

Brockbank (1983) surveyed 11 transects in the habour where surficial sediments were collected and grain size distributions calculated (Fig. 5). A summary of grain-size distribution data are presented in Appendix Two. The coarsest grain-sizes are found near mean high water (MHW) and on the east coast of the North Harbour. The finest grain-sizes are found on intertidal flats in the Eastern Otamatea and Oruawharo harbour arms (flooded valley complex), the Oyster Point area, and the north coast of the Pouto Peninsula. It can also be presumed that fine grain-sizes can be found on the intertidal flats of the northern North Harbour. Mid-range grain-sizes dominate the harbour mouth and Tapora region, and also extend into the Southern Harbour.

Figure 5.
Bathymetric map of Kaipara Harbour illustrating the sampling effort and location of work undertaken by Brockbank, 1983).

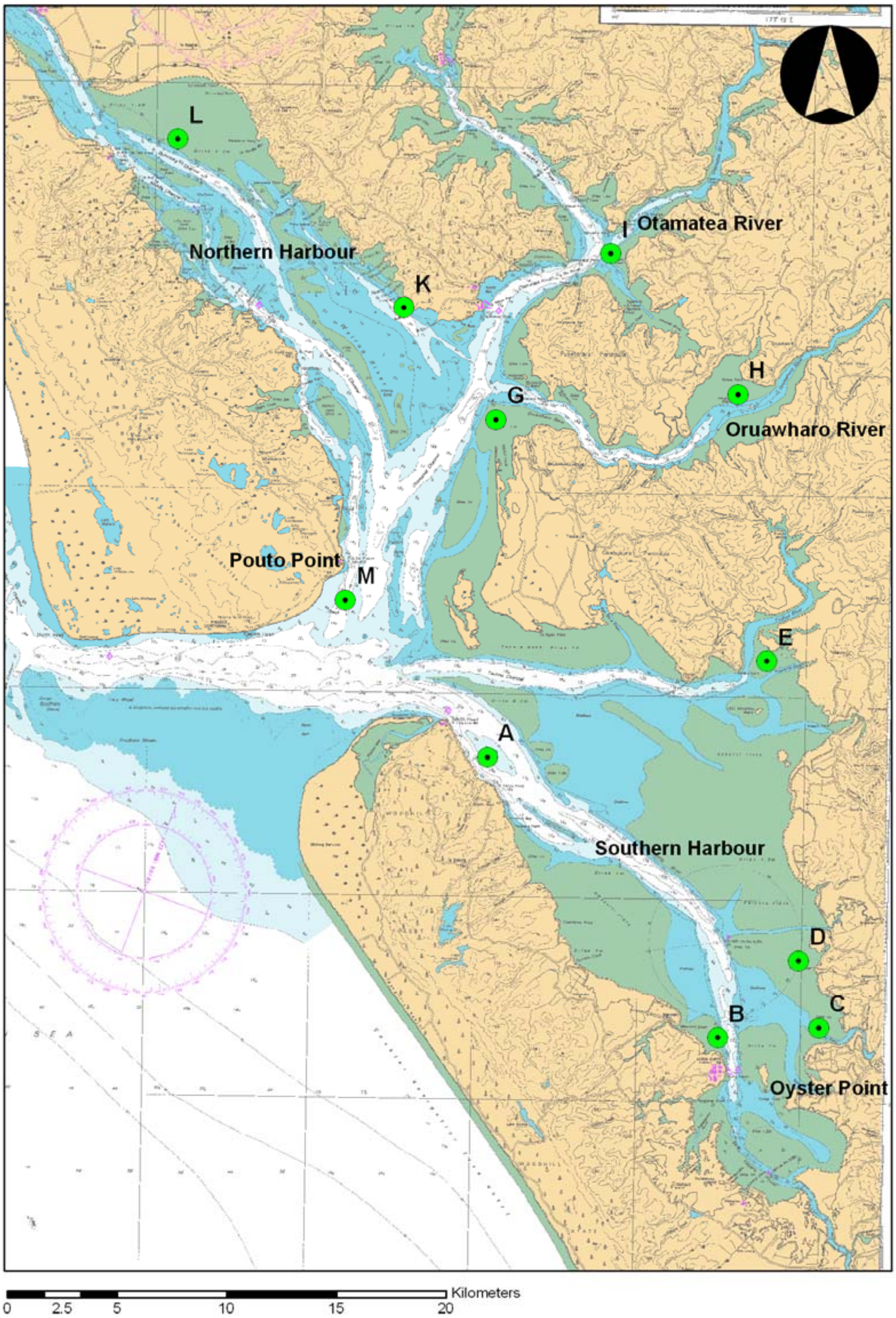
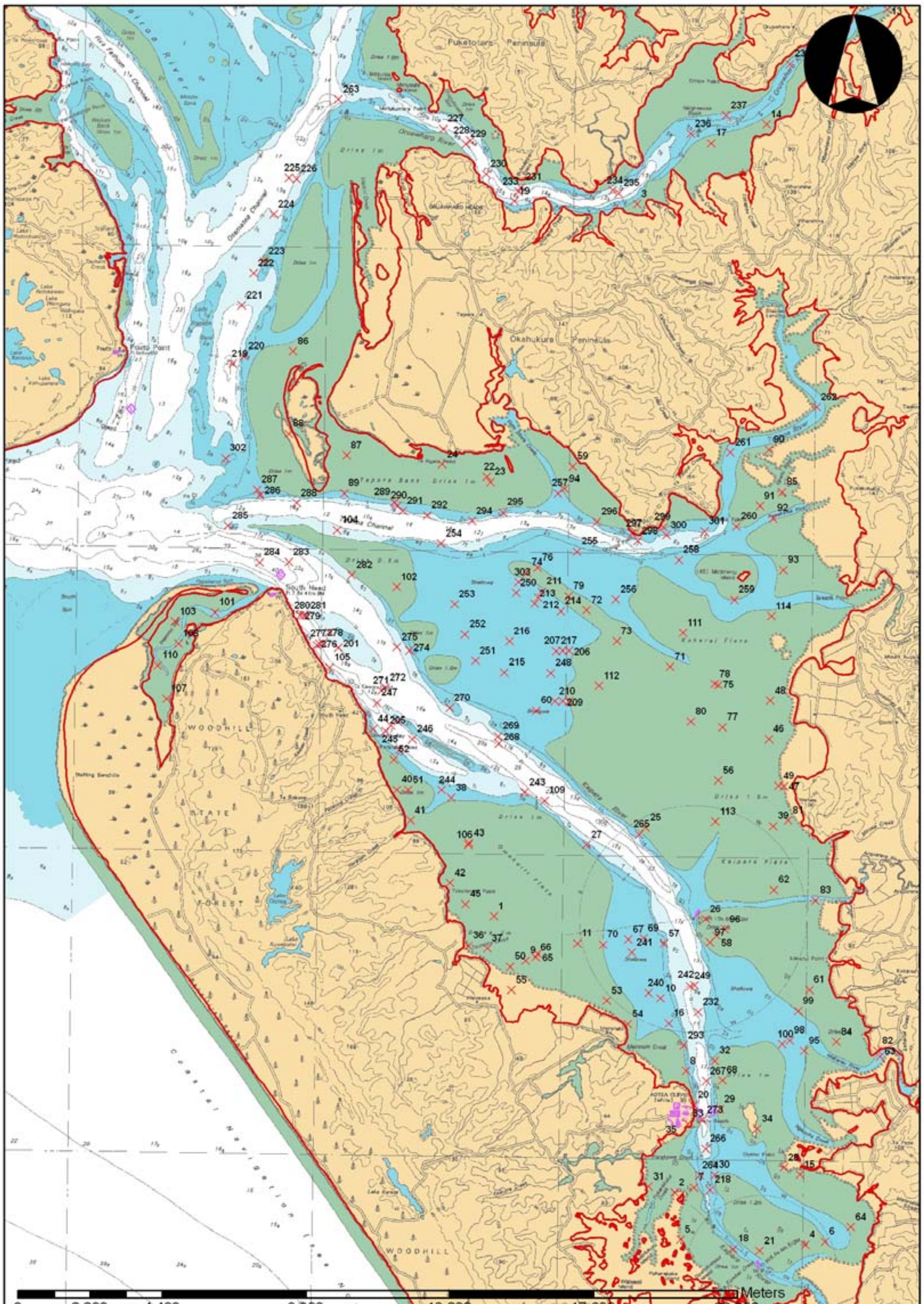


Figure 6.

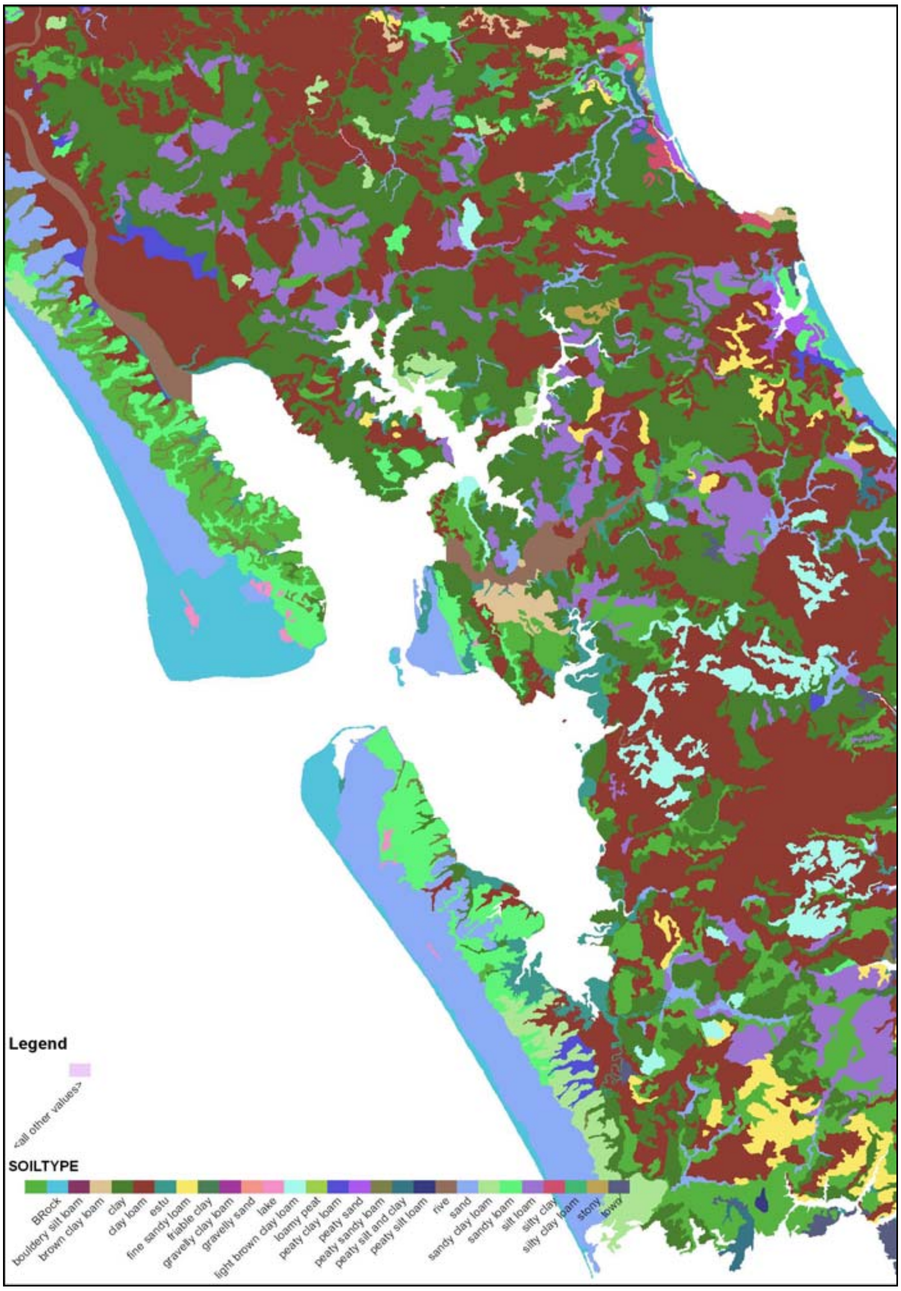
Map illustrating the sampling effort undertaken by Hewitt & Funnell (2005). Red crosses show the location of the sediment samples collected. Note: site numbers for data presented in Appendix One.



3.3 Sediment contaminants

The Kaipara Harbour is predominantly a rural catchment with some contaminant inputs from urban areas. Urban development is increasing around the Harbour, for example, at South Head, Pahi and along Oneriri Road on the Puketotara Peninsula overlooking the Otamatea River. (IKHMG, 2008). Background metal concentrations in sediments in the Harbour will tend to reflect the local geology and soils types of these rural areas. Clays, loams, sand and a combination of these surround the Harbour (Fig. 7).

Figure 7.
Soil types in the Kaipara catchment. Adapted from Wilde, Willoughby & Hewitt (2000).



Natural geology contributes a significant amount of the background concentration of heavy metals that can be detected in harbour sediments. Metals associated with the soils found surrounding the Kaipara Harbour include aluminium, iron, manganese and magnesium (pers. Comm. J. Reed 2008 20 November). If metal concentrations, or other chemicals that are not present in natural soils e.g., DDT, are higher than local background concentrations, the implication is that the source is from anthropogenic activities such as the spraying of rural soils by horticultural/agricultural activities that enhance concentrations of Cu, Zn, Cd, Hg for example, or enhanced Cu and Zn concentrations from nearby urban activities. The overall concern for the environment comes from the potential impacts that anthropogenic activities are having on the local environment – i.e., increasing heavy metal concentrations over and above those typical detected from the natural geology.

Sources of contaminants associated with practices conducted on rural land in the Kaipara Harbour catchment include: nutrients (nitrate, ammonia, nitrogen and phosphorus) from animal excretion (often from diffuse sources), sewage runoff from farming practices (e.g., sewage effluent runoff from animal sheds), polycyclic aromatic hydrocarbonsm (PAHs) from wood burning and pesticides and insecticide use from horticulture (pers. Comm. J. Reed 2008 20 November). Contaminants widely used as ingredients in insecticides in NZ include chlorophenols, lindane, dichlorodiphenyl-trichloroethane (DDT, and related analogues, DDD and DDE), dieldrin and aldrin. In addition, the pesticides (Bti and methoprene) were used to eradicate the southern saltmarsh mosquito (MOH, 2008). These contaminants are likely to be detected in harbour sediments deposited close to known or likely sources.

With respect to anthropogenic inputs of heavy metal contaminants, copper and zinc have been widely used in fungicides and pesticides since the early 1900's and are still in use today; cadmium has been used in fertilisers in some of NZ's rural areas; and lead arsenate was widely used between 1900 and the early 1970's.

Urban areas include large towns such as Helensville, Dargaville and Wellsford but also Kumeu–Huapai and Waimauku townships and smaller townships, such as Tinopai, Whakapirau, Baylys Beach, and Pahi. Population in the region is predicted to grow by 3 to 5% annually (IKHMG, 2008).

Sources of contaminants, including chemicals, heavy metals, pathogens and nutrients, from urban areas include: road runoff (heavy metals and petroleum hydrocarbons); roof runoff (heavy metals, i.e., copper and zinc), wastewater leakage (all the smaller townships are on septic sewerage systems; IKHMG, 2008) from septic tanks and discharges from the wastewater treatment plants at Helensville, Maungaturoto, Kaiwaka, Dargaville, and Te Kopuru (nutrients, *E.Coli*, *Enterococci* and faecal coliforms) There are landfill sites surrounding the Kaipara Harbour and samples are regularly taken to monitor the sediment on site and leachates (NRC, 2002). Typical contaminants in landfill leachates include concentrations of heavy metals.

4 Conclusions

The literature review shows that there have been relatively few comprehensive studies of sediments and sedimentation in the Kaipara Harbour. Substantial changes in catchment landcover have occurred following European settlement and large-scale deforestation. The resulting landcover changes will have resulted in increased rates of soil erosion and consequently sedimentation in the harbour, as observed in other North-Island estuaries.

Present-day sediment inputs, sediment compositions and sedimentation rates in the Kaipara Harbour are not well quantified. The estuarine system is almost certainly infilling, although monitoring has been very limited. The ultimate sources and/or relative contribution of sediments are also unknown. The Kaipara Harbour has substantially infilled with marine and catchment-derived sediments, and as a consequence some 40% of its high-tide area is occupied by intertidal flats. The catchment derived sediments likely to be the main source of sediments deposited on the extensive tidal flats today.

Radioisotope dating using a combination lead-210 (^{210}Pb) and caesium-137 (^{137}Cs) have been successfully applied to accurately determine SAR in a number of North Island estuaries. These techniques also enable areas of preferentially fine-sediment accumulation to be identified. Such studies can now also be completed by compound-specific isotope techniques to identify the sources of catchment sediments deposited in estuaries.

Targeted sampling to determine concentrations of both background and anthropogenic concentrations of metals is recommended. Analysis of specific contaminants such as nutrients, bacteriological markers, PAHs and organochlorines in sediments is recommended where known sources of these contaminants occur, for example, close to discharge points, or at depositional areas in the inter-tidal zone. Such targeted sampling will assist ARC and NRC to assess contaminant risk and locate any sources of contaminants in the Harbour. Particle size and total organic carbon content of sediments are useful measures at all sites as these can aid the interpretation of contaminant distributions.

In summary, the literature review has identified that:

- There is no quantitative information on sediment accumulation rates in the Kaipara Harbour.
- There is limited information on bed-sediment composition.
- Hewitt & Funnell. (2005) undertook a comprehensive sampling of bed sediments in the southern Kaipara. However, sediments were classified into size classes only, so that there is no detailed information on sediment particle size distributions.
- There are no data on contaminants in harbour-bed sediments, in particular anthropogenic concentrations of metals.

A lack of baseline information around sedimentation and contaminants for the Kaipara Harbour was identified during the literature review.

Recommendations are as follows:

- Conduct core sampling at strategic locations as necessary to determine SAR within the harbour.
- Undertake a sampling programme to gather detailed particle size distributions for the entire harbour as bed sediment composition information is limited.
- Conduct targeted sampling to determine concentrations of background and anthropogenic metals.

5 Acknowledgements

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7 Appendix 1

Table: Appendix one, sample locations and particle size distributions as analysed by Hewitt & Funnell (2003), collected from the Southern Kaipara Harbour.

Sample ID	x	y	depth	vcoarse	pmed	pfine	pmud
1	259128.18	5955298.9	0	0.9	1.18	92.75	5.16
2	265009.21	5947087.54	0.22	0.19	0.61	12	87.19
3	262544.54	5977278.08	0	17.83	5.83	11.83	64.51
4	269070.27	5945675.29	0.71	1.33	0.67	93.87	4.12
5	265261.24	5945663.07	0	2.38	5.9	17.49	74.24
6	269675.92	5945791.49	0	0.06	0.2	71.5	28.24
7	265597.93	5947269.07	0.3	0.33	0.33	39.05	60.28
8	265196.47	5950822.61	-0.89	0.02	1.12	73.6	25.27
9	260157.82	5953988.39	0	0.2	0.36	89.6	9.85
10	264312.53	5953006	-1.52	0.02	0.07	98.13	1.78
11	261706.06	5954585.5	0	0.54	2.44	70.15	26.87
12	271206.51	5984923.25	0	0	0	3.41	96.59
13	269910.38	5983573.33	0	0	0.39	6.04	93.57
14	266382.99	5979891.7	0	36.5	8.63	40.59	14.27
15	268807.2	5947800.19	0	0.82	0.16	96.32	2.7
16	264601.71	5952261.03	-0.13	0.25	1.01	80.94	17.8
17	264719.65	5979247.19	0	76.84	4.83	8.16	10.17
18	266883.01	5945449.63	-1.2	0.01	0.57	70.38	29.03
19	258790.31	5977207.84	-9.23	0.36	0.36	63.29	35.99
20	265471.81	5949791.87	-0.36	1.34	30.71	65.59	2.36
21	267680.69	5945415.72	0.12	0	0.04	34.08	65.88
22	258313.9	5968732.89	0	0.26	16.19	83.19	0.36
23	258427.26	5968582.48	0	0.13	10.7	87.95	1.22
24	256939.62	5969055.31	0	0.11	6.18	91.15	2.56
25	263631.93	5958219.73	0	0	0	99.29	0.71
26	265588.83	5955497.1	0.19	0	0.18	99.4	0.42
27	261855.38	5957615.62	-3.85	0.04	0.23	99.58	0.14
28	268305.57	5948005.43	0.16	0.01	0.06	97.39	2.54
29	266280.43	5949700.63	0.34	4.8	0.49	54.01	40.7
30	266204.46	5947685.35	-0.49	0.38	0.53	97.78	1.32
31	264201.76	5947241.97	0.25	5.34	15.27	63.32	16.07
32	266064.67	5951179.4	0	0	0.03	97	2.97
33	265320.12	5949212.53	0	7	23.05	68.73	1.22
34	267445.34	5949151.46	0.46	0	0.1	88.74	11.16
35	264520.16	5948694.29	0	4.15	2.41	87.65	5.8
36	258388.7	5954361.7	0	0.42	11.08	28.65	59.84
37	258962.36	5954305.59	0	0.21	0.59	75.87	23.33
38	257659.87	5958873.83	-0.64	0.7	14.53	83.76	1
39	267535.25	5958434.66	0	0.19	0.03	96.16	3.63
40	255993.17	5959041.62	0	0.07	12.72	81.36	5.84
41	256439.02	5958125.06	0	6.01	57.94	25.6	10.46
42	257736.3	5956258.99	0	0.57	20.08	77.06	2.29

Sample ID	x	y	depth	vcoarse	pmed	pfine	pmud
43	258257.14	5957506.26	0	0	0.15	99.77	0.08
44	255173.01	5960871.05	-5.78	3.47	63.01	32.71	0.81
45	258232	5955634.37	0	0.07	5.47	89.58	4.88
46	267279	5961088.25	0	0.57	0.17	92.8	6.46
47	267806.81	5959671.18	0	0.22	0.88	98.1	0.81
48	267277.65	5962269.67	0	0.01	0.28	92.62	7.09
49	267645.4	5959671.27	0	0.07	0.07	97.65	2.22
50	259686.53	5953781.69	0	0.24	0.73	32.01	67.02
51	256341.06	5959053.23	0	0.09	5.54	74.83	19.54
52	255859.38	5959966.88	-1.54	0	0.01	96.83	3.16
53	262682.71	5952861.61	0	17.21	5.31	77.3	0.18
54	263350.92	5952185.98	0	5.04	3.4	23.48	68.08
55	259755.91	5953061.82	0	0.02	4.11	94.99	0.88
56	265795.86	5959755.62	0	0	0.57	83.08	16.36
57	282267.96	5955162.23	0	0.09	0.26	89.17	10.48
58	265951.99	5954996.18	0	0.38	0.12	94.28	5.22
59	260923.17	5969171.83	0	0.02	6.82	93.05	0.11
60	260149.86	5961657.08	-0.34	0	0	99.88	0.12
61	268851.88	5953471.86	0.06	11.64	0.27	84.15	3.95
62	267636.18	5956486.41	0	0.18	0.28	97.34	2.2
63	271097.66	5951516.54	0	0.3	0.25	17.78	81.67
64	270442.07	5946267.27	0	0.02	0.04	39.29	60.66
65	260502.97	5954210.1	0	4.22	0.84	88	6.94
66	260460.19	5954104.52	0	7.26	0.86	70.21	21.68
67	263260.32	5954774.94	-1.02	0.4	0.62	96.01	2.98
68	266313.69	5950586.54	0.56	0.36	0.99	82.93	15.72
69	263720.48	5954826.44	-1.53	4.01	0.52	90.14	5.32
70	262488.69	5954578.24	-0.07	1.19	0.33	87.78	10.7
71	264166.3	5963166.53	0	0.02	0.37	97.66	1.96
72	261542.32	5964787.91	0	1.17	0.45	23.6	74.79
73	262500.43	5963881.53	0	0	0.33	99.62	0.05
74	259663.75	5965870.31	0	6.06	0.46	91.11	2.36
75	265669.08	5962675.88	0	0.57	0.44	88.62	10.37
76	259995.88	5966029.45	0	0.15	0.48	99.19	0.18
77	283769.39	5961857.95	0	0.15	0.44	98.7	0.71
78	265557.43	5962700.95	0	0.38	0.14	85.89	13.58
79	260971.66	5965195.89	0	0	0.01	98.78	1.21
80	264882.42	5961520.77	0	0.08	0.46	92.43	7.03
81	267977.43	5958628.67	0	0.26	0.21	98.43	1.11
82	271024.17	5951699.57	0	2	1.04	45.74	51.22
83	268921.7	5956214.51	0	4.26	0.45	92.72	2.57
84	269753.81	5951911.84	0	0.16	0.34	99.41	0.09
85	267362.91	5968670	0	0	0.08	98.73	1.18
86	252235.04	5972318.21	0.61	0.32	20.52	78.27	0.9
87	254000.22	5969201.79	0.33	0.19	9.84	84.94	5.03
88	252205.59	5969790.92	0.11	8.23	89.13	0.12	2.52
89	253980.74	5968042.53	-1	0	7.11	92.76	0.14
90	266896.17	5969945.48	0	0.25	0.65	12.29	86.8
91	266694.63	5968209.74	0	0.07	0.32	91.95	7.66

Sample ID	x	y	depth	vcoarse	pmed	pfine	pmud
92	267111.13	5967852.65	0	0.04	0.2	92.74	7.02
93	267504.86	5966284.62	0	0	0.04	99.36	0.6
94	260700.08	5968473.52	0	0.52	0.28	98.99	0.22
95	268785.74	5951597.18	0	0.02	0	99.81	0.17
96	266197.03	5955213.82	0	0	0.05	99.01	0.94
97	265760.39	5954791.1	0	0.32	0.26	99.26	0.17
98	268320.82	5951895.59	0	0.02	0.15	99.44	0.39
99	268538.07	5952811.96	0	6.21	0.21	79.01	14.57
100	268091.34	5951767.26	0	0.35	0.15	94.25	5.24
101	250188.65	5964232.04	0	0.04	0.2	92.74	7.02
102	255706.96	5965250.46	-0.26	0	0.01	98.78	1.21
103	248991.59	5963890.09	0	0	7.11	92.76	0.14
104	253822.96	5966910.91	-9.01	0.07	12.72	81.36	5.84
105	253768.32	5962685.67	-16.28	8.23	89.13	0.12	2.52
106	258249.56	5957457.89	0	0.26	16.19	83.19	0.36
107	248830.2	5961519.88	0	0.24	0.73	32.01	67.02
108	249120.12	5963223.78	0	0.26	16.19	83.19	0.36
109	260519.28	5958914.87	-20.46	0.32	20.52	78.27	0.9
110	248510.6	5962534.16	0	0.26	0.21	98.43	1.11
111	264511.21	5964225.25	0	1.17	0.45	23.6	74.79
112	262016.88	5962489.39	0	0.52	0.28	98.99	0.22
113	265758.27	5958497.98	0	0.15	0.48	99.19	0.18
114	267185.82	5964856.63	0	0	0.01	98.78	1.21
201	254013.42	5963320.1	-11.17	0.34	2.59	96.46	0.61
202	253708.93	5963772.29	-7.58	0.19	20.15	79.45	0.21
203	255935.38	5961136.95	-11.72	0.27	0.99	89.16	9.58
204	255712.2	5960993.68	-17.45	0.06	0.75	35.91	63.27
205	255553.83	5960831.87	-13.16	0.04	0.6	98.34	1.02
206	261071.35	5963538.56	0	0.39	0.33	99.07	0.21
207	260863.97	5963521.72	0	0.31	0.83	95.99	2.87
208	261124.83	5961983.56	0	2.05	0.59	94.67	2.69
209	260932.12	5961978.23	-0.03	0.2	0.33	98.28	1.2
210	260695	5961956.85	-0.11	0.1	0.34	98.36	1.19
211	260141.56	5965306.18	0	0.18	0.77	92.24	6.81
212	260052.49	5965120.49	0	4.03	1.73	91.35	2.89
213	259950.49	5964915.92	0	1.19	0.94	97.6	0.28
214	260755.93	5964723.57	0	0.29	0.65	97.9	1.16
215	259115.59	5962777.99	-0.13	0.09	0.69	97.96	1.26
216	259230.49	5963735.83	0	1.33	0.85	96.06	1.76
217	260672.93	5963498.11	0	0.29	0.23	98.95	0.53
218	266087.23	5947221.89	-3.15	6.08	3.85	82.46	7.6
219	250414.23	5971855.63	-21.66	2.09	1.42	96.17	0.32
220	250734.67	5972097.15	-8.31	5.83	14.09	79.82	0.26
221	250606.03	5973659.3	-9.9	0.74	23.99	74.68	0.59
222	250914.58	5974656.18	-8.82	0.08	32.22	67.16	0.53
223	251223.96	5975036.72	-4.76	0.1	2.75	97.15	0
224	251463.24	5976484.85	-10.5	0.05	4.38	94.8	0.77
225	251878.91	5977614.67	-11.59	25.76	32.38	41.45	0.4
226	252105.43	5977597.64	-8.45	0.02	0.54	98.98	0.45

Sample ID	x	y	depth	vcoarse	pmed	pfine	pmud
227	256517.8	5979328.28	-7.26	0.1	2.99	96.12	0.79
228	257366.03	5979006.67	-10.67	0.2	0.9	89.94	8.96
229	257232.39	5978894.48	-10.56	4.01	0.68	59.59	35.71
230	257889.43	5978002.63	-17.48	0.34	0.51	38.51	60.64
231	258971.7	5977643.92	-4.8	16.19	2.23	69.45	12.12
232	265489.86	5952641.54	-7.7	0.36	1.35	85.14	13.15
233	258899.76	5977505.52	-10.11	0.04	0.65	66.82	32.49
234	261786.38	5977667.59	-8.39	49.85	2.46	32.33	15.35
235	261971.92	5977591.62	-10	55.55	3.37	26.67	14.42
236	264083.4	5979503.45	-1.77	4.39	0.58	12.31	82.72
237	265142.78	5980112.89	-1.93	0.65	0.65	15.13	83.56
238	267027.98	5981771.09	0	0	1.7	4.11	94.19
239	268090.88	5982703.89	0	4.17	1.17	13.97	80.69
240	263950.58	5953161.72	-1.08	5.3	0.78	70.82	23.1
241	263390.08	5954374.3	-1.02	2.14	0.78	87.97	9.1
242	265345.13	5953464.31	-9.64	0.65	1.85	87.22	10.28
243	259893.64	5959130.86	-9.33	0.98	8.24	80.48	10.3
244	257350.75	5959093.2	-2.23	4.31	3.26	91.35	1.09
245	256000.28	5960264.08	-5.57	0.18	0.22	98.31	1.29
246	256398.05	5960608.47	-12.84	2.59	51.35	45.16	0.9
247	255261.32	5961673.86	-15.36	0.14	0.56	98.47	0.84
248	260536.3	5962822.13	-0.14	0.12	0.38	98.76	0.74
249	265208.58	5953427.83	-10	0.05	0.61	84.58	14.76
250	259366.1	5965224.48	0	2.37	1.33	91.2	5.11
251	258213.11	5963092.02	0	8.52	1.61	88.17	1.7
252	257861.26	5963886.89	0	0	0.65	98.2	1.15
253	257496.58	5964796.33	-0.96	1.35	1.72	94.99	1.94
254	257008.76	5966631.22	-7.14	0.02	1.13	98.12	0.73
255	261171.65	5966571	-4.4	0.24	0.99	96.04	2.72
256	262423.48	5965156.56	0	0	0.42	96.15	3.43
257	260505.37	5968328.55	0	0.28	0.69	98.38	0.65
258	264288.08	5966447.95	-3.09	0.02	1.09	98.56	0.33
259	266035.45	5965301.92	0	0	0.17	96.11	3.72
260	266001.62	5967547.33	0	0.55	2.84	85.82	10.79
261	265720.67	5969807.7	0	0.77	0.19	10.21	88.82
262	268293.54	5971311.55	0	1	1.53	22.15	75.33
263	253286.93	5980087.17	-10.2	0	1.74	97.89	0.37
264	265760.55	5947654.02	-2	1	1.25	51.38	46.37
265	263433.86	5958004.42	-0.73	2.54	1.8	92.65	3.01
266	265901.31	5948470.32	-5.28	0.63	0.16	14.87	84.34
267	265833.55	5950542.76	-10	2.64	2.92	78.11	16.34
268	259043.32	5960594.08	-18.24	2.23	0.97	96.21	0.59
269	259016.41	5960818.75	-7.99	0.05	0.53	99.15	0.27
270	257494.14	5961618.23	-5.16	1.35	4.87	93.49	0.28
271	255378.19	5962055.86	-15.36	0.11	0.33	99.45	0.11
272	255495.88	5962149.88	-15.02	1.67	9.79	88.47	0.07
273	265760.69	5949342.06	-10	0	0.49	28.4	71.12
274	256182.37	5963323.66	-4.03	4.84	4.61	90.2	0.35
275	255800.8	5963406.54	-10.36	0	7.13	92.77	0.1

Sample ID	x	y	depth	vcoarse	pmed	pfine	pmud
276	253347.2	5963357.55	-22.24	0.49	14.86	84.66	0
277	253424.12	5963413.05	-23.59	1.18	6.78	89.8	2.24
278	253526.89	5963432.83	-19.49	0.03	1.25	95.59	3.13
279	252802.13	5964240.39	-18.16	0.07	13.76	84.91	1.26
280	252913.02	5964248.56	-21.11	11.83	32.69	54.84	0.63
281	252984.33	5964254.67	-19.25	0.26	26.69	72.78	0.28
282	254316.8	5965546.99	-3.52	0.12	17.75	82	0.12
283	252379.35	5965868.92	-27.66	0.06	4.35	94.87	0.72
284	251490.92	5965822.51	-33.04	0.74	13.69	85.42	0.16
285	250472.48	5966897.43	-6.49	4.92	63.67	29.84	1.57
286	251416.99	5967869.52	-2.33	0.05	6.49	92.58	0.88
287	251315.21	5968042.61	0.25	1.26	44.94	53.58	0.23
288	252533.77	5967681.28	-13.63	0.92	7.28	88.81	3
289	255527.64	5967843.41	-1.41	0.8	1.47	96.88	0.84
290	255623.53	5967732.47	-4.44	0.14	17.06	82.25	0.55
291	255795.62	5967588.34	-7.91	4.31	16.18	77.77	1.74
292	256547.43	5967486.46	-6.31	0.16	0.65	99.13	0.06
293	265090.11	5951601.09	-2.06	0.42	2.55	86.94	10.09
294	257918.47	5967372.06	-9.34	0.13	4.62	95.16	0.09
295	258857.37	5967678.13	-3.46	11.43	1.39	86.22	0.96
296	261736.05	5967509.9	0	0.49	4.28	80.7	14.52
297	262821.97	5967198.85	-0.78	0.89	3.77	86.16	9.18
298	263014.82	5966968.35	-6.19	0.35	2.32	96.01	1.33
299	263777.26	5967434.12	0	0.19	0.33	84.23	15.25
300	263880.48	5967187.47	-5	0.58	3.57	94.3	1.55
301	265041.7	5967359.19	-6.04	20.73	3.92	67.26	8.09
302	250315.44	5968959.26	-2.15	3.26	49.78	46.61	0.35
303	259430.52	5965559.23	0	0.02	0.26	96.92	2.8

8 Appendix 2

Table: Appendix two, grain-size distributions analysed by Brockbend (1983) from Kaipara Harbour.

			Sediment Parameters		Grain-size
	Environment Sampled	Mode	Mean	Sorting	(mm)
A: South Heads					
	Beach MHW	2.00	1.98	0.33	0.796
	Beach Mid-tide	2.50	2.55	0.52	0.697
	Beach low water	2.50	2.41	0.44	0.737
	Cliff face	2.50	2.30	0.45	0.732
	Slumped cliff	2.50	2.48	0.46	0.727
	Backshore ironsand	3.00	2.75	0.28	0.824
	Backshore "coffee rock"	2.50	2.29	0.39	0.763
	Beach MHW	2.50	2.29	0.33	0.796
	Beach Mid-tide	2.50	2.26	0.45	0.732
	Beach low water	2.50	2.57	0.51	0.702
B: Shelly Beach					
	Beach low water	2.50	2.24	0.50	0.707
	Beach Mid-tide	2.50	2.00	0.45	0.732
	Beach MHW	2.00	1.73	0.58	0.669
	Beach MHW	2.00	1.85	0.46	0.727
	Shore platform	2.50	2.50	0.51	0.702
	Flats low water	2.50	2.15	0.31	0.807
	Flats low water	2.50	2.24	0.35	0.785
C: Makarau River					
	Mangrove mud	N.A.	N.A.	N.A.	N.A.
	Backshore clay soil	pan	4.13	0.53	0.693
D: South Harbour East Coast					
	Beach MHW	-1.00	0.34	1.44	0.369
	Beach MHW	2.00	1.42	0.97	0.511
	Shore platform	2.50	2.54	0.64	0.642
E: Stable's Landing					
	Beach MHW	2.00	0.19	1.61	0.328
	Mudflat	N.A.	N.A.	N.A.	N.A.
F: Tapora Flats					
	Face of foreshore	2.50	2.00	0.41	0.753
	Beach MHW	2.50	2.02	0.52	0.697
	Flats mid-tide	2.50	2.40	0.33	0.796
	Flats low water	2.50	2.40	0.41	0.753
	Flats mid-tide	2.50	2.36	0.34	0.790
	Flats mid-tide	2.50	2.32	0.33	0.796
	Beach MHW	2.50	2.35	0.36	0.779
G: Journey's End					
	Creek low water	3.00	3.22	80.00	0.107
	Flats mid-tide	2.50	2.44	0.35	0.785

			Sediment Parameters		Grain-size
	Environment Sampled	Mode	Mean	Sorting	(mm)
	Flats mid-tide	2.50	2.57	0.43	0.742
	Beach MHW	2.50	2.41	0.37	0.774
	Face of foredune	2.50	2.52	0.34	0.790
	Beach MHW	2.50	2.37	0.32	0.801
	Clay mud mid-tide	N.A.	N.A.	N.A.	N.A.
	Flats mid-tide	2.50	2.53	0.42	0.747
H: Oruawharo River					
	Beach MHW		Not sieved		
	Mudflat mid-tide	N.A.	N.A.	N.A.	N.A.
	Mudflat mid-tide	N.A.	N.A.	N.A.	N.A.
	Beach MHW	2.00	0.11	1.30	0.406
I: The funnel - Otamatea River					
	Beach backshore	0.50	0.17	0.95	0.518
	Beach MHW	1.50	1.23	0.68	0.624
	Beach Mid-tide	2.00	1.62	0.97	0.511
	Mudflat low water	3.50	2.82	0.86	0.551
	Beach MHW	1.00	0.81	0.92	0.529
	Mudflat low water	3.00	2.80	0.59	0.664
	Beach MHW	-1.00	-0.68	0.97	0.511
	Mudflat mid-tide	-1.00	1.05	2.15	0.225
	Beach MHW	2.00	0.26	1.29	0.409
J: Matakohe					
	Mudflat mid-tide				
		N.A.	N.A.	N.A.	N.A.
K: North Harbour East Coast					
	Cliff face	3.00	2.32	0.74	0.599
	Beach backshore	2.00	1.66	0.26	0.835
	Beach MHW	1.50	0.62	1.02	0.493
	Beach MHW	1.50	1.06	0.63	0.646
	Beach Mid-tide	0.50	0.68	1.10	0.467
	Beach MHW	1.50	0.91	1.43	0.371
	Beach Mid-tide	2.00	1.79	0.87	0.547
	Beach MHW	1.00	1.43	1.47	0.361
L: North Pouto Coast					
	Mudflat mid-tide	N.A.	N.A.	N.A.	N.A.
	Beach Mid-tide	2.00	1.65	0.54	0.688
	Beach Mid-tide	2.50	3.44	1.00	0.500
	Beach MHW	2.50	1.75	0.60	0.660
	Cliff face	2.50	2.31	0.35	0.785
	Beach MHW	1.50	1.51	0.65	0.637
	Flats mid-tide	2.5	3.25	0.92	0.529
M: Pouto Beach					
	Beach Mid-tide	2.50	2.42	0.41	0.753
	Face of foredune	2.50	2.44	0.27	0.829

			Sediment Parameters		Grain-size
	Environment Sampled	Mode	Mean	Sorting	(mm)
Bioresearches: Oyster Point					
	Mudflat mid-tide	3	3.03	0.80	0.574
	Mudflat low water	3.5	3.85	0.62	0.651
	Mudflat near island	3	2.92	0.45	0.732
	Mud creek	pan	4.25	0.33	0.796
	Mudflat mid-tide	3	2.94	0.46	0.727
	Mudflat low water	3	3.09	0.50	0.707
	Mudflat mid-tide	pan	4.17	0.39	0.763
	Mudflat low water	3	3.32	0.57	0.674
	Mudflat mid-tide	pan	4.22	0.36	0.779
	Mudflat low water	3	3.24	0.60	0.660