Kaituna River Re-diversion Project: Ongatoro/Maketū estuary condition and potential ecological effects

Prepared for:

Bay of Plenty Regional Council

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Cover Photo: Maketū estuary, May 2014 (taken by S. Iremonger, Bay of Plenty Regional Council)

Contents

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1 Introduction

1.1 Background

The Ongatoro/Maketū estuary is a shallow[1], inter-tidal estuary located north of Te Puke. It covers an area of about 233 ha, including about 13 ha within Papahikahawai lagoon which is largely isolated to the rest of the estuary. Currently the major freshwater input to the estuary is from the Kaituna River via Fords cut (3 m^3/s, 24 hour average for a mean tide, at mean river flow). The Waitipuia Stream is the next largest freshwater inflow and enters in the southern part of the estuary (mean flow about 0.34 m^3/s), as do a number of small drains.

In 1957 the Kaituna River was diverted directly out to sea via the Te Tumu cut. This substantially changed the hydrology and ecology of the estuary. Adverse ecological and cultural effects that have been reported as a result of this diversion include:

- Accelerated in-filling and expansion of the flood tide delta from sand entering from the estuary entrance, and consequential loss of tidal prism (i.e. smaller estuary volume) (Murray 1978, Goodhue 2007).

- Loss of mussel beds from the expanding flood tide delta and a decline in the size and abundance of other kaimoana species (Murray 1978).

- A substantial loss of wetland (about 160 ha lost in 1956) with a corresponding loss of habitat for wetland and estuarine species (KRTA 1986).

- A decline in the mauri of the estuary.

Culverts and flap gates were installed at Fords Cut in 1995 to re-divert some water back to the estuary. These become fully operational in 1998, and allow about 3.4 m^3/s of water (3 m^3/s from the Kaituna River water and 0.4 m^3/s from the sea) into the estuary via Fords Cut (24 hour average for a mean tide, at mean river flow).

The volume of water re-diverted back into the estuary is relatively small[2] and although some improvements have been observed the volume hasn't been sufficient to reverse many of the adverse effects of the original diversion (Park 2011). There have been ongoing calls from the Maketū community for the Kaituna River to be re-diverted back into the Ongatoro/Maketū Estuary.

As part of a process to address these negative effects, Bay of Plenty Regional Council (BOPRC) and other agencies together with the community developed the non-statutory 'Kaituna River and Ongatoro/Maketū Estuary Strategy'. The 'Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement Project' was established to help achieve the objectives in the strategy. The goal of the Project is:

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[1] The mean depth is 0.51m at high tide and the volume is about 197,000 m^3 and 1,185,200 m^3 at low tide and high tide respectively (DHI 2014 model).
[2] Mean flow in Kaituna River at Te Matai is 39.5 m^3/s (Park 2010).

'To significantly increase the volume of water (particularly freshwater) flowing from the Kaituna River into Ongatoro/Maketū Estuary by 2018 in a way that maximises the ecological and cultural benefits (particularly wetlands and kaimoana), while limiting the economic cost and adverse environmental effects to acceptable levels.'

River Lake Ltd and Opus International Consultants were commissioned by BOPRC to provide ecological advice to identify wetland creation opportunities and to assess the potential effects of the project prior to applying for resource consents.

This report describes the current condition of the Ongatoro/Maketū estuary and the lower Kaituna River and assesses the potential effects of the re-diversion. A discussion of the potential effects on terrestrial habitat, birds and wetland restoration potential is provided in MacGibbon (2014); a discussion of changes in the wetland over time is provided in Park (2014); and the results of modelling estuary hydrodynamics for the current and proposed scenarios is provided in DHI (2014). The proposed works are described in Everitt (2014).

1.2   Report structure

This report is structured according to key components of work undertaken in the lower Kaituna River and Ongatoro/Maketū Estuary during the summer of 2013/2014. In particular these were:

- Macro-algae in Maketū estuary

- Shellfish and benthic macrofauna in Maketū estuary

- Dissolved oxygen fluctuations

- Fish in the Maketū estuary and lower Kaituna River

- Macroinvertebrate fauna of lower Kaituna River

2   Algae and seaweed in Maketū estuary

2.1   Cover of algae and sea grass in Maketū estuary

Excessive algal accumulations are a key feature of eutrophication in estuaries. It can be unsightly, fowl fishing nets, smother and displace sea grass beds, change the dissolved oxygen regime, contribute to anoxic sediments and reduce the diversity and abundance of shellfish and benthic macrofauna. The algae cover was assessed in order to characterise the current state of Maketū estuary.

2.1.1   Cover and spatial variation

The cover of algae and sea grass in the Maketū estuary was determined using February 2014 aerial photography and site surveys (see Park 2014). The algae were mapped in three classes: 20-50%, 50-80% and >80% cover. This found that about 30% (71 ha) of Maketū estuary is covered in algae of greater than 50% cover (Figure 2.1, Table 2.1)[3].

The lower estuary (towards the mouth) generally has sparse algal cover. Patches of sea lettuce (predominantly *Ulva pertusa*[4]) occur in the main channel (about 40% cover) attached to stable substrate such as cockle shells. Occasionally rafts of sea lettuce drift down the coast (from Tauranga Harbour) adding external inputs.

Gracilaria sp[5] is the most dominant species throughout the estuary and is particularly common along the margins of the mid and upper estuary. *Gracilaria* sp. can be loosely attached to the substrate but is often free-floating. Dense accumulations occur in hollows and on the edges of channels where current velocities are slow. These algae also include sea lettuce, *Ulva flexuosa* var pilifera and *Ulva clathrata*. *Ulva clathrata* and *Ulva Intestinalis* (syn. *Enteromorpha intestinalis*) is dominant along with *Gracilaria* sp. on the southern estuary margin adjacent to Maketū Road.

Free-floating sea lettuce and *Gracilaria* sp. were found to accumulate to > 0.5m depth in the main channel along the southern margin of the mid-estuary.

Large parts of the upper estuary were covered by free-floating *Gracilaria* sp. and *Ulva flexuosa* – with thick accumulations in depressions. In the upper estuary and in parts of the southern estuary, epiphytic algae species grow over the *Gracilaria* sp. A marine species of the diatom *Melosira* sp. was common. In the upper estuary the cyanobacteria *Oscillatoria* sp. grew as an epiphyte. The cyanobacteria *Lyngbya* sp. was also present[6].

The western end of the old Papahikahawai channel is mostly cut off from the rest of the estuary to form a lagoon. This is a highly productive system with thick mats of *Ulva flexuos*a var *pilifera* and the

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[3] Based on current estuary area of 235 ha, including Papakahawai lagoon.

[4] *Ulva lactuca* may also be present. *U. pertusa* and *U. lactuca* look very similar and are difficult to distinguish in the field.

[5] Probably *Gracilaria chiensis* but the species was not confirmed.

[6] The Cawthron Institute identified these species as most likely to be: *Oscillatoria nigro-veridis* but it lacked the distinctive filament ends of this species; and *Lyngbya majuscule*, but was below the usual minimum diameter for this species.

benthic cyanobacteria *Lyngbya* sp. These form rafts floating over large sections of the water (see Photo 2.4 and cover photo).

Lyngbya sp. is a benthic, filamentous, nitrogen-fixing cyanobacterium. It blooms in eutrophic estuaries with adverse effects such as smothering benthic communities, and reducing grazing of fish and invertebrates. It also contains secondary metabolites and toxins which can cause asthma and dermatitis. After long periods of warm temperatures and calm weather, bubbles within the algal mat matrix cause it to float to the surface (Ahern et al. 2008). The presence of the benthic cyanobacteria *Lyngbya* sp. indicates a nutrient-rich system. It is probably responding to internal cycling of nutrients, i.e. the release of dissolved phosphorus, ammonia and ferrous iron from the anoxic bottom sediments.

Most of the Maketū estuary has a firm sandy substrate, but anoxic mud overlays this in areas where algae accumulations occur, such as areas of low current velocity, depressions, and channel margins. Organic mud was particularly deep in the upper estuary (about 1-5cm depth) and in the Papahikahawai lagoon (12 to 25cm). This mud originated from the decomposition of overlying algal material. In Papahikahawai lagoon, partially decomposed *Lyngbya* sp. was still visible in the upper layers of the mud.

It is estimated that about 29% (68 ha) of the estuary has some organic mud overlying the sand substrate. This estimate was derived assuming organic mud forms under all free-floating algae, i.e. it excludes the area of attached sea lettuce within channels of the lower estuary.

Only a tiny remnant (ca. 40 m^2) of sea grass beds (*Zostera* sp.)[7] remain in the Maketū estuary on sand flats near Kakaho Island, west of the domain. This location was the most seaward extent of *Zostera* sp. found during a survey in 1977. At this time sea grass was dominant in the middle and upper estuary as far as Fords cut. The largest areas of sea grass were between mid and low water, adjacent to the channels (Park 2014, Murray 1977, Bioresearches 1976).

2.1.2   Short term variation in algal cover

The precise location of algae in the estuary changes with seasons, tides and weather events. The aerial cover of sea lettuce in Tauranga harbour is greater in the spring (de Winton et al. 1998) and comparisons of historic aerial photography suggests that this is also the case in the Maketū estuary.

The percentage cover of macro-algae was assessed in 20 quadrats along three transects in the Maketū estuary on eight occasions between 19 November 2013 and 24 February 2014 (total of 60 quadrats) (see Figure 2.2). The total algal cover was reasonably stable during the summer in the southern estuary near Maketū Road and in the channels however, the mud flats of the southern estuary showed considerable variation in sea lettuce cover. Some of the variation was due to weather (e.g. a storm reduced cover on 29 Nov 2013). Similar variation in sea lettuce cover was found on mudflats of Tauranga harbour, with peak cover in spring and summer (de Winton et al. 1998).

There is evidence to suggest that algal cover and the extent of accumulations have got worse over the last 10 to 25 years. Surveys in 1976 and 1977 suggest that muddy areas were limited to the western end of the estuary (BioResearches 1976). Sea lettuce (*Ulva lactuca*) was common but generally attached to pebbles, polychaete casings and cockle shells. Sea lettuce was most dense in the middle of the estuary,

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[7] Probably *Z. muelleri* (see Jones et al. 2008)

east of Papahikahawai Island, in the south west side of the estuary and in channels were currents were slow (1977).

More recently, the accumulation of *Gracilaria* has appeared to have increased in the last 10 years, and in the southern estuary *Ulva clathrata* has become much more common in the last five years (Stephen Park , BOPRC, pers comm 2014).
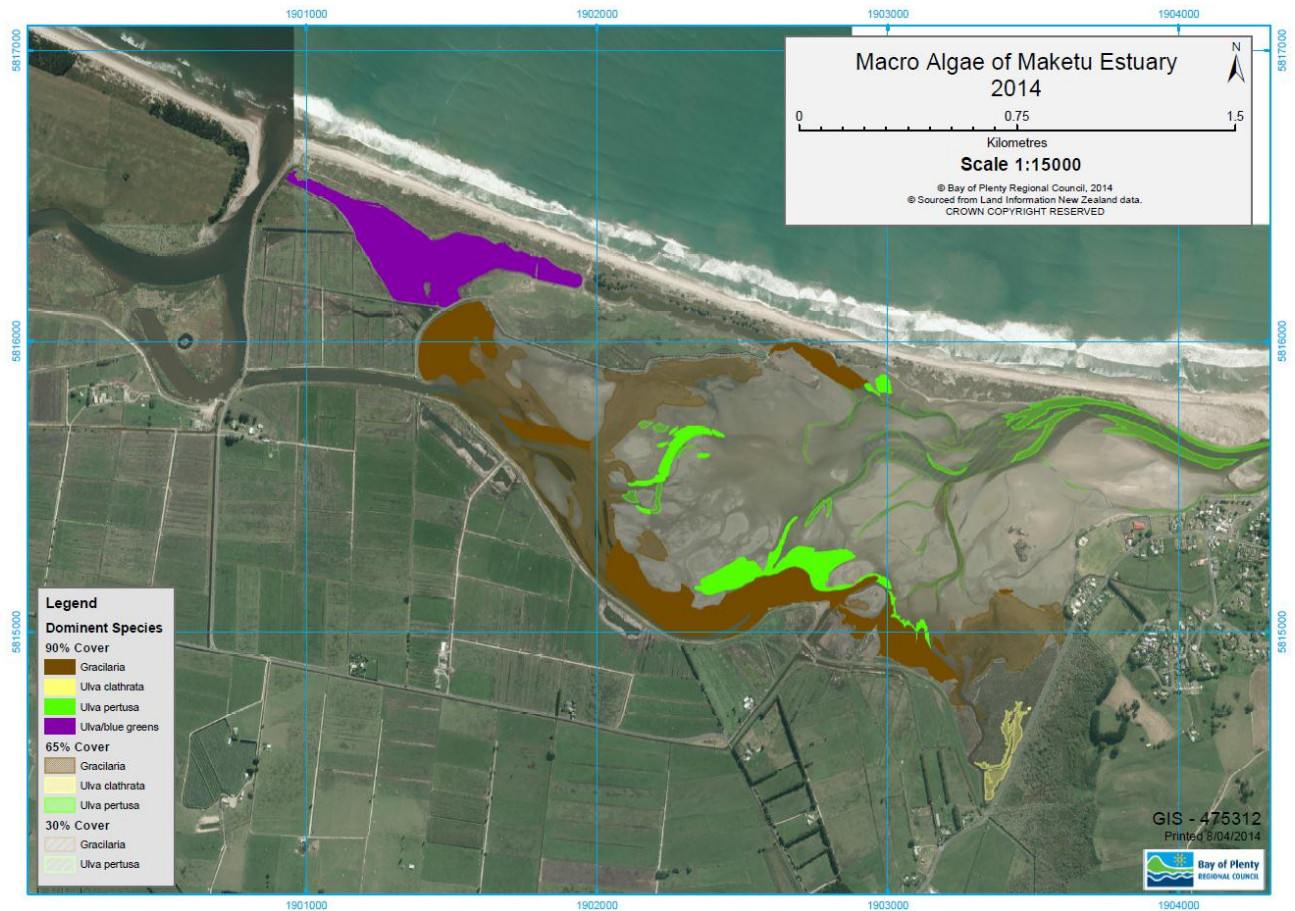
Figure 2.1: Vegetation and algal cover in the Maketū estuary.

Table 2.1: Area (hectares) of algal cover in the Maketū estuary

Species	35%	65%	90%
Ulva clathrata / U intestinalis	0.0	1.09	0.0
Ulva pertusa (sea lettuce)	8.62	4.66	5.76
Gracilaria sp.	1.62	26.5	20.4
Ulva flexitosa / Lyngbya sp	0.0	0.0	12.5
sum *Ulva* sp */Gracilaria* sp.	10.2	32.2	26.2
sum	**10.2**	**32.2**	**38.7**

Cover class ranges:

35% = 20-50% cover, 65%=50-80% cover , 90%=80-100% cover

Figure 2.2: Location of transects assessing algal cover, and transects for assessing algal biomass in Maketū estuary.
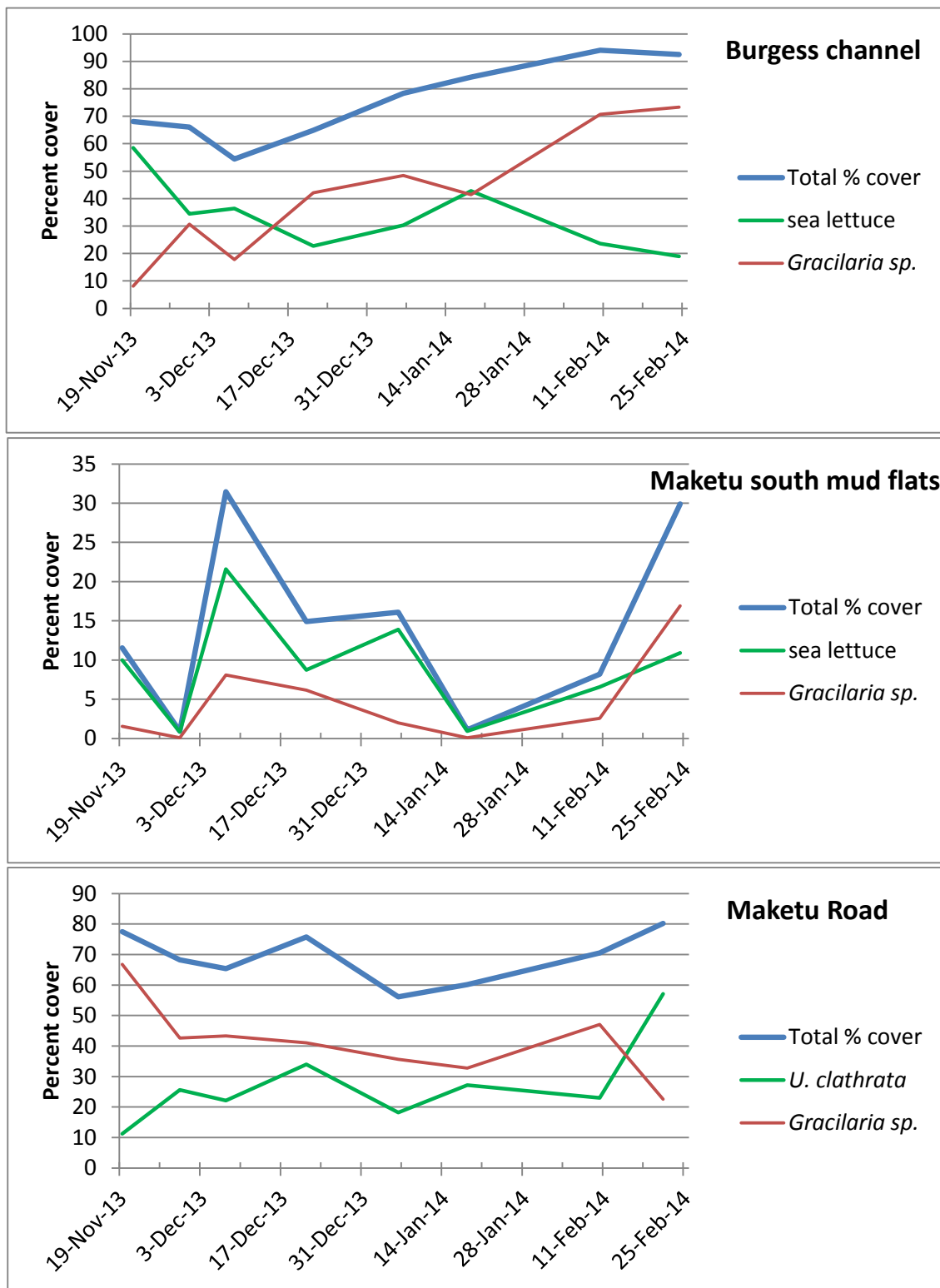
Figure 2.3: Change in average algal cover along transects in Maketū estuary south, November 2013 to February 2014.

Photo 2.1: Collecting algae and sediment samples in Maketū estuary south (east site).

Photo 2.2: Dense accumulation of *Gracilaria* sp with epiphytic diatoms and underlying anoxic mud in Maketū estuary south (March 2014).

Photo 2.3: Cyanobacteria (*Oscillatoria* sp.) epiphytic on Gracilaria in the upper Maketū estuary.

Photo 2.4: Dense accumulations of *Lyngbya* sp. in Papahikahawai lagoon (2014)

2.2   Algal biomass, nutrient content and sediment influence

The biomass and nutrient content of algae and underlying sediments was assessed in order to estimate the mass of nutrients that can potentially be flushed from the estuary and the relative importance of the internal nutrient flux compared to the external nutrient load.

2.2.1   Sampling method

The biomass and nutrient content of algae and underlying mud was assessed along four transects in the Maketū estuary on 8 March 2014 – upper mid-estuary, south estuary east, south estuary west, and from Papahikahawai lagoon (see Figure 2.2). All algae were collected from within five (0.25 m^2) quadrats, equally spaced along each transect. Algal samples were returned to the laboratory where they were washed, picked clean of any macro-fauna, squeezed and spun in a mesh bag to remove excess water, and weighed to determine wet weight. For each site, a sub-sample from each replicate was bulked into a single sample, weighed to establish wet weight and sent to Hill Laboratories for analysis of dry weight, total carbon (TC), total nitrogen (TN) and total phosphorus (TP).

The top 2.6 cm[8] of substrate was sampled from within each quadrat using a 5.7 cm diameter corer. Fifteen replicate cores were collected (e.g. three per quadrat) and bulked into a single sample (i.e. 0.03828 m^2 sampled). The sediment was frozen, weighed and sent to Hill Laboratories for analysis of dry matter, density, TN, TP and total organic carbon (TOC). Pore-water was extracted using a centrifuge and analysed for TN and TP. The average depth of unconsolidated mud overlaying sandy substrate was measured in the field for each replicate quadrat.

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[8] The intent was to collect the top 2cm of sediment but a retrospective calculation using wet weight, density and sample area estimated actual depth sampled to be about 2.6cm. Nutrient concentrations are typically more concentrated close to the sediment surface so sampling deeper will 'dilute' samples.

2.2.2   Results

The nutrient content of algae in samples was 2.68% to 4.24% for nitrogen (N), and 2.75% to 3.49% for phosphorus (P) (Table 2.2). These values are relatively high and indicate that the algae was not limited by either N or P. For sea lettuce in Tauranga harbour, growth limitation was indicated when cellular N or P were below 1.5% and 0.1% (dry wt) respectively (de Winton et al. 1998). These values are likely to be lower for *Gracilaria* sp which can grow in lower nitrogen concentrations than sea lettuce (Lartigue et al 2003, Teichberg et al. 2008, Jenson 2007).

Benthic macro-algae typically have a ratio of C:N:P of 215:14:1 (by weight) and a C:N ratio of 15 (Atkinson and Smith 1983). The nutrient ratios in samples dominated by *Gracilaria* sp. suggested that algae were replete in P and that if nutrients were limiting growth it would be N rather than P. The nutrient ratios of samples dominated by *Lyngbya* sp. suggest that the algae were replete in both N and P (Table 2.2).

Samples from Papahikahawai lagoon had relatively high N and P concentrations compared to other samples. This probably reflects nitrogen-fixing by the cyanobacteria *Lyngbya* sp., which is dominant in the lagoon, and the release of P from anoxic sediments (Table 2.2).

The concentration of organic carbon and nutrients in the surface sediments under the algae in the main estuary were relatively low compared with guidelines developed by Robinson and Stevens (2008)[9]. In contrast the Papahikahawai lagoon surface sediment had high N concentrations (indicating a 'poor rating') and moderately high organic carbon (indicating a 'fair rating') (see Table 2.2). These sediments were anoxic.

The mean biomass of algae along transects was high - about 240 to 850 g dry wt/m^2. In Tauranga estuary, 100% algal cover corresponds to about 100 g dry wt/m^2, but is considerably higher when algae accumulate in layers (Park 1994 in de Winton et al. 1998) (Table 2.3).

An estimate was made of the total amount of algae and associated mud in the estuary by multiplying the concentration per square metre by the aerial coverage of algae and the cover class ratio. This found that the 81 ha of algal coverage corresponded to about 442 tonnes dry weight, 13.2 tonnes N, and 1.36 tonnes P (Table 2.3). Unconsolidated anoxic mud was estimated to cover a smaller area (about 68 ha) because it was not generally associated with attached algae in the lower estuary. Nevertheless, it still contained about 22.2 tonnes N, and 3.5 tonnes P (Table 2.3). In contrast the water in the estuary at high tide was estimated to contain about 0.473 tonnes of N and 0.0417 tonnes of P[10].

The amount of organic mud in the southern part of the estuary which will have little impact from the re-diversion was estimated to cover about 12.4 ha. The corresponding amount of total carbon, TN and TP in the sediments were 29 tonnes, 4.0 tonnes and 0.71 tonnes respectively.

Pore-water N and P was respectively 1.6% to 2.8% and 1.2% to 2.5% of sediment N and P on a per metre basis (Table 2.2). The lower concentration of pore-water N in the Papahikahawai lagoon sample

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[9] Robertson and Stephens (2008) rated sediment as 'good' when TN was 0.05-0.2 g/100g, TP 0.002-0.005 g/100g, and TOC 1-2%.

[10] The mass of nutrients in estuary water during high tide was estimated using an average concentration during high tide of 0.4 mg N/L, 0.035 mg P/L, estuary volume of 1.185 million m^3, and estuary area of 2.2 ha.

(24 mg/L) was probably due to dilution as samples were collected underwater in low-density sediments. The concentration of TN and TP in the sediment pore-water was respectively 24 to 52 mg/L and 2.9 to 9 mg/L compared to an average TN and TP concentration in the estuary water of respectively 0.4 to 0.52 mg/L and 0.035 to 0.053 mg/L (high tide and low tide respectively). On an aerial basis TN and TP in the pore-water were respectively 613 to 840 mg/m^2 and 56.5 to 149 mg/m^2; compared to TN and TP in the overlying water at high tide of 215 mg/m^2 and 19 mg/m^2 respectively. This shows that nutrients derived from underlying anoxic mud are likely to be a more dominant source than nutrients derived from the overlying water.

Table 2.2: Biomass and nutrient content of algae and underlying sediment in Maketū estuary sites, March 2014.

Site name	Upper mid-estuary	Mid-estuary E	Mid-estuary W	Papahikahawai Lagoon
Algae	*Gracilaria / Ulva* sp			*Lyngbya* sp
Algal wet weight (g)	442.6	386.9	382.7	415.7
Algal dry Matter (g/100g wet)	16.9	12.4	14.5	15.7
Algal dry weight (g)	74.8	48.0	55.5	65.3
Algal TC (g/kg dry)	379.2	349.4	356.9	319.7
Algal TN (g/kg dry)	29.0	27.5	26.8	42.4
Algal TP (g/kg dry)	2.75	2.83	3.27	3.49
TC:TN	13.1	12.7	13.3	7.5
TN:TP	10.5	9.7	8.2	12.1
TC:TP	138	124	109	91
Sediment				
Wet weight (g/sample)	1452	1724	1522	1265
Soft sediment depth (cm)	4.4	0.8	2.5	18.3
Sediment Dry Matter (g/100g)	57	63	44	22
Sediment density (g/mL)	1.43	1.58	1.48	1.2
Sediment TP (g/100g dry wt)	0.022	0.021	0.032	0.044
Sediment TN (g/100g dry wt)	0.16	0.12	0.17	0.54
Sediment TOC (g/100g dry wt)	1.44	0.84	1.31	4.1
TC:TN	9.0	7.0	7.7	7.6
TN:TP	7.3	5.7	5.3	12.3
Pore-water volume (L/sample)	0.618	0.977	0.844	0.632
Pore-water TN (mg/L)	52	49	38	24
Pore-water TP (mg/L)	3.5	9	4.7	2.9
% pore-water N : sediment N	2.4%	1.6%	2.8%	2.4%
% pore-water P : sediment P	1.2%	2.3%	1.9%	2.5%

Pore water volume was calculated using the difference between dry weight and wet weight and assuming the density of water was 1.01 g/mL.

Table 2.3: Algal biomass and nutrient content in Maketū estuary after adjusting for cover and aerial extent (based on sampling in February 2014)

Algae	*Gracilaria/Ulva*			*Lyngbya*	Total
% cover	**20-50%**	**50-80%**	**80-100%**	**80-100%**	
Spatial extent (ha)	10.3	32.2	26.2	12.6	81.2
Site sampled	**Upper**	**Mid E**	**Mid W**	**Lagoon**	
Wet weight (kg/m2)	1.8	3.4	6.3	10.0	
Dry weight (g/m2)	242	456	847	1573	
TC (g/m2)	92	159	301	431	
TN (g/m2)	7.0	12.5	22.6	57.1	
TP (g/m2)	0.66	1.3	2.8	4.7	
Estuary wet weight (tonnes)	64	708	1478	880	**3,130**
Estuary dry weight (tonnes)	8.7	95.6	200	138	**442**
Estuary TC (tonnes)	3.3	33.3	71.0	37.8	**145**
Estuary TN (kg)	251	2619	5322	5016	**13,207**
Estuary TP (kg)	24	269	650	414	**1,357**

Notes

Adjusted for % cover by multiplying by: 0.35, 0.65 and 0.9 for 20-50% cover, 50-80% cover, and 80-100% cover respectively. *Lyngbya* was multipled by 0.7 because the mats sampled had been concentrated by the wind.

For mapping purposes, areas of <20% cover were not recorded.

Table 2.4: Nutrient contained in top 2.6cm of sediment under algal accumulations in Maketū estuary (based on sampling in February 2014). The top layer of sediment was generally anoxic mud.

Algae	*Gracilaria/Ulva*			*Lyngbya*	Total
% cover	**20-50%**	**50-80%**	**80-100%**	**80-100%**	
Spatial extent (ha)	1.6	27.6	26.2	12.6	67.9
Site sampled	**Upper**	**Mid E**	**Mid W**	**Lagoon**	
Wet weight (kg/m2)	37.9	45.0	37.3	33.1	
Dry matter (g/g)	0.57	0.63	0.44	0.22	
TOC (g/m2)	311	238	215	298	
TN (g/m2)	34.6	34.1	27.9	39.3	
TP (g/m2)	4.8	6.0	5.2	3.2	
Estuary wet weight (tonnes)	607	12434	9765	4148	**26,954**
Estuary TC (tonnes)	5.0	65.8	56.3	37.4	**164**
Estuary TN (kg)	554	9400	7304	4928	**22,185**
Estuary TP (kg)	76	1645	1375	402	**3,498**
Depth of soft sediment (cm)	4.3	1	1	18.3	

Notes

This method assumes that nutrients are primarily available in the top 2.6 cm of sediment. Areas with soft sediments deeper than 2.6 cm will have considerably more nutrients stored in the sediment (e.g. about 7 times more in the lagoon).

Sediment was not adjusted for percent cover because it was more evenly spread across the estuary.

The spatial extent excluded the area covered by sea lettuce with 35% & 65% cover, as this was mostly attached algae in the lower estuary with little associated mud.

2.3   Algal colonisation and growth in channels

The rate of algae colonisation and growth was assessed in Maketū estuary to better understand the factors controlling growth in the lower estuary.

Artificial substrates (bricks) were installed at two sites in the main channel of the mid-estuary in order to measure the rate of algal colonisation and growth (see Figure 2.2). Seven replicate bricks were installed at each site on 3 February 2014 and the percentage cover of algae and height of the algae was measured weekly. A number of replicates were partially buried by mobile sands during the experiment, and these were excluded from the analysis.

Colonisation was first observed two weeks after installing the bricks as small attachments of *Gracillaria* sp. and *Ulva* sp., however over time *Ulva* sp. started to dominate at both sites. Percentage cover of algae on the bricks increased steadily but the height of the algae remained low (<1cm) until 13 March (about 24-31 days after initial colonisation), after which there was a rapid increase in algal height - primarily *Ulva* sp. (Figure 2.4). The dominant *Ulva* sp. on the bricks were *U. pertusa* (sea lettuce) and *U. clathrata* (see photos in Appendix 3).

Snails were common on the bricks and the growth curves are consistent with significant grazing pressure causing variations in algal covers and maintaining low algal height for some time. It is likely that rapid increase in *Ulva* sp. height after 13 March reflects a reduction in grazing pressure as the algae reached a height that made grazing by snails more difficult. This is consistent with a reduction in % cover on some bricks even while the mean height increased. The impact of grazing on algal growth prevented any meaningful estimate of the specific growth rate (μ) which would have provided another estimate as to whether nutrients were limiting or not.

The percentage cover appeared to increase most rapidly at site A compared to site B. This would be consistent with more nutrients being available at this site from the southern estuary. However there appeared to be no significant difference in cover or algal height between the two sites by 18 March.
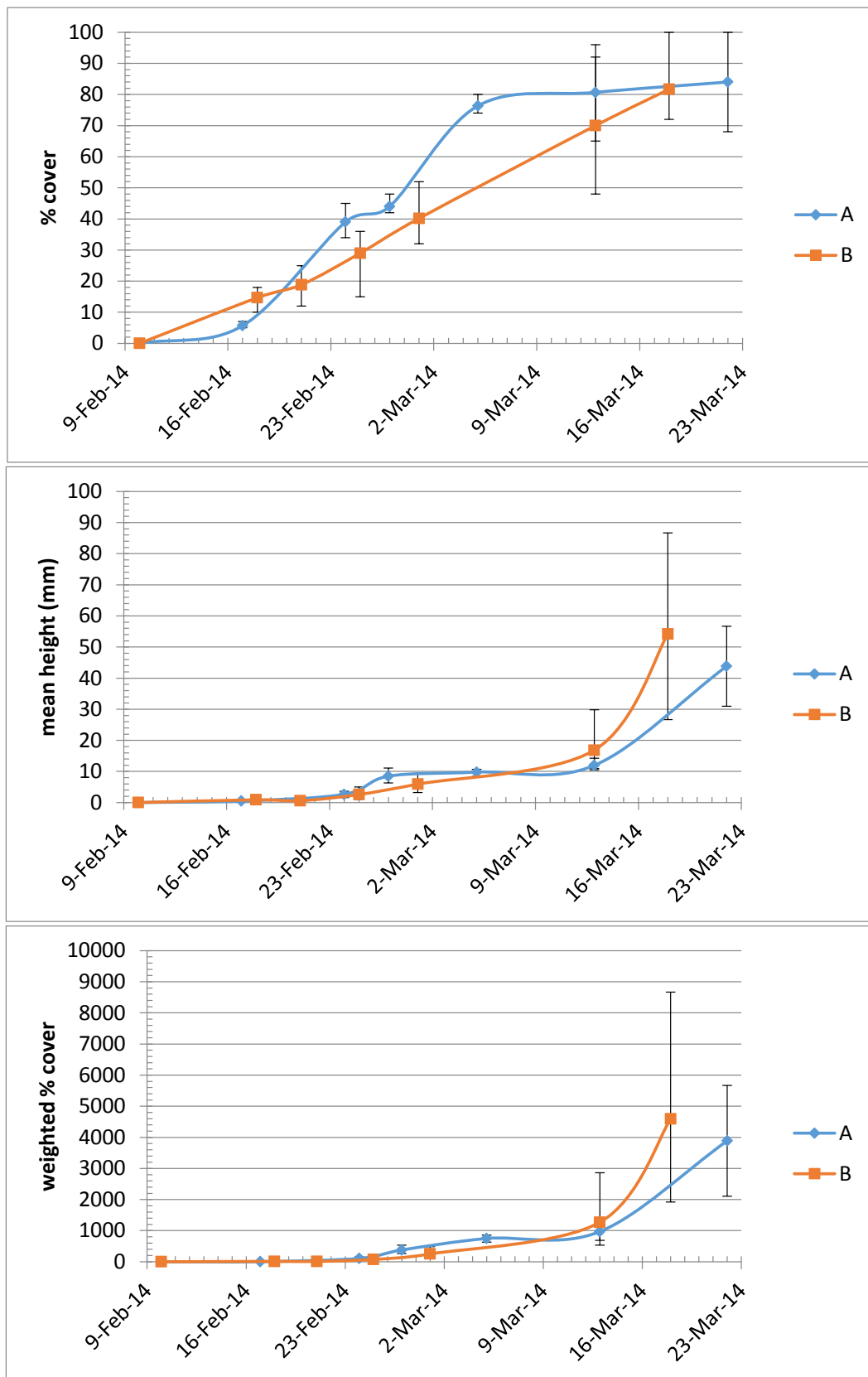
Figure 2.4: Sea lettuce colonisation and growth on bricks placed at two sites (A and B) in the main channel mid-estuary. Weighted cover is % cover multiplied by average height. Error bars are minimum and maximum of replicates.

2.4   Discussion of potential effects

2.4.1   Drivers of algal growth and accumulation

The cover and biomass of algae (e.g. *Gracilaria* sp, *Ulva* sp. etc) in the Maketū estuary is determined to a large extent by loss processes such as burial, the net export of algae flushed from the estuary, the grazing pressure from macrofauna and fish, and the growth rates. Key factors determining the growth rate of algae include water temperature, salinity, external nutrient supply (e.g. from streams) and internal nutrient supply (e.g. from the estuary sediment).

Many of these factors are inter-connected with positive and negative feed-back loops. For example, high nutrient loads favour fast-growing algal species that accumulate excess biomass. Decomposition of algae can lead to anoxic sediment; anoxic sediments lead to accelerated release of dissolved phosphorus and ammonium and reduced denitrification. This increased nutrient availability stimulates further algal growth. These positive feedbacks also create a challenge for restoration. Once sediments become anoxic it becomes much harder to restore a system to a less eutrophic condition because the release and cycling of nutrients from the sediment provide a buffer against any reductions in external nutrient load. This is known as hysteresis, where a system returns to its original trophic condition along a different path, with different species and nutrient requirements.

2.4.2   Algal flushing and accumulation

Algae in Maketū estuary is found both attached to substrate and free-floating in channels. Free-floating algae accumulate in low velocity areas, back waters and along the estuary margin, where it can continue to grow if conditions are suitable. On occasions, large amounts of sea lettuce are exported from Tauranga harbour (de Winton et al. 1998) and deposited along the coast east of Tauranga. These events are likely to contribute to free-floating algae found in Maketū estuary. Once *Ulva* sp. has been pulled from its attachment it does not reattach itself. However, it is common for polychaete worms to 'capture' sheets of algae, incorporate them into their burrows and anchor it to the substrate (de Winton et al. 1998).

The transport of free-floating algae is a major mechanism by which nutrients and carbon can be transported around estuaries and exported from estuaries (Flindt et al. 2007). This is likely to be the case in Maketū estuary due to the large amount of biomass, carbon and nutrients estimated to be within these drifting algae accumulations.

Change in current speed and flushing due to re-diversion

Hydraulic modelling by DHI (2014) found that the re-diversion will cause an increase in current velocity over most of the estuary. Furthermore the net residual current velocity significantly increases towards the estuary entrance throughout the whole estuary. The greatest increase in current velocity will occur in the upper estuary, south of Papahikahawai Island and in Papahikahawai lagoon (see Table 2.5).

Unconsolidated mud and silt is transported when water velocities exceed 0.05 m/s (Hjulstrøm 1935). Free-floating algae start to be transported at current velocities > 0.03 m/s, with the rate of transport substantially greater when velocities exceed 0.1 to 0.2 m/s (Flindt et al. 2007). *Gracilaria* sp. can be loosely attached to underlying mud and in these circumstances the velocity required to transport it is

likely to be closer to 0.2 m/s (the threshold for transport of consolidated mud (Hjulstrøm 1935)). Increased current velocity decreases the probability of drifting algae persisting in a location. No free-floating algae has been observed in areas of the Maketū estuary with currents greater than 0.2 m/s (e.g. sites P6 and P5) – thus supporting the literature that flushing will occur at lower velocities.

The re-diversion will increase maximum and residual current speeds sufficiently in the upper and mid-estuary to flush accumulations of free-floating algae and organic mud to the ocean. These areas currently accumulate algae and have poor benthic invertebrate species diversity and abundance; ecological health is expected to considerably improve as a result of increased flushing. There will remain some areas of low velocity (e.g. in the southern estuary and the western end of what is now Papahikahawai lagoon) where accumulation of algae and mud may continue to persist, but overall there is expected to be a reduction in mud and algal biomass. Small reductions in velocity are predicted in parts of the mid-estuary (see Figure 2.5, P2 and P5 in Table 2.5) but the maximum velocity will remain sufficient to flush drifting algae and mud. Furthermore, the residual velocity in these areas increases towards the entrance (DHI 2014).

Movement of algae as bed load contributes to sediment re-suspension by physically abrading the sediment (Canal-Verges 2010). In the long term, the reduced accumulation of algae and mud in the upper estuary may improve water clarity.

In the lower Maketū estuary sea lettuce is often found attached to stable substrate (e.g. cockle shells) or anchored to the substrate by polychaete worms that 'capture' sheets of algae and incorporate them into their burrows (see de Winton et al. 1998). The increased current speeds will not prevent the accumulation of algae attached in this way but the increased scour is likely to reduce the length of attached sea lettuce.

Table 2.5: Changes in the maximum current speed on estuary bed (mean tide) before and after re-diversion (derived from graphs in DHI 2014).

Estuary location	DHI site	Velocity 7-Day low flow (m/s)		Velocity mean river flow (m/s)	
		current	after	current	after
Upper estuary	P1	0.03	0.2	0.02	0.2
Upper channel	P6	0.2	0.41	0.21	0.42
Upper mid-estuary	P4	0.02	0.12	0.04	0.14
Mid-estuary flats	P2	0.15	0.14	0.14	0.14
Mid-estuary channel	P5	0.2	0.15	0.2	0.15
Mid-estuary (Burgess drain)	P3	0.04	0.06	0.04	0.06

2.4.3 Salinity effect on algal growth

Response of Gracilaria and *Ulva* sp. to salinity

Salinity is an important variable affecting the growth and distribution of algae. When exposed to salinity changes, macro-algae alter their internal osmotic pressure in order to prevent loss of internal molecules – this takes energy that could otherwise be used for growth.

Gracilaria sp*.* has a broad tolerance range for temperature and salinity (e.g. 10 – 45 psu)[11]. For *G. vermiculophylla* the optimum salinity is 15 to 30 psu. Growth rate reduces at salinities below 15 psu and when exposed to low salinity (<5 psu) for 2 to 4 days it does not recover (Jenson 2007, Nejrup and Pedersen 2012). *G. verrucosa* had an optimum salinity of about 25 psu. Growth increased with temperature and the effect of salinity on photosynthesis was more pronounced at low temperature (Dawes 1984). *G. verrucosa* grown without nutrients had less tolerance of low salinity compared to plants grown with nutrients.

The growth of *Ulva intestinalis* is also depressed by low salinity (< 18 to 24 psu) (McAvoy and Klug 2005). Both *Gracilaria* sp. and *Ulva* sp*.* had less tolerance of low salinity when grown without nutrients (Dawes 1984, McAvoy and Klug 2005). Thus benefits of lowering salinity are greater if nutrient levels are also reduced.

There is evidence that an abrupt change in salinity, in addition to the absolute value, decreases growth in *U. lactuca* (Lartigue et al 2003).

Salinity changes due to re-diversion

Hydraulic modelling by DHI (2014) found that the re-diversion will cause relatively small changes in salinity within the estuary (Figure 2.6). Following the re-diversion the median salinity in bottom water (averaged over a tidal cycle) during a mean river flow would be:

- upper estuary tidal flats (Pt 2): 16 psu (an increase of 4.6 psu),

- upper estuary channel (Pt 3): 20.6 psu (an increase of 6.1 psu),

- upper mid-estuary (Pt 4 & 5): 19.1 psu (a decrease of 2.1 psu),

- mid-estuary (Pt 6 & 7): 23.7 psu (a decrease of 4.7 psu),

- southern estuary (Pt 8): 26.3 psu (a decrease of 3.4 psu),

- lower estuary sand flats (Pt 9): 31.8 psu (a decrease of 3 psu),

- lower estuary channel (Pt 10): 24.5 psu (a decrease of 6.3 psu),

- Papahikahawai lagoon will have relatively low salinity water of 10-15 psu compared to current measured values of 26-28 psu.

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[11] Psu = practical salinity units and is the same as parts per thousand (ppt)

The salinity would be considerably higher during periods of low flow in the Kaituna River compared to mean flow (e.g. about 30 psu in the mid-estuary) and the change in salinity would be less at all sites (e.g. a decrease of 2.3 psu mid-estuary) (DHI 2014). The effect of the river flow on salinity will be considerably greater in the upper estuary (e.g. Papahikahawai lagoon will have bottom water salinity of 20-25 psu during a seven day low flow compared to 10-15 psu during a mean flow).

Overall, the re-diversion will cause a small decrease in salinity in most of the estuary. In the middle and lower estuary the effect of this salinity reduction on algal growth will be minor because mean salinity will still be within or close to the optimum range for growth. However it is moving in the right direction and some degree of additional stress on *Ulva* sp. growth can be expected.

The upper estuary will have a small increase in median salinity but the daily minimum salinity will decrease (see DHI 2014). Increasing the overall salinity will slightly reduce salinity stress on *Ulva* sp. and *Gracilaria* sp. but the increased variation and low daily minimum salinity may increase stress (see Lartigue et al 2003), and the combined effect is difficult to predict. However, overall the salinity change in the upper estuary is relatively small and effects on algae are likely to be minor.

Papahikahawai lagoon will have the largest potential improvements in ecological health due to the re-diversion; salinity is predicted to reduce 50% to levels likely to start limiting the growth of *Ulva* sp and *Gracilaria* sp., and the daily fluctuation in salinity will increase. These changes are likely to cause a change in algal species composition and will possibly favour species with a wide salinity tolerance (e.g. *Gracilaria* sp. compared to sea lettuce).

The lowest salinity in the estuary is amongst the wetland adjacent to the Waitipuia Stream that enters in the southern estuary. The model predicted little change in salinity amongst the wetland but a small decrease in salinity along the wetland margin (Figure 2.6).

2.4.4   Nutrient effect on growth rates

Algal growth rates are strongly influenced by the amount of nutrients available for growth. Fast-growing species tend to have higher nutrient requirements than slow-growing species. For example, *Ulva lactuca* has a higher growth rate than *Gracilaria vermiculophylla* when N was in plentiful supply (Lartigue et al 2003, Teichberg et al. 2008), but *Gracilaria* sp. can maintain maximum growth rates under both low light conditions and small concentrations of nitrogen (about 0.007 mg N/L) which provides a competitive advantage (Jenson 2007).

To some extent, algae (including *Ulva* sp, *Gracilaria* sp, and *Lyngbya*) can be uncoupled from fluctuating nutrient supply by an ability to store nitrogen within the plant tissue and use these nutrient reserves when external nutrients are no longer available (de Winton et al. 1998, Nejrup and Pedersen 2012, Arthur et al. 2009). *Gracilaria* sp. has a greater capacity to store nitrogen (Teichberg et al. 2008). Sea lettuce does not appear to store P (de Winton et al 1998).

Change to external nutrient supply due to the re-diversion

DHI (2014) modelled the potential change in nitrogen (N) and phosphorus (P) concentrations in the Maketū lagoon as a result of the re-diversion. They used a dilution model which included mean inputs from the Kaituna River, surrounding drains and the ocean. The model did not include any biological processes (e.g. nutrient uptake) or internal loading from sediments or fauna. Nevertheless, the model

provides useful information for assessing how nutrient concentrations in the estuary may change due to changes in external loading.

Modelling indicates that mean[12] concentrations of total nitrogen in the Maketū estuary are currently: 0.5 to 0.7 mg/L in the upper estuary, 0.2 to 0.5 mg/L in the mid-estuary, 0.1 to 0.3 mg/L in the lower estuary, and 0.7 to >1 mg/L in the southern estuary. Mean concentrations of total phosphorus in the Maketū estuary are currently: 0.05 to 0.06 mg/L in the upper estuary, 0.02 to 0.05 mg/L in the mid-estuary, 0.01 to 0.03 mg/L in the lower estuary, and 0.06 to 0.1 mg/L in the southern estuary (Figure 2.7, DHI 2014).

The modelling by DHI (2014) showed that under mean river flow conditions there will be a small decrease in nutrient concentration in the upper estuary and southern estuary and a small increase (in the order of 5 to 15%) in the mid-estuary and lower estuary. In the mid estuary there is a predicted shift in the existing nutrient gradient towards the mouth resulting in an increase of 0.1 and 0.01 mg/L for TN and TP respectively (see Figure 2.7). The patterns are broadly similar for both nitrogen and phosphorus. The patterns are generally the inverse of what was observed for salinity, with the exception of the southern estuary where greater influence from the Kaituna River dilutes the higher nutrient concentrations from the Waitipuia Stream.

There is a risk that a decrease in nutrient concentration in the upper estuary will potentially decrease the rate of any algal growth, while a small increase in the mid and lower estuary will potentially increase the rate of algal growth and shift competitive advantage to faster growing species e.g. *Ulva* sp. compared to *Gracilaria* sp. There are a number of factors that will mitigate these potential effects occurring as a result of the re-diversion. Firstly, while small nutrient increases in the mid-estuary may encourage algal growth, the small decline in salinity will help reduce it (and vice-versa in the upper estuary). Secondly, cellular concentrations of N and P collected from algae (mostly *Gracilaria* sp) in the upper mid-estuary and southern estuary suggest that nutrients are not currently limiting algal growth, which reduces the extent to which additional nutrients cause direct changes in algal growth. Thirdly, a significant portion of algal nutrient requirements are likely to come from internal nutrient loads and the re-diversion will reduce this nutrient source by flushing anoxic mud and algal accumulations (see following section).

The modelling shows that the highest nutrient concentrations in the Maketū estuary are in isolated pockets near drain inputs, and in the southern estuary due to the influence of Waitipuia Stream. Additional flow from the re-diversion will dilute the influence of the Waitipuia Stream and push it eastward, resulting in the greatest reduction in nutrient concentrations in the western part of the southern estuary. During rain events, the nutrients from the Waitipuia Stream become a much more dominant influence on the mid and lower estuary (DHI 2014). The re-diversion is likely to result in a small reduction in algal growth in the southern estuary, but in order to see substantial ecological improvements in this part of Maketū Estuary, attention should be given to managing nutrients (N and P) entering the estuary from Waitipuia Stream and the drains.

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[12] Mean concentrations under mean river flow conditions as modelled by DHI (2014).

Change to internal nutrient supply due to the re-diversion

Estuaries typically have strong benthic-pelagic coupling resulting in considerable nutrient flux from the sediments. There are a number of reasons for this: often there are high densities of benthic fauna (e.g. shellfish) that directly filter and cycle nutrients (e.g. Pratt et al. 2014). Benthic biota also cause bioturbation that increases interactions with the sediment. Changes in salinity, which is a defining characteristic of estuaries, can also cause the release of iron-bound phosphorus from particles as iron reacts with sulphides to form sulphide precipitates (Jorden et al. 2008). Pratt et al. (2014) found ammonia flux from sediments in relatively healthy estuaries to be commonly around 20 mg/m^2/day. If applied to the 240 ha of the Maketū estuary this would equate to a flux of 48 kg/day, but could be twice this value.

The extent of nutrient flux from sediments dramatically increases when sediments become anoxic. Anoxic conditions can cause the reduction of iron and aluminium in sediments and the consequent release of phosphorus previously bound to these metals. Anoxic sediments also release ammonium to overlying water and reduce iron into the dissolved, bioavailable (ferrous) form. Furthermore, widespread anoxia also reduces potential for denitrification by restricting nitrification and resulting in nitrogen being present primarily in the reduced form (i.e. total ammoniacal nitrogen).

Because of this, internal nutrient loading often becomes more dominant in highly eutrophic systems, resulting in a tipping point where algal biomass is maintained by internal nutrient loads and somewhat uncoupled from external loads. Prolific algal growth results in accumulation of organic matter and sediment anoxia. Sediment anoxia releases dissolved nutrients (ammonium, phosphorus and ferrous iron), and this supports further algal growth and further anoxic conditions. The nutrient can also cause a shift towards algal species that grow quickly and have a high demand for nutrients such as cyanobacteria. Nitrogen-fixing cyanobacteria provide another positive feed-back, increasing internal nitrogen loads as the algae fix nitrogen from the atmosphere. The N-fixing process requires ferrous iron to form the enzyme nitrogenise. As it takes energy, dissolved N (e.g. ammonium) is preferentially used for growth when available (Arthur et al. 2009).

This pattern of internal nutrient loading is apparent in the upper Maketū estuary, margins of the Southern estuary and in Papahikahawai lagoon. These areas have thick accumulations of algae (*Gracilaria* sp, *Ulva* sp. and *Lyngbya* sp.) and accumulations of organic, anoxic mud. In parts of the southern estuary *Gracilaria* sp. is covered by epiphytic diatoms (*Melosira* sp). The upper estuary has *Melosira* sp, as well as cyanobacteria (*Oscillatoria* sp. and *Lyngbya* sp.) growing as benthic mats on the mud and epiphytic over *Gracilaria* sp. In Papahikahawai lagoon *Lyngbya* sp. is so prolific that the benthic mats float to the water surface to form thick and extensive floating rafts.

Nutrient fluxes have not been directly measured in Maketū lagoon but the relative importance of nutrient flux from the anoxic sediments in the estuary can be implied by the relative amount of nutrients in these pools and nutrient concentrations of pore-water. The top 2.6 cm of anoxic mud in the estuary were estimated to contain 22.2 tonnes of N and 3.5 tonnes of P. The part of the estuary likely to experience more flushing (i.e. not the southern estuary) has about 18.2 tonnes of N and 2.79 tonnes of P. This corresponds to 364 kg N/day and 55.8 kg P/day (assuming a 2% flux) which is likely to be removed as a result of the re-diversion. In contrast the water in the estuary at high tide was estimated to contain about 473 kg of N and 41.7 kg of P. The concentration of TN and TP in the sediment pore-water was about 100 times higher than concentrations in the overlying water. When converted to an

aerial basis (i.e. per square metre) the amount of TN and TP in the pore-water of the top 2.5cm of sediment was three to five times higher than that in the overlying water.

These calculations suggest that the nutrient flux from anoxic mud associated with algal accumulations is a major source of nutrients and probably a more important source than nutrients available in the overlying waters, thus flushing these sediments would significantly reduce the nutrients available for growth of macro-algae. These benefits will be particularly apparent in areas where anoxic mud occurs but will also extend further down the estuary. Furthermore, increased flushing will directly remove nutrients contained in algal biomass and reduce the accumulation of this nutrient pool.

2.4.5   Changes in grazing pressure on algae (a positive feedback)

Grazing appears to have a substantial influence on the growth and accrual of *Ulva* sp. in the Maketū estuary. Grazers known to feed on macroalgae include mullet, sea hare (*Aplysia* sp*.),* chiton, and various molluscs. It is possible that flushing of anoxic mud and algal accumulations as a result of the re-diversion will improve habitat conditions for grazers by reducing fine sediments, and increasing dissolved oxygen. This in turn will increase the rate of algal grazing, and further reduce algal accrual.

2.4.6   Potential effects of the re-diversion on remnant sea grass beds

Sea grass beds support a high diversity of invertebrate fauna and are generally considered to be a sign of a healthy estuary (Alfro 2006). Despite sea grass (*Zostera* sp.) once being dominant in the mid and upper Maketū estuary, now only a tiny remnant remains. There are a number of possible reasons for the decline in sea grass beds that are discussed in Park (2014). These include smothering by epiphytes and algae, increase in sediment anoxia, increase in salinity, increase in nitrogen concentrations, and estuary sedimentation.

Probably the main effect of the re-diversion on the potential of sea grass beds to survive and re-establish in the estuary is the small reduction in salinity. Although sea grass (*Zostera* sp.) are tolerant of a wide range of salinity they are sensitive to high salinity during key periods of reproduction. Sea grass relies on both vegetative and sexual reproduction for the maintenance of existing beds and colonization of new areas. In areas that are environmentally stable, sea grass survives using perennial rhizomes. In contrast, sea grass that are exposed to high summer water temperatures and large fluctuations in salinity favour an annual life history, with recruitment by germination of seeds. Flowering and germination is favoured by low salinity, for example there are 1.5 times more flowers produced at 17 psu compared to 33 psu (Ramage and Schiel 1998).

Lower salinity and less algae as a result of the proposal is expected to increase the likelihood of sea grass seed germination and potentially open up additional habitat for colonisation. The lower salinities also increase sea grass tolerance to high nitrogen concentrations (see discussion in Park 2014).

2.4.7   Potential effects of establishing wetland on land north of Fords cut

Part of the Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement Project includes a proposal to widen Ford's cut, and removing stop banks and causeway around farmland north of Ford's cut in order to reconnect it to the estuary and create wetland. The potential for wetland creation in this

area is discussed in detail by MacGibbon (2014), and my comments relate to potential impacts on the wider estuary.

In the short term there is a risk that the flooding of farmland will result in a release of phosphorus from the soil. However, in the medium and long term flooding the farmland and creating up to 40ha of wetland will contribute to a reduction in nutrients to the estuary. Currently about 672 kg/yr of nitrogen (assuming the current landuse leaches 21 kg/ha/year and there is 20% attenuation) is likely to leach from this land. This will cease and over time additional N will be removed by denitrification within the wetland. The amount of potential denitrification is difficult to quantify without first determining wetland design and hydraulic loading.

Current velocity over the area is expected to be low so there is a risk that algae may accumulate in this area, as it currently does in the upper estuary, if wetland plants are not quickly established. This risk can be managed by using fill to raise the ground level on the west and north of the land. Creating a gradient to higher ground and pockets where surface water can pool will also increase the potential diversity of wetland plants that can be establish.

It is recommended that the land slopes back from Ford's cut on a shallow gradient (i.e. 1:10 to 1:30) starting from below the spring low tide level. This will provide much better habitat diversity compared to steep sides.
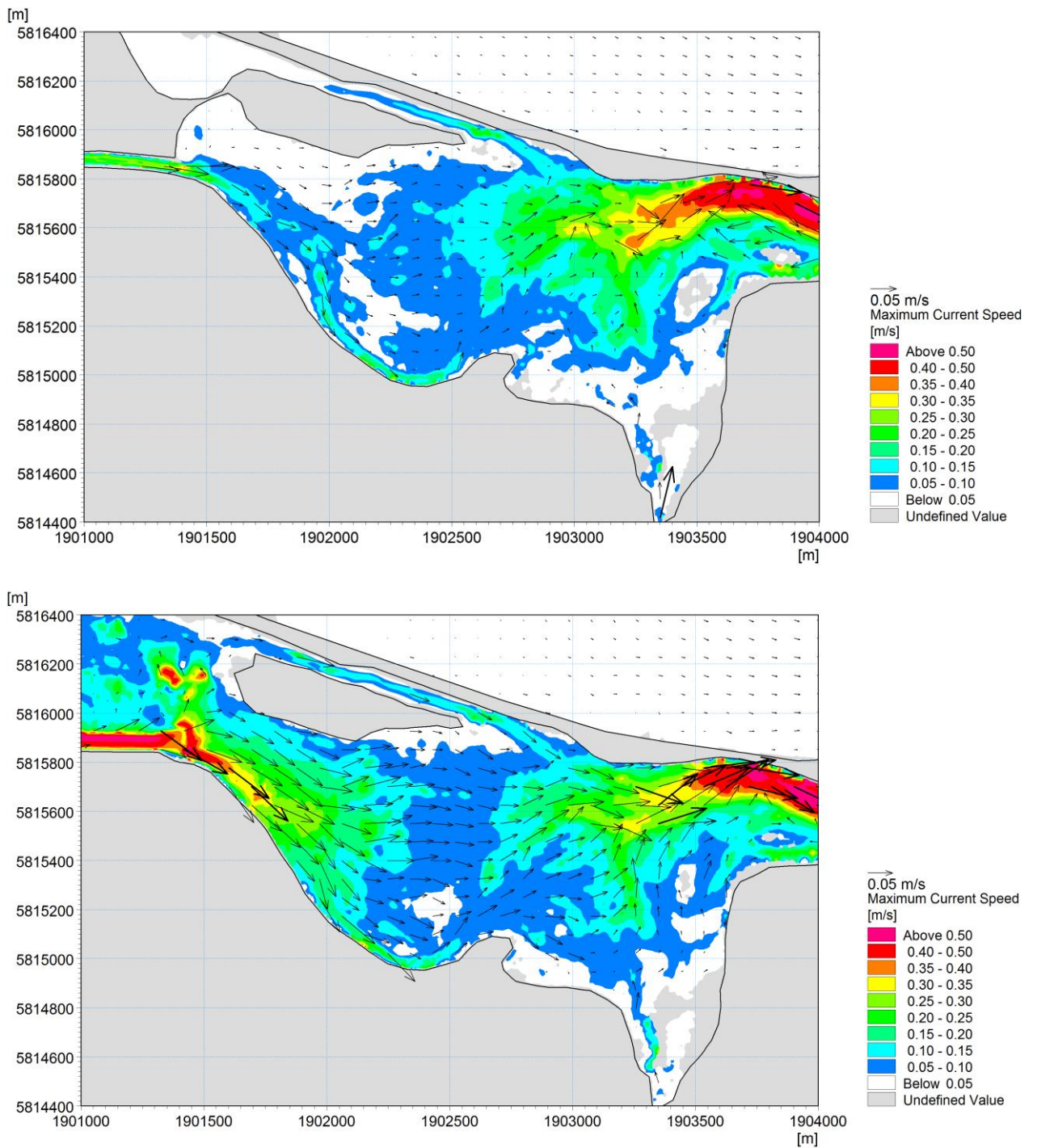
Figure 2.5: Maximum current speed and direction during a mean River flow and mean tide in the Maketū estuary for the existing (top) and proposed (bottom) scenario (from DHI 2014 model). Note that much of the area north of Ford's cut is intended to be planted as wetland.
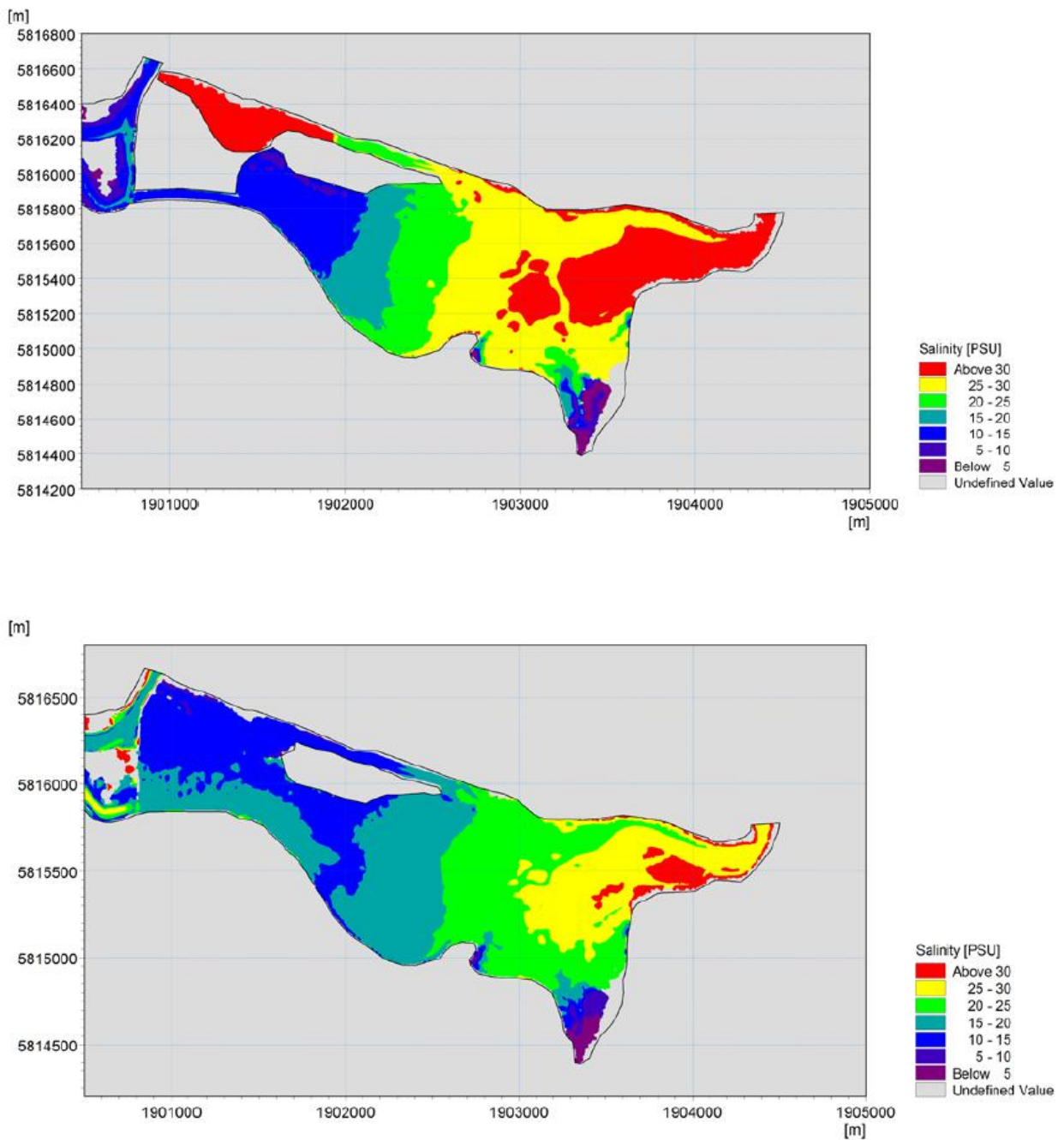
Figure 2.6: Mean salinity on the estuary bed modelled for the existing (top) and proposed (bottom) scenario for a mean river flow and averaged over a neap spring tidal cycle (DHI 2014). Note that the measured salinity in Papahikahawai lagoon was 26-28 psu rather than the >30 psu assumed in the model of the existing scenario.

Figure 2.7: Mean total nitrogen concentration in the Maketū estuary modelled for the existing (top) and proposed (bottom) scenario for a mean river flow and averaged over a neap spring tidal cycle (DHI 2014). Note that much of the area north of Ford's cut is intended to be planted as wetland.

2.5　Summary

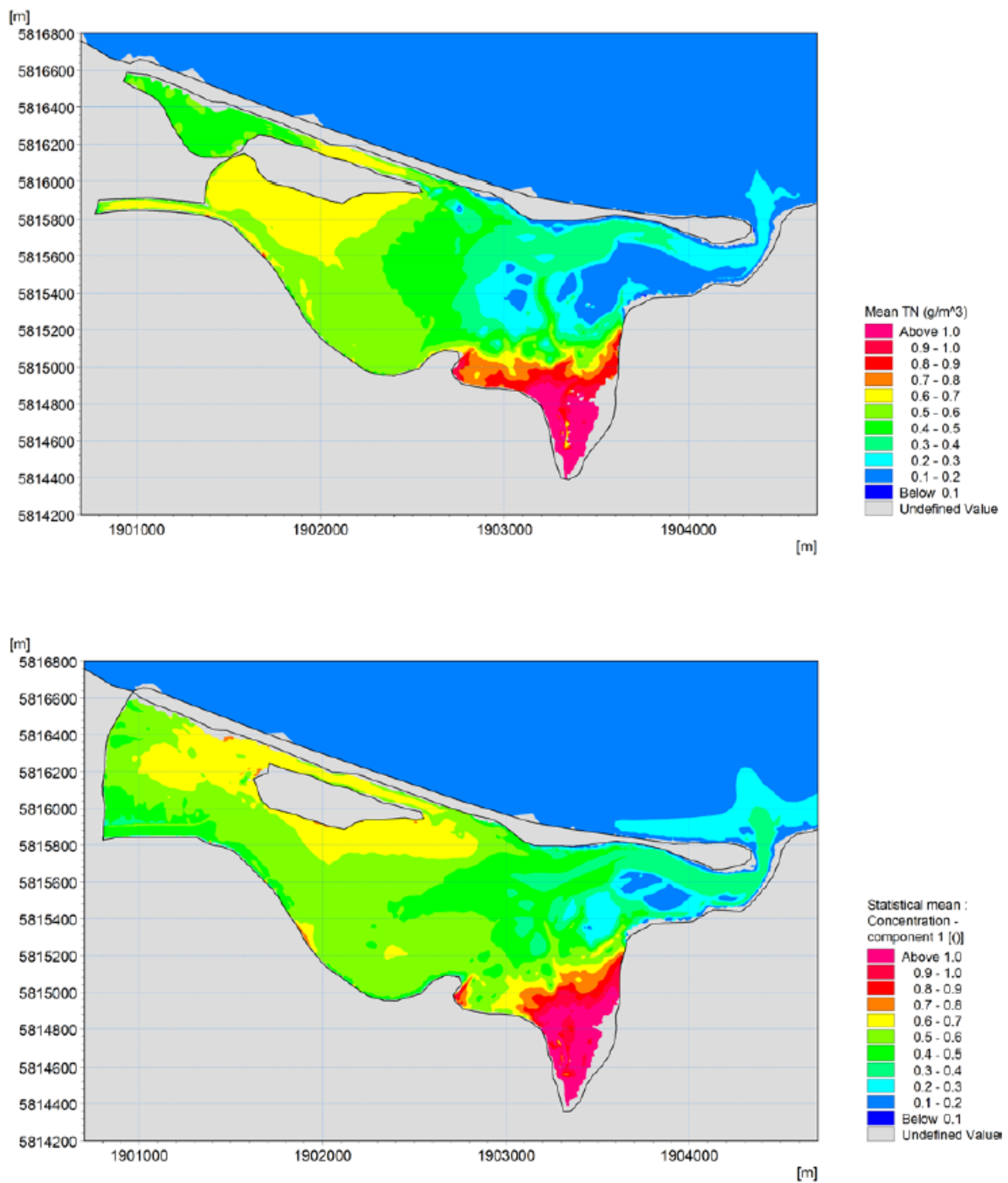The key messages of this section are:

- About 30% (71 ha) of Maketū estuary is covered in algae of greater than 50% cover. The dominant algae species are sea lettuce (predominantly *Ulva pertusa*) and *Gracilaria* sp. *Ulva flexuosa* var *pilifera* is common in the mid-estuary. *Ulva clathrata* and *Ulva intestinalis* is common amongst *Gracilaria* sp. along the margins of the southern estuary.

- Dense accumulations of free-floating macro-algae (mostly *Gracilaria* sp., *Ulva pertusa* and *Ulva flexuosa*) are common in the upper estuary, mid-estuary and along the margins of the southern estuary. The Papahikahawai lagoon is dominated by floating mats of *Ulva flexuosa* var *pilifera* and the cyanobacteria *Lyngbya* sp. Anoxic mud accumulates beneath these mats and mud is estimated to cover 29% (68 ha) of the estuary to depths of between 1 to 25 cm.

- The re-diversion will cause an increase in current velocity over most of the estuary. Furthermore the net residual current velocity significantly increases towards the estuary entrance. This will substantially increase the flushing from the estuary of algal accumulations and associated anoxic mud. The largest improvements in flushing will occur in the upper estuary, south of Papahikahawai Island and in Papahikahawai lagoon.

- The re-diversion will result in relatively small changes in salinity in most parts of the estuary. The majority of the estuary will have a small decrease in salinity, the upper estuary a small increase, and Papahikahawai lagoon a substantial decrease – closer to its natural condition. The small decrease in salinity is expected to cause a small and relatively minor reduction in the growth rates of *Ulva* sp. and *Gracilaria* sp. in the mid-estuary.

- The availability of nutrients for algal growth is a function of the nutrient loads from both external sources (e.g. rivers and drains) and internal sources (e.g. release from sediment). Parts of the Maketū estuary are highly eutrophic and are likely to be partially decoupled from external nutrient sources due to high internal loading from anoxic sediments and N-fixing cyanobacteria.

- For most of the estuary the change in nutrient concentrations from increased river water is inversely proportional to changes in salinity, i.e. the re-diversion will cause a small decrease in concentration the upper estuary and a small increase in the mid and lower estuary. However, the small overall increase in external nutrient load will be balanced by a decrease in internal nutrient load due to the flushing of anoxic mud and algal accumulations from the upper estuary, mid-estuary and Papahikahawai lagoon.

- Internal nutrient loading is likely to be particularly strong in the Papahikahawai lagoon due to nitrogen-fixing by cyanobacteria and release of N and P from deep anoxic mud. These nutrient loads will be substantially reduced due removing barriers and increasing current velocities.

- In the southern estuary the re-diversion model found little impact on current velocity but a decrease in both salinity and nutrients. This is because the Waitipuia Stream and drain inputs

result in the southern estuary having the highest concentration of (externally sourced) nutrients and this will be diluted and pushed westward as a result of the re-diversion.

- The health of Maketū estuary has reduced with the loss of sea grass beds. A small overall reduction in salinity as a result of the proposal will increase the likelihood of sea grass seed germination and potentially open up additional habitat for colonisation or restoration.

- The proposed re-diversion is expected to result in an overall decrease in algae cover and improvement in ecological health in the Maketū estuary. However, excessive algae accumulations will still be apparent in places. In addition to the proposed re-diversion, attention should be given to reduction nutrient loads to the estuary. Reducing nutrient loads will be particularly import in order to see significant ecological improvements in the southern part of the Maketū estuary. In particular, attention should be given to managing nitrogen entering the estuary from Waitipuia Stream and nearby drains. An important start will be identifying the main nutrient sources within this catchment.

- Monitoring of algae cover and biomass in the estuary will be a key way to assess the benefits of the re-diversion over time.

3   Shellfish and benthic fauna in the estuary

3.1   Introduction

Benthic invertebrates (e.g. pipi, cockle) are valued as fishery and are an important food source for fish and birds. They are also useful as bioindicators to detect and monitor environmental changes. This is because they integrate water and sediment quality conditions over time, and rapidly respond to natural and/or anthropogenic-caused stress.

Maketū estuary was historically renowned for its plentiful supply of pipi (Matheson 1991, Goodhue 2007). There are historical reports that mussel and oyster beds also occurred within the Maketū estuary prior to the Te Tumu diversion (Murray 1978). Pipi are still common in the lower estuary. Mussel have declined with the influx of sand, but have returned to rocks near the estuary entrance following erosion of sand from this area. However they are still absent from the shellflats of the lower estuary. Oysters are now rare, but in the past may have been seeded from attempts at oyster farming in the upper estuary.

This chapter describes the current state of shellfish, infauna and epifauna in the Maketū estuary based on field surveys and the sampling of 39 sites across the estuary in 2013/14. There are a number of sites in the estuary where shellfish and macrofauna have been sampled over a number of years. This monitoring has been reported in other documents and is not repeated here. In particular:

- BOPRC have monitored four sites in the mid to lower Maketū estuary as part of the estuarine benthic monitoring programme since 1993. Recent results are described in Park (2012) who noted that all sites showed marked changes in species and sediment parameters in response to highly dynamic changes in sand erosion, deposition and migration as the estuary continues to infill.

- BOPRC has also undertaken regular compliance monitoring as part of the current consent for the current Kaituna-Maketū river re-diversion through Ford's cut. Sites are in the mid and lower estuary with sampling occurring at the high, mid and low tide sections every two years. Recent results are described in Park (2011), who notes that monitoring found no adverse impact on cockle densities from the freshwater being re-diverted back into the estuary. Adverse impacts on the cockle bed densities (and possibly size) have occurred at sites nearer the entrance as a result of sand migration into the estuary.

- The Maketū Taiapure Committee has undertaken a baseline survey of shellfish beds in the lower Maketū estuary (up to ca. 550 m from the entrance). The monitoring focused on pipi (*Paphies australis*) and cockle/tuangi (*Austrovenus stutchburyi*). The result of sampling in 2012 found that 95% of the shellfish in this area were pipi and 5% cockle. Epifauna were dominated by top shells (*Diloma subrostrata*) and whelks (*Cominella* sp). The mean density of pipi in the channel zone was ca. 400 to 1400 /m^2 (Gaborit-Haverkort 2012).

3.2   Methods

3.2.1   Sampling methods

Shellfish and epifauna were sampled from 39 sites across the Maketū estuary. Additional samples were collected in a subset of eight of these sites to characterise infauna and sediment chlorophyll *a* (see Figure 2.1 and Appendix 4). The sites chosen were primarily intertidal mudflats; channels were generally avoided. The survey focused on the mid to upper estuary where the impact of the proposed diversion is expected to be most obvious. The survey did not target pipi (*Paphies australis*), which dominate in the lower estuary, with adults in the channels and juvenile higher on the sand flats. However the extent of pipi in the main channel was determined during an estuary visit on 29 January 2014. This also characterised the species composition of the lower estuary and rocky shore near the entrance.

Sampling was undertaken during low tides during the period 26 November 2013 to 16 January 2014. For the shellfish sampling, eight replicate sediment cores were randomly collected over a 10m radius of the site location. Cores were taken in the sand/mud flats to a depth of 15 cm using a 13cm diameter stainless steel corer (i.e. 0.0133 m^2 per replicate)[13]. The sediment from each core was sieved through a 2mm mesh and all shellfish identified and counted. Cockle / tuangi (*Austrovenus stutchburyi*) and wedge shell / hanikura (*Tellina liliana* (syn. *Macomona Liliana*)) were measured and counted in 5mm size classes.

Epifauna abundance was assessed with eight randomly placed 0.25 m^2 quadrat[14]. Within each quadrat, all crab holes and macrofauna >2mm were identified and counted.

For the infauna sampling, eight replicate sediment cores were randomly collected within a 10 m radius of the site location. Cores were taken in the sand/mudflats to a depth of 15 cm using a 13 cm diameter stainless steel corer (i.e. 0.0133 m^2 per replicate and 0.1062 m^2 per 8 replicates). The sediment from each core sample was placed into labelled plastic bags and returned to the laboratory for processing. In the lab, samples were sieved through a 1 mm mesh and all large macrofauna able to be identified by eye were counted and recorded immediately. All smaller less readily identifiable macrofauna were removed and preserved in alcohol. Each of these preserved samples had all macrofauna counted and identified to species level where possible using a stereo microscope. The 1 mm mesh size is consistent with method used for regional macrofauna monitoring of estuaries (Park 2012).

At all sites, the average depth of the anoxic layer (Redox Discontinuity Profile (RDP)) was recorded for each replicate core sample. Robertson and Stevens (2008) have developed interim indicators and ratings for estuaries based on the National Estuarine Monitoring Protocol (Robertson et al. 2002). The ratings for RDP are: very good = >10cm, good = 3 to 10cm, fair = 1 to 3cm; poor = <1cm.

At the eight macrofauna sample sites, sediment was collected for analysis of chlorophyll *a* using a small (25mm diameter) corer and taking 10 replicate samples of the sediment to a depth of 2 cm. The replicates were taken randomly with the 10 m radius of the site location and bulked into a single sample for analysis.

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[13] In terms of resolution this means that if one individual was found in the sample it is recorded as 9.4 /m^2.
[14] In terms of resolution this means that if one individual was found in the sample it is recorded as 0.5 /m^2.

Grain size analysis (including percentage mud (<0.075mm) and sediment nutrient concentrations were measured from a bulked sample collected in a previous survey at the same site – these coincided with 14 of the sites. Sediment samples were collected at high tide from a boat using a trawl dredge. This sampled about the top 10 cm of sediment. Areas with dense cover of seaweed were avoided because they could not be practically sampled with this method. The results of this sampling are not presented because the sampling method was biased to underestimate the amount of fine mud in the estuary compared to standard methods (which focuses on the top 2cm of sediment from random locations in a quadrat (Robertson et al. 2002).

3.2.2   Statistical analysis

The software package Primer v6 (Clarke and Warwick, 1994) was used to perform Bray Curtis Cluster analysis on the data along with a similarity profile (SIMPROF) permutation test to identify any significant differences between clusters (i.e. *p*-value <0.05). Prior to cluster analysis biological data was transformed using a square root transformation and a triangular similarity matrix created using Bray-Curtis method.

The Shannon–Wiener index (H') was calculated using the software package Primer v6 (Clarke and Warwick, 1994). In simple terms this is the weighted combination of the total number of species (richness) and the extent to which the total abundance is spread equally amongst the observed species (evenness). High values of H' are representative of more diverse communities; a community with only one species would have an H' value of 0. If the species are evenly distributed then the H' value would be high. The H' value tells us about not only the number of species but how the abundance of the species is distributed among all the species in the community.

Figure 3.1: Location of shellfish and macrofauna sampling sites. Additional infauna samples were collected at the eight sites with the red squares. Google Earth image from September 2012.

3.3   Results

3.3.1   Broad scale patterns

The Maketū estuary has a number of different zones recognised by physical separation and the dominance of different species of flora and fauna. These are briefly described below:

Rock shore entrance

The rocky shore margin north of the boat ramp towards the entrance had diverse assemblage of fauna indicative of reasonable ecological health. Sea lettuce growth was sparse although dense rafts of sea lettuce occasional washed up along the beach near the estuary entrance. Common fauna typically of this zone are: Black mussel (*Xenostrobus pulex*), Green lipped mussel (*Perna canaliculus*), Limpet (*Notoacmea helmsi*), Chiton (*Chiton glaucus*), Oyster (*Crassostrea virginica* and *Saccostrea cucullata*), Barnacle (*Elminius modestus*), Mudflat anemone (*Anthopleura aureoradiata*), Cats eye / Pūpū (*Turbo smaragdus*), Oyster borer (*Haustrum scobina*).

Lower estuary

Much of the lower estuary had healthy populations of cockle (*Austrovenus stutchburyi*) and pipi (*Paphies australis*). Juvenile pipi dominated the lower sand flats along with top shell (*Diloma subrostrata*), Horn shell / Koeti (*Zeacumantus subcarinatus* and *Z. lutulentus*), Tunnelling mud crab (*Austrohelice crassa* (syn. *Helice crassa*)), Pillbox crab (*Halicarcinus whitei*), Sand dollar (*Fellaster zelandiae*), and Cushion starfish (*Patiriella regularis*). Sea hare (*Aplysia* sp) were common in the lower estuary near the boat ramp, where they were feeding on sea lettuce. Mudflat anemone (*Anthopleura aureoradiata*) was common in the channels and epiphytic on cockles.

The seaward section of the main channel was dominated by mature pipi (4.5 – 6cm length). Pipi occurred in the channels to about 1.5km upstream from the entrance[15] after which they were rare. The size of the pipi tended to increase further upstream. Cockle became common in the channels about 0.6 km from the entrance and were common throughout the mid-estuary to about Papahikahawai Island. Patches of sea lettuce were common (about 40% cover) in the main channel of the lower estuary where it was attached to shells; free-floating accumulations were absent from the main channel.

The substrate in the main channel (mid to lower estuary) was variable. In places fine mud and anoxic reducing conditions were within 4cm of the surface (causing blackening of shells of pipi, cockle and wedge shell). There were also patches of mobile pumice sand where shellfish were rare and sea lettuce absent.

Sections of the flood tide delta (e.g. site 55 north of the domain) had few species, probably due to the mobility of sand in this area.

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[15] The entrance was defined as opposite Te Awhe Rd.

Mid-estuary

The mid-estuary fauna tended to be dominated by cockle and wedge shell / Hanikura (*Tellina liliana* syn. *Macomona liliana)*), with hornshell, topshell and mud whelk (*Cominella glandiformis*) also common here. The western section of the mid-estuary had an anoxic depth layer indicative of good condition (>3cm). Anoxic conditions were closer to the surface further up the estuary.

The main channel runs along the southern margin of the mid-estuary. Accumulations of free-floating *Gracilaria* sp. and sea lettuce occurred within this channel and along the northern edge. *Gracilaria* sp. and free-floating sea lettuce also accumulated south of Papahikahawai Island.

Southern estuary (entrance to Waitipuia Stream)

Dense accumulations of *Gracilaria* sp. and (to a lesser extent) sea lettuce occurred along the southern margin of the estuary, near the entrance of Waitipuia Stream. These areas had black anoxic mud over the sandy base. Cockle and wedge shell was generally sparse, although there were occasional patches in the smaller channels with large number of small cockles congregating on the surface.

Secondary channels had accumulations of unattached sea lettuce and *Gracilaria* sp. decomposing on the channel edges, with black anoxic mud occurring underneath. This was also common in the upper estuary.

There was evidence of shallow groundwater flowing under the southern estuary at about 61 cm depth and above a firm layer of shell (65cm deep) indicative of an earlier estuary bed level. The shallow groundwater had dissolved oxygen of 3% to 10%, and salinity of 5.6 to 13.6 psu (8985 to 20,600 µS/cm). The groundwater was less saline and more oxygenated in locations closer to shore (i.e. at 160m compared to 370m from the shore).

Upper estuary

Large parts of the upper estuary were covered by free-floating *Gracilaria* sp. and *Ulva flexuosa* – particularly in small channels and depressions. Anoxic mud was common under these areas. Epiphytic algae was common in the upper estuary, including a marine species of the diatom *Melosira* sp, and the cyanobacteria (*Oscillatoria* sp.), which was often growing over the top of the seaweed *Gracilaria*.

There was evidence of the old Papahikahawai Island wetland at a depth of about 5 to 10cm below the surface. Interestingly this peat layer was oxic, despite the overlying sand being anoxic – indicating that the anoxia was driven by the accumulation of carbon in the surface sediments. There was also some indication of a possible groundwater influence as the deeper water was less saline than the overlying water, but there was no obvious flow as observed on the southern estuary margin.

Pipi were absent from this part of the estuary and cockle and wedge shells were sparse. Mud snail (*Amphibola crenata*), estuary snail (*Potamopyrgus estuarinus*) and crab holes were common; although, in the most western sites thick accumulations of algae and anoxic mud excluded all invertebrate fauna.

Papahikahawai lagoon

The western end of the old Papahikahawai channel is mostly cut off from the rest of the estuary to form a lagoon; a 600mm pipe and flapgate (currently held open) is the only connection. This is a highly

productive system with thick mats of *Ulva flexuosa var pilifera* and the benthic cyanobacteria *Lyngbya* sp. forming rafts that float over large sections of the water. The substrate is marine sand but this is covered by 10 to 25cm of anoxic, organic mud from the decomposing algae. No benthic invertebrates were found in this lagoon, and it is expected that fauna will be restricted to very tolerant species such as amphiods living in the thin layer of water above the floating mats and mosquito fish observed on the lagoon margins.

3.3.2   Clustering of sites based on macrofauna community composition

The composition of the macrofauna community was strongly associated with location within the estuary. Figures 3.2 to 3.4 show the results of a cluster analysis for infauna, shellfish and epifauna respectively. The species composition of each group showed a significant difference (<5%) using a Brays Curtis similarity and SIMPROF test (see Appendix 2 for the Dendrograms and further description).

The composition of infauna clustered sites into four groups (Figure 3.2, Table 3.1). These were:

- No or few species present, these sites were in the upper estuary (Group 10, site 33 and 35b).

- Low species diversity and few shellfish, located in the south (Group 12, site 53)

- Moderate cockle density, abundant horn shell and abundant polychaeta (Scoloplos sp and Aquilaspio sp.), located in the upper mid-estuary (Group 11, sites 40 and 41).

- Abundant cockle and wedgeshell, located mid estuary (Group 13, sites 48, 51 and 56).

The composition of shellfish clustered sites into three groups (Figure 3.3, Table 3.2). These were:

- No shellfish present located in the upper estuary, upper mid-estuary or southern estuary (Group 10). These sites were often associated with anoxic sediment and high algal cover.

- Sites with sparse cockle, generally located in the upper and upper mid-estuary (Group 11). Some of these sites were near the high tide level.

- Sites with abundant cockle, generally located in the mid and lower estuary (Group 12).

It should be noted that few pipi (*Paphies australis*) were found in the sampling because their habitat was not sampled, i.e. lower estuary sand flats (juvenile pipi) and mid to lower estuary channels (mature pipi).

The composition of shellfish clustered sites into four groups (Figure 3.4, Table 3.2). These were:

- Almost no species present, these sites were in the upper estuary (Group 10, site 33, 45 and 35d).

- Few species and low density (Group 9, sites 40b and 50).

- Epifauna dominated by crab holes, mud snail (*Amphibola crenata*), and/or estuarine snail (*Potamopyrgus estuarinus*), generally located in the upper estuary (Group 11).

- Abundant epifauna dominated by hornshell (*Zeacumantus* sp.) (Group 12) and abundant epifauna with higher diversity (Group 13). These sites were typically in the mid and lower estuary and the difference between Group 12 and 13 was not statistically significant.

Figure 3.2: Groups of infauna sample sites in the Maketū estuary based on species composition using a Bray Curtis similarity and SIMPROF test.

Figure 3.3: Groups of shellfish sample sites in the Maketū estuary based on species composition using a Bray Curtis similarity and SIMPROF test. Group 10 had no shellfish present.
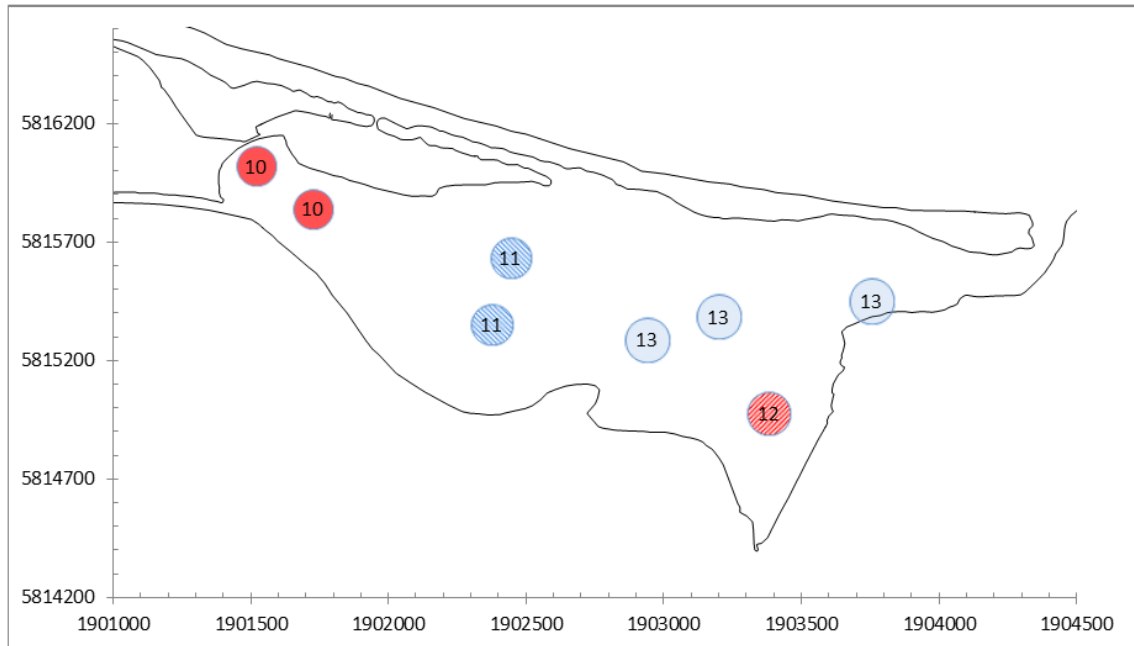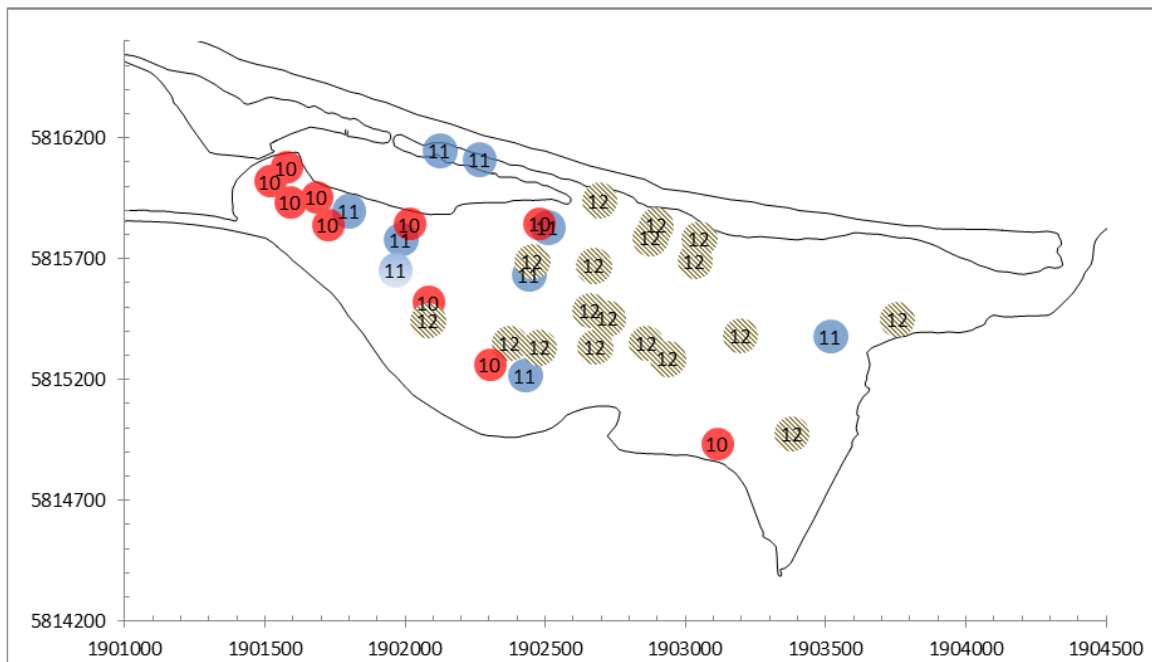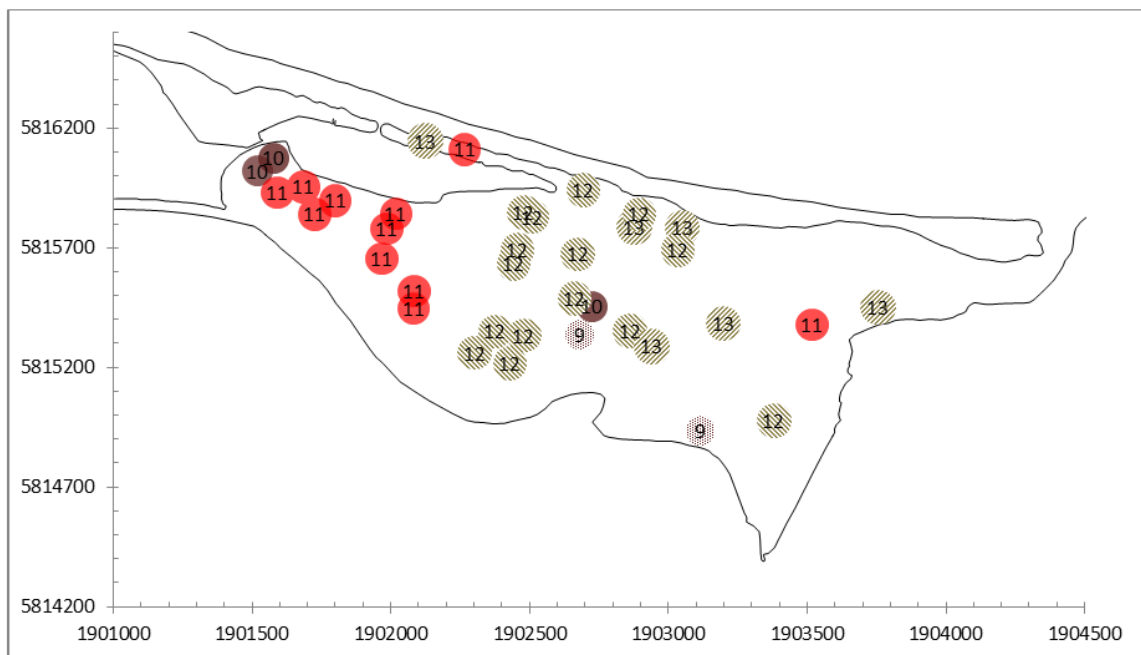

Figure 3.4: Groups of epifauna sample sites in the Maketū estuary based on species composition using a Bray Curtis similarity and SIMPROF test. Group 10 had almost no epifauna present and Group 9 very low abundance. .

Table 3.1: Infauna abundance (per m^2) and diversity in the Maketū estuary (summer 2013/14).

Estuary location		upper		upper-mid		lower-mid		south	lower
Species name	common name	33	35B	40	41	48	51	53	56
Austrovenus stutchburyi	Cockle / Tuangi	0	0	160	38	499	509	19	1564
Tellina liliana	Wedge shell	0	0	9	19	480	471	47	113
Paphies australis	Pipi	0	0	0	9	0	0	0	0
Cominella glandiformis		0	0	28	9	47	19	0	28
Diloma subrostrata	Harbour Top shell/ Whetiko	0	0	0	0	9	9	0	0
Zeacumantus lutulentus	Horn shell	0	0	556	245	9	47	0	85
Notoacmea helmsi		0	0	19	0	0	9	0	0
Halicarcinus whitei	Pillbox crab	0	0	9	0	0	9	0	0
Macrophthalmus hirtipes	Stalk eyed crab	0	0	0	9	0	0	0	0
Hemigrapsus crenulatus	Hairy hand crab	0	0	19	0	0	0	0	0
Anthopleura aureoradiata		0	0	9	19	47	424	0	188
Perinereis nuntia		0	160	19	47	28	9	38	28
Heteromastus filiformis		0	0	9	47	132	57	0	38
Macroclymenella stewartensis		0	0	9	0	0	0	0	0
Aquilaspio aucklandica		0	0	217	330	141	66	396	283
Scolecolepides benhami		0	47	75	122	19	9	38	0
Orbinia papillosa		0	0	0	0	9	9	0	38
Glycera species		0	0	9	0	0	0	0	0
Scoloplos cylindifer		0	0	414	245	235	226	28	490
Hyboscolex longiseta		0	0	0	0	0	0	9	0
Aonides oxycephala		0	0	0	0	217	1008	0	311
Magelona dakini		0	0	0	0	19	9	0	38
Nicon aestuariensis		0	0	94	28	0	0	0	0
Worms		0	0	0	9	0	28	0	9
Depth to anoxic layer (cm)		0.6	1.3	2.1	2.0	4.1	5.0	1.3	5.6
Chl *a* (mg/kg)		12.7	22.4	45.6	22.3	29.5	17.1	8.2	19.4
Chl *a* + Phe (mg/kg)		31.9	22.5	48.5	24.5	33.7	17.2	9.8	21.7
Diversity indexes									
Total No. sp.		0	2	16	14	14	17	7	13
Total abundance (/m2)		0	207	1658	1177	1893	2920	575	3212
Taxa richness (d)		n.a.	1.0	4.9	4.7	4.0	4.4	3.0	3.2
Pielous evenness index (J')		n.a.	0.8	0.7	0.8	0.8	0.7	0.6	0.7
Shannon diversity index (H')		0.0	0.5	1.9	2.0	2.0	1.9	1.1	1.7

Table 3.2: Shellfish and epifauna abundance (per m^2) in the Maketū estuary (2013/14).

Estuary location		upper estuary											upper mid-estuary											
Species	common name	33	35D	35C	35E	35A	35B	37	37A	37B	37C	37D	36A	39A	40	40A	45	45A	41	41A	43	43A	43D	43B
Crab holes		0	0	7.5	32	4	8	48	19	20	17	25.5	18	12.5	0	0	0	0	0	0	0	24	5.5	78.5
Cominella gladiformis	mud welk	0	0	0	0	0	0	0	0	0.5	0	7.5	1	6.5	16	5.5	0	4.5	7	8	0.5	2.5	19.5	15
Diloma subrostrata	Harbour Top shell / Whetiko	0	0	0	0	0	0	0	0	0	0	0	2	5.5	2.5	4	0	6	14.5	3.5	6	6	3.5	47.5
Zeacumantus lutulentus	Horn shell	0	0	0	0	0	0	0	0	0	0	2.5	5.5	17	100	23.5	0	12.5	107.5	85	29.5	105.5	14	33
Zeacumantus subcarinatus	Horn shell	0	0	0	0	0	0	0	0	0	0	0	0	0	19.5	0.5	0	0.5	0	0	0	0	1.5	52
Microlenchus huttoni		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
Notoacmea helmsi		0	0	0	0	0	0	0	0	0.5	0	1.5	0	0.5	5	0	0	15.5	14	5	0	1	0	0
Neoguruleus sinclarii		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus whitei	Pillbox crab	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Hemigrapsus crenulatus	Hairy hand crab	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0.5	0	0
Elminius modestus		0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Astrohelice crassa	Tunnelling mud crab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fellaster zelandiae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthropleura aureoradiata		0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	1	0.5	0	0	0	0
Amphibola crenata	Mud snail	0	0.5	43.5	35	14	50.5	26	42	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0
Macrophthalmus hirtipes	Stalked eyed crab	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potamopyrgus estuarinus		0	0	35.5	55.5	78	79.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrovenus stutchburyi	Cockle / Tuangi	0	0	0	0	9	0	0	9	28	0	75	0	75	57	659	179	452	38	104	0	47	631	867
Tellina liliana	Wedge shell	0	0	0	0	0	0	0	0	0	0	9	0	0	28	320	0	603	0	28	0	0	386	273
Nucula hartvigiana	Nut shell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclomactra ovata	Ruheruhe Trough shell	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paphies australis	Pipi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	19	0	0	0	0	9
depth to anoxic layer (cm)		0.6	0.0	2.0	1.0	1.3	1.3	6.0	3.8	2.4	2.8	2.5	2.0	2.0	2.1	3.6	4.6	4.4	2.0	2.0	0.0	2.0		
Diversity indicies																								
Total No. sp.		0	1	3	3	4	3	3	3	5	2	6	4	6	11	7	1	7	7	7	3	6	8	9
Total abundance (m2)		0	1	87	123	105	138	75	70	59	35	122	27	117	232	1051	179	1094	201	234	36	186	1062	1394
Spp richness (d)				0.65	0.58	0.94	0.56	0.68	0.73	2.29	0.46	2.14	1.59	2.05	2.75	1.94	0.00	1.89	1.66	1.82	0.91	1.40	2.18	1.84
Pielous eveness index (J')				0.84	0.97	0.44	0.77	0.62	0.60	0.34	1.00	0.66	0.65	0.84	0.50	0.75	0.00	0.83	0.49	0.45	0.47	0.46	0.80	0.88
Shannon diversity index (H')		0.00	0.00	0.92	1.07	0.61	0.85	0.68	0.66	0.55	0.69	1.18	0.91	1.51	1.20	1.47	0.00	1.62	0.95	0.87	0.52	0.83	1.66	1.94

Estuary location		Papahikahawai channel		lower mid-estuary								Southern		lower estuary	
Species	common name	38A	38	43C	47	47A	47B	40B	48B	48	51	50	53	55	56
Crab holes		184.5	59	3.5	3	113.5	32	0.5	0	45	129	0	39	58	10.5
Cominella gladiformis	mud welk	0	0.5	9	3	18	3	2	31.5	76.5	38	0	7	0	117.5
Diloma subrostrata	Harbour Top shell / Whetiko	9.5	0.5	11.5	8	50	16	1.5	16	7.5	26.5	3	4.5	0	54
Zeacumantus lutulentus	Horn shell	114	2.5	90.5	11	7	12	1.5	33	29	32.5	0	41.5	0	62.5
Zeacumantus subcarinatus	Horn shell	0	0	14.5	0.5	16	0	0	0	2.5	0	0	0	0	0
Microlenchus huttoni		0	0	0	0	0	0	0	0	4.5	0	0	1	0	0.5
Notoacmea helmsi		0	0	0	0	0	1	0	0	3	43.5	0	0	0	111.5
Neoguruleus sinclarii		0	0	0	0	0	0	0	0	1.5	0	0	2	0	3.5
Halicarcinus whitei	Pillbox crab	0	6.5	0.5	0.5	0	0	0	0	0.5	0	0	2	0	0
Hemigrapsus crenulatus	Hairy hand crab	0	0.5	0	1.5	0	0	0	0	0	0	0	0	0	0
Elminius modestus		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astrohelice crassa	Tunnelling mud crab	0	0	0	0	0	0	0	0	0	0	0	2.5	0.5	0
Fellaster zelandiae		0	0	0	0	0	0	0	0	0	0.5	0	0	0	5.5
Anthropleura aureoradiata		77.5	0	0	0	0	0	0	0	132.5	10.5	0	0	0	0
Amphibola crenata	Mud snail	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macrophthalmus hirtipes	Stalked eyed crab	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Potamopyrgus estuarinus		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrovenus stutchburyi	Cockle / Tuangi	28	47	1648	292	349	75	217	584	254	1488	0	85	9	1272
Tellina liliana	Wedge shell	0	0	452	480	38	367	528	480	433	499	0	57	0	339
Nucula hartvigiana	Nut shell	0	0	0	0	19	0	9	9	0	113	0	0	0	0
Cyclomactra ovata	Ruheruhe Trough shell	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paphies australis	Pipi	0	0	0	0	0	0	9	0	0	0	0	0	0	0
depth to anoxic layer (cm)		3.0	2.3	0.0	4.9	6.3	5.4	5.0	5.9	4.1	5.0	0.0	1.3	8.1	5.3
Diversity indicies															
Total No. sp.		6	7	9	9	8	7	8	6	12	10	1	10	3	10
Total abundance		414	117	2231	800	610	507	768	1154	990	2381	3	241	68	1976
Spp richness (d)		1.09	2.08	1.95	2.82	1.74	1.94	2.87	1.41	2.48	1.96	0.00	2.74	0.74	1.90
Pielous eveness index (J')		0.65	0.37	0.68	0.76	0.70	0.82	0.56	0.89	0.70	0.82	0.00	0.68	0.09	0.79
Shannon diversity index (H')		1.16	0.72	1.49	1.68	1.45	1.59	1.16	1.60	1.75	1.90	0.00	1.56	0.10	1.82

3.3.3   Spatial variation in macrofauna

The spatial variation in macrofauna in the Maketū estuary has been illustrated using a bubble plot overlaid on the outline of the estuary. Taxa richness (i.e. total number of taxa) is greatest in the middle and lower estuary. Taxa richness is lowest in the upper estuary (with no taxa at site 33), margins of the southern estuary where *Gracilaria* is abundant (site 50), and high on the flood tide delta (site 55) (Figure 3.5 and 3.6). The Shannon–Wiener index was less than 2 at all sites in the estuary and <1 in most sites of the upper estuary, indicating poor diversity (Table 3.2).

Total abundance of individuals showed a similar pattern to taxa richness, i.e. abundance was greatest in the middle to lower estuary, and lowest abundance in the upper estuary and southern estuary – particularly in areas where seaweed accumulates. Almost all sites south of Papahikahawai Island had low shellfish abundance, although the surface-feeding horn shell (*Zeacumantus* sp*)* was abundant at sites (e.g. 40, 41, 43A). Papahikahawai channel had moderate abundance but a qualitative survey of the inner lagoon found no benthic species (Figure 3.7 and 3.8).

Cockle were most abundant in the middle and lower estuary, with highest densities of over 1900 cockle/m^2 at sites 43c, 51 and 56. The upper estuary and southern estuary had either very sparse cockle density or none at all (Figure 3.9). Interestingly the mean size of cockle appeared to be greatest in the very sparse populations. Overall the size of cockles in the estuary was small; cockle commonly grow to 35mm in width but the maximum size found in the Maketū estuary was 33mm and at most sites they were less than 20mm in width (Figure 3.10).

Wedge shell were restricted to the middle and lower estuary and largely absent from the upper estuary and south of Papahikahawai Island (Figure 3.11). Wedge shell have deep burrows (5-15cm below the surface) and it is possible that their distribution is restricted by remnants of peat from the old Papahikahawai Island or sediment anoxia common in this area.

The distribution of infauna and shellfish may be largely explained by the extent to which the sediment was anoxic (Figure 3.12). Sediments in the upper estuary and southern estuary generally had an anoxic layer only 2cm below the surface. The exceptions to this were sites on higher ground (e.g. sites 37 and 37a). This anoxia was to a large extent associated with accumulations of *Gracilaria* and sea lettuce.
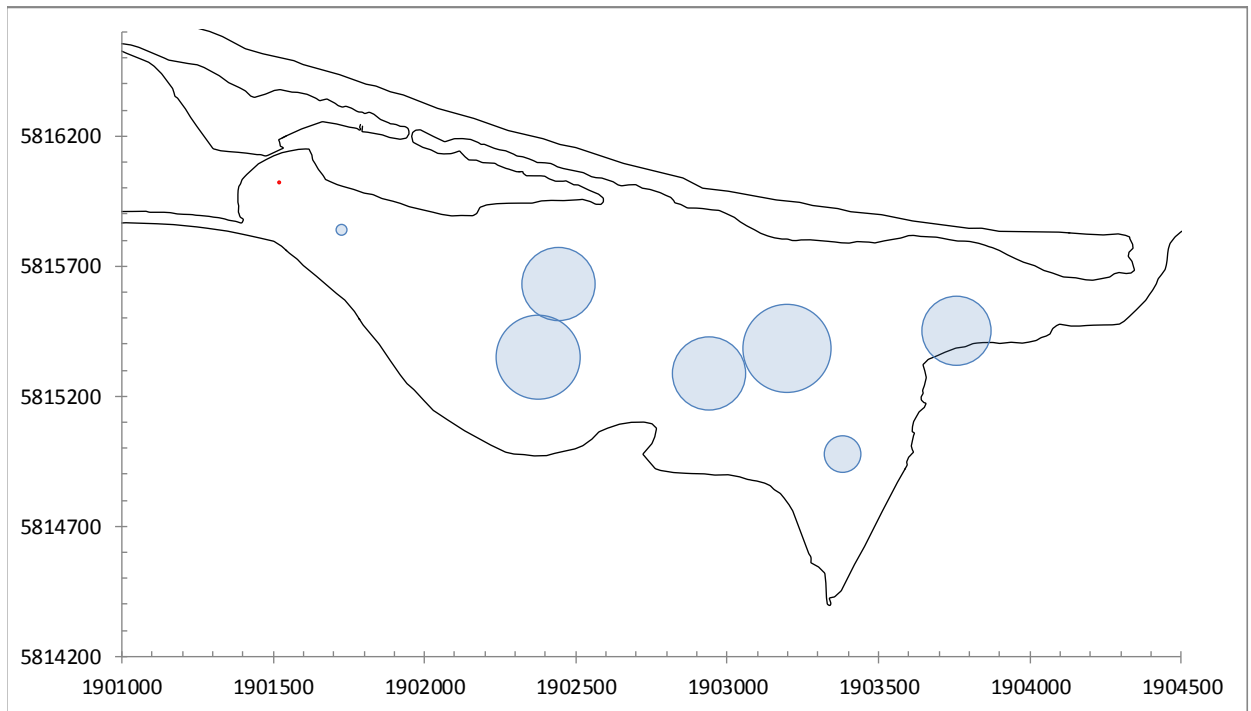
Figure 3.5: Total number of macrofauna taxa at Maketū estuary infauna sample sites. The smallest bubble = 0 taxa (red), the largest bubble = 17 taxa.
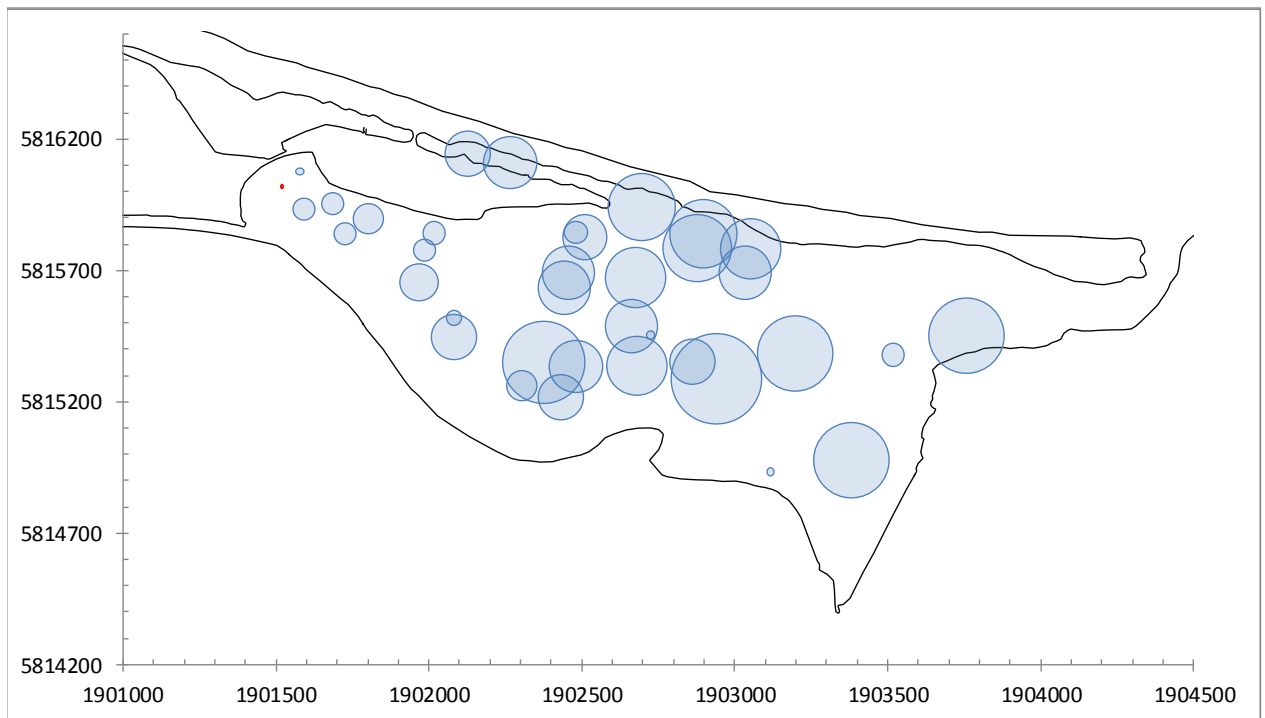

Figure 3.6: Total number of epifauna and shellfish taxa at Maketū estuary sample sites- indicated by the width of the bubble, red dots = no fauna, the largest bubble = 12 species.
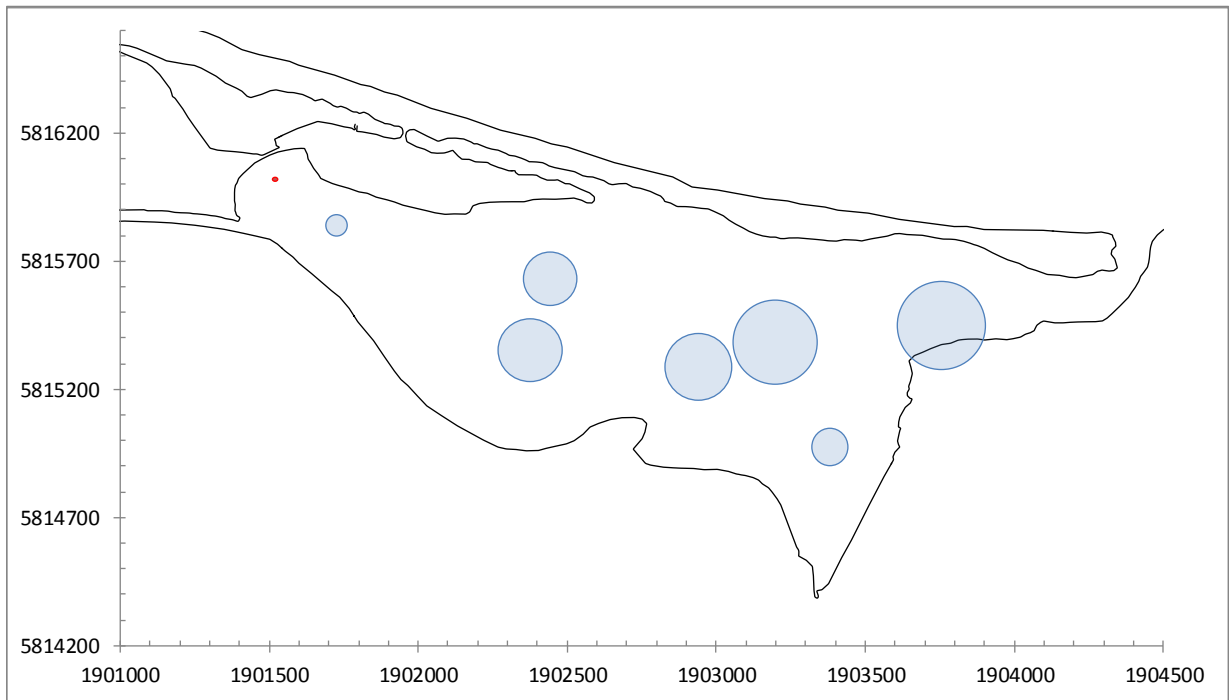
Figure 3.7: Total abundance of macrofauna at Maketū estuary infauna sample sites. The smallest bubble = 0 individuals (red), the largest bubble = 3212 individuals/m^2.
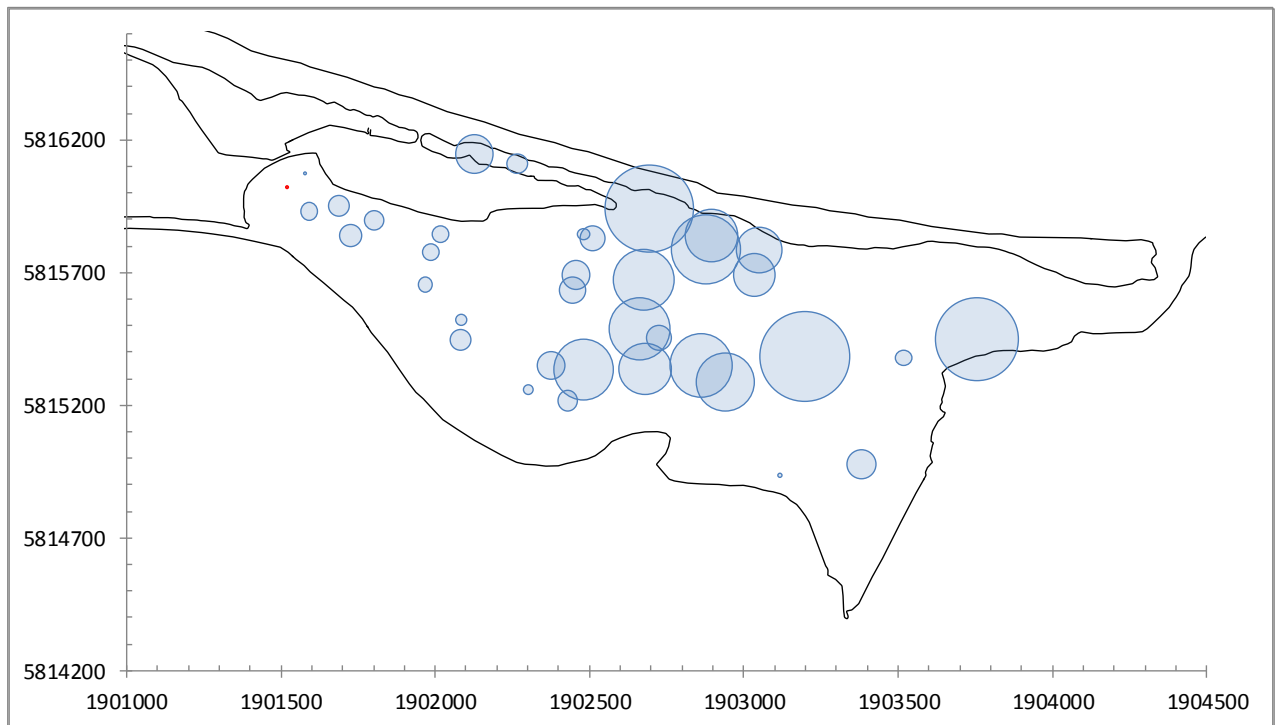
Figure 3.8: Total abundance of epifauna and shellfish at Maketū estuary sample sites. The smallest bubble = 0 individuals (red), the largest bubble area = 2381 individuals/m^2.
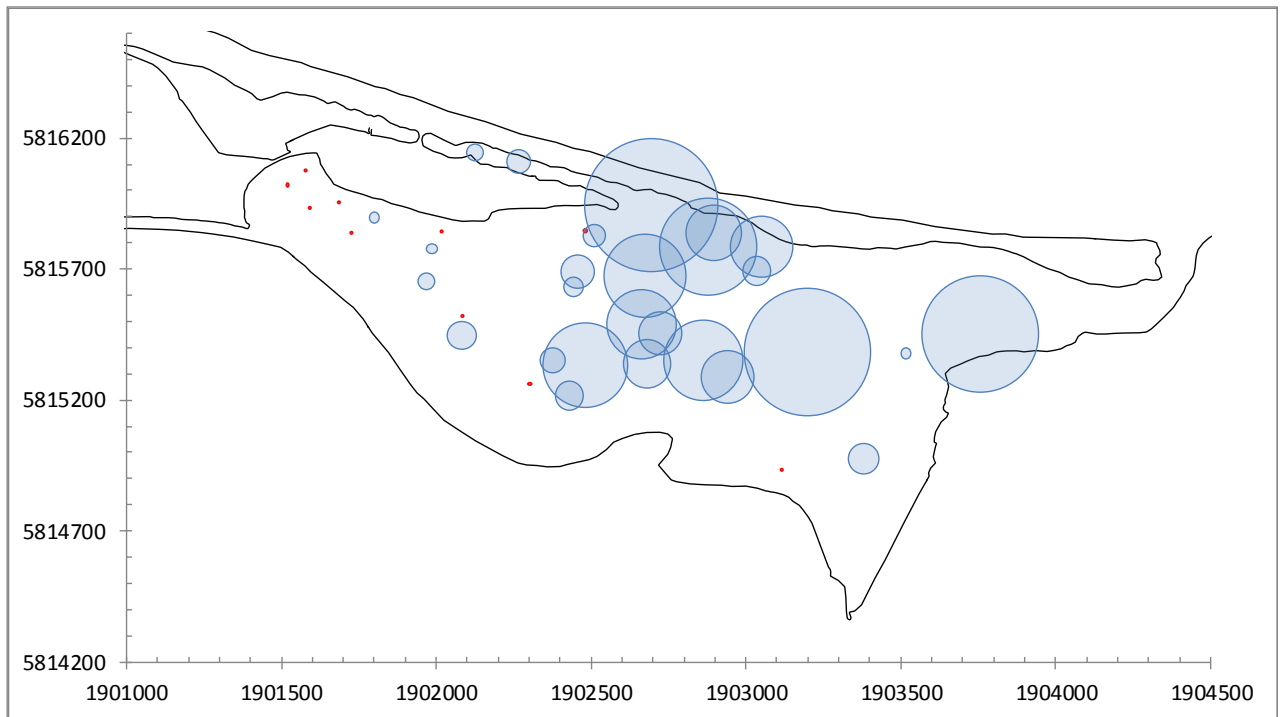
Figure 3.9: Abundance of cockle in the Maketū estuary. Abundance is indicated by the area of the bubble, red dots = no cockle, the largest bubble = 1648 cockle/m^2.
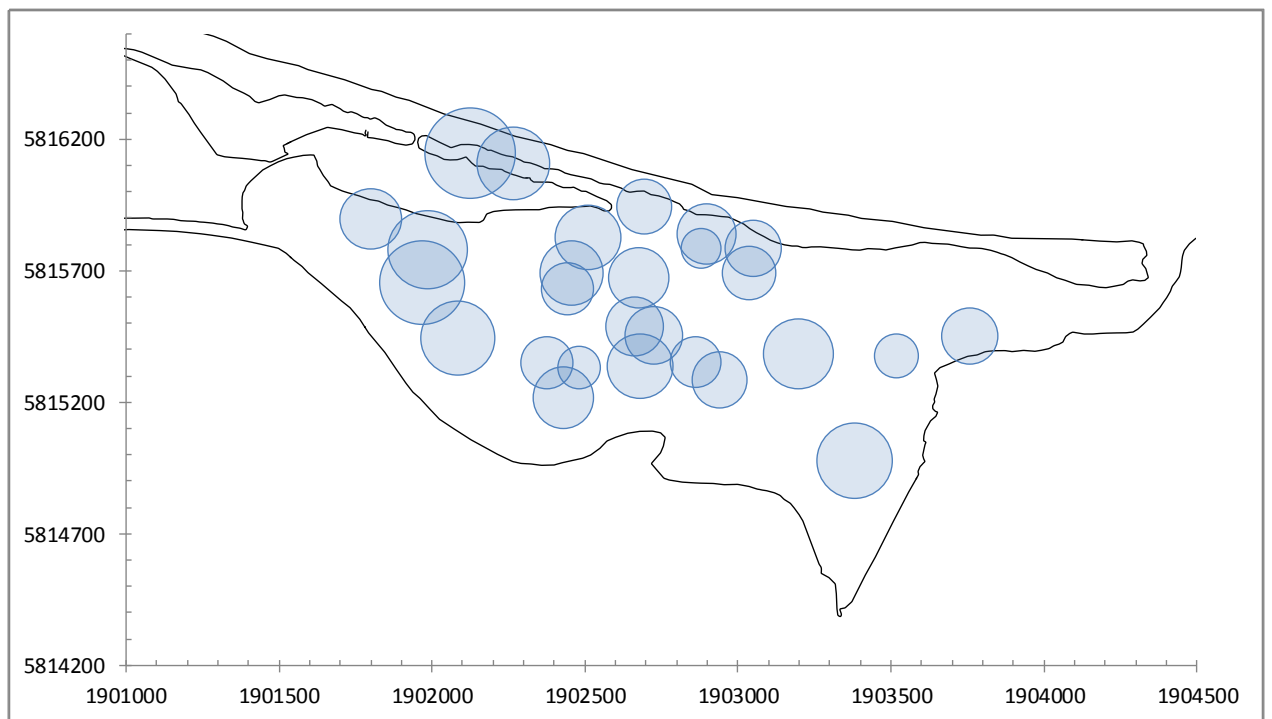

Figure 3.10: Mean width of cockle in Maketū estuary sites. Size is indicated by the width of the bubble, the smallest bubble = 12.5cm width, the largest was = 25.8cm.
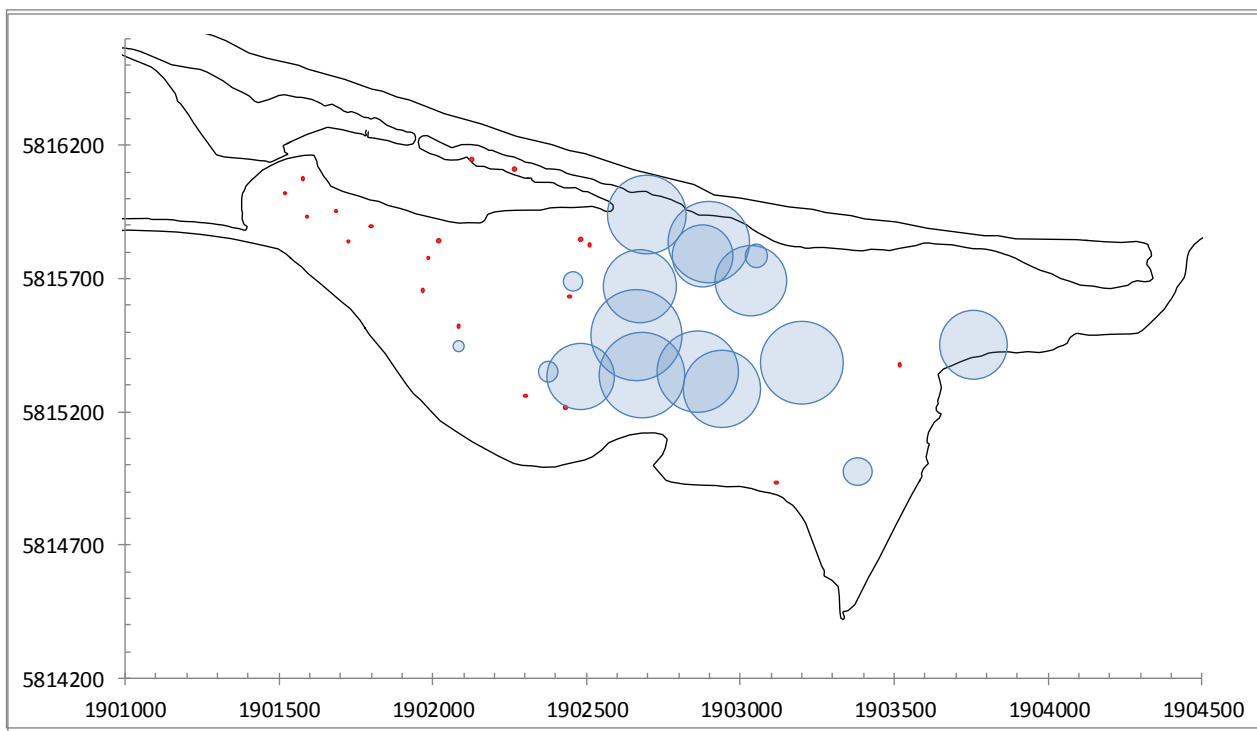
Figure 3.11: Abundance of wedge shell in the Maketū estuary. Abundance is indicated by the area of the bubble, red dots = no wedge shell, the largest bubble = 603 wedge shell/m^2.
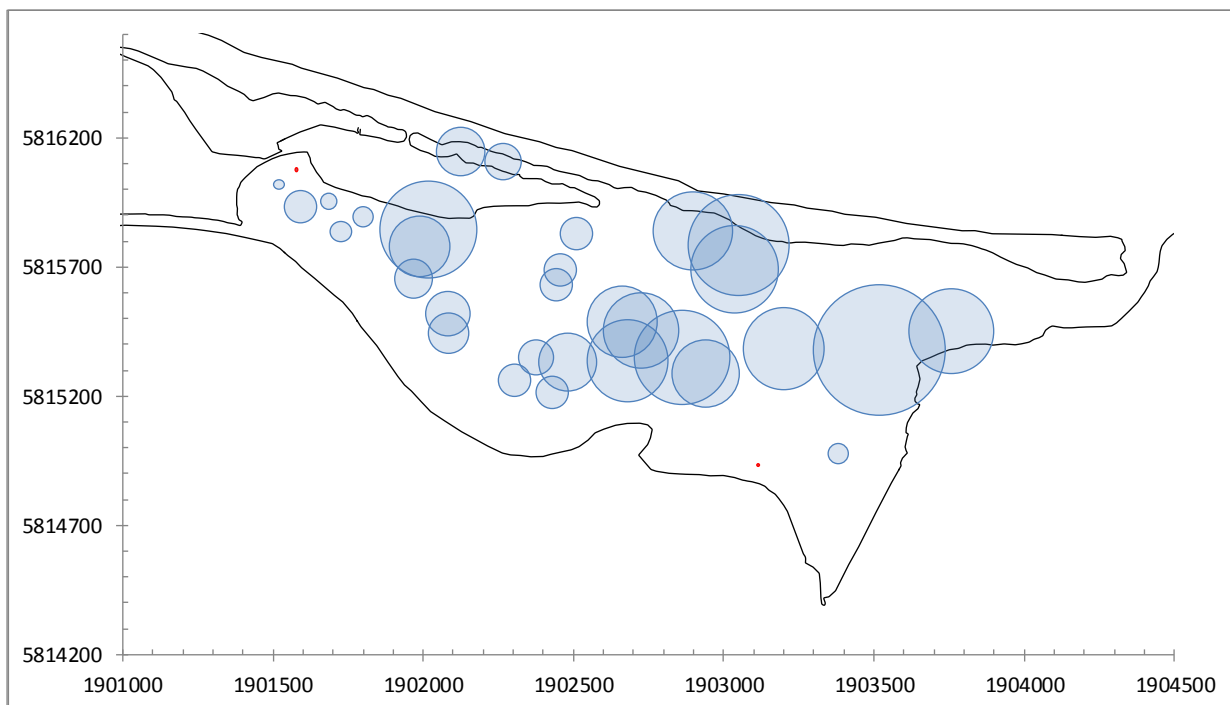

Figure 3.12: Depth to the anoxic sediment at sites in the Maketū estuary. Depth is indicated by bubble width, red dots = 0cm, the largest bubble = 8.1cm.

3.4   Discussion and potential effects

The distribution of shellfish in estuaries is controlled by a range of factors. Environmental factors that are likely to change as a result of the proposed re-diversion of the Kaituna River are: a small reduction in salinity, increase in current speeds, flushing of free-floating algae from the mid to upper estuary and from Papahikahawai lagoon, and a flushing of anoxic mud, and erosion of the flood tide delta in the lower estuary. The potential effects of these changes on shellfish are considered below.

Salinity

Hydraulic modelling by DHI (2014) found that the re-diversion will cause relatively small changes in salinity within the estuary. Small increases in salinity will occur in the upper estuary (an increase of about 4.5 to 6 psu), and small decreases will occur in the mid, southern and lower estuary (decreasing by about 3 to 6.5 psu). Median salinity during a median river flow will be above 20 psu in the mid and lower estuary (see discussion in previous chapter).

The salinity would be considerably higher during periods of low river inflow compared to mean flow (e.g. about 30 psu in the mid estuary) and the change in salinity less at all sites (e.g. a decrease of 2.3 psu mid-estuary) (DHI 2014). The effect of the river flow on salinity will be considerably greater in the upper estuary (e.g. Papahikahawai lagoon will have bottom water salinity of 20-25 psu during a seven day low flow compared to 10-15 psu during mean flow).

Cockle /tuangi reduce their rate of feeding at salinities less than 18 psu (Larcombe 1971). However if there is a high rate of food supply low salinity appears to have little effect on growth rates down to about 7 psu (Marsden 2004). The feeding behaviour of tuangi gives them some tolerance of tidally fluctuating salinity, because by feeding at high tide they avoid exposures to low salinity water.

Pipi prefer more saline conditions than cockle. Prolonged exposure of pipi to low salinity <10 psu significantly affects survival, but they are tolerant of short-term (up to 20 days) exposure (McLeod and Wing 2008).

The changes in salinity due to the proposal are expected to have negligible impact on the inward extent of cockle or pipi in the estuary. Parts of the estuary currently occupied by cockle are predicted to remain above 20 psu (median salinity in bottom water during mean flow), so changes in feeding behaviour as a result of lower salinity are not expected to occur. Similarly, the predicted decrease in salinity in the channels of the lower estuary is relatively small and not sufficient to impact on pipi beds (median salinity remaining above 24 psu during a mean flow).

It is possible that the increase in salinity near the channel of the upper estuary may open up additional cockle habitat, but this will only occur if there is a reduction in anoxic mud associated with algal growth in the upper estuary.

Increase in current speeds and flushing

Hydraulic modelling by DHI (2014) found that the re-diversion will cause an increase in current velocity over most of the estuary. Furthermore the net residual current velocity significantly increases towards

the estuary entrance. The greatest increase in current velocity will occur in the upper estuary, south of Papahikahawai Island and in Papahikahawai lagoon. These areas currently accumulate algae and have poor benthic invertebrate species diversity and abundance.

Increasing current velocity towards the entrance will have several potential effects:

- Firstly it is expected to stop the expansion (and possibly erode) the flood tide delta in the lower estuary. This is expected to have negligible impact on shellfish in the lower estuary because estuary invertebrate are generally mobile and able to adapt their location. For example, Hull et al. (1998) showed that pipi are an active burrower capable of responding rapidly to inundations and uncoverings by sediments. Also, the areas more likely to experience erosion of sand (flood tide delta and possibly parts of the upper estuary) have relatively low invertebrate densities (Gaborit-Haverkort 2012).

- Secondly, increasing current velocity within the predicted range is likely to provide more food for filter feeders such as cockle and pipi, by increasing flow (see Jones et al. 2011). This is likely to be most apparent in the upper mid-estuary where cockle are present but current speeds are currently low.

- Thirdly an increase in residual outgoing currents will help flush fine mud and free-floating algae towards the entrance and out of the estuary (discussed in the previous chapter). Reducing dense algal accumulations and associated organic mud will very likely increase benthic invertebrate species diversity and abundance of shellfish (e.g. cockle). This is further discussed below.

There will be some locations where current speeds will remain low and change little; including parts of the mid-estuary and the southern part of the estuary (see DHI 2014, and previous chapter). There is not expected to be any significant change in accumulation of mud or algae in these areas.

Influence of algal accumulations, mud and anoxia on shellfish

Cockle are sensitive to low dissolved oxygen concentrations. Marsden and Bressington (2009) found that algal mats on the surface of the sediment significantly lowered the dissolved oxygen concentration of the sediment pore-water to < 3.5 mg/L; this effect was greater for the *Ulva* spp. treatment than for *Gracilaria* sp. As a result cockles buried themselves less deeply under algal mats. Further experiments showed that bivalves exposed to oxygen concentrations of 2-3 mg/L buried closer to the sediment surface. Under hypoxic condition (<2 mg/L) cockles migrated to the sediment surface after 3.5 days and died after 11 days exposure to these conditions. These experiments were done at a temperature of 15°C, and the effect will be considerably more extreme in the Maketū estuary during summer where mean daily water temperature is often above 20°C.

Whitmore (2013) did a research project in the Maketū estuary comparing the abundance of cockle and epifauna under *Ulva intestinalis* mats and on adjacent mudflat. The site was in the southern estuary adjacent to Maketū Road. He found that under *U. intestinalis,* the most common species were cockle (100 /m^{2}, 56%), followed by mudcrab (*Astrohelice crassa*) (23%) and Amphipoda (12%). On adjacent mud flats the most common species was cockle (157 /m^{2}, 52%), followed by Gastropoda (29%) and *A.*

crassa (15%). Cockle were significantly more abundant on the mud flats without algae and had a higher condition index.

Thrush et al. (2003) developed regression model from 19 North Island estuaries to predict the occurrence of macrofaunal species. This model found that both the probability of occurrence and abundance of cockles and nutshells declined with increasing mud content. Wedge shell had maximum abundance at about 20% mud content. Species with a preference for low mud content included the suspension feeding cockle (*Austrovenus* sp.), the surface deposit feeder nut shell (*Nucula hartvigiana*), and the surface deposit feeding polychaete *Aonides oxycephala*. Species with a preference for high mud content included the scavenging and burrowing crab (*Astrohelice crassa*) and the sediment-living omnivore (*Nicon aestuariensis*) (Thrush et al. 2003).

3.5   Summary

The key messages of this section are:

- The lower Maketū estuary is in reasonable ecological health with a relatively diverse range of macrofauna and dense populations of cockle / tuangi (*Austrovenus stutchburyi)*, wedge shell / hanikura (*Tellina liliana*) and pipi (*Paphies australis*). An exception was higher ground on the flood tide delta which had few macrofauna species.

- Juvenile pipi were abundant on sand flats in the lower estuary (near the boat ramp), and adult pipi were abundant in the main channel of the lower estuary to about 1.5km upstream from the entrance. Patches of sea lettuce were common (about 40% cover) in the main channel of the lower estuary where it was attached to shells; free-floating accumulations were absent from the main channel.

- The mid-estuary, east of Papahikahawai Island, had a relatively diverse range of macrofauna taxa and moderate to high abundance of macrofauna – including cockle and wedge shell. The depth of the anoxic layer in sediment was generally >3cm, indicating good ecological condition. The western part of the mid-estuary generally had low species richness and low shellfish abundance – although horn shell (*Zeacumantus* sp*)* was often abundant.

- The southern margin of the estuary had dense accumulations of *Gracilaria* sp. and (to a lesser extent) sea lettuce (*Ulva pertusa*), with several centimetres of black anoxic mud underneath. Shellfish (cockle and wedge shell) were sparse as were most other infauna.

- The upper estuary was characterised by extensive cover of free-floating algae (mostly *Gracilaria* sp. and sea lettuce), anoxic conditions close to the sediment surface, low diversity and low abundance of benthic macrofauna. Epifauna were generally limited to mud crabs, mud snail (*Amphibola crenata*), and estuarine snail (*Potamopyrgus estuarinus*). Wedge shell and cockle were absent from a large number of sites in the upper estuary. The more western parts had particularly poor ecological health with diatoms (*Melosira* sp.) and cyanobacteria (*Oscillatoria* sp., and *Lyngbya* sp.*)* growing as epiphytes over the *Gracilaria* sp. In the worst sites (with dense

algae and anoxic mud) no benthic fauna were present – not even mud snails which are tolerant of low oxygen conditions.

- The Papahikahawai lagoon had thick mats of *Ulva flexuosa var pilifera* and the benthic cyanobacteria *Lyngbya* sp., forming floating rafts over large sections of the water. Years of algae decomposition has formed a thick layer (10 to 25cm) of anoxic, organic mud over the surface. No benthic invertebrates were found in the lagoon.

- A general decrease in salinity in the estuary as a result of the re-diversion is expected to have only minor effect on the distribution of shellfish and cockle in the Maketū estuary.

- General increases in current speeds across most of the estuary, and in particular an increase residual current speed towards the ocean, will have overall positive impacts on the benthic invertebrate fauna by improving the rate of food supply for filter feeders such as cockles and by reducing the extent of the estuary that is currently degraded by accumulations of free-floating algae and the associated anoxic mud. Improvements will be particularly evident in the upper estuary, mid-estuary south of Papahikahawai Island and in what is currently Papahikahawai lagoon. The re-diversion is expected to have little impact on the southern estuary, near Waitipuia Stream input.

- Monitoring of macrofauna and depth of anoxic layer of sediments in the estuary will be a key way to assess the benefits of the re-diversion.

4   Dissolved oxygen fluctuations

4.1   Introduction

Oxygen is fundamental for most aquatic organisms and the concentration of dissolved oxygen (DO) is a key aspect of fish habitat quality.

Oxygen solubility in water is driven by a number of processes including the rate of depletion (e.g. through Biological Oxygen Demand (BOD)), the rate of reaeration (e.g. through photosynthesis and turbulence), temperature, and salinity. DO concentrations change on a diurnal cycle, responding to the photosynthesis and respiration of algae and aquatic plants. In highly productive systems these fluctuations can be extreme. Accumulation of decomposing vegetation and organic rich mud also exert an oxygen demand, and further reduce DO concentrations.

The ability of fish to survive in hypoxic environments depends on the magnitude of DO decline, how long they are exposed to low dissolved oxygen, the type of fish, their age and their health. They are also affected by other environmental conditions such as temperature. Water bodies with low DO typically have a low diversity and low abundance of fish species (Franklin 2014). As DO decreases it is harder for fish to breathe and they will change their behaviour, such as reducing activity to save energy, increased ventilation of the gills, increased use of aquatic surface respiration (ASR)[16], increased air breathing, and changing habitat locations (Dean & Richardson 1999, Davies-Colley et al. 2013). Fish frequently display a preference for locations with higher levels of DO, and avoid hypoxic water, even at otherwise preferred locations (Richardson et al. 2001).

Landman et al. (2005) found that common smelt, juvenile common bullies and juvenile rainbow trout were particularly sensitive to low DO, with 50% mortality at DO levels of 1 mg/L occurring after 0.6, 0.6 and 1 hour respectively, and 100% mortality for all species within four hours. Juvenile inanga (*Galaxias maculatus*) were also sensitive to low DO, with a 48-h LC_{50} concentration of 2.6 mg/L (at 15 ^{o}C). Urbina et al. (2011) found that 70% and 94% of inanga exhibited avoidance behaviour (i.e. trying to jump out of the water) when the DO dropped below 1.9 and 1.5 mg/L respectively. Eel species were tolerant of low DO with lethal concentrations less than 1 mg/L (Landman et al. 2005). These values are likely to under-predict the effects of low DO at higher water temperatures (typical in the Maketū estuary) because higher temperatures result in higher metabolism and higher oxygen tolerance thresholds (Davies Colley et al. 2013).

The ANZECC (2000) guidelines sets a minimum DO for marine waters at 80% saturation (or greater than 6 mg/L). This is a reasonably conservative value appropriate for sensitive fish communities. Franklin (2014) developed criteria for protection of New Zealand fish communities. Imperative targets are the minimum acceptable criteria for minimising the likelihood of significant detrimental effects for the majority of fish species. The guideline criteria should be the minimum requirement for protecting salmonids and early life stages of all species (see Table 4.1).

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[16] The surface film of water has elevated oxygen due to diffusion from the atmosphere. ASR behaviour utilises this thin layer of higher DO.

Table 4.1: Recommended DO criteria for freshwater fish. The imperative protection level is the minimum recommended protection level, and the guideline protection level the target protection level (from Franklin 2014).

Dissolved Oxygen		Dissolved oxygen (mg/L)
7-day mean (mg L^{-1})	Guideline	8.0
	Imperative	7.0
7-day mean minimum (mg L^{-1})	Guideline	6.0
	Imperative	5.0
Instantaneous minimum (mg L^{-1})	Guideline	5.0
	Imperative	3.5

4.2   Dissolved oxygen in the Maketū estuary

Data loggers were installed at seven locations around the Maketū estuary to record dissolved oxygen (DO), temperature, salinity and depth (selected locations) (see Figure 4.1)[17]. The loggers were installed at a depth of about 25-40cm below the water surface at low tide and 20 to 60 cm above the bed. Calibration readings were taken before and after placement.

The monitoring found that all sites had large fluctuations of DO indicative of high primary productivity and very low daily minimum DO concentrations - regularly less than 1 to 2 mg/L. Water temperature was high at all sites, commonly reaching a daily maximum of 25 to 26°C and occasionally over 29°C (Figures 4.2 to 4.6).

The Waitipuia Stream (upstream of the flapgate) commonly had daily minimum DO < 1mg/L. The two monitoring locations on the Waitipuia channel within the estuary had similar DO regimes, with daily minimum DO commonly less than 2 mg/L and very large diurnal fluctuations i.e. a range of 25% to 250% and 30% to 240% saturation for the sites 200m and 490m downstream respectively. On some occasions low levels of DO persisted to early afternoon (see Figure 4.2). The diurnal fluctuation in DO (driven by plant photosynthesis and respiration) was overlaid with a tidal pattern, with a pulse of oxygenated water apparent on the incoming tide just after low tide. However this tidal pattern was weaker during neap tides (Figure 4.3).

The mid-estuary site was located in the main channel but nevertheless showed wide diurnal fluctuations in DO (i.e. 30% to 200% saturation) and a daily minimum DO of 1.1 mg/L. The decline in DO was most apparent when low tides occurred in the early morning. The diurnal DO fluctuations were overlaid by two different tidal patterns; firstly, a pulse of oxygenated water on the incoming tide just

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[17] Additional DO monitoring was done in tributary drains but the data is not presented here.

after low tide, and secondly a smaller pulse of oxygenated water near high tide from the inflow of the Kaituna River (Figure 4.4).

Dissolved oxygen in the upper estuary dropped to less than 1 mg/L. The diurnal DO pattern was overlaid with a secondary peak in DO associated with a pulse of oxygenated water entering from the Kaituna River near high tide. Salinity at this site declined during the deployment of the loggers which may have been associated with the neap tides and movement of the *Gracilaria* bed close around the loggers. It is also possible that it was influenced by fresh groundwater in the sediments, as sediments 0.5m deep tend to be less saline than those near the surface (Figure 4.5).

A logger was placed at two sites consecutively in the Papahikahawai lagoon. Anoxic conditions recorded after the first day at the first site were probably due to soft anoxic sediments smothering the logger. The second site was located in open water near a deep channel but the daily minimum DO still dropped to less than 1 mg/L (Figure 4.6).

At the upper and mid-estuary sites the concentration of DO was higher and the extent of fluctuations less on the 7 – 8 February. This was probably due to stormy weather at the time with rain, wind and increased river flows. Cooler water would reduce respiration rates, cloud would reduce light and photosynthesis, and the wind would dramatically increase reaeration.
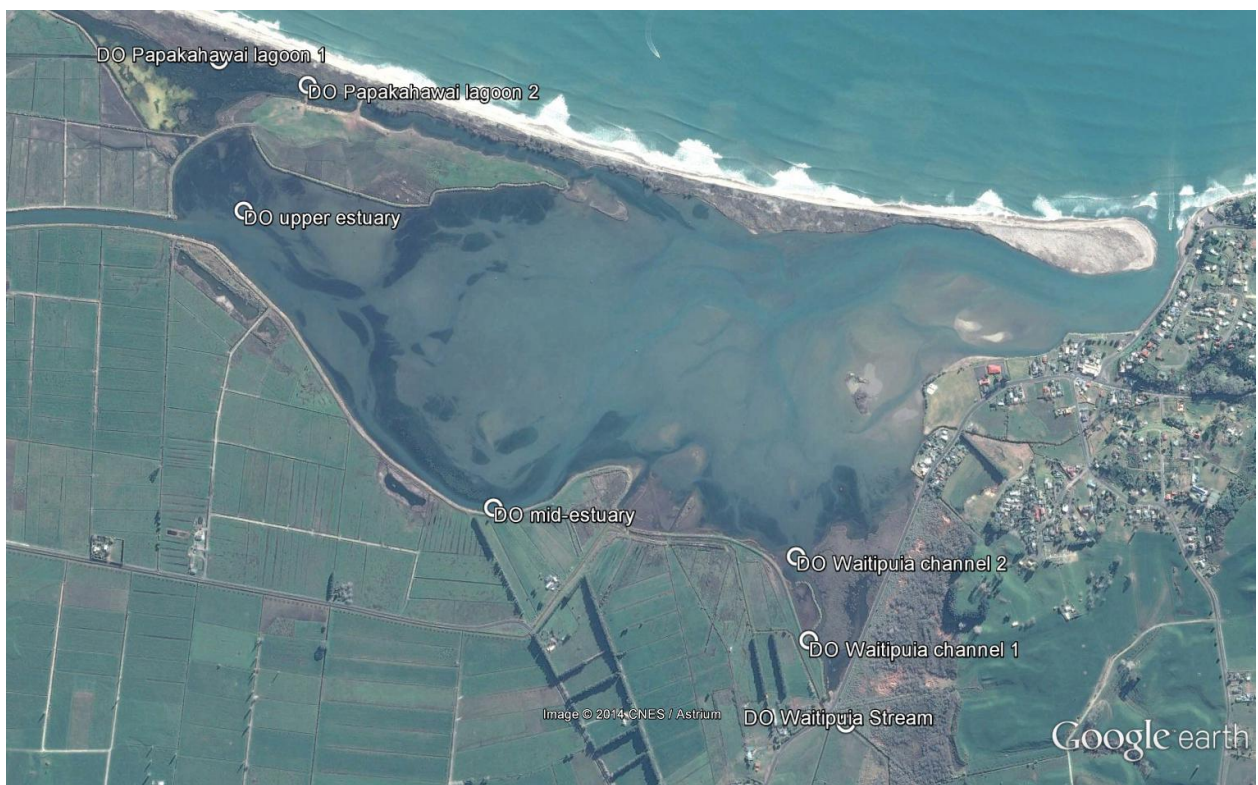

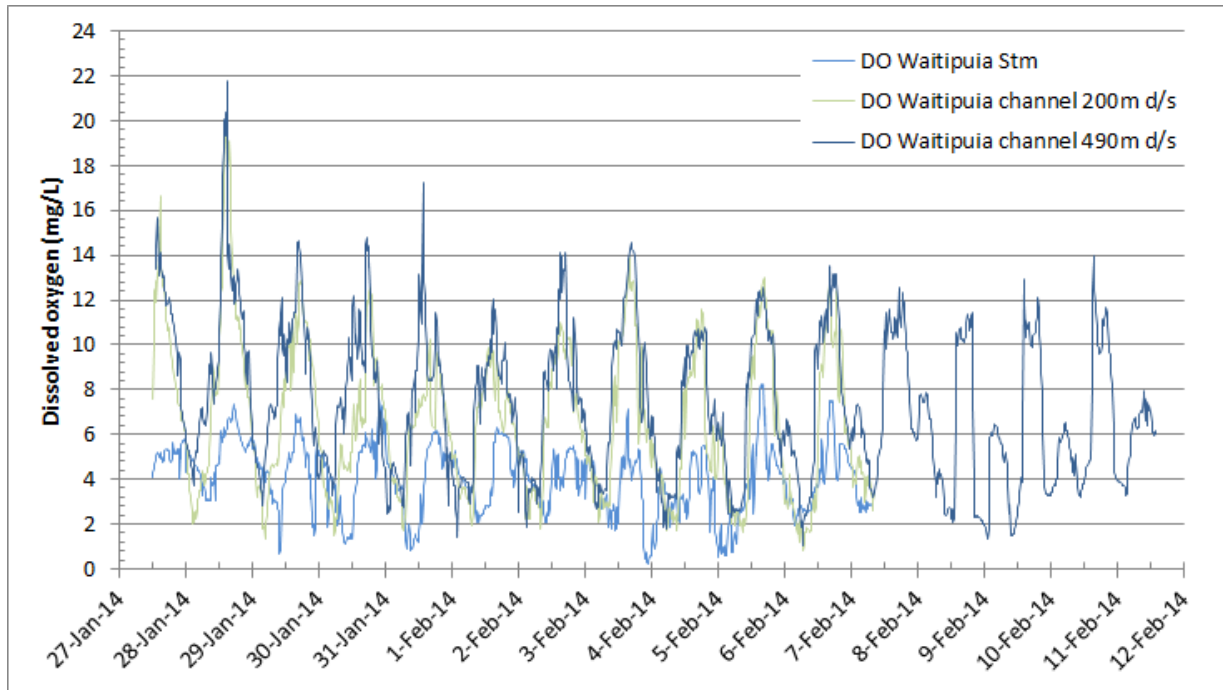**Figure 4.1:** Location of dissolved oxygen loggers in the Maketū estuary.

Figure 4.2: Dissolved oxygen in Waitipuia Stream upstream of flapgate, 200m downstream of flapgate and 490m downstream of flapgate.
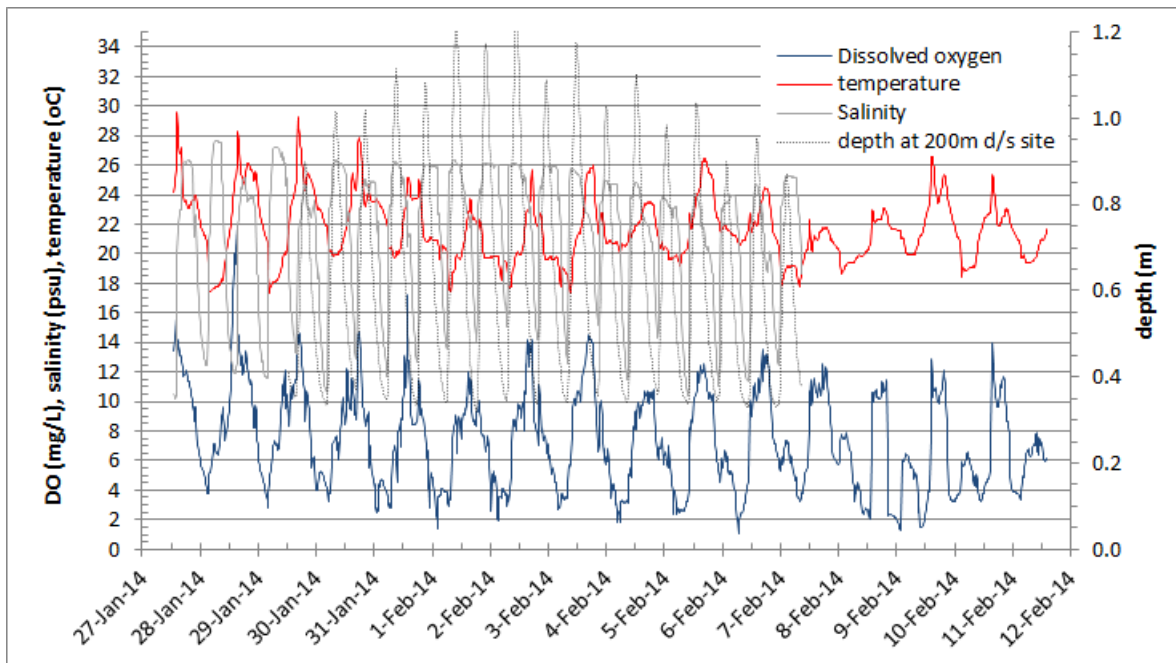
Figure 4.3: Dissolved oxygen, temperature, salinity and water depth in Waitipuia channel 2 (490m downstream of flapgate). The depth record is from Waitipuia channel 1 (200m d/s).

Figure 4.4: Dissolved oxygen, temperature, salinity and depth at the mid-estuary site.

Figure 4.5: Dissolved oxygen, temperature and salinity at the upper estuary site. The decline in salinity from 10 February likely to be due to neap tides and/or *Gracilaria* moving close to the logger.

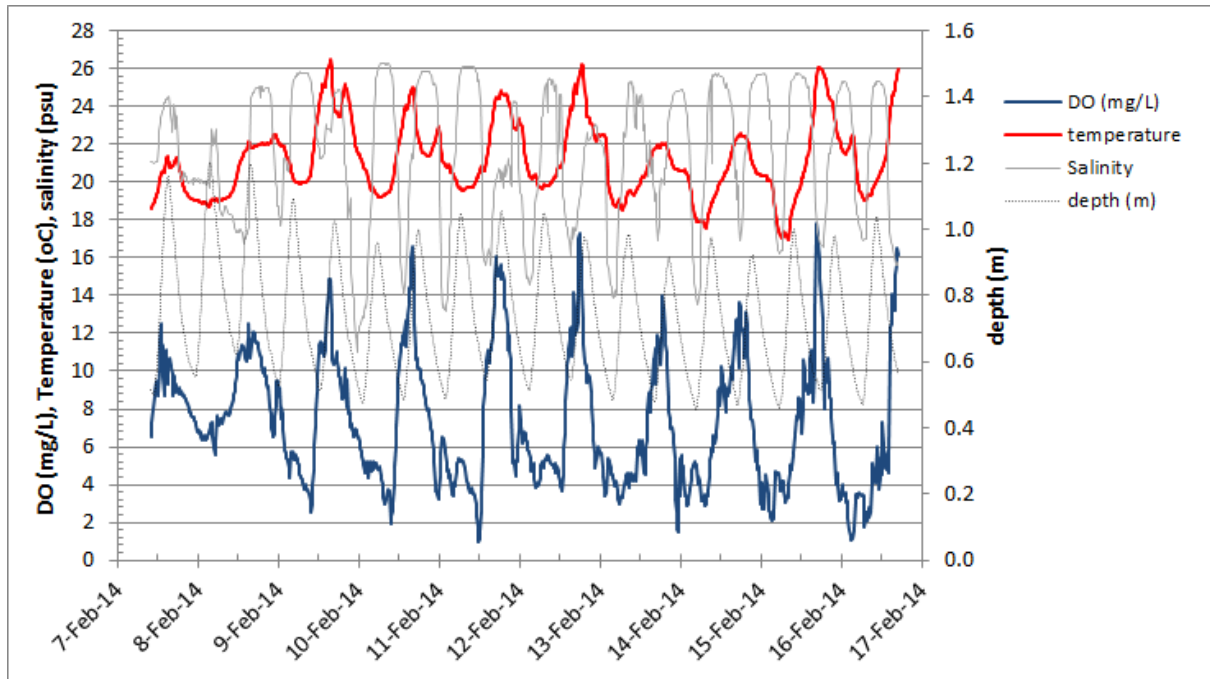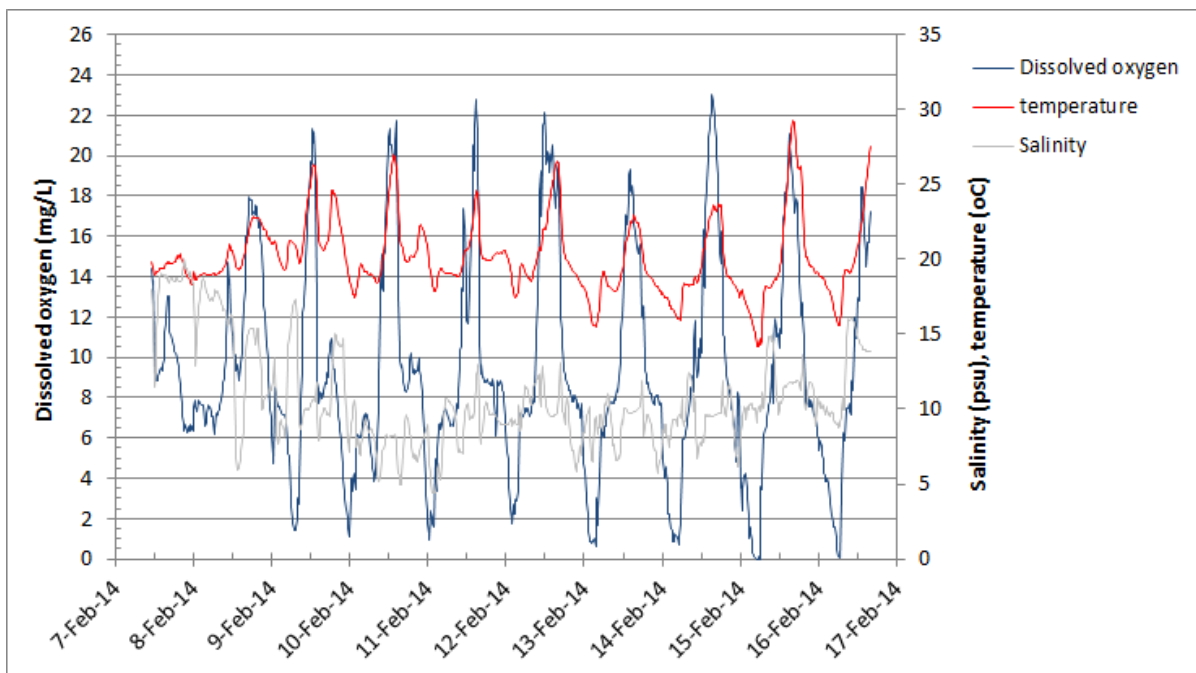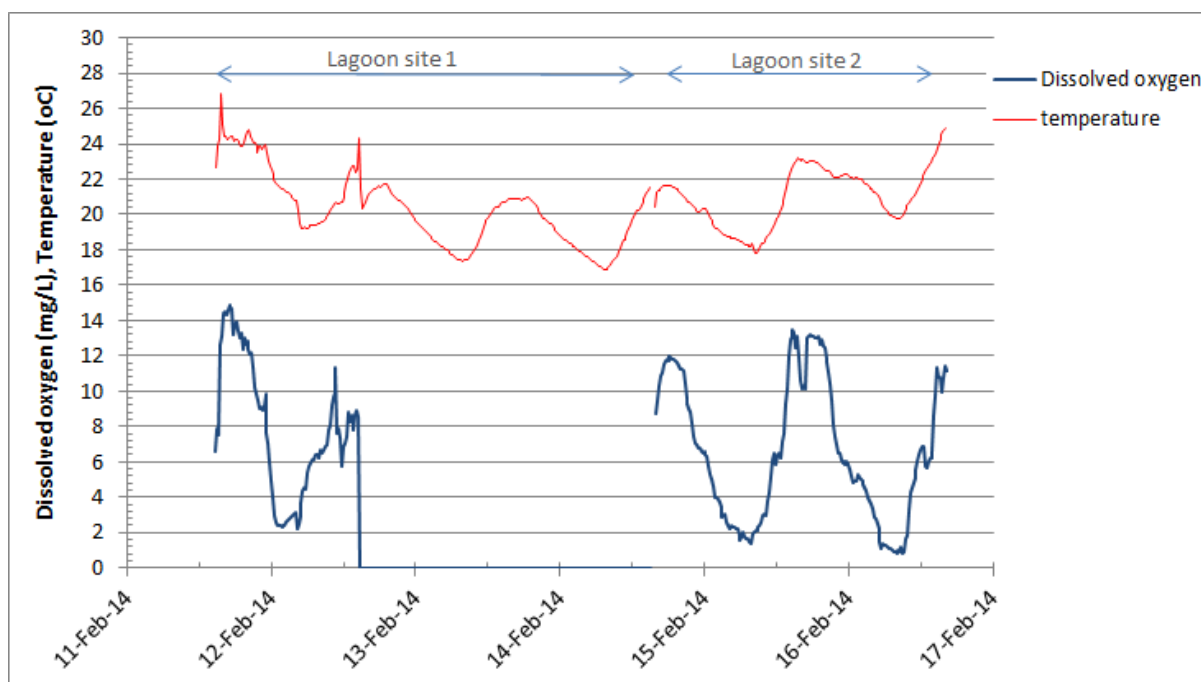**Figure 4.6**: Dissolved oxygen, temperature and salinity in Papahikahawai lagoon. The logger was located at site 1 from 11 -14 February, and at site 2 from 14 to 17 February. Anoxic mud moved over the logger at site 1 on 12 February.

4.3   Ecosystem metabolism

Ecosystem metabolism is a measure of how much organic carbon is produced and consumed in river ecosystems; it is the combination of primary productivity and ecosystem respiration. A system rich in nutrients will have a high gross primary productivity (GPP) and high ecosystem respiration (ER). The ratio of production to respiration (P/R) indicates the extent to which the metabolism is dominated by internal or external sources of carbon during the period being assessed. In river systems poor health is indicated by GPP>8 g O_2/m^2/day and ER>10 O_2/m^2/day (Young et al. 2004).

Ecosystem metabolism was calculated using the 'Two Station River Metabolism Estimator v1.0' spreadsheet model. The methods used in this model are described in Young et al. (2004) and Young et al. (2006). These methods were designed for river and applying them to estuaries is complicated by tidal changes in water depth, inflows for oxygenated water from the sea and, in the case of Maketū estuary, from the river. These complications were addressed by careful selection of time periods used in the analysis. Dates were chosen to ensure a high tide and outgoing tide at night, and the dark period was chosen to avoid this influence of inflows from the sea. These criteria meant that the defined 'dark period' was limited to 3-4 hours. Respiration and production was calculated for the Waitipuia Stream and Mid-estuary site, at these sites reasonable fits were obtained with R-squared values of 0.86 and 0.71 respectively.

The two sites in the Maketū estuary had high GPP and high ER. The P/R ratio in the Waitipuia channel site was 0.67, suggesting a source of carbon / oxygen demand – perhaps from the Waitipuia Stream or net accumulation of decomposing algae /seaweed in the area (Table 4.2). The P/R ratio at the mid

estuary site was close to 1 (0.94), suggesting that the very low DO concentrations measured at this site (Figure 4.4) were primarily driven by the very high GPP and ER from algae in the channel.

Ecosystem metabolism was not calculated for the upper estuary but wide fluctuations in DO suggest that it is likely to be considerably greater than the mid-estuary site and the thick accumulations of fine organic mud (about 6cm deep) suggest that respiration may be a more important process.

Table 4.2: Ecosystem metabolism at two sites in the Maketū estuary.

Ecosystem metabolism	Waitipuia channel (490m d/s)	Mid-estuary
Gross O_2 respiration (gO_2/m^2/day)	-68.1	-123.1
Gross O_2 production (gO_2/m^2/day)	45.8	115.4
Net O_2 metabolism (gO_2/m^2/day)	-22.3	-7.7
P/R	0.67	0.94

Waitipuia channel site assessed for period 4 to 5 February
Mid estuary site assessed for period 9 to 10 February.

4.4   Discussion of potential effects

Respiration and photosynthesis from the accumulation of *Ulva* sp. and *Gracilaria* sp. in the middle and upper parts of the Maketū estuary causes very large diurnal fluctuations in dissolved oxygen. The daily minimum DO concentration was commonly less than 2 mg/L in the mid-estuary and commonly less than 1 mg/L in the upper estuary and in Papahikahawai lagoon. These are sufficiently low concentrations to exclude many fish from sections of the estuary during the early morning when concentrations are lowest. Thus there is expected to be high temporal variability in the amount of estuary habitat available for fish – with more of the estuary available at high tide and during the afternoon /early evening.

The proposed re-diversion will improve dissolved oxygen levels in the estuary in several ways. Firstly, a larger inflow of water will increase the pulse of oxygenated water from the river. Secondly, a larger inflow will increase current speed in many parts of the estuary which will increase the reaeration coefficient, although the extent of this effect has not been quantified. Thirdly, the proposal will increase flushing of free-floating macroalgae that currently accumulate in the channels and backwaters of the upper and mid-estuary. This is the most important effect as it will reduce primary production and respiration which drives diurnal DO fluctuations.

The upper estuary and Papahikahawai lagoon will have the most improvement in DO concentrations as a result of the proposal. The southern part of the estuary, near Waitipuia Stream, is expected to improve, but to a lesser extent because the modelling indicates less change in currents and flushing from this area.

4.5   Summary

Key messages from this section are:

- Accumulation of *Ulva* sp. and *Gracilaria* sp. in the middle and upper parts of the Maketū estuary causes very high rates of gross primary production and ecosystem respiration. This results in large diurnal fluctuations in dissolved oxygen, with daily minimum DO concentrations commonly less than 2 mg/L in the mid estuary and commonly less than 1 mg/L in the upper estuary and in Papahikahawai lagoon.

- The low concentration of DO in the mid and upper estuary is significantly worse than guideline values for protection of fish and sufficient to exclude many fish species from these sections of the estuary during the early morning when concentrations are lowest.

- The Papahikahawai lagoon had a particularly minimum DO that is likely to exclude many fish from the lagoon. Even in tolerant fish such as mosquito fish the low night time concentrations are likely to cause avoidance behaviour such as air breathing or aquatic surface respiration.

- The proposal will improve the dissolved oxygen regime in many sections of the estuary by reducing the accumulation of free-floating algae and increasing re-aeration due to increased current speeds. This improvement will be particularly apparent in the upper estuary and Papahikahawai lagoon.

- Repeating the dissolved oxygen monitoring post re-diversion would provide a useful measure by which to assess the success of the diversion and would augment monitoring of algal cover.

5   Fish

5.1   Maketū Estuary and lower Kaituna River

Estuaries are important habitat for fish, providing sheltered habitat and rich food supply – particularly for juveniles which often use estuaries as a rearing habitat. Adults often enter to feed during high tide. The Maketū estuary and Kaituna River mouth are commonly fished for kahawai, mullet, flounder and whitebait. Fouling of nets by sea lettuce is a nuisance that frustrates the use of set nets in the estuary itself (Julian Heutau pers . comm. 2014).

Fish surveys of the Maketū estuary and surrounding streams/drains were undertaken by Erin Bocker during January and February 2014 as part of her MSc research. The sampling was carried out according to the New Zealand Freshwater fish Sampling Protocols (Joy et al. 2013), using 6 fykes and 12 gee-minnows over a 150m. Three trials were carried out at each location, two overnight and one during the day (Photo 5.1). At some sites, additional trapping was done with fewer nets. Six sites were sampled downstream of flapgates, five in the estuary (see Figure 5.1) and one at Bells Road drain[18].

A total of 16 fish species (plus shrimp (Mysidae) and snapping shrimp (*Alpheus* sp.)) were caught around the estuary margins. The most abundant fish were mosquito fish (introduced), shortfin eel, cockabully, parore, common bully, giant bully and inanga (Table 5.1). The average size of shortfin eel caught was reasonably small (40cm), but there was a wide size range from elva to over 1m in length (see Table 5.2). Shortfin eel were particularly abundant at the entrance to Waitipuia Stream with 620 caught in the channel below the flapgate and 60 caught in the stream above the flap gate (including unidentified eel[19]) in two day/night trials. This dramatic difference in number suggests that the flapgate is preventing many eel from utilising the full range of habits in the estuary, stream and wetland.

The netting method probably underestimates the abundance of pelagic and shoaling fish species in the Maketū estuary. Mullet, flounder, kahawai and parore are all common in the estuary, particularly at high tide. Large shoals of inanga were observed on a number of occasions trying (mostly unsuccessfully) to enter Waitipuia Stream downstream of the flap gate. Although not a fish, sea hare (*Aplysia* sp.) are also common in the lower estuary where they feed on sea lettuce. Local residents recall that in the past sea horses have been common in the estuary, but none were observed in recent surveys.

Boubee and Baker (2005) provide an inventory of fish in the Kaituna River using information from the NZ Freshwater Fish database, literature and surveys. A total of 19 fish species were identified in the lower Kaituna River (15 native and 4 introduced). Longfin and shortfin eel were the most frequently recorded fish, while common bully and smelt formed significant diadromous populations in the lower river.

Diadromous fish species identified by Boubee and Baker (2005) as present in the lower Kaituna River but not caught by netting in the estuary or drains include: torrent fish (*Cheimarrichthus fosteri*), giant kokopu (*Galaxias argenteus*), koaro (*Galaxias brevipinnis*), banded kokopu (*Galaxias fasciatus*), lampray (*Geotria australis*), common smelt (*Retropinna retropinna*) and black flounder (*Rhombosolea retiaria*). Rainbow and brown trout are also present. Combining the inventory by Boubee and Barker (2005) and

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[18] Sampling also occurred upstream of the flapgates but the results are not presented here.
[19] Some eels were not identified on occasions when large numbers were caught, but they were probably short fin.

the netting in the estuary itself indicates that a total of 24 fish species either utilise or pass through the estuary or Kaituna River mouth.

Figure 5.1: Location of fish survey sites in the Maketū estuary, Jan and Feb 2014.

Table 5.1: Fish caught in the Maketū estuary using fyke nets and gee minnow traps, Jan to Feb 2014.

Common name	Scientific name	Papakahawai channel	Maketu South	Waitipuia Stream mouth	Burgess drain	Fords cut	Bell Rd Main Drain	Total
Common bully	*Gobiomorphus cotidianus*	1	156	18		1	17	193
Giant bully	*Gobiomorphus gobioides*		4	58		10	30	102
Redfin bully	*Gobiomorphus huttoni*						6	6
Longfin eel	*Anguilla dieffenbachii*			2		5	8	15
Shortfin Eel	*Anguilla australis*	72	140	313	375	79	15	994
Eel (unidentified) *	*Anguilla sp.*			322	228	52	2	604
Gambusia	*Gambusia affinis*		443	5	2		422	872
Goldfish	*Carassius auratus*			2			5	7
Inanga	*Galaxias maculatus*		5	16	1		127	149
Shrimp sp.	Mysidae	942	273	1779	1016	984		4994
Grey mullet	*Mugil cephalus*		17		16			33
Yellow eyed mullet	*Aldrichetta forsten*	1		2		1		4
Cockabully	*Grahamina nigripenne*			68	4	155		227
Flounder	*Rhombosolea plebeian*			1		1		2
Kahawai	*Arripis trutta*				1	1		2
Parore	*Girella tricuspidata*	39		20	26	123		208
Snake eel **	*Ophisurus serpens*	1				1		2
Spotty	*Notolabrus celidotus*					1		1
Snapping shrimp	*Alpheus sp*	4						4

Notes:
*probably shortfin eel but identification not confirmed due to large numbers.
 ** Snake eel identification was not confirmed and may be a eel worm *(Scolecenchelys breviceps*)
Large shoals of inanga were observed around Waitupuia Stream/Singletons flapgate although few were caught in the nets.

Table 5.2: Average size (in cm) of fish caught in the Maketū estuary January to February 2014.

Common name	Scientific name	Papakahawai channel	Maketu South	Waitipuia Stream mouth	Burgess drain	Fords cut	Bell Rd Main Drain	overall mean (cm)
Common bully	*Gobiomorphus cotidianus*	3.0	3.3	2.9		4.0	5.0	3.5
Giant bully	*Gobiomorphus gobioides*		10.4	11.9		17.0	13.6	13.3
Redfin bully	*Gobiomorphus huttoni*						6.2	6.2
Longfin eel	*Anguilla dieffenbachii*			102.0		36.0	56.2	51.2
Shortfin Eel	*Anguilla australis*	50.7	43.4	30.0	37.2	43.4	37.2	40.3
Eel (unidentified)	*Anguilla sp.*			48.0	50.0		37.5	47.4
Gambusia	*Gambusia affinis*							
Goldfish	*Carassius auratus*			14.5			8.6	10.3
Inanga	*Galaxias maculatus*		5.8	5.9	6.0		8.3	7.6
Shrimp sp.	Mysidae							
Grey mullet	*Mugil cephalus*		19.4		16.7			18.3
Yellow eyed mullet	*Aldrichetta forsten*	17.5		33.0		26.0		27.4
Cockabully	*Grahamina nigripenne*			6.5	6.2	6.2		6.3
Flounder	*Rhombosolea plebeian*			14.0		6.5		10.3
Kahawai	*Arripis trutta*				35.0	28.0		31.5
Parore	*Girella tricuspidata*	2.7		3.7	3.0	5.9		4.6
Snake eel	*Ophisurus serpens*	100.0				100.0		100.0
Spotty	*Notolabrus celidotus*					15.0		15.0
Snapping shrimp	*Alpheus sp*	5.3						5.3

5.2   Inanga spawning and rearing habitat

The amount of potential whitebait habitat in the lower Kaituna River is substantially less than in the past due to drainage of wetlands, loss of riparian vegetation and the use of flap gates on drains and streams (Hamill et al. 2013). Mitchell (1994) noted that flapgates on all but two of 13 major tributaries to the lower Kaituna River had effectively blocked whitebait spawning habitat. Nevertheless, there remain a number of important areas of whitebait rearing, and potential spawning habitat along the lower river and tributary streams. These include potential habitat in the Waitipuia Stream and Arawa wetland if fish-friendly flap gates were installed, whitebait rearing habitat in the borrow pits (about 3.8km upstream of the entrance and 500m from the proposed take), and the Kaituna wetland. Shoals of inanga were observed trying to enter Waitipuia Stream (the largest tributary entering the estuary) but were being blocked by the flapgate.

Inanga spawn in autumn (mostly February to mid-April) amongst dense grasses and vegetation near the spring tide level (where salinity drops to about 0.3 psu in the water surface on a spring tide). This is a narrow vertical band of about 20cm, so considerably more habitat is available when the high water level can spill over to flat area or gently sloping banks (Hickford et al. 2010, McDowall 2000).

In order to establish the maximum spatial extent of the salt wedge, and hence the location of potential inanga spawning habitat in the lower Kaituna River, a salinity survey was undertaken during a period of low flow and spring high tide on 6 January 2014. A castaway CTD unit was used to collect salinity depth profiles at multiple points up and across the Kaituna River, near the time of high tide for the incoming tide and outgoing tide. There was very little difference in the depth profiles across the river at any one time, so a single representative transect was chosen for each transect up the river for a flooding and ebbing tide.

The extent of potential inanga spawning habitat is estimated by the extent of the salt wedge in the surface water (0.15m depth). This extended to about 2.5km to 3.1km upstream (Figure 5.2, surface layer on outgoing tide). The precise location for spawning will vary by hundreds of metres according to the precise river flow and tide heights. The point 2.5 km upstream is roughly opposite the downstream section of the Kaituna wetland. Dense grass along the river margin provides a small amount of potential spawning habitat, but the steep, near vertical bank reduces the potential habitat to a very narrow margin of river (see Photo 5.2). More extensive areas of land are flooded on a spring tide on the true left bank of the river however many of these areas are vulnerable to stock damage.

There was strong salinity stratification in the river at a depth of about 0.8m and 1.4m respectively for sites 1.3 and 2.35km upstream, and salinity dropping below 1psu at 0.77m and 1m depth respectively (Figure 5.3). At the point of the proposed intake the surface water was fresh on the incoming tide but slightly brackish (about 2psu) on the outgoing tide.

A second survey of the salt wedge extent was undertaken on 1 to 5 April 2014 when river flows were lower. This found the bottom of the salt wedge extending to 4km upstream (Ellery and Hughes 2014). On this occasion inanga eggs were found both in the borrow pits (1.7 km upstream) and 3.2km upstream (on the true left (TL)), i.e. 1.5km difference on the same spawning occasion. This suggests that the salt wedge is only an approximate indicator of where inanga spawn. The borrow pits have been managed for inanga habitat but this is the first time spawning has been confirmed at this site (see Photo 5.4 for location of spawning at the borrow pits).

Mitchell (1994) identified whitebait spawning sites and eggs over a long section of the river, from roughly opposite the borrow pits (1.7 km upstream) to the Raparahoe channel (6.6 km upstream). Larval fish studies indicated that spawning could be occurring as much as 11km upstream – within the zone of tidal influence but well above the limit of salt water penetration. Tidally influenced tributaries were particularly important spawning areas. The most significant spawning ground was found on a small tributary and cut-off meander known as Cabbage Tree Creek, about 4.2 km upstream on the River's true left.

The whitebait fishery is not only dependent on whitebait spawning habitat but also whitebait rearing habitat. Gently sloping vegetated riparian margins and wetland provide better habitat for inanga compared to steep vertical banks. Peter Ellery used gee-minnow traps to assess fish abundance and use of contrasting habitat types: rock rip-rap, vertical vegetated banks and sloping vegetated banks (see Photo 5.3). Ten gee-minnow traps were placed in each habitat type in the lower Kaituna River near the proposed intake (about 1.3 km upstream); the sampling was repeated in five occasions between April 2011 and April 2012. The most commonly caught fish were bully and inanga. Bully had similar abundance across all habitat types, but inanga had much greater abundance at sloping vegetated banks compared to vertical banks or rock rip-rap (Table 5.3). Inanga, bully and smelt were more abundant during sampling occasions in January and April.

Table 5.3: Abundance of fish in contrasting habitat types: rock rip-rap, vertical vegetated banks and sloping vegetated banks. 10 traps were used at each habitat type on five occasions April 2011 to April 2012. The habitats sampled were about 1.3 km upstream near the proposed intake (from P. Ellery, unpublished).

Habitat type	Inanga	Smelt	Bullies	Eels
Rock rip-rap	3	6	46	1
Vegetated vertical banks	4	6	50	2
Vegetated sloping banks	92	9	47	1

Photo 5.1: Location of fish surveys at Waitipuia Stream (left) and Burgess drain (right)

Photo 5.2: The true right bank of the Kaituna River at 2.4 km upstream, near the maximum extent of the saline water during a spring high tide.

Photo 5.3: Location of entrance to proposed channel (1.3km upstream), facing upstream at high tide. Note the vertical vegetated banks in the foreground and rock rip-rap in the distance*.*

Photo 5.4: Location of inanga spawning at the borrow pits (from Ellery and Hughes 2014).
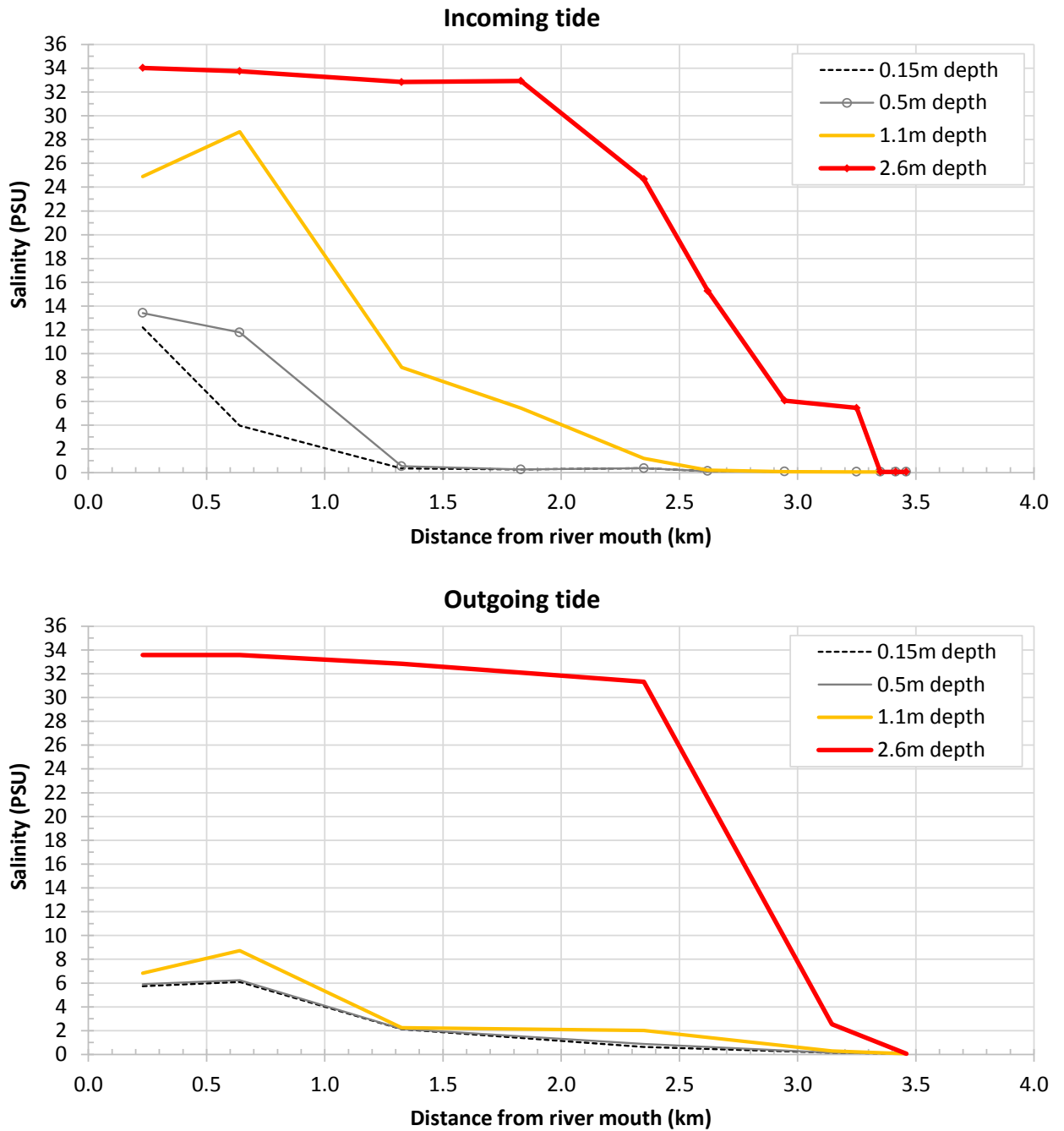
Figure 5.2: Change in salinity with distance upstream during a spring high tide (6 January 2014). The top graph is for the incoming tide and the bottom graph for the outgoing tide. The proposed intake for the diversion is 1.3km upstream.
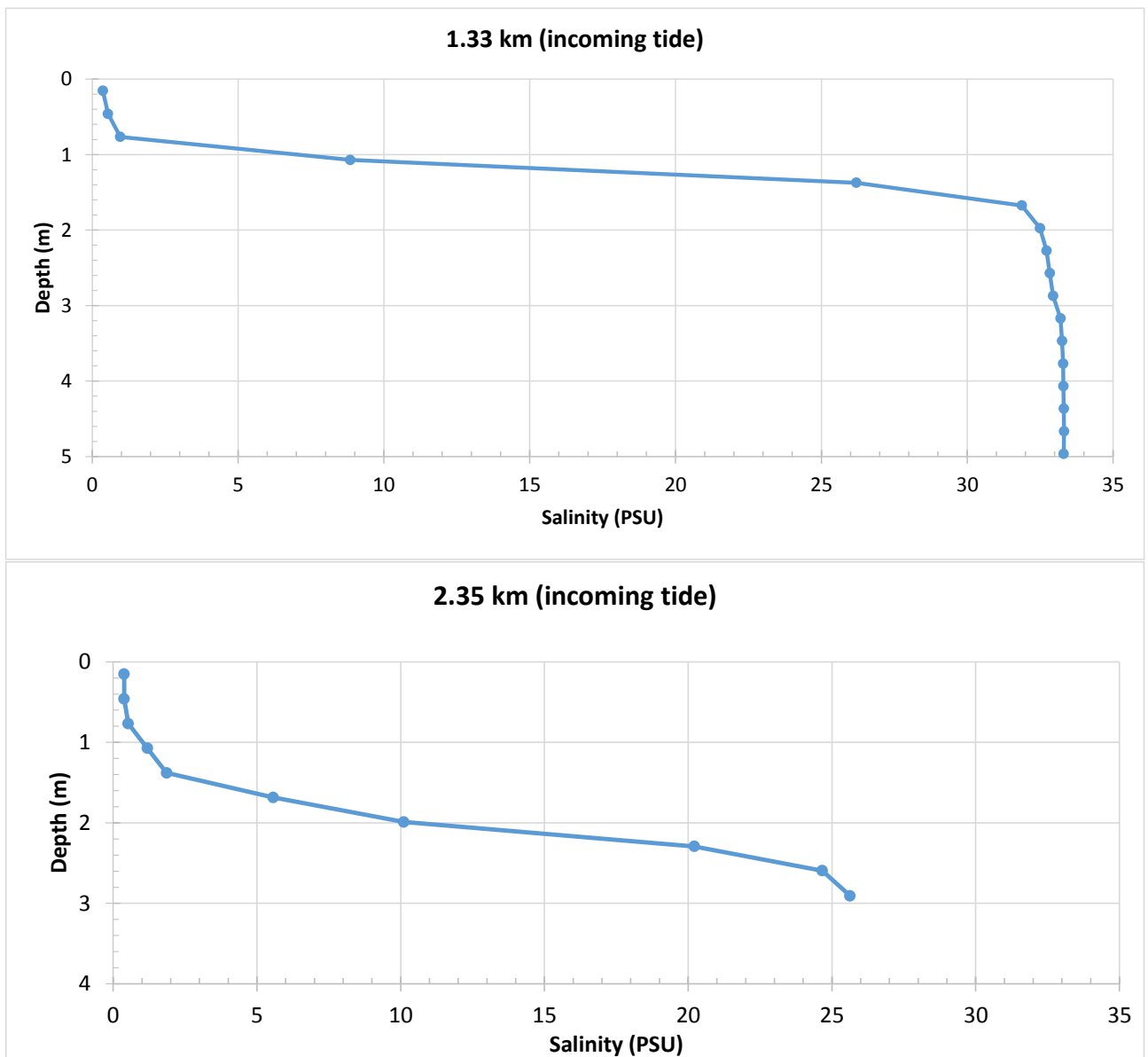
1.33 km (incoming tide)

2.35 km (incoming tide)

Figure 5.3: Salinity depth profile at the point 1.3km upstream (top, proposed intake) and 2.35 km upstream (bottom).

5.3   Discussion of potential effects

The Maketū estuary provides a nursery and feeding ground for a number of fish. However the extent of habitat suitable for fish in the estuary is reduced by low dissolved oxygen concentrations and suitable feeding habitat is indirectly reduced by extensive areas of anoxic sediments that exclude invertebrates (see previous chapters). The proposal will increase current speeds and the ability of the estuary to flush accumulations of free-floating *Gracilaria* and *Ulva* sp. and the anoxic mud that accumulates beneath them - particularly in the upper estuary and Papahikahawai lagoon. It is expected that reducing algal biomass and anoxic mud will both improve dissolved oxygen levels and improve habitat for benthic invertebrate fauna, which in turn provides fish habitat and feeding areas.

The ability of fish to move from the estuary to surrounding streams and wetlands is limited by flapgates. Waitipuia Stream is the largest tributary to the estuary and it is recommended that consideration is given to retrofitting a fish-friendly flap gate to this stream to allow fish movement and open up inanga habitat in the wetland.

The proposal will affect the salinity in the lower Kaituna River and the extent of the salt wedge. The modelling shows that the section of river below the proposed intake (1.3 km upstream) will become considerably more saline after the re-diversion, including channels draining the wetland below this point (DHI 2014). The effect is most evident in the surface water (i.e. river margins) rather than on the bed of the main river channel which is already saline. Fish in the lower Kaituna River have wide salinity tolerances and there is a wide diversity of fish in Fords cut (with similar high salinity) so overall the increased salinity downstream of the proposed intake is not expected to have a significant impact on fish.

The model was not sufficiently detailed to predict the absolute extent of the salt wedge (e.g. <0.5 psu), but there is an indication from the maximum salinity graphs that the extent of the salt wedge may increase by about 200 metres upstream. This change will have negligible impact on potential inanga spawning sites because the change is negligible in the context of natural variability caused by differences in river flow[20] and variation in spring tide tidal heights.

The inanga rearing habitat in the borrow pits is connected to the river via drains with the level set at about half tide. The proposal is not expected to cause any significant change of salinity in the borrow pits. Although the model output shows an increase in salinity in the borrow pits, this is an artefact of the assumed initial conditions (i.e. 0 psu for the current situation and 35 psu for the proposed) and the pits were not flooded in the modelled tidal cycle (DHI 2014). During a spring tide, at low river flow, the model found the salinity in the river at a depth of half-tide would change from 20 to 24 psu. This is a small change compared to changes due to different river flows and expected to have minor impact on the ecology in the borrow pits. The effect would be positive if the small salinity increase reduced the growth of hornwort in the borrow pits.

About 100m of current wetland margin will be lost to form the proposed intake at about 1.3km upstream of the mouth. This part of the river has primarily vegetated vertical banks, and there is potential to mitigate the loss of some riparian habitat by creating additional, sloping riparian habitat along the edge of the new channel, thus providing considerably more potential inanga habitat. If this is done there will be a net gain in potential fish habitat along the wetland edge of the new channel. In addition, the proposal intends to create a large area of salt marsh wetland adjacent to the estuary east of Fords Road which, if suitably designed, will have potential for whitebait rearing habitat. Nevertheless the loss of existing wetland margin could be further reduced if the intake was moved about 70m upriver. Other implications for shifting the location would also need to be considered such as erosion risk.

It is recommended that the northern side of the new channel has a 'soft' planted margin and gently sloping banks down to below spring low tide. This will maximise the potential for whitebait rearing habitat. It will also partially mitigate for the loss of about 100m of wetland edge to allow for the

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[20] The maximum salt wedge changes by over 900m between the mean flow and the 7-day five year low flow.

entrance to the proposed new channel. It would also maximise the net gain in wetland from the project.

5.4   Summary

Key messages from this section are:

- There are 24 fish species that either utilise or travel through the estuary or Kaituna River mouth. Fish commonly observed in the main body of Maketū estuary are kahawai, mullet, flounder and parore. Fish common around the estuary margins are shortfin eel, cockabully, common bully, giant bully, inanga and the introduced mosquito fish.

- Shoals of inanga were observed trying to enter Waitipuia Stream (the largest tributary entering the estuary other than the Kaituna River) but were being blocked by the flapgate.

- As discussed in other chapters, the extent of habitat suitable for fish in the estuary is reduced by low dissolved oxygen concentrations and suitable feeding habitat is indirectly reduced by extensive areas of anoxic sediments.

- The saline wedge suggests that potential inanga spawning habitat would be in the vicinity of the Kaituna wetland 2.5 to 3.1 km from the entrance. The location of the saline wedge varies with river flows and tide heights.

- Observations of inanga egg sites indicate that inanga can spawn over a much wider range (about 1.7 to 6.6 km upstream from the entrance).

- It is recommended that consideration is given to installing a fish friendly flap gate to Waitipuia Stream outlet to allow fish movement and open up inanga habitat.

- It is recommended that the northern side of the new channel has a 'soft' planted margin and gently sloping banks. This will maximise the potential for whitebait rearing habitat. It will also compensate for the loss of about 100m of wetland edge to allow for the entrance to the proposed new channel.

- There would be more net gain in wetland rearing habitat by shifting the intake about 70m up river; however other implications from changing the location also need to be considered including potential risk from erosion.

- There is potential to design wetland restoration intended for the farmland east of Ford's Road to enhance whitebait rearing habitat.

- Future fish surveys in the estuary margins could be considered in order to assess the success of restoration measures.

6   Macroinvertebrate fauna in lower Kaituna River

6.1   Invertebrate sampling results

The aquatic macroinvertebrate community can provide an indication of river health and the food available for fish. The lower Kaituna River bed and river margins were sampled for aquatic macroinvertebrates in January 2014 to describe their composition and assess the likely changes due to the proposal. Five transects were sampled across the river (Figure 6.1). At each transect, three benthic grab samples were collected across the river width using a 20cm diameter grab sampler, and bulked into a single replicate. Riparian margins were sampled using a kick net with 500 micron mesh size, using the semi-quantitative method for soft-bottomed streams – Protocol C2 of Stark et al. (2001). Samples were processed using 200 fixed count + scan for rare taxa (Protocol P2, Stark et al. (2001)).

The survey found low Macroinvertebrate Community Index (MCI) scores at most sites, reflecting the dominance of taxa tolerant of wide changes in salinity. Higher MCI scores for benthic grab samples of transects T1 and T2 were probably anomalies due to the very small number of taxa at the site (Table 6.1). Note that due to the significant number of marine taxa, MCI scores need to be interpreted with caution.

The dominant taxa at all transects were amphipods and snails (*Potamopyrgus* sp.). The borrow pits were also dominated by snails (*Potamopyrgus antipodarum*). *Chironomus* sp. were very abundant at transect 3 and 4 and juvenile pipi were very abundant at the mid channel sites of T4 (0.68 km from the entrance).

Samples from mid-channel of T1 (2.4km upstream) and T2 (1.8km upstream) had few taxa (richness of 2 to 5) and the abundance of these taxa was low. This probably reflects the mobile (pumice sand) stream bed and variable salinity as the location of the salt wedge shifts with tides and river flow. At these sites, higher species diversity was found on the steep vegetated banks on the edge of the river compared to the river bed.

Marine taxa were present at all transects except the borrow pits, but were particularly common in transects T3, T4 and T5 (all within 1.3 km of the entrance). At site T3 (1.3km), higher species diversity was found in samples from the vegetated bank compared to samples collected from the rock rip-rap (see Table 6.1).

6.2   Discussion of potential effects

Modelling indicates that the section of Kaituna River below the proposed intake (1.3 km upstream) will become considerably more saline (DHI 2014) after the re-diversion. This section of the river is a zone of transition and dominated by saline tolerant species. The change is likely to result in a shift in the composition of invertebrate species on the river edge towards more saline tolerant species, but the overall effect is expected to be minor. The bed of the main river channel is already saline in this section so there will be negligible effect on river bed fauna. However it is possible that the spatial extent of pipi beds in the lower Kaituna River may extend further upstream towards the proposed intake as the section of the river below the proposed intake becomes saline for longer periods of time.

The borrow pits were dominated by tolerant freshwater species. It is possible that the water entering the borrow pits at high tide becomes a little more saline as a result of the diversion (see previous chapter);

however the most abundant species in these ponds were snails (*Potamopyrgus antipodarum*) that are tolerant of saline water and were found as far down the river as site T4, which experiences high salinities. There is not expected to be any significant change as a result of the possible small increase in salinity. The borrow pits had the lowest MCI-sb score of all the samples.

Higher species diversity was found on vegetated banks compared to rock rip-rap and it is recommended that the northern site of the new constructed channel has a 'soft' vegetated edge to maximise invertebrate species diversity and interaction with the wetland.

6.3   Summary

Key messages from this section are:

- The greatest abundance and species diversity of aquatic macroinvertebrates in the lower Kaituna River tidal zone occurs on the river banks and riparian margins. The river bed had few taxa due to the mobile pumice sands. Pipi are abundant near the mouth (e.g. from 0.7km upstream) where the water is more saline and the substrate more stable.

- It is recommended that the northern site of the new constructed channel has a 'soft' vegetated edge, with sloping margins to maximise invertebrate species diversity and interaction with the wetland.

Figure 6.1: Location of macroinvertebrate sample transects in the Kaituna River (January 2014)

Table 6.1: Aquatic macroinvertebrates in the Kaituna River bed and bank margins (January 2014). Taxa in bold are marine species.

TAXON	MCI-sb score	Borrow Pits	T1 (2.4 km)			T2 (1.8 km)			T3 (1.3 km)				T4 (0.68 km)		T5 (0.73 km)	
			TL	Mid	TR	TL	Mid	TR	TL	Mid	TR	TR rip-rap	Mid	TR	Mid	TR rip-rap
CRUSTACEA																
Amarinus lacustris	5.1								1				5		1	6
Isopoda	4.5					7		4	48	2	1		3	86	1	6
***Macrophthalmus* species (marine crab)**	-								6	1	1				4	1
Mysidae	6.4			3		6		3						6		
Paracalliope fluviatilis	5.5		3		6	30		3						32		
Paracorophium species	5.5						39	26	24	12	18	1			77	176
Paratya species	3.6	6	1		288	6				2	12	2			1	3
Podoceridae (marine amphipod)	-															2
Talitridae	5.5										3					
Tanaidacea	6.8							5	12		21	2				3
DIPTERA																
Chironomus species	3.4								342		1		4	300		
Limonia species	6.3		3													
Orthocladiinae	3.2		9		6	1		1			9			4	2	
Tanytarsini	4.5							1			2	1		2		
EPHEMEROPTERA																
Deleatidium species	5.6										1					
HEMIPTERA																
Sigara species	2.4		1													
LEPIDOPTERA																
Hygraula nitens	1.3							1								
MOLLUSCA																
***Amphibola crenata* (mudflat snail)**	-														1	
***Austrovenus stutchburyi* NZ cockle)**	-														2	
***Cominella* species (whelk)**	-														1	
Gyraulus species	1.7	54				6		1	6	2						
Halopyrgus pupoides	-								6		2	12		42	14	107
Lymnaeidae	1.2	60				6										
***Paphies australis* (Pipi)**	-												212			
Physa / Physella species	0.1	1				1										
Potamopyrgus antipodarum	2.1	1506	873	1	1230	1680	1	109	1608	5	181	121	21	218		
Potamopyrgus estuarinus	**2.1**		6			6			36	1	20	4	2	62	150	29
Sphaeriidae	2.9	1														
OLIGOCHAETA	3.8	1			1	6	1	1		1					1	
PLATYHELMINTHES	0.9	42				6										
POLYCHAETA	6.7			17			24			13	1	1	17	4	2	2
TRICHOPTERA																
Oxyethira albiceps	1.2									3						
Paroxyethira species	3.7				6	6										
Number of taxa		8	7	3	7	11	5	10	10	9	15	8	7	11	12	9
Number of EPT taxa (excl. Hydroptilidae)		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
% EPT taxa (excl. Hydroptilidae)		0	0	0	0	0	0	0	0	0	6.7	0	0	0	0	0
MCI-sb score		41	72	101	65	61	90	78	78	75	84	89	80	83	84	97
SQMCI-sb score		2.0	2.1	6.4	2.4	2.3	5.8	2.9	2.5	4.4	3.0	2.3	3.4	3.1	2.7	4.9

Names in bold indicate typical marine or estuarine taxa

TL = true left, TR = true right, mid = benthic grab sample from middle of channel (three samples across the channel were bulked into a single sample. Samples TL and TR were kick net samples from the river bank using Protocol C2 of Stark et al. (2001).

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Appendix 1: Cockle sizes in Maketū estuary sites

Table A1: Mean cockle site in the Maketū estuary 2013/14 survey

Estuary location	site	mean size	max size	min size
upper estuary	35A	17.5	17.5	17.5
	37A	22.5	22.5	22.5
	37B	24.2	27.5	22.5
	37D	21.3	27.5	17.5
upper mid-estuary	36A	17.5	17.5	17.5
	39A	17.5	22.5	12.5
	40	15.0	17.5	12.5
	40A	12.3	22.5	7.5
	45	16.4	22.5	12.5
	45A	16.5	22.5	7.5
	41	15.0	17.5	7.5
	41A	18.4	27.5	12.5
	43A	18.5	22.5	12.5
	43D	17.5	27.5	12.5
	43B	11.5	22.5	7.5
Papakahawai channel	38A	25.8	27.5	22.5
	38	20.8	27.5	7.5
lower mid-estuary	43C	15.8	27.5	7.5
	47	17.0	27.5	7.5
	47A	16.3	22.5	7.5
	47B	15.4	22.5	7.5
	40B	18.8	22.5	7.5
	48B	14.4	27.5	7.5
	48	16.0	22.5	7.5
	51	20.0	27.5	2.5
Southern	53	21.5	32.5	17.5
lower estuary	55	12.5	12.5	12.5
	56	15.9	27.5	2.5

Appendix 2: Clustering of sites based on macrofauna communities

Replicates from the eight infauna sample sites differentiated into four clusters showing a significant difference using the Brays Curtis similarity and SIMPROF test (Figure A1). These were:

- Site 33 (upper estuary) and one replicate of site 35b were distinctive by having no infauna species present. Site 35b (upper estuary) had only two species present, but a SIMPROF test on a zero-adjusted Bray Curtis similarity matrix found no significant difference between site 33 and 35B and differentiated these two sites from all others.

- Site 53 (southern estuary) had low species diversity and low density of cockle or wedge shell.

- Site 40 and 41 (both upper mid-estuary) were distinguished by having abundant horn shell and moderate cockle density (the polychaeta *Scoloplos* sp and *Aquilaspio* sp. were also abundant).

- Sites 48, 51 and 56 (middle and lower estuary) were differentiated by having abundant cockle and wedge shell.

The 39 epifauna sample sites differentiated into five clusters showing a significant difference using the Brays Curtis similarity and SIMPROF test (Figure A2). These were:

- Upper estuary sites 33 and 45 were distinctive by having no epifauna; site 35D almost none (just one mud snail in a 2m^2 sample).

- Site 50 (south) and 48B (upper mid estuary) were distinguished by having very sparse epifauna.

- Groups A, B (sites 35A, 35E, 35B, 35C, 37, 37A, 37C (all upper estuary) had epifauna dominated by crab holes, mud snail (*Amphibola crenata*), and estuarine snail (*Potamopyrgus estuarinus*) in the more western sites. Groups C and D (37B, 37D (both upper estuary), site 38 (Papahikahawai channel) and site 55 (lower estuary)) had epifauna dominated by crab holes. However there was no significant difference between these two groups.

- Groups E, F and G (sites 41, 41A, 40, 43C (upper mid-estuary), 53 (southern), 36A, 43A, 39A, 47B (upper mid-estuary), 43D, 47, 45A, 40A, 43 (upper mid-estuary) and 48B (mid estuary) were distinguished by abundant horn shell. Group E had hornshell and no crab holes, group F had hornshell and crab holes, and group G had horn shell, crab holes, mud whelk and occasionally top shell.

- Group H (sites 43B and 47A (mid-estuary near Papahikahawai Is), group I (sites 51 and 56 (lower mid-estuary and lower estuary), site 38 A (Papahikahawai channel) and site 48 (lower mid-estuary) were distinguished by having a greater number of epifauna species. Horn shell, top shell and crab holes were abundant at all these sites. The individual groups were distinguished by: Group H had both species of horn shell (*Zeacumantus subcarinatus* and *Z. lutulentus)* in abundance, group I had abundance of *Notoaacmema* sp., and sites 38A and 48 also had abundant *Anthropleura* sp.

The 39 shellfish sample sites differentiated into three clusters showing a significant difference using the Brays Curtis similarity and SIMPROF test (Figure A3). These were:

- No shellfish were found at 10 sites (sites 33, 35D, 35C, 35E, 35B, 37, 37C, 43, 36A and 50) of which all were in either the upper estuary, upper mid-estuary or southern estuary. These sites were often associated with anoxic sediment and high algal cover.

- Shellfish group A, group B and sites 37B and 41 (upper and upper mid-estuary) all had either very sparse or sparse cockle. Group A (sites 55 (lower), 35A and 37A (upper)) had very sparse cockle and all these sites were located near the high tide level. Group B (sites 38A, 38 (Papahikahawai channel), 39A, 43A (upper mid-estuary)) had sparse cockle. Site 37B had sparse cockle and rough shell (*Cyclomactra ovate*), and site 41 had sparse cockle and pipi.

- Shellfish groups C, group D and sites 47A, 47B and 45 (mid estuary) all had abundant cockle. Group C (sites 43C, 43B, 40A, 40B, 47, 48, 45A, 43D, 48B, (mid-estuary), 51 and 56 (lower estuary)) had very abundant cockle and abundant wedge shell. Group D (sites 37D, 53, 40, 41A) had common cockle and wedge shell. Site 47B (lower mid-estuary) had abundant wedge shell but less abundant cockle, site 47A (lower mid-estuary) abundant cockle but only less abundant wedge shell and nutshell (*Nucula* sp). At Site 45 (upper mid-estuary) cockle were common but there were no wedge shell.

It should be noted that few pipi (*Paphies australis*) were found in the sampling because their habitat was not sampled, i.e. lower estuary sand flats (juvenile pipi) and mid to lower estuary channels (mature pipi).
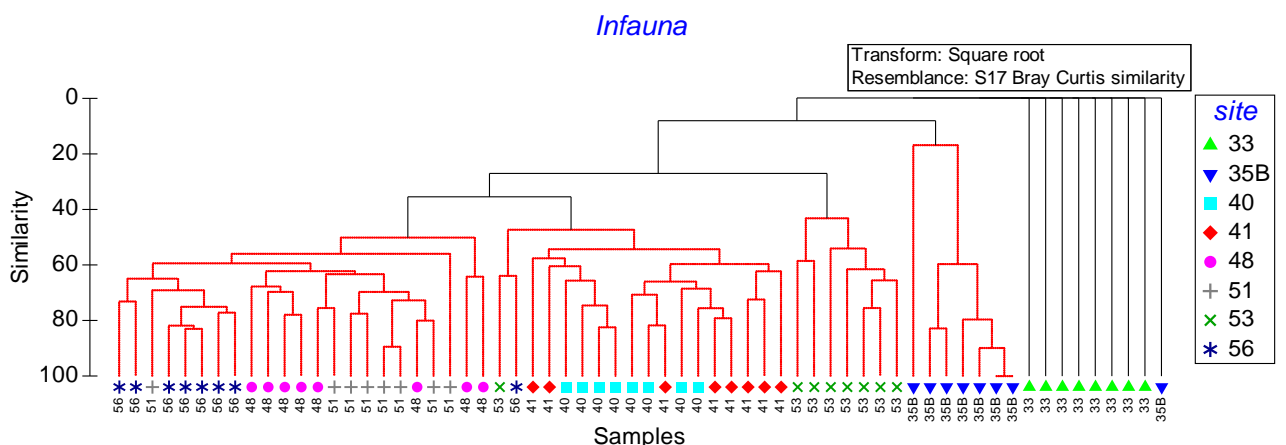

Figure A1: Dendrogram showing Bray Curtis similarity of infauna sample sites/replicates in the Maketū estuary. Groups connected by a red dotted line indicate that a SIMPROF test found no significant difference at the 5% level. Site 33 and one replicate of 35B had no fauna present.
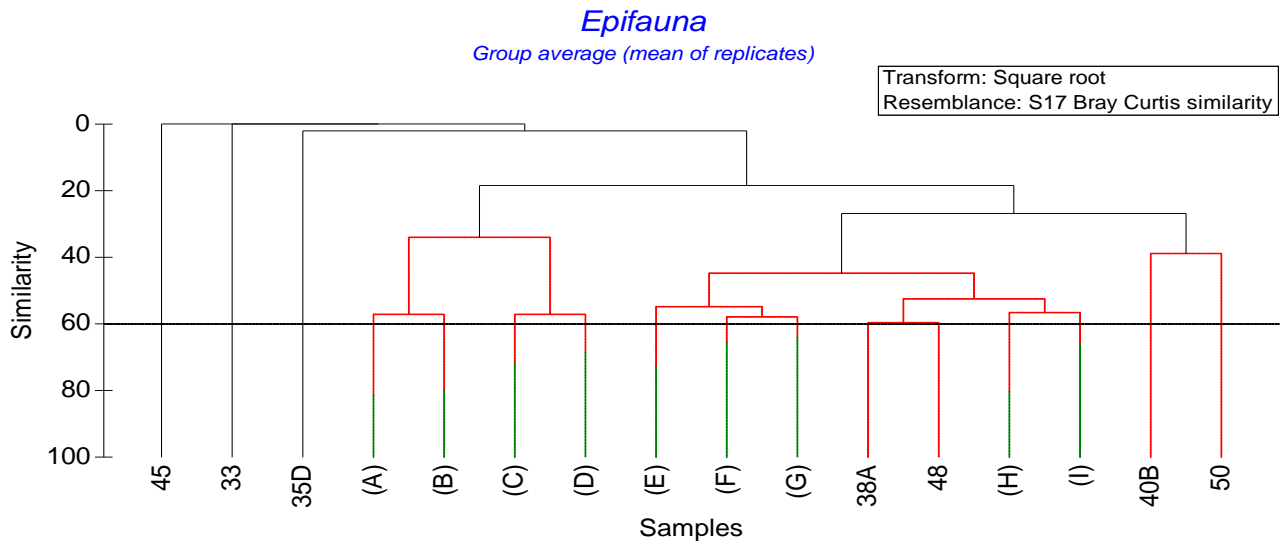
Epifauna
Group average (mean of replicates)

Figure A2: Dendrogram showing Bray Curtis similarity of Epifauna sample sites in the Maketū estuary. Groups connected by a red dotted line indicate that a SIMPROF test found no significant difference at the 5% level. Site 33 and 45 had no epifauna, site 35D had only one mud snail present. Group A = 35A+35E+35B+35C, Group B = 37+37A+37C, Group C =37B+37D, Group D = 38+55, Group E = 41+41A+40+43C, Group F = 53+36A+43A+39A+47B, Group G = 43D+47+45A+48B+40A+43, Group H = 43B+47A, Group I = 51+56.
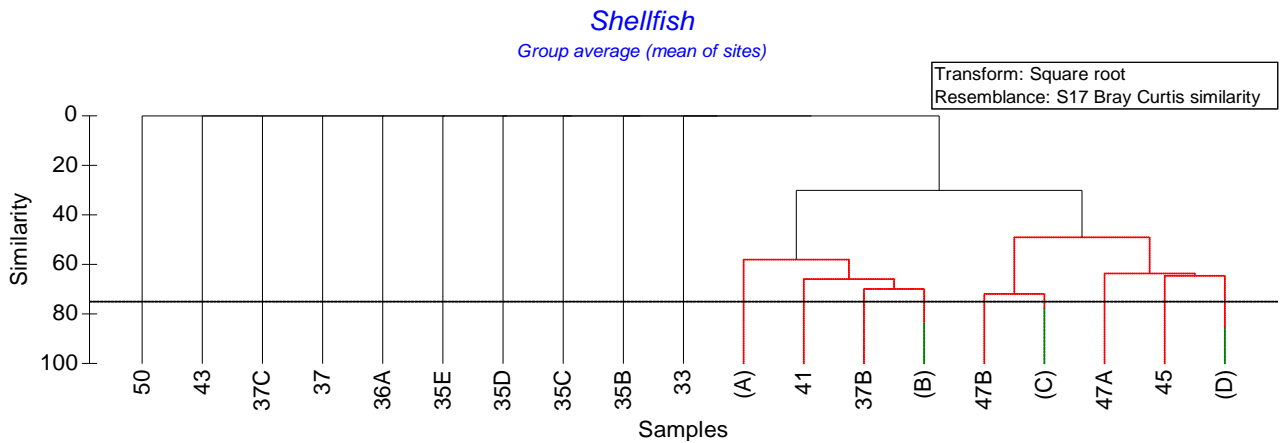
Shellfish
Group average (mean of sites)

Figure A3: Dendrogram showing Bray Curtis similarity of shellfish sample sites in the Maketū estuary. Groups connected by a red dotted line indicate that a SIMPROF test found no significant difference at the 5% level. No shellfish were present at sites: 43, 50, 33, 35B, 35C, 35D, 35E, 36A, 37, or 37C. Group A = 55+35A+37A, Group B = 38A+39A+38+43A, Group C = 51+43C+56+40A+43B+40B+47+48+45A+43D+48B, Group D = 37D+53+40+41A.

Appendix 3: Algal growth on bricks in Maketū estuary

Appendix 4: Benthic macrofauna sample sites in Maketū estuary, January 2014.