Ecological and water quality assessment, Ashley River/Rakahuri - Saltwater Creek Estuary (Te Akaaka)

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Executive summary

Environment Canterbury completed several ecological investigations, sediment quality, intertidal sediments and macrobiota and water quality monitoring within the Ashley River/Rakahuri-Saltwater Creek Estuary (Te Akaaka) between 2004 and 2016. Some of the data collected are presented in other Environment Canterbury reports. However, these data are scattered. In this report, the data within other reports are presented, along with monitoring data that have yet to be published, to provide an overview of the habitats, water quality and ecological health of Te Akaaka.

Te Akaaka comprise 84.79 ha of saltmarsh and freshwater wetland in 2014, and 146.1 ha of non-vegetated sediment in 2013. Sea rush rushland, marsh ribbonwood shrubland and saltmarsh herbfield were the vegetation types that occupied the largest area. The sediment types that had the largest area were firm mud/sand, soft mud/sand, mobile sand, firm sand and very soft mud/sand.

The sediments within the central part of the estuary are variable over time. The temporal differences in the depth and distribution of the gravel, sand and mud in this area are likely to be driven by sediment inputs, river flows/floods and the hydrodynamics within the estuary. This difference over time is a notable feature of this estuary.

Forty-one animal taxa have been found living in/on the sediments in the central part of the estuary. Not all taxa were identified, but, of those that have been, almost all are also found in other estuarine intertidal areas in Canterbury. However, the worm *Euzonus* sp. has not been found elsewhere in Canterbury. The number of taxa and individuals present over time is variable. Of note was the marked difference in the 2014 macrobiota from that in previous years. I am of the opinion that this difference was as a consequence of two high rainfall events (34.2 mm over 24 hours and 51.2 mm over 48 hours) in the month prior to sampling. The high river flows would have caused significant disturbance, re-suspension and re-distribution of the sediment and the macrobiota living in it.

The water quality results indicate that the freshwater from the river and creeks flowing into the estuary are the most significant source of nitrite-nitrate nitrogen in estuary water.

The current state of the estuary has been assessed using the data collected. This assessment is in terms of the water quality classification for this estuary, as described in the Regional Coastal Environment Plan (RCEP) (Environment Canterbury, 2012) and the significant issues facing New Zealand estuaries (see tables below). The results indicate that there has been habitat loss and that there is potential for eutrophication of Te Akaaka. Sediment deposition could be having an ecological effect, but sediment metal and PAHs concentrations are unlikely to be having an ecological effect, in this estuary. The water quality within Te Akaaka does not meet the requirements for the water quality classification of Coastal AE and Coastal CR as designated in the RCEP (Environment Canterbury, 2012).

Regional Coastal Environment Plan coastal water classification	Met	Evidence
Coastal AE water (water quality for ecosystem health)	No	Near the estuary mouth the NNN, DIN (mostly NNN), DRP, TSS concentrations and turbidity are frequently above comparison values and therefore potentially influencing ecosystem health. In the flow of Taranaki Creek the NNN, DIN (mostly NNN), DRP, TSS concentrations, turbidity and DO % concentrations are frequently above/below comparison values and therefore potentially influencing ecosystem health.
Coastal CR water (water quality for contact recreation)	No	Faecal indicator bacteria concentrations, at the site monitored over the summer, frequently exceed guideline values. The Suitability for Recreation Grade at this site is POOR.
Coastal SG water (water quality for shellfish gathering)	No	Water quality standards for water overlying shellfish were NOT MET at the two sites monitored in 2014-2016

Estuarine Issue	Status	Evidence
Habitat Loss	definitely	Straight edges where saltmarsh and freshwater wetland vegetation meet the land.
Eutrophication	potentially	8.2 ha of macroalgae in December 2013. The NNN and DIN concentrations are frequently above comparison values.
Disease Risk	possibly	Faecal indicator bacteria concentrations above guideline values for contact recreation and shellfish gathering. The source of the faecal contamination is birds and ruminants.
Sedimentation	possibly	15.5 ha of very soft mud/sand and 33.3 Ha of soft mud/sand in December 2013. These sediments are adjacent to the Saltwater Creek and Taranaki Creek channels and also in upper reaches where water energy is low.
Toxins	present but unlikely to be having an ecological effect	Recorded metal/metalloid and polycyclic aromatic hydrocarbons (PAHs) unlikely to be having an ecological effect. There are differences between sites and over time in metal/metalloid concentrations. The vehicles travelling along SH1 are the likely source of the PAHs in estuary sediment downstream of SH1.

Table of contents

List of Figures

List of Tables

1 Introduction

There is a range of types of estuaries in New Zealand (http://www.niwa.co.nz/coasts-and-oceans/nz-coast/learn-about-coastal-environments/estuary-types). Ashley/Rakahuri Saltwater Creek Estuary (Te Akaaka) is an example of a tidal lagoon/barrier enclosed lagoon. It is also classified as a shallow intertidal dominated estuary (SIDE) (Robertson *et al.,* 2016a). Te Akaaka is a semi-enclosed embayment, with a free connection to the sea at one end and a number of freshwater sources at the other and fresh and salty waters mix within the estuary.

Estuaries are rich in life and support a diversity of plants and animals, including benthic microalgae, macroalgae, anemones, worms, shellfish, snails, crabs, shrimps and sand hoppers (Figure 1-1). In some estuaries there are meadows of *Zostera muelleri* (seagrass, eel grass, karepo) which provide habitat for juvenile flounder, cockles, crabs and topshell snails at greater densities than areas without seagrass (Jones and Marsden, 2005).

Figure 1-1: Crab and mudflat snail from the estuary

Estuaries provide important feeding grounds, nurseries and transitional habitat for fish migrating between marine and freshwater systems to breed. The abundant invertebrates present are food for fish and bird species. Such fish species include yellow-eyed mullet, sand flounder, yellow bellied flounder, common smelt, common sole and estuary stargazer. Bird species include the bar-tailed godwit, pied and black stilts, oystercatchers, dotterels, wrybill, terns, shags and gulls. Six of the native shorebirds that feed in Canterbury estuaries are classified as nationally threatened and black stilts are endangered (Dowding and Moore, 2006). Shellfish, such as cockles and pipis, occur in most estuaries, with these species collected by traditional and recreational fishers. Saltmarsh habitats (rushfield, herbfield, etc.) typically occurs at the margins of most estuaries.

1.1 Key issues for estuaries

Estuaries are at the bottom end of rivers/creeks/streams and, as such, activities within the catchments that influence the freshwater flowing into the estuary, indirectly influence the estuary. As well, estuaries, with their birds, fish and wetlands, calm water and being adjacent to the open coast are popular recreational areas that typically have adjacent human settlements.

Urban development, urban environments and rural farming activities all release sediment, nutrients and contaminants into freshwater, and thence, to estuaries and coastal water. Of immediate threat to estuaries are: sediments from both historic and present day land clearance; sediments for land use activities; contaminants from urban environments including stormwater, general road runoff and industrial activities; road runoff from highways; contaminants from rural activities, including the use of herbicides, pesticides and veterinary products, nutrients from farming activities; reclamation of coastal margins (including estuary margins), and sea level rise associated with climate change.

The major issues for New Zealand estuaries, as summarised by Stevens and Robertson (2007), are listed in Table 1-1.

Table 1-1: Summary of major issues affecting most New Zealand estuaries

(From Stevens and Robertson, 2007)

Issue	Impact
Sedimentation	If sediment inputs are excessive, an estuary infills quickly with muds, reducing biodiversity and human values and uses.
Eutrophication	Eutrophication is an increase in the rate of supply of organic matter to an ecosystem. If nutrient inputs are excessive, the estuary experiences macroalgal and/or phytoplankton blooms, anoxic sediments, lowered biodiversity and nuisance effects for local residents.
Toxins	If potentially toxic contaminant inputs (e.g. heavy metals, pesticides, ammonia, emerging contaminants) are excessive, estuary biodiversity is threatened and shellfish and fish may be unsuitable for eating.
Habitat Loss	If habitats (such as saltmarsh) are lost or damaged through drainage, reclamation, building of structures, stock grazing or vehicle access, biodiversity and estuary productivity declines. If the natural terrestrial margin around the estuary is modified by forest clearance or degraded through such actions as roading, stormwater outfalls, property development and weed growth, the natural character is diminished and biodiversity reduced.
Disease Risk	If pathogen inputs are excessive, the disease risk from bathing, wading or eating shellfish increases to unacceptable levels.

Sedimentation

Estuaries are natural sinks for sediment and sediment accumulates naturally over time and results in infilling. This process can be accelerated if the quantity of sediment transported in the freshwater increases above natural levels. Over the past 150 years, development in estuary catchments has increased dramatically in New Zealand. Urban development, agriculture, land clearance, forestry and wetland drainage releases fine sediment into rivers, which is transported to the estuaries. Erosion of exposed river banks is also an issue during flood events. Estuaries that were dominated by coarse grained sandy sediments in the past have begun to infill with fine grained muddy sediment.

The input of terrestrial sediment impacts the community composition of estuarine intertidal flats through changes in the grain size distribution and chemistry of the estuary sediment. Pulses of high sediment deposition smother the estuarine plants and animals and elevated suspended sediment concentrations in the water column have ecological impacts. The distribution and abundance of invertebrate macrofauna is directly related to sediment grain size (Thrush *et al*., 2003). Species that are intolerant of fine sediment, such as pipi (*Paphies australis*), decline in abundance and, as the sediments becomes muddy, species diversity declines and only fine sediment tolerant species remain. The deposition of sediment smothers habitats, such as seagrass meadows and shellfish beds. Elevated suspended sediment loads in water decrease the light availability for plants, including seagrass, reduce the feeding efficiency of filter feeders, and influence the feeding efficiency of predatory fish.

Eutrophication
Within an estuary, macroalgae growth is an indicator of elevated concentrations of the dissolved form of nutrients. Sources of the nutrients nitrogen (N) and phosphorus (P) entering rivers and estuaries originate from discharges of human wastewater, fertiliser runoff from land and animal excreta. Extensive macroalgae growth is an ecological problem, as the live macroalgae cover the seabed, and hence aquatic life, and also traps fine sediment which results in the accumulation of mud (Stevens and Robertson, 2012). Dead macroalgae can cover the seabed and, as it rots, it releases organic matter and nutrients into the sediments. Microbial activity breaks down the macroalgae, but consumes the oxygen in the sediment (Kennish, 2002). This reduces sediment oxygenation, which can result in black anoxic sediment and the death of sediment-dwelling organisms. The release of nutrients fuels ongoing macroalgae growth. When the macroalgae dies, decomposers also deplete the oxygen in the water, which can result in fish kills and the death of other aquatic life. Decaying macroalgae are smelly and unsightly.

Habitat loss
Development of the terrestrial boundaries of estuaries, such as areas of saltmarsh, removes the natural buffer zone which would normally allow an estuary to respond to changing sea levels, protect the coastline from erosion and trap fine sediment. Native saltmarsh and wetland habitat have been drained and replaced by artificial structures such as seawalls, farmland and urban development. Habitat loss also occurs through the reclamation of the seabed and ongoing disturbance, such as use of vehicles within an estuary.

Disease risk
Human sewage, mammal (dogs, sheep, cows etc.) and bird faeces and industry waste are sources of pathogens, including viruses, bacteria and protozoa, entering river and estuary water. These can cause gastroenteritis, salmonellosis and hepatitis A and other illnesses. These pose a risk to recreational users and shellfish consumers.

Toxic contamination
Stormwater discharges, industrial spills, road runoff, air pollution, wastewater overflows, oil spills, herbicides, pesticides, medicinal and veterinary products release potentially toxic compounds including heavy metals and emerging organic contaminants into surface water. In estuaries, many of the contaminants bind to fine sediment to then settle to the seabed and accumulate in the bed sediment. Contaminated seabed sediment may have significant ecological impacts. Fish and shellfish feeding in contaminated waters can become toxic to animals and humans through bioaccumulation of contaminants within their tissues. Toxic macroalgae and phytoplankton blooms can also contaminate shellfish and pose a risk to human health.

1.2 Evaluation of the ecology and water quality of Te Akaaka

1.2.1 Objective

The objective of this report is to describe the current state of the ecology and water quality of Te Akaaka. This is just one of the documents completed to provide information on the current state of the land, water (surface water and ground water), social and economic environment for a defined area of the Waimakariri zone.

1.2.2 Source of the data

The information presented in this report is from ecological investigations and ecological and water quality monitoring that has been undertaken by or for Environment Canterbury in Te Akaaka over the last eleven years. Environment Canterbury have not surveyed the fish or bird populations of this estuary.

1. Mapping of the saltmarsh and freshwater wetland vegetation in 2004 (Grove *et al.*, 2012)[1] and 2014.
2. Broad-scale habitat mapping of the non-vegetated intertidal sediments (Woods and Bolton-Ritchie, in draft).
3. Assessment of the intertidal sediments and macrobiota in the southern and central part of the estuary (Fenwick *et al.,* 2006)[2].
4. Monitoring[3] of sediment quality at one site within the estuary (Bolton-Ritchie and Lees, 2012)[4].
5. Monitoring of the intertidal sediments and macrobiota at one site within the estuary.
6. Monitoring of water quality for ecosystem health at two sites within the estuary.[5]
7. Monitoring of water quality for contact recreation at one site within the estuary.

This report:

1. provides data on the habitats of Te Akaaka;
2. provides data on the sediments and benthic macrobiota of Te Akaaka;
3. provides water quality data and assesses whether the water quality provides for the maintenance of the estuary aquatic ecosystem, i.e. Coastal AE water;
4. Provides microbial water quality data and assesses whether the water quality provides for contact recreation, i.e. Coastal CR water;
5. evaluates the ecological health of Te Akaaka; and
6. provides an assessment of Te Akaaka in terms of the key issues for New Zealand estuaries.

[1] http://ecan.govt.nz/publications/Reports/**coastal**-wetlands-report.pdf
[2] Report can be found at http://ecan.govt.nz/publications/Pages/surface-water-reports.aspx#waimak
[3] Monitoring is routine sampling at a site over time.
[4] Report can be found at http://ecan.govt.nz/publications/Pages/surface-water-reports.aspx#coastal
[5] Environment Canterbury also monitors water quality at sites on the river and creeks flowing into the estuary

2 Te Akaaka

Te Akaaka receives freshwater from the Ashley River/ Rakahuri, Saltwater Creek, Taranaki Creek and a number of small lowland creeks (Figure 2-1). Within the catchments of these rivers/creeks there are the urban areas of Rangiora, Woodend, Pegasus township and Waikuku with continued urban growth in these urban areas. Te Akaaka currently has one opening to the sea; the location of this opening does vary over time.

The Ashley River/Rakahuri is a medium-size foothills fed river that drains extensive pastoral farmland. Saltwater Creek is a lowland, predominantly spring fed creek, and like the Ashley River/Rakahuri drains extensive pastoral farmland. Taranaki Creek is a lowland, spring fed creek and also flows through farmland, however there is increasing urbanisation in the catchment with stormwater discharged into this creek. There is intensive rural land use within the catchments and changing rural land use including intensification of irrigated land.

The river and creek mouths form separate arms of the estuary with other arms of mudflat merging into the saltmarsh vegetation. The estuary has an extensive area of saltmarsh vegetation and non-vegetated intertidal sediments including the long area behind Ashworths Spit (Figure 2-1).

The coastal marine area of Te Akaaka, as designated by the Environment Canterbury (2012), is shown in Figure 2-2. Of note is that the designated coastal marine area does not extend up Saltwater Creek to the extent of the tidal influence. The coastal marine area of this estuary is classified as an Area of Significant Natural Value (Environment Canterbury, 2012) with the following values:

- Maori cultural values;
- Protected areas;
- Historic places;
- Coastal landforms and associated processes;
- Ecosystems, flora and fauna habitats;
- Marine mammals and birds;
- Wetlands, Estuaries and coastal lagoon.

The Regional Coastal Environment Plan water quality classification, for the whole of the estuary and the coastal area immediately outside of the estuary, in Pegasus Bay is Coastal CR[6] water (Environment Canterbury, 2012). A designation of Coastal CR water means that the water quality must be managed for the maintenance of aquatic ecosystems (Coastal AE water) and for contact recreation. There Coastal CR water does not have to meet the criteria for Coastal SG water, which is water quality for shellfish gathering. However, this estuary is a significant source of pipis and cockles (shellfish) for Tē Rūnanga o Ngāi Tūāhuriri and recreational gatherers.

[6] Contact Recreation

Figure 2-1: Aerial view (2012) of Te Akaaka

Locations: a-Saltwater Creek, b-Ashley River/Rakahuri, c-Taranaki Creek d-Waikuku, e-general area of mouth, f-Ashworths Spit, g-Pegasus Bay

Figure 2-2: Currently designated coastal marine area boundary

3 Habitat mapping

The saltmarsh and the intertidal sediment types of most of the coastal marine area and the freshwater wetlands immediately adjacent to the estuary have been mapped by Environment Canterbury staff. The data collected provide information on the aquatic vegetation diversity and the ecological habitats of the estuary. One thing to note is that there was no precise mapping of margins and in particular modifications to margins including seawalls, fences, vehicle tracks and stormwater pipes. The precise mapping of margins does provide data for the assessment of the key issue of habitat loss.

The present day habitats in and around Te Akaaka are different from those in pre-European times. The landscape in the area changed with the arrival of European settlers. The settlers cut drainage channels to drain small lakes and swamp land and for general land drainage. As well river control works in the form of stop banks confined rivers to set courses, reducing the flow of water to support the functioning of swamps and other water bodies (Waitangi Tribunal Reports, 1995). An example of the complexity of waterways and swamp land south of Te Akaaka, prior too much of this modification, can be seen in Figure 3-1.

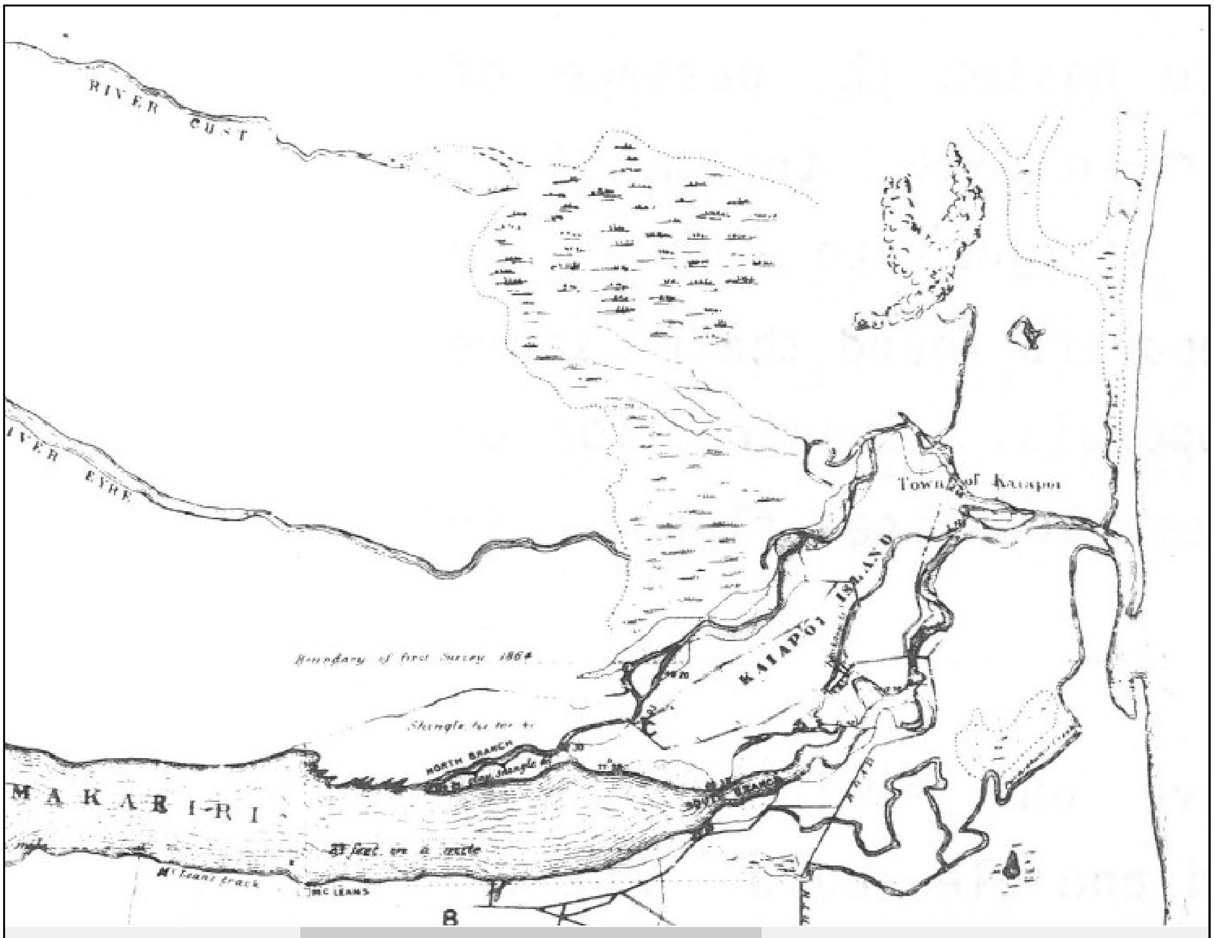

Figure 3-1: Waterways and swamp land south of Te Akaaka in 1865 (from a map of a portion of the Plains of Canterbury)

3.1 Saltmarsh and freshwater wetlands

The mapping of the saltmarsh and freshwater wetland of Te Akaaka was undertaken in 2004 and 2014. The methods used are described in Grove *et al.* (2012). The 2004 maps are available as a layer on Canterbury maps and in the Environment Canterbury GIS system. The 2014 map has just been finalised and will be available as a GIS layer in the near future. The distribution of the saltmarsh and freshwater wetland of Te Akaaka in 2014 is shown in Figures 3-2 and 3-2.

Figure 3-2: Wetland and terrestrial habitats in the Te Akaaka survey area, in 2014

Palustrine - wetland which lacks flowing water, contains ocean-derived salts in concentrations of less than 0.5 parts per thousand and is non tidal

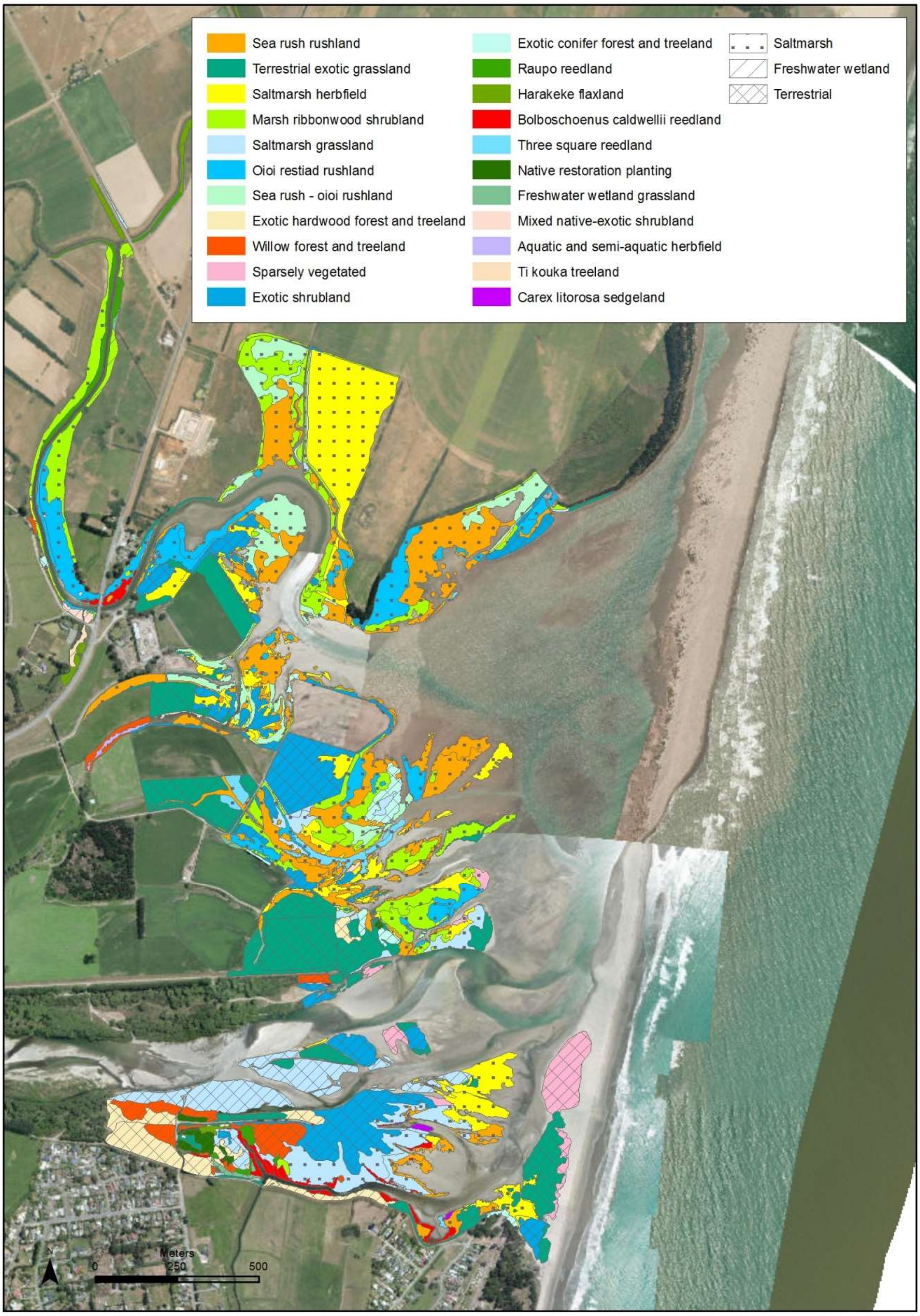

Figure 3-3: Vegetation types in the Te Akaaka survey area, in 2014

Figure provided by Mark Parker of Environment Canterbury

In 2014 the total area of vegetation was 149.76 hectares with 85.67 hectares of this being estuarine vegetation (Table 3-1). The wetland vegetation in this estuary is dominated by sea rush rushland, marsh ribbonwood shrubland and saltmarsh herbfield (Table 3-2). There has been a change in the vegetation, notably in the southern-mid part of the estuary between 2004 and 2014 (Figure 3-4). The present day estuary mouth is further north than it was in 2004. The northern expansion of the vegetation on the eastern shoreline could be as a result in a change in the location of the estuary mouth. However, local residents have noted the extension of the vegetation coincided with a change to the path taken by vehicles travelling from Waikuku to the estuary mouth. Therefore it is possible that an increase in aquatic vegetation on the eastern shoreline results from a combination of both these changes. The expansion of the western vegetation into the estuary is likely a result of the change in the location of the estuary mouth. The change in the location of one of the river braids has resulted in the erosion of vegetation.

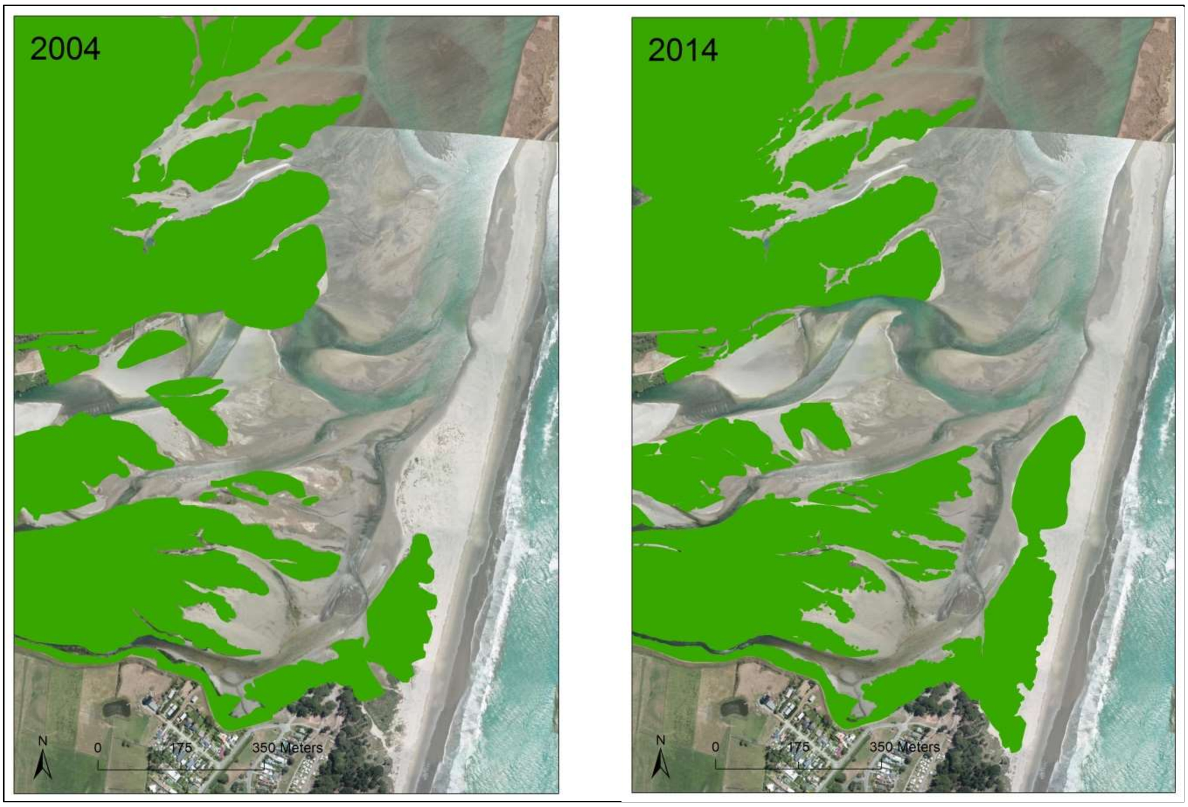

Figure 3-4: Extent of the mapped vegetation in the southern part of the estuary in 2004 and 2014

NOTE: The background aerial map is from 2012

The vegetation type map (Figure 3-3) shows that the large northern area of saltmarsh herbfield has straight borders. This suggests that at the edges of the herbfield there has been habitat loss through reclamation or drainage for conversion to farmland. There are also straight borders between estuarine tidal vegetation and farmland and palustrine vegetation and farmland. These also suggest that at the edges there has been habitat loss through reclamation or drainage for conversion to farmland.

Of note is that some areas of estuarine vegetation are not actually located within the coastal marine area as designated in the RCEP (Figures 2-2 and 3-2). An overlay of the two maps is provided in Appendix 1.

Table 3-1: Area (ha) of the aquatic vegetation habitat types in Te Akaaka in 2014

Habitat type	Area (Ha)
Estuarine	84.79
Palustrine	1.50
Riverine	5.95
Terrestrial	56.63

Table 3-2: Area (ha) of each vegetation type in each habitat in Te Akaaka in 2014

Habitat type	Structural classification	Vegetation type	Area (Ha)
Estuarine	Marsh	Flaxland	0.16
		Grassland	1.49
	Saltmarsh	Grassland	7.23
		Herbfield	18.94
		Reedland	2.57
		Rushland	39.51
		Sedgeland	0.16
		Shrubland	14.53
		Sparsely vegetated	0.20
Palustrine	Marsh	Flaxland	0.28
		Grassland	0.19
		Rushland	0.08
		Sedgeland	0.04
	Swamp	Flaxland	0.43
		Grassland	0.09
		Reedland	0.40
Riverine	Marsh	Flaxland	0.03
		Forest	2.07
		Grassland	0.05
		Shrubland	0.59
		Treeland	0.18
	Shallow water	Herbfield	0.21
		Rushland	0.37
		Sparsely vegetated	0.03
		Tussockland	0.04
	Swamp	Flaxland	0.96
		Reedland	1.41
Terrestrial		Treeland	7.58
		Fernland	0.05
		Forest	1.35
		Grassland	26.55
		Herbfield	0.37
		Sandfield	2.93
		Scrub	2.40
		Shrubland	15.33
		Tussockland	0.05
		Vineland	0.03

3.2 Non-vegetated intertidal sediments

In December 2013, a broad scale method (Robertson *et al.*, 2002) was used to map the spatial distribution of the substrate within the non-vegetated intertidal area of this estuary. The methods and classifications used are described in the report by Woods and Bolton-Ritchie (in draft). The total intertidal area was 146.1 ha (Figure 3-5).

3.2.1 Intertidal substrate

The dominant intertidal substrates were firm mud/sand, soft mud/sand and mobile sand (Table 3-3, Figure 3-5).

Table 3-3: The intertidal substrates in Te Akaaka, December 2013

NOTE: The area of vegetation and water cover are not included in analysis

Dominant substrate	Area Ha	%	Comments
Firm mud/sand	40.3	27.6	Common behind Ashworths Spit and upper branches.
Firm mud/sand/gravel	0.4	0.3	Along edges of Saltwater Creek, small patch near estuary mouth.
Firm sand	20.0	13.7	At the edge of sand dunes and in the well flushed central area.
Firm sand/clay	0.6	0.4	One area present near estuary mouth.
Firm sand/gravel	0.6	0.4	Four patches in centre opposite estuary mouth.
Mobile sand	23.2	15.9	Extensive in the central, well flushed area near the mouth.
Stone/cobble	1.1	0.7	Uncommon, present in main flow of the Ashley River/Rakahuri.
Stone/cobble/sand	7.2	4.9	Common in main flow of the Ashley River/Rakahuri, 1 ha covered in high density macroalgae.
Soft mud/sand	33.3	22.8	Extensive in northern half, Saltwater Creek and southernmost branch of Ashley River/Rakahuri.
Soft sand	3.9	2.7	Near mouth and along the edge of sand dunes.
Very soft mud/sand	15.5	10.6	In upper margins and stream inlets, especially Saltwater Creek.
Total	**146.1**	**100**	

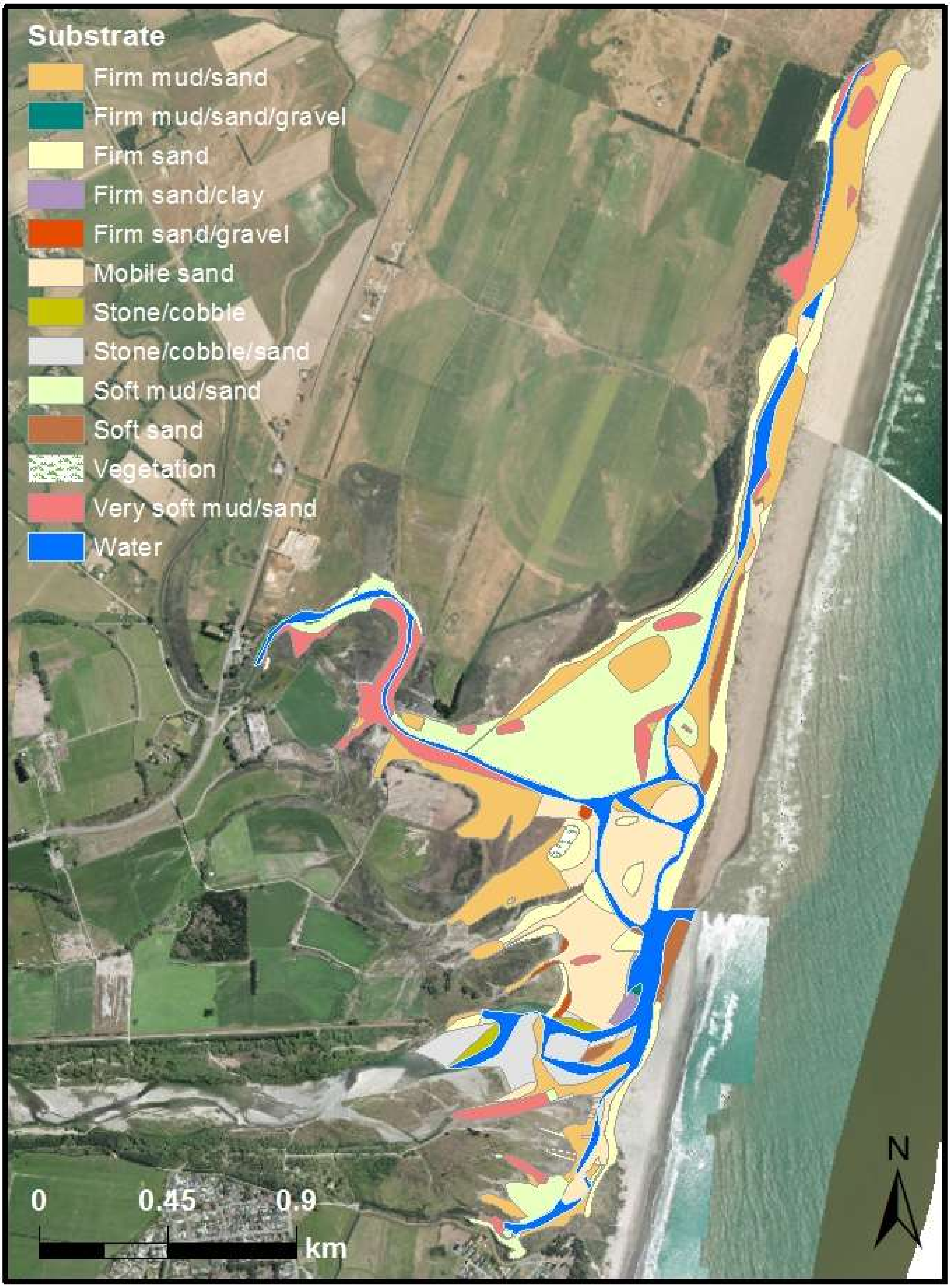

Figure 3-5: The intertidal substrates of Te Akaaka, December 2013

To show the influence of each of the three different freshwater inflows on the intertidal substrate in the estuary, there are zoomed in views in Figures 3-6 to 3-8.

The large area of very soft mud/sand and soft mud/sand close to the mouth of Saltwater Creek suggests this creek is a significant source of fine sediment to this estuary (Figure 3-6). Mud, which is silt plus clay, is fine sediment that remains in suspension in flowing freshwater but on mixing with saline water flocculates and drop out of the water column. The fine sediment then settles and remains in areas of low water movement as well as being trapped by vegetation. The more mud in the seabed sediment, the softer it is, as noticed when walking on it.

The Ashley River/Rakahuri is a significant source of gravel to the estuary (Figure 3-7). The area of exposed gravel within the estuary is influenced by the size and number of floods that occur in the river. Between flood events there is movement of the sand, in particular, by natural processes such that sand does cover a lot of the gravel. The extensive area of mobile sand to the north of where the river flows into the estuary does vary in extent over time (refer to section 6 of this report) and there is gravel under the sand.

The area of very soft mud/sand and soft mud/sand around the mouth of Taranaki Creek suggests this creek, like Saltwater Creek, is a significant source of fine sediment to this estuary. It is possible that tidal flushing in the Taranaki Creek area has reduced over time as the estuary mouth has migrated north (see section 3.1), which may have changed the accumulation rate of mud in the Taranaki Creek area.

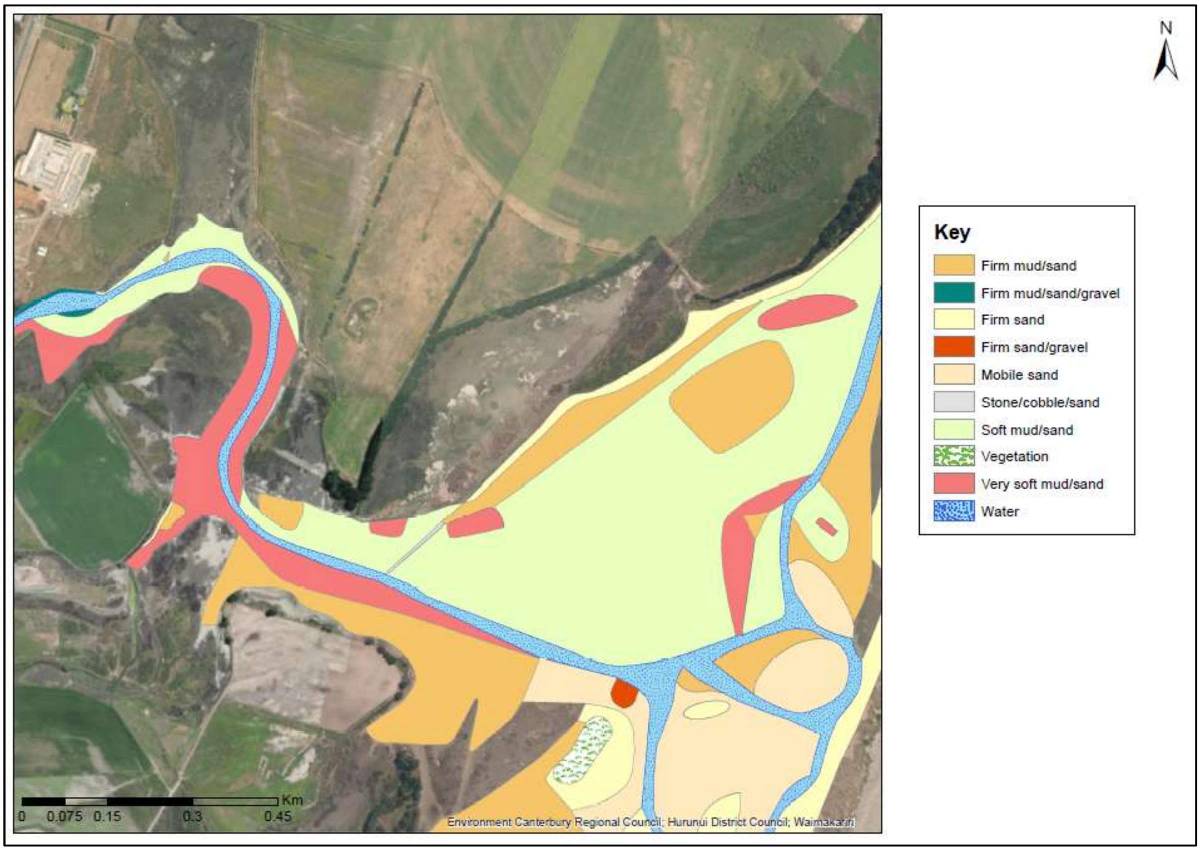

Figure 3-6: The intertidal substrate in proximity to where Saltwater Creek flows into the estuary, December 2013

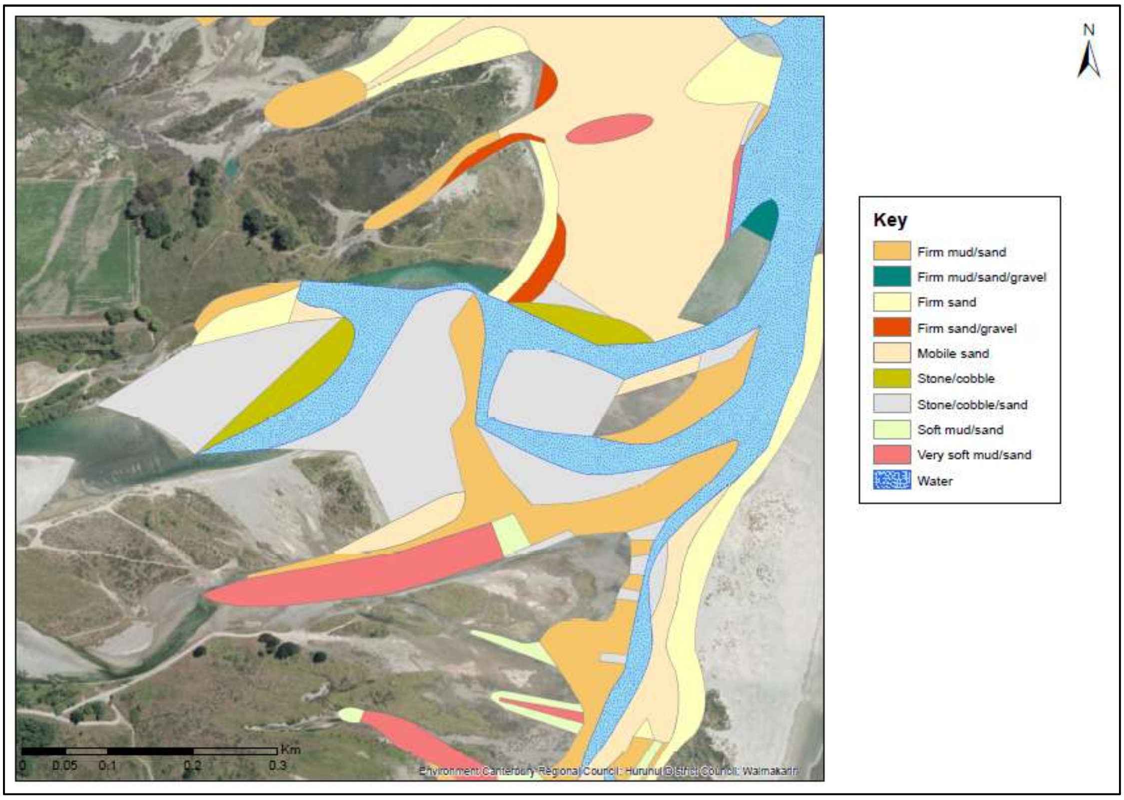

Figure 3-7: The intertidal substrate in proximity to where the Ashley River/Rakahuri flows into the estuary, December 2013

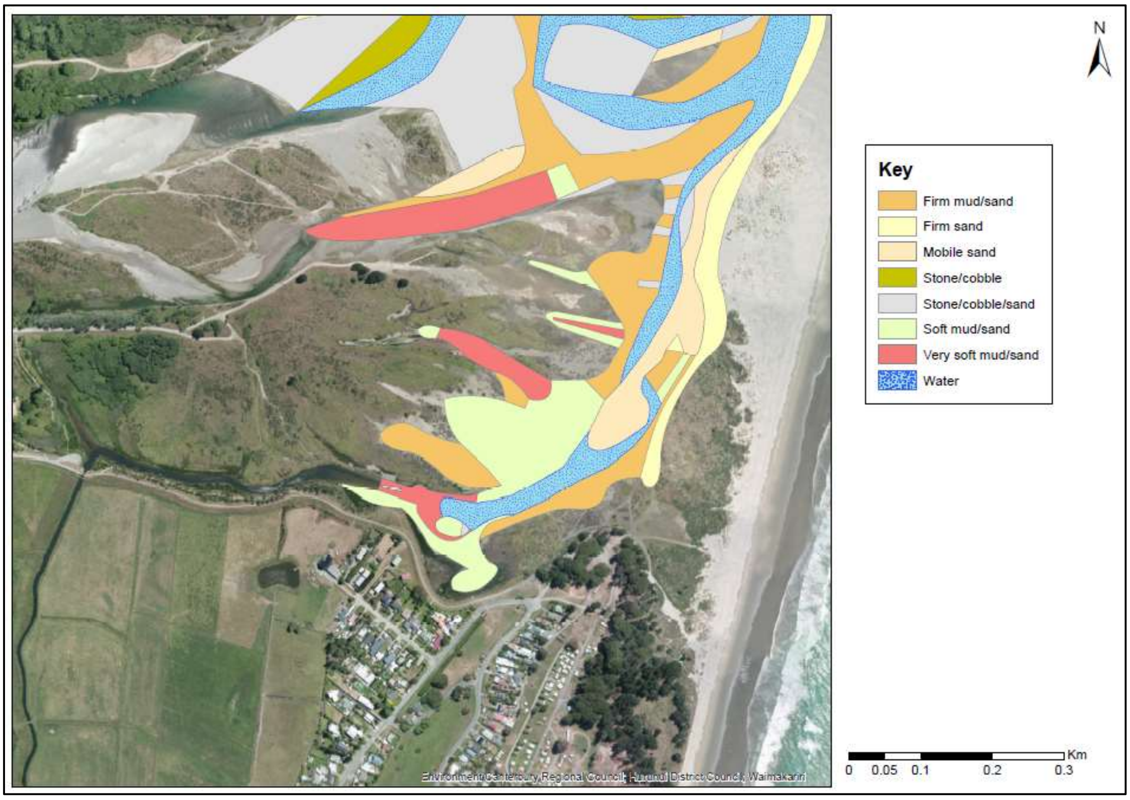

Figure 3-8: The intertidal substrate in proximity to where Taranaki Creek flows into the estuary, December 2013

3.2.2 Macroalgae

In December 2013 macroalgae covered 5.6 per cent (8.2 ha) of the estuary (Figures 3-9 and 3-10, Table 3-4). Species included *Ulva compressa* and *Gracilaria chilensis*. A green turfing macroalga was found in lower Ashworths Creek but this was not identified. Extensive macroalgae blooms grew on the soft mud of the Saltwater Creek margins and patches were present at the Ashley River/Rakahuri inlets to the estuary. This extensive area of macroalgae does indicate that there is a plentiful supply of nutrients, notably dissolved inorganic nitrogen (nitrogen is the nutrient that limits productivity in marine systems).

Figure 3-9: Macroalgae around the margins of Saltwater Creek

Table 3-4: Summary of intertidal macroalgae cover in Te Akaaka, December 2013

High cover ≥ 70%; Medium cover 30 -70%; Low cover ≤ 30%

Algae Cover	Area of algae (ha)	% of area of algae	% of total area (ha)	Comments
Low	1.6	19.4	1.1	Small patches present in upper reaches, especially in the vicinity of freshwater inflows.
Medium	1.3	16.3	0.9	Small patches present in upper reaches, especially in the vicinity of freshwater inflows.
High	5.3	64.3	3.6	Extensive around Saltwater Creek, small patches at inlets of Ashley River/Rakahuri and in Ashworths Creek.
Total	**8.2**	**100.0**	**5.6**	

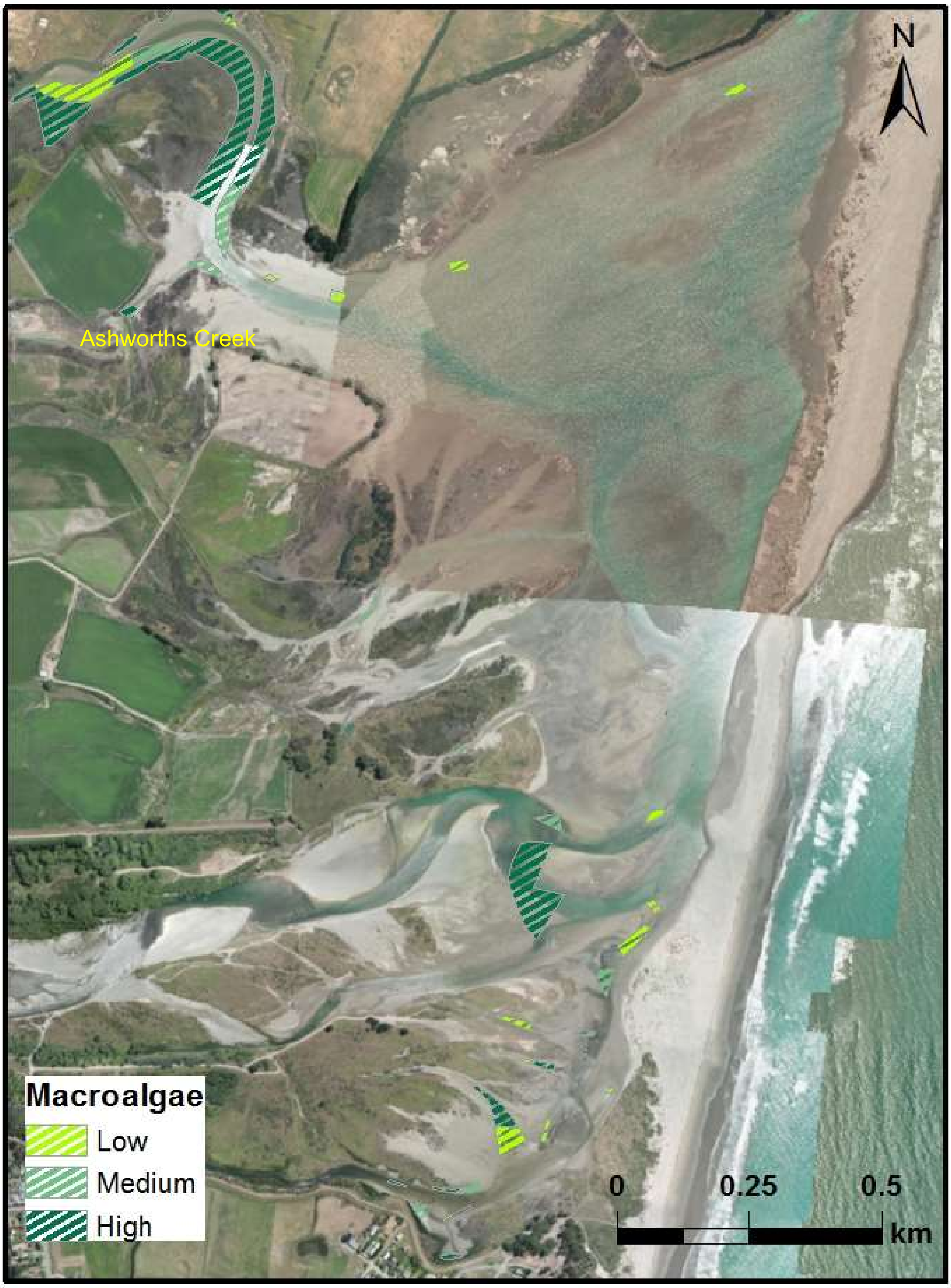

Figure 3-10: Macroalgae cover in Te Akaaka, December 2013

Macroalgae species included *Gracilaria chilensis*, *Ulva compressa* and one unidentified green turfing species (in Ashworths Creek)

Figure 3-11: Photo of mobile sand at low tide in the estuarine area behind Ashworths Spit

The sand dunes along Ashworths Spit in the distance

3.3 Discussion

Habitat loss

There are several straight borders between saltmarsh herbfield and farmland, between estuarine tidal vegetation and farmland and palustrine vegetation and farmland. These lengths of straight borders indicate habitat loss through reclamation or spraying for conversion to farmland. No mapping of the margins has been undertaken to assess for habitat loss through habitat destruction, for example, by vehicle use. There is evidence of habitat disturbance through vehicles driving into the estuary from the area at the end of the road along the northern Ashley River/Rakahuri stopbank.

Sedimentation and eutrophication

Sedimentation and eutrophication are significant issues for estuaries both in New Zealand and internationally and the Te Akaaka results suggest they are also an issue for this estuary. The substrate results indicate there are fine sediment inputs into the estuary notably from Saltwater Creek and Taranaki Creek. The macroalgae results indicate there are elevated nutrient concentrations, and hence inputs, notably in the Saltwater Creek area but also in the south of where the Ashley River/Rakahuri flows into the estuary.

The occurrence of fine sediment in low energy areas of an estuary, such as found in Te Akaaka is typical and not unexpected. To determine if sedimentation is actually an issue for this estuary more work needs to be done. This includes measuring sedimentation rate, measurement of grain size distribution at numerous sites in the estuary and regular broad scale mapping to assess for changes in the distribution of the extent of soft and very soft mud/sand over time. It would also be useful to take cores through the soft sediment at two or three sites and have then dated so as to determine changes in the sediment type and sedimentation rate over time.

Eutrophication of estuaries is driven by the enrichment of water by nutrients, especially nitrogen and/or phosphorus from land, atmosphere, or adjacent seas, and which leads to: increased growth, primary production and biomass of algae, changes in the balance of organisms, and water quality degradation.

The response to nutrients is often exacerbated by the presence of muds (lower pore water exchange, increased sediment bound nutrients) and hydrological conditions.

In recent years work has been underway on developing a New Zealand Estuary trophic index (ETI) (Robertson *et al.,* 2016a and 2016b). The documents provide thresholds for various indicators which are then used to classify an estuary into one of four bands.

A - Minimal eutrophication
B – Moderate eutrophication
C – High eutrophication
D – Very high eutrophication

The indicators[7] used in an estuary such as Te Akaaka, to determine the band are:

Primary indicator

- *Macroalgae*

Supporting indicators

- *Water column dissolved oxygen*
- *Sediment total organic carbon*
- *Sediment total nitrogen*
- *Sediment redox potential*
- *Total sulphur and total sulphides*
- *Sedimentation (includes mud content of the sediment)*
- *Extent of seagrass*
- *Macroinvertebrate index*

Analysis of the sediment and macroalgae mapping results provide some indication of the trophic state of this estuary in 2013. However, the macroalgae data collected were not to the detail required in the ETI (Robertson *et al.,* 2016b) (See Appendix 2) and sediment grain size analyses were not undertaken to assess actual mud content of the sediments designated as soft mud/sand and very soft mud/sand.

In 2013, macroalgae covered 8.2% of the available intertidal habitat. This puts Te Akaaka into band B, i.e. moderate eutrophication. In 2013, soft and very soft mud/sand made up 33.4% of the area of the available intertidal habitat. I have no data as the % mud content of this soft and very soft mud/sand, but if the % mud in the sediment is >25% it would put Te Akaaka into band D, i.e. Very high eutrophication. If the % mud in the sediment in soft mud/sand is <25%, but the % mud in very soft mud/sand is > 25% then it would put Te Akaaka into Band C. The results presented in Figure 5-8 show that the % mud in seabed sediment from this estuary can be > 25%.

Detailed work will need to be undertaken in the future to determine the actual trophic state of Te Akaaka.

[7] The details of the indicators are provided in Appendix 2

4 Sediment quality

Human activities are a source of environmental contaminants such as trace metals and polycyclic aromatic hydrocarbons (PAHs). For example, many houses have galvanised iron roofing, a source of zinc, and other buildings have pipes and electrical wiring made of copper that can be washed into the environment. Additionally, numerous industrial processes result in waste that can contain contaminants, while vehicles contribute metals and hydrocarbons to the environment through vehicle exhausts, tyre wear and oil spots left on the roads (Timperley *et al.,* 2005).

Metals and other contaminants that reach the sea are either dissolved in water or adsorbed onto fine sediment (silt and clay) particles or organic matter (such as leaves, twigs). More metal contaminants are adsorbed onto sediment particles than are dissolved in water. When these contaminated sediment particles reach an estuary such as Te Akaaka they flocculate out of the water column to settle to the seabed. Because they are fine sediment particles they settle to the seabed in the low energy areas and over time accumulate in such areas.

There are known thresholds above which contaminant concentrations in sediment can be toxic to marine life, thus all contaminants that enter the marine environment can potentially affect ecosystem health.

4.1 One-off study (Central and southern estuary, 2005)

In 2005 Environment Canterbury commissioned NIWA to undertake an assessment of the mid-tide level sediments and the associated macrobiota in the southern and central portion of Te Akaaka (Fenwick *et al.,* 2006). The aim of that study was to document the estuary's state and to provide baseline data for future monitoring. The sampling sites and the typical sediment characteristics at each site are shown in Figure 4-1. At each site two composited sediment samples were collected and analysed for metal (cadmium, chromium, copper, lead, nickel and zinc) and metalloid (arsenic) concentrations as well as sediment grain size. The results are presented in Table 4-1.

All recorded metal and metalloid concentrations were below (ANZECC, 2000) ISQG-low trigger values, that is, they were unlikely to be having an ecological effect.

There were differences in metal and metalloid concentrations between sites. Metals and metalloids adsorb to fine sediment particles (notably clay and silt particles; clay + silt = mud), therefore differences in sediment type between locations likely accounts for much of the difference between sites including the differences between the firm muddy sand and firm sand sites.

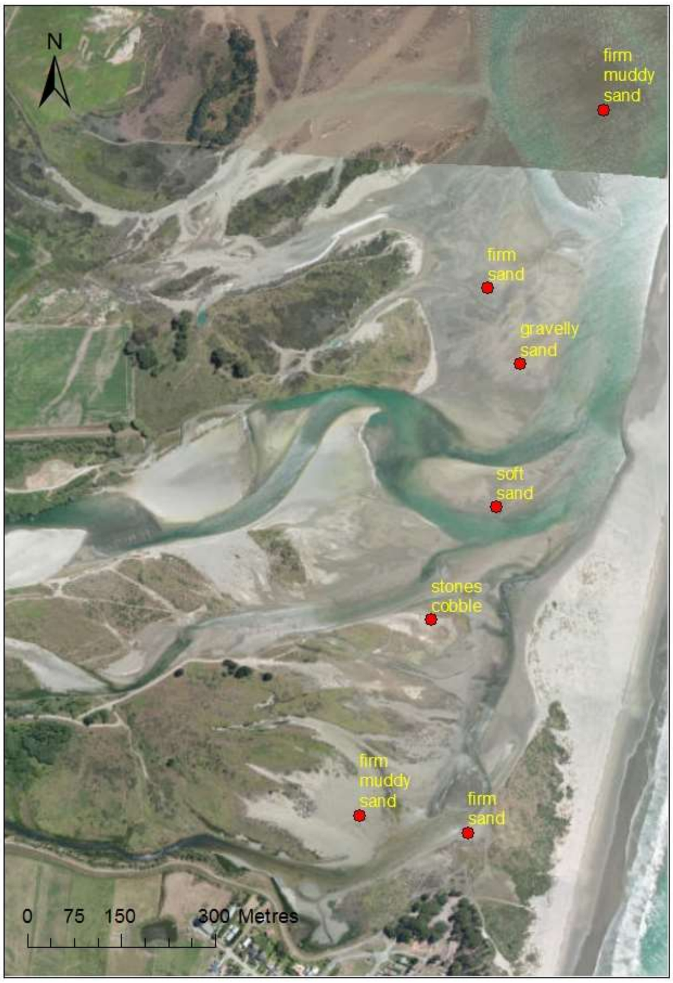

Figure 4-1: Sites sampled and the sediment type at each in 2005

Table 4-1: Metal and metalloid concentrations (mg/kg) at sites sampled 2005

Sampling station	arsenic	cadmium	chromium	copper	lead	nickel	zinc
Firm sand (north)	4.4	0.01	8.5	3.2	6.16	7.3	24.0
Firm sand (north)	4.4	0.01	8.2	2.9	6.22	6.8	24.4
Firm muddy sand (north)	4.2	0.02	11.0	5.0	8.38	10.1	34.3
Firm muddy sand (north)	4.0	0.02	12.1	5.4	8.46	10.6	36.5
Gravelly sand	2.9	0.01	8.2	2.7	5.05	7.3	21.1
Gravelly sand	2.9	0.01	8.7	3.4	5.6	8.3	23.6
Soft sand	3.0		7.7	2.6	5.28	6.9	21.2
Soft sand	2.9	0.01	7.7	2.6	5.49	7.1	21.8
Stones cobble	4.3	0.02	12.2	6.0	9.22	11.6	38.1
Stones cobble	3.5	0.02	11.8	5.3	7.92	11.0	34.2
Firm muddy sand (south)	3.9	0.03	12.9	6.9	9.94	12.3	42.9
Firm muddy sand (south)	4.4	0.02	13.8	7.8	12.0	12.6	47.3
Firm sand (south)	4.1	0.02	10.7	5.4	8.52	10.1	33.7
Firm sand (south)	4.3	0.02	11.3	5.1	8.05	10.1	33.1
ANZECC ISQG-low	**20**	**1.5**	**80**	**65**	**50**	**21**	**200**

4.2 Monitoring

Sediment quality monitoring at one site within Te Akaaka began in 2010. The site (Figure 4-2) was sampled as part of a region wide programme (Bolton-Ritchie and Lees, 2012). This site was selected as the Te Akaaka site for the following reasons:

1. Potential for contamination
2. Large enough area of muddy sediment for sampling. Mud is fine-grained sediment while sand is a coarser-grained sediment. Metals and other contaminants adsorb to fine-grained sediment rather than coarse-grained sediment therefore muddy sediment was a prerequisite. The methodology requires a 50 m by 20 m area of muddy sediment to sample.

The sampling methods used and the 2010 results are presented in a report by Bolton-Ritchie and Lees (2012). The collected sediments were analysed for a range of contaminants as well as sediment grain size distribution and total organic carbon. Information on the contaminants monitored are provided in Appendix 3.

The 2010 data indicated all metal and metalloid and polycyclic aromatic hydrocarbons (PAHs) concentrations were below (ANZECC, 2000) ISQG-low trigger values, that is, they are unlikely to be having an ecological effect. However, we did find that the sediment contained PAHs (these are likely to come from vehicles travelling along SH1), and an elevated concentration of mercury, which may be a result of human activity (but the specific source of the mercury is unknown).

This site (Figure 4-3) has now been sampled three times; the sampling dates being 23 August 2010 (three composite sediment samples), 8 April 2013 (three composite sediment samples) and 26 August 2014 (five composite sediment samples). The concentrations of the metals cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) and the metalloid arsenic (As) over time are presented in Figures 4-4 to 4-6. The results show that metal/metalloid concentrations at the site are not increasing over time but there has been some variability in concentrations between sampling occasions.

Figure 4-2: Location of the sediment quality sampling area downstream of where SH1 crosses Saltwater Creek

The concentrations of 16 PAHs were measured on each sampling occasion. For two PAHs all measured concentrations were below the analytical level of detection, therefore no results are provided for them. The results for the other PAHs (normalised to 1% total organic carbon) are provided in Table 4-2 and presented in Figure 4-7. The concentration of all but one of the PAHs in 2010 was notably higher that in 2013 and 2014. The lower PAH concentrations in 2013 and 2014 than in 2010 could result from:

1. deposition of sediment over top of the sediment sampled in 2010;
2. flushing away of the surface layer sampled in 2010;
3. deposition of sediment to the surface, such that it integrates into the surface sediment and dilutes the contaminants.

In 2010 the sediment mud content was 55.5%, in 2013 it was 92.5% and in 2014 it was 79%. These results indicate sediment grain size does change over time; this change likely comes from the deposition of fine sediment in low to normal flows and the flushing away of sediment during high flows.

Figure 4-3: Photo of the sediment quality sampling area

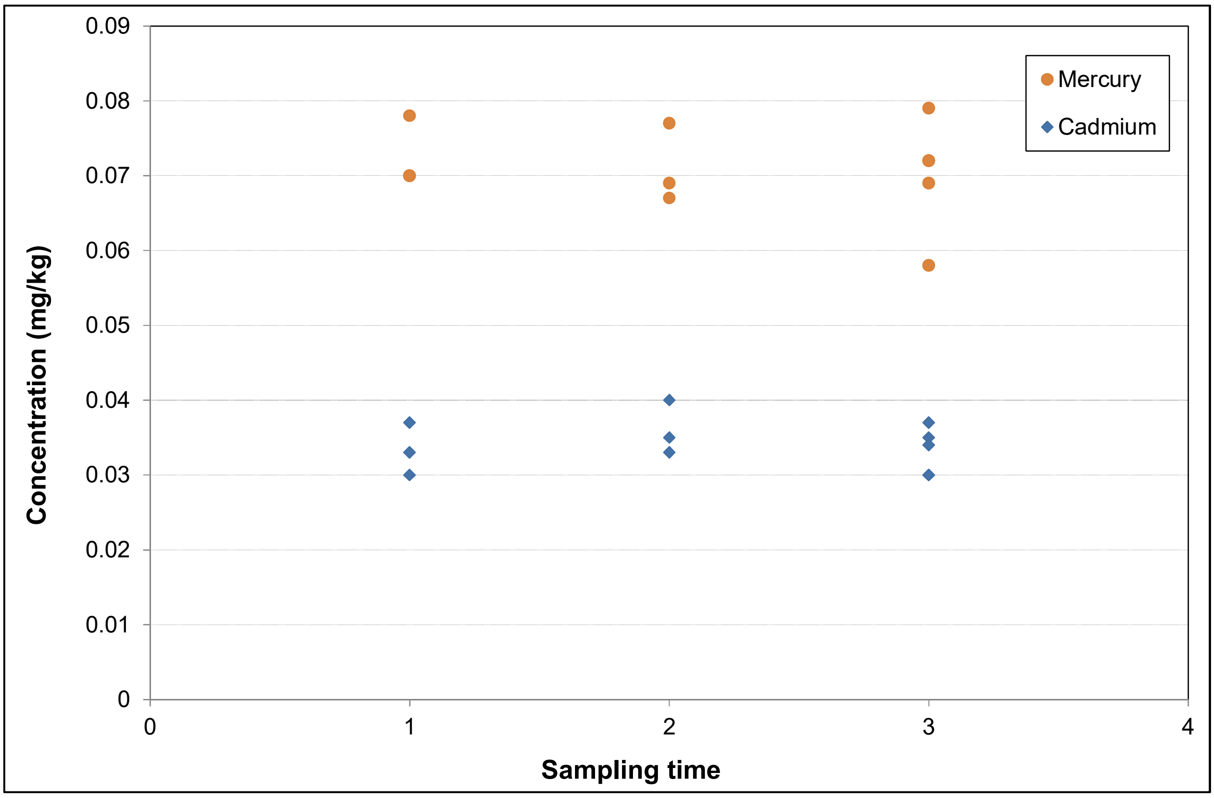

Figure 4-4: Mercury and cadmium concentrations (mg/kg) at the site over time
Sampling time 1 – 2010, 2 – 2013, 3 – 2014

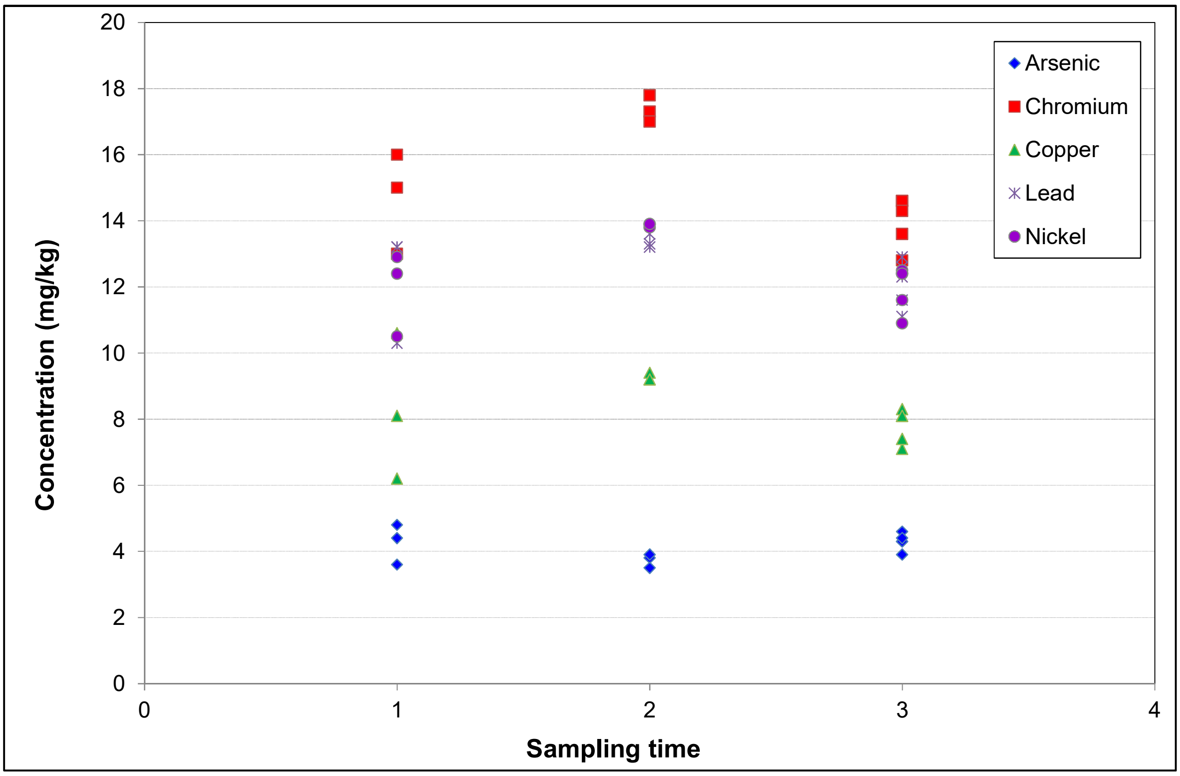

Figure 4-5: Arsenic, chromium, copper, lead and nickel concentrations at the site over time
Sampling time 1 – 2010, 2 – 2013, 3 – 2014

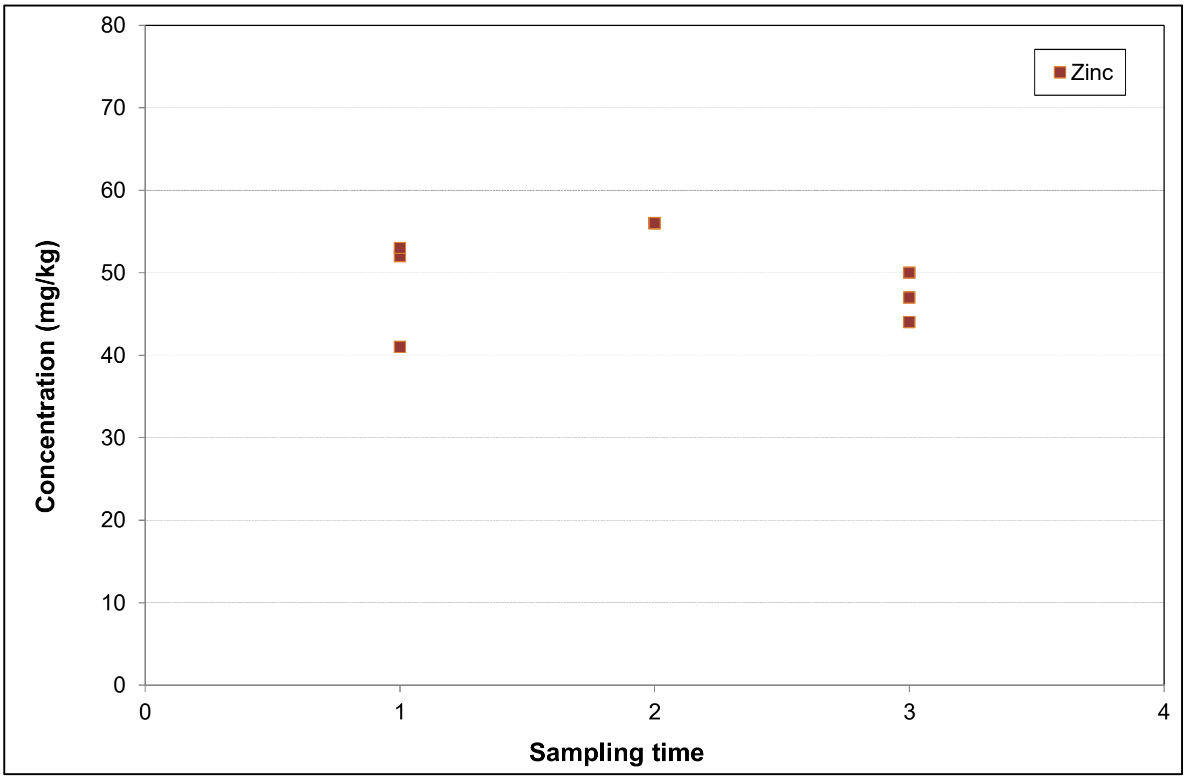

Figure 4-6: Zinc concentrations (mg/kg) at the site over time
Sampling time 1 – 2010, 2 – 2013, 3 – 2014

Table 4-2: PAH concentrations (mg/kg) over time

Blank spaces – concentration below the analytical level of detection

	2010	2013	2014	ISQG-low
Acenaphthylene	0.004			0.044
Anthracene	0.005		0.004	0.085
Fluorene	0.005	0.005	0.005	0.019
Phenanthrene	0.024	0.012	0.013	0.240
Benzo[a]anthracene	0.071		0.013	0.261
Benzo[a]pyrene (BAP)	0.074	0.002	0.017	0.430
Chrysene	0.051		0.017	0.384
Dibenzo[a,h]anthracene	0.009		0.002	0.063
Fluoranthene	0.092	0.006	0.025	0.600
Pyrene	0.099	0.010	0.024	0.665
Low molecular wt. PAHs	0.090	0.041	0.074	0.552
High molecular wt. PAHs	0.396	0.022	0.099	1.7
Benzo[b]fluoranthene + Benzo[j] fluoranthene	0.095	0.010	0.029	
Benzo[g,h,i]perylene	0.056	0.011	0.016	
Benzo[k]flouranthene	0.036		0.010	
Indeno(1,2,3-c,d) pyrene	0.056	0.002	0.012	

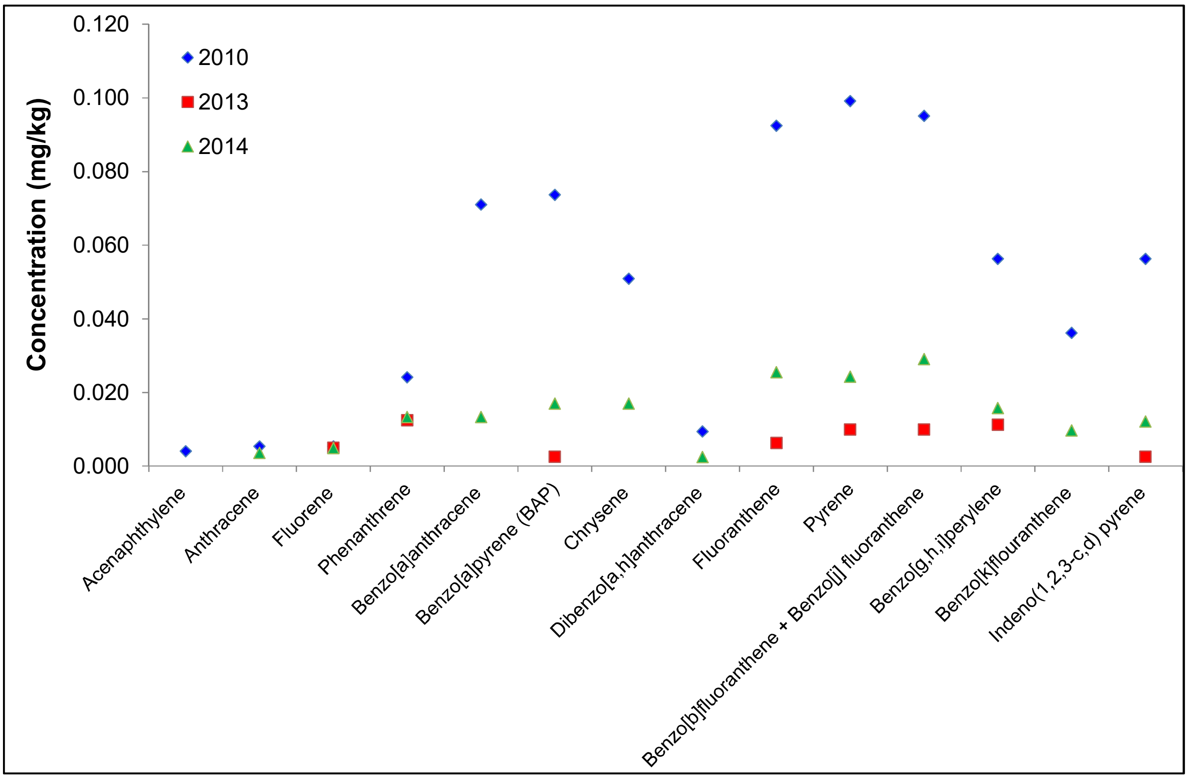

Figure 4-7: PAH concentrations (mg/kg) over time

5 Intertidal sediments and macrobiota

Healthy intertidal estuarine sediment supports a diversity of animals, including anemones, snails, shellfish, worms, crabs and hoppers. The presence, abundance and survival of these animals (biota) depend on the grain size distribution of the mudflat sediment, the quality of the mudflat sediment that they live on or in, and the quality and salinity of the water. The diversity and abundance of animals living on and in the mudflats provides food for fish and birds while shellfish, such as cockles, are a valued food item for many people. In addition these sediment-living animals, by their normal actions of feeding and burrowing, keep the sediments well oxygenated and healthy.

The grain size and quality of mudflat sediment has the potential to be impacted by:

- soil that runs off the land and into the rivers and estuary;
- hydrodynamics (and resulting transport or deposition of sediment);
- inputs of organic matter eg. plant debris such as leaves, twigs, rotting seaweed and dead phytoplankton, faecal matter, dead animals;
- the quality of the overlying water, including high nutrient concentrations or low oxygen concentrations;
- contaminants such as metals, pesticides and herbicides that enter the rivers and the estuary in stormwater and other legal and illegal discharges.

The features of the sediment that influence the types and abundance of the animals that live on or in it are:

- the sediment grain size composition;
- the amount of organic matter in the sediment;
- the concentrations of potentially toxic contaminants.

5.1 One-off study (central and southern, 2005)

Sediments and macrobiota were collected from seven sites within the central and southern area of this estuary (Figure 4-1) in 2005. The details of the sampling and results are presented in Fenwick *et al.* (2006).

The following is a summary of the findings of the 2005 study.

1. Sediments varied widely from firm sandy muds to gravelly sand and gravel indurated over mud.
2. Muddy sediments retained water on their surfaces, whereas coarser sediments were free draining. Coarser sediments lacked any subsurface structure, but profiles of muddy sediments showed a shallow aerobic surface horizon, an intermediate light grey layer and deeper dark grey to black areas.
3. Sediment mud content varied widely, and organic content was low in all samples, ranging from 0.8 % in gravelly sand and soft sand to 2.1 % in firm muddy sand. The organic content of other sediment samples was around 1.5 %.
4. The benthic macrobiota comprised 16 species of invertebrates. Macrophytes were absent and algae were common at one site only. Most species were quite restricted in their distribution among sites.
5. There were no obvious patterns to the distributions of most species, except the abundance of the gastropod *Amphibola crenata* and the burrowing crab *Austrohelice crassa* tended to increase with decreasing sediment mud content. Also, a marine isopod was concentrated at sites closest to the estuary's opening to the sea.

6. The quantitative composition of the macrofauna varied substantially between sites over relatively small spatial scales (100-300 m), probably as a result of the highly variable hydrodynamic environment and physical conditions.
7. The investigation could not identify which factors were important determinants of macrofaunal pattern.

5.2 Annual intertidal sediments and macrobiota monitoring

The intertidal sediments and macrobiota monitoring includes the monitoring of sediment characteristics including grain size distribution and sediment chemistry, the presence and abundance of animals in and on the sediment, the % cover of the sediment surface by macroalgae and the size of edible shellfish.

The aims of the Environment Canterbury intertidal sediments and macrobiota monitoring programme are:

- Provide an assessment of the state of the sediments and macrobenthic communities at selected sites in the Canterbury region;
- Identify trends of change in the sediments and macrobenthic communities;
- Identify any ecological issues;
- Provide a baseline and/or context for future studies;
- Provide context to consent applications, and compliance monitoring results;
- Monitor the Council's progress towards achieving the objectives of the RCEP.

Environment Canterbury began annual intertidal estuarine sediments and macrobiota monitoring at a number of sites in Canterbury in 2009. One of the monitoring sites is within Te Akaaka.

5.2.1 Methods

Sampling sites

The initial sampling area was the intertidal flat north of the mouth of the Ashley River/Rakahuri and south of Saltwater Creek. This area was sampled from 2009-2011. However, some of the samples collected did not contain any estuarine macrobiota and other samples contained a low number of different species and a low number of individuals. That is, the data collected indicated this was not a suitable area for monitoring the sediments and macrobiota in this estuary over time[8]. In 2011 an additional area was sampled (macrobiota only), with this area south of the initial area, and closer to the mouth of the Ashley River/Rakahuri mouth. From 2012 sampling was only carried out in the southern area (Figure 5-1).

Samples are collected from the mid-low tide region in an area 60 m along the shore (parallel to the coast/water channel) by 20 m down the shore (perpendicular to the coast/water channel). The GPS co-ordinates of each corner of the sampling area are recorded on each sampling occasion. The GPS co-ordinates of the landward right-hand corner of this area are used to re-locate the sampling site (Appendix 4).

The location of the landward right-hand corner of the sampling site has differed over time (Figure 5-2). In 2011 a slightly different site in the northern area was sampled in the hope of finding more macrobiota species and individuals, i.e., a better monitoring site. The reason for the difference in sampling location between years in the southern area is because of the nature of the sediments. This estuary has large

[8] These results do suggest that environmental conditions at this location in the estuary are generally unsuitable for intertidal life. I suspect it is the nature of the sediment, but more work is required to determine if this is the case.

areas of cobble substrate with the depth of the fine sediment (sand/mud) over the cobbles differing between years (Figure 5-3). For sampling, the ideal is to have at least a 10 cm deep covering of sediment over the cobbles. However when sampling we did find that the depth of the sediment was variable over the sampling site. The depth of the sediment is influenced by river flows/floods and the hydrodynamics within the estuary. This difference over time is a feature of this estuary but not of the other sites sampled elsewhere in Canterbury.

Figure 5-1: Intertidal sediment and macrobiota sampling areas

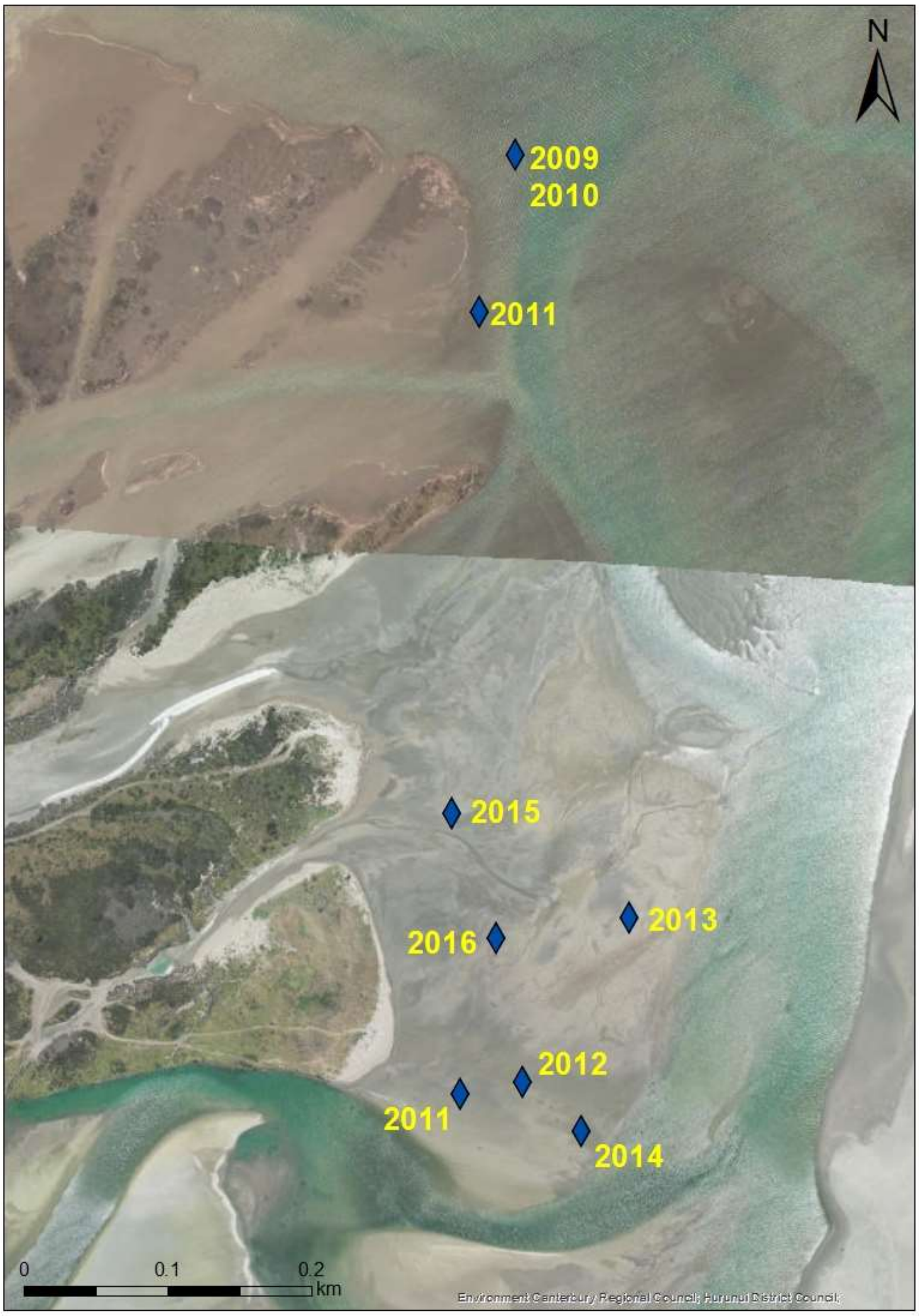

Figure 5-2: Location of the sampling sites over time

Figure 5-3: The northern 2011 sampling site when viewed in 2012

Sample collection and analyses
The 60 m by 20 m area was divided into twelve 10 m by 10m plots (Figure 5-4). Randomly generated cartesian co-ordinates determined where the samples were collected from (i.e. sampling station) within each plot. The following samples were collected from each plot:

- one surface (top 20 mm) sediment sample;
- one 130 mm diameter x 150 mm deep core.

And one 50 cm x 50 cm (0.25 m^2) quadrat was sampled.

Twelve sediment samples were collected. Sediment samples were composited, with each composite sample including sediment from three plots thus giving a total of four sediment samples for analysis. All sediment chemical analyses were carried out by Hill Laboratories and the sediment grain size analyses were carried out at Waikato University. The details of the analytical methods are provided in Appendix 5.

Twelve core samples were collected. Each core sample was sieved through a 0.5 mm screen and the material retained on the screen stored in alcohol. The animals present in each core sample (infauna) were sorted from the debris using a binocular microscope. The animals were then identified where possible to species level and counted. The shell length of the cockles, wedge shells and pipis and the height of mud snails were measured.

Twelve, 50 cm x 50 cm (0.25 m^2) quadrats were sampled. The number of each different type of animal on the surface of the sediment (epifauna), the percentage of the surface covered by seaweed (epiflora) and the number of crab burrows in each quadrat was counted and recorded. Only plants and animals visible to the naked eye were counted.

Figure 5-4: Sampling in the estuary in 2013

Crab burrows
Crab burrows are common in estuaries. Burrows are easily counted but whether a crab lives in the burrow is not known. The type of crab in the burrow is also not known. The two common crabs that burrow in Canterbury estuaries are the stalk-eyed mud crab (*Hemiplax hirtipes*) and the mud crab (*Austrohelice crassa*).

Cockles (*Austrovenus stutchburyi*)
Cockles live just below the sediment surface. The size classes described in the results are:
Recruits 0 – 5 mm
Juveniles 5 – 20 mm
Reproductive adults >20 mm
Edible size >35 mm

5.2.2 Data analyses

Microsoft Excel 2010, STATISTICA (version 7) and PRIMER (version 6) (Clarke and Warwick, 2001) were used for data analyses and graphing.

There are currently no national indicators that can be applied to the data to describe the relative state of the sediments and macrobiota, for example, good health, poor health, very poor health. Rather the data are summarised and results compared to guidelines values where available. The information obtained provides an indication of the state of the sediments and macrobiota.

For the sediment data the sediment grain size distribution and sediment chemistry data are summarised. The results for total organic carbon (TOC), total reactive phosphorus (TRP) and total nitrogen (TN) are compared to values that provide an indication of the state of enrichment of the sediments (Table 5-1).

Table 5-1: Ecological stress classification based on sediment total organic carbon (TOC), total reactive phosphorus (TRP) and total nitrogen (TN) concentrations

(TRP from Robertson and Steven, 2013, TOC and TN from Robertson *et al.*, 2016)

Ecological stress description	TOC (%)	TN (mg/kg)	TRP (mg/kg)
No stress	<0.5	<250	≤200
Minor stress	0.5 - 1	250 - 1000	200 - 500
Moderate stress	>1 - 2	>1000-2000	501 - 1000
Significant stress	>2	>2000	> 1000

For the macrobiota, summary data on the animals living in the sediment and the animals and obvious plant species on the surface of the sediment are presented.

Multi-Dimensional Scaling (MDS) ordination and a cluster analysis were used to investigate similarities and differences between sites over time in the presence and abundance of infauna. The Bray-Curtis similarity measure of $\log_{10}(x+1)$ transformed infauna data was used to generate the similarity matrix. This similarity matrix was used to produce an MDS ordination and a cluster diagram. The cluster diagram provides the per cent similarity of the infauna between sites and between years; the MDS does not provide this. In this MDS ordination, sites are plotted in a spatial array. On the MDS plot the more similar the biological community, the closer together the sites on the plot. Each plot has a stress value, which is a goodness-of-fit measure, of how well the 2-dimensional ordination of points on the plot represents the actual values in the similarity matrix (Clarke and Warwick, 2001). Low stress values indicate a good ordination and the plot is not a misleading interpretation of the data.

NOTE: at the time of finishing this report the 2016 sediments data were available but the macrobiota data were not.

Figure 5-5: The fine sediment over lying the cobbles in the Southern area

5.2.3 Results

Sediments

General description of the surface sediment profile

Northern area

2009 – ~ 1mm of freshly deposited sediment on surface, below which was grey sandy/clay with orange streaks or brown/grey sandy/clay.

2010 – light grey muddy sand with orange streaks (Figure 5-6)

2011 – light grey sand with a high clay content and orange streaks (Figure 5-6)

Southern area

2011 – surface firm mobile sand, with medium -coarse sand below

2012 – loose sand over cobbles

2013 – loose grey sand over a dark grey layer with high clay content, medium-coarse sand below (Figure 5-7). Profiles did vary through the site

2014 – coarse grey sand at the surface, grey sand clay layer, medium-coarse sand below (Figure 5-7). Profiles did vary through the site.

2015 – highly variable profiles through the site. From muddy sand over dark grey sand/mud (Figure 5-7) to only coarse sand

2016 – highly variable profiles through the site. From variable depth surface layer of sandy silt over dark grey sand/mud (Figure 5-7), to no distinct layering

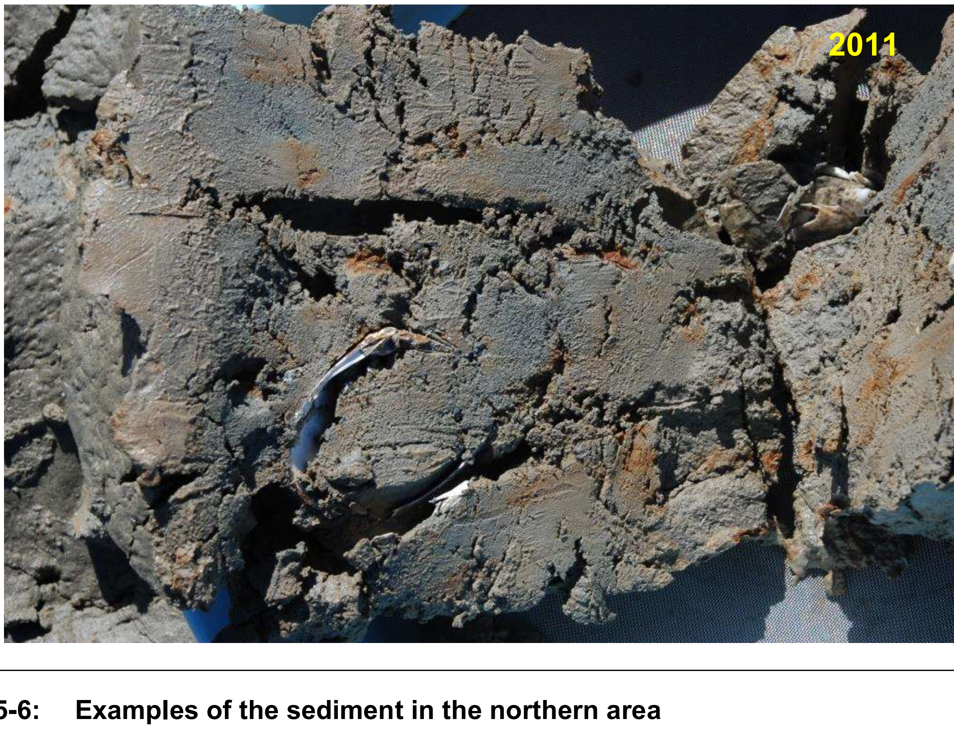

Figure 5-6: Examples of the sediment in the northern area

Figure 5-7: Examples of the sediment in the southern area

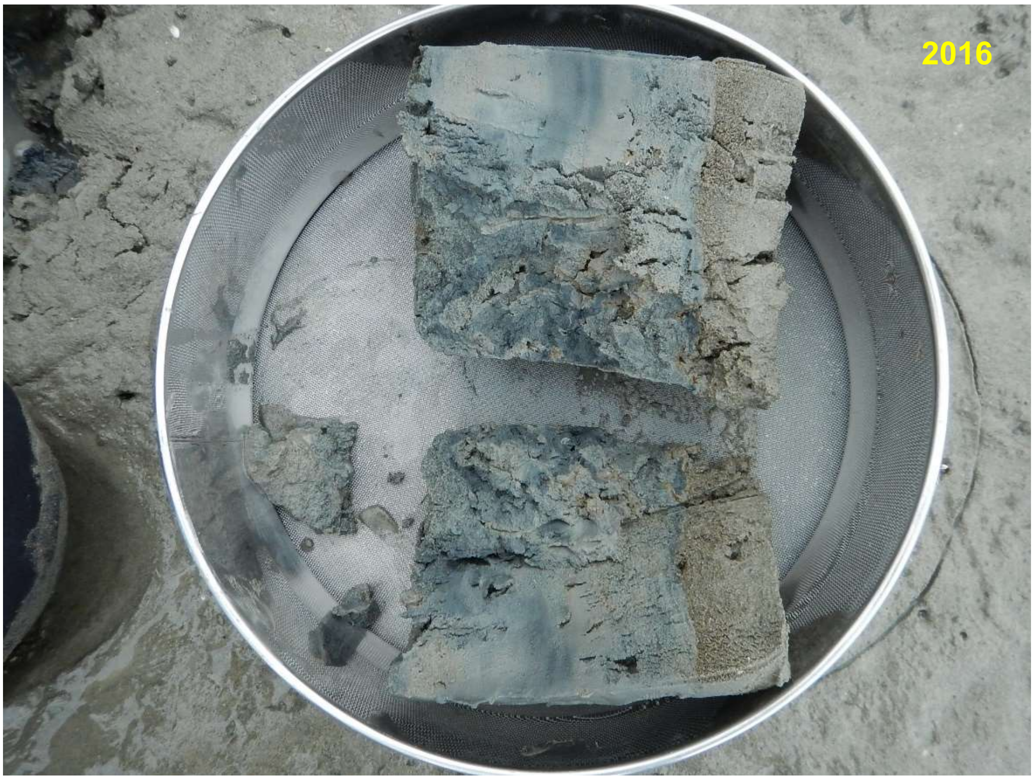

Figure 5-7 continued: examples of the sediment in the southern area

Sediment grain size composition
The grain size composition of the top 2 cm of sediment at the sites over time is shown in Figure 5-8. The sediment in the southern area is predominantly sand while that in the northern area is mud-sand.

In the northern area the per cent sand was lower in 2011 than in 2009 and 2010 while the opposite was the case for mud. In the southern area the sediment was 100% sand in 2012, with up to 15% mud in 2013, 27% mud in 2014 and 2015 and 40% mud in 2016. It appears that in both the northern and southern areas there was an increase in the % mud and a decrease in the % sand over time. However, sampling was not undertaken at exactly the same location every year (refer to section 5.2.1 Methods). That is, the results could be because of differences in the location of the sampling site rather an indication of trends in sediment grain size composition.

Future investigations are required to assess the dynamics of the sediment (sand, mud and gravel) within this estuary.

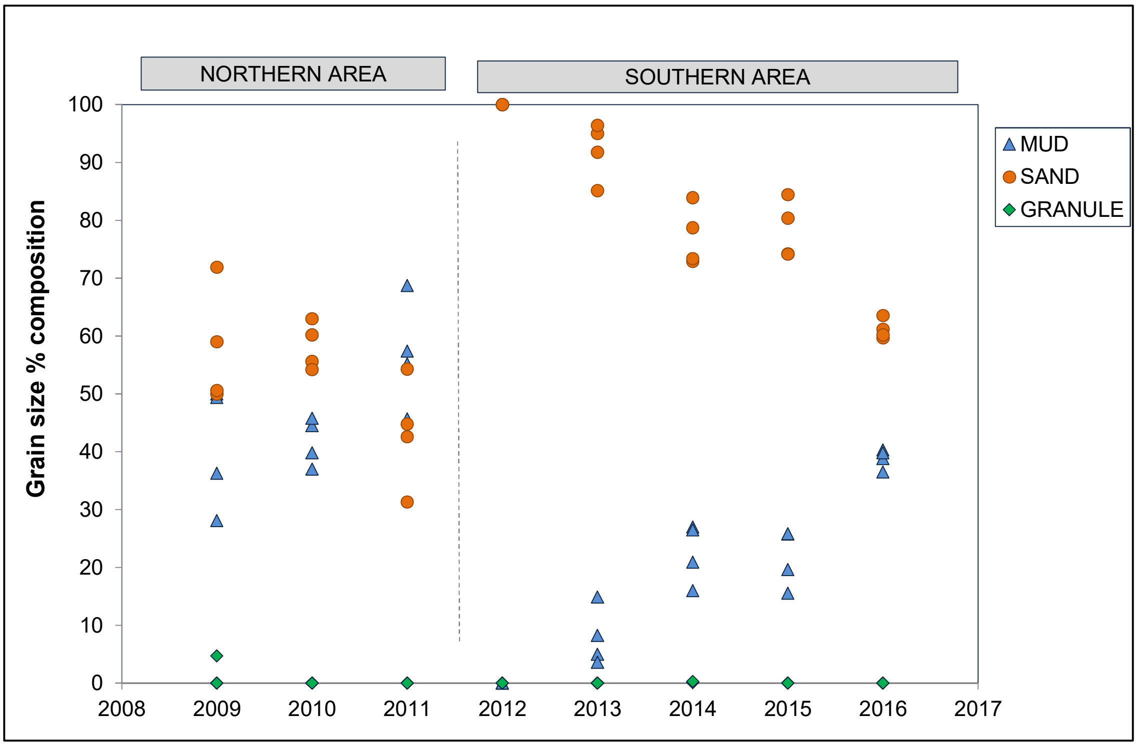

Figure 5-8: Grain size composition at the sampling sites over time

Sediment chemistry

The organic matter content, total organic carbon, total reactive phosphorus, total nitrogen and chlorophyll-a concentrations are shown in Figure 5-9. Total organic carbon was not measured in 2009 and chlorophyll-a was not measured in 2011. For total nitrogen (TN) many of the laboratory results were below the analytical detection level (ADL), these results were not plotted on the graph. The dotted lines on the TN and DRP graphs mark the boundaries between ecological stress levels, as described in Table 5-1.

The per cent organic matter and total reactive phosphorus concentrations increase as the percentage of mud increases (Figure 5-10). There is a statistically significant correlation between the % organic matter and % mud ($p = 0.00$, $r^2 = 0.53$), and between total reactive phosphorus concentration and % mud ($p=0.00$, $r^2 = 0.756$). There is also a statistically significant correlation between the % organic matter and total reactive phosphorus concentrations ($p = 0.00$, $r^2 = 0.566$).

In 2014 the chlorophyll-a concentration in two samples was notably higher than concentrations on any other sampling occasion. Sediment chorophyll-a concentration provides a measure of the abundance of microphytobenthos - microalgae that inhabits the surface of the sediment. An abundance of microphytobenthos can be seen by the naked eye as a green or brownish film on the sediment surface. The high chorophyll-a concentration in two samples suggests an abundance of microphytobenthos, but because the high concentrations were only it two samples it also indicates the patchiness of microphytobenthos. In the two samples with a high chorophyll-a concentration the per cent organic matter was higher than in the other two samples and the highest recorded TN, TRP and TOC concentration occurred in the sample with the highest chorophyll-a concentration.

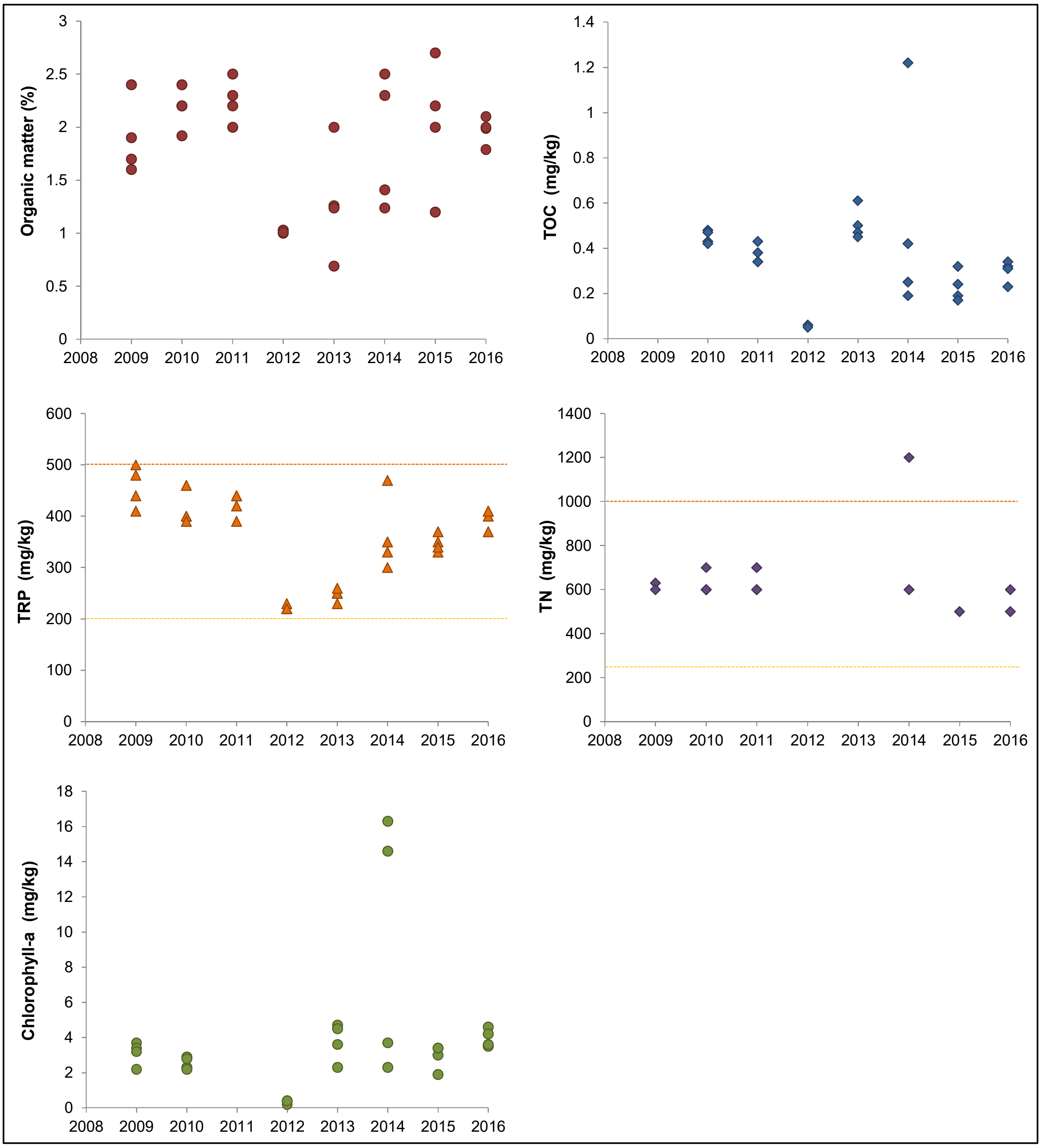

Figure 5-9: Chemistry of the surface sediments over time

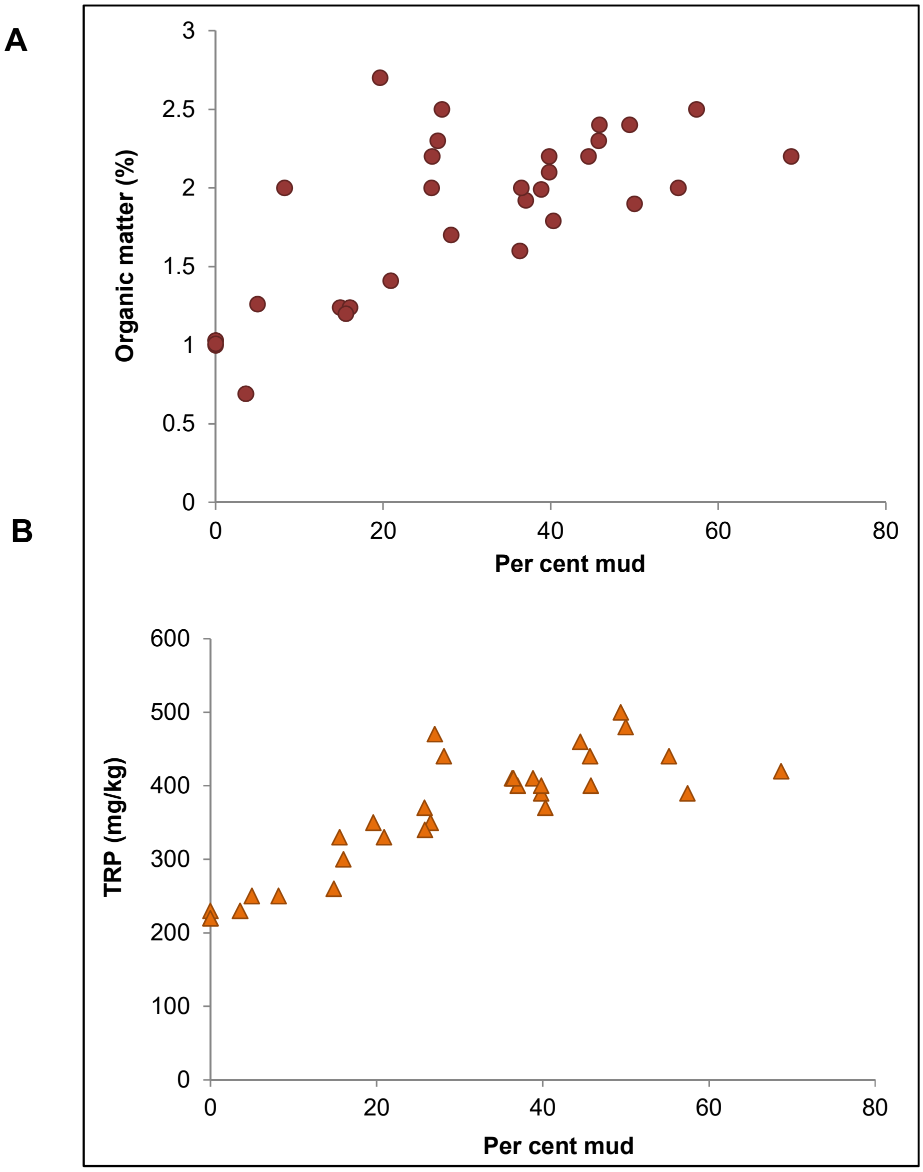

Figure 5-10: Relationship between A. % organic matter and % mud, and B. total reactive phosphorus and % mud

The TOC, TRP and TN results (Figure 5-9 and Appendix 6) indicate that, apart from the influence of unexplained outliers in 2014 (possibly caused by an abundance of microphytobenthos), at worst there is minor ecological stress (enrichment) of the sediments at the sampling sites.

Macrobiota

Forty-one taxa were present in the collected samples (Table 5-2). This number of taxa is lower than the 59 reported from the Estuary of the Heathcote and Avon Rivers/Ihutai (Bolton-Ritchie, 2015). Almost all the taxa identified are found in estuarine intertidal areas in Canterbury. However, the worm *Euzonus* sp. has not been found elsewhere in Canterbury. *Euzonus* sp. was only found in the southern area in 2011. The sediment at the time of sampling was 100% sand, so it could be that this worm is intolerant of any mud.

Table 5-2: Taxa recorded from Te Akaaka

Animal group	Scientific name	Common name
Snails and shellfish	*Amphibola crenata*	mud snail
	Arithritica bifurca	small bivalve
	Austrovenus stutchburyi	cockle
	Paphies australis	pipi
	Paphies donacina	tuatua
	Potamopyrgus estuarinus	
	Mactra ovata	fragile shell bivalve
	Tellina liliana	wedge shell
	Turbonilla sp.	
	Gastropod AsA	
worms	*Aglaophamus macroura*	
	Boccardia syrtis	
	Capitellid spp.	
	Euzonus sp.	
	Hemipodus simplex	
	Heteromastus filiformis	
	Nicon aestuariensis	
	Pectinaria australis	
	Perinereis vallata	
	Phyllodocid sp.	
	Scolelepis sp.	
	Scolecolepides benhami	
	Oligochaetes	
Crustacea	Amphipod Ash1	hopper
	Austrohelice crassa	mud crab
	Austrominius modestus	barnacle
	Halicarcinus cooki	pill-box crab
	Halicarcinui whitei	pill-box crab
	Hemiplax hirtipes	stalk-eyed mud crab
	Metacirolana japonica	louse
	Isopoda AsB	
	Isopoda BpB	louse
	Paracorophium excavatum	hopper
	Phoxocephalid sp.	hopper
	Ostracod Ash	
	Unidentified natant decapod (juv).	shrimp
Insecta	Orthocladiinae	
	Oxyethira sp.	Caddis
	Hexatominae	
	Muscidae	Fly larva
Nemertea	nemertine	ribbon worm

Core samples (animals living on/in the sediment)

The total number of taxa in each core ranged from 0-14, with 0-5 snails and shellfish, 0-8 worm, 0-4 Crustacea and 0-2 other taxa per core (Figure 5-11). The southern area typically supported more taxa, and in particular worm taxa, than the northern area.

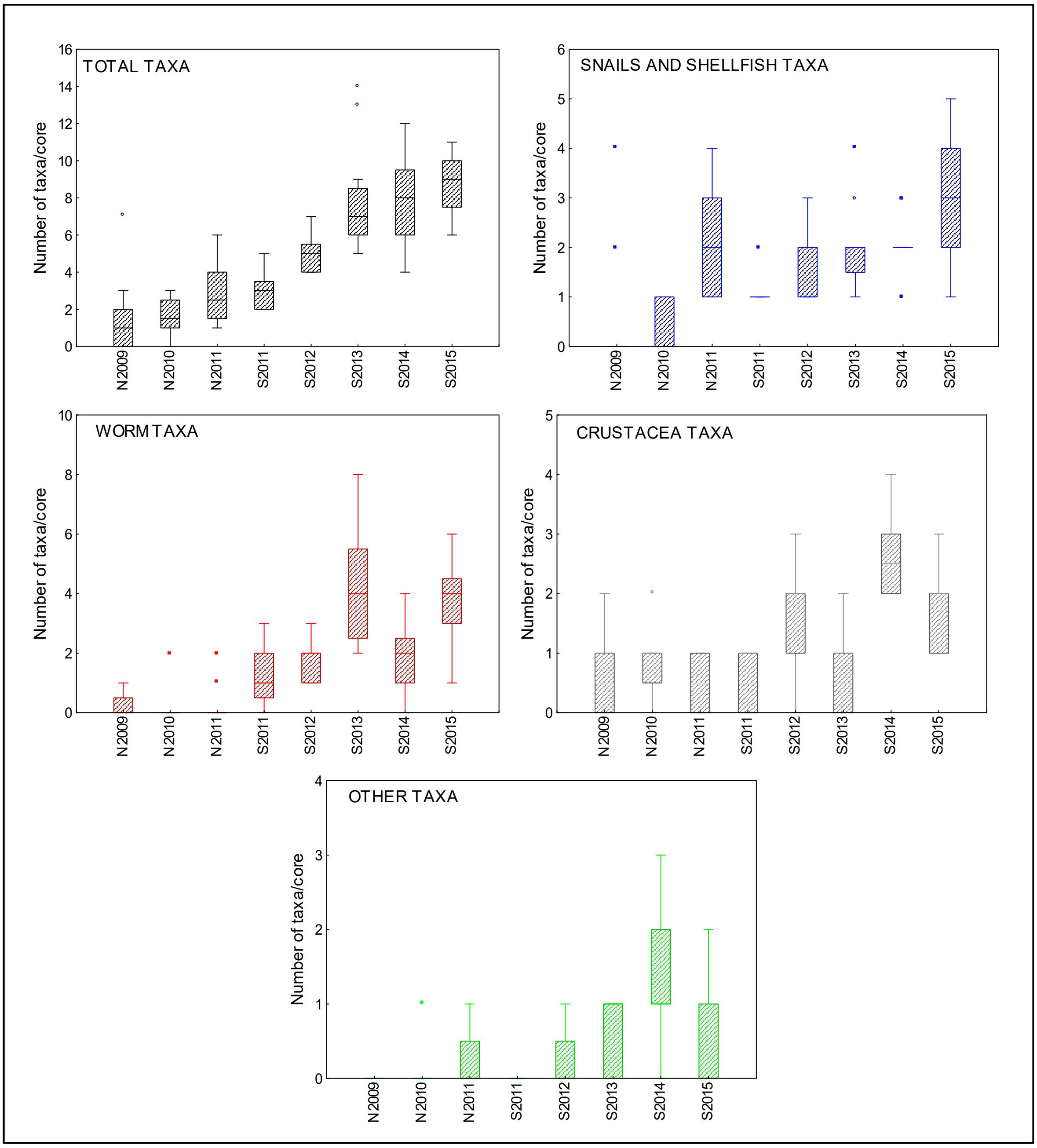

Figure 5-11: Number of taxa present in the cores over time

The number of individuals per core was used to calculate the number of individuals per square metre (i.e. density). The density ranged from 0-66,109, with 0-26,625 snails and shellfish, 0-28,054 worm, 0-53,250 Crustacea and 0-584 other taxa (Figure 5-12). Densities were lower in the northern that the southern area. Densities in the southern area differed between years with the lowest density in 2011 and the highest density in 2014. In 2014, densities ranged from 844 to 66,109/m^2 as a result of the very variable densities of worm and Crustacea individuals.

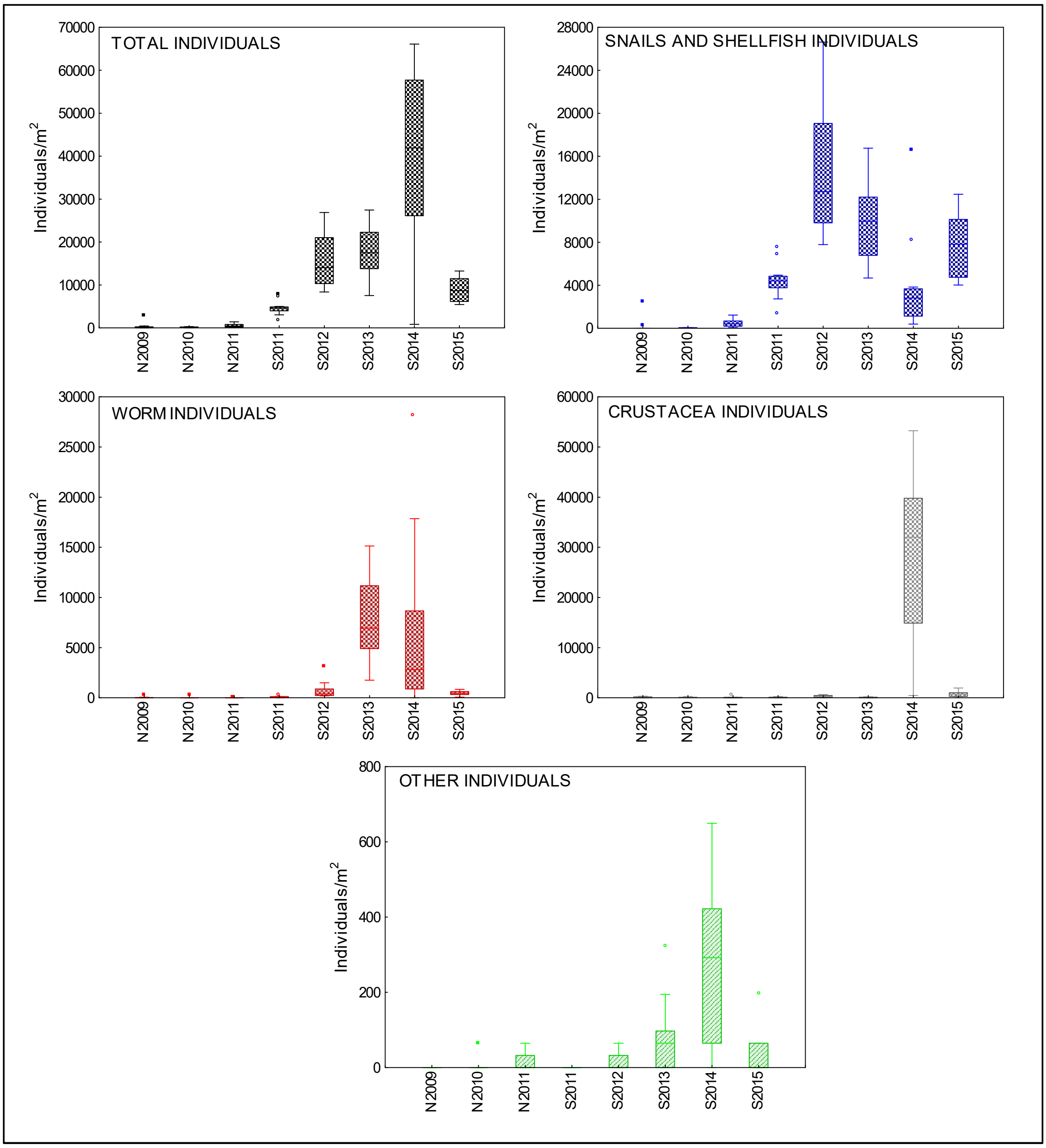

Figure 5-12: Number of individuals/m² over time

The five most abundant taxa present in the cores as well as the total number of individuals of each taxa in the cores on each sampling occasion are listed in Table 5-3. There is a clear difference between areas in the most abundant taxa.

Table 5-3: The five most abundant taxa and the total number of individuals in the cores each year

NORTHERN AREA					
2009		2010		2011	
Taxa	total individuals	Taxa	total individuals	Taxa	total individuals
cockle	26	mud crab	15	cockle	70
mud crab	18	Amphipod Ash1	3	mud crab	11
small bivalve	10	fragile shelled bivalve	2	pipi	6
fragile shelled bivalve	3	*Scolecolepides benhami*	2	small bivalve	5
Boccardia spp.	3	cockle	1	fragile shelled bivalve	4

SOUTHERN AREA					
2011		2012		2013	
Taxa	total individuals	Taxa	total individuals	Taxa	total individuals
pipi	818	pipi	2654	pipi	1773
Isopod BpB	14	*Scolelepis* sp.	122	*Scolelepis* sp.	1283
Scolelepis sp.	8	*Austrominius modestus*	29	*Boccardia* spp.	66
Euzonus sp.	5	*Paracorophium excavatum*	22	cockle	47
Aglaophamus macroura	4	Oligochaetes	10	*Nicon aestuariensis*	43

SOUTHERN AREA			
2014		2015	
Taxa	total individuals	Taxa	total individuals
Paracorophium excavatum	5044	pipi	821
Oligochaetes	1186	cockle	589
pipi	677	mud crab	74
Metacirolana japonica	44	*Metacirolana japonica*	43
Potamypyrgus sp.	42	*Paracorophium excavatum*	20

In the northern area and over the three years of sampling, eight taxa are listed in Table 5-3. Cockles, mud crabs and fragile shelled bivalves are in the five most abundant taxa each year. The small bivalve was one of the five most abundant taxa in two of the years. *Boccardia* spp, *Scolecolepides benhami,* Amphipod Ash1 and pipi were one of the five most abundant taxa in one of the years.

In the southern area and over five years, fourteen taxa are listed in Table 5-3. Pipis are the only taxa in the five most abundant taxa each year. The cute-as-a-button worm *Scolelepis* sp. and the hopper *Paracorophium excavatum* are listed in three of the years and the louse *Metacirolana japonica* and oligochaete worms are listed in two of the years. The 2014 macrobiota is probably different as a consequence of two high rainfall events (Appendix 7) in the month prior to sampling. This included 34.2 mm over 24 hours and 51.2 mm over 48 hours (16.4 and 34.8 mm respectively in each 24 hour period). As a consequence of the rainfall river flows would have been significant, resulting in significant disturbance, re-suspension and re-distribution of fine sediment within the estuary.

The MDS plot (Figure 5-13) and the cluster plot (Figure 5-14) depicts the similarities/differences in the presence and abundance of infauna over time. The stress value for the MDS plot is 0.02 which means the two-dimensional ordination is an excellent representation of the data. There is a clear separation of the northern area infauna from the southern area infauna. Within the northern area the 2009 and 2011 infauna were most similar (~ 70% similarity) with the 2010 infauna having around 50 % similarity with the 2009 and 2011 infauna. Within the southern area the 2012 and 2013 infauna were most similar (~ 60% similarity), while the 2014 infauna has the lowest similarity to the infauna from other years.

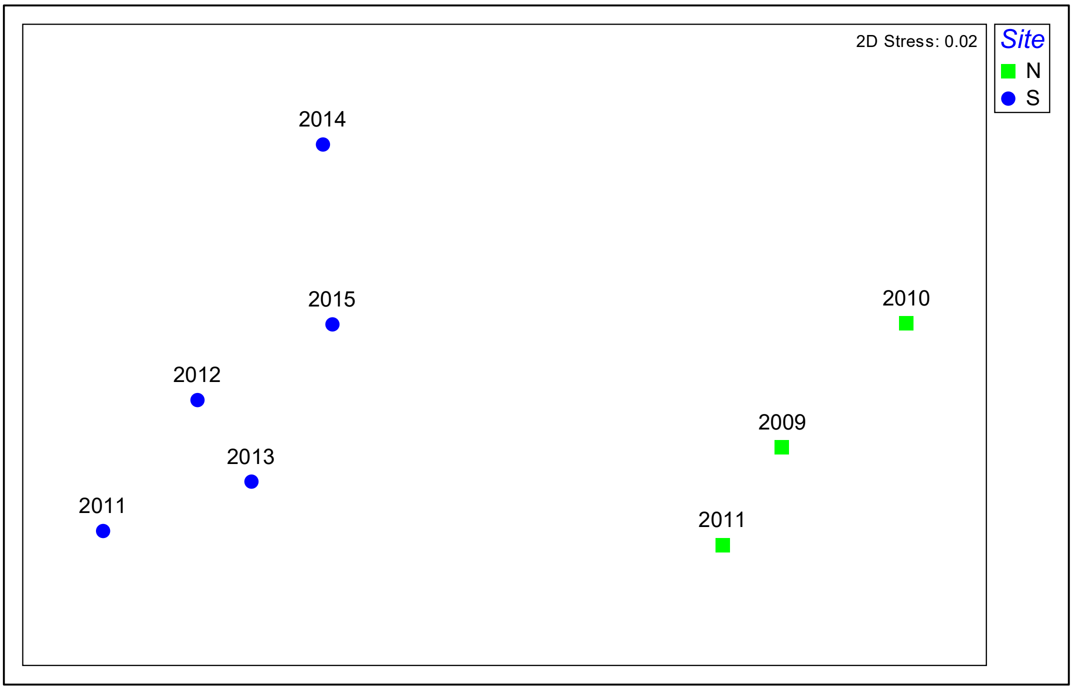

Figure 5-13: MDS plot of the infauna community over time

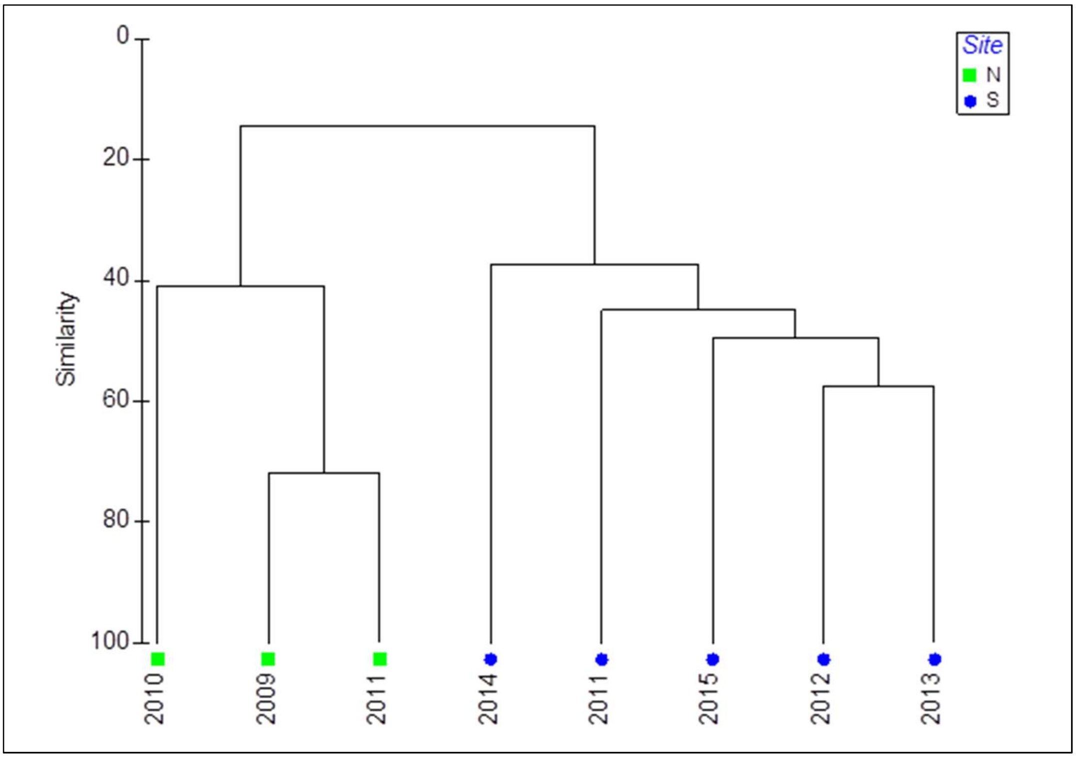

Figure 5-14: Cluster plot of the infauna community over time

Shellfish

Cockles and pipis occur in both the northern and southern sampling areas. The densities of cockles and pipis in the cores samples on each sampling occasion and their size distribution are provided in Tables 5-4 and 5-5.

Table 5-4: Abundance and size distribution of cockles (*Austrovenus stutchburyi*) in the core samples

	Year	Total number of cockles	% Recruits	% Juveniles	% Reproductive	% Edible
Northern area	2009	26	70	15	15	
	2010	1	100			
	2011	70	80	4	16	
Southern area	2011	2	100			
	2012	5	100			
	2013	47	100			
	2014	4	100			
	2015	589	99	1		

There were typically low densities cockles in the core samples, apart from in 2015. In 2015 there were more cockles than the total of all those recorded in the other six years. Most of the cockles present in the samples were recruits, that is, individuals smaller than 5 mm long. No edible-sized individuals and few reproductive sized individuals were present in the samples. The low number of individuals and the prevalence of recruits suggest that while there is limited recruitment of individuals to these areas, most do not survive to reach reproductive size.

Within Te Akaaka, the harvestable sized pipis can be found in sandy areas near the estuary mouth. However, the baby pipis (recruits) are more widespread in the estuary, as a consequence of broadcast spawning. Pipis can float in the water column and move, however, many of the baby pipis that settle through the estuary will not make it to adult size as a consequence of natural factors. The abundance of small pipis in the areas surveyed reflects successful spawning of the adult pipis within and adjacent to the estuary.

Pipi recruits (individuals smaller than 5 mm long) were abundant in the southern area but only a few were found in the northern area.

Table 5-5: Abundance and size distribution of pipis (*Paphies australis*) in the core samples

	Year	Total number of pipis	% ≤ 5 mm	% 5 - 10 mm	> 10 mm
Northern area	2009	3	100		
	2010	0			
	2011	6	100		
Southern area	2011	818	88	12	
	2012	2654	96	4	
	2013	1773	100		
	2014	677	64	6	
	2015	821	91.5	8	0.5 (all <13 mm)

On the sediment surface (Epifauna and epiflora)
No epifauna taxa, such as mud snails and mud whelks, were present in the sampled quadrats. No epiflora taxa, such as sea lettuce, *Ulva lactuca* and the red seaweed *Gracilaria chilensis* were present in the sampled quadrats. However, there were crab burrows and fragile shell bivalve openings (Figure 5-15). Fragile shell bivalve openings were only seen in the northern area, with this observation supported by the presence of empty shells within this area, but not in the southern area. In the southern area the opening are only crab burrows (Figure 5-16). A summary of the number of crab burrow/fragile shell bivalve openings is provided in Table 5-6.

Table 5-6: Summary of the number of crab burrow/fragile shell bivalve openings per m²

	NORTHERN AREA			SOUTHERN AREA				
	2009	2010	2011	2011	2012	2013	2014	2015
	Crab burrow and fragile shell bivalve openings			Crab burrow openings				
Minimum	44	260	60			0	0	280
Mean	68	375	126			4	25	717
Maximum	120	452	172			36	68	2192

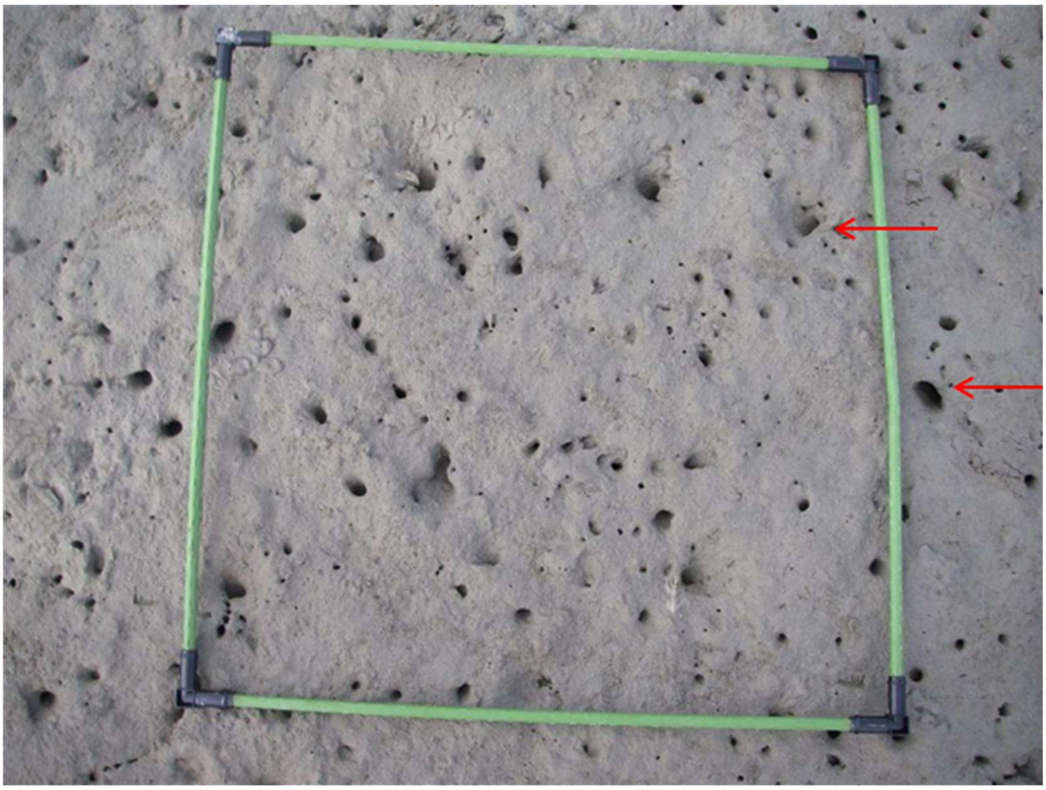

Figure 5-15: Crab burrows (circular) and fragile shell bivalve openings (ovate), 2010

Red arrows indicate the oblong openings of the fragile shell bivalve

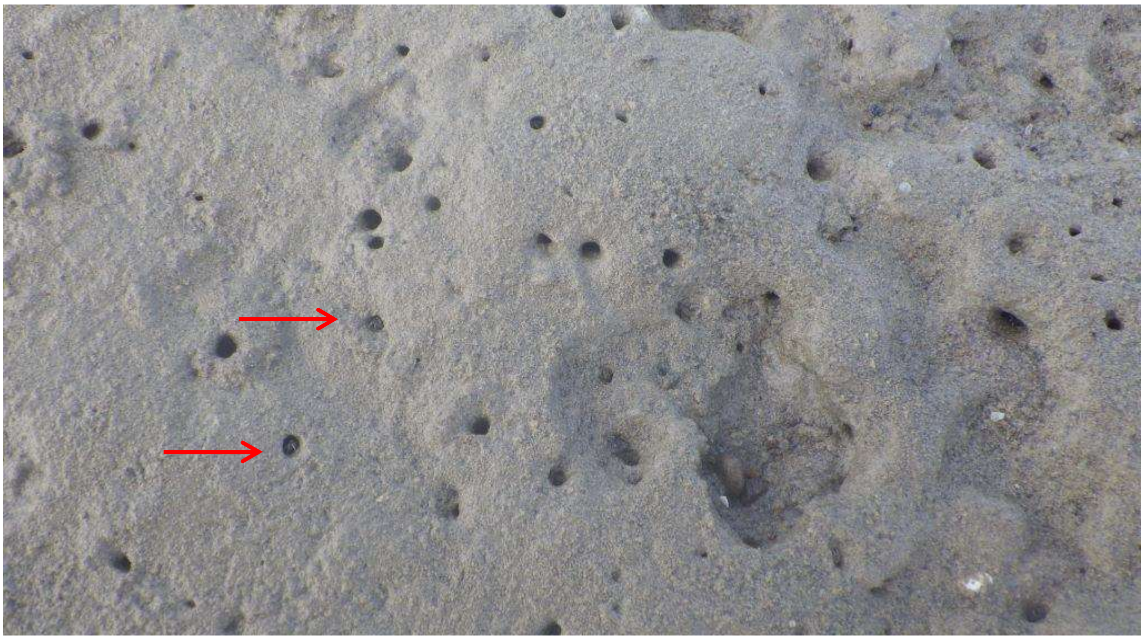

Figure 5-16: Crab burrow openings, 2015

Red arrows indicate very small crabs in the burrow opening

6 Water quality for ecosystem health

Good water quality is required for the plants and animals that live in the estuary to function normally. For the water to be of good quality it should not contain unnaturally high concentrations of nutrients or sediment and must contain sufficient oxygen.

6.1 Methods

6.1.1 Sampling and laboratory analysis

Water quality samples have been collected from two sites within the estuary. The location of these sites is shown in Figure 6-1.

Figure 6-1: Water quality sampling sites within Te Akaaka

The Estuary 1 site is always near the estuary mouth. The location of the estuary mouth does change over time so the exact location of the sampling site also varies over time. The location of the Estuary 1 site on the map indicates where the mouth was when sampling began at this site. Site 2 is within the channel from Taranaki Creek. The details of the sampling regime are in Table 6-1.

Table 6-1: The sampling regime at each site

Site	Sampling frequency
Estuary 1	Quarterly (September, December, March, June) since September 2007 Monthly July 2014-June 2016
Estuary 2	Monthly July 2014-June 2016

All sampling was carried out by Environment Canterbury staff. Sampling was random with respect to state of the tide. Sampling occurred from low tide, when the water sampled would be mostly fresh water, to high tide when the water sampled would be a mix of sea water with the freshwater.

On-site measurements of salinity, water temperature, dissolved oxygen and dissolved oxygen % saturation were collected, and water colour, wind and weather conditions noted. Water samples were collected and analysed in an IANZ accredited laboratory for 11 parameters (Table 6-2). Detailed information on these parameters is provided in Appendix 8.

Table 6-2: Water quality parameters

*only in 2014-2016

Parameter	Unit
Total ammoniacal nitrogen (NH_4N)	mg/L
Nitrite-nitrate nitrogen (NNN)	mg/L
Total nitrogen (TN)	mg/L
Dissolved reactive phosphorus (DRP)	mg/L
Total phosphorus (TP)	mg/L
Turbidity	NTU
Total suspended solids (TSS)	mg/L
Chlorophyll-a	mg/L
pH	
Enterococci	number/100 mL
faecal coliforms*	CFU/100 mL

Between 2007 and 2012 laboratory analyses were carried out in the Environment Canterbury laboratory and by Hill Laboratories. Following the 22 February 2011 earthquake, all analyses were carried out by

Hill Laboratories for five months. The Environment Canterbury laboratory closed in October 2012 and since November 2012 all analyses were carried out by Hill Laboratories.

6.1.2 Data analyses

Quarterly data - Estuary 1 site
The data were analysed or graphed to assess for:

- potential for the water quality to influence ecosystem health;
- relationships between parameters;
- variability of each measured parameter;
- trends over time.

To assess the potential for the water quality to be influencing ecosystem health, results are compared to sea water trigger values/comparison values (Appendix 9). To assess for relationships between measured parameters a matrix plot of all parameters was constructed. From the matrix plot the parameters that appeared to be correlated were identified and investigated. To show the variability over time for each parameter a plot of the recorded values against time was constructed. To assess for trends in nutrients and total suspended solids concentrations and turbidity over time, the Mann-Kendall analysis in TIME TRENDS v.5.0 was applied to the data.

Monthly data 2014-2015 and 2015-2016– Estuary 1 and Estuary 2 sites
For each site the data were analysed or graphed to assess for:

- potential for ecological impacts;
- variability of each measured parameter.

As well data from the two sites were graphed together to compare water quality. There were insufficient data for trend analysis.

To assess the potential for the water quality to be influencing ecosystem health, results were compared to sea water trigger values/comparison values (Appendix 9). For site 2 (which is influenced by Taranaki Creek water, results were also compared to fresh water comparison values (Appendix 9). There is a notable difference between the comparison values for freshwater compared to sea water (Appendix 9). This is a significant issue both for the assessment of water quality in this estuary and nationally.

Water quality index
A water quality index is a tool for simplifying the reporting of water quality data. Details of the index are provided in Appendix 10. The index generates a value which is used to categorise the water quality as either very good, good, fair, poor or very poor.

6.2 Results

6.2.1 Quarterly sampling at Estuary 1 site

Potential for ecological impacts
The data collected are summarised in Table 6-3.

Recorded nitrite-nitrate nitrogen, dissolved inorganic nitrogen (mostly NNN) and total suspended solids concentrations and turbidity are higher than the sea water comparison values in 20 % or more of the samples. That is, they are potentially influencing the ecological health of the estuary at this site (Table

6-3). However, the more detailed evaluation below suggests this is an over-simplification of water quality for ecosystem health in this estuary because of the relative influence of freshwater and coastal water at different states of the tide.

Table 6-3: Summary of water quality data collected quarterly at Estuary 1 site since September 2007

Total number of samples = 37

Parameter	units	Range	Median	Comparison value (CV) upper	Number of samples above CV
Total ammoniacal nitrogen	mg/L	<0.005 - 0.096	0.015	0.5	0
Nitrite-nitrate nitrogen	mg/L	<0.001 - 0.87	0.11	0.05	28
Dissolved inorganic nitrogen	mg/L	0.006 - 0.966	0.155	0.25	11
Dissolved reactive phosphorus	mg/L	0.001 - 0.09	0.012	0.02	6
Total suspended solids	mg/L	1.8 - 2500	19	25	16
Chlorophyll-a	mg/L	0.0002 - 0.0052	0.0015	0.004	4
Turbidity	NTU	1.01 - 320	5	10	13
Enterococci	MPN/100 mL	<10 - 1100	10.5	140	1

Parameter	units	Range	Median	Comparison value (CV) lower	Number of samples below CV
Dissolved oxygen	% saturation	77.2 - 108.5	96.7	80	1

Parameter	units	Range	Median
Salinity	ppt	0.05 - 38.5	11.5
pH		7.3 - 8.2	7.9
Water temperature	°C	7.3 - 20	11.2
Total nitrogen	mg/L	0.143 - 1.6	0.27
Total phosphorus	mg/L	0.009 - 0.55	0.028

Relationship between some parameters

The salinity at the time of sampling ranged from 0.5 ppt (parts per thousand), which is freshwater, to 33.2 ppt, which is sea water. The sea water 2.5 to 10 kilometres from shore in Pegasus Bay typically has a salinity of 33 - 34.5 ppt.

The correlation between salinity and water quality parameter concentrations was assessed. There is a statistically significant correlation between salinity and nitrite-nitrate nitrogen concentrations (Figure 6-2) and salinity and pH (Figure 6-3). The highest NNN concentrations occur when the salinity is lowest, with concentrations decreasing with increasing salinity. This result indicates that freshwater is the most significant source of NNN to the water at this site. The lowest pH was in low salinity water with pH increasing as salinity increased. The pH of sea water is 8 – 8.1, with sea water a very good pH buffer. The results indicate the pH of the freshwater is 7.5 – 7.8.

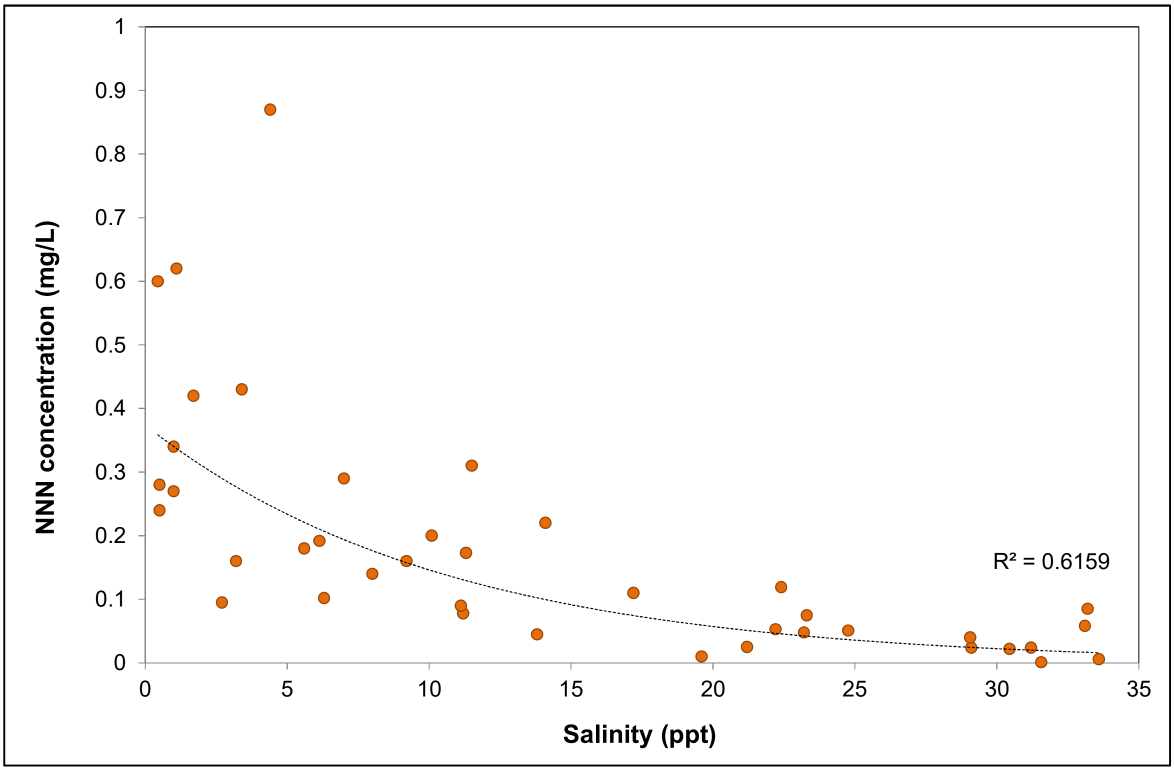

Figure 6-2: The correlation between salinity and nitrite-nitrate nitrogen concentrations

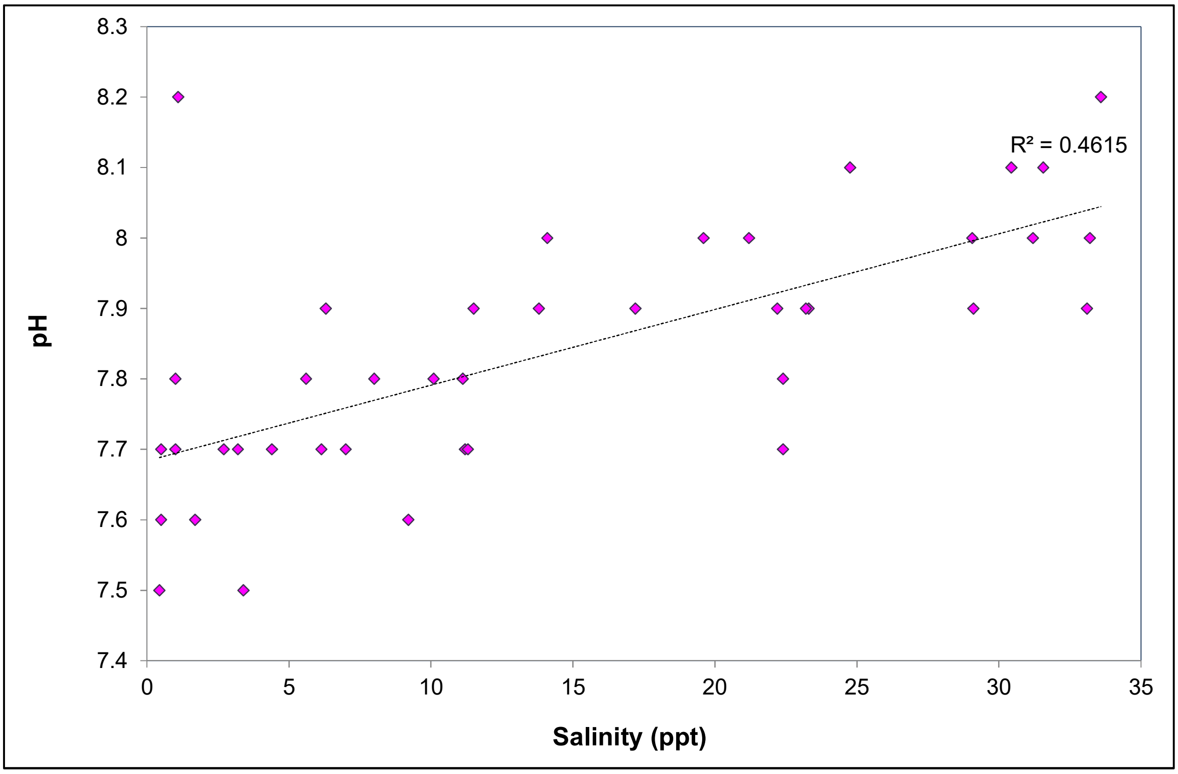

Figure 6-3: The correlation between salinity and pH

There was no correlation of salinity with total ammoniacal nitrogen, dissolved reactive phosphorus, total phosphorus and total suspended solids. That is, the freshwater flows are not a significant source of the total ammoniacal nitrogen, dissolved reactive phosphorus, total phosphorus and total suspended solids concentrations at the sampling site. Results also indicate that turbidity and dissolved oxygen % saturation are not driven by freshwater flows. However, the lowest DO % saturation was at salinities lower than 12 ppt (Figure 6-4).

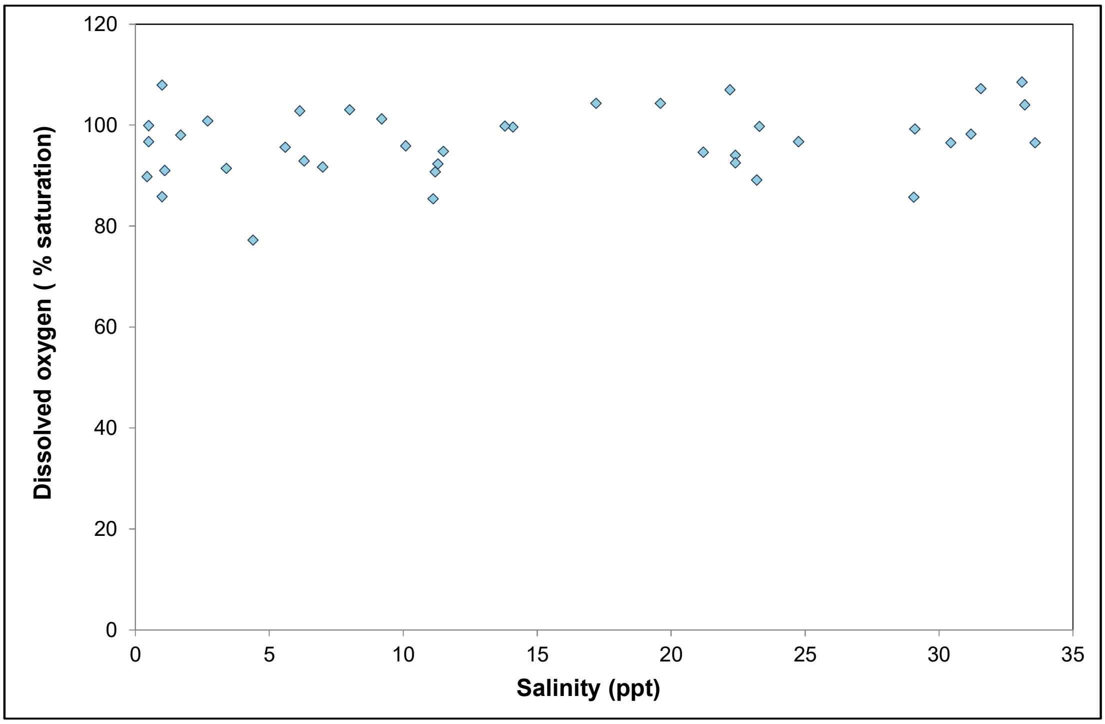

Figure 6-4: A plot of dissolved oxygen % saturation against salinity

Total suspended solids (TSS) concentration is a measure of the quantity of particles within the water column. It includes inorganic (non-living) particles such as the sand and mud stirred up from the seabed and soil washed off the land, as well as organic (from living things) particles like detritus (dead plant or animal material) and live organisms. Turbidity is a relative measurement of light scattering by suspended particles in water. Informally, turbidity is considered synonymous with 'cloudiness' or loss of visual clarity (MfE, 1994). There will be a clear relationship between TSS and turbidity if the suspended solids come from one source. However, if the suspended solids come from a number of sources, eg river water, re-suspended estuary bed, sea water there will be no clear relationship between the two parameters.

Suspended particles affect the amount of light that penetrates into the water and hence the growth of plant plankton and seaweeds. It also affects feeding and other behaviours of animals. Visible clarity of water is important for aesthetic and safety aspects of recreational water use. Reduction in clarity can affect the behavioural pattern of fish and macro-invertebrates, especially migratory and predatory species.

There is no correlation between TSS concentration and turbidity at this site (Figure 6-5). This indicates that the sediment is from different sources.

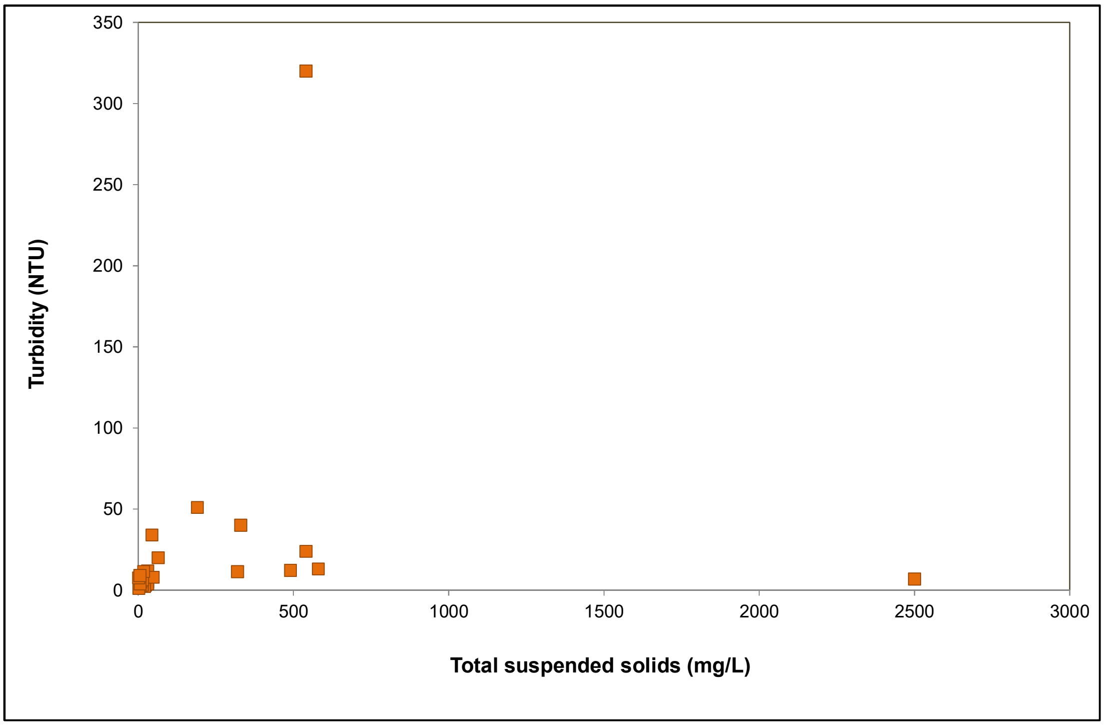

Figure 6-5: The relationship between total suspended solids and turbidity

There was no relationship between rainfall volume (Rangiora -CLIFLO site 17244) (total rainfall in the five days prior to sampling) and TSS and turbidity. However, the highest recorded turbidity did occur after 84.2 mm of rain in the five days prior to sampling in June 2014.

Water quality over time

Plots of the water quality parameters over time show season patterns and the variability in concentrations (Figures 6-6 to 6-9). No statistically significant trends of an increase or decrease in nutrient and total suspended solids concentrations or turbidity were found.

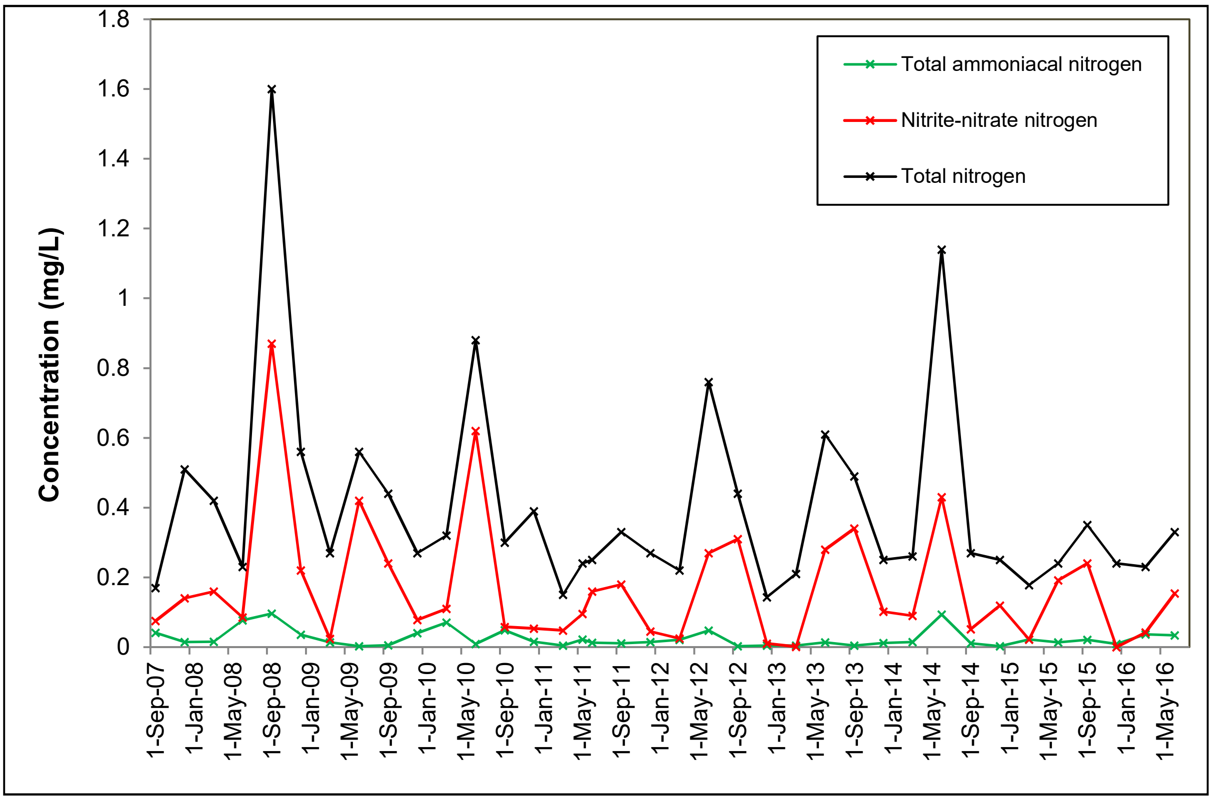

Figure 6-6: Nitrogen concentrations (mg/L) over time

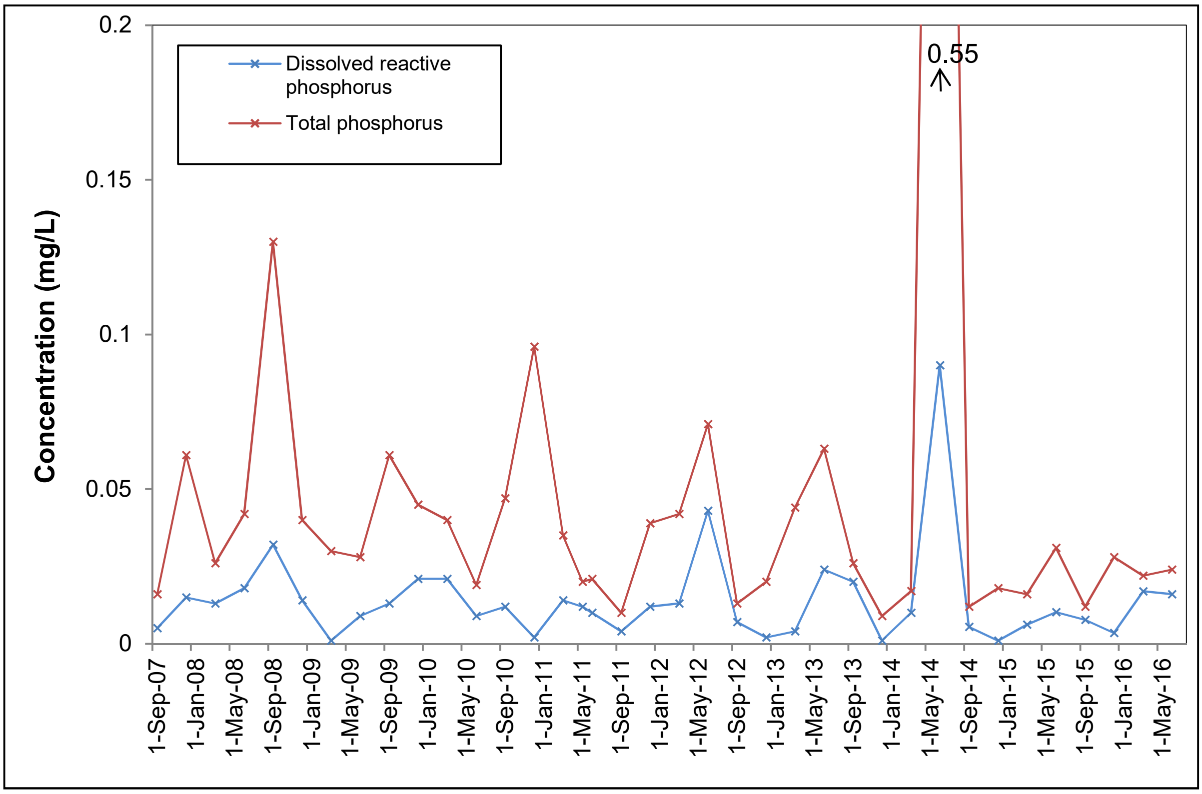

Figure 6-7: Phosphorus concentrations (mg/L) over time

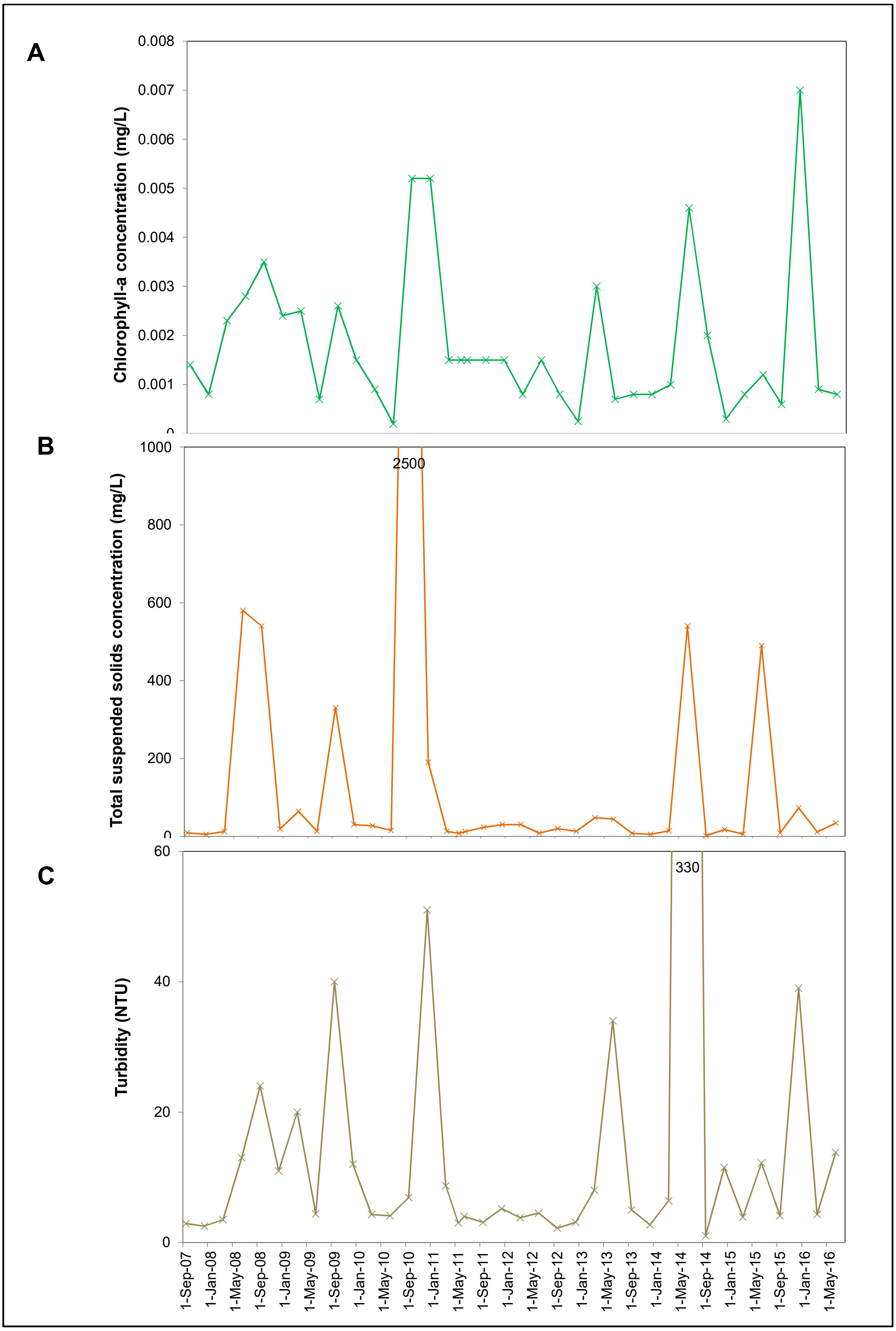

Figure 6-8: Parameters over time

A Chlorophyll-a B Total suspended solids C Turbidity

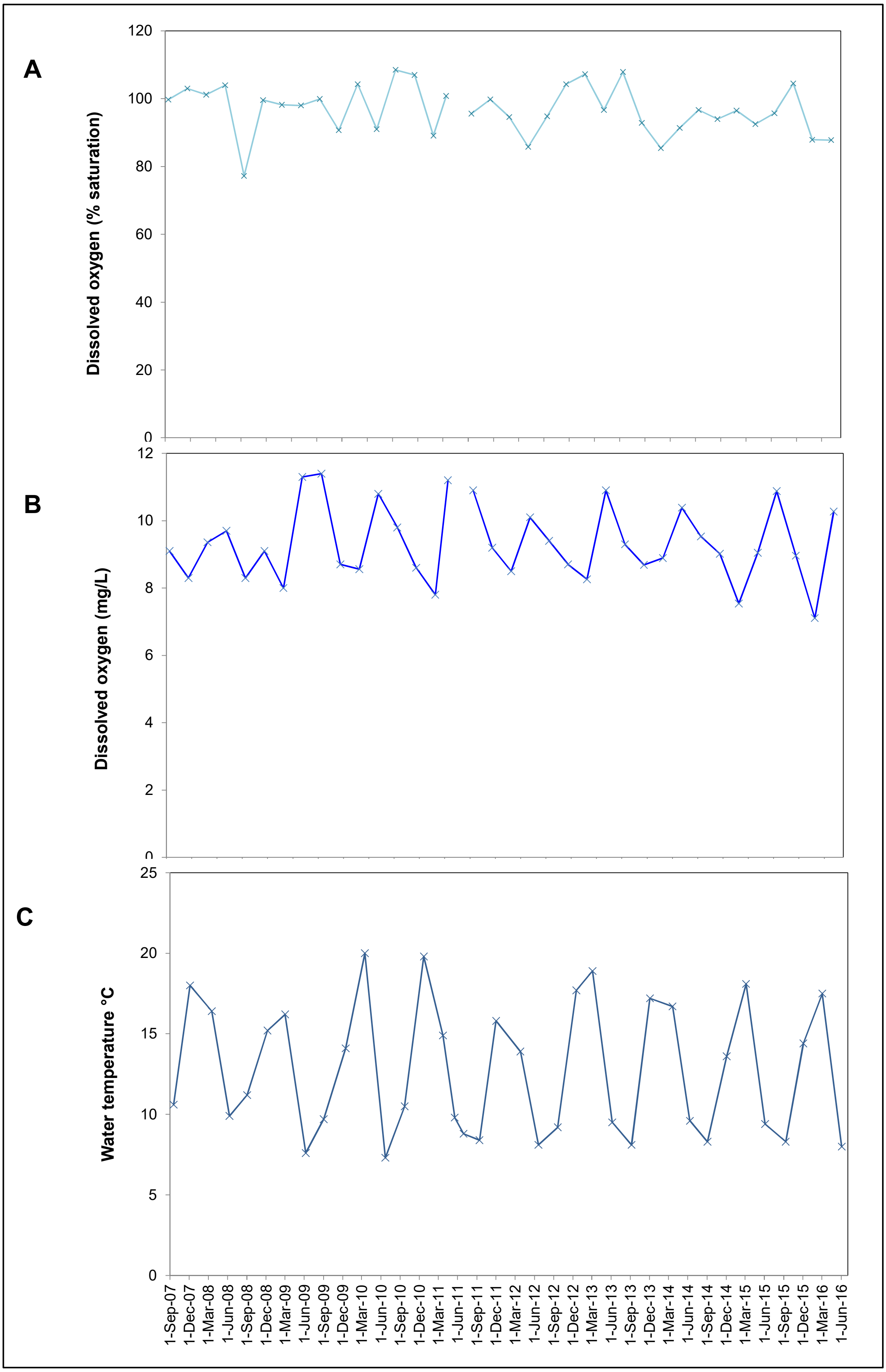

Figure 6-9: Parameters over time
A Dissolved oxygen (% saturation) B. Dissolved oxygen C Water temperature

6.2.2 Monthly data at Estuary 1 and Estuary 2 sites

Potential for ecological impacts

Estuary 1 site, 2014-2016

Recorded nitrite-nitrate nitrogen, dissolved inorganic nitrogen (mostly NNN) and turbidity are higher than the sea water comparison values in 20 % or more of the samples (Table 6-4). That is, they are potentially influencing the ecological health of the estuary at this site. This result is similar to that for the quarterly data. As for the quarterly data, NNN concentrations do vary with salinity (Appendix 11).

Table 6-4: Summary of water quality data collected monthly at Estuary 1 site, 2014-2016

Total number of samples = 24

Parameter	units	Range	Median	Comparison value (CV) upper	Number of samples above CV
Total ammoniacal nitrogen	mg/L	<0.005 - 0.085	0.0095	0.5	0
Nitrite-nitrate nitrogen	mg/L	<0.001 - 0.6	0.137	0.05	15
Dissolved inorganic nitrogen	mg/L	0.0095 - 0.61	0.174	0.25	5
Dissolved reactive phosphorus	mg/L	0.001 - 0.025	0.006	0.02	1
Total suspended solids	mg/L	1.2 - 490	19	25	4
Chlorophyll-a	mg/L	<0.0002 - 0.007	0.0007	0.004	1
Turbidity	NTU	1.01 - 73	8.1	10	11
Enterococci	MPN/100 mL	<10 - 121	<10	140	0

Parameter	units	Range	Median	Comparison value (CV) lower	Number of samples below CV
Dissolved oxygen	% saturation	71.4- 104.5	93.3	80	1

Parameter	units	Range	Median
Salinity	ppt	0.44 - 38.5	15.1
pH		7.1 - 8.1	7.8
Water temperature	°C	5.5 - 18.1	11.5
Total nitrogen	mg/L	0.155 - 0.7	0.27
Total phosphorus	mg/L	0.002 - 0.047	0.028

The water quality index for the 12 months of July 2014- June 2015 was 64.2, this means the water quality was FAIR.

The water quality index for the 12 months of July 2015- June 2016 was 60.5, this means the water quality was FAIR.

Estuary 2 site, 2014-2016

Recorded nitrite-nitrate nitrogen, dissolved inorganic nitrogen (mostly NNN), dissolved reactive phosphorus and turbidity are higher than the sea water comparison values in 20 % or more of the samples (Table 6-5). That is, they are potentially influencing the ecological health of the estuary at this site. As for the Estuary 1 site, NNN concentration does vary with salinity (Appendix 11).

Recorded dissolved reactive phosphorus and turbidity are higher than the freshwater comparison values in 20 % or more of the samples (Table 6-5). That is, they are potentially influencing the ecological health of the estuary at this site.

Table 6-5: Estuary 2 site summary of 2014-2016 water quality data and assessment against both sea water and freshwater comparison values

Total number of samples = 24

Parameter	units	Range	Median	Sea water comparison value (CV) upper	Number of samples above sea water CV	Freshwater comparison value (CV) upper	Number of samples above freshwater CV
Total ammonical nitrogen	mg/L	<0.01 - 0.15	0.027	0.5	0	1.43	0
Nitrite-nitrate nitrogen		0.013 - 0.84	0.23	0.05	19	0.444	2
Dissolved inorganic nitrogen		0.0181- 0.964	0.2615	0.25	13	1.5	0
Dissolved reactive phosphorus		<0.001 - 0.162	0.0285	0.02	15	0.016	16
Total suspended solids		3.1 - 31	12.3	25	3	25	3
Chlorophyll-a		0.0002 - 0.0104	0.0012	0.004	2	0.004	2
Turbidity	NTU	3.4 - 18.1	9.25	10	9	5.6	18
Enterococci	MPN/100 mL	1 - 226	20	140	2		

Parameter	units	Range	Median	Sea water comparison value (CV) lower	Number of samples below sea water CV	Freshwater comparison value (CV) lower	Number of samples below freshwater CV
Dissolved oxygen	% saturation	44.8 - 103.4	81.9	80	11	70	9

Parameter	units	Range	Median
Salinity	ppt	0.24 - 25.01	2.01
pH		7.03 - 8.04	7.61
Water temperature	°C	5.4 - 19.2	13.7
Faecal coliforms	CFU/100 mL	22 - 460	185
Total nitrogen	mg/L	0.22 - 1.37	0.46
Total phosphorus	mg/L	0.00 6 - 0.23	0.0695

The water quality index, based on sea water trigger values, for the 12 months of July 2014- June 2015 was 43, this means the water quality was POOR.

The water quality index, based on sea water trigger values, for the 12 months of July 2015- June 2016 was 42.5, this means the water quality was POOR.

The water quality index, based on freshwater trigger values, for the 12 months of July 2014- June 2015 was 61, this means the water quality was FAIR.

The water quality index, based on freshwater trigger values, for the 12 months of July 2015- June 2016 was 51.6, this means the water quality was POOR.

Comparison between sites

There are differences in water quality between the two sites. The differences are highlighted in the plots of total nitrogen and dissolved reactive phosphorus concentrations and dissolved oxygen %saturation (Figure 6-10). These plots show:

- DRP and TN concentrations are more variable at site 2 than site 1
- DRP and TN concentrations are typically higher at site 2 than site 1
- DO %saturation is typically lower at site 2 than site 1

Site 2 is within the channel from Taranaki Creek and hence Taranaki Creek water does influence the water quality at this site. The water quality results for site 2 indicate that Taranaki Creek is a source of phosphorus and nitrogen to Te Akaaka. The results also suggest that the dissolved oxygen saturation in Taranaki Creek water is frequently low. The water at site 1, depending on the state of the tide, is a mix of freshwater from Taranaki Creek, Ashley River/Rakahuri and Saltwater Creek as well as seawater. As a consequence of this mix, nutrient concentrations are not as variable as those at site 2 and the water is typically well saturated with dissolved oxygen.

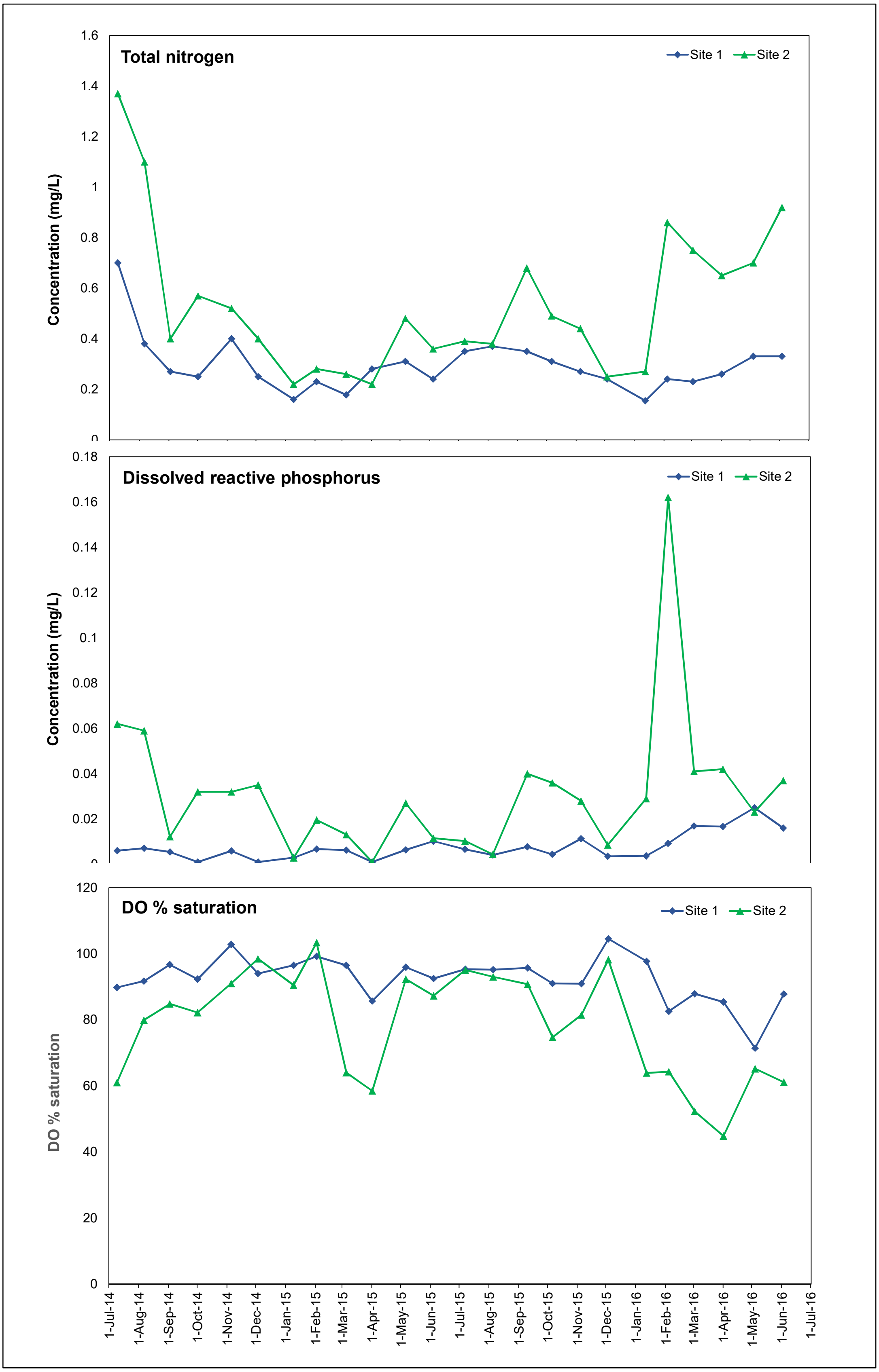

Figure 6-10: Monthly parameter concentrations at sites 1 and 2, 2014-2016

7 Microbiological water quality

To determine if there is faecal matter in the water, faecal indicator bacteria (FIB) concentrations are measured. The higher the number of FIB in the water, the higher the likelihood that disease-causing bacteria, viruses and Protozoa will be present and hence the higher the health risk. National guidelines are used to assess FIB concentrations to determine the suitability of water quality for contact recreation and the quality of the water overlying shellfish as an indication of the shellfish being safe to eat.

7.1 Water quality for contact recreation

Environment Canterbury monitors FIB concentrations, weekly for 15 weeks, at around 90 popular swimming sites in the region each summer. *Escherichia coli (E.coli)* is the FIB measured in fresh water and enterococci is the FIB measured in sea water. In estuarine areas both are measured. From November 2000 to March 2011 there was weekly (for fifteen weeks) summer monitoring of FIB concentrations at the Estuary 2 site (Figure 7-1). The summer monitoring at this site ceased in 2011. However, monitoring was re-instated at the start of the summer of 2015-2016. This monitoring followed the MfE/MoH (2003) guidelines.

The contact recreation monitoring site (Estuary 2 site) is within the flow of Taranaki Creek and therefore concentrations of the freshwater faecal indicator bacteria *E. coli* were used to assess the suitability of the site for contact recreation. The *E.coli* concentrations recorded over time are presented in Figure 7-1.

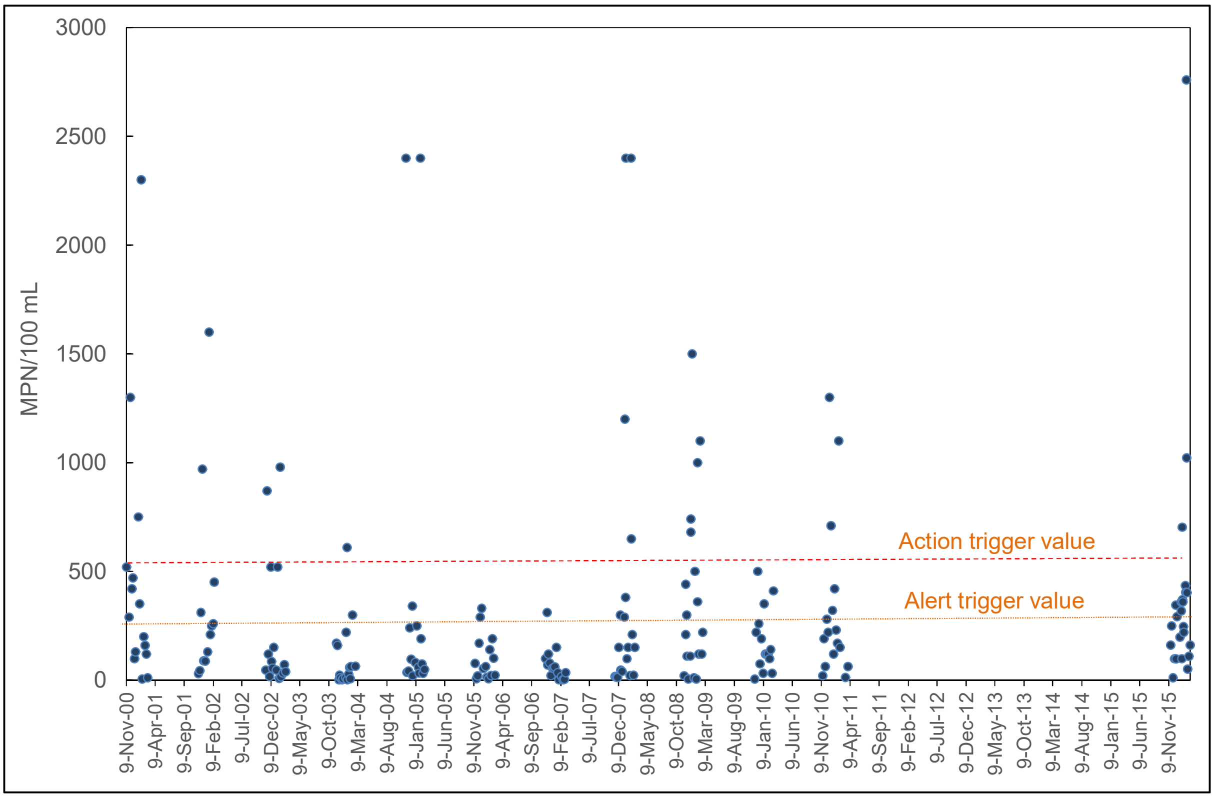

Figure 7-1: ***E.coli* concentrations at the Estuary 2 site each summer**

The actual maximum recorded *E.coli* concentration was 9200 MPN/100 mL, but to clearly see the recorded concentrations, the maximum value on the graph is 3000 MPN/100 mL. Over the 12 summers of sampling there were four values between 3000 and 9200 MPN/100 mL. The MfE/MoH (2003) guidelines provide alert (260 *E.coli*/100 mL) and action (550 *E.coli*/100 mL) trigger values. Exceedence of these values prompts management responses as described in the guidelines. Over time there have been frequent exceedences of the alert and action trigger values (Figure 7-1).

The FIB concentrations in combination with an assessment of the risk of faecal contamination are used to calculate the suitability for recreation grade for each site. The potential sources of the faecal contamination at this site are:

- incidence and density of bird life;
- Creek discharging close to the recreational area with the creek water potentially affected by:
    - urban stormwater;
    - high-intensity agricultural/rural activities;
    - unrestricted stock access;
    - incidence and density of feral animal/bird populations.

The suitability for recreation grade at this site has mostly been poor (Table 7-1). A poor grade means that the water quality at this site is generally not suitable for contact recreation. There is permanent signage near to this site warning that the water quality is not suitable for contact recreation.

Table 7-1: Suitability for recreation grade over time

Year	Suitability for recreation grade
2003-2004	Poor
2004-2005	Poor
2005-2006	Poor
2006-2007	Poor
2007-2008	Fair
2008-2009	Poor
2009-2010	Poor
2010-2011	Poor

7.2 Water quality for shellfish safe to eat

Cockles and pipis are collected from the estuary for human consumption. These shellfish filter the overlying water to get their food. When filtering the water they can also ingest bacteria, Protozoa and viruses and accumulate these on their gills and in their gut. Large quantities of these micro-organisms in the shellfish can make people who eat the shellfish sick.

To determine if the shellfish were suitable for human consumption, faecal coliforms concentrations were measured in the water collected monthly from the Estuary 1 and Estuary 2 sites. The results obtained were assessed against the MfE/MoH (2003) microbiological guidelines for shellfish-gathering waters.

As an indication of the shellfish being safe to eat faecal coliform concentrations in the water should meet the following bacteriological guideline values:

- median concentration shall not exceed 14/100 mL; and
- no more than 10% of samples should exceed 43/100 mL

The results (Table 7-2) suggest that shellfish collected from both sites would not be safe for human consumption.

Table 7-2: Faecal coliform concentrations (CFU/100 mL) at each site in 2014-2015 and 2015-2016

2014-2015			2015-2016		
Date sampled	Estuary 1	Estuary 2	Date sampled	Estuary 1	Estuary 2
9-Jul-14	120	150	7-Jul-15	150	52
6-Aug-14	68	90	5-Aug-15	32	22
2-Sep-14	4	110	10-Sep-15	40	60
1-Oct-14	74	69	6-Oct-15	44	100
5-Nov-14	150	250	5-Nov-15	40	200
3-Dec-14	60	240	3-Dec-15	3	50
9-Jan-15	2	170	12-Jan-16	49	270
2-Feb-15	120	460	4-Feb-16	240	410
5-Mar-15	44	430	2-Mar-16	130	290
1-Apr-15	38	230	1-Apr-16	30	260
6-May-15	160	460	4-May-16	190	350
4-Jun-15	63	110	3-Jun-16	44	110
Median	65.5 ☹	200 ☹	Median	44 ☹	155 ☹
% > 43	75 ☹	100 ☹	% > 43	58 ☹	92 ☹

7.3 Source of the faecal indicator bacteria

In 2016 ESR staff carried out faecal source tracking at the Estuary 1 and Estuary 2 sites (Pantos and Moriaty, 2016). Sampling was during dry weather. The laboratory analyses involved using quantitative polymerase chain reaction (qPCR) and a suite of markers including one general faecal marker as well as specific markers.

The results indicate that birds and ruminants (sheep, cows/cattle, goats, deer) are the source of the faecal contamination in this estuary during dry weather. The contribution from ruminants is low (1-10%) with most of the faecal contamination coming from birds.

8 Evaluation of the results

8.1 Habitats of Te Akaaka

In 2014 84.79 ha of estuarine vegetation was mapped within this estuary. This estuarine vegetation consisted of flaxland, grassland, herbfield, reedland, rushland, sedgeland and shrubland. As well as the estuarine vegetation there was also mapping of palustrine, riverine and terrestrial vegetation.

In 2013 146.1 ha of intertidal un-vegetated intertidal mudflat was mapped. The sediment types within Te Akaaka include firm mud/sand, firm mud/sand/gravel, firm sand, firm sand/clay, firm sand/gravel, mobile sand, stone/cobble, stone/cobble/sand, soft mud/sand, soft sand and very soft mud/sand.

8.2 Ecological health of Te Akaaka

8.2.1 Eutrophication

The December 2013 broad scale mapping found 8.2 ha (5.6% of the estuary) of the intertidal sediment covered by the macroalgae *Ulva compressa* and *Gracilaria chilensis.* This suggests there is nutrient enrichment within the estuary, notably adjacent to the Saltwater Creek channel and in an area where the Ashley River/Rakahuri flows into the estuary. Macroalgae have not been found at the sediment and macrobiota monitoring sites within the central region of the estuary. The 2013 results show that excessive macroalgae growth does occur within Te Akaaka. Therefore there is potential, if nutrient concentrations increase in the estuary, that eutrophication could become a significant problem here.

8.2.2 Sedimentation

The broad scale mapping found 15.5 ha (10.6% of the estuary) of very soft mud/sand and 33.3 ha (22.8% of the estuary) of soft mud/sand. The grain size composition of these sediments is likely to have a medium to high percent of mud. The rivers and creeks flowing into the estuary will be the source of the mud. The largest areas of very soft mud/sand are adjacent to the Saltwater Creek channel; this does indicate that this creek is a source of fine sediment (silt +clay)[9] to this estuary. There are also areas of very soft mud/sand and soft mud/sand around the upper reaches of the Taranaki Creek channel; this does indicate that Taranaki Creek is a source of fine sediment. The muddy sediments are also in the inner reaches of this estuary where water energy is low and hence the fine sediments drop out of the water column and settle to the seabed. The occurrence of fine sediment in low energy areas

[9] Silt + clay = mud

of an estuary including in aquatic vegetation, such as found in Te Akaaka is typical and not unexpected. However, because there are no historic data it is not possible to determine if the extent of very soft mud/sand and soft mud/sand in the estuary has increased over time or that the actual grain size distribution in the low energy areas has changed. To determine if sedimentation is actually an issue for this estuary more work will need to be carried out.

8.2.3 Habitat loss

The vegetation mapping shows that where some areas of saltmarsh and freshwater wetland meet the land there are straight borders. This suggests that at the edges there has been habitat loss through reclamation.

8.2.4 Disease risk

The water quality is POOR for contact recreation. The water quality overlying shellfish beds indicates that the shellfish are not safe to eat. These results indicate there is faecal contamination within Te Akaaka. The sources of the faecal matter are wading and sea birds, which are abundant within the estuary, and ruminants, from the river and creek catchments.

8.2.5 Toxic contamination

The recorded metal/metalloid and PAHs concentrations are all below ANZECC (2000) ISQG-low trigger values, which indicates they are unlikely to be having an ecological effect. There are differences between sites and over time in metal/metalloid concentrations. The vehicles travelling along SH1 are the likely source of the PAHs in estuary sediment downstream of SH1.

8.3 Water quality

The water quality classification for the estuary is Coastal CR water (Environment Canterbury, 2012). This means that the water quality must be managed for the maintenance of aquatic ecosystems (Coastal AE water) and for contact recreation. Coastal CR water does not have to meet the criteria for Coastal SG water, which is water quality for shellfish gathering.

8.3.1 Water quality for ecosystem health (Coastal AE water)

Estuary 1 site (near the mouth of the estuary)

The nitrite-nitrate nitrogen (NNN), dissolved inorganic nitrogen (mostly NNN), dissolved reactive phosphorus (DRP) and total suspended solids (TSS) concentrations and turbidity are potentially influencing ecosystem health at this site. The freshwater from the river and creeks is the most significant source of NNN to the water at this site.

Estuary 2 site (in the flow of Taranaki Creek)

The nitrite-nitrate nitrogen, dissolved inorganic nitrogen (mostly NNN), dissolved reactive phosphorus, total suspended solids concentrations, turbidity and dissolved oxygen % saturation are potentially influencing ecosystem health at this site.

The water quality at Estuary site 1 is better than that at Estuary site 2.

8.3.2 Water quality for contact recreation (Coastal CR water)

One site was sampled from November 2000 to March 2011 with sampling re-instated in late 2015. This site has a Suitability for Recreation Grade of POOR which means that this site is generally not suitable for contact recreation.

8.3.3 Water quality for shellfish gathering (Coastal SG water)

At present the water in Te Akaaka is not classified as Coastal SG water. The MfE/MoH (2003) standards for faecal coliform concentrations in water, as an indication of shellfish safe to eat, are not being met.

8.4 Summary

The results indicate that there has been habitat loss and that there is potential for eutrophication of Te Akaaka. Sediment deposition could be having an ecological effect, but sediment metal and PAHs concentrations are unlikely to be having an ecological effect, in this estuary. The water quality within Te Akaaka does not meet the requirements for the water quality classification of Coastal AE and Coastal CR as designated in the RCEP (Environment Canterbury, 2012).

9 Recommendations

The following are recommended for future water quality and ecological investigations and monitoring in Te Akaaka.

1. Determination of eutrophication susceptibility. This requires determining the flushing potential, the dilution potential, nutrient inputs and nutrient load susceptibility (Robinson, *et al.,* 2016a).
2. Development and implementation of a programme to assess current trophic state and to monitor trophic state over time (important considerations are location of sites, parameters to be measured, frequency of sampling, seasonality of sampling) ((Robinson, *et al.,* 2016b).
3. Annual mid-summer broad-scale monitoring to assess for the occurrence of macro-algae.
4. Monthly water quality monitoring for ecosystem health at the site near the estuary mouth.
5. Five-yearly monitoring of sediment quality at two sites – present site adjacent to Saltwater Creek and downstream from SH1 and a site in proximity to where Taranaki Creek flows into the estuary.
6. Monitoring of cockles and pipis from sites in the estuary to assess for *E.coli* concentrations in shellfish flesh.
7. Establish stations at various locations in the estuary and begin to monitor sedimentation.
8. Annual monitoring of the sediments and macrobiota at one site within the estuary?

In addition, it would be ideal to undertake baseline surveys of the fish and bird populations of this estuary.

10 Acknowledgements

Philip Grove carried out the mapping of the aquatic vegetation. The vegetation maps for this report were produced by Mark Parker. Emma Woods carried out the mapping of the non-vegetated intertidal sediments. Surface water science field staff, notably Fay Farrant and Rachel Webster, carried out the water quality sampling. The following surface water science staff Annabel Barnden, Patrick Less, Fay Farrant and Sophie Moloney assisted with the annual sampling of the intertidal sediments and macrobiota samples and the processing of the macrobiota samples. I appreciate comments on the report provided by Makarini Rupene. This report was reviewed Matt Dodson from Environment Canterbury and Dr. Graham Fenwick from NIWA.

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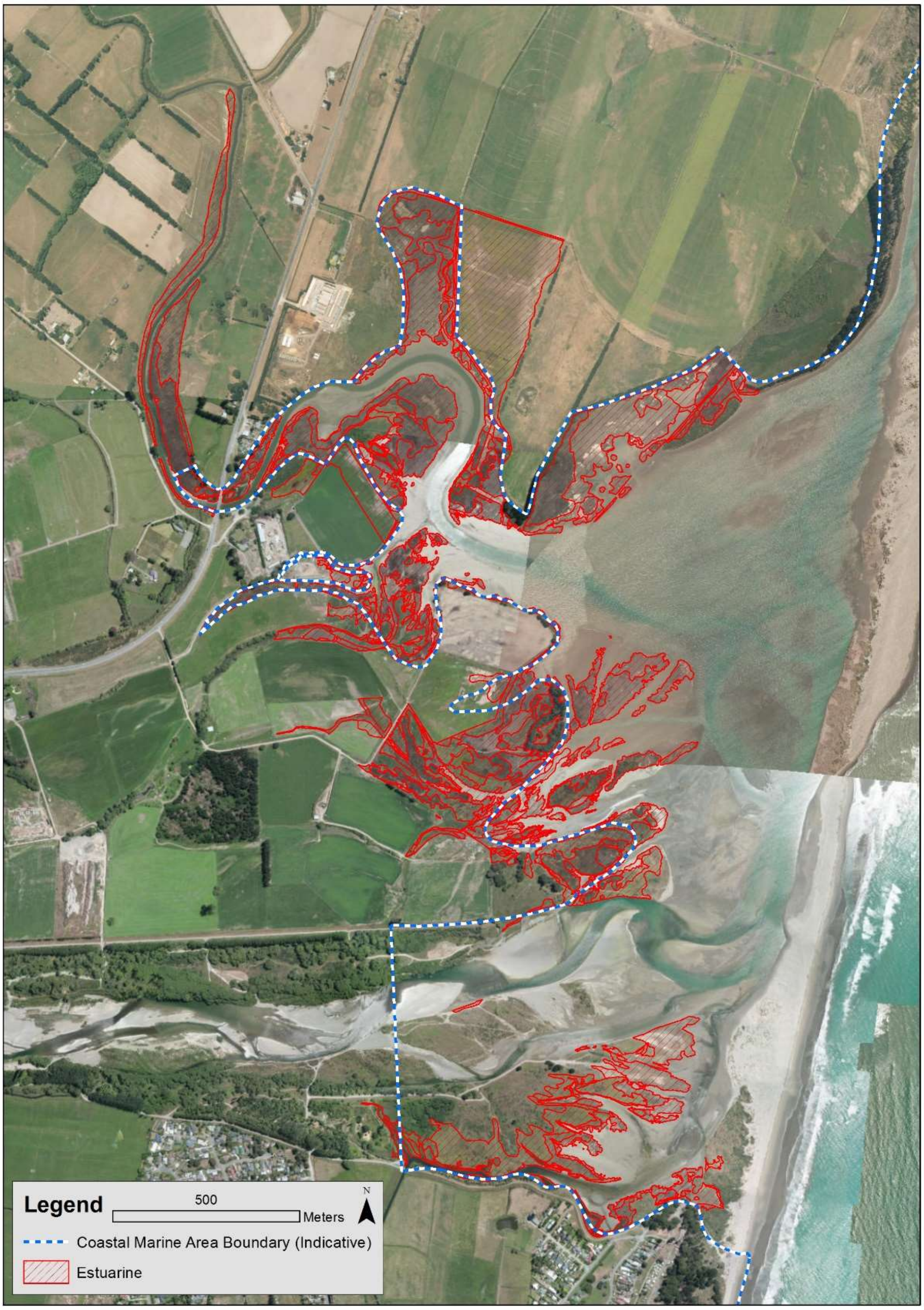
Appendix 1: Overlay of Coastal boundary (from RCEP, 2012) and estuarine wetlands in Te Akaaka



Appendix 2: Information on the New Zealand Trophic Index

Copied from Robertson *et al.*, 2016a

This ETI combination package of ecological response indicators, thresholds, and nutrient loads, tailored for estuary type, provides a more direct risk-based linkage to estuary ecological values than nutrient concentrations or loads alone. Its weight of evidence approach, with multiple ecological response indicators and indicator thresholds and load/response relationships developed from relevant estuary ecological gradients, is expected to produce a robust assessment of eutrophication for most NZ estuary types, and to provide preliminary, screening-level, load limit guidance. For setting final load limits, the ETI recommends the use of more robust approaches; preferably relevant measured nutrient load/ecological response gradients, but if unavailable, using the modelling approaches it describes.

Estuary wide

Primary indicator

Macroalgae

% cover on Available Intertidal Habitat (AIH)
Affected Area (AA) of >5% macroalgae (ha)*
AA/AIH (%)*
Average biomass ($g.m^2$ wet weight) of AIH
Average biomass ($g.m^2$ wet weight) of AA
% algae >3cm deep in sediment (entrained)

Secondary indicators

Dissolved oxygen

7 day mean*
7 day mean minimum*
1 day minimum*

Total organic carbon (top 2 cm)

Total nitrogen (top 2 cm)

Redox potential (mV)

Total sulphur and Total sulphides

Sedimentation

% Mud Content (mean over whole estuary)
% Estuary Area with Soft Mud ** (>25% sediment mud content)
Mean Sedimentation Ratio Current Sed Rate (CSR) : Natural Sed Rate (NSR)
% Estuary Area with Sedimentation Rate (mm/yr) exceeding 5 x NSR

Submerged aquatic vegetation (Extent % of estimated natural state cover)

Macroinvertebrate index (AMBI)

For individual sites

Total organic carbon (top 2 cm)

Total nitrogen (top 2 cm)

Redox potential (mV)

% mud content

Macroinvertebrate index (AMBI)

Appendix 3: Information on sediment contaminants metals, metalloid and PAHs

Arsenic
Historically, arsenic was used as an insecticide in sheep dip. Currently it's used to treat timber (tanalised timber) and with lead arsenate as a common pesticide in orchards. The ANZECC (2000) ISQG-low trigger value is 20 mg/kg.

Cadmium
Cadmium is used in rechargeable nickel-cadmium batteries, solar panels, vehicle tyres and brakes, paint pigment, for electroplating of steel and is also present in superphosphate fertiliser. The ANZECC (2000) ISQG-low trigger value is 1.5 mg/kg.

Chromium
Chromium is used as a pigment in paint and in processes such as manufacturing stainless steel, treating timber (tanalised wood), tanning leather, and electroplating. The ANZECC (2000) ISQG-low trigger value is 80 mg/kg.

Copper
Copper can be used in electrical wiring, vehicle brake pads, rooves, pipes, industrial machinery, fungicides and herbicides, boat antifouling paint and to treat timber (tanalised wood). The ANZECC (2000) ISQG-low trigger value is 65 mg/kg.

Lead
Lead can be found in lead acid batteries, SCUBA diving weight belts, bullets and shot, boat ballast, electrodes and solder, and in PVC plastic. It's also used in building construction and balancing car wheels. Lead used to be an additive in petrol. The ANZECC (2000) ISQG-low trigger value is 50 mg/kg.

Mercury
Historically there were many uses for mercury. Now it is commonly used for the manufacture of industrial chemicals and in electrical and electronic applications. Mercury is also found in batteries and dental amalgams and gaseous mercury is used in fluorescent lamps. The ANZECC (2000) ISQG-low trigger value is 0.15 mg/kg.

Nickel
Nickel is used in many industrial and consumer products including stainless steel, magnets, coinage, rechargeable batteries, vehicle brake pads, electric guitar strings, and special alloys like nickel steels and nickel cast irons. It is also used for plating and as a green tint in glass. The ANZECC (2000) ISQG-low trigger value is 21 mg/kg.

Zinc
Zinc is used as an anti-corrosion agent in the galvanisation of iron and steel. It is found in metal fencing, lampposts, metal rooves, car bodies, batteries, as a sacrificial anode on ships, in alloys such as brass, in paints, in rubber to protect against UV damage, and in sunscreen. The ANZECC (2000) ISQG-low trigger value is 200 mg/kg.

PAHs
Polycyclic aromatic hydrocarbons (PAHs) occur in oil, coal and tar deposits, and are present in fossil fuels. Background levels of PAHs are found naturally in the environment from events such as forest fires and volcanic activity. However, they predominantly occur in the environment as they are released during the incomplete combustion of carbon-containing fuels like coal, oil, petrol, diesel, fuel oils, fats and tobacco. Other potential sources of PAHs in Canterbury intertidal areas are oil spills and fuel leakages from boats, and hydrocarbon residues from roads that are transported into the coastal environment by rainwater. As a pollutant, PAHs are concerning because some are carcinogenic and

mutagenic. Numerous chemical compounds are PAHs, but, those tested for have been identified by the US Environmental Protection Authority as hazardous to human health.

Appendix 4: Co-ordinates (NZTM) of the upper shore right hand corner of the sampling area

	Year	Sampling date	Easting	Northing
Northern area	2009	25-May-09	1577461	5209223
	2010	31-Mar-10	1577461	5209223
	2011	25-Mar-11	1577436	5209114
Southern area	2011	19-May-11	1577423	5208571
	2012	10-Apr-12	1577466	5208579
	2013	2-Mar-13	1577540	5208693
	2014	20-Mar-14	1577507	5208545
	2015	25-Mar-15	1577417	5208766
	2016	8-Mar-16	1577448	5208679

Appendix 5: Details of the sediment analyses

Analysis	Method	Analytical Detection limit
Ash	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 21st ed. 2005.	0.04 g/100g dry wt
Organic matter	Calculation: 100 - Ash (dry wt).	0.04 g/100g dry wt
Total organic carbon	Catalytic combustion (900°C O^2) separation. Thermal Conductivity Detector [Elementar analyser]	
Total reactive phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Total nitrogen	Catalytic combustion (900°C O^2) separation. Thermal Conductivity Detector [Elementar analyser]	variable
Chhlorophyll-a	Extraction with 95% Ethanol, Spectroscopy. Subcontracted to NIWA Hamilton	0.1 mg/kg
Sediment grain size (2009 -2013)	Malvern lazer sizer particle size analysis	
Sediment grain size (2014)	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis). Wet sieving through a series of 6 graded sieves	0.1 g/100 gm dry weight for each sieve

Appendix 6: Assessment of the ecological stress, i.e. enrichment status, of the sediment

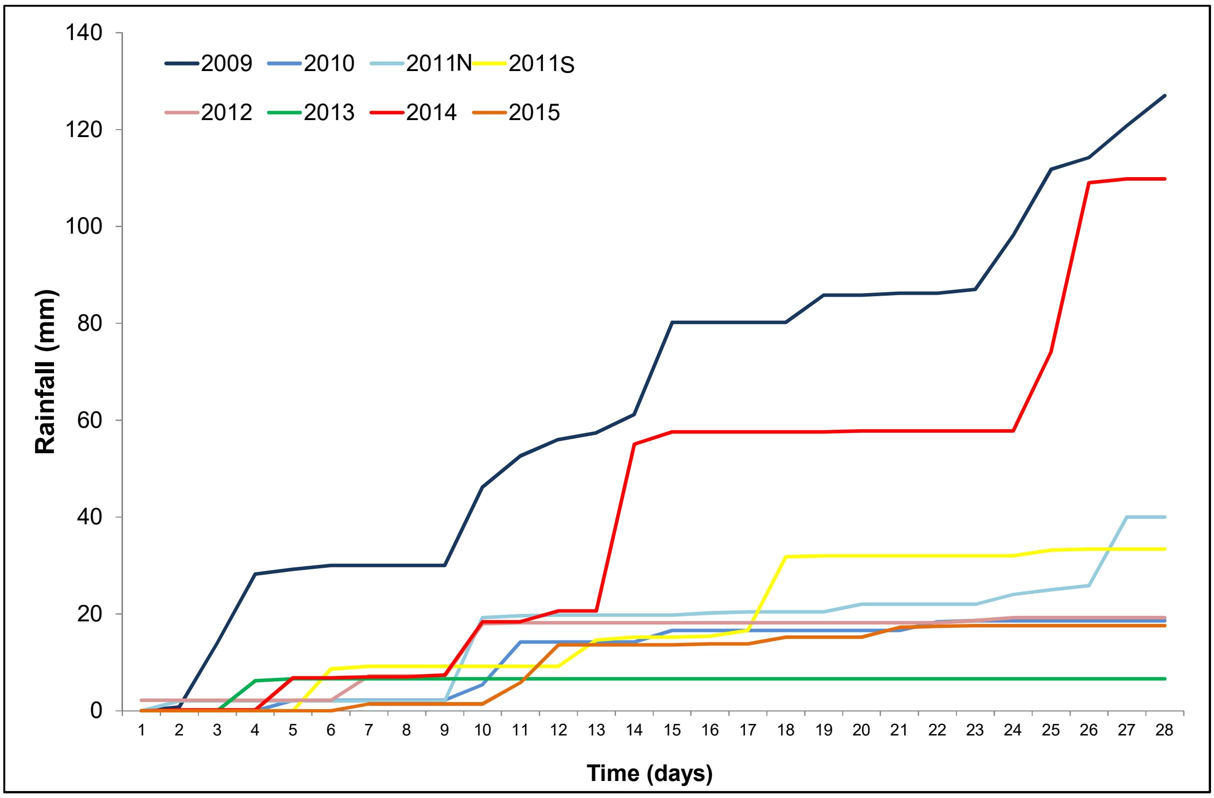
Orange – moderate stress
Yellow – minor stress
Green – no stress

	YEAR	TOC	TRP	TN
NORTHERN AREA	2009		410	< 500
	2009		440	< 500
	2009		480	630
	2009		500	600
	2010	0.43	400	600
	2010	0.48	460	700
	2010	0.47	400	600
	2010	0.42	390	600
	2011	0.38	440	700
	2011	0.34	420	700
	2011	0.43	390	600
	2011	0.34	440	600
SOUTHERN AREA	2012	0.06	220	<500
	2012	0.06	220	<500
	2012	0.06	230	<500
	2012	0.05	220	<500
	2013	0.5	250	<1300
	2013	0.47	250	<1300
	2013	0.61	260	<1300
	2013	0.45	230	<1300
	2014	1.22	470	1200
	2014	0.19	300	<500
	2014	0.42	350	600
	2014	0.25	330	<500
	2015	0.24	350	<500
	2015	0.32	370	500
	2015	0.19	330	<500
	2015	0.17	340	<500
	2016	0.32	410	< 500
	2016	0.23	370	< 500
	2016	0.34	400	600
	2016	0.31	410	500

Appendix 7: Cumulative rainfall in the 28 days prior to sampling

Data from a site in Rangiora (Latitude -43.3286, Longitude 172.6111)

Data obtained from NIWA - CLIFLO[10] (site 17244)



[10] http://cliflo.niwa.co.nz/

Appendix 8: Details of the water quality parameters

Salinity
Salinity is a measure of how salty the water is. The sea water 2.5 to 10 kilometres from shore in Pegasus Bay typically has a salinity of 33 - 34.5 ppt (parts per thousand). Freshwater has a salinity of 0 ppt.

Total ammoniacal nitrogen
The total ammonaical nitrogen (NH_4N) that occurs naturally in water is from the breakdown of once living and non-living nitrogenous matter and from gas exchange with the atmosphere. Total ammoniacal nitrogen is also formed during the breakdown of human and other animal excreta. Ammonia is a non-persistent and non-cumulative toxin to aquatic life.

Nitrate-nitrite nitrogen (NNN)
Nitrate is the common form of nitrogen found in natural waters. Nitrate is changed by natural processes to nitrite when there is no oxygen; when oxygen is present the nitrite quickly forms nitrate. Nitrate and nitrite are formed during the breakdown of total ammoniacal nitrogen. They also occur in fertilisers applied to land to enhance plant growth, but fertiliser does flow off the land and into the nearest waterway particularly with rainfall. Over application of fertilisers can also result in leaching of nitrate into groundwater, which then resurfaces into waterways as springs. Nitrate and nitrite also occur in wastewater which can occasionally be discharged into the rivers if sewerage infrastructure is damaged or pumping stations overflow. In freshwater nitrate is toxic to aquatic life at elevated concentrations.

Dissolved inorganic nitrogen
In estuarine and coastal waters dissolved inorganic nitrogen (DIN) is the primary limiting nutrient for phytoplankton and algal growth.

$$DIN = NNN + NH_4N$$

Dissolved reactive phosphorus (DRP)
Phosphorus occurs naturally in water with the concentrations typically reflecting the concentrations in the surrounding soil and rock. The volcanic rocks/soils of Banks Peninsula contain more phosphorus than the soils of the Canterbury plains. Phosphorus occurs in fertilisers applied to land to enhance plant growth, but fertiliser can dissolve in rain and flow into the nearest waterway. Phosphorus is also a constituent of dishwashing liquid and washing powders and hence is present in household wastewater.

Chlorophyll-a
Chlorophyll-a concentration is used as a measure of the amount of plant plankton (phytoplankton) in the water, i.e. the higher the chlorophyll-a concentration the more plankton in the water. Chlorophyll-a concentrations of 0.005 mg/L or more can result in discolouration of the water.

Dissolved oxygen % saturation
Dissolved oxygen (DO) is essential for aquatic animals to survive. DO % saturation can exceed 100% when oxygen gas is dissolved in the water. The results obtained are spot measurements. However, DO % saturation at a site does vary during the day and is influenced by water temperature. For DO % saturation the comparison value is a lower limit value. If the recorded DO % saturation is below this

lower limit there is the potential for fish and other marine life to be affected because the ease with which they respire is affected.

Total suspended solids (TSS)

Total suspended solids (TSS) concentration is a measure of the amount of particles within the water column. It includes inorganic (non-living) particles such as the sand and mud stirred up from the seabed and soil washed off the land, as well as organic (from living things) particles like detritus (dead plant or animal material) and live organisms. Suspended particles affect the amount of light that penetrates into the water and hence the growth of plant plankton and seaweeds. It also affects feeding and other behaviours of animals.

The recorded TSS concentrations could be from inputs to the estuary from rivers and drains but there is also re-suspension of seabed sediment by the action of wind driven waves.

Turbidity

Turbidity is a relative measurement of light scattering by suspended particles in water. Informally, turbidity is considered synonymous with ‘cloudiness’ or loss of visual clarity (MfE, 1994). Visible clarity of water is important for aesthetic and safety aspects of recreational water use. Reduction in clarity can affect the behavioural pattern of fish and macro-invertebrates, especially migratory and predatory species.

Appendix 9: Sea water and fresh water comparison values

Sea water

For some of the parameters in sea water (estuary and coastal sites), there are trigger values in the RMA, the ANZECC (2000) guidelines and the MfE/MoH (2003) Microbiological Water Quality Guidelines. However, for Chlorophyll-a, TSS, turbidity, NNN, DRP and DIN there are no developed NZ trigger values. Turbidity, NNN and DRP values are compared with values used by the Otago Regional Council (Otago Regional Council, 2007). Chlorophyll-a concentration is compared with values used by the Waikato Regional Council[11]. For TSS I have used the freshwater comparison value and for DIN I have referred to a comparison value from the literature (Alber and Sheldon, 2011). These are the most appropriate comparison values at the time of writing this report. It could well be that in the future, the comparison values selected for Chlorophyll-a, TSS, turbidity, NNN, DRP and DIN are replaced by other values that are developed and are more applicable to the estuarine environment. However, for now I have used the values to provide **an indication** of the state of the water quality at the two sampling sites. The comparison values for sea water are presented in the table below. NOTE: I consider that the terms satisfactory, medium and fair, as used in the column 'Source of comparison value' have a similar meaning in terms of water quality.

Parameter	Units	Comparison value	Source of comparison value
Dissolved oxygen	% saturation	80	RMA
Enterococci	MPN/100 mL	140	MfE/MoH (2003)
TSS	mg/L	25	A Canterbury freshwater value (Stevenson *et al.,* 2010)
Chlorophyll-a	mg/L	0.004	Upper value for satisfactory water quality, Waikato Regional Council
turbidity	NTU	10	Upper value for medium water quality, Otago Regional Council (2007)
Dissolved reactive phosphorus	mg/L	0.02	
Nitrite-nitrate nitrogen	mg/L	0.05	
Dissolved inorganic nitrogen	mg/L	0.25	Upper value for fair WQ (Alber and Sheldon, 2011)
Total ammoniacal nitrogen	mg/L	0.5	ANZECC (2000) 99% level of protection

[11] The information is from the Waikato Regional Council website, the website address is provided in the References at the end of this report.

Fresh water

Parameter	Units	Comparison value	Source of comparison value
Dissolved oxygen	% saturation	70% (spring fed plains), 90% (Hill fed lower)	Environment Canterbury (2011, 2015)
turbidity	NTU	5.6	ANZECC (2000) NZ Lowland rivers
TSS	mg/L	25	Stevenson *et al.* (2010)
Chlorophyll-a		0.004	I have used the one for sea water
Dissolved reactive phosphorus		0.016	Environment Canterbury (2011, 2015)
Nitrite-nitrate nitrogen		0.444	ANZECC (2000) NZ Lowland rivers
Dissolved inorganic nitrogen		1.5	Environment Canterbury (2011, 2015)
Total ammonical nitrogen		default is 1.43 (spring fed plains), 0.9 (Hill fed lower) (varies with pH)	ANZECC (2000)

NOTE: Taranaki Creek and Saltwater Creek are classified as spring fed plains and the Ashley River/Rakahuri is classified as Hill fed lower (Environment Canterbury 2011, 2015)

Appendix 10: Details of the water quality index

The index used here is derived from the Canadian Council of Ministers for the Environment (CCME) water quality index (CCME, 2001).

The index consists of three factors:
Scope - the number of parameters not meeting the water quality comparison value
Frequency - the number of times these comparison values are not met
Amplitude – the amount by which the comparison values are not met

The parameters used to calculate the index:

- Total ammoniacal nitrogen for toxicity
- Nitrite-nitrate nitrogen for effects on phytoplankton and macroalgae growth
- Dissolved reactive phosphorus for effects on phytoplankton and macroalgae
- Total suspended solids for effects on clarity and sedimentation
- Enterococci for effects on suitability for recreation

Dissolved oxygen, temperature, pH and salinity were not included because these are spot measurements that show diurnal and state of the tide variability.

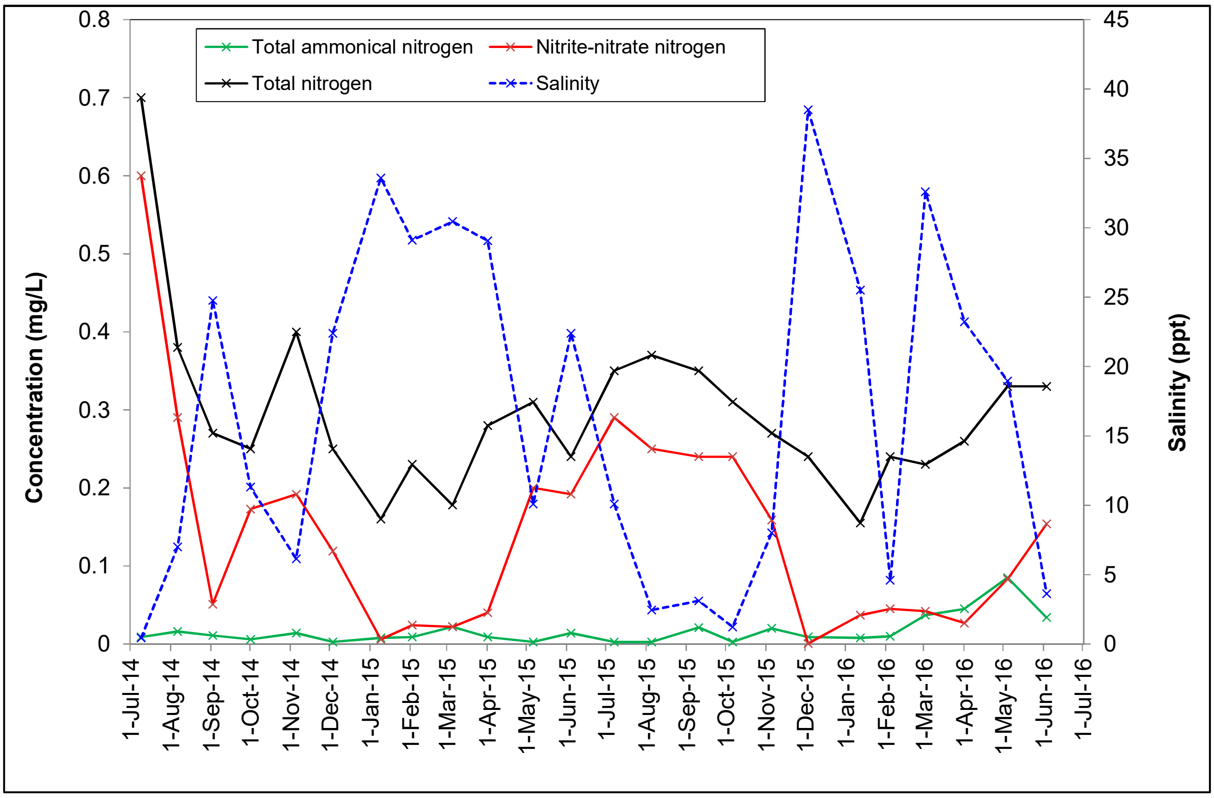
The CCME Water Quality Index Calculator 1.2 was used to calculate the Index value for each site for each year of monthly sampling. The index values which range from 0 to 100 were then used to categorise the water quality at a site. The Index categories used have been modified from those described in the CCME Water Quality Index 1.0 User's manual (CCME, 2001), in that the range of values in the Poor – Very Good categories are equal (Table 6-5).

Index categories for the water quality index

Very Good	85 -100
Good	70 - 84.9
Fair	55 - 69.9
Poor	40 - 54.9
Very poor	0 - 39.9

Appendix 11: Plots of salinity and nitrogen concentrations at each site, 2014-2016

Estuary 1 site



Estuary 2 site