Estuarine Environmental Assessment and Monitoring:

A National Protocol

PART B:

Development of the Monitoring Protocol for New Zealand Estuaries:

Appendices to the Introduction, Rationale and Methodology

LIST OF APPENDICES

APPENDIX A: BACKGROUND INFORMATION DESCRIBING REFERENCE ESTUARIES 1

Appendix A 1. Otamatea Arm 2
Appendix A 2. Ohiwa Estuary 8
Appendix A 3. Ruataniwha Estuary 13
Appendix A 4. Waimea Estuary 17
Appendix A 5. Havelock Estuary 22
Appendix A 6. Avon-Heathcote Estuary 27
Appendix A 7. Kaikorai Estuary 34
Appendix A 8. New River Estuary 40

APPENDIX B: BROAD-SCALE HABITAT MAPPING 46

Appendix B 1: Summary of the broad-scale habitat mapping characteristics 46
B.1.1. Otamatea Arm 46
B.1.2. Whangamata Estuary 50
B.1.3. Ohiwa Estuary 56
B.1.4. Ruataniwha Estuary 60
B.1.5. Waimea Estuary 64
B.1.6. Havelock Estuary 68
B.1.7. Avon-Heathcote Estuary 72
B.1.8. Kaikorai Estuary 76
B.1.9. New River Estuary 80
Appendix B 2: Components of the broad-scale habitat classification system 84

APPENDIX C: FINE-SCALE ENVIRONMENTAL MONITORING DETAILS 92

Appendix C 1: Estuary site selection: site coordinates 92
Appendix C 2: Fine-scale data analysis methodology 95
Appendix C 3: Summary of the analytical results for individual reference estuaries ... 103
Appendix C 4: Fine-scale environmental monitoring results 134

LIST OF TABLES

Table A1: Otamatea Arm catchment landuse 4
Table A2: Ohiwa Estuary catchment land use 10
Table A3: Ruataniwha Estuary catchment land use 15
Table A4: Specific yields (kg/ha/yr) for the Aorere River 16
Table A5: Waimea Estuary catchment landuse. 19
Table A6: Havelock estuary catchment landuse 24
Table A7: Avon-Heathcote Estuary catchment landuse. 30
Table A8: Kaikorai Estuary catchment landuse 37
Table A9: New River Estuary catchment landuse 42
Table A10: Non-point sources of pollution into the New River Estuary 44
Table A11: Point sources of pollution into the New River Estuary 44
Table A12: The broad-scale details of the habitat mapping of the Otamatea Arm 49
Table A13: The broad-scale details of the habitat mapping of the Whangamata Estuary 55
Table A14: The broad-scale details of the habitat mapping of the Ohiwa Estuary 59
Table A15: The broad-scale details of the habitat mapping of the Ruataniwha Estuary 63
Table A16: The broad-scale details of the habitat mapping of the Waimea Estuary 67
Table A17: The broad-scale details of the habitat mapping of the Havelock Estuary 71
Table A18: The broad-scale details of the habitat mapping of the Avon-Heathcote Estuary 75
Table A19: The broad-scale details of the habitat mapping of the Kaikorai Estuary 79
Table A20: The broad-scale details of the habitat mapping of the New River Estuary 83
Table A21: Adapted Estuarine and palustrine components of UNEP-GRID classification 85
Table A22: Estuarine classification system based on Atkinson (1985) system. 87
Table A23: The coordinates of the four corners of the sampling sites within each of the reference estuaries. 92
Table A24: Physical and chemical sediment properties of sites in the Kaipara Estuary (Otamatea Arm). 103
Table A25: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Kaipara Estuary (Otamatea Arm) 104
Table A26: Summary of the 15 most abundant infaunal species sampled at the Otamatea Arm 105
Table A27: Summary of all epifaunal species sampled at the Otamatea Arm 105
Table A28: Physical and chemical sediment properties of sites in the Ohiwa Estuary 107
Table A29: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Ohiwa Estuary 108
Table A30: Summary of the 15 most abundant infaunal species sampled at the Ohiwa Estuary 109
Table A31: Summary of all epifaunal species sampled at the Ohiwa Estuary 109
Table A32: Physical and chemical sediment properties of sites in the Ruataniwha Estuary 111
Table A33: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Ruataniwha Estuary 112
Table A34: Summary of the 15 most abundant infaunal species sampled at the Ruataniwha Estuary 112
Table A35: Summary of all epifaunal species sampled at the Ruataniwha Estuary 113
Table A36: Physical and chemical sediment properties of sites in the Waimea Estuary 115
Table A37: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Waimea Estuary 115
Table A38: Summary of the 15 most abundant infaunal species sampled at the Waimea Estuary 116
Table A39: Summary of all epifaunal species sampled at the Waimea Estuary 117
Table A40: Physical and chemical sediment properties of sites in the Havelock Estuary 119

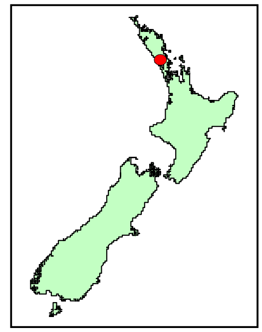
Table A41: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Havelock Estuary 120
Table A42: Summary of the 15 most abundant infaunal species sampled at the Havelock Estuary 121
Table A43: Summary of all epifaunal species sampled at the Havelock Estuary 121
Table A44: Physical and chemical sediment properties of sites in the Avon-Heathcote Estuary ... 123
Table A45: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Avon-Heathcote Estuary 124
Table A46: Summary of the 15 most abundant infaunal species sampled at the Avon-Heathcote Estuary 125
Table A47: Summary of all epifaunal species sampled at the Avon-Heathcote Estuary 125
Table A48: Physical and chemical sediment properties of a site in the Kaikorai Estuary 127
Table A49: Physical and chemical sediment properties (standardised to 100% mud) of a site in the Kaikorai Estuary 128
Table A50: Summary of the 15 most abundant infaunal species sampled at the Kaikorai Estuary 129
Table A51: Physical and chemical sediment properties of sites in the New River Estuary 130
Table A52: Physical and chemical sediment properties (standardised to 100% mud) of sites in the New River Estuary 131
Table A53: Summary of the 15 most abundant infaunal species sampled at the New River Estuary 132
Table A54: Summary of all epifaunal species sampled at the New River Estuary 132
Table A55: Nested ANOVAs for each estuary variable 135
Table A56: Results of one-way ANOVAs assessing variability between sites within each estuary for each characteristic. 136
Table A57: Global tests for differences between sites (averaged across all estuary groups) and estuaries (using sites as sample) 137
Table A58: Breakdown of average dissimilarity between site groups A & B and the Kaikorai based on the infauna communities 138
Table A59: Breakdown of average dissimilarity of sites between groups A and B based on the infauna communities 139
Table A60: Breakdown of average dissimilarity of sites between groups A and B, B-1 and B-2, B-1 and B-3 and B-2 and B-3, based on the epifauna assemblages 140
Table A61: Pearson correlation matrix of transformed chemical, physical and biological data[1]. **A**: raw data, and **B**: after normalising to mud content 144
Table A62: Pearson correlation matrix of site-averaged, appropriately transformed, physical, chemical and biological data[1]. **A**: not normalised, **B**: normalised to mud content 145
Table A63: Eigenvalues, percent variation and cumulative percent variation of un-normalised and normalised physical and chemical data explained by principal component (PC) axes 1:10. .. 147
Table A64: Euginevectors of the transformed physical and chemical variables 147
Table A65: Pearson product moment correlation coefficients for site-averaged physical and chemical data used in BIOENV procedure 148
Table A66: The best correlations from the BIOENV procedure (Primer), indicating which variables, or combination of variables, best captured the patterns biotic (epifauna and infauna), as indicated by strength of correlation; ρ 0-1 149
Table A67: One-way ANOVAs with estuary as factor (for estuaries with >2 sites) and site as replicate comparing CVs between estuaries for each variable 152
Table A68: Test for inter-site homogeneity of coefficients of variation for each estuary 153
Table A69: Estimated mean (near "actual") coefficient of variation (± 95 % CI) from plots of CV against *n* for each variable in each estuary. 155
Table A70: Mean values for each variable in each estuary with corresponding minimum detectable difference (bracketed); based on the recommended sample size (CBP), mean (near actual) CV and actual mean values. 155

LIST OF FIGURES

Figure A1: The area of different habitats in the Otamatea Arm of the Kaipara Estuary 46
Figure A2: Otamatea Arm – Map structural class habitat 47
Figure A3: Otamatea Arm – Map of dominant cover habitat...48
Figure A4: The area of different habitats of the Whangamata Estuary, showing the results from the present study and historical studies...50
Figure A5: Whangamata Estuary – Structural class habitat map from the present study.................51
Figure A6: Whangamata Estuary – Dominant cover habitat map from the present study 52
Figure A7: Whangamata Estuary (1944) – Map of identified habitat 53
Figure A8: Whangamata Estuary (1965) – Map of identified habitat 54
Figure A9: The area of different habitats of the Ohiwa Estuary..56
Figure A10: Ohiwa Estuary – Structural class habitat map 57
Figure A11: Ohiwa Estuary – Dominant cover habitat map...58
Figure A12: The area of different habitats of the Ruataniwha Estuary 60
Figure A13: Ruataniwha Estuary – Structural class habitat map..61
Figure A14: Ruataniwha Estuary – Dominant cover habitat map 62
Figure A17: Waimea Estuary – Dominant cover habitat map..66
Figure A18: The area of different habitats of the Havelock Estuary 68
Figure A19: Havelock Estuary – Structural class habitat map 69
Figure A20: Havelock Estuary – Dominant cover habitat map..70
Figure A21: The area of different habitats of the Avon-Heathcote Estuary.....................................72
Figure A22: Avon-Heathcote Estuary – Structural class habitat map 73
Figure A23: Avon-Heathcote Estuary – Dominant cover habitat map...74
Figure A24: The area of different habitats of the Kaikorai Estuary 76
Figure A25: Kaikorai Estuary – Structural class habitat map...77
Figure A26: Kaikorai Estuary – Dominant cover habitat map 78
Figure A27: The area of different habitats of New River Estuary..80
Figure A28: New River Estuary – Structural class habitat map 81
Figure A29: New River Estuary – Dominant cover habitat map..82
Figure A30: An example of how the cost benefit point (CBP) and near 'actual CV' are derived from a randomized plot of mean CV ± 95 % CI with increasing sample number...........................102
Figure A31: MDS ordination of the Bray-curtis similarities of infauna data (a), and the same ordination superimposed with circles of increasing size with increasing content of the environmental variables, %Mud (b), Lead, Pb (c) and total phosphorus, TP (d) 150
Figure A32: Box and whisker plots of recommended number of samples at CBP (a), mean (near actual) CV (b) and fraction of measurable change (c) for all variables..................................156
Figure A33: Performance summary of the G*Power model (α = 0.05 and β = 0.20) and formular for predicting *n* for a t-test (Zar 1999, α = 0.05 and β = 0.10) comparing samples size (*n*) in relation to minimum detectable change (% change) for a range of variables with differing CVs (G*Power: a, Zar: b), and sample size plotted against CV for five different levels of minimum detectable change (G*Power: c, Zar: d)...159

APPENDIX A: BACKGROUND INFORMATION DESCRIBING REFERENCE ESTUARIES

Appendix A 1. Otamatea Arm



Location, size and estuary type

The Otamatea estuary is a large (approximately 1700 ha) arm extending north-east of the Kaipara Harbour, Northland. For the current project, the estuary was considered to end at the headlands where the Otamatea River joins the Arapaoa and Whakaki Rivers entering the wider Kaipara Harbour.

The greater Kaipara Harbour is classified as a fluvial erosion, barrier enclosed (double-spit) estuary. The Harbour consists of an upper and lower arm enclosed by the northern and southern barrier spits (mainly dune sands), a wide mouth that is extensively barred and a flooded valley complex to the north-east, containing the Otamatea Estuary.

A view of the Otamatea Arm of the Kaipara Harbour

Morphology and hydrology

The Kaipara Harbour is an extensive drowned valley system with steeply cliffed margins and low, swampy marginal flats. It is the largest estuarine (as defined for this study), inlet in New Zealand, with a tidal range of 2.68 m (spring tide) and 1.52 m (neap tide), and a tidal compartment of 1990 million m^3 during a spring high tide. The Otamatea arm of the estuary extends to the north-east. The estuary is shallow and well-flushed by the tides.

The main freshwater input to the Kaipara overall is from the Otamatea, Wairau and Kaiwaka Rivers and other small streams, which provide a relatively small amount of freshwater to the estuary.

Consequently the Otamatea Arm is not influenced by large salinity variations. There is low freshwater input into the Otamatea Arm, of less than 0.5 m^3/s from the Pukekaroro and Hakaru Rivers (based on the limited data available).

Human occupation

The Kaipara Harbour region was an important coastal resource for early Maori settlements in the region.

Early European settlers felled much of the native kauri and beech forests by around 1910, and used the harbour to transport the timber south by barge. There are a number of small towns within the wider Kaipara Harbour catchment, as well as the larger cities of Dargaville, Helensville and Wellsford. Within the catchment of the Otamatea arm, the major towns are Maungaturoto and Kaiwaka. Urban development is relatively minor compared to some other estuaries around New Zealand. The Northland Regional Council has jurisdiction over the Otamatea region.

Catchment characteristics

Area

The total area of the Otamatea estuary catchment is approximately 614 km^2.

Geology and soils

The geology of the Otamatea catchment is highly variable, however it is dominated by beds of marine sedimentary sandstone, mudstone and limestone of various ages, formed as the sea level fluctuated over millions of years. The Kaipara Estuary is underlain by rocks of the West Northland Chaos-breccia, consisting of chert, argillaceous micrite and glauconitic sandstone, in a matrix of bentonitic clay (Ballance & McCarthy 1975). The geology of the northern side of the Otamatea arm consists of concretionary micaceous sandstone from the Cretaceous period with pockets of younger siltstone and sandstone along the northern river boundary. The northernmost region of the Otamatea catchment features calcareous shales and argillaceous limestones with younger deposits of limestone and glauconitic sandstone bands. The upper catchment is a mixture of parahaki volcanics, and further limestone, mudstone and glauconitic sandstone beds of varying ages. The majority of the marine sedimentary rock is soft and has been weathered to form an undulating landscape. There are more recent deposits of higher terrace sediments and alluvial soils accumulating along the lowlands and estuary beds.

The soils of the region are extremely varied due the complexity of different parent materials. They are typically strongly weathered, northern yellow-brown clays and fertile, dark, heavy soils leached of calcium carbonate. These generally overlay soft limestone and mudstone. There are highly fertile, lime-rich rendzina soils surrounding the Otamatea estuary arm. The alluvial material in the terrace deposits and semi-tidal sections of the channels result from the weathering and transportation of the sedimentary rocks that dominate the region. The heavy rainfall of the region means that the soils are prone to erosion.

Land use

The Otamatea estuary catchment drains mainly hilly and rolling lands featuring extensive agricultural development. The catchment is now mainly agricultural, (*i.e.* nearly 80% prime pastoral land used primarily for dairying, beef and sheep farming). As a result of the past extensive deforestation for agricultural development, the hillside areas of soft mudstone, sandstone and limestone soils are highly prone to erosion and landslides. The remaining catchment consists of scrub and native and exotic forest (~19%) with other uses, including urban development comprising a total of less than 1% (Table A1).

Table A1: Otamatea Arm catchment landuse

Land Use	Area (ha)	Cover (%)
Prime Pastoral	49029	79.8
Indigenous Forest	4489	7.3
Scrub	3698	6.0
Planted Forest	3602	5.9
Mangrove	249	0.4
Inland Water	120	0.2
Prime Horticultural	119	0.2
Urban	82	0.1
Bare Ground	19	0.0
Coastal Sands	8	0.0
Total	61414	100%

Source: LCDB1 (2001)

An example of Otamatea Arm marshland and farmland

Estuary values and uses

It is difficult to separate the values and uses of the Otamatea Arm from those of the greater Kaipara Harbour. We will therefore extend this discussion to include the integral unit of the Kaipara Harbour and estuary arms.

The Kaipara Harbour Estuary is an important local resource and is popular for water-based recreation, such as fishing, netting, shellfish gathering, boating and water-skiing. The Estuary is used for a number of commercial activities; *e.g.* oyster farming, fishing and sand extraction. Although the Harbour was once a major port, the difficulties of access through the extensively barred entrance have restricted its development. Nonetheless it provides an access-way to the coast beyond the Harbour entrance.

The Kaipara Harbour is well-known for its high primary production. Its arms support one of the most extensive mangrove areas in New Zealand. Fringe mangrove occurs at the heads of most inlets and creeks draining into the Otamatea Arm. Mangrove habitats are important as areas of high estuarine productivity that have additional follow-on effects on adjoining coastal marine food webs through the export of dissolved and particulate organic materials. They feature a high diversity of benthic invertebrates. Mangroves thrive in the absence of significant wave and tidal action, where rich organic sediments accumulate from the land. Mangrove forests provide an important stabilising role in the estuary, by binding and trapping suspended sediments, and acting as a buffer offering protection for the adjoining terrestrial and estuarine ecosystems.

The Kaipara Estuary is considered to be of high value as fish and wildlife habitat. The harbour and extended estuary arms provide feeding, breeding and nursery grounds for a variety of fish. The extensive intertidal flats and fringing mangroves also provide habitat for numerous bird species, including threatened species such as the New Zealand dotterel and the banded rail, and a variety of migratory wading birds.

For a detailed description of the biology of the estuary, see Morton and Miller (1968).

Water and sediment quality

Few data are available on the water or sediment quality of the Otamatea Arm.

High sediment input to the Otamatea estuary is likely during heavy rainfall events, as the surrounding catchment tends to erode easily due to the composition, as noted above. This is compounded by agricultural and urban development and agricultural runoff. Infilling of estuary boundaries and the loss of mangrove habitat could potentially increase erosion, as well as remove important estuarine wildlife habitat.

Wastewater from the Northland Dairy Factory at Maungaturoto is discharged in the upper reaches of the Otamatea Arm, at a maximum rate of 3000 m^3/day. Studies indicate that it has little impact on dissolved oxygen concentrations in the water column and does not encourage nuisance benthic algal blooms.

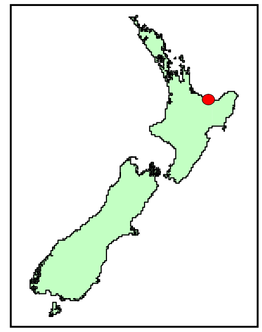
Exotic plant and animal species

Much of the hard shore consists of grey hydraulic limestone, and in the larger water areas and tide channels there is enough water movement to keep them relatively free of silt. These parts of the shore have a wide belt of rock oysters which up to the 1960s consisted of one species only, the Auckland rock oyster (*Crassostrea glomerata*). Subsequently the larger Pacific oyster (*Crassostrea gigas*) has invaded the area. In conjunction with the development of oyster farms, Pacific oyster habitat has now spread over a significant area of the intertidal zone and has dramatically altered previously bare habitat within the estuary.

The invasive saltmarsh cordgrass, *Spartina alterniflora*, was introduced into a number of locations in the Kaipara Harbour during the 1950s. Although it has subsequently become established and has spread in some regions, it is currently limited to a small area (< 0.5 ha) in the Otamatea Arm and is relatively sparsely distributed, occurring primarily in small clumps. Since the spread of *Spartina* can result in considerable alteration of the natural character, hydrological characteristics and ecology of estuaries (Gillespie *et al*. 1990), it should be closely monitored.

Appendix A 2.Ohiwa Estuary

Location, size and estuary type



The Ohiwa Estuary is a fluvial erosion, barrier-enclosed estuary, located between Whakatane and Ohope in the eastern Bay of Plenty, North Island. It comprises one large barrier spit projecting southwards (Ohope spit) and a smaller spit projecting northward (Ohiwa spit), and is therefore classed as a double-spit, enclosed estuary. The estuary area is approximately 2700 ha (mainly saltmarsh, mudflat, sandflat and wetland).

Morphology and hydrology

The Ohiwa Estuary is a valley system drowned by the post-glacial rise in sea level and partially enclosed by the littoral drift formation of the Ohope and Ohiwa sand spits approximately 1000 years ago. The deposition of glacially eroded and weathered sediments and later additions of volcanic pumice resulted in the infilling of the valley systems, creating the Ohiwa Estuary. There are six islands in the estuary.

A view of the Ohiwa Estuary

The estuary is dominated by the influence of the sea. It is a hypersaline estuary; *i.e.* one in which evaporation exceeds freshwater inflow (Daniel 1984). The small freshwater input is derived from

12 small streams and the Nukuhou River (mean annual flow of 1.8 m^3/s) which drains land to the south of the estuary. The ratio of estuary area (ha) to freshwater inflow (m^3/s) is very high at approximately 900.

Marine water enters from the relatively open coastal embayment of the Bay of Plenty with each tide. The estuary is largely drained at low water and is therefore well-flushed, giving it a likely retention time of less than 1 day. Intertidal banks are relatively stable due to the small fetch and generally slight wave energy and the moderate tidal range (approximately 1.5 m during spring tides and 1.3 m during neap tides).

Human occupation

The history of Maori settlement in the Ohiwa region dates back to about 1150 AD, when the first Maori landed at Whakatane and built a pa on Whakatane Heads. Opotiki, situated on the coast east of the Estuary was originally the largest Maori settlement in the region. There was a long history of conflict between local Maori and the European settlers in the eastern Bay of Plenty. Kutarere, on the eastern shores of Ohiwa Estuary, was used as a minor port in the late 1800s to transport goods to the larger township of Opotiki and the surrounding district.

The western end of the Ohope Spit is the site of the main permanent residential zone in the estuary catchment.

Catchment characteristics

Area

The total land area draining into the Ohiwa Estuary is approximately 186 km^2.

Geology and soils

The region surrounding the Ohiwa catchment is highly faulted. The basement rocks are described as Uruwera greywacke of the Jurassic era, consisting of banded argillite, alternating siltstones and sandstones, conglomerates and fine-grained volcanic rock. In the lowlands surrounding the Ohiwa Estuary and much of the southern catchment, Pleistocene marine sandstone with fossils, conglomerates and interbedded pumice tuffs are overlain with slightly younger non-marine conglomerates and pumice tuffs forming terraces 100 to 220 feet above sea level. These more recent deposits of fluvial silt, sand, gravel and pumice appeared around the last interglacial period. The most recent deposits are post-glacial (Holocene) undifferentiated alluvium along the river terraces, a small pocket of peat on the western estuary boundary and the accumulation of undifferentiated dune sand alongside fixed foredunes that make up the estuary spits and beach.

The soils of the lower Ohiwa Estuary catchment are described as yellow-brown loams (with brown granular clay loams from volcanic ash), which are very friable soils derived from fine-textured volcanic ash with clays rich in iron and aluminium. The upper catchment consists of steepland complexes of yellow-brown pumice soils, typically younger than the neighbouring yellow-brown loams. These soils were influenced by two volcanic ash showers from the central North Island that fell 800 and 1700 years ago. The topsoils are largely sands or sandy loams and the subsoils are rhyolite, pumice sands and gravel. The area was poor for grazing due to the cobalt deficiency, until topdressing with cobaltised superphosphate began.

Land use

The predominant land use of the Ohiwa catchment is pastoral dairy farming, making up nearly 50% of the catchment (Table A2). There are exotic forestry plantations (*Pinus radiata*) as well as relatively large discontinuous areas of secondary scrub, shrubland and native forests in the catchment, however much of the scrub and shrublands are being cleared for farming and forestry.

Significant modification of estuary margins has occurred through infilling in conjunction with various urban and rural developments. The infilling has removed some of the productive fringing vegetation, such as mangroves and wetlands, that creates a significant land-sea buffer zone, and provides ecological habitat (*i.e.* breeding, nursery and feeding areas for invertebrates, fish and birds).

Table A2: Ohiwa Estuary catchment land use

Land use	**Area (ha)**	**% Cover**
Prime pastoral	9050	48.8
Indigenous Forest	4671	25.2
Planted Forest	3419	18.4
Scrub	964	5.2
Urban	209	1.1
Coastal Wetlands	141	0.8
Urban Open Space	49	0.3
Prime Horticultural	37	0.2
Bare Ground	17	0.1
Inland Water	3	0.0
Total	18559	

Source: LCDB1 (2001)

Estuary values and uses

The majority of the land around the estuary is farmed and the small commercial fishing port and town of Ohope is located on the Ohope Spit. The estuary is popular for water-based recreation, particularly fishing, and Pacific oysters are farmed commercially in the western end of the estuary. There are picnic areas, boat-launching ramps and a golf course at the eastern end of Ohope Spit.

Daniel (1984) identifies a range of habitats in the estuary that impart high ecological value. These include the high tidal zone (with small areas of herbfield dominated by grass and rushlands), the large intertidal zone and the permanently submerged sub-tidal zone. The intertidal flats make up aproximately 70% of the estuary when exposed at low tide. There are dense areas of rushes found along the borders of the Nukuhou River, and rushlands are common in the main estuary, particularly at the upper limit of tidal reach. Mangrove communities are present below this zone in the upper intertidal areas on protected shores of the estuary. Eelgrass (*Zostera muelleri*) habitat is present outside the estuary fringes, both communities providing important feeding and shelter habitat for juvenile fish. The intertidal zone supports a variety of benthic invertebrates, including gastropods (mud snail, estuarine snail, mud flat whelk, spire shell and top shells), crabs and cockles, wedge shells and the clam *Mactra ovata*. Pacific oysters have spread to other estuary habitats outside the farmed areas. Cockles form dense beds in the low intertidal and subtidal zones of the estuary, while the coarse sands of the subtidal areas near the mouth of the estuary are good habitat for pipi and small beds of horse mussels and scallops.

Estuary inlet in Ohiwa Estuary, showing the high tidal zone

Since the estuary appears to be the southern geographical limit of mangroves in New Zealand, the estuary is of particular scientific interest with respect to the effects of global warming and potential temperature boundary migration.

The shallow, tidal channels are nursery areas for juvenile fish, such as flounder and yellow-eyed mullet, while a variety of other fish enter the estuary to feed. Eels and whitebait also use the estuary. The estuary is also an important habitat for numerous bird species, including waders and waterfowl, some of which are migratory or threatened (Daniel 1984). Daniel (1984) identifies a number of sites within the estuary that have particularly high conservation value due to the above characteristics.

Water and sediment quality

Water quality in the Nukuhou River and estuary is monitored by the Environment Bay of Plenty. The river data (old quarry site) indicates the following:

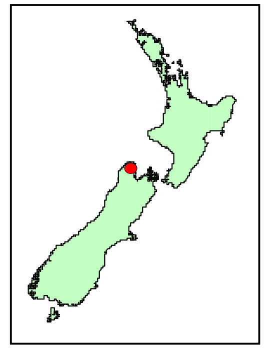
- elevated suspended solids concentrations (due to bank erosion caused by localised geology),
- consistent low water clarity (visibilities around 0.5 m to 2m) due to humic colouration,
- slightly depressed dissolved oxygen (DO) values due to biological oxygen demand (BOD_5) loads,
- elevated nitrogen, phosphorus and faecal indicator levels attributed to agricultural runoff,
- water quality scores for each variable indicate ‘poor’ or ‘degraded’ classifications.

Benthic macrofauna are monitored at a number of sites in the estuary by Environment Bay of Plenty. Results indicate no major decline in the health of benthic communities over the last 10 years (Park 2000). The estuary receives no direct point source discharges of contaminants that the authors are aware of.

Exotic plant and animal species

Introduced Pacific oysters are colonizing the main channels of the estuary and there are anecdotal reports that paddle crabs have invaded the harbour.

Appendix A 3. Ruataniwha Estuary



Location, size and estuary type

The Ruataniwha Estuary is located approximately 83 km northwest of Nelson, in Golden Bay. The estuary covers an area of ~860 ha (mainly saltmarsh, mudflat and wetland). Ruataniwha estuary is a fluvial erosion, barrier-enclosed estuary. It comprises four large barrier spits projecting southwards which creates a relatively extensive stable area within the northern area of the estuary.

Morphology and hydrology

The estuary is dominated by the influence of the sea and to a smaller extent by its major river input, the Aorere River (mean annual flow is 73 m^3/s). The River is known to rise rapidly, causing channels to overflow and damage farmland. The Aorere flows at 15 m^3/s or less for about 90% of the time, indicating that flood events may have considerable influence on estuarine characteristics.

Marine water enters from the relatively sheltered coastal embayment of Golden Bay with each tide. The maximum tidal range is 4.2 m during spring tides (with a minimum during neap tides of 2.4 m) resulting in extensive intertidal flats. Although the depths were not measured, it is anticipated that the mean depth at high water is in the 1-3 m range. The estuary is very well-flushed and drains almost completely at low water giving it a likely flushing time of less than one day. Wave energy is relatively slight due to the small fetch in the area.

Although the estuary is marine dominated, the river input is relatively high compared with many other estuaries in New Zealand of similar shapes and origins. This is depicted in the estuary area (ha) to mean freshwater inflow (m^3/s) ratio (*i.e.* the size of the river inflow in relation to the area which it can spread over). For the Ruataniwha, the ratio is approximately 19.

Human occupation

Maori settlement in the area probably dates back to at least the 1600s. The area once had a strongly fortified pa and a small Maori settlement existed on the tip of the southern sandspit. Europeans settled in the area from the 1840s and gold was discovered in the Aorere valley in 1857. Current human occupation within the Ruataniwha catchment is small, approximately 120 inhabitants.

Catchment characteristics

Area

The area of the Ruataniwha catchment is 767 km^2 with 92% of that comprising the Aorere River catchment.

Geology and soils

The catchment is dominated by steep forested regions of the block-faulted Haupiri and Wakamarama Ranges and a broad terraced valley. Major rock types include:

1. Older rocks (Cambrian 500,000 years) which have been pushed over younger rocks and in the process were overturned.
    - Buller terrane rocks, which along with Takaka terrane rocks are the oldest structural units in New Zealand. They lie to the west of the Anatoki Fault and are predominantly made up of basal Ordovician, continent-driven, quartz-rich turbidites of the Greenland Group and overlying black shale, siltstone and quartz sandstone.
    - Takaka terrane rocks containing a wide variety of structurally complex rock types (including sedimentary, metamorphic and volcanic).
2. Miocene-Cretaceous deposits of marine mudstone.
3. Recent (late Pleistocene) alluvium and terrace gravels in the main valley.

The lower Aorere valley consists of recent alluvial soils. Further up the valley the soils are gley podzols while, the upland areas are dominated by steepland podzolized yellow-brown earths, subalpine gley soils and gley podzols.

Land use

The catchment covers the mountainous area draining into the Aorere River and is dominated by native forest and scrub (Table A3). Approximately 10% of the catchment area is pastoral. There are 57 dairy farms within the catchment. Stock numbers in the valley, as determined using Agribase (2000), are 13229 dairy cattle, 6429 sheep, 1704 beef cattle and 150 deer. The Tasman District Council is responsible for environmental management of the catchment and estuary under the RMA (1991).

The major freshwater input is from the Aorere River, having a catchment of 702 km^2 with a large percentage of the catchment area draining mountainous, native forest-covered land.

Table A3: Ruataniwha Estuary catchment land use

Land use	Area (ha)	Cover (%)
Indigenous Forest	50334	65.6
Scrub	11296	14.7
Prime Pastoral	8679	11.3
Tussock	5358	7.0
Bare Ground	537	0.7
Inland Water	405	0.5
Planted Forest	50	0.1
Urban	15	0.0
Prime Horticultural	5	0.0
Coastal Wetlands	4	0.0
Total	**76681**	

Source: LCDB1 (2001).

Estuary use

The estuary has been classified as nationally important due to the presence of threatened birds such as banded rail and bittern (Davidson *et al.* 1990). The estuary also has an extensive shellfish resource and is used for commercial cockle harvesting. Because the estuary empties during each tidal cycle, it does not have a significant resident fish population (except perhaps in some permanently flooded wetland areas) but it is expected to serve as an important migratory and nursery area for a variety of fish. The estuary is important for whitebait species (Davidson *et al.* 1990).

The majority of the land around the estuary is farmed and the small commercial port of Collingwood is located at the southern end. The estuary is popular as a focal point for water-based recreation, particularly fishing. Significant modification of estuary margins poses threats to wetlands.

Water and sediment quality

The estuary receives no direct point source discharges of contaminants. The upper reaches of the river are characterised by clean waters with low nutrients and coliforms, high clarity and oxygen. During low flows the composition is similar in the lower reaches, but at times of flood flows, faecal coliforms, suspended solids, and most nutrients are elevated (Nottage 2001). Water quality in the estuary has not been monitored but it is expected to also be relatively high, particularly in times of low flow. Specific yields of various key contaminants discharged to the estuary from the Aorere catchment are given in Table A4.

Table A4: Specific yields (kg/ha/yr) for the Aorere River (Nottage 2001)

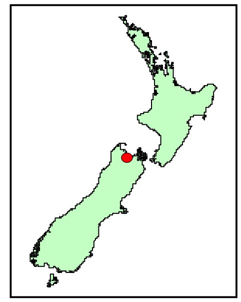
Variable	Aorere River
Total N	16.7
Nitrate-N	11.1
Ammonia-N	0.8
TP	2.5
DRP	0.5
SS	667.8

Exotic plant and animal species

Pacific oysters have colonised areas along the main channels of the estuary (Davidson *et al.* 1990).

Appendix A 4. Waimea Estuary

Background information



A bibliography of environmental information on Waimea Inlet and surrounds has been prepared by the Tasman District Council and Cawthron Institute (TDC 1998). This has been updated as part of the present report, and used to access information for the following preliminary description of the estuary.

Location, size and estuary type

Waimea Estuary is a shallow, bar-built inlet located within Tasman Bay adjacent to the city of Nelson. According to the nomenclature proposed by Hume & Herdendorf (1988), it may be classed as a fluvial erosion, barrier (island)-enclosed estuary. One of the largest in New Zealand, it has been estimated to cover a total area of 34.6 km^2, with 28.7 km^2 comprising a variety of intertidal flat habitats (primarily over mud and sand substrata). The remainder consists of subtidal areas; *e.g.* river and tidal channels (Davidson & Moffat 1990). Ten islands within the inlet, totalling approximately 296 ha, contribute to the considerable habitat heterogeneity.

Bell Island in Waimea Estuary with Nelson suburbs in the background

Morphology and hydrology

There are two tidal openings to the estuary located at opposite ends of the barrier island, Rabbit Island. Due to its broad, shallow configuration and the tidal range of up to 4.2 m, the tidal compartment of ~62 x 10^6 m^3 is largely drained with each ebbing tide resulting in a relatively rapid flushing rate. In support of this, Heath (1976) estimated the residence time for Waimea Inlet to be ~14.4 hours (or 1.2 tidal periods) as a lower limit, however somewhat longer times might be expected if we assume a partial return of inlet water with succeeding tides.

Freshwater contributions are minor in comparison to the size of the tidal compartment, resulting in a salinity range of 30-35 ppt throughout most of the estuary (Gillespie & Asher 1999). However, reduced salinities have been reported for some localised areas in the vicinity of freshwater discharge channels (Gillespie & Asher 1999). The main freshwater inflow to the estuary is via the Waimea River and its tributaries, including the Roding, Lee, Wairoa and Waiiti rivers that drain the southern and eastern catchments. The resulting freshwater discharge (annual mean flow 20.8 m^3/s), separates into a primary and a secondary channel at Rabbit Island to coincide with the two tidal openings. The primary channel, taking the majority of the flow, is presently on the Eastern side of the Island. A number of smaller streams (total mean annual flow, 0.55-0.65 m^3/s) also contribute to the total fresh water inflow.

Human occupation

Waimea Inlet and the surrounding lands have been occupied since the 1500's. A large but fluctuating Maori presence was associated with the Waimea Pa and 35 archaeological sites have been recorded, including 27 Maori midden or oven sites (Davidson & Moffat 1990).

Europeans colonised the area in the 1840's and began an intensive programme of land development, resulting in significant changes to the estuary and its surrounds (Davidson & Moffat, 1990). The present population within an 8 km radius of the Inlet is approximately 45,000.

Catchment Characteristics

Area

The total Waimea Estuary catchment area is 812 km^2.

Geology and Soils

Much of the central lower estuary catchment is relatively flat or undulating, particularly the Waimea Plain and the river valleys. However, the catchment extends south to the Gordon Range and east to encompass the eastern slopes of the Richmond and Bryant Ranges and the Dun Mountain, draining predominantly steeply sloped land. The Dun Mountain 'mineral belt' region contains ultramafic rock formations that are particularly high in metals such as copper, nickel and chromium (Grindley & Watters 1965). The composition of the estuary catchment and its soils reflect the complicated geological structure and history of the region. Most soils are characteristically of low natural fertility, however the fertile, deep, fine soils on the lower flood plain of the Waimea River are a notable exception (Chittenden *et* al. 1966). The catchment soils impart a physical (*e.g.* texture) and chemical (*e.g.* heavy metal) 'signature' to the estuary substratum.

Land use

During the period of Maori and European settlement, but primarily within the past 150 years, land use modification to the estuary margins has been significant, thereby restricting the ecological connectivity between the terrestrial and coastal sea environments. These modifications include the draining of freshwater wetlands, burning and logging of coastal native forests, urban development (domestic and industrial), rubbish disposal, and livestock grazing. The Inlet is situated in close proximity to the urban and industrial areas of Nelson, Stoke and Richmond.

Some of these uses have resulted in a loss of intertidal habitat (*e.g.* fringing mudflat and saltmarsh) through infilling, particularly on the Nelson (eastern) side of the Inlet. Owen & Sell (1985) estimate that approximately 200 ha of intertidal habitat has been removed in this way.

The greater estuary catchment is presently dominated by native bush, exotic forests and pastoral development, however a variety of other agricultural and urban uses are also represented, particularly within the lower regions (Table A5).

Table A5: Waimea Estuary catchment landuse.

Land use	**Area (ha)**	**Cover (%)**
Planted Forest	25877	31.9
Indigenous Forest	25359	31.2
Prime Pastoral	20797	25.6
Scrub	3950	4.9
Tussock	2414	3.0
Prime Horticultural	1425	1.8
Urban	645	0.8
Total	**81170***	

* Includes some minor uses not defined.
Source: LCDB1 (2001)

Estuary values and uses

Waimea Inlet is recognised as playing a significant role in the integration of terrestrial and coastal sea ecosystems; *e.g.* by providing critical habitat for a variety of plant and animal species, maintaining coastal productivity, and nourishing the marine food web. High value is placed on the

Inlet's terrestrial → wetland → coastal aquatic continuum as wildlife (*e.g.* waterfowl), fish and invertebrate habitat. The Inlet has been classed by the Department of Conservation as a wetland of National importance, one of 73 in the country. It has also been ranked as an estuary of international importance for migratory birds (Schuckard 2002). Its significance is mainly due to its large size and the potential ecological importance of its complex, heterogeneous physical and biological structure.

Estuary visual/aesthetic values are very important to the region, particularly for residential developments along the estuary margins (*e.g.* Monaco, Mapua, Bests Island) and elevated subdivisions in Nelson, Stoke and Richmond.

In view of the high ecological, biodiversity and aesthetic values placed on the Inlet, some shore/wetland walkways and reserves have been established (*e.g.* Higgs reserve, Waimea Inlet Walkway) and the estuary is of potential importance to a developing ecotourism industry. The Inlet is used for a variety of recreational pursuits, including boating, swimming, waterskiing, waterfowl shooting, and fishing (*e. g.* for whitebait, flounder, kahawai). The pressure of increasing recreational usage is seen as a particular threat to the natural character of the estuary (Davidson & Moffat 1990).

The Inlet is also used for wastewater discharge including treated sewage (Bell Island regional sewage treatment facility), and stormwaters from industrial, agricultural (horticulture, drystock farming, dairying) and urban (Stoke and Richmond) sources. Areas of Rabbit and Bell islands have been used for the land disposal of sewage sludge from the Bell Island oxidation ponds since 1993 and 1996, respectively.

Water and sediment quality

Some of the above varied uses indicate potential threats of contamination to environmental quality. Studies of faecal indicator bacteria concentrations in waters and shellfish (Gillespie & Asher 1999, 2001) indicate that the Inlet (with the exception of the immediate mixing zone down current from the Bell Island wastewater outfall) is suitable for contact recreational activities, but unsuitable for shellfish gathering for human consumption. Freshwater inflows and direct runoff from estuary margins were seen as primary contributors of bacterial contamination.

Effluent discharge from the Nelson regional sewerage facility at Bell Island may be perceived as a particular threat to the estuary environment. However, conditions for effluent discharge and composition, as well as receiving environment monitoring requirements, have been adopted, as part of the consenting process, to minimise this threat. Monitoring reports thus far conclude that, due to the ebb-tide discharge schedule and the flushing characteristics of the outfall location, enrichment effects to the estuary have been minimal (Gillespie *et al*. 2001a, b). Localised reductions in water and sediment quality in the vicinity of industrial and domestic point source discharges occurred prior to establishment of the Bell Island treatment facility. These have recovered to a more natural condition since incorporation with the regional wastewater treatment scheme in 1983 (Gillespie *et al*. 1992).

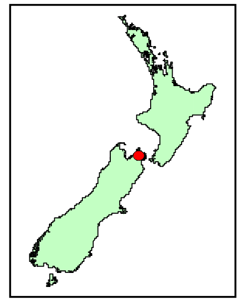
An additional threat to ecological health is perceived as a result of chemical leachates from contaminated soils. This has occurred at a Fruitgrowers Chemical industrial site bordering on the Inlet at Mapua (Woodward-Clyde (NZ) Ltd 1996). The 3.3 ha site was found to contain high levels of primarily DDT and dieldrin and both have been observed in sediments of the Mapua channel. The site is presently the subject of remedial action.

Exotic plant and animal species

The exotic saltmarsh cordgrass, *Spartina anglica* was introduced into Waimea Inlet during the 1930's through a series of intentional plantings. After a period of some 50 years it had become well established, covering > 30 ha and including several dense monospecific stands. In view of its impact on the natural character of the Inlet, a herbicide spray programme was implemented, 1986-1999, as a means of control. The spray programme was highly successful, and *Spartina* has been largely eradicated from the Inlet. Simultaneous environmental monitoring, suggested that short-term herbicide effects on native habitats were minimal (Gillespie *et al*. 1990). Although long-term effects (*e.g.* sediment redistribution and reorganisation of native habitats) are yet to be determined, areas previously colonised by *Spartina* seem to have returned to a 'natural' character (Gillespie, unpublished).

A more recent invasion by an exotic bivalve, the Pacific oyster (*Crassostrea gigas*), occurred in the Nelson region during the early 1980's (Bull 1981) and subsequently spread to Waimea Inlet within a few years. It has now become well established in a number of intertidal locations within the Inlet. The resulting oyster beds and shell banks result in localised pockets of sediment enrichment, and represent a significant departure from the natural character.

Appendix A 5. Havelock Estuary



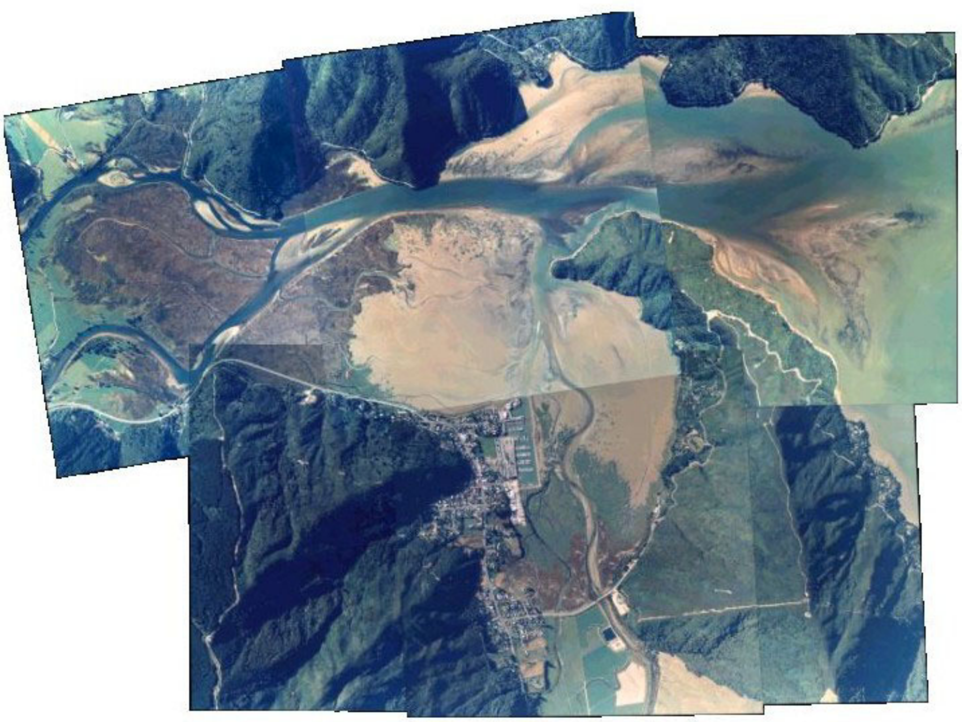
Location, size and type

The Havelock Estuary is a fluvial-erosion, headland-enclosed estuary covering an area of about 900 ha. It is located at the inner-most reach of Pelorus Sound (Marlborough Sounds), adjacent to the Havelock township.

Morphology and hydrology

The Estuary consists of two arms receiving freshwater input from separate rivers, the Kaituna River in the south and the Pelorus River in the west, which are linked by the main harbour entrance channel at low tide. The two arms of the estuarine complex are partly enclosed by a headland (Cullen Point) extending to the west.

The Estuary complex consists primarily of intertidal mud-flat and extensive saltmarsh habitats surrounded by Marlborough Sounds hill country. The largest permanent channels of the estuary are the main Pelorus River, the Pelorus flood channel and the Kaituna River.



A mosaic of aerial photos of the Havelock estuary and river channels

There is significant freshwater inflow in relation to the estuary area, resulting in an important dilution effect of the seawater which creates frequent low salinity conditions within the estuary. Tides are semi-diurnal with a maximum range of 4.2 m during spring tides and 1.5 m during neap tides. Since a majority of the estuary volume is drained with each ebbing tide, it is well-flushed, however the extension of the drowned river channel of Pelorus Sound creates an unusual pattern of estuarine hydrology in the Havelock Estuary. Headland-enclosed, fluvial-eroded estuaries in New Zealand typically have small fluvial input compared to the tidal prism and the hydrology is therefore generally dictated by tidal currents (Hume & Herdendorf 1988). However, the seawater residence times are relatively longer for some areas of Pelorus Sound, and it is probable that salinity in the region of the Havelock Estuary is reduced for extended periods of time due to the long distance from the estuary to the open sea.

The major freshwater input is from the Pelorus River (annual mean flow of 54.4 m^3/s on average (Heath 1976)), while the Kaituna contributes considerably less (0.6 m^3/s, based on only 69% of the catchment). Minor contributions occur from a number of smaller streams. Particularly during flood events and periods of elevated flow, conditions of reduced seawater salinities can extend considerably beyond the estuary mouth into Pelorus Sound.

Catchment characteristics

Area

The total estuary catchment area is an estimated 1046.6 km^2.

Geology and soils

The geologic and soil makeup of the Kaituna catchment consist largely of schist and lowland yellow/brown earths. The Pelorus catchment contains primarily greywhacke and argillite with lesser areas of basic volcanics and ultramafics. A portion of the Dun Mountain mineral belt, also within the Pelorus catchment, contains ultramafic rock formations that are particularly high in metals such as copper, nickel and chromium (Grindley & Watters 1965). Soils in the Pelorus are largely upland and podzolised yellow/brown earths and lowland yellow/brown earths.

Land use

The Havelock Estuary catchment is predominantly steeply sloped native forest, particularly in upper regions, with pastoral land (including dairy farming) in lower regions contributing approximately 13% of the land use by area (Table A6). Urban developments are minor, covering only 7% of the catchment area. In general, the catchment is less developed compared to many other New Zealand estuaries. Catchments of the two main tributaries of the estuary contrast considerably in land use. The smaller Kaituna catchment contains about 50% pasture while the Pelorus contains a larger percentage of pristine native beech/podocarp and < 10% pasture.

Table A6: Havelock estuary catchment landuse.

Land Use	Area (ha)	Cover (%)
Indigenous Forest	68247	65.2
Prime Pastoral	13475	12.9
Planted Forest	12892	12.3
Scrub	8713	8.3
Bare Ground	497	0.5
Tussock	326	0.3
Inland Water	204	0.2
Coastal Wetlands	121	0.1
Inland Wetlands	106	0.1
Urban	77	0.1
Urban Open Space	2	0.0
Total	**104660**	

Source: LCDB1 (2001)

During the period of Maori and European settlement, but primarily within the past 150 years, land use modification to the estuary margins has been significant. Residential, industrial and agricultural developments have occurred in areas bordering, and in some cases displacing, intertidal wetlands. Farm animals graze some peripheral salt marsh areas. Some areas adjacent to the township of Havelock have been filled in for industrial uses or marina and port development. Regular dredging is carried out in the main navigational channel in order to maintain access these areas.

Estuary Values and Uses

The ecological/conservation values of the Havelock Estuary are heightened by the fact that it is a significant and integral component of the greater Pelorus Sound ecosystem, and that it is by far the most extensive area of intertidal salt marsh in the Marlborough Sounds. Due to the entrainment within the drowned river valley confines of the Pelorus Sound, the physical, chemical and biological composition of outwelling waters from the Estuary can theoretically have a significant effect on a major proportion, if not the entire, Sound ecosystem. Possible follow-on effects of estuary production and nutrient processing to important mussel aquaculture growing areas in Pelorus Sound have not been evaluated, but could be significant. Estuary habitats provide feeding and/or breeding grounds for a wide variety of wetland bird species, including banded rail, Australasian bittern, oystercatcher, black swan, ducks, herons, shags, black-fronted and Caspian terns and pukeko (Davidson & Brown 2000).

Recreational uses of the estuary include boating, fishing (surf casting, flounder fishing, whitebaiting) and waterfowl shooting. The Havelock port and marina facilities service the local fishing and aquaculture vessels, and a growing number of recreational and charter boats.

Water and Sediment Quality

Due to the high freshwater inflow, the mass transport of nutrients and sediment into the estuary is considerable, particularly during periods of heavy rainfall. Thus, eutrophication (nutrient enrichment) and sedimentation are potential issues. Although nitrogen, phosphorus, suspended solids and faecal indicator bacteria concentrations are generally higher in the Kaituna River, mass transport loads are dominated by the Pelorus; *e.g.* 79, 84, 88 and 63%, respectively (Shearer 1989). Sediment loads of estuary tributary streams are perceived to have increased due to agricultural and forestry practices in the lower catchments. After periods of heavy rainfall, a visible sediment plume often extends seaward from the estuary throughout much of Pelorus Sound. Sediment accretion within the estuary is also significant, and it is particularly enhanced within the large areas of salt marsh.

Other perceived water and habitat quality issues include contaminant loads from a variety of non-point sources; *e.g.* stock grazing in estuary margins, antifoulants and hydrocarbons from onshore marina and port activities, sawdust and refuse dump leachates, agricultural pesticides.

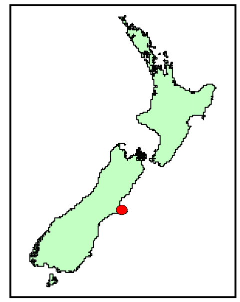
Exotic plant and animal species

The exotic saltmarsh cordgrass, *Spartina anglica* was introduced into both the Kaituna and Pelorus arms of the estuary through a series of intentional plantings, probably dating back to the 1930s. After a period of some 50 years it had become well established, covering > 50 ha, and including several dense monospecific stands with characteristic tidal creek drainage systems. These large, dense stands of *Spartina* have considerably altered the natural character and function of the estuarine ecosystem and they provide a source for spread to other growing sites in the Marlborough Sounds. Determination of an appropriate management rationale for this species will require information on its rate and direction of spread at different sites, and consideration of both the positive and negative implications (*e.g.* sediment distributions, nutrient dynamics and productivity) both within the estuary and in Pelorus Sound.

A more recent invasion by an exotic bivalve, the Pacific oyster (*Crassostrea gigas*), occurred in the Marlborough Sounds region during the late 1970's (Bull 1981) and subsequently spread to Havelock Estuary. It has now become well established in a number of intertidal locations within the estuary. The oyster beds and shell banks result in localised pockets of sediment enrichment and represent a significant departure from the natural character.

Appendix A 6. Avon-Heathcote Estuary

Background information



The majority of the background information for this section was sourced from the excellent summary reviews provided in the "Assessment of environmental effects for Christchurch wastewater discharge" (URS 2001), "The estuary – where our rivers meet the sea" (Christchurch City Council 1992) and "The ecology of the Avon-Heathcote estuary" (Knox & Kilner 1973).

Location, size and estuary type

The Avon-Heathcote Estuary is a relatively small (800 ha), bar built, intertidal inlet located adjacent to the city of Christchurch. It is a fluvial erosion, barrier enclosed estuary comprising one large barrier spit (New Brighton Spit), projecting 4 km south-eastwards towards Sumner.

Morphology and hydrology

The Avon-Heathcote Estuary is relatively shallow (mean depth 1.4 m at Mean High Water Springs) and most of its area (~ 85%) is intertidal sand and mudflats. Tides are semi-diurnal with a maximum range of 2.2 m at spring tides and 1.7 m at neap tides. Saline waters may penetrate to approximately 10 km up both the Avon and Heathcote valleys. Since a majority of the total mean tidal + freshwater inflow (~ 8.3×10^6 m^3) is drained with each ebbing tide, the estuary is well flushed, however an estimated 44% of the inflowing freshwater would be expected to return with the following tide (Knox & Kilner 1973).

The hydrological environment of the estuary is dominated by input from the sea through tidal action, and the two river inputs. Both the Avon and Heathcote Rivers are spring-fed by subsurface aquifers from the Waimakariri and upper Canterbury plains (and small streams from the Port Hills also contribute to around one third of the Heathcote River catchment). Both rivers flow through predominantly urban catchments. Mean annual flows are 1.9 and 1.0 m^3/s for the Avon and Heathcote rivers, respectively.

The shallow depth and strong tidal and wind action means that the estuary is subject to considerable vertical mixing, however salinity profiles indicate that some stratification is usually present. Detailed surveys of salinity ranges at different tidal heights (Estcourt 1962, Knox & Kilner 1973) suggest significant freshwater influences throughout the estuary but particularly within the upper Avon and Heathcote arms. Salinities of 24-33 ppt are the norm for sites near the tidal opening while reduced salinities <10 ppt are common at sites >3 km inland from the estuary mouth. Sites in the upper river arms range from full freshwater to about 24 ppt.

Human occupation

People have lived beside the estuary for at least 600-700 years. The early Maori history of the area is discussed in CCC (1992). Many Maori artifacts, burial sites and middens have been found in the area. Maori kaika (settlements) were located at Rae Kura (near Redcliffs), Te Kai o te Karoro (near Brighton) and Tauhinu Korokio near the Heathcote River mouth. The estuary, which was once much larger than it is at present, due to the surrounding wetland areas that have subsequently been drained, was a highly valued food gathering site for South Island Maori who harvested eels (tuna), lamprey (karakara), whitebait (inanga) and flounder (patiki). Cockles, pipis and other molluscs were also collected. In pre-European times the extensive wetlands bordering the estuary contained healthy populations of wetland birds (*e.g.* bitterns, rails, fernbirds and black stilts). With European settlement, beginning in the 1840s, the estuary margins were rapidly modified during subsequent urban development.

Drainage of wetlands resulted in a shift in the existing bird communities to include new species such as spur-winged plovers, welcome swallows, white-faced heron and numerous introduced songbirds.

The estuary was an important port of call for many ships until the early 1900s, when rapid siltation made such activities impossible. The Christchurch wastewater treatment plant and oxidation ponds were developed on sand dunes that originally formed the western edge of the estuary. The land/sea interface of much of the estuary now has a hard, man-made border.

Catchment characteristics

Area

The total catchment area of the estuary is ~188 km^2.

Geology and soils

The estuary basin is a tiny remnant of the arm of the sea that once separated Banks Peninsula from the Southern Alps. This arm was gradually filled by material eroded from the mountains to form the Canterbury Plains. The Avon and Heathcote Rivers originally opened separately into the resulting bay at the eastern end of the original arm. Long-shore currents transported sediment from the Waimakariri, forming a sand spit to the south, pushing the outlet of the Avon River southwards, until the bay was cut off from the open sea but for a narrow channel confined against the volcanic mass of the Port Hills (Knox & Kilner 1973).

The geology of the catchment of the Avon-Heathcote Estuary is varied, based on the two distinct regions that dominate. Banks Peninsula is made of old basalt volcanic rocks from the Upper Tertiary period, while the plains of Canterbury consist of the quaternary gravels and stream alluvium of the lower floodplains and terraces, washed down by the rivers and glaciers. The foundation of the Southern Alps is Pre-Cretaceous greywacke, a hard and close-joining rock type. The Canterbury downland has been eroded from softer sedimentary Tertiary rocks (mainly calcareous limestone and chalk) that overlay the older greywacke basement.

The soils overlaying the northern slopes of the Port Hills are described as mainly southern yellow-grey earths, with steepland red-brown granular loams and brown clays (volcanic soils rich in iron and aluminium) over much of Banks Peninsula, related to the underlying volcanic rock. They are friable clays with high iron content, able to fix soluble phosphates but leach and lose fertility easily. Soils of the Port Hills are prone to erosion as they contain fine loess soil derived from wind-deposited glacial outwash, lying on older volcanic rock. Young yellow-brown sands make up the Brighton spit and coastal areas of Pegasus Bay, and Christchurch and much of lower Canterbury are built on the recently accumulated alluvial soils and gley soils with a high groundwater. The layers of gravel, silt and sand mean that rain and river water seeps rapidly into the gravel, forming freshwater aquifers that feed the Avon, Heathcote and Styx rivers. The upper catchment containing the Canterbury foothills is predominantly yellow-grey stony soils formed under tussock grassland. The soils are seaonally dry, characterized by greyish weak-structured loamy topsoil in a shallow layer over gravel.

Land use

During the period of Maori and European settlement, but primarily within the past 150 years, land use modification to the estuary catchment and margins has been considerable, thereby restricting the ecological connectivity between the terrestrial and coastal sea environments. These modifications include the draining of freshwater wetlands and the burning and logging of coastal native forests to make way for urban development (domestic and industrial). As a result, significant changes have occurred in the characteristics, relative proportions and function of the various intertidal habitats within the estuary. These changes (1850s -1970s) are discussed by Knox and Kilner 1973. Some of these modifications have resulted in a loss of intertidal habitat (*e. g*. particularly fringing mudflat and saltmarsh) through infilling.

The Avon-Heathcote Estuary bordered by Christchurch suburbs and the Port Hills.

The inlet is situated in close proximity to the urban and industrial areas that now constitute more than 50% of the total catchment area (Table A7). A lower but significant proportion of the catchment is used for livestock grazing.

Table A7: Avon-Heathcote Estuary catchment landuse.

Land use	Area (ha)	Cover (%)
Urban	10512.0	56.0
Prime Pastoral	5050.63	26.9
Urban Open Space	1225.1	6.5
Tussock	591.6	3.2
Planted Forest	579.2	3.1
Inland Water	322.6	1.7
Scrub	276.5	1.5
Prime Horticultural	189.3	1.0
Indigenous Forest	22.7	0.1
Bare Ground	13.15	0.1
Total	**18782.6**	

Source: LCDB1 (2001)

The Estuary Bed

Physical characteristics

In general, the estuary bed is composed of mixtures of coarse shell fragments, sands and fine silt and clay. Sediment organic contents are closely associated with the distribution of the silt-clay fraction. The sediments around the river mouths are relatively muddy, and an extensive area of muddy sediments also occurs in front of the Christchurch Wastewater Treatment Plant (CWTP) oxidation ponds. In other areas, and particularly near the estuary mouth, the sediments are dominated by sands.

Biological characteristics

The estuary bed supports a diverse array of plant and animals.

Plant life includes microalgae, macroalgae, eelgrass and marginal rushes, grasses, sedges and herbfields.

The benthic invertebrate community of the tidal flats has been divided into three main groups based on environmental gradients (Marsden 2000):

1. River deposition zones: Sediments near the mouths of the two rivers contain high densities of deposit-feeding mud-snail and comparatively small numbers of polychaetes.
2. Oxidation pond zone: Sites immediately adjacent to the oxidation pond discharges contain fine, muddy sediments with a high organic content. They are dominated by large densities of organic enrichment-tolerant polychaetes (*Boccardia polybranchia* and *Scolecolepides benhami*) and moderate densities of cockles and other bivalve molluscs.
3. Mid-estuary, bivalve-dominated, zones: Sites in the mid-reaches of the estuary with sandier sediments contained a very large biomass of cockles and the small wedge shell, *Tellina liliana*.

Thirty-four fish species have been recorded in the estuary (James 1999). Many are not permanent residents, but spend only part of their life cycle in the estuary. They include seasonal species (*e.g*. whitebait), permanent species (*e.g*. triplefins, cockabullies, spotties and rockfish), species that spend their juvenile stages in the estuary but migrate freely between the estuary and the sea as adults (*e.g*. flounder and mullet), transitory marine species (*e.g*. kahawai, red cod, barracouta, red gurnard) and migratory species (*e.g*. eel, trout, lamprey).

Bird communities that frequent estuary habitats include ducks, geese, swans, gulls, terns, shags/cormorants, pukeko, swallows, herons, spoonbills and kingfisher.

Estuary values and uses

The Avon-Heathcote estuary is a significant social and recreational resource to the large urban population that lives on its doorstep. It is also an important scientific and educational resource which has provided subjects/topics for numerous Canterbury University student projects and theses. Due to its prominent and accessible position in a highly populated area, the aesthetic values of the estuary are considerable. A system of walkways and reserves has been established to help preserve these values.

Estuary-based activities include fishing, netting, kayaking, birdwatching, picnicking, power boating, rowing, running, school group visits, shellfish gathering, sunbathing, surfing, swimming, wind surfing, walking, volleyball, and yachting (URS 2001).

Other significant, but conflicting, uses of the estuary relate to the close proximity of urban (domestic and industrial) developments, which have altered shore margin and intertidal habitats. The most important of these is the presently existing discharge of 130,000-160,000 m^3 per day of wastewaters from the CWTP.

Considerable value is attached to the diverse biological resources that are linked with the productive estuarine habitats. The estuary and the oxidation ponds, together, are recognised as outstanding wildlife areas of national and, arguably, international importance, primarily due to the varied birdlife that they support (CCC 1992, Sagar 2000). Nutrient enrichment from the CWTP has likely enhanced the value of the estuary with respect to the productivity of some bird species.

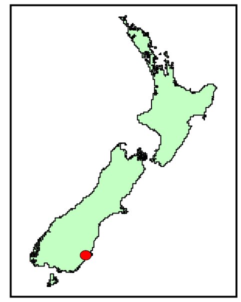
Water and sediment quality

Some estuary-based activities (*e.g.* fishing, swimming, and shellfish gathering, in particular) have been seriously degraded, curtailed or precluded by nutrient enrichment and/or bacteriological and chemical contamination associated with conflicting uses (*e.g.* urban sewer overflows, stormwater and wastewater discharges, faecal contamination from birdlife). The major contaminants include nutrients, bacterial and viral pathogens, heavy metals and potentially toxic organics. Sediment loading can also affect water quality; either through associated contaminants or by physical mechanisms that reduce clarity or inhibit biological activity on the seabed.

Urban inputs of nutrients have increased the overall productivity of the estuary to levels where nuisance growths of micro and macroalgae are common. The sediments near the oxidation pond outlets contain elevated concentrations of nutrients and support dense growths of macroalgae. The intertidal flats have a history of blooms of macroalgae involving species of *Ulva* (sea lettuce), *Gracilaria* and *Enteromorpha*. Periodically, detached macroalgae form large drifting mats that settle and decompose in areas of poorer circulation. The area of mudflats between the CWTP oxidation ponds and the Heathcote River is particularly prone to such deposition.

Since 1974, treated wastewater (which is coloured green as a result of elevated microalgal concentrations) from the oxidation ponds has been released into the estuary only after high tide, when it mixes more rapidly with seawater. Tracer studies indicate that at least 45% of the released wastewater returns into the estuary on the next incoming tide (Lincoln Environmental 1994). The CWTP wastewater contributes around 90% of the daily nitrogen input and 98% of the phosphorus input into the estuary.

Appendix A 7. Kaikorai Estuary



Location, size and estuary type

The Kaikorai Estuary is a small (< 200 ha) shallow estuary located 10 km to the southwest of central Dunedin.

Morphology and hydrology

The estuary was formed from a drowned river valley approximately 6,000-12,000 years ago during the last period of sea-level rise. As the sea-level rose (approximately 2-3 m over present levels), it inundated the Kaikorai Stream and valley, which drains the hills to the southwest of Dunedin. Since approximately 4,000 years ago, the sea-level has gradually dropped to its present level. About 100 years ago a sand bar formed where the mouth of the estuary is today. The effect of the sand bar has been to trap the incoming sediment in the estuary, causing it to silt up. Wilson (1989) indicated that this process of bar building and silting up may have occurred during the geological past and he suggests that a core sample from the estuary may reveal distinctive sedimentary patterns associated with siltation.

Because the Kaikorai Estuary is relatively small and the bed is approximately 1 m higher than sea level, the tidal influence of high salinity seawater is limited. For example, during a low rainfall period (late June 2000) with the mouth open, the salinity in the lower estuary was 3.9 parts per thousand (ppt) at low water and 23 ppt (*i.e.* 70% seawater) at high water. However, on other occasions when the mouth has been blocked, the salinity at the lower site is expected to be much lower. The Otago Regional Council have recorded salinity at the lower estuary on approximately 13 occasions between 1983 and 2000 (range 0.1 – 16 ppt). The state of the estuary mouth or tidal height was not recorded on these occasions.

The impact of sand bar formation and periodic mouth closure has led to rapid siltation within the estuary. The source of the silts has been attributed to the local loessial deposits. The resulting effect has been to limit the tidal input of water such that the estuary can now be categorised as micro-tidal (tidal range 1 m) with fast moving currents confined to the main channel and tributaries. The estuary is now dominated by shallow mudflat habitat which acts as an extremely good trap for both marine and land-sourced sediments. This is helped by the fact that the estuary is very exposed to the wind, particularly from the southwest, which pushes up the estuary. This produces turbulence in the shallow water and surface sediments. Wilson (1989) undertook sediment analyses to show that the Kaikorai Estuary sediments are exposed to "violent hydrodynamic conditions". In relation to sediment transport and deposition, such impacts lead to greater retention of fine silts.

Wilson (1989) undertook grain size analyses on surficial sediments from 4 sites in the Kaikorai Estuary. The results indicate two main fractions, a poorly sorted fine sand and a poorly sorted medium silt. Sediment transects near the main channel in the middle and upper estuary were silt-dominated sites (51-69% silt, 31-49% sand). A mid estuary transect closer to the westward shore was more sandy (67% sand, 33% silt). The fact that all the samples exhibited very similar grain-size distributions indicated that:

- the estuary was well-mixed
- there was a constant supply of sediment

The data indicated that the source of the sand was primarily from the beach and the silt from the loessial cover of the Kaikorai catchment.

The major freshwater input to the estuary is from the Kaikorai Stream (12 km long, lowest recorded flow is 0.024 m^3/s, mean annual flow is 0.318 m^3/s with approximately 50% of this flow resulting from overflow from the Mt Grand water treatment station. Abbots Creek is the other major tributary to the head of the estuary.

Human occupation

Kaikorai (Kaikarae) was known to the earliest of the presently known people to inhabit Te Waipounamu, the South Island (the Waitaha, Kati-Mamoe and Kai-Tahu). An old settlement near the mouth of the river relied heavily on food resources in the catchment area. The estuary was an important source of freshwater kai, eels and flax. This area was also on the pathway of the old trails south from Otakou on the Otago Peninsula.

James Cook discovered and explored the Otago coast in the late 1700's, and European and American sealers and whalers soon followed. At this time, the estuary was surrounded by native bush catchment and the estuary was covered with native flaxes and rushes. During the 1800's much of the catchment was cleared for agriculture and urban development. In addition, major drainage works were undertaken within the estuary to reclaim land for farming purposes, and later for a golf course, two landfills and a wastewater treatment plant. These reclamations have reduced the estuary area by approximately one third. In addition to the pastoral use of land, several industries were established in the early 1870's. These included a brick works, a flax mill and mining of coal, sand and gold.

During the 1850's and 60's shallow draft ships were able to negotiate their way up the estuary as far as the Main South Road. Since the sandbar formed at the mouth of the estuary and the estuary began to silt up, this has no longer been possible. Now, at low water, almost the entire estuary is less than 70cm deep.

Catchment characteristics

Area

The total catchment area of the estuary is ~ 55 km^2.

Geology and soils

The Haast Schist basement rock of the Dunedin region (Wilson 1989) is approximately 300 million years old. During the Tertiary Period (20-60 million years ago) the schist was overlain with a 500m thick wedge of marine sediments (breccia, sandstone and limestone). The marine sediment rock type immediately below and outcropping around the estuary is Abbotsford formation (including mudstones, sandstones, siltstones with diatomaceous and carbonaceous layers) (McMillan 1983). Taratu formation outcrops on the western side of the estuary and is a conglomerate consisting of quartz fragments and pebbles. The conglomerate has been mined for alluvial gold with little success.

The catchment of the Kaikorai estuary also has a number of volcanic rock types, 5-24 million years old, originating from the Dunedin Volcano of East Otago.

Much later, during the cold Quaternary Period (approximately 10,000-2 million years ago), the lowlands were partly covered with glacial outwash gravels and a mantle of loess. This is apparent in the Pleistocene terrace deposits which form many of the flat areas immediately surrounding the estuary. The terraces consist mainly of glauconitic quartz sand and volcanic cobbles, with minor fragments of Haast Schist. The entire area of the catchment is covered by loess deposits ranging in thickness from 400 mm on the rolling hills surrounding the estuary to 1800 mm on the land near sea level.

Soils, which have formed on the loessial deposits, tend to have high cation exchange capacities and also high nutrient levels. In contrast, soils which have formed on the Recent sand dunes around the Waldronville area (immediately to the east of the estuary) have low cation exchange capacity values.

The immediate sub-surface sediments of the estuary were investigated during the 1990's in association with the two landfill developments flanking each side of the upper reaches of the estuary. The thickness of alluvium (clayey silts, silts, sandy silts and sands) measured at these locations varied from 3.7 to more than 15 m (Beca Steven 1993).

Land use

Catchment land use characteristics are described in Table A8. The dominant uses are grassland pasture (54%), urban open space (21%) with scrub and native and planted forest contributing 22%.

Industrial sites have traditionally been, and still are, confined to areas bordering the Kaikorai Stream and the upper estuary. There is now extensive development of lifestyle blocks in the agricultural land around the estuary. Two major landfills have been established on the estuary margin.

Table A8: Kaikorai Estuary catchment landuse

Land Use	Area (ha)	Cover (%)
Prime Pastoral	2927	53.5
Urban Open Space	1135	20.8
Scrub	517	9.5
Indigenous Forest	427	7.8
Planted Forrest	260	4.8
Coastal Wetlands	114	2.1
Bare Ground	60	1.1
Tussock	18	0.3
Inland Wetlands	10	0.2
Total	**5468**	

Source: LCDB1 (2001)

Water and sediment quality

Concern for water quality within the Kaikorai catchment has existed for more than 100 years. Attention has centered on the estuary which has improved in recent years but currently still shows signs of a degraded ecosystem, typified by nutrient enriched water and sediments, algal blooms, and anoxic sediments. Water quality problems have most likely been exacerbated by infilling and bank encroachment, periodic mouth closure, channeling of tributaries, past spills and point and non-point source contaminant entry from a significantly modified catchment. A review of the sources of contaminants to the estuary (Ryder 1994) indicated that nutrients, waterborne pathogens and heavy metals were the contaminants of greatest concern. A study of sediment geochemistry (Wilson 1989) showed potentially toxic levels of lead and zinc in the estuary sediments.

Sources of Contaminants

Contaminants enter the Kaikorai from a number of sources. These include:

- periodic pollution events (mainly historical) resulting from industrial discharges and spills,
- sewage and urban stormwater discharges,
- runoff from agricultural and forestry activities,
- landfill leachate and wind-blown debris,
- mining runoff,
- discharge of excess water from Mt Grand water treatment plant at the head of the catchment.

Contaminants include:

- potentially toxic chemicals such as heavy metals, ammonia, and complex organic chemicals (*e.g*. pesticides, polycyclic aromatic hydrocarbons (PAHs)),
- oxygen demanding substances (e.g. decaying algae, human and animal faeces, ammonia, sulphides),
- plant nutrients (*e.g*. phosphorus and nitrogen),
- waterborne pathogens
- sediment

Estuary values and uses

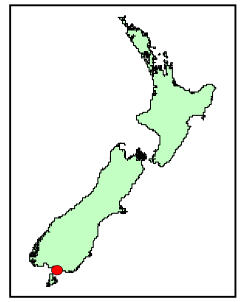
The estuary provides habitat for a large variety of wetland bird species (Beca Steven 1993). Within the estuary there are 4 distinct habitats which provide for their different needs: the upper estuary rushlands, the marshland herbfields, the lagoon proper and the marginal vegetation. The predominant species groups in order of importance are waterfowl, gulls and waders. Compared with other estuaries in the region it has a large and diverse bird population.

Historical information on fishlife and benthic invertebrates in the estuary, although very limited, indicates that species diversity is relatively low. Fish species recorded as present in the estuary include flounder, mullet, whitebait, eel and brown trout. In relation to benthic invertebrates, the majority of the estuary is dominated by small, short-lived 'opportunistic' species (tolerant to organic enrichment and freshwater) such as chironomids, oligochaetes and amphipods. Larger surface deposit feeders (*Amphibola* and crabs) were present in low numbers in the lower portion of the estuary.

Studies of phytoplankton and benthic microalgae have not been undertaken in the estuary but they are likely to contribute significantly to photosynthetic production. Rooted plants are found throughout the estuary margins but cover has seriously declined since European times. They show a strong gradient up valley from salt marshes to freshwater swamps. The estuary is of botanical interest because plant species and communities are diverse, it is located close to Dunedin, it provides varied habitat for the area's bird population, it is representative of lagoon type botany, some parts are relatively unaltered botanically and it has scenic value.

A view of the Kaikorai Estuary

Appendix A 8. New River Estuary



Location, size and estuary type

The New River Estuary is a fluvial erosion, barrier enclosed estuary located adjacent to the city of Invercargill, in the southern region of the South Island. It is bounded by one large barrier spit projecting eastwards towards Bluff enclosing an area of approximately 3500 ha.

Morphology and hydrology

The New River Estuary has an average depth of 3-4 metres.

The major river input into the New River Estuary is from the Oreti River (42 m^3/s, catchment area 3400 km^2), which also includes the flow of the Makarewa River (16 m^3/s). Additional lesser inputs come from the Waihopai River 3 m^3/s, and several smaller steams.

Human occupation

Maori settlement (which could have occurred as early as the 12^{th} century) in the Oreti catchment was concentrated around the New River Estuary, principally in the two kaika (villages), one at Omaui and the other at Oue. Numerous others have been identified, but these are considered to be camping places which were occupied for a short time until local stocks of eel, whitebait or shellfish declined. In 1850 Pakeha observers estimated the population of the two kaika to be about 20 each (Chandler 1977). Oue had been abandoned by 1862 and Omaui retained some inhabitants until 1880. Special spiritual value is placed on Omaui as it is the location where Maui stood to pull Stewart Island.

In 1770 Cook visited the South and his subsequent reports attracted a host of sealers and later whalers. Two whaling stations were established at New River in 1836, one at Omaui and the other at Oue. Gradually the agricultural potential of the Southland area was recognised with accompanying effects on the estuary as a result of extensive drainage, clearing, reclamation, flood protection, stocking and urban development works. The New River Estuary was once the major trading port of Southland but today pleasure craft have difficulty in negotiating the channels.

Catchment characteristics

Area

The New River Estuary has the third largest catchment in Southland (3950 km^2).

Geology and soils

The rocks of the estuary catchment have a relatively complicated geological and climatic setting. The intensely folded and uplifted rocks of the Southland syncline (greywacke, basaltic tuffs, diorite, gabbro etc) are wedged between the old hard Fiordland rocks and the huge block of softer and younger Otago schists. During the Tertiary period the lower-lying parts of the syncline were filled with younger sediments (limestones, mudstones and sandstones) and associated lignites. Much later in the cold late Quaternary period, the lowlands were partly covered with glacial outwash gravels and mantled with loess. The basement rocks of the syncline dictate the direction of flow of the major river systems in the catchment. The Oreti River flows through a gap in the syncline near Dipton. The rocks of the New River Estuary catchment can be divide into four broad groupings:

1. The late Paleozoic basic and plutonic volcanics and ultramafites of the Livingston and Red Mountains.
2. The Mesozoic geosynclinal rocks of the Taringatura and Hokonui Hills, and North Range.
3. The Tertiary sedimentary rocks of the Hedgehope and Browns area.
4. The quaternary gravels and stream alluvium of the lower floodplains and terraces.

In general the soils that have developed in the catchment are weakly to moderately acid and consequently tend to leach certain chemicals easily (particularly plant nutrients). This is generally managed artificially with the addition of fertilizer and lime to farmlands. The soils of the catchment have developed in a relatively moist climate. They are mainly of the Yellow-Brown Earth group (or related stony soils) compared with the dense gley soils which predominate on lowlands to the north. Southern recent soils derived from alluvial silts from Tertiary sediments, greywackes and loess dominate the Southland Plains area.

Land use

The majority of the New River catchment (65%) is used for stock grazing while native forests, tussock, planted forests and scrub cover comprises 34% (Table A9). The Oreti River catchment (3400 km^2), which comprises about 97% of the New River Estuary catchment, consists of high country tussock lands in the upper reaches and in the middle and lower reaches it drains heavily stocked sheep, cattle and deer country and the gradient flattens considerably. The river becomes tidal in the lower 20 kilometres. The Waihopai River catchment is almost wholly pasture or cultivated land. Prior to European settlement, most of this land was wet and swampy. Extensive drainage, flood control and channel clearance activities have been undertaken to convert it to productive farmland.

Invercargill City, with a population of approximately 50,000 is situated adjacent to the north-eastern shore of the Waihopai Arm.

Table A9: New River Estuary catchment landuse

Land Use	Area (ha)	Cover (%)
Prime Pastoral	226011	64.5
Indigenous Forest	41878	12.0
Tussock	33318	9.5
Planted Forest	20118	5.7
Scrub	15392	4.4
Bare Ground	9894	2.8
Inland Wetlands	2499	0.7
Urban	530	0.2
Inland Water	320	0.1
Urban Open Space	157	0.0
Mines Dumps	101	0.0
Prime Horticultural	71	0.0
Coastal Wetlands	0.2	0.0
Total	**350290**	

Source: LCDB1 (2001)

Estuary Values and Uses

The importance of the estuary lies in its close proximity to Invercargill. It is used for a variety of organised club activities (power boating, water skiing, rowing, sea scouts, triathalons, ornithological groups, fishing and whitebaiting). Bird study by professional, amateur and school groups is popular. Hunting of waterfowl in the open season is a traditional activity in one of the largest areas to which the public retain free access.

The estuary is Southland's most important feeding area for waders and other water birds (74 species recorded from the area). High numbers of migrants (Eastern bar-tailed godwits, South-Island pied oyster catchers, turnstones and knots) use the estuary and NZ and banded dotterel (both threatened NZ migrants) are frequent visitors (Hare *et al*. 1990). Exceptionally high numbers of waterfowl occur around the city landfill.

The estuary and lower Oreti River support a wide range of resident and migratory fish species (Sutton 1977), including flounders, sole, eel, lamprey, mullet, smelt, whitebait, trout, torrent fish, stargazer and globefish. It provides extensive rearing and spawning habitat for marine and freshwater species.

Several small areas of the estuary maintain a natural state and are representative of the districts lowland vegetation.

Water and Sediment Quality

Trophic Status

A recent review of the trophic status of the New River Estuary (Robertson 2001) indicated the following.

1. The New River Estuary receives high loadings of nitrogen and phosphorus from both point and non-point sources (Tables A10 and A11). Although non point sources are the major contributor, the Invercargill wastewater discharge is significant, and it may be more significant as a localised source of bioavailable nitrogen at times of low river flow.
2. As a consequence of the elevated nutrient loadings, the nitrogen and phosphorus concentrations within the estuary generally exceed theoretical guideline levels above which phytoplankton and/or macroalgal (*e.g.* sea lettuce) growth problems may occur.
3. Despite exceedance of low risk guideline levels, observations indicate that the New River Estuary is not eutrophic but is in the medium or mesotrophic stage of the eutrophication process. This results in a generally productive ecology with elevated phytoplankton concentrations, localised macroalgal blooms and anoxic sediments. At this stage, the estuary has not reached a widespread eutrophic status but does include localised areas that are eutrophic (*e.g.* landfill lagoon area).
4. The major reason for the absence of widespread nuisance plant growths in the estuary is that factors other than nutrients are likely to be limiting phytoplankton and macroalgal growth. These other factors include the short residence time of the estuary (for phytoplankton) and a combination of the absence of suitable attachment sites, strong flushing, grazing pressure and low water clarity. Such factors likely contributed to the observed absence of nuisance plant growth in the vicinity of the Invercargill City Council (ICC) wastewater outfall at Clifton.

Table A10: Non-point sources of pollution into the New River Estuary

Non-point sources	Pollutants	Reference
Agricultural inputs and primary industry	Nutrients, faecal coliforms, SS, dissolved solids (DS), pesticides (in some situations)	Robertson (1993), Ryder (1995)

Point-source discharges

Table A11: Point sources of pollution into the New River Estuary

Point Sources	Pollutants	Reference
Meat processing plants (x2)	Faecal micro-organisms	Robertson (1993)
Abattoir, tannery, wool scours (x2)	Suspended solids (SS)	Ryder (1995)
Small community sewage scheme (Otarara, Winton, Lumsden, Browns)	Organic matter	
	Inorganic nutrients	
Large sewage scheme (servicing Invercargill)	Metals	
Small private sewage schemes	Trace organic compounds	
Fish processors		
Dairy shed wastes		
Land drainage water		
Gravel washing plants		
Urban stormwater		
A large municipal landfill (Waihopai Arm of estuary)		

Contaminant sources

Contaminant mass loads to the Oreti catchment and estuary are estimated in Robertson (1993). The estimates indicate that the major sources of suspended sediment and nutrients are likely to be from non-point agricultural runoff but significant loadings of nutrients are also contributed from freezing works discharges. The Invercargill City treated wastewater discharge was a major contributor of readily oxidisable organic matter and faecal coliforms, and a significant contributor of nutrients. The discharge resulted in localised symptoms of organic enrichment, however there was no evidence of potentially toxic contaminants (Robertson & Jensen 2000). Mass loads of sediments, nutrients and oxygen-demanding substances to the estuary from Invercargill's urban stormwater (Ryder 1993) was estimated to be considerably less than contributions from the rural catchment, particularly from the Waihopai River. However, urban stormwater was identified as the major input of potentially toxic hydrocarbons and metals (*i.e.* nickel and lead).

The ICC landfill leachate discharges to a lagoon created in the estuary basin of the Waihopai Arm and subsequently into the estuary proper. This is recognised as an additional source of localised comtamination in terms of nutrient enrichment and waterborne disease risk.

Exotic plant and animal species

The invasive saltmarsh cordgrass, *Spartina anglica*, was first introduced into the estuary in 1930 (Lee & Partridge 1983) and subsequently spread to cover large monospecific stands. It has been viewed as a threat to the natural character and ecology of the estuary and therefore serious attempts have been made to control it. In spite of this, *Spartina* currently covers an area of > 100 ha and has the potential to continue to expand to cover increasing areas of the estuary.

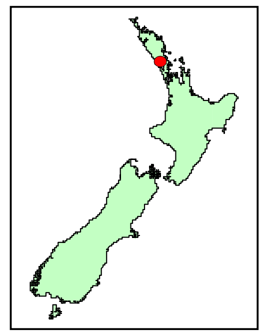
Spartina in the New River Estuary

APPENDIX B: BROAD-SCALE HABITAT MAPPING[1]

Appendix B 1: Summary of the broad-scale habitat mapping characteristics

B.1.1. Otamatea Arm

The survey of habitats in the Otamatea Arm of the Kaipara Estuary (see summary Figure A1 and detailed results in Table A12) indicated a narrow range of intertidal habitat types dominated by unvegetated substrate covering 40% of the estuary area (primarily very soft mud). The other extensive habitats were mangrove scrubland, covering nearly 20% of the estuary (330 ha), and oyster shellfish beds covering 10% (165 ha) of the total. Other minor habitat included small areas of rush and grassland. There was a very large extent of subtidal water in the Otamatea Arm, permanently covering around 40% of the total estuary area. The habitat maps of Otamatea Arm are presented in Figures A2 and A3.



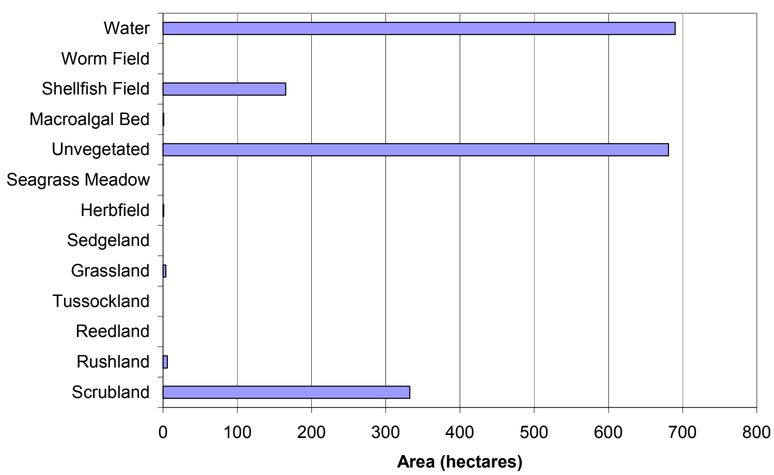


Figure A1: The area of different habitats in the Otamatea Arm of the Kaipara Estuary

[1] Broad-scale GIS mapping information is provided on the CD that accompanies this document.

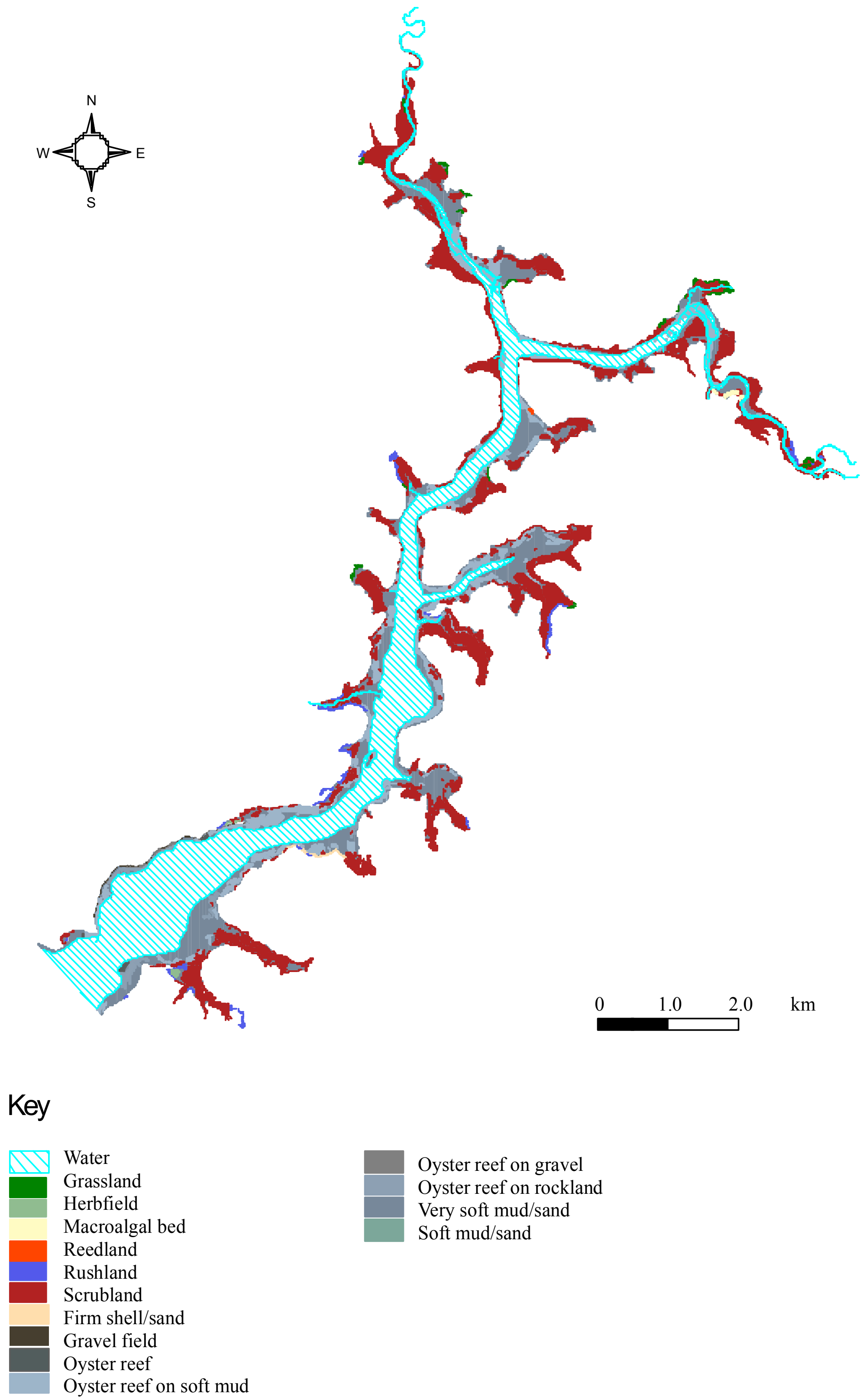


Figure A2: Otamatea Arm – Map structural class habitat

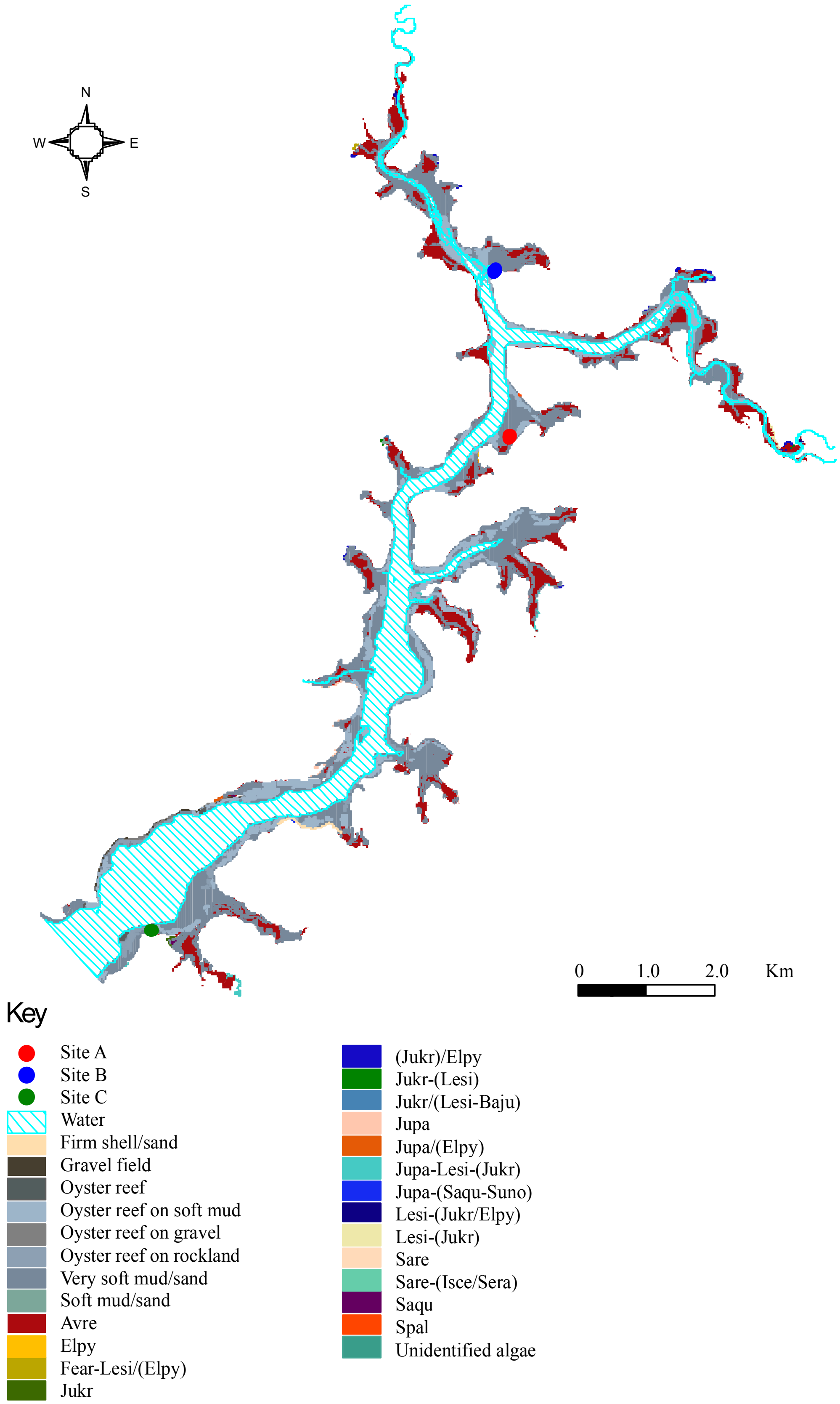
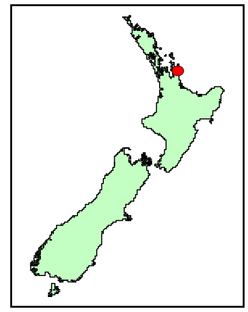


Figure A3: Otamatea Arm – Map of dominant cover habitat

Table A12: The broad-scale details of the habitat mapping of the Otamatea Arm

Habitat Groupings	Area (hectares)	% Total Area
Scrubland	332.45	19.37%
Avicennia marina var *resinifera*	332.45	19.37%
Rushland	5.72	0.33%
Juncus kraussii	1.17	0.07%
Juncus pallidus	1.86	0.11%
Leptocarpus similis	1.11	0.06%
Juncus pallidus - Leptocarpus similis	1.45	0.08%
Leptocarpus similis - Festuca arundinacea	0.14	0.01%
Reedland	0.26	0.02%
Spartina alterniflora	0.26	0.02%
Grassland	3.61	0.21%
Elytrigia pycnanpha	3.61	0.21%
Herbfield	0.91	0.05%
Sarcocornia quinqueflora	0.88	0.05%
Samolus repens	0.08	0.01%
Unvegetated	680.97	39.67%
Gravel Field	4.12	0.24%
Firm Shell/Sand	0.87	0.05%
Rockland	13.50	0.79%
Soft Mud/Sand	0.11	0.01%
Very Soft Mud/Sand	662.38	38.59%
Macroalgal Bed	0.96	0.06%
Unidentified	0.96	0.06%
Shellfish Field	165.22	9.63%
Oyster Field	165.22	9.63%
Water	690.06	40.20%
Total Area Of Estuary (ha)	**1,716.41**	

B.1.2. Whangamata Estuary



The broad-scale survey of intertidal habitats in the Whangamata Estuary (see summary Figure A4 and detailed results in Table A13) indicated a relatively narrow range of habitats dominated by unvegetated substrate, mangrove scrubland and seagrass (eelgrass, *Zostera* sp.). The unvegetated habitat covered ~ 56% of the estuary area, and consisted of various mud/sand substrate types. The mangrove scrubland covered 22% of the estuary (102 ha) and eelgrass beds extended over 13% (60 ha). Other habitat included small areas of rushland, tussockland and herbfield. In Figure A4, the information generated from the habitat maps of the present study (Figures A5 and A6) is compared with historical maps from 1944 (Figure A7) and 1965 (Figure A8). The changes in relative proportions of mangrove and eelgrass are evident over time, as the mangrove habitat has expanded and area of eelgrass has declined.

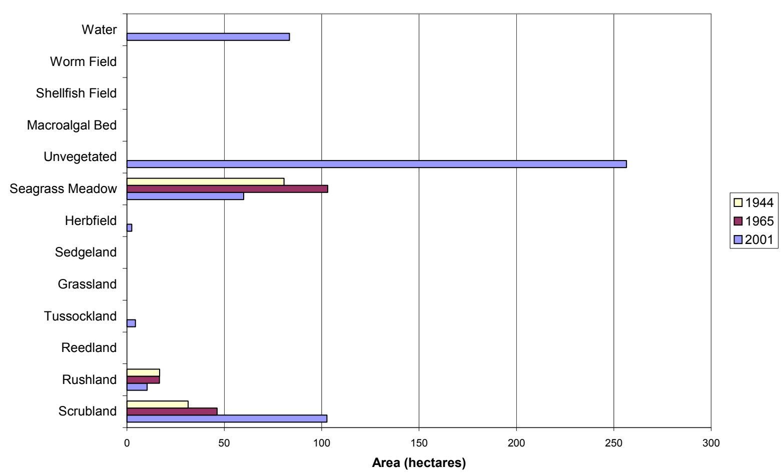


Figure A4: The area of different habitats of the Whangamata Estuary, showing the results from the present study and historical studies.

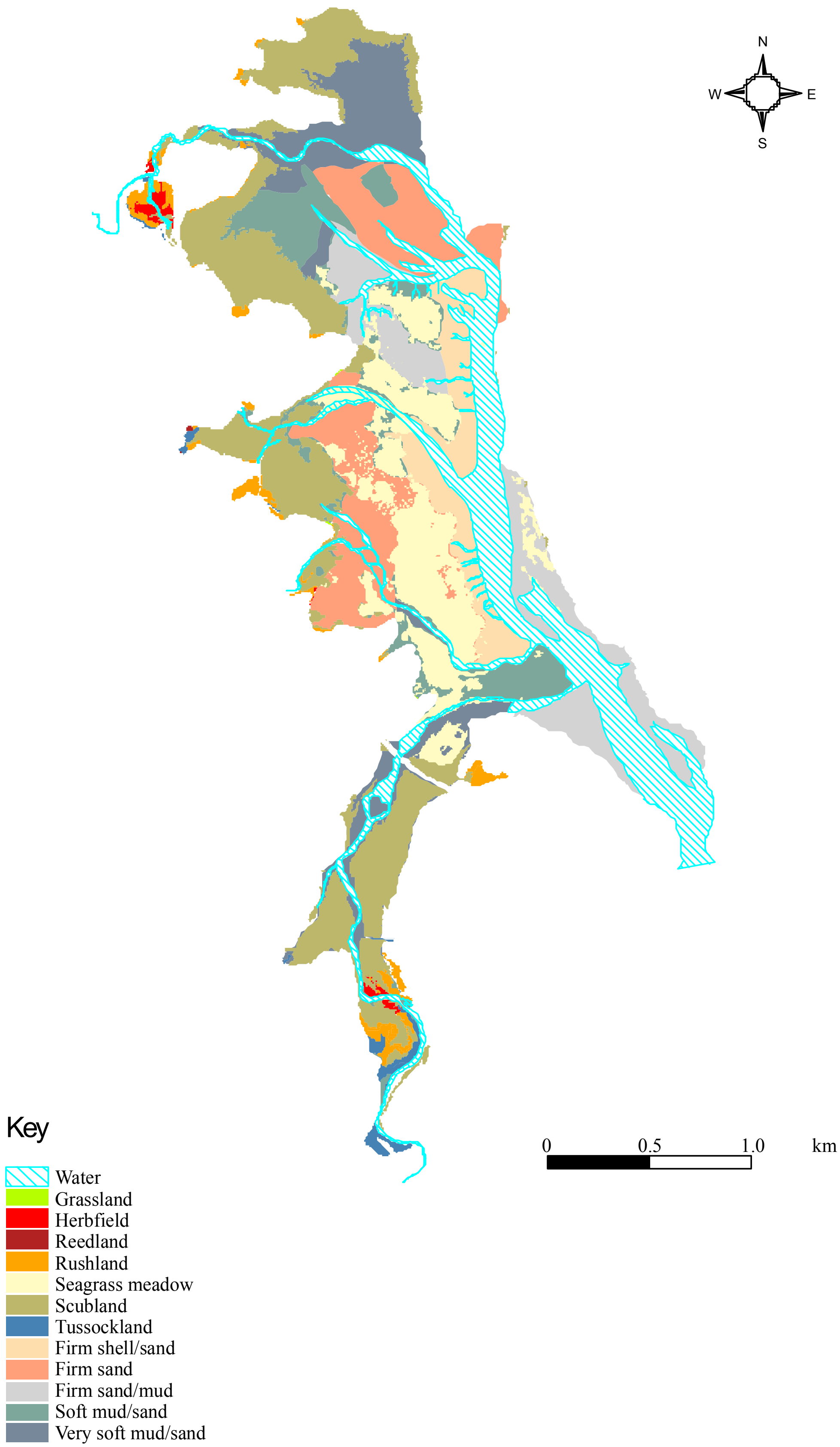


Figure A5: Whangamata Estuary – Structural class habitat map from the present study

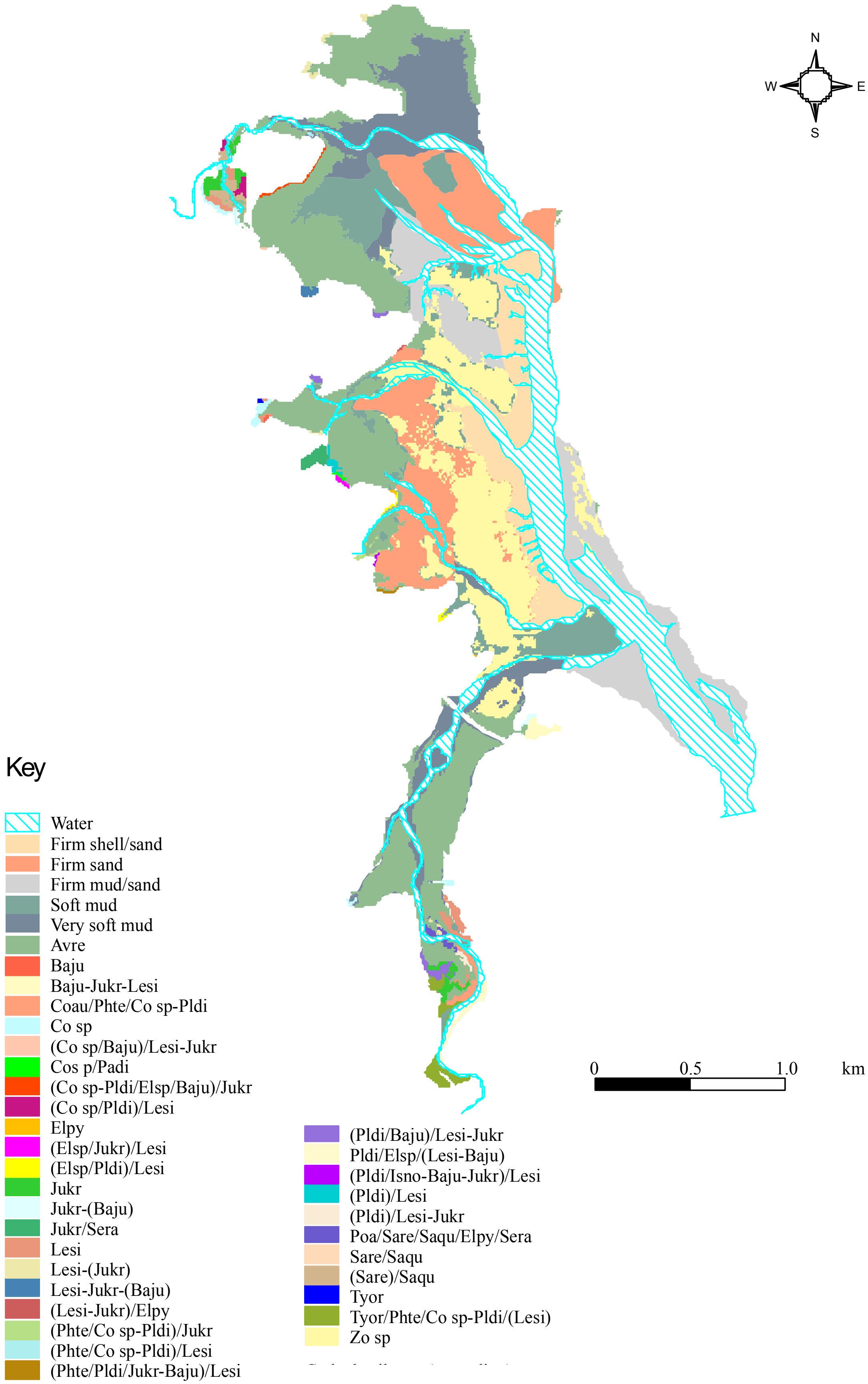


Figure A6: Whangamata Estuary – Dominant cover habitat map from the present study

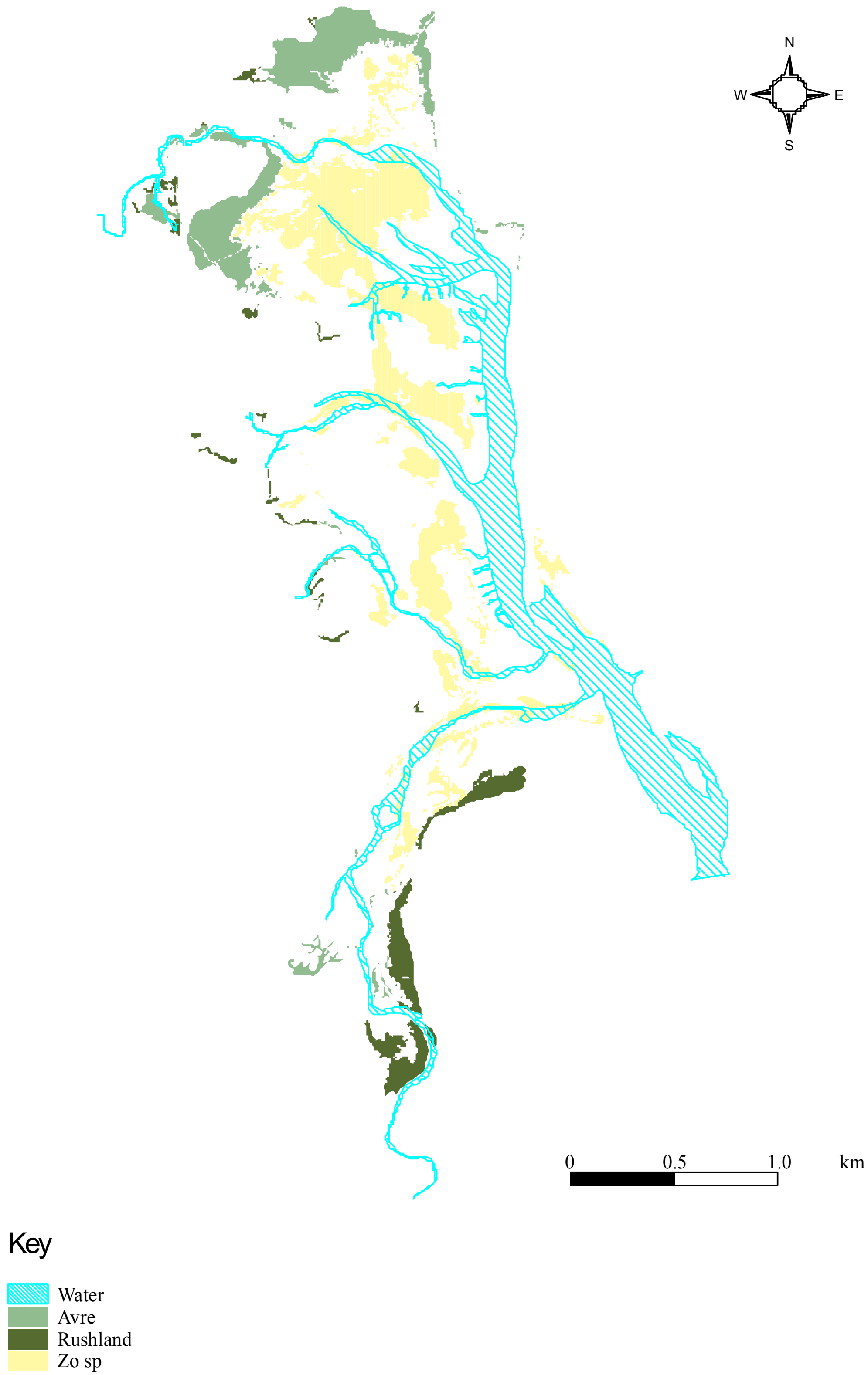


Figure A7: Whangamata Estuary (1944) – Map of identified habitat

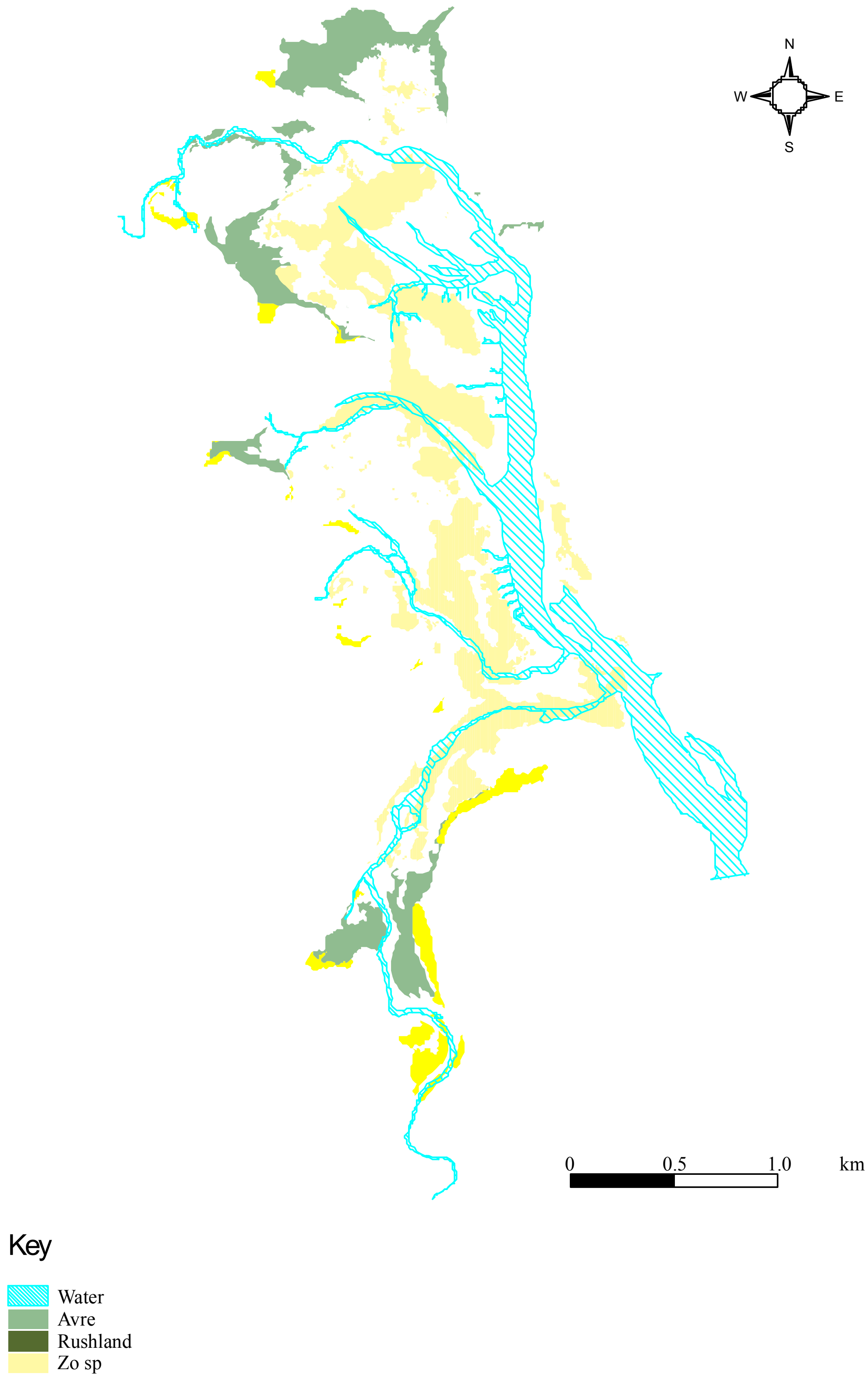
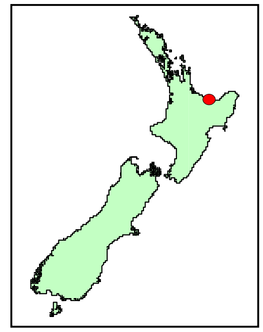


Figure A8: Whangamata Estuary (1965) – Map of identified habitat

Table A13: The broad-scale details of the habitat mapping of the Whangamata Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	102.69	22.33%
Avicennia marina var *resinifera*	101.97	22.17%
Plagianthus divaricatus - Eleocharis sphacelata	0.72	0.16%
Rushland	10.38	2.26%
Baumea juncea	0.02	0.01%
Juncus kraussii	2.70	0.57%
Leptocarpus similis	4.03	0.88%
Juncus kraussii - Leptocarpus similis	1.84	0.40%
Juncus kraussii - Selliera radicans	0.89	0.19%
Baumea juncea - Juncus kraussii - Leptocarpus similis	0.90	0.20%
Reedland	0.06	0.01%
Typha orientalis	0.06	0.01%
Tussockland	4.40	0.96%
Cortaderia sp.	0.86	0.19%
Cortaderia sp. - *Paspalum distichum*	0.06	0.01%
Cordyline australis - Phormium tenax - Cortaderia species - Plagianthus divaricatus	1.00	0.22%
Typha orientalis - Phormium tenax - Cortaderia sp. - *Plagianthus divaricatus*	2.48	0.54%
Grassland	0.07	0.02%
Elytrigia pycnanpha	0.07	0.02%
Herbfield	2.54	0.55%
Sarcocornia quinqueflora	1.73	0.38%
Sarcocornia quinqueflora - Samolus repens	0.03	0.01%
Poa - Samolus repens - Sarcocornia quinqueflora - Elytrigia pycnanpha - Selliera radicans	0.78	0.17%
Seagrass Meadow	59.72	12.99%
Zostera sp.	59.72	12.99%
Unvegetated	256.42	55.75%
Firm Sand	70.24	10.11%
Firm Shell/Sand	28.45	6.19%
Firm Mud/Sand	46.52	10.11%
Soft Mud/Sand	64.47	14.02%
Very Soft Mud/Sand	46.74	10.16%
Water	83.41	18.14%
Total Area Of Estuary (ha)	**459.96**	

B.1.3. Ohiwa Estuary



The survey of intertidal habitats in the Ohiwa Estuary (see summary Figure A9 and detailed results in Table A14) indicated that the area was dominated by unvegetated substrate (primarily firm sand), contributing to 68% of the total estuary area. The extent of mangrove (*Avicennia marina* var. *resinfera*) scrubland and seagrass (*Zostera novazelandica*) beds are similar, both covering approximately 4% of the estuary. Macroalgal beds of *Gracilaria chilensis* covered 56 hectares (2%), and the remaining estuary area was made up of rushland and small areas of sedgeland, herbfield, tussock, grass and reed. The habitat maps generated for the Ohiwa Estuary are presented in Figures A10 and A11.

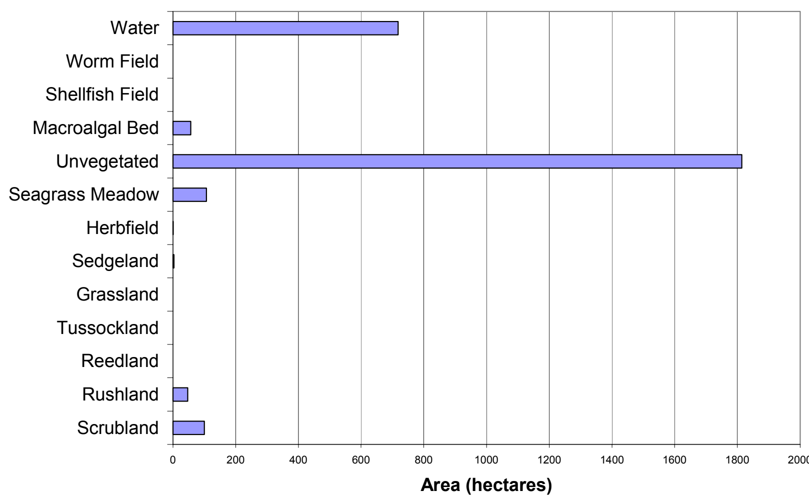


Figure A9: The area of different habitats of the Ohiwa Estuary

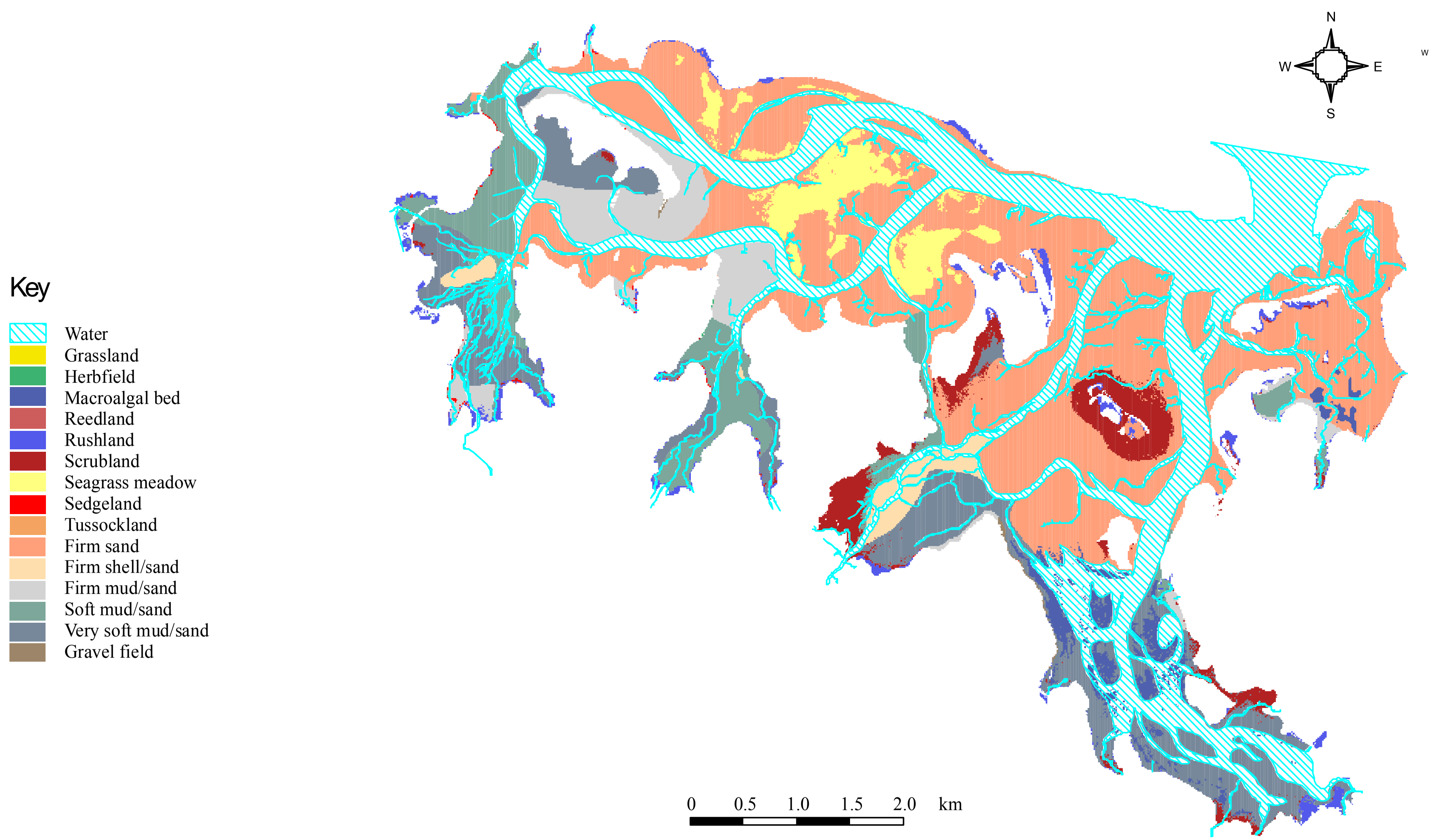


Figure A10: Ohiwa Estuary – Structural class habitat map

Appendix 57

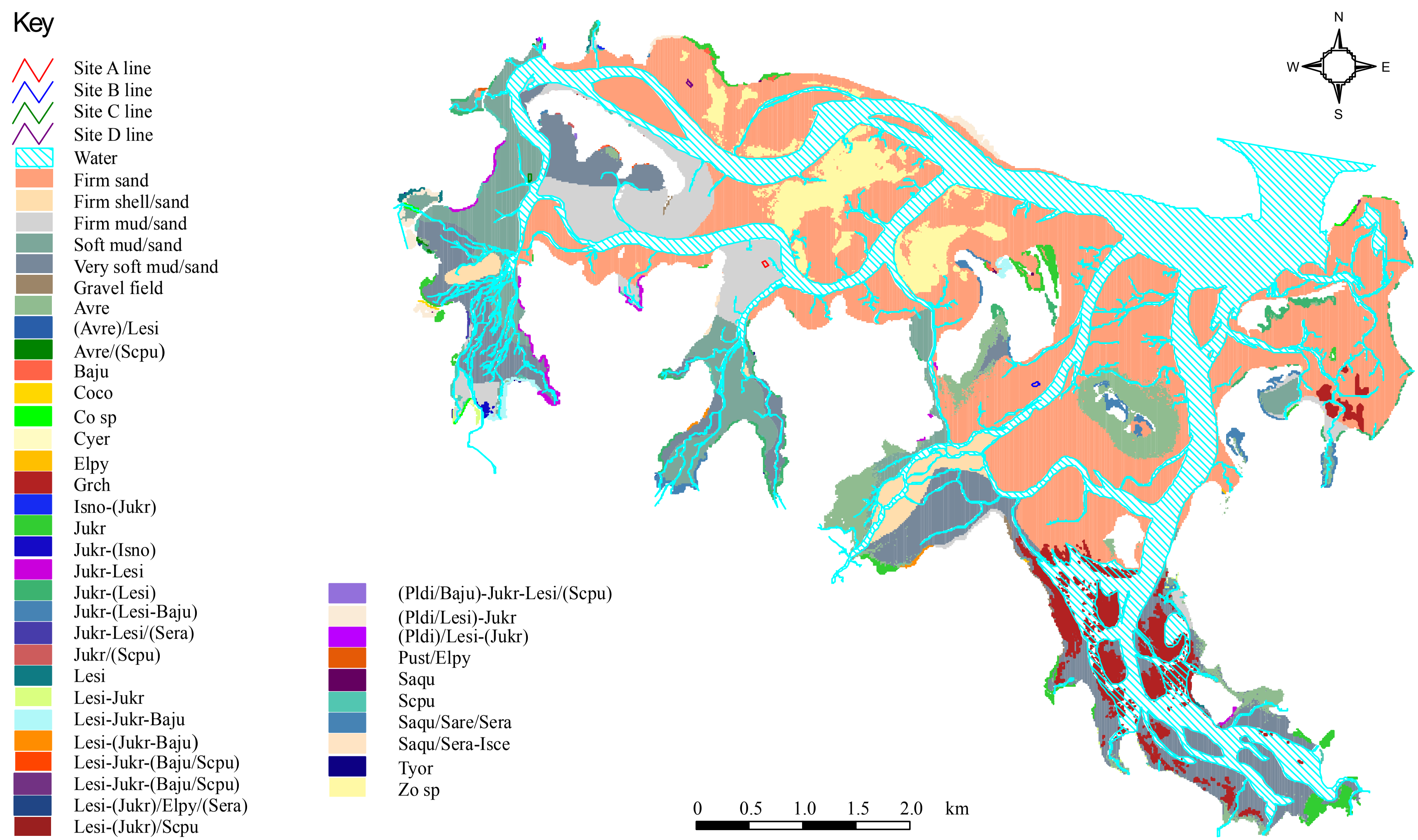
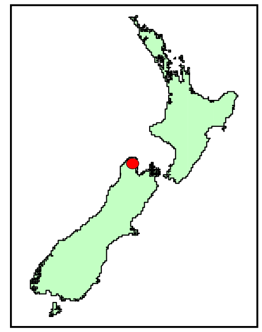


Figure A11: Ohiwa Estuary – Dominant cover habitat map

Table A14: The broad-scale details of the habitat mapping of the Ohiwa Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	100.11	3.73%
Avicennia marina var *resinfera*	100.10	3.73%
Rushland	46.94	1.75%
Baumea juncea	0.30	< 0.01%
Isolepis nodosa	0.04	0.01%
Juncus kraussii	37.19	1.39%
Leptocarpus similis	2.95	0.11%
Juncus kraussii - Leptocarpus similis	2.70	0.10%
Leptocarpus similis - Elytrigia pycnanpha	0.15	0.01%
Leptocarpus similis - Schoenoplectus pungens	0.11	< 0.01%
Baumea juncea - Juncus kraussii - Leptocarpus similis	3.51	0.13%
Reedland	0.19	0.01%
Typha orientalis	0.19	0.01%
Tussockland	0.56	0.02%
Cortaderia sp.	0.51	0.020%
Puccinella stricta - Elytrigia pycnanpha	0.06	< 0.01%
Grassland	0.05	< 0.01%
Festuca arundinacea	0.05	< 0.01%
Sedgeland	2.86	0.11%
Cyperus eragrostis	0.08	< 0.01%
Schoenoplectus pungens	2.78	0.10%
Herbfield	0.74	0.03%
Cotula coronopifolia	0.03	< 0.01%
Sarcocornia quinqueflora	0.06	< 0.01%
Samolus repens - Sarcocornia quinqueflora - Selliera radicans	0.08	< 0.01%
Sarcocornia quinqueflora - Selliera radicans - Isolepis cernua	0.15	0.01%
Seagrass Meadow	106.96	3.99%
Zostera sp.	106.96	3.99%
Unvegetated	1813.97	67.61%
Gravel Field	3.44	0.13%
Firm Sand	1081.40	41.53%
Firm Shell/Sand	41.83	1.56%
Firm Mud/Sand	140.25	4.02%
Soft Mud/Sand	183.14	6.83%
Very Soft Mud/Sand	363.64	13.55%
Macroalgal Bed	56.74	2.12%
Gracilaria chilensis	56.74	2.12%
Water	718.11	26.77%
Total Area Of Estuary (ha)	**2682.85**	

B.1.4. Ruataniwha Estuary



The broad-scale survey of intertidal habitats in the Ruataniwha estuary (see summary Figure A12 and detailed results in Table A15) indicated that the area was dominated by unvegetated habitat (69% of the total estuary area, covering 593 ha), a similar pattern to the other reference estuaries. Most of the unvegetated habitat was firm sand and firm mud/sand, both covering around 24% of the total estuary area. The vegetated habitats were dominated by rushland (13% of the total estuary), mostly searush, *Juncus krausii* and jointed wirerush, *Leptocarpus similes*, beds. Scrubland (mostly gorse, *Ulex europaeus*) and seagrass (*Zostera novazelandica*) covered 13.5 ha and 12.0 ha of intertidal estuary, respectively. There were minor areas of herbfield, and a very small amount of grass and tussock cover. The structural class habitat map generated for the Ruataniwha Estuary is presented in Figure A13 and the dominant cover details are in Figure A14.

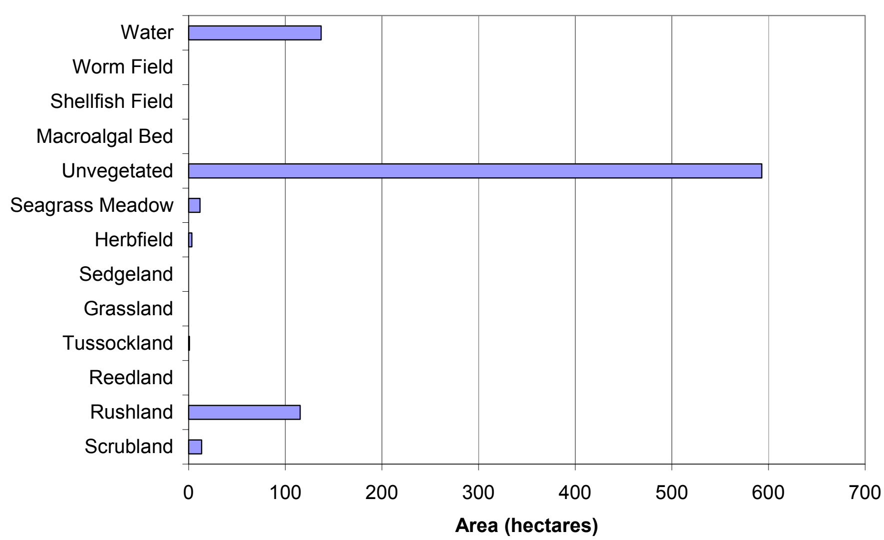


Figure A12: The area of different habitats of the Ruataniwha Estuary

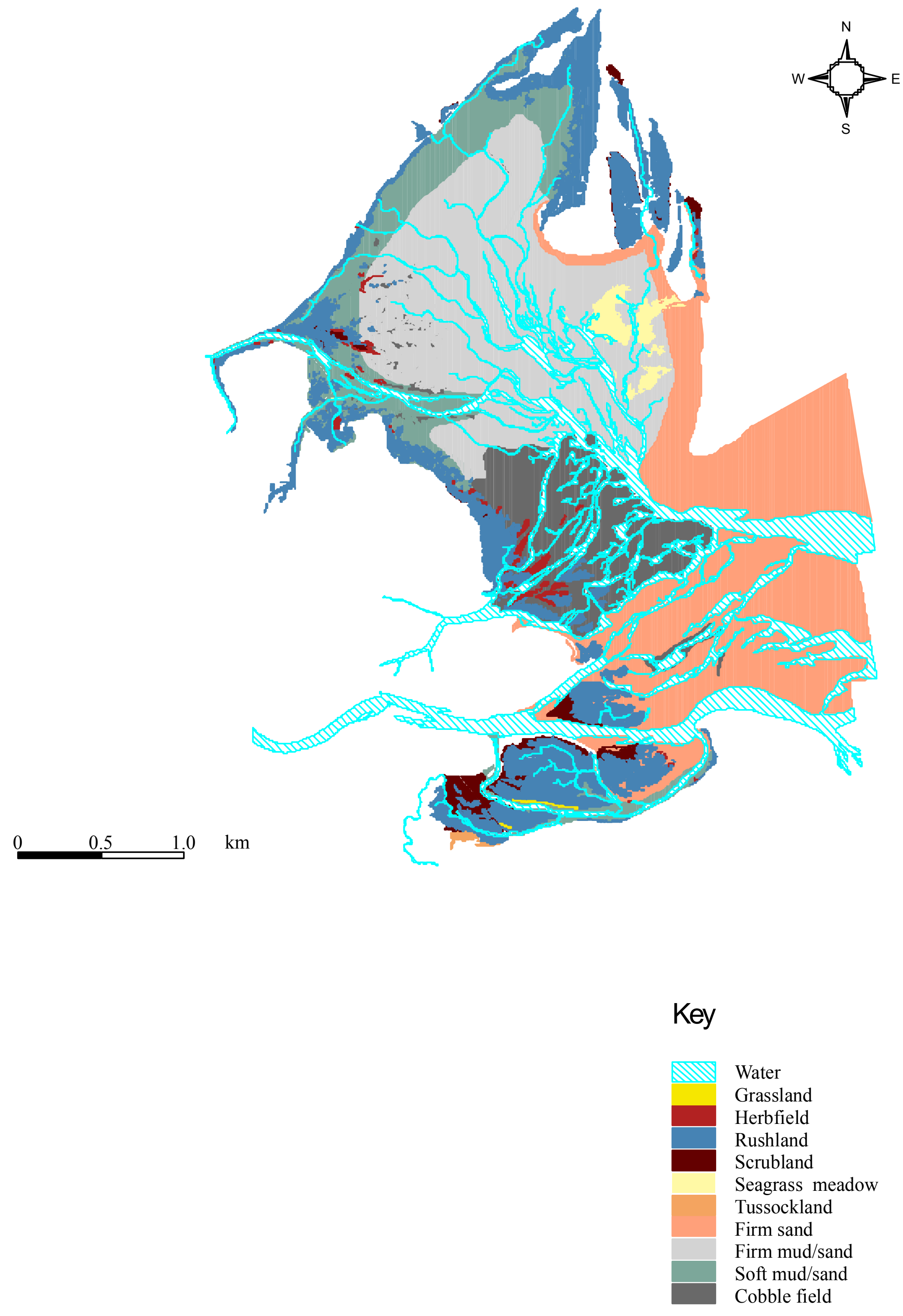


Figure A13: Ruataniwha Estuary – Structural class habitat map

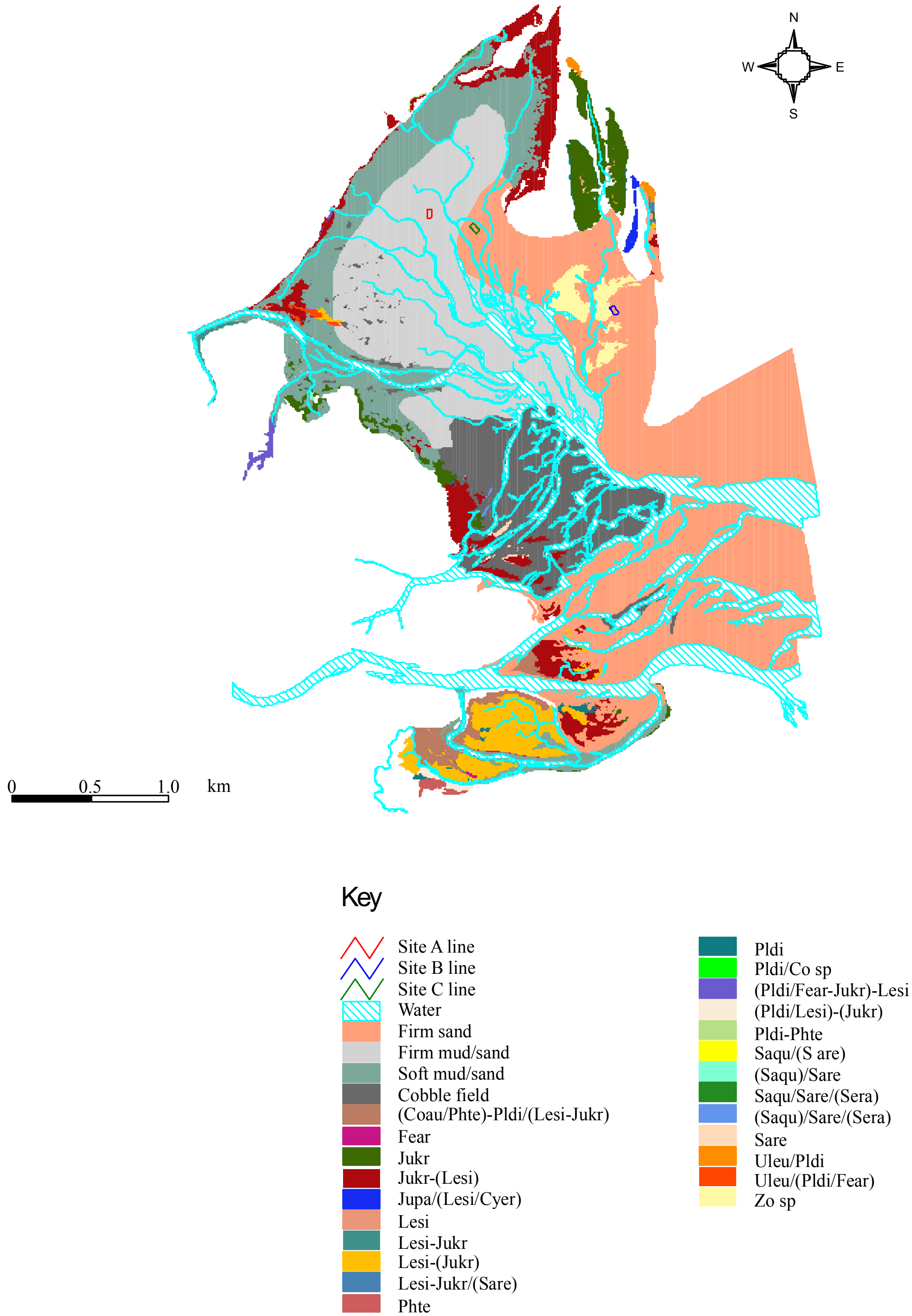
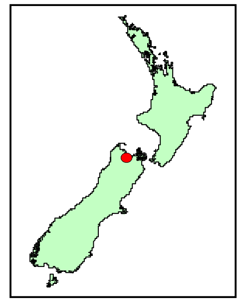


Figure A14: Ruataniwha Estuary – Dominant cover habitat map

Table A15: The broad-scale details of the habitat mapping of the Ruataniwha Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	13.49	1.56%
Ulex europaeus	11.00	1.27%
Plagianthus divaricatus	1.14	0.13%
Plagianthus divaricatus - Cortaderia sp.	0.03	0.00%
Plagianthus divaricatus - Phormium tenax	0.05	0.01%
Ulex europaeus - Plagianthus divaricatus	1.27	0.15%
Rushland	115.40	13.36%
Juncus kraussii	81.81	9.47%
Juncus pallidus	1.04	0.12%
Leptocarpus similis	30.76	3.56%
Juncus kraussii - Leptocarpus similis	1.80	0.21%
Tussockland	0.94	0.11%
Phormium tenax	0.94	0.11%
Grassland	0.19	0.02%
Festuca arundinacea	0.19	0.02%
Herbfield	3.45	0.40%
Sarcocornia quinqueflora	0.06	0.01%
Samolus repens	3.34	0.39%
Sarcocornia quinqueflora - Samolus repens	0.05	0.01%
Seagrass Meadow	11.87	1.38%
Zostera sp.	11.87	1.38%
Unvegetated	592.93	68.67%
Cobble Field	85.54	9.91%
Firm Sand	213.76	24.76%
Firm Mud/Sand	204.07	23.63%
Soft Mud/Sand	89.56	10.37%
Water	137.07	15.87%
Total Area Of Estuary (ha)	**863.476**	

B.1.5. Waimea Estuary



The broad-scale survey of intertidal habitats in the Waimea estuary (see summary Figure A15 and detailed results in Table A16) indicated that the area is dominated by unvegetated habitat (77% of the total estuary area, covering 2480 ha). Almost half of the unvegetated habitat was classified as soft mud (34% of the total estuary area). The remaining unvegetated areas consisted of a variety of habitats, the most predominant of which were firm mud and firm sand (23% and 10% of the total cover, respectively) and cobble and gravel beds, together covering 8% of the total area. The vegetated habitats were diverse, although each covered less than 4% of the total estuary. Herbfields were the most abundant, covering 123 ha, of which *Sarcocornia quinqueflora* (glasswort) was the most dominant. Approximately 98 ha of the estuary (3% of the total cover) were described as rushland, and the majority of this was *Juncus kraussii* (searush). A mixture of macroalgal species formed beds covering 2% of the estuary, and there were minor areas of oyster fields, seagrass, tussock and scrub. The habitat maps of Waimea Estuary are presented in Figures A16 and A17.

An example of Sarcocornia quinqueflora, Waimea estuary

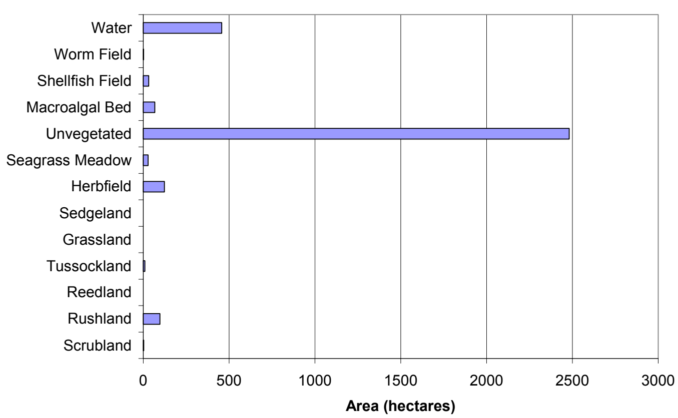


Figure A15: The area of different habitats of the Waimea Estuary

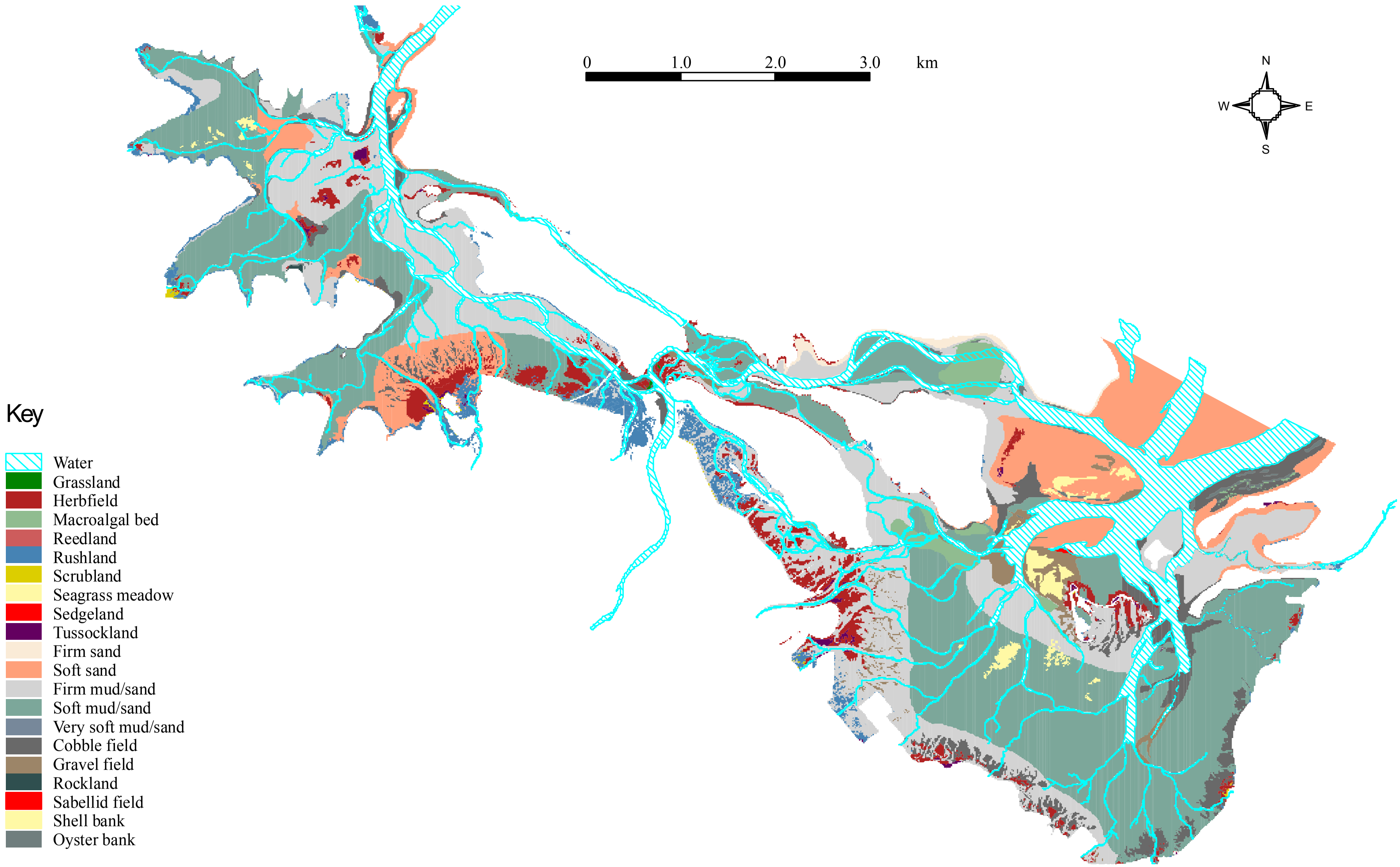


Figure A16: Waimea Estuary – Structural class habitat map

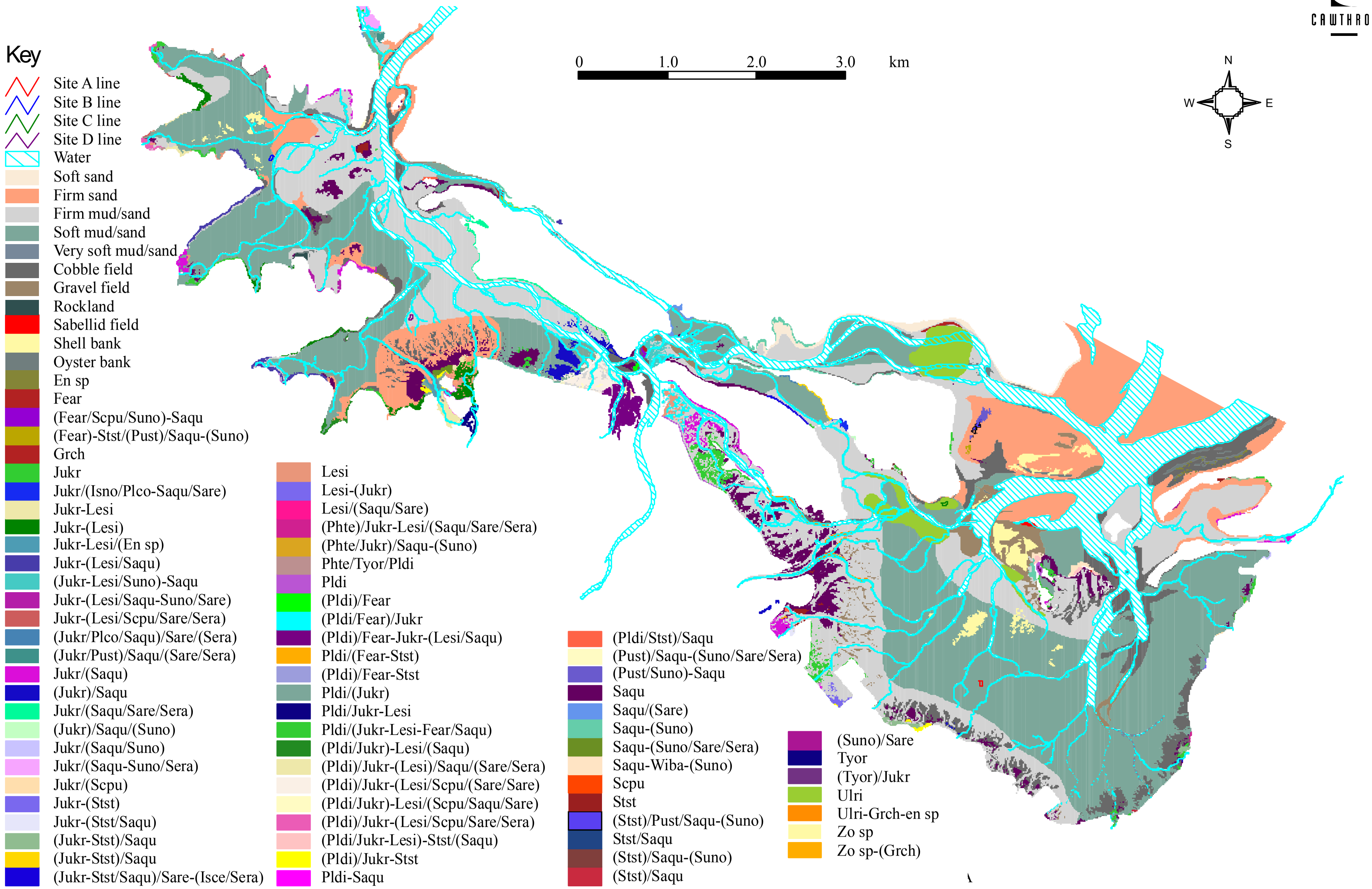
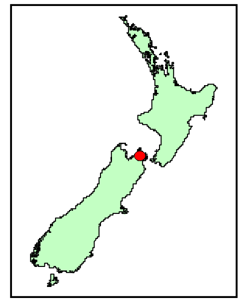


Figure A17: Waimea Estuary – Dominant cover habitat map

Table A16: The broad-scale details of the habitat mapping of the Waimea Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	3.28	0.10%
Ulex europaeus	3.16	0.10%
Plagianthus divaricatus - Sarcocornia quinqueflora	0.13	< 0.01%
Rushland	97.85	3.05%
Juncus kraussii	66.99	2.09%
Leptocarpus similis	8.95	0.28%
Festuca arundinacea - Juncus kraussii	15.66	0.49%
Juncus kraussii - Leptocarpus similis	4.14	0.13%
Plagianthus divaricatus - Juncus pallidus - Leptocarpus similis	1.56	0.05%
Reedland	0.01	< 0.01%
Typha orientalis	0.01	< 0.01%
Tussockland	9.54	0.30%
Stipa stipoides	6.70	0.21%
Stipa stipoides - Sarcocornia quinqueflora	0.48	0.02%
Festuca arundinacea - Stipa stipoides	0.34	0.01%
Juncus kraussii - Stipa stipoides	1.95	0.06%
Phormium tenax - Typha orientalis - Leptocarpus similis	0.06	< 0.01%
Grassland	0.38	0.01%
Festuca arundinacea	0.38	0.01%
Sedgeland	0.12	< 0.01%
Schoenoplectus pungens	0.12	< 0.01%
Herbfield	123.13	3.84%
Sarcocornia quinqueflora	119.22	3.72%
Samolus repens	0.92	0.03%
Juncus kraussii - Sarcocornia quinqueflora	0.55	0.02%
Puccinella stricta - Sarcocornia quinqueflora	0.98	0.03%
Sarcocornia quinqueflora - Wilsonia backhousei	2.01	0.06%
Seagrass Meadow	28.02	0.87%
Zostera novazelandica	28.02	0.87%
Unvegetated	2,480.80	77.39%
Cobble Field	180.57	5.63%
Gravel Field	71.09	2.22%
Firm Sand	340.81	10.63%
Firm Mud/Sand	764.81	23.86%
Rockland	0.68	0.02%
Shell Bank	3.87	0.12%
Soft Mud/Sand	1,093.98	34.13%
Soft Sand	14.92	0.47%
Very Soft Mud/Sand	10.08	0.31%
Macroalgal Bed	66.86	2.09%
Entermoprpha sp	3.37	0.11%
Ulva sp. - *Gracilaria chilensis* - *Enteromorpha* sp.	4.33	0.14%
Shellfish Field	32.02	1.00%
Oyster Field	32.02	1.00%
Worm Field	1.70	0.05%
Sabellid Field	1.70	0.05%
Water	456.92	14.25%
Total Area Of Estuary (ha)	**3,205.74**	

B.1.6. Havelock Estuary



The broad-scale survey of intertidal habitats of Havelock Estuary (see summary Figure A18 and detailed results in Table A17) indicated a relatively diverse range of habitats, dominated by unvegetated substrate contributing to 37% of the total cover (approximately 300 ha out of the total 817 ha). This was primarily very soft mud and soft mud (together making 36% of the total cover) with a small gravel field making up the remaining unvegetated substrate. Rushland was the other dominant intertidal habitat, covering 23% of the estuary, and consisted of a combination of *Juncus kraussii* and *Leptocarpus similis* (searush and jointed wirerush). The remaining habitats were reedland (*Spartina anglica*, cord grass), gorse and manuka scrubland and a 20 ha oyster field. There were minor areas of macroalgal bed, herbfield and seagrass. The structural class habitat map is presented in Figure A19 and the dominant cover map is presented in Figure A20.

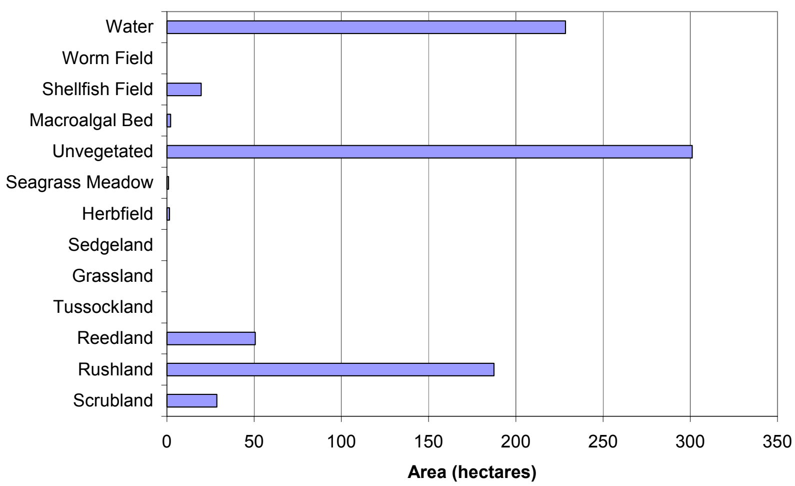


Figure A18: The area of different habitats of the Havelock Estuary

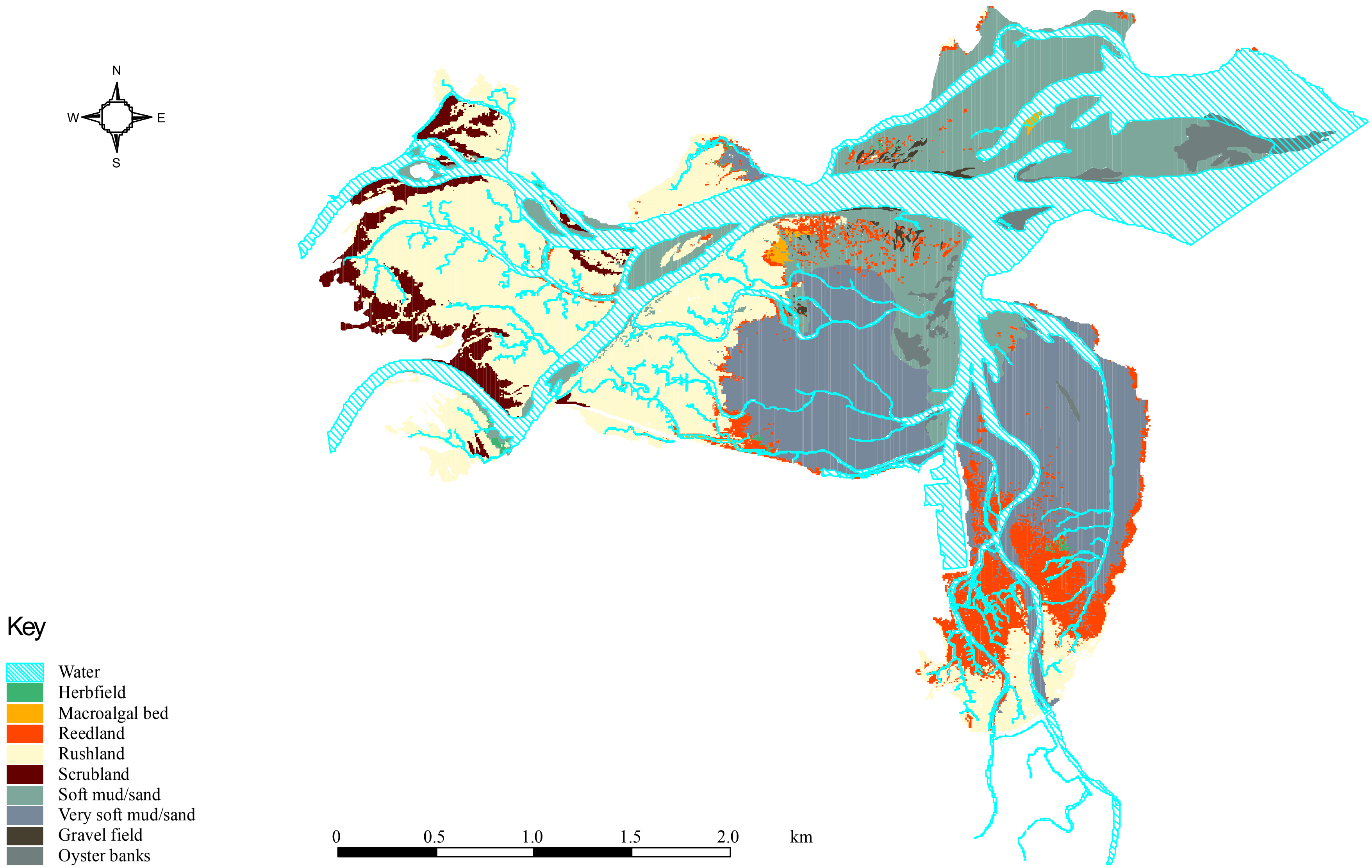


Figure A19: Havelock Estuary – Structural class habitat map

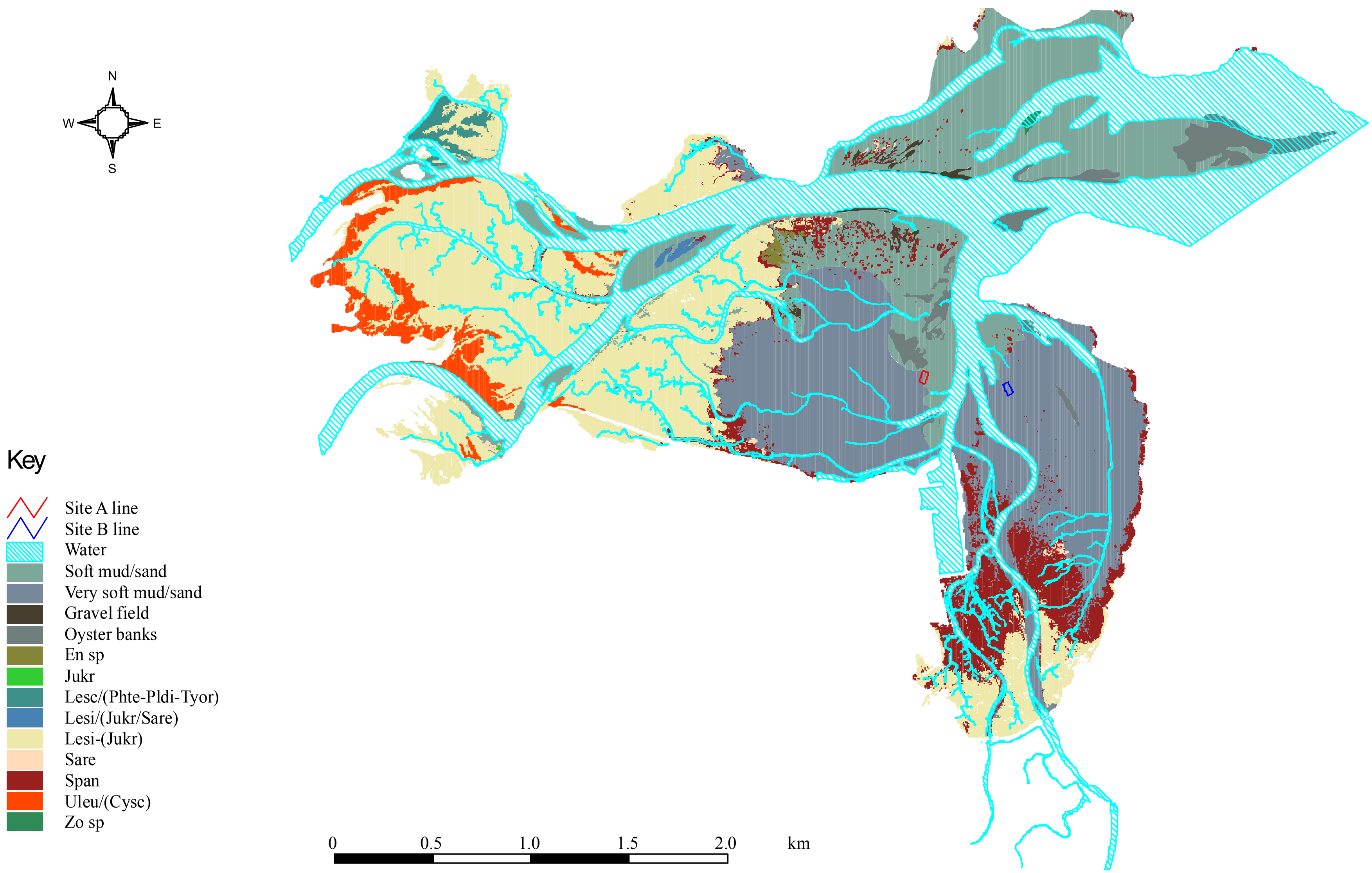
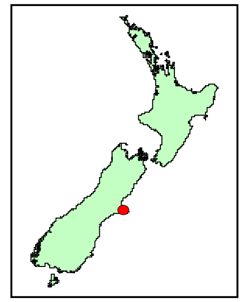


Figure A20: Havelock Estuary – Dominant cover habitat map

Table A17: The broad-scale details of the habitat mapping of the Havelock Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	28.65	3.51%
Leptospermum scoparium	4.81	0.59%
Plagianthus divaricatus	23.84	2.92%
Rushland	187.41	22.93%
Juncus kraussii	0.11	0.01%
Juncus kraussii - Leptocarpus similis	187.30	22.92%
Reedland	50.61	6.19%
Spartina anglica	50.61	6.19%
Herbfield	1.45	0.18%
Samolus repens	1.45	0.18%
Seagrass Meadow	0.90	0.11%
Zostera novazelandica	0.90	0.11%
Unvegetated	301.11	36.84%
Gravel Field	3.80	0.46%
Soft Mud/Sand	131.81	16.13%
Very Soft Mud/Sand	165.50	20.25%
Macroalgal Bed	2.12	0.26%
Entermoprpha sp.	1.22	0.15%
Shellfish Field	19.68	2.41%
Oyster Field	19.68	2.41%
Water	228.41	27.95%
Total Area Of Estuary (ha)	**817.32**	

B.1.7. Avon-Heathcote Estuary



The broad-scale survey of intertidal habitats in the Avon-Heathcote estuary (see summary Figure A21 and detailed results in Table A18) indicated a narrow range of habitats dominated by unvegetated substrate, which contributed to 66% of the total cover (approximately 470 ha of the estuary's total area of 706 ha). The unvegetated habitats were primarily firm mud (27% of the total cover), mobile sand (11%) and firm sand and firm shell/sand (together representing 20% of the total area). The most abundant vegetated habitat was macroalgal beds of *Gracilaria chilensis* and, to a lesser extent, *Ulva* sp. (sea lettuce), covering 6.2% of the total estuary area. Seagrass (*Zostera novazelandica*, eelgrass) habitat covered nearly 2% of the estuary, and the remaining habitat featured small areas of rushland, combining *Leptocarpus similis* (jointed wirerush) and *Juncus kraussii* (searush). The habitat maps are provided in Figures A22 and A23.

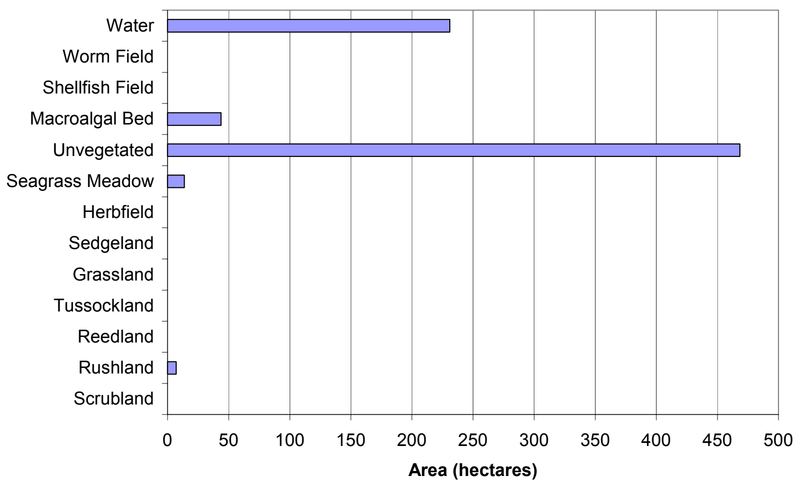


Figure A21: The area of different habitats of the Avon-Heathcote Estuary

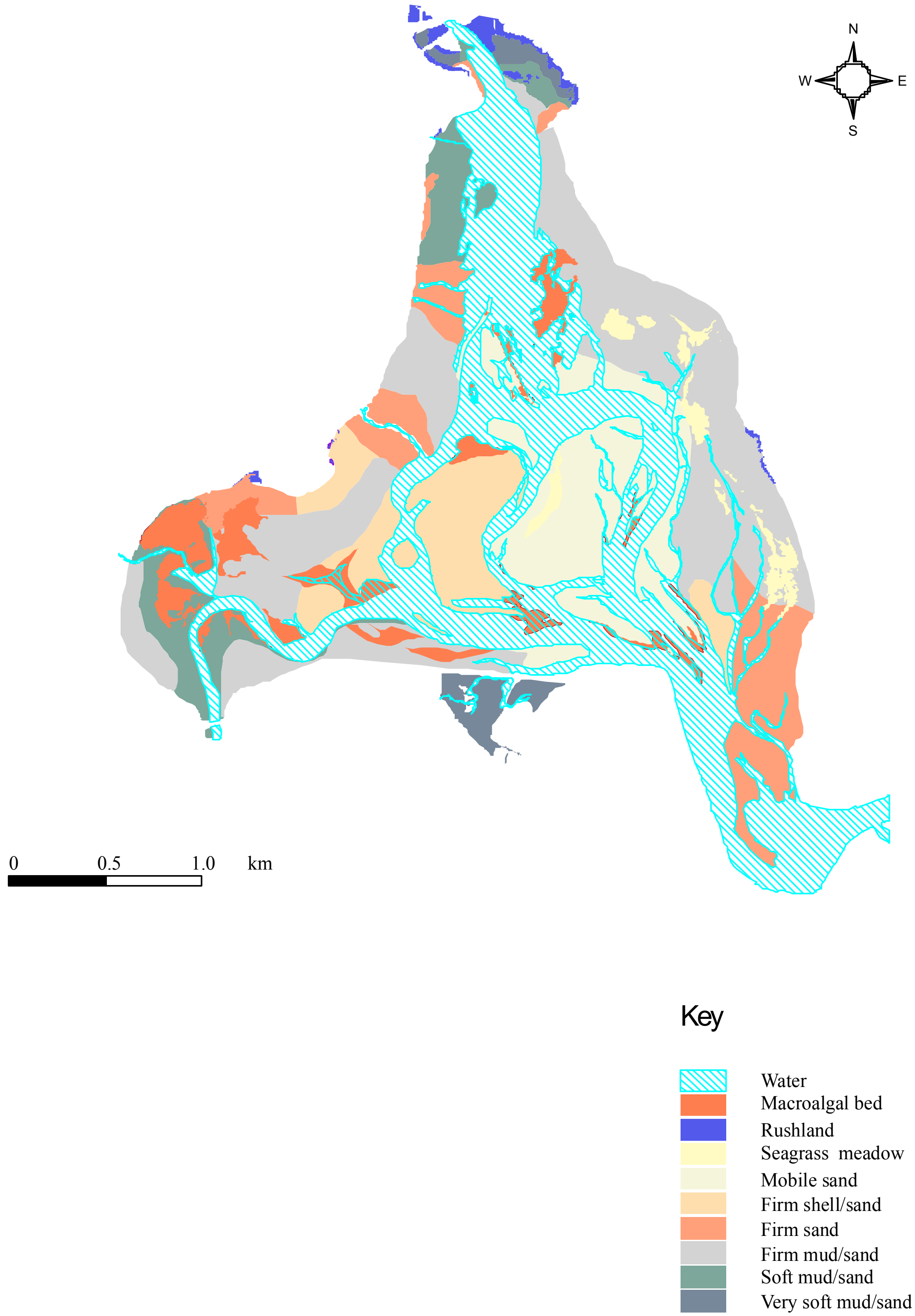


Figure A22: Avon-Heathcote Estuary – Structural class habitat map

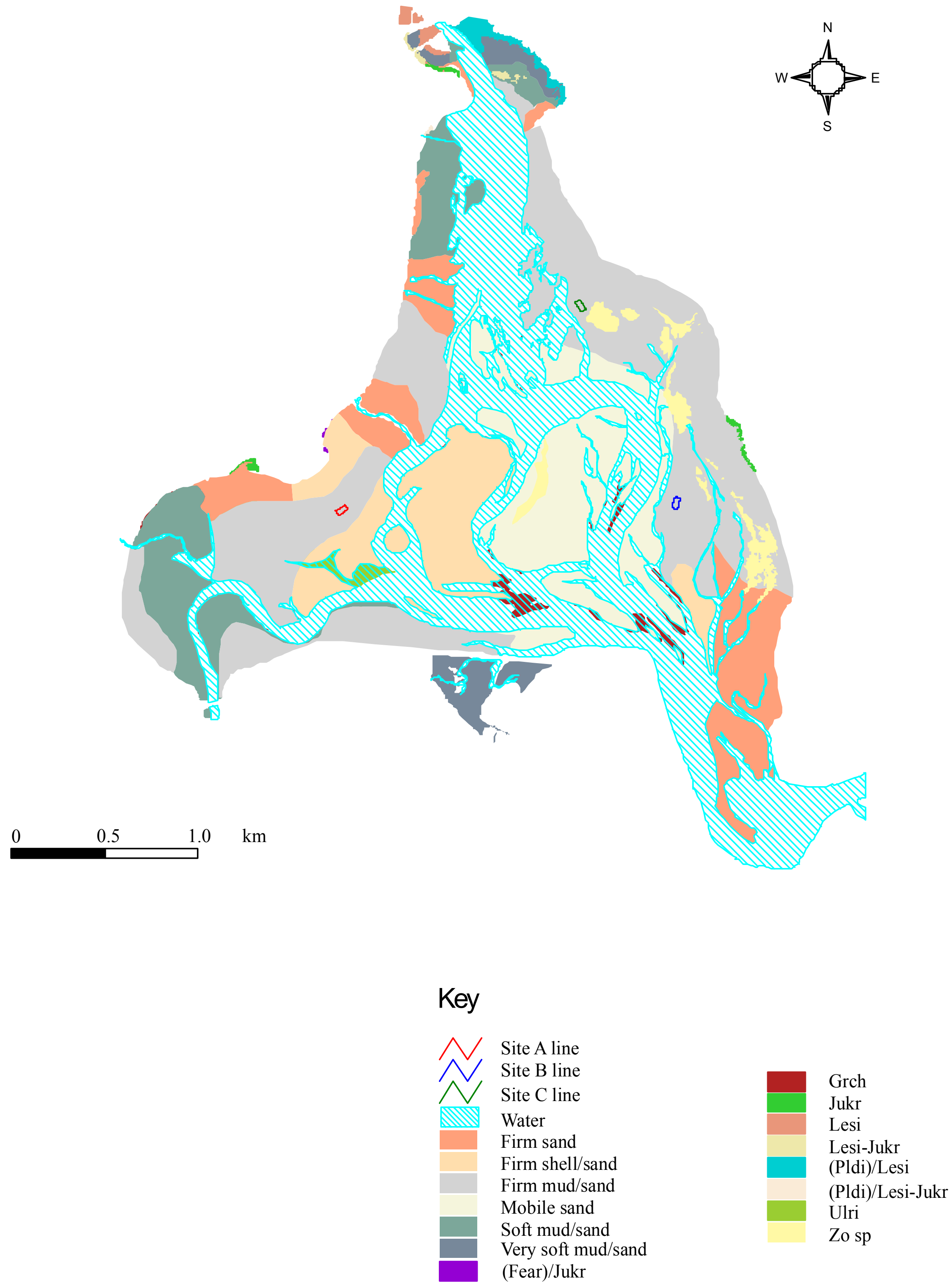
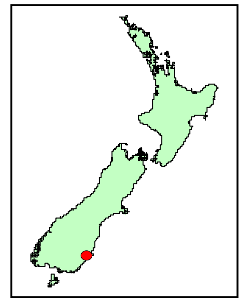


Figure A23: Avon-Heathcote Estuary – Dominant cover habitat map

Table A18: The broad-scale details of the habitat mapping of the Avon-Heathcote Estuary

Habitat Groupings	Area (hectares)	%Total Area
Rushland	7.16	1.01%
Juncus kraussii	1.18	0.17%
Leptocarpus similis	5.17	0.73%
Juncus kraussii - Leptocarpus similis	0.82	0.12%
Seagrass Meadow	13.72	1.94%
Zostera novazelandica	13.72	1.94%
Unvegetated	468.45	66.30%
Firm Sand	65.56	9.28%
Firm Shell/Sand	62.06	8.78%
Firm Mud/Sand	191.77	27.14%
Mobile Sand	79.85	11.30%
Soft Mud/Sand	53.02	7.50%
Very Soft Mud/Sand	16.19	2.29%
Macroalgal Bed	43.76	6.19%
Gracilaria chilensis	29.33	4.15%
Ulva sp.	14.43	2.04%
Water	231.00	32.69%
Total Area Of Estuary (ha)	**706.62**	

B.1.8. Kaikorai Estuary



The survey of intertidal habitats in the Kaikorai Estuary (see summary Figure A24 and detailed results in Table A19) indicated a relatively broad range dominated by upper estuary herbfield (primarily a mix of sea primrose *Samolus repens* and batchelors button *Cotula coronopifolia*), unvegetated substrate (primarily firm sand and soft mud/sand), rushland (primarily a mix of jointed wire rush, *Leptocarpus similis*, tall fescue *Festuca arundinacea*, and ribbonwood *Plagianthus divaricatus*), grassland and scrubland. The structural class and dominant cover habitat maps are presented in Figure A25 and A26, respectively.

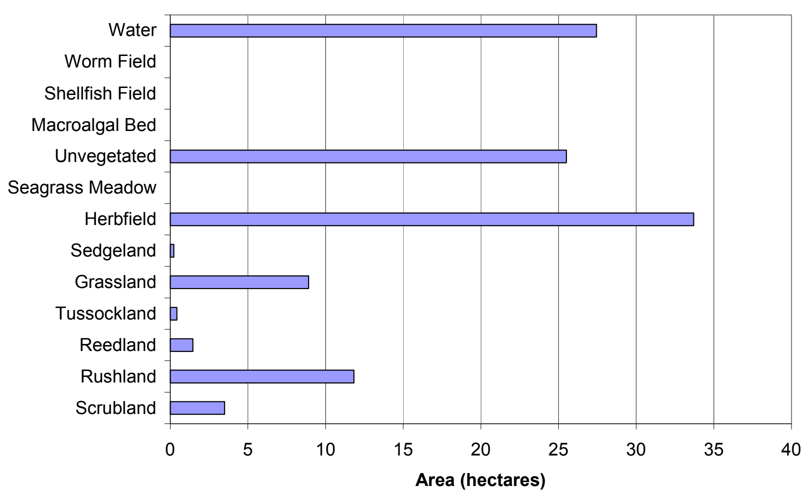


Figure A24: The area of different habitats of the Kaikorai Estuary

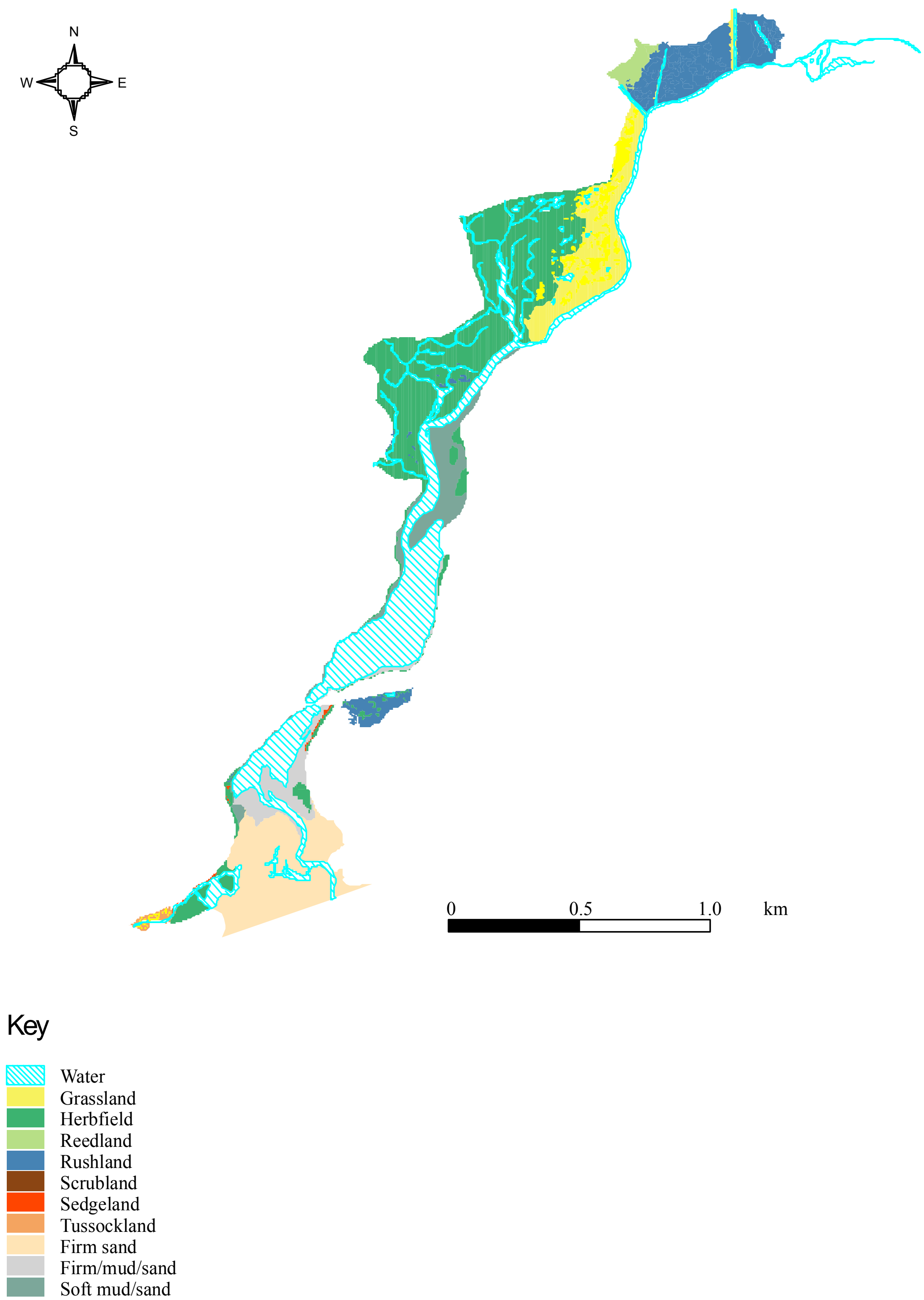


Figure A25: Kaikorai Estuary – Structural class habitat map

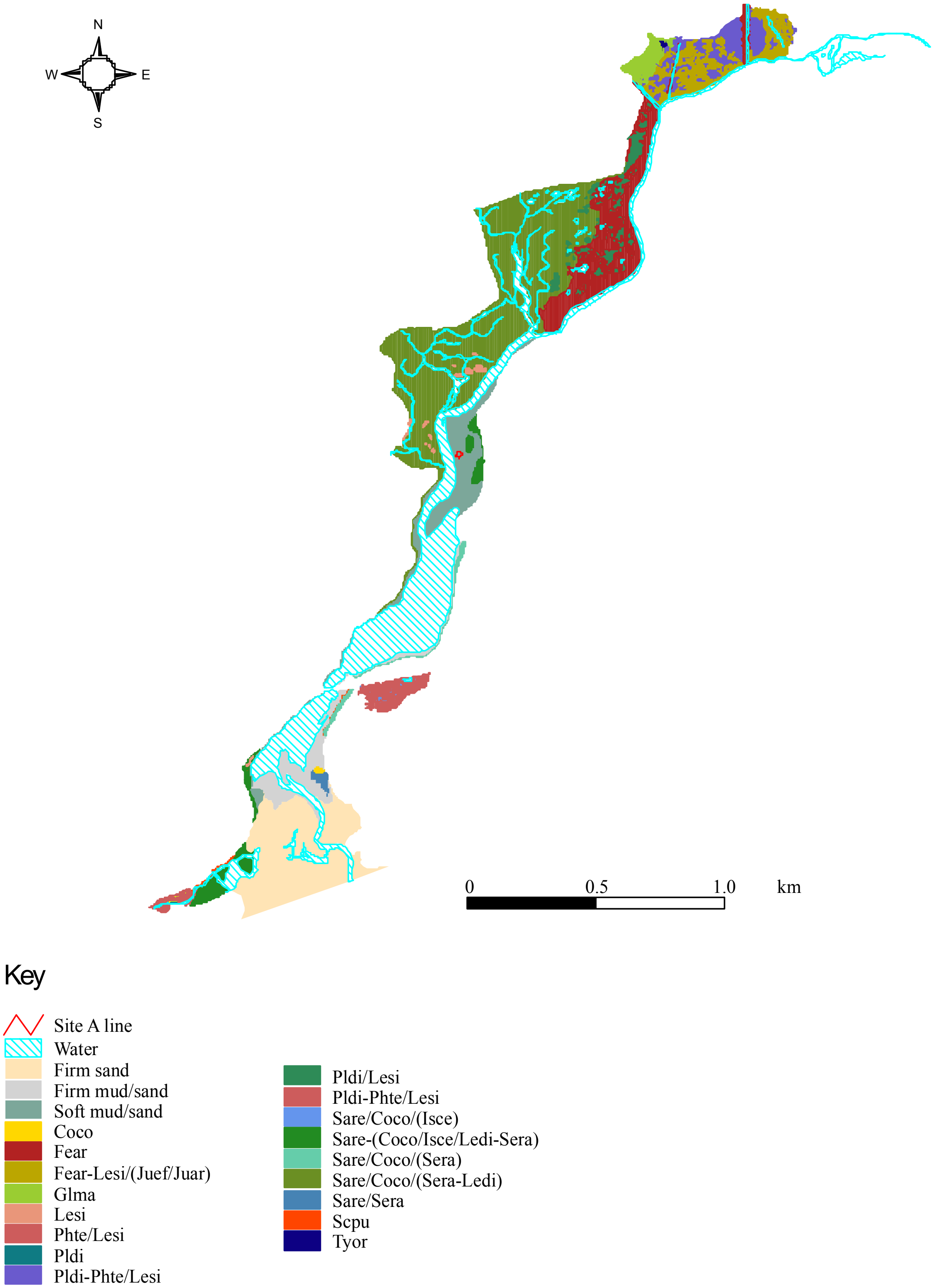
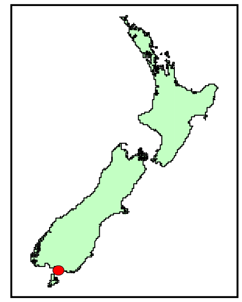


Figure A26: Kaikorai Estuary – Dominant cover habitat map

Table A19: The broad-scale details of the habitat mapping of the Kaikorai Estuary

Habitat Groupings	Area (hectares)	%Total Area
Scrubland	3.66	3.23%
Ulex europaeus	0.16	0.14%
Plagianthus divaricatus - Leptocarpus similis	3.50	3.10%
Rushland	11.83	10.47%
Leptocarpus similis	0.28	0.24%
Leptocarpus similis - Festuca arundinacea	4.30	3.81%
Plagianthus divaricatus - Phormium tenax - Leptocarpus similis	1.74	1.54%
Plagianthus divaricatus - Juncus pallidus - Leptocarpus similis	5.52	4.88%
Reedland	1.46	1.29%
Glyceria maxima	1.36	1.20%
Typha orientalis	0.10	0.090%
Tussockland	0.43	0.38%
Phormium tenax - Leptocarpus similis	0.43	0.38%
Grassland	8.92	7.89%
Festuca arundinacea	8.92	7.89%
Sedgeland	0.22	0.20%
Schoenoplectus pungens	0.24	0.22%
Herbfield	33.71	29.83%
Cotula coronopifolia	0.06	0.06%
Samolus repens	2.50	2.22%
Samolus repens - Cotula coronopifolia	30.79	27.24%
Samolus repens - Selliera radicans	0.35	0.31%
Unvegetated	25.50	22.57%
Firm Sand	14.23	12.59%
Firm Mud/Sand	4.98	4.40%
Soft Mud/Sand	6.30	5.57%
Water	27.45	24.29%
Total Area Of Estuary (ha)	**113.01**	

B.1.9. New River Estuary



The broad-scale survey of intertidal habitats of New River Estuary (see summary Figure A27 and detailed results in Table A20) indicated a relatively diverse range of habitats, dominated by unvegetated substrate contributing to 58% of the total cover (approximately 2470 ha out of the total 4225 ha). This was primarily firm sand (31% of the total cover), mobile sand (11%) and firm mud and soft mud (together representing around 11% of the total area). There were minor areas of very soft mud, and shell and rock beds. The vegetated habitats in the intertidal region of the New River estuary were diverse. The most abundant vegetated habitat was *Leptocarpus similis* (Jointed wirerush) rushland, covering 7.5% of the estuary (318 ha). The remaining habitats were reedland (*Spartina anglica*, cord grass), seagrass beds (*Zostera* sp., eelgrass), and macroalgal beds (predominantly *Gracilaria chilensis*). There were minor areas of tussock, grassland, sedgeland and herbfield. The structural class habitat map of New River Estuary is in Figure A28 and the dominant cover map is presented in Figure A29.

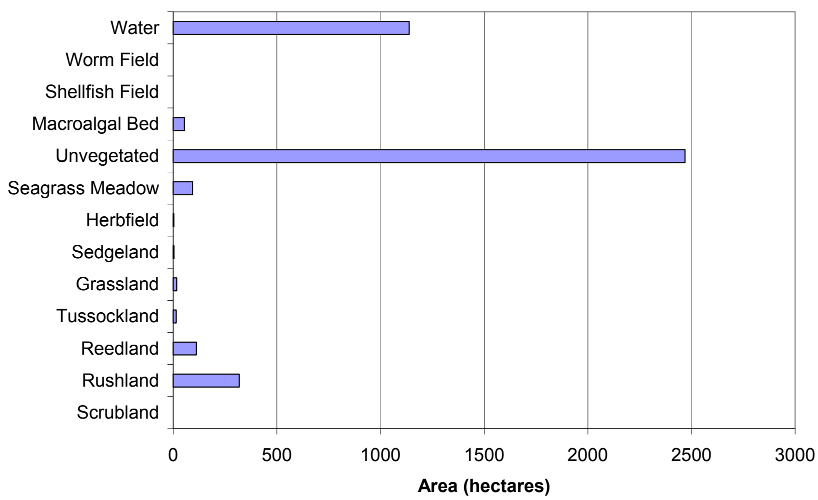


Figure A27: The area of different habitats of New River Estuary

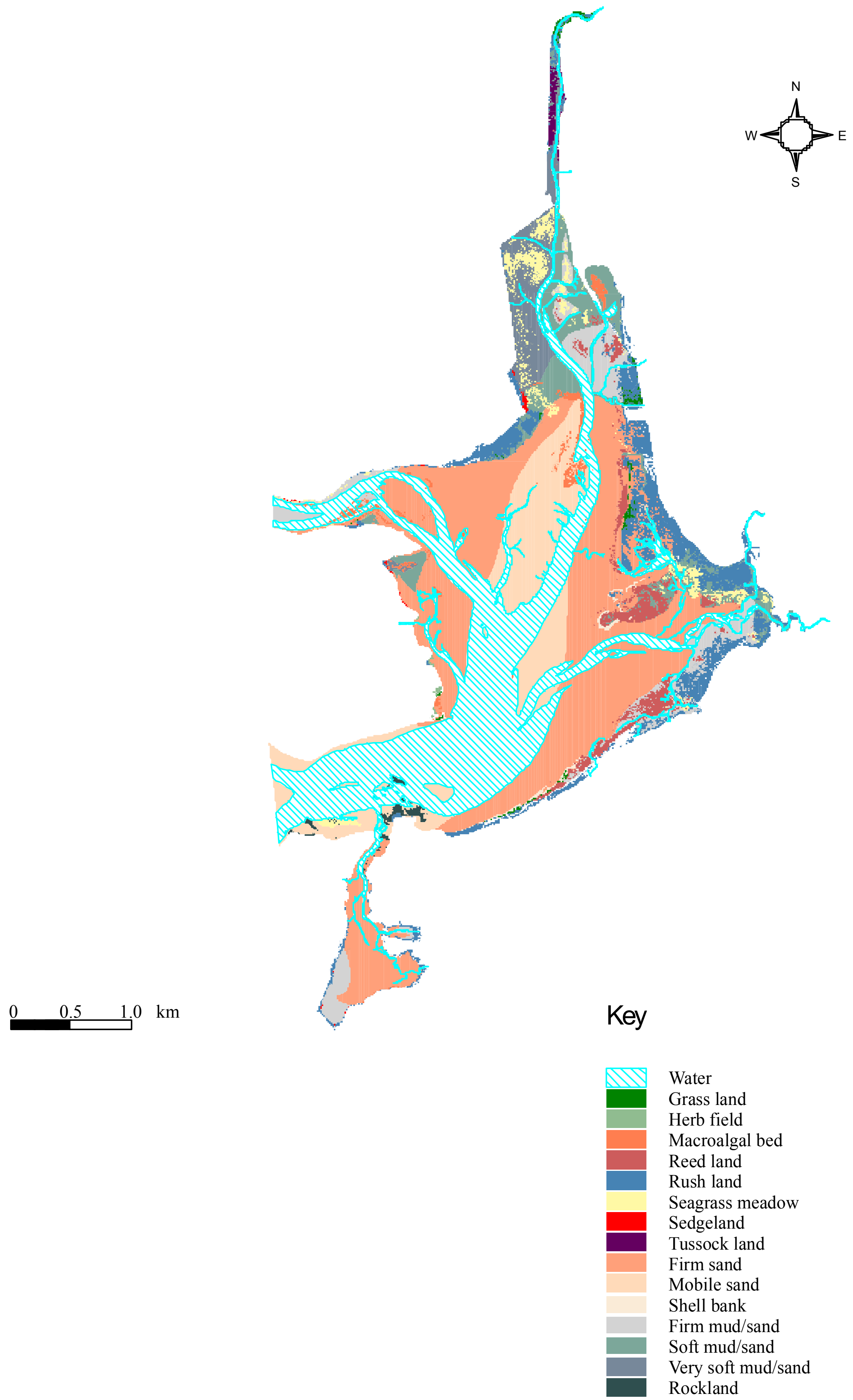


Figure A28: New River Estuary – Structural class habitat map

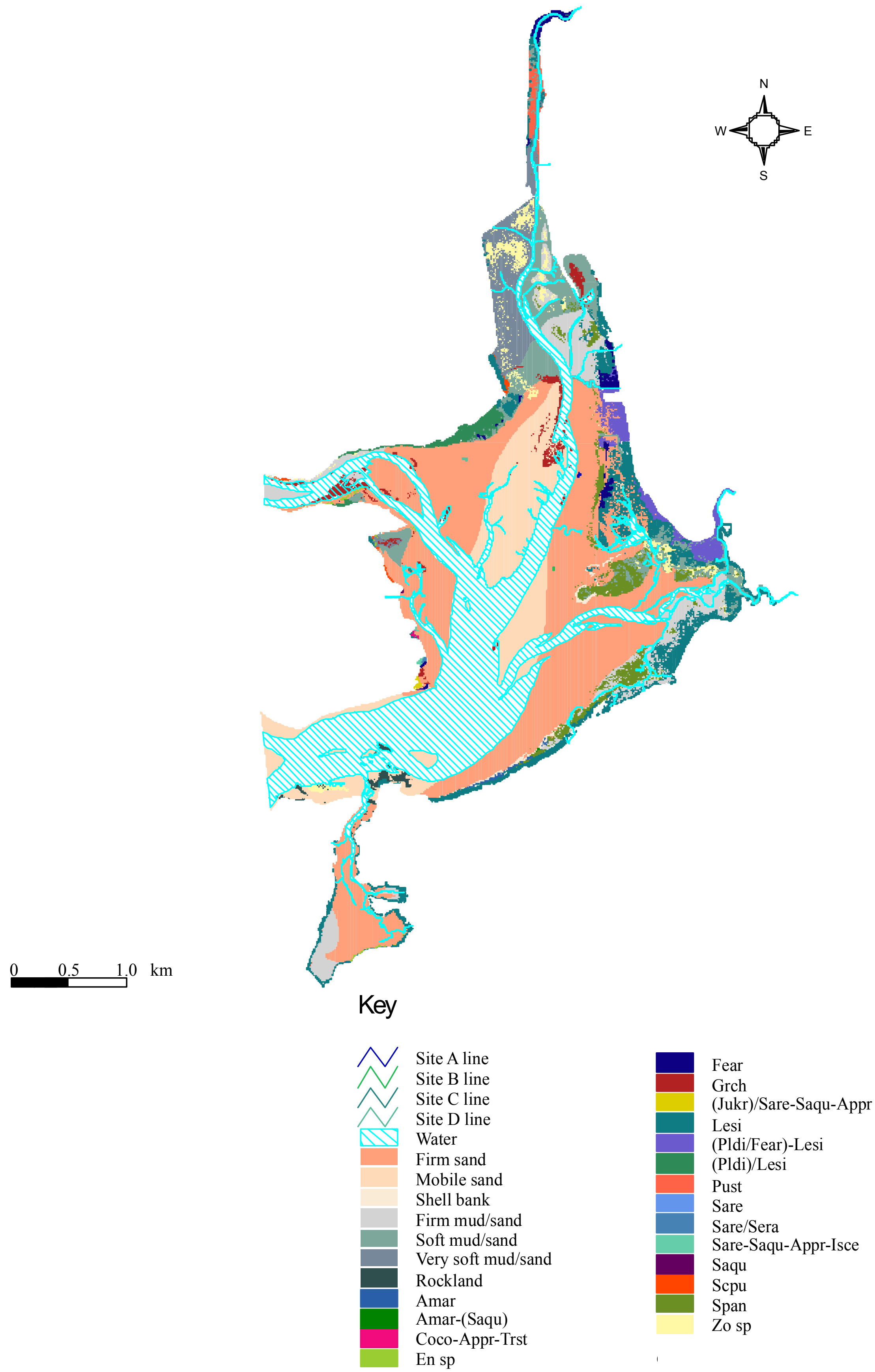


Figure A29: New River Estuary – Dominant cover habitat map

Table A20: The broad-scale details of the habitat mapping of the New River Estuary

Habitat Groupings	Area (hectares)	%Total Area
Rushland	318.92	7.55%
Leptocarpus similis	318.92	7.55%
Reedland	112.26	2.66%
Spartina anglica	112.26	2.66%
Tussockland	14.93	0.35%
Puccinella stricta	14.93	0.35%
Grassland	17.06	0.40%
Ammophila arenaria	2.61	0.06%
Festuca arundinacea	14.44	0.34%
Sedgeland	4.25	0.10%
Schoenoplectus pungens	4.25	0.10%
Herbfield	3.05	0.07%
Sarcocornia quinqueflora	0.16	< 0.01%
Samolus repens	0.05	< 0.01%
Samolus repens - Selliera radicans	0.54	0.01%
Cotula coronopifolia - Apium prostratum - Triglochin striata	0.45	0.01%
Samolus repens - Sarcocornia quinqueflora - Apium prostratum - Isolepis cernua	1.84	0.04%
Seagrass Meadow	93.63	2.22%
Zostera sp.	93.63	2.22%
Unvegetated	2,468.64	58.43%
Firm Sand	1,321.25	31.27%
Firm Mud/Sand	241.61	5.72%
Mobile Sand	471.78	11.17%
Rockland	20.12	0.48%
Shell Bank	14.31	0.34%
Soft Mud/Sand	241.41	5.71%
Very Soft Mud/Sand	158.16	3.74%
Macroalgal Bed	54.32	1.29%
Entermoprpha sp	2.58	0.06%
Gracilaria chilensis	51.74	1.23%
Water	1,137.98	26.93%
Total Area Of Estuary (Ha)	**4,225.03**	

Appendix B 2: Components of the broad-scale habitat classification system

Table A21: Adapted Estuarine and palustrine components of UNEP-GRID classification

Level I Hydrosystem	**Level IA Sub-System**	**Level II Wetland Class**	**Level III Structural Class**	**Level IV Dominant Cover**	**Habitat Code**
Estaurine	Intertidal/supratidal	Saltmarsh	Grassland	*Ammophila arenaria*, "Marram grass'	Amar
(alternating				*Elytrigia pycnanph*,, "Sea couch"	Elpy
saline and				*Festuca arundinacea*, "Tall fescue"	Fear
freshwater)				*Paspalum distichum*, "Mercer grass"	Padi
			Herbfield	*Apium prostratum*, "Native celery"	Appr
				Cotula coronopifolia , "Bachelor's button"	Coco
				Leptinella dioica	Ledi
				Plantago coronopus, "Buck's-horn plantain"	Plco
				Samolus repens, "Primrose"	Sare
				Sarcocornia quinqueflora, "Glasswort"	Saqu
				Selliera radicans, "Remuremu"	Sera
				Suaeda novae – zelandiae, "Sea blite"	Suno
				Triglochin striata, "Arrow-grass"	Trst
			Reedland	*Glyceria maxima*, "Reed sweetgrass"	Glma
				Spartina anglica, "Cord grass"	Span
				Spartina alterniflora, "Smooth cord grass"	Spal
				Typha orientalis, "Raupo"	Tyor
			Rushland	*Baumea juncea*, " Bare twig rush"	Baju
				Isolepis nodosa, "Knobby clubrush"	Isno
				Juncus artoiculatus, "Jointed rush"	Juar
				Juncus effuses, "Softrush"	Juef
				Juncus kraussii, "Searush"	Jukr
				Juncus pallidus, " Pale rush"	Jupa
				Leptocarpus similis, "Jointed wirerush"	Lesi
				Wilsonia backhousei	Wiba
			Sedgeland	*Cyperus eragrostis*, "Umbrella sedge"	Cyer
				Cyperus ustulatus, "Giant umbrella sedge	Cyus
				Eleocharis sphacelata, "Bamboo spike-sedge"	Elsp
				Isolepis cernua, "Slender clubrush"	Isce
				Schoenoplectus pungens, "Three-square"	Scpu

Level I Hydrosystem	Level IA Sub-System	Level II Wetland Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
			Scrub	*Avicennia marina var. resinfera*, “Mangrove”	Avre
				Cordyline australis, “Cabbage tree”	Coau
				Cytisus scoparius, “Broom”	Cysc
				Leptospermum scoparium, “Manuka”	Lesc
				Plagianthus divaricatus, “Saltmarsh ribbonwood”	Pldi
				Ulex europaeus, “Gorse”	Uleu
			Tussockland	*Cortaderia* sp., “Toetoe”	Co sp
				Phormium tenax, “New Zealand flax”	Phte
				Poa, “Silver tussock”	Poa
				Puccinella stricta, ”Salt grass”	Pust
				Stipa stipoides, “Needle tussock”	Stst
		Seagrass meadows	Seagrass meadow	*Zostera* sp., “Eelgrass”	Zo sp
		Macroalgal bed	Macroalgal bed	*Enteromorpha* sp.	En sp
				Gracilaria chilensis	Grch
				Ulva sp., “Sea lettuce”	Ulri
		Mud/sandflat	Firm shell/sand (<1cm)		Firm shell/sand
			Firm sand (<1cm)		Firm sand
			Soft sand		Soft sand
			Mobile sand (<1cm)		Mobile sand
			Firm mud/sand (0-2cm)		Firm mud/sand
			Soft mud/sand (2-5cm)		Soft mud/sand
			Very soft mud/sand (>5cm)		Very soft mud/sand
		Stonefield	Gravel field		Gravel
			Shingle field		Shingle
			Cobble field		Cobble
		Boulderfield	Boulder field		Boulder
		Rockland	Rockland		Rock
		Shell bank	Shell bank		Shell
		Shellfish field	Cocklebed		Cockle
			Musselreef		Mussel
			Oysterreef		Oyster
		Worm field	Sabellid field		Sabellid
	Subtidal	Water	Water		Water

Table A22: Estuarine classification system based on Atkinson (1985) system.

Level 1 Hydrosystem	**Level 1A Subsystem**	**Level2 Wetland class**	**Level 2A Wetland form**
Estuarine	Intertidal (int)	Saltmarsh (sm)	Estuary (est)
	Subtidal (sub)	Seagrass meadow (sg)	
	Nontidal (non)	Algae flat (af)	Lagoon (lag)
	Supratidal (sup)	Mud flat (mf)	
		Sand flat (sf)	
		Cobble flat (cf)	
		Rocky reef (rf)	
	Inter-dunal (id)	Swale marsh (sw)	Dune slack (ds)

The identified vegetation patches were classified using an interpretation of the Atkinson system (Table A22), described below:

- The individual vegetation species have been named by using the two first letters of their Latin species and genus names *e.g.* Pldi = ribbonwood, *Plagianthus divaricatus*.
- / separates canopy vegetation *e.g.* Pldi/Lesi (ribbonwood is taller than jointed wire rush).
- - separates vegetation with approximately the same height *e.g.* Lesi-Jukr (jointed wire rush is the same height as searush).
- ( ) are used for subdominant species *e.g.* (Pldi)/Lesi = dominant cover is jointed wire rush and subdominant cover is ribbonwood. The use of ( ) is not based on percentage cover but from the subjective observation of which vegetation is the dominant or subdominant species within the patch.
- The classification always starts with the tallest vegetation type and works down *e.g.* (Pldi/Baju)/Lesi-Jukr = a patch with a dominant cover of jointed wire rush and searush (which are of the same height) with a subdominant cover of ribbonwood and *Baumea juncea* (which are taller than the dominant cover).

Naming sequence protocol: 2A/1A/2. e.g. est/int/sm=estuarine intertidal seagrass meadow
lag/non/sm=lagoonal nontidal saltmarsh

Definition of classification Level III Structural Class

Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions. The growth form occurs in all species of *Donatia, Gaimardia, Hectorella, Oreobolus,* and *Phyllachne* as well as in some species of *Aciphylla, Celmisia, Centrolepis, Chionohebe, Colobanthus, Dracophyllum, Drapetes, Haastia, Leucogenes, Luzula, Myosotis, Poa, Raoulia,* and *Scleranthus.*

Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and in which the herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and in which the lichen cover exceeds that of any other growth form or bare ground.

Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. If the reed is broken the stem is both round and hollow – somewhat like a soda straw. The flowers will each bear six tiny petal-like structures – neither grasses nor sedges will bear flowers, which look like that. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either hollow or have a very spongy pith. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata.* Some species, covered by Rushland or Sedgeland classes (below), are excluded.

Rushland: Vegetation in which the cover of rushes in the canopy is 20-100% and in which the rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in the rush growth form are some species of *Juncus* and all species of *Sporadanthus, Leptocarpus,* and *Empodisma.* Tussock-rushes are excluded.

Sedgeland: Vegetation in which the cover of sedges in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. “Sedges have edges.” Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it’s probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Included in the sedge growth form are many species of *Carex, Uncinia,* and *Scirpus.* Tussock-sedges and reed-forming sedges (c.f. REEDLAND) are excluded.

Scrub: Woody vegetation in which the cover of shrubs and trees in the canopy is > 80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants < 10 cm diameter at breast height (dbh).

Tussockland: Vegetation in which the cover of tussocks in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussocks include all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and > 10 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium,* and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia.*

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is > 80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥ 10 cm dbh. Tree ferns ≥ 10cm dbh are treated as trees.

Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occassionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain cholorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae that can be seen without the use of a microscope.

Firm mud/sand: A mixture of mud and sand, the surface appears brown and may have a black anaerobic layer below. When walking on the substrate you'll sink 0-2 cm.

Soft mud/sand: A mixture of mud and sand, the surface appears brown and may have a black anaerobic layer below. When walking on the substrate you'll sink 2-5 cm.

Very soft mud/sand: A mixture of mud and sand, the surface appears brown, often with a black anaerobic layer below. When walking on the substrate you'll sink greater than 5 cm.

Mobile sand: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal currents and often forms bars and beaches. When walking on the substrate you'll sink less than 1 cm.

Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance impossible.

Soft sand: Substrate containing greater than 90% sand. When walking on the substrate you'll sink greater than 2 cm.

Stonefield/gravelfield: Land in which the area of unconsolidated gravel (2-20 mm diameter) and/or bare stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. The appropriate name is given depending on whether stones or gravel form the greater area of ground surface. Stonefields and gravelfields are named from the leading plant species when plant cover of ≥ 1%.

Boulderfield: Land in which the area of unconsolidated bare boulders (> 200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulderfields are named from the leading plant species when plant cover is ≥ 1%.

Rockland: Land in which the area of residual bare rock exceeds the area covered by any one class of plant growth-form. Cliff vegetation often includes rocklands. They are named from the leading plant species when plant cover is ≥1%

Cocklebed: Area that is dominated by cockle shells.

Musselreef: Area that is dominated by one or more mussel species.

Oysterreef: Area that is dominated by one or more oyster species.

APPENDIX C: FINE-SCALE ENVIRONMENTAL MONITORING DETAILS

Appendix C 1: Estuary site selection: site coordinates

Table A23: The coordinates (New Zealand Map Grid) of the four corners of the sampling sites within each of the reference estuaries.

Estuary	NZMG-E (m)	NZMG-N (m)
Otamatea		
Site A	2635462.37296	6559176.55405
	2635493.19016	6559229.07265
	2635504.59954	6559218.28530
	2635451.13807	6559186.81578
Site B	2635281.62648	6561695.75661
	2635241.79836	6561645.63072
	2635268.38241	6561701.38948
	2635255.42363	6561641.42141
Site C	2630163.05039	6551826.45148
	2630105.77414	6551842.62488
	2630103.12706	6551828.03509
	2630161.75258	6551841.39285
Ohiwa		
Site A	2869571.92872	6347951.85244
	2869599.33850	6347965.35717
	2869630.84002	6347914.21884
	2869604.24799	6347900.30929
Site B	2872093.85515	6346807.05286
	2872150.02973	6346830.28393
	2872164.63042	6346803.21063
	2872108.84673	6346780.66514
Site C	2867408.58102	6348772.69578
	2867379.44716	6348767.86527
	2867386.53995	6348708.93377
	2867415.52525	6348713.81945
Site D	2868875.67117	6349651.92643
	2868856.99800	6349630.07630
	2868899.69382	6349588.03711
	2868919.61093	6349610.81783
Ruataniwha		
Site A	2481549.15192	6061885.40422
	2481578.81642	6061886.23948
	2481571.78504	6061825.97660
	2481544.32828	6061825.93246
Site B	2482719.14727	6061282.72335
	2482752.90495	6061232.99936
	2482692.87589	6061269.33770
	2482726.53206	6061219.74566

Estuary	NZMG-E (m)	NZMG-N (m)
Site C	2481837.70411	6061799.79102
	2481876.69746	6061755.33232
	2481816.58230	6061778.44549
	2481856.06481	6061733.47783
Waimea		
Site A	2525273.09365	5987710.50462
	2525301.36818	5987718.99385
	2525306.86530	5987659.72806
	2525278.28790	5987650.22492
Site B	2517342.20559	5993604.60397
	2517368.86560	5993592.07105
	2517340.47963	5993539.49690
	2517313.27186	5993551.95742
Site C	2524854.34653	5989674.86913
	2524912.56286	5989686.18315
	2524909.97730	5989715.87601
	2524851.42064	5989704.33532
Site D	2518888.17120	5991761.67680
	2518917.25281	5991753.83814
	2518928.51944	5991810.79295
	2518899.09086	5991819.50914
Havelock		
Site A	2574419.50979	5992683.71754
	2574401.42228	5992627.40356
	2574429.29962	5992617.27421
	2574447.25939	5992673.75551
Site B	2574851.23190	5992626.20776
	2574850.40172	5992557.05053
	2574875.87662	5992572.05323
	2574825.30695	5992611.55689
Avon-Heathcote		
Site A	2487144.71411	5739772.25194
	2487159.37042	5739746.90537
	2487192.73595	5739807.46749
	2487207.48805	5739782.04015
Site B	2488943.33227	5739792.08805
	2488971.10525	5739780.81258
	2488960.16882	5739849.69565
	2488987.82732	5739838.31048
Site C	2488424.20385	5740887.91739
	2488455.58164	5740837.42806
	2488481.55603	5740851.94403
	2488449.69764	5740902.82627

Estuary	NZMG-E (m)	NZMG-N (m)
Kaikorai		
Site A	2308040.98566	5473473.03714
	2308018.31026	5473466.34677
	2308030.52552	5473456.58986
	2308029.46818	5473483.35691
New River		
Site A	2152152.77853	5406021.52272
	2152182.85172	5406015.82825
	2152166.15911	5405956.74419
	2152136.94021	5405962.69961
Site B	2151700.08231	5404387.92392
	2151729.59614	5404385.57425
	2151718.43400	5404326.28855
	2151687.82034	5404326.04969
Site C	2149190.71789	5404351.34363
	2149241.22504	5404319.10534
	2149224.21507	5404294.63002
	2149173.80777	5404327.05641
Site D	2150190.05763	5406272.86654
	2150183.68383	5406243.63194
	2150124.94362	5406256.68245
	2150130.20135	5406286.55846

Appendix C 2: Fine-scale data analysis methodology

Analysis of the environmental data obtained in the fine-scale survey at the reference estuaries was approached in three main steps:

Step 1: Comparing the estuaries
Step 2: Examining the relationships amongst environmental variables
Step 3: Determining the optimum sample size

Statistical analyses of the fine-scale section were conducted using SYSTAT® (version 10), PRIMER (version 5.1.2) and Microsoft® Excel (2002) software packages, and tests from statistical reference text (*e.g.* Zar 1999).

Step 1: Comparing the estuaries

The mean value for each environmental variable was calculated for each site within an estuary, with the associated error expressed as 95% confidence intervals (CIs). For comparative purposes, the infauna abundance was standardized to the number of individuals per 0.1 m^2. Infauna and epifauna richness were expressed as the number of taxa encountered per core and per quadrat, respectively. Abundance and diversity results were displayed as stacked bar graphs, providing a visual indication of the dominant organism types. In some instances, lower taxonomic levels were specified in addition to a more general higher grouping, *i.e.* Class Gastropoda and Sub-Class Opisthobranchia. In this example, the upper level (Class: Gastropoda) includes everything other than that which is included in any specified sub-group/ings (*i.e.* Sub-Class: Opisthobranchia). Groups that represented less than 1% of the total number of animals encountered were pooled to form a composite group, termed 'Others'. A full set of the raw data is provided in the CD that accompanies this document.

Univariate Analysis

A mixed-model nested (or hierarchical) analysis of variance (ANOVA) was used to compare the degree of variation between estuaries with the degree of variation within estuaries for each variable (*e.g.* total nitrogen, total phosphorus, copper). In this model, 'estuary' was treated as the fixed factor and the 'sites' within estuaries were treated as nested (or random) factors. Prior to analysis, the data were examined for normality (Kolmogorov-Smirnov test, lilliefors) and for homoscedasticity (Levene's test) and, when pertinent, the data were appropriately transformed. Once transformed, the data were assumed to be sufficiently normal (Zar 1999).

The mixed-model nested ANOVA was limited to estuaries with two or more sites, *i.e.* excluding Kaikorai Estuary data from this part of the spatial analysis. Additionally, two of the three sites at Ruataniwha estuary did not have chlorophyll *a* and phaeophytin measurements, and two of the three sites at the Kaipara Estuary did not have epifauna (quadrat) data. Therefore, analyses in those estuaries were not possible with those variables. Multiple one-way ANOVAs were then produced using 'site' as the fixed factor to determine which estuaries contained the most variation between sites, and for which variables.

Box. A.1. How to interpret the results

The nested (or hierarchical) ANOVA is a variation on a crossed model ANOVA, where site is nested within estuary as a subgroup. The model compares the total variability that occurs among the samples with the variability that is attributed to estuary groups (source = estuary), and similarly, the total variability with that which can be attributed to the subgroups (source = site). The results are expressed as the F-ratio and significant probability (= P).

Multivariate Analyses

Multivariate statistical procedures were applied to examine relationships between biotic assemblages and the physical and chemical characteristics. For these analyses, data were examined in a site-averaged form. Mean abundance and diversity data from each site (12 replicates) were fourth-root-transformed to increase the relative importance of the sub-dominant taxa in the results. Presence/absence ordinations were also undertaken for comparison. Non-parametric multi-dimensional scaling (MDS; Kruskal & Wish 1978) was used to produce dendrograms and ordination plots based on Bray-Curtis similarities between sites for the infauna (from cores) and epifauna (from quadrats) data separately.

Box A.2. How to interpret the results

Sample ordinations place samples in a two, three or multi-dimensional space according to their similarities or differences in species composition. If a two-dimensional representation explains a sufficient amount of the differences, the samples differences can be viewed spatially on a 2-D plot, where the distance between samples corresponds appropriately to the degree of difference. The usefulness of the MDS display in representing relationships is indicated by the stress statistic; < 0.1, indicates the depiction was very good, > 0.3 indicates the depiction was poor (Clarke & Warwick 1994). The degree of similarity that they share can also be represented quantifiably by a cluster diagram. Relationships between the sites, as dictated by the two community types (infauna and epifauna) and the environmental data, were depicted and described according to this procedure.

Significant differences between sites in the biological composition of the samples were tested by an analysis of similarities using a two-way nested permutation-randomisation test based on Bray-Curtis similarities (two-way nested ANOSIM; (Clarke 1993). This procedure is the multivariate equivalent to the univariate two-way nested ANOVA model, and similarly, had 'sites' nested within 'estuary'. Ordinations of the environmental data were produced using principal components analysis (PCA) for both normalised and un-normalised mean site data. Prior to these analyses, the environmental data were appropriately transformed to maximise normality and normalised to permit comparisons in euclidean distances. Sites A and B in the Ruataniwha Estuary were omitted from the analysis, as chlorophyll *a* data was not obtained from these sites.

Box A.3. How to interpret the results

A two-way nested ANOSIM (with 'site' nested within 'estuary') is the multivariate equivalent of the univariate nested ANOVA; the difference being that ANOSIM is based on a simple non-parametric permutation procedure, applied to a similarity matrix that underlies a corresponding ordination. Such a procedure is particularly well-suited to analysing species abundance data, whereas, the univariate procedure only compares overall sample abundance or species richness. It is important to note whether or not the significance level is less than 5%., as it indicates how many of the permuted statistics were greater than or equal to global R (for summary, see Clarke & Warwick 1994).

Step 2: Examining the relationships between environmental variables.

The inter-relationships between the environmental and biological variable were initially examined using Pearson product-moment correlation coefficient matrices, with accompanying Bonferroni adjusted probabilities (Zar 1999). Correlations were compared at both the replicate (*i.e.* $n_{max} = 288$) and site-average (*i.e.* $n_{max} = 24$) levels. Prior to analysis, data were appropriately transformed to enhance normality. Data were examined both prior to, and following normalisation, to mud content. Biotic data and normalised environmental data were then compared in a correlation matrix to permit further examination of the relationships between nutrients and chemicals once the influence of mud content was removed. Missing data were deleted in a pairwise fashion (Zar 1999).

Relationships between the biotic ordinations (infauna and epifauna) and the environmental data were further examined using the BIOENV procedure, a multivariate analysis (Clarke & Warwick 1994). This procedure attempted to identify the combination of environmental variables which best grouped the sites, in a manner consistent with the observed biological patterns (MDS ordinations). Prior to BIOENV analysis, the variables that were highly correlated ($\rho > 0.85$) were identified using Draftsman Plots and Pearson product moment correlation coefficients. One of each pair of the highly correlated variables was removed from the analysis under the assumption that the other was a suitable surrogate. The variable to be removed was prioritised based on the ease and cost of measurement (*i.e.* favouring those that were measured more easily and cheaply). This process was repeated prior to each BIOENV procedure, as some sites with incomplete data sets had to be removed from the environmental data set to permit the particular analysis.

The similarity matrices for the biotic assemblages (infauna and epifauna) were examined using Bray-Curtis similarities after both a presence/absence and a fourth-root transformation. The matrix for the environmental variables was created using both un-normalised and normalised (to mud content) transformed data, both normalised to euclidean distance. The biotic matrices were then compared to the environmental matrix using the spearman rank correlation method, and the best four results were recorded (with their correlation coefficient).

Box A.4. How to interpret the results

Correlation coefficients are on a scale of ρ = -1 to 1, where a positive correlation implies that for the increase in values of one variable r, the other variable also increases; a negative correlation implies that an increase in one variable is accompanied by a decrease in the other. The closer the value is to -1 or 1, the stronger the intensity of the association between the two variables; ρ = 0 implies no correlation.

Step 3: Determining the optimum sample size

Optimum sample size analyses were carried out using combinations of the 12-replicates per site data sets, collected in the present study. The optimum sample number for each variable was explored by examining estimates of sample variation with increasing sample number (*n*) following methods similar to those described by (Bros & Cowell 1987) and (Hewitt *et al.* 1993). The coefficient of variation (CV, a measure of relative precision) was used as the indicator of variance instead of sample standard error (SE). The use of CVs was recommended by (Bros & Cowell 1987) and was adapted by Hewitt *et al.* (1993) for similar analyses.

Box A.5. Formulae:

$CV = SD/ mean$
$SE = SD/\sqrt{n}$

Box A.6. Technical Note on coefficient of variation (CV)

The use of CV was favoured over SE for the following reasons:

- The relationship between SE and increasing n (decreasing asymptotic function as n approaches zero), given a constant SD, is unaltered by the magnitude of SD. The variable component of SE is therefore, SD.
- Taking the relative measure of variation (SD/mean) facilitates comparisons between different variables with different units and different magnitudes of means.
- The size of the standard deviation, relative to the mean (or difference between means) is the functional sample statistic that is used in conventional power analysis software packages and in sample size estimation procedures described by Zar (1999).
- Measuring relative precision also permitted averaging of CV's between sites and on some occasions, between estuaries, to provide an overall measure of variance for some indicators.

The CV was calculated for randomly chosen combinations of the data from each of the estuary data sets. To avoid problems associated with drawing a range of sample sizes from a fixed pool, Bros & Cowell (1987) recommended using data combinations to represent subsamples of sizes $n = 2, \ldots,$ N/2 (*i.e.* from two replicates through to the maximum number of replicates sampled (N) divided by two = maximum draw size). Therefore, if the samples from only one site were to be used (*i.e.* 12 replicates), then the maximum sample draw size that could be examined would be six. In order to explore variation beyond a sample size (n) of six, pooling was necessary. However, most variable exhibited significant variation between estuaries, which prevented pooling at the 'estuary' level. Therefore, pooling data within estuaries was only possible on some occasions and was explored on a variable-by-variable basis.

Pooling of sites was undertaken when both the mean values and the relative precisions (CVs) were not significantly different between sites ($\alpha = 0.05$). The variation in CV between estuaries for each variable was analysed using a one-way ANOVA (with 'estuary' as the factor). Inter-site homogeneity of CVs (within estuary) was tested when the number of sites within the estuary was > 1 (*i.e.* excluding Kaikorai Estuary) (Zar 1999). When no significant variation was identified ($\alpha = 0.05$) between all sites within an estuary, they were combined to produce a pool of up to 48 replicates (4 sites x 12 replicates) for that variable. When significant variation was detected, the most outlying site was identified, either subjectively in the case of CVs, or by examination of the least squares means in SYSTAT® for the means analysis, and removed from the data. This process was repeated until either the remaining sites were not significantly different, or there were less than

2 sites. In most cases, only one site needed to be removed in order to meet this criterion (typically providing 24 or 36 replicates).

Randomised Sub-Sample Draws

For sample draws with less than one million possible combinations (different combinations of *n* possible from the replicate pool, or *nCr*), the mean, 95th and 5th percentiles of CV were calculated from a maximum of 1000 unique random sub-sample draws. Where the number of possible combinations was greater than one million, only the first 1000 random combinations generated were used. Although combinations were not necessarily unique, the considerably large pool size, from which random sub-samples were drawn, reduced the likelihood of drawing the same combination twice. The 5th and 95th percentiles were used to indicate the distribution of the variance about the mean CV. This was favoured over minimum and maximum values as it is less likely to over-estimate the reasonably attainable CV (Hewitt *et al.* 1993).

The resulting plots demonstrated how the size of the variance changed in relation to the estimate of the mean CV as the sample number (*n*) increased from 2 to 24 (or where only three sites were pooled, 2 to 18) (Figure A30). The upper line of the plot, or 95th percentile, represented the attainable maximum likely CV (CV_{95}) for a given *n*, and the middle line represented the mean CV (CV_{mean}). As the line approached n_{max}, it approximated the 'actual' variation for that variable in that particular estuary (*i.e.* represented the fine-scale spatial variability for that variable). The bottom black line represented the minimum likely expected CV (CV_{05}), at a given *n*. The CV_{95} was the line of most interest for determining the minimum acceptable sample size. Other studies have used criteria based around the change in the slope of this line relative to the initial slope (~ 20 % change) as a quantitative means of defining the minimum acceptable sample size (Bros & Cowell 1978, Hewitt *et al.* 1993). In the case of extremely patchy data, the point at which the variation in the estimate (*e.g.* difference between CV_{95} and CV_{mean}) is sharply reduced may be used. In the current study, the point of maximum benefit for minimum 'cost' (cost benefit point = CBP) was subjectively defined as the point beyond the greatest change in the slope of the line and immediately before a point at which no substantial gain in precision was made for further 5 *n* increases in sample size.

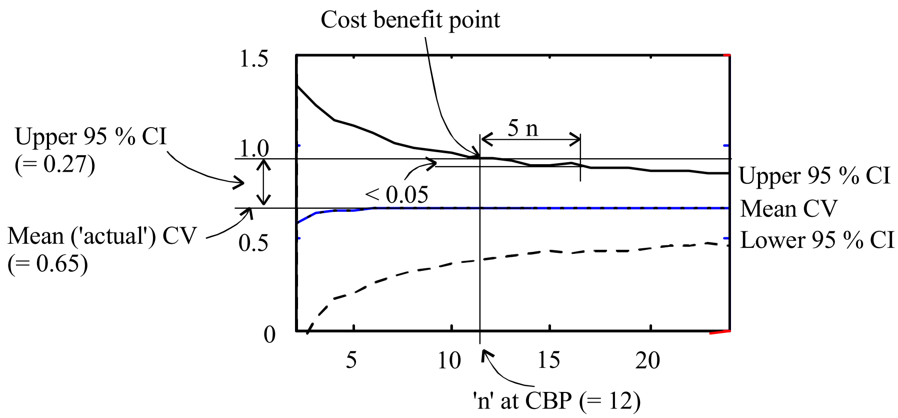
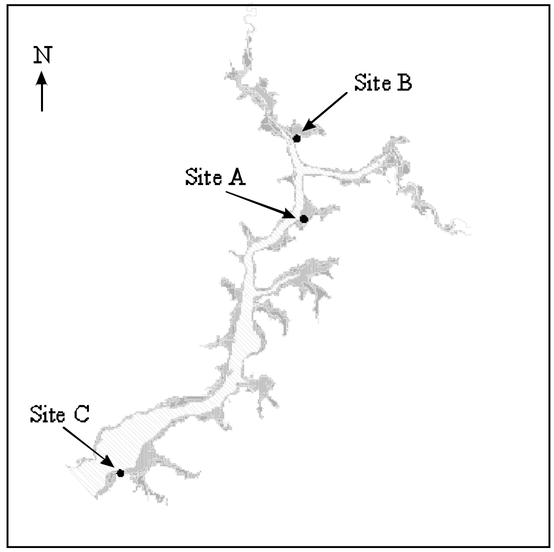


Figure A30: An example of how the cost benefit point (CBP) and near 'actual CV' are derived from a randomized plot of mean CV ± 95 % CI with increasing sample number.

Appendix C 3: Summary of the analytical results for individual reference estuaries

C.3.1 Otamatea Arm (Kaipara Harbour)



Physical and Chemical Characteristics

The physical and chemical properties of the Otamatea Arm sediments at mid-low water sites are summarised in Table A24. The substrata of all three Otamatea sites contained relatively high mud contents (70% for two upper sites and 35% for the more seaward, lower, site) and whole sediment samples had elevated organic matter (AFDW) and nutrient (N and P) concentrations compared with the other reference estuaries. Despite the high mud content of the samples, sediment trace metal contaminants were generally low, and were all below the corresponding ANZECC ISQG-Low trigger values.

Table A24: Physical and chemical sediment properties of sites in the Kaipara Estuary (Otamatea Arm).

Variable	Site A	Site B	Site C	Estuary mean (±1SD)	Estuary range (min - max)	ANZECC mg/kg (dry)	
						ISQG- Low	*ISQG- High*
Gravel, %w/w[1]	10.1	0.4	17.2	9.2 ± 8.4	0.05 - 33.8	n/a	n/a
Sand, %w/w[2]	22.8	31.6	49.6	34.6 ± 13.7	14.9 - 57.5	n/a	n/a
Mud, %w/w[3]	67.2	68.1	33.3	56.2 ± 19.8	21.3 - 77.6	n/a	n/a
Ash free dry weight, %w/w	5.9	6.7	4.5	5.7 ± 1.1	1.7 - 7.8	n/a	n/a
Total Nitrogen, mg/kg (dry)	1942.0	1758.0	1192.0	1630.6 ± 391	800 - 2400	n/a	n/a
TP, mg/kg (dry)	537.3	468.3	572.4	526 ± 53	443 - 619	n/a	n/a
Cadmium, mg/kg (dry)	0.1	0.1	1.0	0.4 ± 0.5	0.1 - 1.2	1.5	10
Chromium, mg/kg (dry)	22.4	20.6	18.6	20.5 ± 1.9	14 - 33	80	370
Copper, mg/kg (dry)	16.3	16.1	9.0	13.8 ± 4.2	7.7 - 18	65	270
Lead, mg/kg (dry)	10.4	8.8	14.8	11.4 ± 3.1	7.3 - 17	50	220
Nickel, mg/kg (dry)	11.0	9.2	7.9	9.4 ± 1.6	5.5 - 14	21	52
Zinc, mg/kg (dry)	61.8	58.3	43.4	54.5 ± 9.7	37 - 71	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

However, once normalised for mud content, the data (Table A25) showed a very different result. In particular, the mud fraction had relatively low concentrations of organic matter, phosphorus, nitrogen and heavy metals compared to the normalised values for other estuaries. These data were consistent with the expected relatively low level of contaminant entry to this section of the Kaipara Harbour, and the fact that much of the catchment consists of easily eroded fine silts and clays.

Table A25: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Kaipara Estuary (Otamatea Arm)

Variable	Site A	Site B	Site C	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight, %w/w	8.9	10.0	14.0	10.94 ± 0.26	2.37 - 18.78
Total Nitrogen, mg/kg (dry)	2918.0	2602.0	3733.0	3084.3 ± 583.5	2100 - 6000
TP, mg/kg (dry)	808.8	692.0	1849.8	1116.9 ± 637.4	605.67 - 2840.38
Cadmium, mg/kg (dry)	0.2	0.1	3.3	1.2 ± 1.8	0.13 - 5.63
Chromium, mg/kg (dry)	33.7	30.1	58.7	40.8 ± 15.5	24.39 - 84.51
Copper, mg/kg (dry)	24.6	23.8	28.7	25.7 ± 2.6	17.6 - 41.31
Lead, mg/kg (dry)	15.7	13.1	48.8	25.9 ± 19.9	10.1 - 79.81
Nickel, mg/kg (dry)	16.6	13.5	25.2	18.5 ± 6.1	11.3 - 37.09
Zinc, mg/kg (dry)	93.3	86.3	138.9	106.2 ± 28.6	70.54 - 206.57

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

The results of the macroinvertebrate analyses show that the sites had a moderate infauna species richness (total species count = 40) and low-medium mean infauna abundance (510 m^{-2}), probably due to the very high mud contents.. No epifauna data were collected at the two inner sites, however abundance and richness were relatively low nearer the mouth.

Overall, the communities were numerically dominated by small deposit-feeding polychaetes (bristle worms) that live and feed within and on the surface of the muds, and filter-feeding bivalves (primarily cockles) that feed on phytoplankton and organic detritus in the overlying water column (Table A26). The other feeding groups that are typically encountered within New Zealand estuarine sediments (*e.g*. omnivores, carnivores, grazers) were also present at these sites.

In terms of epifauna, the site near the mouth was dominated by gastropods (marine snails), both in terms of abundance and species present (Table A27). The majority of the snails at these sites graze on microalgae and detritus on the mud surface but the common carnivorous/scavenging whelk, *Cominella glandiformis*, was also found (generally in clumps on decaying organisms).

Table A26: Summary of the 15 most abundant infaunal species sampled at the Otamatea Arm. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Taxon	Description	Feeding Group	Abundance (mean number per core)			
			Estuary	***Site A***	***Site B***	***Site C***
Heteromastus filiformis	Polychaete worm	Deposit feeder	15.08	12.75	19.00	13.50
Austrovenus stutchburyi	Bivalve	Suspension feeder	11.14	4.75	0.25	28.42
Oligochaeta	Oligochaete worm	Deposit feeder	10.06	16.50	13.25	0.42
Paraonidae	Polychaete worm	Deposit feeder	6.94	2.33	18.17	0.33
Nereidae	Polychaete worm	Omnivore	3.86	1.42	2.50	7.67
Aonides sp.	Polychaete worm	Surface deposit feeder	3.36	0.00	0.00	10.08
Sphaerosyllis hirsula	Polychaete worm	Omnivore	3.11	0.00	0.00	9.33
Cirratulidae	Polychaete worm	Deposit feeder	2.56	0.00	0.08	7.58
Prionospio sp.	Polychaete worm	Surface deposit feeder	2.31	1.67	0.17	5.08
Macomona liliana	Bivalve	Suspension feeder	1.42	0.83	0.08	3.33
Helice crassa	Crab	Deposit feeder & scavenger	1.25	1.17	2.08	0.50
Nucula hartvigiana	Bivalve	Suspension feeder	0.92	0.00	0.00	2.75
Arthritica bifurca	Bivalve	Suspension feeder	0.72	0.08	0.00	2.08
Anthopleura aureoradiata	Sand flat anemone	Filter feeder	0.64	0.00	0.00	1.92
Nemertea	Nemertean worm	Carnivore	0.64	0.50	0.92	0.50

Table A27: Summary of all epifaunal species sampled at the Otamatea Arm. Data are presented as average species abundance per quadrat (0.25 m²)

Taxon	Description	Feeding Group	Abundance (mean number per 0.25 m²)	
			Estuary*	**Site C**
Zeacumantus lutulentus	Marine snail	Grazer on microalgae & detritus	6.08	6.08
Diloma subrostrata	Marine snail	Grazer on microalgae & detritus	5.08	5.08
Diloma zelandica	Marine snail	Grazer on microalgae & detritus	1.00	1.00
Cominella glandiformis	Marine snail	Carnivore & scavenger	0.83	0.83
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	0.33	0.33
Haminoea zelandiae	Nudibranch	Grazer on microalgae & detritus	0.08	0.08
Chiton Unid.	Chiton	Grazer on microalgae	0.08	0.08

* = Epifauna data were not collected from site A and B in the Otamatea Arm.

Benthic algae

No significant macroalgal cover was present at the Otamatea sites.

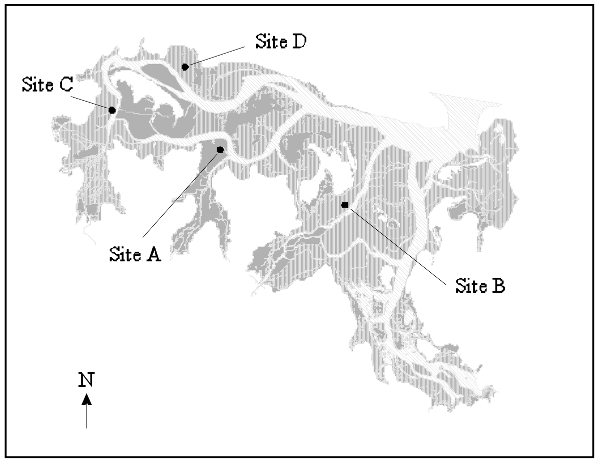
Visual observations and concentrations of chlorophyll *a* and phaeophytin, at all three sites, indicated moderately productive benthic microalgal communities on the muddy sediments. Dense mat developments consistent with highly enriched conditions were not observed, however very high phaeophytin concentrations were observed at Site C suggesting that decomposing plant detritus (*e.g.* sea lettuce) may have been responsible. Microscopic examinations were not carried out to determine species composition at the Kaipara sites.

Summary

The Otamatea sites were very muddy and dominated by animals living within the sediments rather than on top. The muds had relatively low metal concentrations which, taken in combination with our knowledge of the likely inputs, is indicative of low potential for toxicity impacts. Although the sites appeared to be moderately productive, in terms of benthic microalgae, the mud was very fluid, thus providing a generally unstable habitat for macroinvertebrates (*e.g.* burrowing and tube-building polychaetes were likely unable to establish due to the difficulty of keeping tubes open). Such factors may have been responsible for limiting the species abundance and diversity of both epifauna and infauna. In spite of this, the sites selected appear to be appropriate for long-term monitoring because they are representative of the Otamatea Arm as a whole.

C.3.2 Ohiwa Estuary

Physical and chemical characteristics



The physical and chemical properties of the Ohiwa estuary sediments at mid-low water sites are summarised in Table A28. The four Ohiwa sites were all sand-dominated (64-94% sand < 2 mm & > 63 µm %w/w) with some mud (8-32% mud). Whole sediment samples from these sites had moderate-low organic matter (AFDW) and nutrient (N and P) concentrations. Sediment trace metal contaminants were also generally low, and were all below corresponding ANZECC ISQG-Low trigger values. The situation doesn't change much when the data is normalised for mud content (Table A29). That is, the mud fraction (at all sites) still contained relatively low levels of organic matter, phosphorus, nitrogen and trace metals. This is consistent with the expected relatively low level of contaminant entry into the Ohiwa Estuary.

Table A28: Physical and chemical sediment properties of sites in the Ohiwa Estuary

Variable	**Site A**	**Site B**	**Site C**	**Site D**	**Estuary mean (±1SD)**	**Estuary range (min - max)**	**ANZECC mg/kg (dry)**	
							ISQG-Low	*ISQG-High*
Gravel (%w/w)[1]	3.8	2.8	3.6	1.7	3 ± 0.9	0.4 - 12.6	n/a	n/a
Sand (%w/w)[2]	64.5	89.2	69.8	84.3	77 ± 11.7	52.9 - 92.2	n/a	n/a
Mud (%w/w)[3]	31.7	8.0	26.7	14.0	20.1 ± 11	6.7 - 44	n/a	n/a
Ash free dry weight %w/w	2.7	2.0	2.0	1.4	29.9 ± 14.2	0.7 - 3.7	n/a	n/a
Total Nitrogen mg/kg (dry)	775.0	433.3	775.0	616.7	650 ± 162.6	250 - 1000	n/a	n/a
TP mg/kg (dry)	323.8	260.8	293.8	233.8	2 ± 0.5	212 - 350	n/a	n/a
Cadmium mg/kg (dry)	0.1	0.1	0.1	0.1	0.1 ± 0	0.1 - 0.2	1.5	10
Chromium mg/kg (dry)	9.4	6.7	8.3	5.3	278 ± 39.1	2.2 - 12	80	370
Copper mg/kg (dry)	5.1	3.0	5.4	2.6	0.1 ± 0	2.2 - 6.8	65	270
Lead mg/kg (dry)	5.0	0.7	6.6	1.3	7.4 ± 1.8	0.5 - 9.5	50	220
Nickel mg/kg (dry)	5.4	3.1	4.4	2.7	4 ± 1.4	2.1 - 5.9	21	52
Zinc mg/kg (dry)	35.5	25.7	32.5	17.1	3.4 ± 2.9	15 - 38	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

Table A29: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Ohiwa Estuary

Variable	**Site A**	**Site B**	**Site C**	**Site D**	**Estuary mean (±1SD)**	**Estuary range (min - max)**
Ash free dry weight %w/w	8.7	25.5	7.6	10.2	13 ± 8.4	4.63 - 41.43
Total Nitrogen mg/kg (dry)	2516.0	5502.4	3074.4	4582.2	3918.7 ± 1369.8	1699.7 - 7462.7
TP mg/kg (dry)	1059.5	3318.3	1153.9	1727.5	1814.8 ± 1044.9	670.45 - 3971.43
Cadmium mg/kg (dry)	0.3	1.3	0.4	0.8	0.7 ± 0.4	0.23 - 1.89
Chromium mg/kg (dry)	31.1	86.1	31.5	39.3	47 ± 26.3	12.22 - 108.96
Copper mg/kg (dry)	16.7	37.5	20.7	19.2	23.5 ± 9.5	11.36 - 46.27
Lead mg/kg (dry)	16.1	9.4	26.1	10.6	15.5 ± 7.6	2.16 - 47.17
Nickel mg/kg (dry)	17.7	38.9	17.0	20.0	23.4 ± 10.4	12.5 - 50.75
Zinc mg/kg (dry)	116.0	326.5	126.0	128.2	174.2 ± 101.6	81.82 - 388.06

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

The results of the assessment of benthic animals at the four sites in the Ohiwa Estuary show a moderate species richness (total taxa count = 30-42 per site or 13-17 per core) and medium mean abundance of 460-1000 m^{-2} for the sediment dwelling animals (infauna). The abundance of surface dwelling animals (epifauna) was low (60 m^{-2}) at the muddiest site (Site A) and relatively high at the more sandy site D (450 m^{-2}). The mean number of epifauna taxa per core was relatively high at all the sites (range 4-7) compared with the other reference estuaries.

Infauna abundance within the Ohiwa sediments was primarily due to contributions from polychaetes (small marine worms), bivalves (predominantly cockles), nematodes and anthozoans (anemones), while species richness was dominated by the polychaetes and bivalves (Table A30). A total of 53 taxa were recorded across the four sites. The spectrum of dominant feeding groups encountered was typical of that observed in other estuaries; including deposit feeders, suspension and filter-feeders, scavengers and omnivores. Epifaunal taxa at the Ohiwa Estuary were dominated by gastropod species (marine snails), however, bivalves (particularly the cockle *Austrovenus stuchburyi* and the nut shell *Nucula hartvigiana*) were the most abundant species (Table A31). Due to the dominance of gastropods and bivalves, grazers and deposit-feeders were the most common epifaunal feeding groups.

Table A30: Summary of the 15 most abundant infaunal species sampled at the Ohiwa Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	**Description**	**Feeding Group**	**Abundance (mean number per core)**				
			Estuary	***Site A***	***Site B***	***Site C***	***Site D***
Prionospio sp.	Polychaete worm	Surface deposit feeder	21.38	38.00	13.17	1.58	32.75
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	11.96	13.17	12.58	8.75	13.33
Heteromastus filiformis	Polychaete worm	Deposit feeder	11.40	3.67	0.42	29.75	11.75
Anthopleura aureoradiata	Sand flat anemone	Filter feeder	9.69	34.50	2.17	1.75	0.33
Nucula hartvigiana (nut shell)	Bivalve	Deposit feeder	8.46	4.42	2.75	0.92	25.75
Macomona liliana (wedge shell)	Bivalve	Suspension feeder	5.27	3.67	5.25	8.58	3.58
Paraonidae	Polychaete worm	Deposit feeder	5.02	12.92	0.00	4.58	2.58
Nereidae	Polychaete worm	Omnivore	4.48	7.42	3.17	4.17	3.17
Amphipoda	Amphipod	Mobile scavenger	2.02	2.67	0.17	0.92	4.33
Nematoda	Nematode	Varied	1.79	0.00	0.00	0.00	7.17
Aonides sp.	Polychaete worm	Surface deposit feeder	1.54	0.08	5.25	0.00	0.83
Arthritica bifurca	Bivalve	Suspension feeder	1.40	0.75	0.00	1.50	3.33
Maldanidae (bamboo worm)	Polychaete worm	Deposit feeder	1.08	3.17	0.25	0.00	0.92
Sphaerosyllis hirsula	Polychaete worm	Omnivore	1.04	3.83	0.08	0.08	0.17
Oligochaeta	Oligochaete worm	Deposit feeder	1.02	0.00	3.50	0.33	0.25

Table A31: Summary of all epifaunal species sampled at the Ohiwa Estuary. Data are presented as average species abundance per quadrat (0.25 m²)

Species	**Taxanomic Group**	**Feeding Group**	**Abundance (mean number per 0.25 m²)**				
			Estuary	***Site A***	***Site B***	***Site C***	***Site D***
Austrovenus stutchburyi (cockle)	Bivalvia	Suspension feeder	29.69	1.50	12.92	48.25	56.08
Zeacumantus lutulentus	Gastropoda	Grazer on microalgae & detritus	11.17	3.25	3.33	15.92	22.17
Nucula hartvigiana (nut shell)	Bivalvia	Suspension feeder	7.00	0.00	0.00	0.83	27.17
Elminius modestus (barnacle)	Cirripedia	Filter feeder	4.17	0.00	16.67	0.00	0.00
Diloma subrostrata	Gastropoda	Grazer on microalgae & detritus	3.85	3.75	8.25	0.83	2.58
Cominella glandiformis	Gastropoda	Carnivore & scavenger	3.33	5.08	1.50	2.42	4.33
Notoacmea helmsi	Gastropoda	Grazer on microalgae & detritus	1.79	0.00	6.92	0.00	0.25
Haminoea zelandiae	Opisthobranchia	Grazer on microalgae & detritus	0.19	0.50	0.08	0.00	0.17
Zeacumantus subcarinatus	Gastropoda	Grazer on microalgae & detritus	0.15	0.00	0.58	0.00	0.00
Chiton glaucus	Polyplacophora	Grazer on microalgae	0.13	0.42	0.00	0.00	0.08
Halicarcinus sp.	Decapoda	Omnivore	0.10	0.17	0.25	0.00	0.00
Decapoda (larvae unid.)	Decapoda	Planktonic	0.10	0.08	0.33	0.00	0.00
Cominella adspersa	Gastropoda	Carnivore & scavenger	0.04	0.17	0.00	0.00	0.00

Benthic algae

Macroalgal cover (primarily *Gracillaria*) at the Ohiwa sites was limited to <5%.

Visual observations and measured concentrations of chlorophyll *a* and phaeophytin, at the sites, indicated low to moderately productive benthic microalgal communities. These levels are consistent with normal, unenriched estuarine conditions. Dense mat developments indicating highly enriched sediments were not observed. Microalgal communities were typical of natural estuarine environments and were comprised of a variety of, primarily pennate (rod-shaped), diatoms with some euglenoids at Site B only. The large sigmoid-shaped diatom, tentatively identified as *Pleurosigma* or *Gyrosigma* sp. was dominant at Sites A and C while there were no obvious dominant species at Sites B and D.

Summary

Although the Ohiwa sites contained a significant proportion of mud they were nonetheless dominated by sand. Combined with the moderate nutrient and organic matter levels, and low metal contents, this provided a favourable environment for a diverse and moderately abundant benthic animal community. The sites selected appear to be generally comparable to those of the other REs and appropriate for long-term monitoring.

C.3.3 Ruataniwha Estuary

Physical and chemical characteristics

The physical and chemical properties of the Ruataniwha estuary sediments are summarised in Table A32 and Table A33. Sediments were dominated by sand-sized particles (approximately 86%). Organic content and nutrients were relatively low, reflecting the low mud component of the sediments. Sediment trace metal contaminants were also low, and were all well below ANZECC ISQG-Low trigger levels.

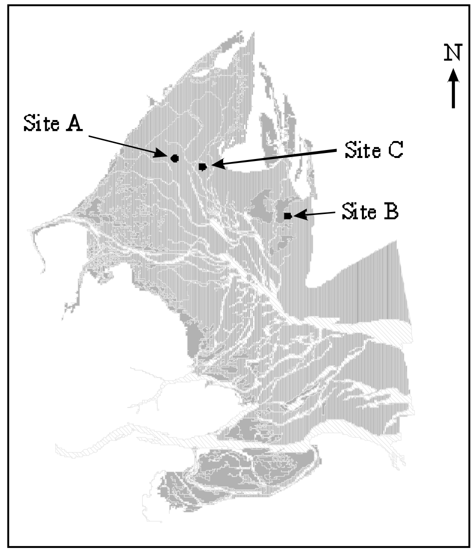


Table A32: Physical and chemical sediment properties of sites in the Ruataniwha Estuary

Variable	Site A	Site B	Site C	Estuary mean (±1SD)	Estuary range (min - max)	ANZECC mg/kg (dry) ISQG-Low	ISQG-High
Gravel, %w/w[1]	0.4	15.7	0.7	5.6 ± 1.8	0.05 - 23.1	n/a	n/a
Sand, %w/w[2]	89.5	75.9	91.2	85.5 ± 0.9	67.3 - 94.3	n/a	n/a
Mud, %w/w[3]	10.2	8.4	9.0	9.2 ± 0.8	5.7 - 17.8	n/a	n/a
Ash free dry weight, %w/w	1.3	0.9	1.4	1.2 ± 0	0.5 - 1.7	n/a	n/a
Total Nitrogen, mg/kg (dry)	250.0	250.0	287.5	262.5 ± 21.7	250 - 700	n/a	n/a
TP, mg/kg (dry)	542.3	396.5	433.7	457.5 ± 11.2	330 - 580	n/a	n/a
Cadmium, mg/kg (dry)	0.1	0.1	0.2	0.1 ± 0	0.02 - 0.3	1.5	10
Chromium, mg/kg (dry)	27.1	20.3	24.7	24 ± 1.3	9.7 - 33	80	370
Copper, mg/kg (dry)	8.7	5.1	7.4	7.1 ± 0.1	4.7 - 9.4	65	270
Lead, mg/kg (dry)	7.6	4.7	1.8	4.7 ± 1.1	0.5 - 8.6	50	220
Nickel, mg/kg (dry)	15.5	12.6	13.0	13.7 ± 0.4	9.7 - 18	21	52
Zinc, mg/kg (dry)	40.8	36.7	35.0	37.5 ± 0.4	32 - 44	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

When the data were normalised for mud content (Table A33), the results were similar (*i.e.* the mud fraction at all the sites had relatively low levels of organic matter, phosphorus, nitrogen and heavy metals). This was consistent with the expected relatively low level of contaminant entry to the Ruataniwha Estuary. Periodic major flood events within the Aorere catchment may also result in an efficient flushing and dispersal of fine sediments and associated components/contaminants into Golden Bay.

Table A33: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Ruataniwha Estuary

Variable	Site A	Site B	Site C	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight %w/w	13.4	11.0	17.0	13.8 ± 3	5.43 - 23.44
Total Nitrogen mg/kg (dry)	2567.1	3051.7	3661.8	3093.5 ± 548.6	1404.5 - 12280.7
TP mg/kg (dry)	5560.5	4831.7	5185.2	5192.5 ± 364.5	2589.89 - 8078.13
Cadmium mg/kg (dry)	1.0	1.5	1.8	1.4 ± 0.4	0.21 - 3.45
Chromium mg/kg (dry)	275.3	247.7	297.4	273.5 ± 24.9	110.23 - 473.68
Copper mg/kg (dry)	89.4	62.5	88.1	80 ± 15.2	41.57 - 126.56
Lead mg/kg (dry)	76.8	58.0	23.4	52.7 ± 27.1	2.81 - 118.97
Nickel mg/kg (dry)	158.5	153.0	157.1	156.2 ± 2.9	67.42 - 245.61
Zinc mg/kg (dry)	420.2	447.3	417.7	428.4 ± 16.4	213.48 - 656.25

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

Infauna abundance and diversity at the Ruataniwha sampling sites were dominated by polychaetes and, to a lesser extent, bivalves (Table A34). The spectrum of feeding groups recorded at these sites was typical of those generally encountered within New Zealand estuarine sediments. Epifauna were dominated by gastropod species, both in terms of abundance and species diversity (Table A35), however, a high abundance of barnacles (Cirripedia) was also observed. The latter require hard substrate for attachment (*e.g.* bivalve shells, rocks or wood).

Table A34: Summary of the 15 most abundant infaunal species sampled at the Ruataniwha Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	Description	Feeding Group	Abundance (mean number per core)			
			Estuary	*Site A*	*Site B*	*Site C*
Heteromastus filiformis	Polychaete worm	Deposit feeder	22.39	1.75	3.17	62.25
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	4.86	3.75	9.33	1.50
Maldanidae (bamboo worm)	Polychaete worm	Deposit feeder	3.39	1.08	1.50	7.58
Aonides sp.	Polychaete worm	Surface deposit feeder	2.11	0.00	6.33	0.00
Macomona liliana (wedge shell)	Bivalve	Suspension feeder	1.86	0.67	0.75	4.17
Prionospio sp.	Polychaete worm	Surface deposit feeder	1.67	0.08	3.08	1.83
Nemertea	Nemertean worm	Carnivore	1.42	0.42	1.17	2.67
Nematoda	Nematode	Varied	1.06	0.00	3.08	0.08
Oligochaeta	Oligochaete worm	Deposit feeder	1.06	0.17	2.75	0.25
Amphipoda	Amphipod	Mobile scavenger	0.75	0.92	0.83	0.50
Capitella capitata	Polychaete worm	Deposit feeder	0.75	0.25	0.42	1.58
Sipuncula	Peanut worm	Deposit feeder	0.72	0.33	1.67	0.17
Nereidae	Polychaete worm	Omnivore	0.72	0.08	1.00	1.08
Polynoidae	Polychaete worm	Carnivore	0.39	0.00	1.17	0.00
Hexatomini sp.	Insect	Deposit feeder	0.36	0.58	0.33	0.17

Table A35: Summary of all epifaunal species sampled at the Ruataniwha Estuary. Data are presented as average species abundance per quadrat ($0.25\ m^2$)

Species	Taxonomic Group	Feeding Group	Abundance (mean number per 0.25 m²)			
			Estuary	***Site A***	***Site B***	***Site C***
Amphibola crenata	Marine snail	Grazer on microalgae & detritus	22.64	12.08	47.75	8.08
Elminius modestus	Barnacle	Filter feeder	6.44	0.00	19.33	0.00
Zeacumantus lutulentus	Marine snail	Grazer on microalgae & detritus	5.61	0.00	16.75	0.08
Diloma subrostrata	Marine snail	Grazer on microalgae & detritus	5.08	3.33	9.25	2.67
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	0.72	0.17	1.50	0.50
Cominella glandiformis	Marine snail	Carnivore & scavenger	0.56	0.00	0.92	0.75
Haminoea zelandiae	Nudibranch	Grazer on microalgae & detritus	0.50	0.00	0.00	1.50
Diloma zelandica	Marine snail	Grazer on microalgae & detritus	0.22	0.00	0.33	0.33
Austrovenus stutchburyi	Bivalve	Suspension feeder	0.17	0.08	0.00	0.42
Halicarcinus sp.	Crab	Omnivore	0.03	0.00	0.00	0.08

Benthic algae

No significant macroalgal cover was observed at the Ruataniwha sites.

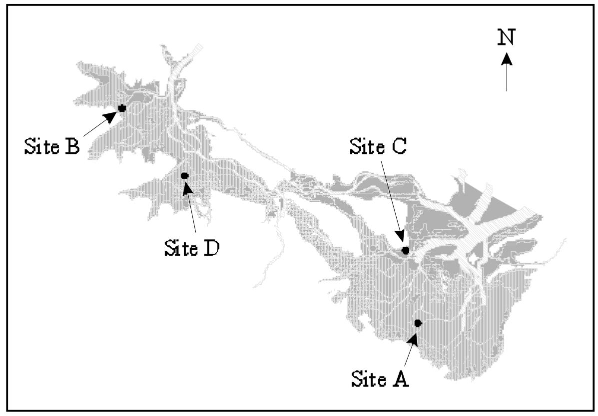
Visual observations and concentrations of chlorophyll *a* and phaeophytin, indicated low density benthic microalgal communities at sites A and B (no visible mat). Dense mat developments indicating highly enriched sediments were not observed, however phaeophytin concentrations were moderately high (185 ± 57 mg m^{-3}) at site C. This may have been an artefact due to inclusion of dead terrestrial plant material (detritus) in the sample. The microalgal species observed at Site C were typical of natural estuarine communities, containing a mixture of, primarily, pennate diatoms (*e.g. Pleurosigma* or *Gyrosigma* sp., *Nitschia* sp.) and euglenoids.

Summary

The three Ruataniwha sites were characterised by primarily sandy (76-91%) sediments. The sites appear to be in a relatively pristine condition according to the characteristics measured, and generally consistent with soft-sediment habitats of the Inlet as a whole. They are therefore considered appropriate for long-term monitoring. However, a large proportion of the Inlet is comprised of hard substrate (*e.g.* cobble) thus restricting the area available for the fine-scale survey. As a result, Sites A and B are relatively close together and one of the two could probably be omitted with minimal loss of information.

C.3.4 Waimea Estuary

Physical and chemical characteristics



The physical and chemical properties of the Waimea estuary sediments at the four sites are summarised in Table A36. The results of sediment grain size analyses indicated that sand predominated (74% sand on average), however there was considerable site to site variability. Mud content was particularly high at sites A and D, containing more than double the mud content at the other two sites. Organic matter (AFDW) was low, particularly for those sites with a lower proportion of mud in the sediments. Nutrients also varied, and higher levels of nitrogen corresponded to sites with a higher mud fraction (sites A and D). Sediment trace metal contaminants were generally low, except for consistently high nickel and chromium concentrations in sediments at all four sites sampled. Nickel exceeded the ANZECC ISQG-High trigger value at all four sites, and one site exceeded the ANZECC ISQG-Low trigger value for chromium concentration. The elevated nickel and chromium levels in the estuarine sediments are consistent with the soils and geology of the Dun Mountain region of the catchment, as the ultramafic rocks are naturally high in copper, nickel and chromium (Grindley & Watters 1965). All other trace metals measured were below ANZECC ISQG-Low trigger values.

A similar pattern was seen once the data were normalised to 100% mud content (Figure A37). All four sites were low in organic content and contained relatively low nutrient levels compared with other reference estuaries in this study. Site C was the only site with moderate levels of nitrogen (3500 mg/kg), and sites B and C contained low to moderate levels of total phosphorus (>2000 mg/kg). The pattern of metal content was similar to previously described, with generally low levels of metals except for elevated concentrations of nickel and chromium. The normalised trace metal concentrations at Site C were higher than the three other Waimea sites. Site C contained the lowest proportion of mud, suggesting therefore that the metals may have been more concentrated within the mud fraction compared with the other sites.

Table A36: Physical and chemical sediment properties of sites in the Waimea Estuary

Variable	Site A	Site B	Site C	Site D	Estuary mean (±1SD)	Estuary range (min - max)	ANZECC mg/kg (dry) ISQG-Low	ISQG-High
Gravel (%w/w)[1]	2.7	0.4	0.9	2.7	1.7 ± 1.2	0.05 - 8.7	n/a	n/a
Sand (%w/w)[2]	65.4	83.7	89.5	56.8	73.9 ± 15.3	25 - 92.5	n/a	n/a
Mud (%w/w)[3]	31.9	15.9	9.6	40.5	24.5 ± 14.2	6.5 - 69.8	n/a	n/a
Ash free dry weight %w/w	1.4	1.1	0.8	2.1	1.3 ± 0.6	0.3 - 2.8	n/a	n/a
TN mg/kg (dry)	633.3	279.2	329.2	783.3	506.3 ± 242.1	250 - 1000	n/a	n/a
TP mg/kg (dry)	440.8	479.8	273.3	539.1	433.3 ± 114.1	243 - 562	n/a	n/a
Cadmium mg/kg (dry)	0.1	0.1	0.4	0.5	0.3 ± 0.2	0.1 - 0.6	1.5	10
Chromium mg/kg (dry)	69.3	44.6	61.3	95.2	67.6 ± 21.1	38 - 110	80	370
Copper mg/kg (dry)	10.3	8.8	7.0	12.3	9.6 ± 2.2	5.7 - 15	65	270
Lead mg/kg (dry)	4.2	6.3	7.7	11.3	7.4 ± 3	0.5 - 13	50	220
Nickel mg/kg (dry)	65.1	72.3	58.3	94.2	72.5 ± 15.6	48 - 100	21	52
Zinc mg/kg (dry)	44.2	38.4	34.5	50.2	41.8 ± 6.8	29 - 54	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

Table A37: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Waimea Estuary

Variable	Site A	Site B	Site C	Site D	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight %w/w	4.6	6.9	8.2	5.1	6.2 ± 1.6	2.11 - 18.46
TN mg/kg (dry)	0.2	0.2	0.4	0.2	0.2 ± 0.1	0.1 - 0.92
TP mg/kg (dry)	1503.6	3168.1	2944.8	1345.7	2240.6 ± 948.7	687.68 - 4584.62
Cadmium mg/kg (dry)	0.3	0.7	4.0	1.2	1.6 ± 1.7	0.14 - 5.61
Chromium mg/kg (dry)	236.7	293.3	660.6	236.4	356.8 ± 204.3	113.18 - 1046.15
Copper mg/kg (dry)	34.2	57.8	75.7	30.5	49.5 ± 21.2	18.62 - 129.23
Lead mg/kg (dry)	11.9	41.4	82.4	28.3	41 ± 30.1	1.84 - 130.77
Nickel mg/kg (dry)	222.7	478.0	628.5	234.6	391 ± 197.3	101.72 - 1015.38
Zinc mg/kg (dry)	148.9	252.9	372.3	124.9	224.7 ± 113	77.36 - 600

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

The results of the assessment of benthic animals at the four sites along the Waimea Estuary show a diverse species assemblage of infauna taxa (22 to 28 taxa per site). Infaunal abundance varied between sites, and was notably lower at site B (28 animals/core), while the other three sites recorded around 70 animals per core. Infaunal abundance and richness were co-dominated by deposit-feeding polychaetes (bristle worms) and bivalves, primarily *Austrovenus stutchburyi* (cockles) and *Arthritica bifurca* (Table A38). The dominance of these taxa were reflected in the feeding-groups, with deposit feeders and suspension feeders being the most abundant, however, the other feeding groups that are typically encountered within New Zealand estuarine sediments (*e.g.* omnivores, carnivores, grazers) were also present at these sites. The variability between sites reflects the patchiness of invertebrate distributions, particularly for species such as cockles, which tend to form beds in an estuary. Site B had consistently lower abundances compared to the other three sites, however, the reasons are unclear. The presence of the capitellid polychaete *Heteromastus filiformis* in high abundances could indicate a shift in the balance of the sediment infauna at Sites A and D, as it is a species that typically favours nutrient enriched sediments (ANZECC & ARMCANZ 2000).

Table A38: Summary of the 15 most abundant infaunal species sampled at the Waimea Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	**Description**	**Feeding Group**	**Abundance (Average number per core)**				
			Estuary	***Site A***	***Site B***	***Site C***	***Site D***
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	13.81	5.75	7.83	25.25	16.42
Heteromastus filiformis	Polychaete worms	Deposit feeder	10.71	12.92	2.83	9.25	17.83
Prionospio sp.	Polychaete worms	Surface deposit feeder	9.04	8.08	2.75	15.83	9.50
Arthritica bifurca	Bivalve	Suspension feeder	6.90	14.25	4.17	3.67	5.50
Potamopyrgus estuarinus	Polychaete worms	Grazer on microalgae & detritus	3.52	12.92	0.42	0.00	0.75
Nereidae	Polychaete worms	Omnivore	3.35	5.17	3.08	2.92	2.25
Macomona liliana (wedge shell)	Bivalve	Suspension feeder	2.33	2.92	1.33	2.58	2.50
Amphipoda	Amphipod	Mobile scavenger	1.35	1.67	1.08	1.92	0.75
Anthopleura aureoradiata	Sand flat anemone	Filter feeder	1.06	1.08	0.17	0.58	2.42
Nucula hartvigiana (nut shell)	Bivalve	Suspension feeder	1.04	0.50	0.17	2.67	0.83
Nemertea	Nemertean worm	Carnivore	1.00	0.42	1.08	1.58	0.92
Aonides sp.	Polychaete worms	Surface deposit feeder	0.90	0.00	0.17	2.42	1.00
Amphibola crenata (mud snail)	Marine snail	Grazer on microalgae & detritus	0.73	2.00	0.08	0.50	0.33
Sipuncula (peanut worm)	Peanut worm	Deposit feeder	0.52	0.67	0.58	0.50	0.33
Boccardia sp.	Polychaete worms	Deposit feeder	0.42	0.58	0.08	0.00	1.00

The abundance and species richness of surface dwelling animals (epifauna) varied considerably among the four Waimea Estuary sites; *i.e.* from 2.1 to 7.4 species on average per quadrat at site B and D, respectively. Epifauna at the Waimea estuary were dominated by gastropod (marine snail) species, both in terms of abundance and the large diversity of species (Table A39). The majority of the snails at these sites graze on microalgae and detritus on the mud surface but the common carnivorous/scavenging whelk (*Cominella glandiformis*) was also found, generally in clumps on decaying organisms. As with the infauna, Site B had much lower abundances of epifaunal species compared to the other three sites.

Table A39: Summary of all epifaunal species sampled at the Waimea Estuary. Data are presented as average species abundance per quadrat (0.25 m²)

Species	Taxanomic Group	Feeding Group	Abundance (Average number per 0.25 m²)				
			Estuary	*Site A*	*Site B*	*Site C*	*Site D*
Zeacumantus lutulentus	Gastropoda	Grazer on microalgae & detritus	11.04	0.08	26.50	14.00	3.58
Austrovenus stutchburyi (cockle)	Bivalvia	Suspension feeder	6.92	19.08	1.75	1.42	5.42
Diloma subrostrata	Gastropoda	Grazer on microalgae & detritus	6.56	5.67	2.42	12.58	5.58
Elminius modestus (barnacle)	Cirripedia	Filter feeder	1.92	0.00	6.67	0.25	0.75
Diloma zelandica	Gastropoda	Grazer on microalgae & detritus	1.19	0.00	0.08	0.00	4.67
Notoacmea helmsi	Gastropoda	Grazer on microalgae & detritus	1.15	1.00	0.42	2.42	0.75
Amphibola crenata	Gastropoda	Grazer on microalgae & detritus	0.94	0.00	0.00	0.08	3.67
Cominella glandiformis	Gastropoda	Carnivore & scavenger	0.40	0.83	0.75	0.00	0.00
Micrelenchus tenebrosus	Gastropoda	Grazer on microalgae	0.31	0.00	0.00	0.83	0.42
Halicarcinus whitei	Decapoda	Omnivore	0.10	0.00	0.08	0.25	0.08
Xenostrobus pulex	Bivalvia	Filter feeder	0.02	0.00	0.00	0.08	0.00
Haminoea zelandiae	Opisthobranchia	Grazer on microalgae & detritus	0.02	0.00	0.00	0.00	0.08

Benthic algae

Three of the four Waimea sites contained a macroalgal cover of <5%, however a mixture of sea lettuce (*Ulva lactuca*) and agar weed (*Gracilaria chilensis*) covered an estimated 29% of Site D.

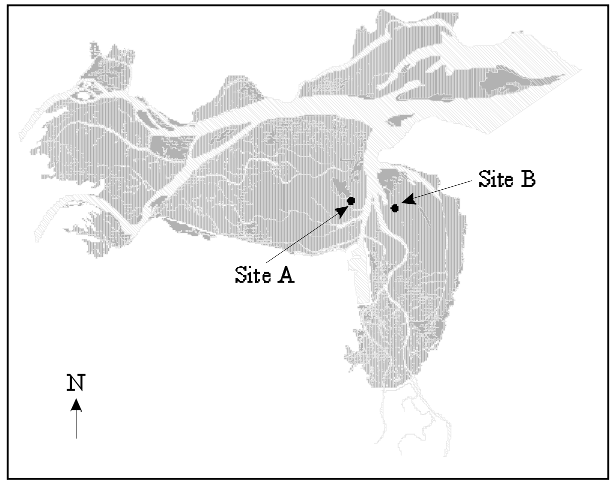
Visual observations and concentrations of chlorophyll *a* and phaeophytin indicated low density benthic microalgal communities at all four sites. Dense mat developments indicating highly enriched sediments were not observed. The communities at all sites were dominated by large, sigmoid-shaped, pennate diatoms tentatively identified as *Pleurosigma* or *Gyrosigma* sp. *Euglena* sp. were co-dominant at Site C, and all sites contained a diverse range of pennate (rod-shaped) and, to a lesser extent, centric (disc-shaped) diatoms. The observed communities were typical of relatively unenriched New Zealand estuaries.

Summary

The four Waimea Estuary sites were characterised by predominantly sandy sediments. All four sites were low in organic content and relatively low in nutrient levels compared with other reference estuaries in this study, however elevated capitellid worm densities at two sites may have been enrichment-related. The mud fraction had relatively low metal concentrations, except for chromium and nickel, which were consistently elevated. This is likely attributed to the naturally high levels of these metals in the catchment. The species richness and abundance of taxa of both infauna and epifauna were suggestive of a well-balance community, although Site B contained reduced abundance of animals. The selected sampling locations were generally comparable to those of the other REs and would appear to provide useful long-term monitoring sites.

C.3.5 Havelock Estuary

Physical and chemical characteristics



The physical and chemical properties of the Havelock Estuary sediments at the two sites are summarised in Table A40. Both sites were primarily sandy (> 70% sand on average), with approximately 20% mud and 4% gravel. Whole sediments samples from these sites had low to moderate levels of organics (as indicated by the ash free dry weight, AFDW). Site A contained moderate levels of nutrients with roughly twice the level of total nitrogen and higher phosphorus than site B. Sediment trace metal contaminants were generally low and below ANZECC ISQG-Low trigger values. The main exception was for nickel, with levels in the sediment at Site A exceeding the ANZECC ISQG-Low value. Chromium values were elevated relative to the other reference estuaries, however, they did not exceed the ANZECC ISQG-Low value. The elevated nickel and chromium levels in the sediments are likely to be attributed to the soils and geology of the Dun Mountain region of the catchment, as the ultramafic rocks in this area are naturally high in copper, nickel and chromium (Grindley & Watters 1965).

Table A40: Physical and chemical sediment properties of sites in the Havelock Estuary

Variable	Site A	Site B	Estuary mean (±1SD)	Estuary range (min - max)	ANZECC mg/kg (dry)	
					ISQG- Low	*ISQG- High*
Gravel, %w/w[1]	6.0	1.6	3.8 ± 3.1	0.5 - 9.3	n/a	n/a
Sand, %w/w[2]	73.6	80.6	77.1 ± 4.9	68.3 - 85	n/a	n/a
Mud, %w/w[3]	20.4	17.8	19.1 ± 1.9	13.4 - 26.1	n/a	n/a
Ash free dry weight, %w/w	1.8	1.3	1.5 ± 0.3	0.7 - 2.3	n/a	n/a
TN, mg/kg (dry)	555.8	287.5	421.7 ± 189.7	70 - 900	n/a	n/a
TP, mg/kg (dry)	393.5	265.5	329.5 ± 90.5	241 - 433	n/a	n/a
Cadmium, mg/kg (dry)	0.2	0.4	0.3 ± 0.2	0.1 - 0.5	1.5	10
Chromium, mg/kg (dry)	70.1	27.4	48.8 ± 30.2	23 - 82	80	370
Copper, mg/kg (dry)	11.2	10.1	10.7 ± 0.7	9.1 - 12	65	270
Lead, mg/kg (dry)	5.6	5.7	5.6 ± 0.1	3.1 - 8.5	50	220
Nickel, mg/kg (dry)	38.1	14.8	26.5 ± 16.4	13 - 41	21	52
Zinc, mg/kg (dry)	51.1	34.8	43 ± 11.5	31 - 53	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

Once normalised for mud content, the data (Table A41) shows that the mud fraction of both sites contained relatively low levels of all trace metals, although nickel, chromium and cadmium were still elevated in comparison to other reference estuaries in this study. The levels of nutrients (nitrogen and phosphorus) and organic matter associated with the mud were low.

Table A41: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Havelock Estuary

Variable	Site A	Site B	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight, %w/w	8.9	7.8	8.4 ± 0.8	3.83 - 14.02
TN, mg/kg (dry)	2836.8	1597.9	2217.3 ± 876	275.6 - 5389.2
T,P mg/kg (dry)	1977.9	1529.3	1753.6 ± 317.2	1100.78 - 2647.44
Cadmium, mg/kg (dry)	0.8	2.4	1.6 ± 1.1	0.39 - 3.73
Chromium, mg/kg (dry)	350.1	157.2	253.7 ± 136.4	112.4 - 448.72
Copper, mg/kg (dry)	55.7	58.2	57 ± 1.7	42.64 - 70.51
Lead, mg/kg (dry)	27.9	33.2	30.6 ± 3.8	13.57 - 47.01
Nickel, mg/kg (dry)	192.5	85.0	138.7 ± 76	62.02 - 250
Zinc, mg/kg (dry)	256.7	200.2	228.4 ± 39.9	151.16 - 333.33

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

Diverse infaunal species assemblages were observed, with sites A and B containing averages of 38 and 19 infaunal taxa, respectively. Site A also had a higher mean abundance of species than Site B. Overall, infaunal abundance and diversity were dominated by deposit-feeding polychaetes (bristle worms) and filter-feeding bivalves, mainly *Austrovenus stutchburyi* (cockles) and *Arthritica bifurca* (Table A42). The other feeding groups that are typically encountered within New Zealand estuarine sediments (*e.g.* omnivores, carnivores, grazers) were also present at these sites.

The species richness of epifauna at the two Havelock Estuary sites was quite low (an average of 1.5 and 4.8 species per quadrat at site A and B, respectively). The epifauna were dominated by gastropods, primarily the mudsnail *(Amphibola crenata)*, and bivalves (refer Table A43). Site A contained a much greater abundance of epifauna, due to the high numbers of the bivalves, *Austrovenus stutchburyi* and *Xenostrobus pulex* compared to low or no occurrences of these species at Site B. There were also low abundances of decapods present in the epifauna samples. It is possible that the Havelock Estuary undergoes frequent periods of low salinity, due to the large freshwater input from two rivers during periods of heavy rainfall. This harsher salinity environment could explain the lower species diversity of benthic invertebrates observed at the Havelock estuary, compared with the other reference estuaries in this study.

Table A42: Summary of the 15 most abundant infaunal species sampled at the Havelock Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	**Descritpion**	**Feeding Group**	**Abundance (mean number per core)**		
			Estuary	***Site A***	***Site B***
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	6.63	8.67	4.58
Arthritica bifurca	Bivalve	Suspension feeder	4.42	0.83	8.00
Heteromastus filiformis	Polychaete worm	Deposit feeder	1.42	2.75	0.08
Oligochaeta	Oligochaete worm	Deposit feeder	1.17	2.33	0.00
Maldanidae (bamboo worm)	Polychaete worm	Deposit feeder	1.00	1.08	0.92
Nicon aestuariensis	Polychaete worm	Omnivore	0.83	0.08	1.58
Prionospio sp.	Polychaete worm	Surface deposit feeder	0.83	1.67	0.00
Amphibola crenata (mud snail)	Marine snail	Grazer on microalgae & detritus	0.79	0.50	1.08
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	0.75	1.25	0.25
Capitella capitata	Polychaete worm	Deposit feeder	0.54	1.08	0.00
Nemertea	Nemertean worm	Carnivore	0.50	0.75	0.25
Macrophthalmus hirtipes	Crab	Deposit feeder & scavenger	0.46	0.83	0.08
Nereidae	Polychaete worm	Omnivore	0.42	0.83	0.00
Orbinia papillosa	Polychaete worm	Deposit feeder	0.38	0.08	0.67
Paraonidae	Polychaete worm	Deposit feeder	0.33	0.67	0.00

Table A43: Summary of all epifaunal species sampled at the Havelock Estuary. Data are presented as average species abundance per quadrat (0.25 m²)

Species	**Description**	**Feeding Group**	**Abundance (per 0.25 m²)**		
			Estuary	***Site A***	***Site B***
Amphibola crenata	Marine	Grazer on microalgae & detritus	91.88	77.17	106.58
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	16.29	31.42	1.17
Xenostrobus pulex (black mussel)	Bivalve	Filter feeder	14.29	28.58	0.00
Crassostrea gigas	Bivalve	Filter feeder	1.83	3.67	0.00
Zeacumantus lutulentus	Marine snail	Grazer on microalgae & detritus	0.54	1.08	0.00
Cominella glandiformis	Marine snail	Carnivore & scavenger	0.54	1.00	0.08
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	0.33	0.67	0.00
Macrophthalmus hirtipes (crab)	Crab	Deposit feeder & scavenger	0.04	0.08	0.00
Hemigrapsus crenulatus (crab)	Crab	Deposit feeder & scavenger	0.04	0.08	0.00

Benthic algae

An approximately 5% cover of agar weed (*Gracilaria chilensis*) was observed at Havelock Site A, while no macroalgae were present at site B.

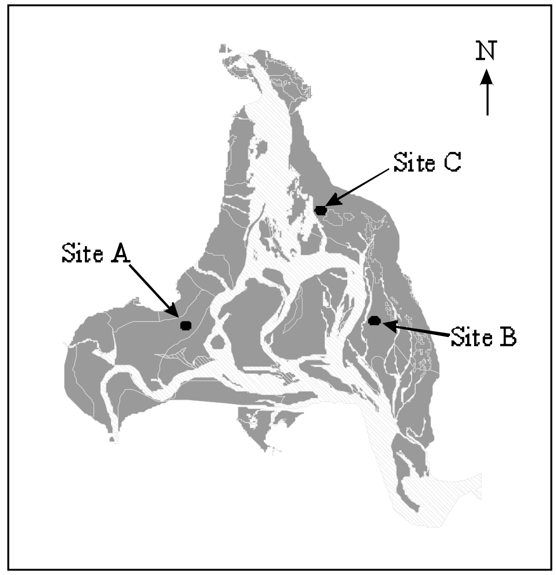
Visual observations and concentrations of chlorophyll *a* and phaeophytin indicated low density benthic microalgal communities at both sites. Dense mat developments indicating highly enriched sediments were not observed. The community at Site A was dominated by large, sigmoid shaped, pennate diatoms tentatively identified as *Pleurosigma* or *Gyrosigma* sp., whereas a mixed community containing a diverse range of pennate (rod-shaped) and, to a lesser extent, centric (disc-shaped) diatoms was observed at Site B. The observed communities were typical of relatively unenriched New Zealand estuaries.

Summary

Sediments at the two Havelock Estuary sites were predominantly sandy, with an average of 20% mud content. The mud fraction had relatively low metal concentrations, except for chromium and nickel, which were elevated to levels approaching those found in estuaries with highly urban catchments. This is inconsistent with the relatively unmodified extent of the Havelock catchment, and is likely attributable to the naturally high levels of these metals in the Pelorus River catchment. Characteristics of the selected sampling locations were generally comparable to those of the other REs and would appear to provide useful long-term monitoring sites.

C.3.6 Avon-Heathcote Estuary

Physical and chemical characteristics



The physical and chemical properties of the Avon-Heathcote Estuary sediments at the three sites are summarised in Table A44. Sediments at the sites were largely composed of sand (93.9% on average) with a small mud fraction of around 5%. Organic content (measured by ash free dry weight, AFDW) was low, reflecting the low mud component of the sediments. Nitrogen was also relatively low, and the total phosphorus was low to moderate, ranging from 298 to 355 mg/kg dry weight. Trace metal concentrations in whole sediment samples were low, and all were well below ANZECC ISQG-Low trigger values.

Table A44: Physical and chemical sediment properties of sites in the Avon-Heathcote Estuary

Variable	**Site A**	**Site B**	**Site C**	**Estuary mean (± 1SD)**	**Estuary range (min - max)**	**ANZECC mg/kg (dry)** *ISQG- Low*	*ISQG- High*
Gravel (%w/w)[1]	1.2	0.3	0.8	0.8 ± 0.5	0.05 - 7.6	n/a	n/a
Sand (%w/w)[2]	93.5	95.5	92.5	93.8 ± 1.5	89.5 - 97	n/a	n/a
Mud (%w/w)[3]	5.3	4.2	6.7	5.4 ± 1.3	2.5 - 9	n/a	n/a
Ash free dry weight %w/w	1.0	1.0	1.0	1 ± 0	0.5 - 1.3	n/a	n/a
TN mg/kg (dry)	404.0	250.0	250.0	301.4 ± 89	250 - 600	n/a	n/a
TP mg/kg (dry)	324.1	323.9	332.6	326.9 ± 5	298 - 355	n/a	n/a
Cadmium mg/kg (dry)	0.1	0.1	0.1	0.1 ± 0	0.1 - 0.1	1.5	10
Chromium mg/kg (dry)	17.1	13.9	15.9	15.6 ± 1.6	12 - 19	80	370
Copper mg/kg (dry)	3.3	2.8	3.5	3.2 ± 0.4	2.4 - 4	65	270
Lead mg/kg (dry)	7.3	4.6	7.2	6.3 ± 1.6	3.5 - 9.1	50	220
Nickel mg/kg (dry)	6.3	7.0	6.5	6.6 ± 0.4	5.1 - 7.5	21	52
Zinc mg/kg (dry)	41.7	32.6	40.6	38.3 ± 5	30 - 46	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

However, once the data was normalised to 100% mud, the measured variables typically increased, as the mud fraction was a small proportion of the total sediments. Therefore they appeared to be more concentrated within that fraction (Table A45). The level of organic matter, nitrogen and phosphorus in the mud were all elevated to moderate levels compared to other reference estuaries in this study, suggesting a moderately enriched estuary. Trace metal concentrations were high in the Avon-Heathcote muds compared to mud-normalised values for most of the other reference estuaries in this study. Zinc and lead levels were particularly elevated, and chromium, cadmium and nickel were found in moderate concentrations, indicative of a highly urbanised catchment.

Table A45: Physical and chemical sediment properties (standardised to 100% mud) of sites in the Avon-Heathcote Estuary

Variable	Site A	Site B	Site C	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight, %w/w	20.2	24.8	15.4	20.1 ± 4.7	8.77 - 42.86
TN, %w/w (dry)	8499.0	6330.0	3860.0	6229.6 ± 2320.8	294.1 - 2941.2
TP, mg/kg (dry)	6912.5	8168.9	5126.3	6735.9 ± 1529	3544.44 - 12640
Cadmium, mg/kg (dry)	2.1	2.5	1.5	2.1 ± 0.5	1.11 - 4
Chromium, mg/kg (dry)	365.4	347.7	244.9	319.3 ± 65.1	188.24 - 720
Copper, mg/kg (dry)	69.4	69.0	54.1	64.2 ± 8.7	41.11 - 136
Lead, mg/kg (dry)	154.2	115.9	109.6	126.6 ± 24.1	76.39 - 276
Nickel, mg/kg (dry)	134.1	176.2	100.4	136.9 ± 38	77.78 - 268
Zinc, mg/kg (dry)	885.8	819.7	624.3	776.6 ± 136	494.12 - 1680

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

Infaunal species richness at the sites sampled in the Avon-Heathcote Estuary varied between 25 and 29 species per site, and were dominated largely by polychaetes (refer Table A46), with the remaining taxa being composed of bivalves and small crustaceans. Site B showed a reduced number of individuals per core, and site A had the greatest number, particularly of the polychaete *Aonides* sp. (approximately 458 individuals per core). The large dominance of a single species of polychaete (*Aonides* sp.), making up more than 85% of the samples, could indicate that the estuary environment is impacted and out of balance in terms of community structure.

Epifaunal species richness at the three Avon-Heathcote sites was high in comparison with some other reference estuaries, with means of 4.4 to 7.7 species per quadrat (Table A47). Species abundance was dominated by gastropods at Site B, while the bivalve *Austrovenus stutchburyi* (cockle) was the most abundant species at sites A and C. A diverse range of feeding groups was observed at these sites; including deposit-feeders, grazers, scavengers and filter-feeders. The lower species and abundance and diversity at Site B may be related to its proximity to the tidal opening and consequent flushing, however it can not be explained by the physical and chemical characteristics.

Table A46: Summary of the 15 most abundant infaunal species sampled at the Avon-Heathcote Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	Description	Feeding Group	Abundance (mean number per core)			
			Estuary	*Site A*	*Site B*	*Site C*
Aonides sp.	Polychaete worm	Surface deposit feeder	276.61	458.42	148.17	223.25
Haploscoloplos cylindrifer	Polychaete worm	Deposit feeder	11.39	12.17	3.42	18.58
Macomona liliana	Bivalve	Suspension feeder	8.67	5.42	7.67	12.92
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	6.53	8.42	5.75	5.42
Heteromastus filiformis	Polychaete worm	Deposit feeder	2.92	3.42	2.67	2.67
Amphipoda	Amphipod	Mobile scavenger	1.72	1.17	0.42	3.58
Prionospio sp.	Polychaete worm	Surface deposit feeder	1.61	0.33	3.58	0.92
Arthritica bifurca	Bivalve	Suspension feeder	1.39	0.42	2.67	1.08
Polydora sp.	Polychaete worm	Surface deposit feeder	1.31	0.00	3.58	0.33
Nereidae	Polychaete worm	Omnivore	1.19	0.50	1.17	1.92
Macrophthalmus hirtipes	Crab	Deposit feeder & scavenger	1.17	1.33	0.92	1.25
Mysidacea	Mysid shrimp	Filter & deposit feeders	1.11	0.00	0.00	3.33
Nemertea	Nemertean worm	Carnivore	0.94	0.75	1.17	0.92
Anthopleura aureoradiata	Sand flat anemone	Filter feeder	0.81	1.33	0.00	1.08
Orbinia papillosa	Polychaete worm	Deposit feeder	0.64	0.00	1.67	0.25

Table A47: Summary of all epifaunal species sampled at the Avon-Heathcote Estuary. Data are presented as average species abundance per quadrat (0.25 m²)

Species	Description	Feeding Group	Abundance (mean number per 0.25 m²)			
			Estuary	*Site A*	*Site B*	*Site C*
Austrovenus stutchburyi	Bivalve	Suspension feeder	7.92	18.00	0.17	5.58
Diloma zelandica	Marine snail	Grazer on microalgae & detritus	4.44	7.58	3.67	2.08
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	4.19	3.92	4.25	4.42
Anthopleura aureoradiata	Sand flat anemone	Filter feeder	2.67	3.67	0.17	4.17
Diloma subrostrata	Marine snail	Grazer on microalgae & detritus	2.64	2.75	3.50	1.67
Micrelenchus tenebrosus	Marine snail	Grazer on microalgae	0.83	0.83	1.58	0.08
Cominella glandiformis	Marine snail	Carnivore & scavenger	0.56	0.00	0.58	1.08
Amphibola crenata	Marine snail	Grazer on microalgae & detritus	0.22	0.42	0.08	0.17
Macrophthalmus hirtipes	Crab	Deposit feeder & scavenger	0.08	0.00	0.00	0.25
Halicarcinus sp.	Crab	Omnivore	0.08	0.08	0.00	0.17
Elminius modestus	Barnacle	Filter feeder	0.06	0.17	0.00	0.00
Hemigrapsus crenulatus	Crab	Deposit feeder & scavenger	0.03	0.08	0.00	0.00

Benthic algae

A varied macroalgal cover (mean <5 to approximately 10% cover) was dominated by sea lettuce (*Ulva lactuca*) at the three Avon-Heathcote sites.

Visual observations and measured concentrations of chlorophyll *a* and phaeophytin, indicated moderately productive benthic microalgal communities at sites B and C. The microalgal communities at these sites were typical of other New Zealand estuarine sites containing diverse mixtures of pennate and centric diatoms. However, a more dense mat development, consistent with enriched conditions, was observed at Site A, which is located in a region affected by the discharge from the Christchurch Wastewater Treatment Plant (URS 2001). At this site, the mean chlorophyll *a* concentration of 111 ± 34 mg m^{-3} was the highest observed amongst the reference estuaries, and a very different microalgal community was observed. Here the most prevalent microalgal species were cyanobacteria (*e.g. Oscillatoria* sp.) and green algae (*e.g. Scenedesmus* sp. and *Chlorococcum* sp.) that are characteristic of oxidation pond communities. Fewer estuarine diatom species were present.

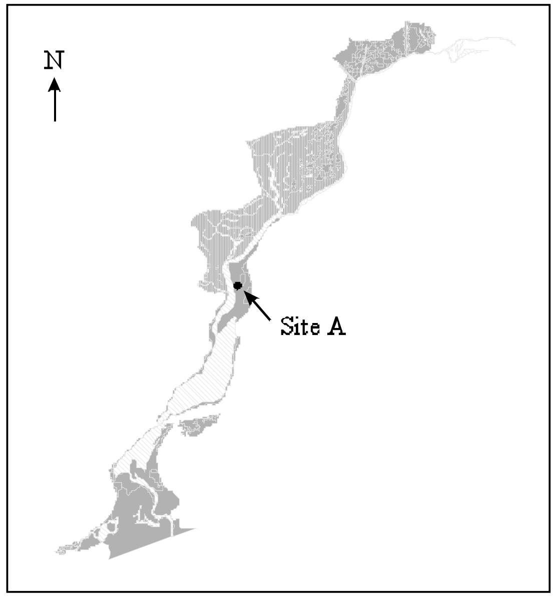
Summary

The level of organic matter, nitrogen and phosphorus in the mud fraction of the Avon-Heathcote sediments (100% mud-normalised data) were all elevated to moderately high levels compared to other reference estuaries, indicating the possibility of some enrichment of the mud fraction. Microalgal biomass (chl *a*) and species composition at one site (Site A) indicated oxidation pond discharge effects. Elevated heavy metal concentrations also suggest contamination from urban and industrial sources. The invertebrate communities contained a diverse range of taxa, particularly the epifauna. However, the large dominance of the polychaete *Aonides* sp. in the infaunal cores suggests the estuary is showing signs of an impacted system.

Although characteristics of the selected sampling locations were generally comparable to those of the other REs, the effects of nutrient enrichment were apparent. The results suggest that the selected site locations would provide useful long-term monitoring sites for the estuary. They also extend the RE data set to include sites affected by urban activities and were therefore important to the protocol development.

C.3.7 Kaikorai Estuary

Physical and chemical characteristics



The physical and chemical properties of the Kaikorai Estuary sediments at the single site (Site A) are summarised in Table A48. The results indicated a soft mud/sand habitat (approx. 70% sand and 27% mud). The organic content (5%) and nutrients (TN of 1700 mg/kg and TP of 750 mg/kg) of whole sediment samples were relatively high, reflecting the moderate mud component of the sediments. Copper and chromium, but particularly lead and zinc levels in the sediments were elevated compared with the reference estuaries in the present study, however, all trace metals measured were below ANZECC ISQG-Low trigger values.

Table A48: Physical and chemical sediment properties of a site in the Kaikorai Estuary

Variable	Site A	Estuary range (min - max)	ANZECC mg/kg (dry) *ISQG- Low*	*ISQG- High*
Gravel (%w/w)[1]	3.4	1.1 - 8.4	n/a	n/a
Sand (%w/w)[2]	69.5	60.8 - 78	n/a	n/a
Mud (%w/w)[3]	27.2	19.7 - 32.6	n/a	n/a
Ash free dry weight %w/w	5.1	3.9 - 6.9	n/a	n/a
TN mg/kg (dry)	1650.0	1500 - 2100	n/a	n/a
TP mg/kg (dry)	798.6	728 - 913	n/a	n/a
Cadmium mg/kg (dry)	0.1	0.1 - 0.1	1.5	10
Chromium mg/kg (dry)	48.4	46 - 51	80	370
Copper mg/kg (dry)	16.8	15 - 19	65	270
Lead mg/kg (dry)	45.3	42 - 49	50	220
Nickel mg/kg (dry)	15.6	14 - 18	21	52
Zinc mg/kg (dry)	184.2	170 - 200	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

Normalisation to 100% mud content (Table A49) resulted in further elevation of organic matter (19%), phosphorus (3000 mg/kg), nitrogen (6145 mg/kg) and the trace metals, chromium, copper, cadmium, nickel and zinc compared with the other reference estuaries. The level of enrichment of the muds for lead (170 mg/kg) and zinc (685 mg/kg) was notably high. This data is consistent with other studies of metal concentrations in the Kaikorai Estuary (Wilson 1989).

Table A49: Physical and chemical sediment properties (standardised to 100% mud) of a site in the Kaikorai Estuary

Variable	Site A	Estuary range (min - max)
Ash free dry weight %w/w	19.2	11.96 - 27.43
TN mg/kg (dry)	6145.5	5214.7 - 8121.8
TP mg/kg (dry)	2992.2	2285.28 - 4345.18
Cadmium mg/kg (dry)	0.4	0.31 - 0.51
Chromium mg/kg (dry)	180.5	147.24 - 233.5
Copper mg/kg (dry)	62.4	52.15 - 76.14
Lead mg/kg (dry)	168.9	141.1 - 223.35
Nickel mg/kg (dry)	58.2	46.01 - 76.14
Zinc mg/kg (dry)	684.7	613.5 - 862.94

TN = total nitrogen; TP = total phosphorus

Macro-invertebrates

The results of the assessment of benthic animals at one representative low-mid water site in the Kaikorai Estuary show that the site had a low infauna species diversity (mean of 6 taxa per core) and medium abundance (330 m^{-2}) compared with the reference estuaries. The abundance and diversity of surface dwelling animals (epifauna) was not measured because the estuary mouth was blocked at the time and the site was under water.

The macrofauna assemblage at the Kaikorai Estuary was distinct from the other reference estuaries. Typically, the reference estuaries have been dominated by polychaetes, and to a lesser extent, bivalve species. While polychaetes were the most diverse group of taxa (Table A50), the Kaikorai Estuary was dominated, in terms of abundance, by amphipods. The overall assemblage, particularly the presence of oligochaetes, chironomid larvae and amphipods, almost certainly reflected the fact that the estuary is prone to prolonged periods of lowered salinities at times of mouth closure.

Table A50: Summary of the 15 most abundant infaunal species sampled at the Kaikorai Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	**Desription**	**Feeding Group**	**Abundance (Average number per core)**	
			Estuary	***Site A***
Amphipoda	Amphipod	Mobile scavenger	182.33	182.33
Copepoda	Copepod	Varied	2.83	2.83
Oligochaeta	Oligochaete worm	Deposit feeder	1.42	1.42
Mysidacea	Mysid shrimp	Filter & deposit feeders	1.25	1.25
Potamopyrgus estuarinus	Marine snail	Grazer on microalgae & detritus	0.75	0.75
Flabellifera	Isopod	Mobile scavenger	0.67	0.67
Chironomid larvae	Insect	Algal grazers	0.58	0.58
Dolichopodidae larvae	Insect	Deposit feeder	0.42	0.42
Heteromastus filiformis	Polychaete worm	Deposit feeder	0.33	0.33
Nereidae	Polychaete worm	Omnivore	0.25	0.25
Spionidae	Polychaete worm	Surface deposit feeder	0.17	0.17
Prionospio sp.	Polychaete worm	Surface deposit feeder	0.08	0.08
Aonides sp.	Polychaete worm	Surface deposit feeder	0.08	0.08

Benthic algae

Macroalgal cover was not measured. Visual observations and measured concentrations of chlorophyll *a* and phaeophytin indicated a moderately productive benthic microalgal community. The community was typical of natural estuarine environments, and comprised a variety of pennate diatoms (primarily *Achnanthes* sp. and *Pleurosigma* or *Gyrosigma* sp.) and centric diatoms (primarily *Mellosira* sp.). This is interesting considering that this estuary is quite different in some respects (e.g. animal community structure and organic matter, nutrient and metal concentrations) and suggests that microalgal species composition may not be a good indicator of estuarine condition.

Summary

The Kaikorai site was sand-dominated but contained a significant mud fraction of 27%. Although chemical and biological characteristics of the Kaikorai site were often inconsistent with those of the other REs, its inclusion in the study was helpful in that it extended the range of estuary types surveyed to cover a lagoonal system with measurable contaminant effects. The centrally located site appeared to be representative of the estuary in general and suitable for long term monitoring.

C.3.8 New River Estuary

Physical and Chemical Characteristics

The four New River Estuary sites were all relatively sandy (> 97% sand), hence whole sediment samples had very low organic matter (AFDW) and nutrient (N and P) concentrations relative to the other reference estuaries. Sediment heavy metal contaminants were also very low, and were all below ANZECC ISQG-Low tigger values (Table A51).

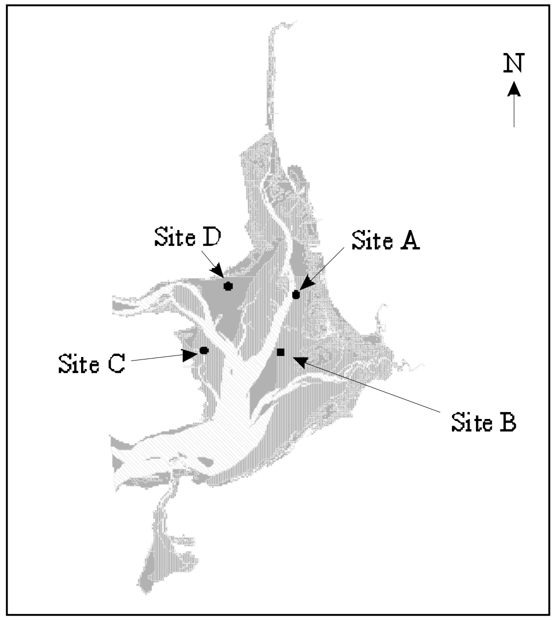


Table A51: Physical and chemical sediment properties of sites in the New River Estuary

Variable	Site A	Site B	Site C	Site D	Average (±1SD)	Estuary range (min - max)	ANZECC mg/kg (dry)	
							ISQG-Low	*ISQG-High*
Grave, %w/w[1]	0.3	0.1	0.2	0.6	0.3 ± 0.2	0.05 - 1.3	n/a	n/a
Sand, %w/w[2]	97.7	98.8	97.6	98.2	98.1 ± 0.6	96.4 - 99.2	n/a	n/a
Mud, %w/w	2.1	1.2	2.2	1.2	1.7 ± 0.5	0.8 - 3.3	n/a	n/a
Ash free dry weight, %w/w	0.7	0.6	0.7	0.5	0.7 ± 0.3	0.3 - 1.4	n/a	n/a
TN mg/kg (dry)	250.0	250.0	250.0	250.0	250 ± 0	250 - 250	n/a	n/a
TP, mg/kg (dry)	259.8	215.9	365.0	232.3	268.3 ± 67	195 - 432	n/a	n/a
Cadmium, mg/kg (dry)	0.1	0.1	0.1	0.1	0.1 ± 0	0.1 - 0.1	1.5	10
Chromium, mg/kg (dry)	8.6	8.4	14.9	12.3	11.1 ± 3.1	6.9 - 16	80	370
Copper, mg/kg (dry)	3.5	3.6	4.6	3.6	3.8 ± 0.5	3 - 4.9	65	270
Lead, mg/kg (dry)	1.1	0.7	0.6	0.5	0.7 ± 0.3	0.5 - 2.6	50	220
Nickel, mg/kg (dry)	4.6	4.3	6.0	5.2	5 ± 0.7	3.5 - 7.3	21	52
Zinc, mg/kg (dry)	15.5	15.4	20.0	17.4	17.1 ± 2.2	13 - 22	200	410

[1]Gravel = sediment grain sizes >2mm %w/w
[2]Sand = sediment grain sizes <2mm & >63µm %w/w
[3]Mud = sediment grain sizes <63um % w/w
TN = total nitrogen; TP = total phosphorus

However, once normalised for mud content, the data (Table A52) show a very different result. In particular, compared to the other reference estuaries the mud fraction has the highest levels of organic matter, phosphorus, nitrogen, cadmium, chromium, copper and zinc contamination. This means that, if the commonly held assumption that the majority of the contaminants are bound to the mud is true, then the New River Estuary muds were particularly rich in nutrients and some trace metals. Further analyses of the mud fraction would be required to assess the validity of this assumption.

Table A52: Physical and chemical sediment properties (standardised to 100% mud) of sites in the New River Estuary

Variable	Site A	Site B	Site C	Site D	Estuary mean (±1SD)	Estuary range (min - max)
Ash free dry weight %w/w	32.7	50.7	31.0	43.7	39.5 ± 9.4	20- 72.73
TN mg/kg (dry)	12784.2	22530.3	11829.8	21271.0	17103.8 ± 5576.3	757.6 - 31250
TP mg/kg (dry)	13150.9	19303.2	17290.3	19842.2	17396.7 ± 3036.1	7666.67 - 28222.22
Cadmium mg/kg (dry)	5.1	9.0	4.7	8.5	6.8 ± 2.2	3.03 - 12.5
Chromium mg/kg (dry)	432.7	756.5	707.1	1042.5	734.7 ± 249.8	254.55 - 1333.33
Copper mg/kg (dry)	176.7	322.1	216.2	306.4	255.3 ± 70.2	109.09 - 450
Lead mg/kg (dry)	60.2	59.2	28.9	42.5	47.7 ± 14.9	17.86 - 173.33
Nickel mg/kg (dry)	235.1	376.7	281.4	446.3	334.9 ± 94.8	139.39 - 633.33
Zinc mg/kg (dry)	781.2	1389.1	946.6	1482.5	1149.8 ± 339.1	484.85 - 2000

TN = total nitrogen; TP = total phosphorus

Biological Characteristics

Infauna, species abundance varied between sites (Table A53). At Site D (the site closest to riverine influence) the small estuarine snail (*Potamopyrgus estuarinus*) dominated. At Site A the tiny bivalve *Arthritica bifurca* dominated. At Site B and C the polychaete (*Sclolepis* sp.) and a mysid shrimp, respectively, dominated. In general the taxa belonged to groups that feed at the sediment surface or the nearby water column. The exception was at Site B where deposit feeding polychaetes were common.

In terms of epifauna, grazing snails (either *Potamopyrgus estuarinus* or the mudflat snail *Amphibola crenata*) dominated at all sites (Table A54).

Table A53: Summary of the 15 most abundant infaunal species sampled at the New River Estuary. Estuary and individual site data are presented as average species abundance per core (0.0133 m²)

Species	Taxonomic Group	Feeding Group	Abundance (mean number per core)				
			Estuary	***Site A***	***Site B***	***Site C***	***Site D***
Potamopyrgus estuarinus	Marine snail	Grazer on microalgae & detritus	28.27	8.33	0.00	0.17	104.58
Arthritica bifurca	Bivalve	Suspension feeder	23.04	67.75	7.25	7.33	9.83
Scolelepis sp.	Polychaete worm	Surface deposit feeder	16.83	37.25	26.33	1.17	2.58
Mysidacea	Mysid shrimp	Filter or deposit feeder	4.06	0.33	0.00	15.75	0.17
Capitella capitata	Polychaete worm	Deposit feeder	3.40	0.50	13.08	0.00	0.00
Cumacea	Cumacean	Filter or deposit feeders	2.29	5.42	1.50	0.08	2.17
Nereidae	Polychaete worm	Omnivore	1.54	3.17	2.25	0.33	0.42
Amphipoda	Amphipod	Mobile scavenger	1.40	0.92	0.33	1.08	3.25
Nemertea	Nemertean worm	Carnivore	1.38	2.00	1.75	1.08	0.67
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	1.31	0.00	0.00	5.08	0.17
Amphibola crenata (mud snail)	Marine snail	Grazer on microalgae & detritus	0.92	0.58	0.25	2.25	0.58
Scolecolepides sp.	Polychaete worm	Surface deposit feeder	0.85	1.83	0.75	0.08	0.75
Macomona liliana(wedge shell)	Bivalve	Suspension feeder	0.67	0.08	0.00	2.58	0.00
Paphies australis (pipi)	Bivalve	Filter feeder	0.42	0.25	0.25	0.08	1.08
Nicon aestuariensis	Polychaete worm	Omnivore	0.35	0.17	0.00	0.25	1.00

Table A54: Summary of all epifaunal species sampled at the New River Estuary. Data are presented as mean species abundance per quadrat (0.25 m²).

Species	Taxonomic Group	Feeding Group	Abundance (mean number per 0.25 m²)				
			Estuary	***Site A***	***Site B***	***Site C***	***Site D***
Potamopyrgus estuarinus	Marine snail	Grazer on microalgae & detritus	36.40	24.75	0.00	0.00	120.83
Amphibola crenata	Marine snail	Grazer on microalgae & detritus	16.15	8.83	7.08	34.00	14.67
Austrovenus stutchburyi (cockle)	Bivalve	Suspension feeder	3.69	0.00	0.00	14.75	0.00
Diloma subrostrata	Marine snail	Grazer on microalgae & detritus	0.52	0.00	0.00	2.08	0.00
Cominella glandiformis	Marine snail	Carnivore & scavenger	0.29	0.00	0.00	1.17	0.00
Notoacmea helmsi	Marine snail	Grazer on microalgae & detritus	0.10	0.00	0.00	0.42	0.00
Paphies australis (pipi)	Bivalve	Filter feeder	0.02	0.00	0.00	0.08	0.00

Benthic microalgae

A mixed macroalgal cover was observed at New River Site C while cover at the remaining three sites was minor.

Visual observations and measured concentrations of chlorophyll *a* and phaeopigments, indicated low to moderately productive benthic microalgal communities at all sites. These levels are consistent with normal, unenriched estuarine conditions. The microalgal community (examined at one site only) was typical of natural estuarine environments, containing a variety of, primarily, pennate (rod-shaped) and to a lesser extent centric (disc-shaped) diatoms.

Summary

The New River Estuary sites were relatively sandy with a <3% mud component. Although the sediments exhibited low overall contaminant concentrations there was some evidence to suggest that the mud component may reflect the opposite and have unusually high concentrations of some contaminants. This is only an indication, and further work would be required for confirmation. The biological data suggested a healthy and balanced macrofaunal community with a trend towards taxa that feed at the sediment surface. The sites were selected to be representative of different regions of the estuary and appear to be suitable for long-term monitoring.

Appendix C 4: Fine-scale environmental monitoring results

Step 1: Comparison of estuaries

The summary statistics of the environmental variables for each of the eight reference estuaries are condensed and compared in Section 6.4 of this document and are presented in their entirety in Appendix C 3.

Technical Box A.7. Monitoring Epifauna

The use of epifaunal species assemblage and abundance as a measure of estuary health has several limitations. The biotic assemblages sampled on the mud surface can differ during different stages of the tidal cycle, the time of day, and under different weather conditions. Also, mobile species (e.g. crabs) can retreat down burrows when disturbed by humans, and are therefore inconsistently sampled as epifauna. In the present study, several species of bivalves typically regarded as infauna were included as epifauna (e.g. the cockle Austrovenus stutchburyi and the nut shell Nucula nitidula), as individuals were often found protruding the sediment surface. Decapods (crabs) also featured as epifaunal species at many of the estuary sites; however, their tendency to retreat to their crab hole when encountered sometimes resulted in them being sampled primarily as infauna.

Univariate Analysis

An aim of Step 1 was to describe and compare the variation that existed among sites within estuaries, as well as among estuaries. One-way ANOVAs were produced to determine if significant variation existed between sites in all estuaries. The results of these analyses were also later used to determine whether pooling of sites within an estuary was justified (refer Step Three of the Results section).

Nested ANOVAs conducted with the normalised data identified both estuary, and sites within estuary as significant sources of variation for all the variables (Table A55). This indicated that estimates of the biological, physical and chemical variables measured in the present study differed from estuary to estuary and also between sites within each estuary. Results of the multiple one-way ANOVAs for each variable in each estuary indicated that significant site to site variation for all of the variables was present in most of the estuaries (Table A56).

Table A55: Nested ANOVAs for each estuary variable. Data were normalised to mud content.

	Source	SS	df	MS	F-ratio	P
%Mud	Estuary	9.002	6	1.5	519.639	0.000
	Site(Estuary)	2.569	16	0.161	55.615	0.000
	Error	0.731	253	0.003		
Chlorophyll a*	Estuary	17.517	5	3.503	83.117	0.000
	Site(Estuary)	16.324	14	1.166	27.662	0.000
	Error	9.02	214	0.042		
Phaeo[1]	Estuary	14.324	5	2.865	117.379	0.000
	Site(Estuary)	4.321	14	0.309	12.645	0.000
	Error	5.247	215	0.024		
AFDW	Estuary	0.065	6	0.011	235.117	0.000
	Site(Estuary)	0.006	16	0.000	7.769	0.000
	Error	0.012	252	0.000		
TN	Estuary	25.404	6	4.234	245.402	0.000
	Site(Estuary)	3.117	16	0.195	11.291	0.000
	Error	4.365	253	0.017		
TP	Estuary	46.73	6	7.788	929.99	0.000
	Site(Estuary)	4.984	16	0.312	37.197	0.000
	Error	2.119	253	0.008		
Cd	Estuary	22.265	6	3.711	112.432	0.000
	Site(Estuary)	45.799	16	2.862	86.728	0.000
	Error	8.35	253	0.033		
Cr	Estuary	58.243	6	9.707	911.046	0.000
	Site(Estuary)	5.691	16	0.356	33.382	0.000
	Error	2.696	253	0.011		
Cu	Estuary	32.977	6	5.496	723.699	0.000
	Site(Estuary)	2.983	16	0.186	24.552	0.000
	Error	1.921	253	0.008		
Pb	Estuary	24.272	6	4.045	61.918	0.000
	Site(Estuary)	15.985	16	0.999	15.292	0.000
	Error	16.529	253	0.065		
Ni	Estuary	69.995	6	11.666	1236.449	0.000
	Site(Estuary)	4.923	16	0.308	32.61	0.000
	Error	2.387	253	0.009		
Zn	Estuary	35.133	6	5.856	724.288	0.000
	Site(Estuary)	4.451	16	0.278	34.407	0.000
	Error	2.045	253	0.008		
AbndInf	Estuary	26.744	6	4.457	125.826	0.000
	Site(Estuary)	12.795	16	0.8	22.574	0.000
	Error	8.962	253	0.035		
DivInf	Estuary	2.042	6	0.34	25.312	0.000
	Site(Estuary)	1.645	16	0.103	7.644	0.000
	Error	3.402	253	0.013		
AbndEpi[2]	Estuary	82.129	5	16.426	66.018	0.000
	Site(Estuary)	153.492	14	10.964	44.065	0.000
	Error	53.494	215	0.249		
DivEpi[2]	Estuary	5.115	5	1.279	67.618	0.000
	Site(Estuary)	8.877	14	0.74	39.113	0.000
	Error	3.499	215	0.019		

1 Ruataniwha removed from analyses (only recorded at 1 of 3 sites)
2 Otamatea Arm removed from analyes (only recorded at 1 of 3 sites)

Table A56: Results of one-way ANOVAs assessing variability between sites within each estuary for each characteristic. In most cases, the number of replicates = 12 and number of sites was between 2 and 4. Bold P-values were significantly different ($\alpha = 0.05$), and were consequently able to be pooled. Successive probability values for each estuary were calculated when significant differences were identified (*i.e.* $P < 0.05$) and represent the probability with the least similar site removed. The least similar sites that were removed are given = 'site/s'.

	Avon-Heathcote			**Havelock**	**Otamatea Arm**			**New River**				**Ohiwa**				**Ruataniwha**			**Waimea**			
# sites→	3		2	2	3		2	4		3	2	4		3	2	3	site	2	4	Site/s	3	2
	P	site	P	P	P	site	P	P	sites/s	P	P	P	site/s	P	P	P		P	P		P	P
%Mud	0.000	**C**	**0.079**	**0.078**	0.000	**C**	**0.743**	0.000	**BC**	-	0.000	0.000	**-**			**0.176**			0.000	**AD**	-	0.000
Chl a	0.000	**A**	**0.758**	0.000	0.000	**C**	**0.314**	0.000	**B**	0.000	-	0.000	**A(B)**	0.011	**0.711**	**-**			**0.796**			
Phaeo	0.026	**C**	0.005	**0.507**	0.000	**C**	**0.071**	0.000	**AB**	-	0.039	0.000	**AD**	-	**0.799**	**-**			**0.404**			
AFDW	**0.984**			0.043	0.001	**C**	**0.238**	**0.137**				0.000	**AD**	-	**0.683**	0.000	**B**	**0.326**	0.000	**D**	0.002	0.050
TN	0.001	**-**		0.002	0.000	**-**		0.000	**AC**	-	**0.223**	0.000	**AC**	-	**0.122**	**0.288**			0.001	**C**	**0.586**	
TP	0.002	**C**	**0.182**	0.001	0.000	**C**	0.003	0.000	**A**	**0.214**		0.000	**BC**	-	0.000	**0.313**			0.000	**AD**	-	**0.410**
Cd	0.002	**C**	**0.219**	0.000	0.000	**C**	**0.290**	0.000	**CD**	-	0.000	0.000	**B**	0.000	**-**	0.000	**C**	**0.068**	0.000	**C**	0.000	
Cr	0.008	**C**	**0.703**	0.000	0.000	**C**	**0.149**	0.000	**AD**	-	**0.423**	0.000	**B**	**0.122**		**0.214**			0.000	**C(B)**	0.017	**0.989**
Cu	**0.059**			**0.427**	0.032	**C**	**0.509**	0.000	**AC**	-	**0.533**	0.000	**B**	**0.079**		0.001	**B**	**0.866**	0.000	**BC**	-	**0.191**
Pb	0.019	**A**	**0.629**	**0.158**	0.000	**C**	0.009	0.039	**C**	**0.359**		0.003	**C**	**0.231**		0.000	**C**	**0.154**	0.000	-		
Ni	0.000	**B**	**0.094**	0.000	0.000	**C**	0.010	0.000	**BD**	-	**0.065**	0.000	**B**	**0.210**		**0.930**			0.000	**BC**	-	**0.506**
Zn	0.021	**C**	**0.819**	0.001	0.000	**C**	**0.242**	0.000	**AC**	-	**0.419**	0.000	**B**	**0.551**		**0.695**			0.000	**BC**	-	0.024
AbnInf	0.000	**A**	0.001	**0.054**	0.001	**C**	**0.238**	0.000	**AD**	-	**0.814**	0.000	**AD**	-	**0.359**	0.000	-		0.002	**B**	**0.894**	
									BC	-	**0.436**		**BC**	-	**0.179**							
DivInf	0.045	**C**	**0.441**	0.000	0.000	**C**	**0.104**	0.008	**B**	**0.130**	*	0.031	**D**	**0.406**		0.003	**A**	**0.631**	**0.125**			
AbndEpi	0.007	**A**	**0.330**	0.000	**-**			0.000	**D(A)**	0.000	0.005	0.000	**AD**	-	**0.065**	0.000	**B**	**0.797**	0.000	**BC**	-	**0.388**
DivEpi	0.000	**B**	**0.113**	0.000	**-**			0.000	**C(B)**	0.000	0.005	0.000	**AC**	-	**0.133**	0.000	**B**	**0.587**	0.000	**CD**	-	**0.326**
													BD	**-**	**0.234**							

Note: Kaikorai was removed from this analysis; Otamatea Arm was removed from epifauna analyses; Ruataniwha was removed from Chl *a* and Phaeo analyses.
"-" = test not appropriate

Multivariate analysis - ANOSIM

The purpose of conducting a multivariate ANOSIM was to subject the data to an alternative means of testing for significant differences between sites and estuaries that is particularly well-suited to comparing species abundance data. The results of this test indicated that significant variation existed both among sites (within estuaries) and between different estuaries (see Table A57). This was true for the infauna and epifauna assemblages, and the physical and chemical data (*i.e.* where the number of permeated statistics greater or equal to the global R was consistently 0, and the significance was 0.001).

Table A57: Global tests for differences between sites (averaged across all estuary groups) and estuaries (using sites as sample). Significance = (1 + number of calculated permutations greater than global R)/(1+number of permutations)), *i.e*. (0+1)/(999+1) = 0.001.

	Infauna abundance		**Epifauna abundance**		**Physical and chemical variables**	
	Among sites	Between estuaries	Among sites	Between estuaries	Among sites	Between estuaries
Sample statistic (global R)	0.701	0.691	0.766	0.639	0.726	0.709
Significance level of sample statistic:	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Number of permutations (Random sample from a large number)	999	999	999	999	999	999
Number of permuted statistics greater than or equal to global R	0	0	0	0	0	0
Significance	0.001	0.001	0.001	0.001	0.001	0.001

Multivariate analysis - Sample Ordination (MDS & PCA)

Multivariate sample ordination was used to provide a spatial representation of the differences between sites within estuary, based on epifauna and infauna assemblages, and on the remaining environmental data (physical and chemical properties). Cluster analyses allowed the similarities or differences between groups of sites to be quantified. It also provided for determining the dominant species that contributed to the observed differences in the ordination groupings (*i.e.* SIMPER analyses).

The infaunal communities at the single sampling site in the Kaikorai Estuary were most distinct from the other sites in the present study, sharing a similarity with the other sites of approximately 20 % (refer Figure 11, Part A Section 6). All four of the New River Estuary sites, and one of the Havelock sites (Site A) were placed in a separate group (Group A) from the remaining sites (Group B), at a similarity of approximately 36 %. The species responsible for the average dissimilarity between the groups (Groups A and B, Group B and Kaikorai) were identified by SIMPER analyses and are presented in Tables A58 and A59. Amphipods were the dominant infauna responsible for distinguishing the Kaikorai site from the other estuary sites, accounting for 9.2 % of the dissimilarity. *Austrovenus stutchburyi* (4.75 %), *Arthritica bifurca* (3.94 %), Copepods (3.6 %) and *Macomona liliana* (3.36 %) also contributed to the dissimilarity of this site. The dissimilarities between groups A and B were contributed to the presence/absence of *Prionospio* sp. (4.71%), *Scolelepis* sp. (4.67%), *Heteromastus filiformis* (4.02%), *Aonides* sp. (3.84%) and *Potamopyrgus estuarinus* (3.72%).

Within Group B (*i.e.* all New River sites and one Havelock site), three of the New River sites (A, B, and D) were at least 60 % similar, while Havelock Site B and New River Site C were separated at a similarity of approximately 50 %. Several of the groupings at the 58 % similarity level were according to estuary. This was true for all sites from within the Ruataniwha, Ohiwa, Waimea and Avon-Heathcote estuaries. The Waimea and Avon-Heathcote estuaries demonstrated the greatest degree of similarity, at 66 and 72 %, respectively.

Table A58: Breakdown of average dissimilarity between site groups A & B and the Kaikorai based on the infauna communities. Species are listed in order of decreasing contribution (top 40 % only). Group B = all sites except for those from New River, Havelock B and Kaikorai. Average dissimilarity between groups = 77.63 %.

Species	Group A and B Av. Abund	Kaikorai Av. Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Amphipoda	1.24	182.33	7.14	4.93	9.20	9.20
Austrovenus stutchburyi	8.22	0.00	3.69	2.50	4.75	13.95
Arthritica bifurca	6.13	0.00	3.06	1.51	3.94	17.89
Copepoda	0.12	2.83	2.80	2.45	3.60	21.49
Macomona liliana	3.00	0.00	2.61	2.03	3.36	24.85
Nemertea	1.01	0.00	2.55	5.03	3.28	28.13
Aonides sp.	37.24	0.08	2.35	0.97	3.02	31.15
Chironomid larvae	0.00	0.58	2.29	6.11	2.95	34.10
Mysidacea	0.89	1.25	2.29	2.49	2.95	37.05
Potamopyrgus estuarinus	5.54	0.75	2.15	1.55	2.78	39.82
Oligochaeta	1.73	1.42	2.15	1.92	2.77	42.59

Table A59: Breakdown of average dissimilarity of sites between groups A and B based on the infauna communities. Species are ordered in decreasing contribution (Top 40 % only given). Average dissimilarity between groups = 63.83 %.

Species	Group A Av.Abund	Group B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Prionospio sp.	7.78	0.00	3.01	2.93	4.71	4.71
Scolelepis sp.	0.03	13.47	2.98	1.48	4.67	9.38
Heteromastus filiformis	11.80	0.18	2.56	1.84	4.02	13.40
Aonides sp.	47.56	0.10	2.45	0.85	3.84	17.24
Potamopyrgus estuarinus	0.80	22.62	2.37	0.96	3.72	20.96
Arthritica bifurca	2.26	20.03	2.24	1.44	3.51	24.46
Austrovenus stutchburyi	9.96	1.97	2.22	1.45	3.48	27.94
Macomona liliana	3.69	0.53	2.15	1.79	3.36	31.30
Cumacea	0.06	1.83	1.76	1.47	2.76	34.06
Anthopleura aureoradiata	2.63	0.00	1.46	1.07	2.28	36.34
Capitella capitata	0.22	2.72	1.45	1.00	2.27	38.61
Oligochaeta	2.21	0.00	1.44	0.88	2.26	40.87

The pattern of epifaunal assemblages did not characterise estuaries well, indicating that variation between sites within estuaries was as great as the variation in sites that occurred between estuaries. The first division of similarity on the dendrogram (refer Figure 12, Part A Section 6) occurred at the 15 % level, at which point two sites from New River (Sites A and D) were separated (forming Group A) from the remaining sites (Group B). The species most responsible for this dissimilarity was *Potamopyrgus estuarinus*, accounting for a large percentage of the dissimilarity (30.5%), followed in decreasing order, by: *Austrovenus stutchburyi, Diloma subrostrata, Amphibola crenata* and *Zeacumantus lutulentus* (Table A60).

At the 50 % level of similarity, four separate groups of epifaunal assemblages could be distinguished, with the Avon-Heathcote being the only estuary with sites that were considered more similar to each other than to sites from other estuaries (forming Group B-1, Figure 12, Part A Section 6). All sites from the Ohiwa and Waimea estuaries were grouped together along with one site from Ruataniwha (Site B) and the single Kaipara site (forming Group B-3). The epifaunal species responsible for the differences between Groups B-1 and B-3, in order of decreasing contribution were: *Zeacumantus lutulentus, Anthopleura aureoradiata, Diloma zelandica, Austrovenus stutchburyi, Micrelenchus tenebrosus, Notoacmea helmsi* and *Amphibola crenata* (Table A60). Group B-2 included both Havelock sites, Sites A and C from Ruatanwha and Sites B and C from New River estuary. Species most responsible for the differences between B-2 and Group B-3, in decreasing order, were: *Zeacumantus lutulentus, Amphibola crenata, Austrovenus stutchburyi, Diloma subrostrata, Cominella glandiformis* and *Elminius modestus* (Table A60).

Table A60: Breakdown of average dissimilarity of sites between groups A and B, B-1 and B-2, B-1 and B-3 and B-2 and B-3, based on the epifauna assemblages. Top 70% of species are given in decreasing order of contribution.

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib	%Cum.%
Average dissimilarity = 86.26	**Group A**	**Group B**				
Potamopyrgus estuarinus	0.00	72.79	26.33	2.68	30.52	30.52
Austrovenus stutchburyi	10.47	0.00	10.15	1.41	11.77	42.28
Diloma subrostrata	2.70	0.00	8.81	2.00	10.21	52.50
Amphibola crenata	3.73	2.38	6.64	1.52	7.70	60.20
Zeacumantus lutulentus	4.18	0.00	6.46	0.95	7.49	67.68
Average dissimilarity = 57.20	**Group B-1**	**Group B-3**				
Zeacumantus lutulentus	0.00	7.90	8.05	2.47	14.06	14.06
Anthopleura aureoradiata	2.20	0.00	6.47	4.48	11.30	25.37
Diloma zelandica	3.49	0.57	6.41	2.22	11.21	36.58
Austrovenus stutchburyi	6.30	14.48	4.88	1.45	8.52	45.10
Micrelenchus tenebrosus	0.76	0.13	4.17	1.90	7.30	52.39
Notoacmea helmsi	3.83	1.17	3.96	1.61	6.93	59.32
Amphibola crenata	0.14	1.35	3.53	2.24	6.17	65.49
Average dissimilarity = 67.26	**Group B-1**	**Group B-2**				
Diloma zelandica	3.49	0.00	9.96	4.78	14.81	14.81
Anthopleura aureoradiata	2.20	0.00	8.43	4.16	12.54	27.35
Notoacmea helmsi	3.83	0.10	7.51	2.16	11.17	38.52
Amphibola crenata	0.14	9.49	7.08	2.53	10.53	49.04
Austrovenus stutchburyi	6.30	5.87	7.06	1.44	10.50	59.55
Micrelenchus tenebrosus	0.76	0.00	6.31	2.73	9.38	68.93
Average dissimilarity = 68.89	**Group B-2**	**Group B-3**				
Zeacumantus lutulentus	0.06	7.90	11.14	1.89	16.18	16.18
Amphibola crenata	9.49	1.35	10.80	1.84	15.67	31.85
Austrovenus stutchburyi	5.87	14.48	9.00	1.18	13.06	44.90
Diloma subrostrata	0.36	4.26	7.12	1.48	10.33	55.23
Cominella glandiformis	0.16	1.50	5.46	1.24	7.92	63.15
Elminius modestus	0.00	2.23	4.67	0.87	6.78	69.93

Technical Box A.8. Understanding multivariate ordinations

Ordination. An ordination is a map of the samples, usually in 2 or 3-dimensions, in which the placement of the samples, rather than representing their geographic sample locations, reflects the similarity of their biological communities or environmental conditions. Generally speaking, the closer together the samples (or in this case sites) are on the plot the more similar they are according to the variable used to construct the plot.

PCA, Principal component analysis is a long established method used to approximate high dimensional information in low-dimensional plots. Each species in a community structure can be considered as one dimension, making species data naturally multidimensional. The appropriateness of a 2-dimensional PCA ordination is indicated by the amount of variability that is explained by the first and second axis (see PC1 and PC2). The more variation explained, the better the approximation.

MDS, Multi-dimensional scaling is a more recent method for arranging high dimensional information in low-dimensional plots. Ordinations are constructed by successively refining the positions of the points (samples) until they satisfy, as closely as possible, the dissimilarity relations between samples. The adequacy of the MDS representation is indicated by stress. Stress <0.05 = excellent, <0.1 = good, <0.2 = potentially useful, >0.3 = poor.

PC1 refers to the first principal component axis, and relates to a best fitting line that bisects the sample points in 2-dimensional space. It is defined as the axis which maximises the variance of sample points projected perpendicularly onto it. The biggest difference between samples takes place along the PC1 axis.

PC2 refers to the second principal component axis, and is defined as the axis perpendicular to PC1.

Step 2: Examining the relationships between environmental characteristics

This section examined the relationships between all measured environmental variables in order to identify those which are closely related, and therefore may have suitable surrogates. Particular emphasis was placed on examining the relationships between biological assemblages (infauna and epifauna) and the other environmental characteristics in order to determine which abiotic features may be the better indicators of biological health.

Univariate Analysis: Correlation Matrix

Raw data

The Pearson correlation matrix for un-normalised data identified a number of notable relationships and non-relationships (Table A61a):

- Percent mud (< 63 µm) was strongly ($r > 0.8$) positively correlated with AFDW and TN, and, to a lesser degree, TP, copper, lead and zinc. Relationships with chlorophyll *a*, phaeophytin and the remaining heavy metals were weakly positive.
- Chlorophyll *a* and phaeophytin were not strongly correlated with any of the other environmental variables.
- Organic content (AFDW) was strongly, positively correlated with the nutrients (TN and TP), and some metals (Cu, Pb and Zn).
- Both TN and TP were positively correlated to the metals copper, lead and zinc, while TP was also correlated with chromium and nickel.
- Apart from cadmium, all metals generally correlated well with other metals and all significant correlations were positive. In particular, copper, chromium, lead, nickel, and zinc were well correlated, although the relationships between lead and chromium, lead and nickel and zinc and nickel were not strong (r < 0.5). Nickel was particularly well correlated with chromium (r = 0.94), as was lead to zinc (r = 0.831).
- Infauna diversity and abundance did not correlate well to any other variables (physical, biological or chemical).
- Epifauna abundance correlated only with epifauna diversity, which was also correlated to infauna diversity.

It is important to note that any correlations with TN, cadmium or lead may be partially confounded due to the arbitrarily assigned value to samples below the analytical detection limits (0.5 x the detection limit). Correlating continuous data with data that has an arbitrary value at the lower end is likely to reduce the intensity of the relationship. Conversely, correlating two sets of data that have a discrete value at the lower end may result in an artificially improved relationship.

Changes using site-averaged data

After site-averaging was carried out, relationships between the physical, nutrient and chemical variables remained largely unchanged (TableA62). However, slight improvements were obtained for most relationships, particularly between the biological variables, infauna and epifauna abundance and diversity. Changes to note were:

- The correlation between infauna abundance and chlorophyll content increased to $r = 0.423$.
- The inverse correlation between infauna diversity and copper concentrations increased (strengthened) to $r = -0.512$.
- The correlation between infauna diversity and diversity of epifauna increased to r = 0.788.
- Generally, correlations between physical, biological and chemical variables were slightly improved (by ca. 5 to 10 %).

Changes using normalised data

Standardising the plant pigment (chlorophyll *a* and phaeophytin), nutrient and chemical data to a sample with 100 % mud content resulted in several changes to the relationships between variables observed using un-normalised data (Table A61 and A62). These were as follows:

- Relationships of nutrients and heavy metals with AFDW were intensified, with several of correlations, particularly using site-averaged data, exceeding 0.8.
- Stronger positive correlations were identified between all of the metals and nutrients, with many correlating very strongly ($r > 0.9$). An exception to this was lead, for which normalisation resulted in weaker relationships with the other metals.
- No strong correlations existed between any of the contaminants and epifauna and infauna. However, the general trend was for weak negative correlations between epifauna abundance and diversity and all nutrient and heavy metal measures.

Table A61: Pearson correlation matrix of transformed chemical, physical and biological data[1]. **A**: raw data, and **B**: after normalising to mud content (*n* ranged from 218-288, cases were deleted pairwise).

A	asin%Mud	logChl a	logPhaeo	asinAFDW	logTN	logTP	logCd	logCr	logCu	logPb	logNi	logZn	logAbnEpi	logDivEpi	logAbnInf
asin%Mud	1														
logChl a	0.192	1													
logPhaeo	0.269	0.367	1												
asinAFDW	0.806	0.3	0.446	1											
logTN	0.84	0.351	0.372	0.888	1										
logTP	0.572	0.147	0.327	0.595	0.572	1									
logCd	0.223	-0.145	0.251	0.19	0.143	0.208	1								
logCr	0.341	-0.224	-0.18	0.124	0.151	0.602	0.274	1							
logCu	0.763	-0.017	0.128	0.644	0.66	0.765	0.274	0.717	1						
logPb	0.554	0.189	0.196	0.556	0.561	0.682	0.316	0.491	0.649	1					
logNi	0.303	-0.245	-0.253	0.008	0.032	0.487	0.247	0.94	0.623	0.388	1				
logZn	0.614	0.184	0.19	0.636	0.642	0.821	0.117	0.618	0.765	0.831	0.451	1			
logAbnEpi	0.123	-0.225	-0.214	0.064	0.21	-0.316	-0.005	-0.102	-0.143	-0.071	-0.101	-0.094	1		
logDivEpi	0.157	0.124	-0.005	0.212	0.25	0.059	-0.001	-0.004	-0.198	0.168	-0.045	0.226	0.452	1	
logAbnInf	-0.135	0.253	0.187	0.004	0.113	-0.078	-0.088	-0.229	-0.336	0.086	-0.315	0.099	0.198	0.371	1
logDivInf	-0.069	-0.059	0.066	-0.11	-0.092	-0.223	0.078	-0.229	-0.386	-0.223	-0.164	-0.233	0.375	0.519	0.405
B															
logTN		0.097	0.015	0.847	1										
logTP		-0.138	-0.19	0.787	0.78	1									
logCd		-0.031	-0.004	0.734	0.852	0.775	1								
logCr		-0.22	-0.238	0.496	0.566	0.816	0.672	1							
logCu		-0.161	-0.185	0.756	0.813	0.918	0.836	0.865	1						
logPb		0.003	-0.109	0.3	0.241	0.446	0.266	0.455	0.395	1					
logNi		-0.25	-0.269	0.312	0.414	0.671	0.563	0.943	0.741	0.363	1				
logZn		-0.076	-0.173	0.764	0.743	0.951	0.705	0.824	0.889	0.59	0.647	1			
logAbnEpi				-0.128	-0.065	-0.262	-0.126	-0.232	-0.263	-0.226	-0.243	-0.226			
logDivEpi				-0.176	-0.24	-0.221	-0.324	-0.225	-0.392	-0.001	-0.258	-0.165			
logAbnInf				0.178	0.187	0.135	0.047	-0.019	-0.052	0.289	-0.141	0.24			
logDivInf				-0.123	-0.109	-0.088	-0.093	-0.167	-0.279	-0.241	-0.138	-0.163			

1 %Mud = % sediment <63 µm; Chl = chlorophyll *a;* Phaeo = phaeophytin; TN = total nitrogen; TP = total phosphorus; AbnEpi = abundance of epifauna; DivEpi = diversity of epifauna; AbnInf = abundance of infauna; DivInf = diversity of infauna.

Table A62: Pearson correlation matrix of site-averaged, appropriately transformed, physical, chemical and biological data[1]. **A**: not normalised, **B**: normalised to mud content (*n* ranged from 218-288, cases were deleted pairwise).

A	asin%Mud	logChl a	logPhaeo	asinAFDW	logTN	logTP	logCd	logCr	logCu	logPb	logNi	logZn	logAbnEpi	logDivEpi	logAbnInf
asin%Mud	1														
logChl a	0.194	1													
logPhaeo	0.296	0.542	1												
asinAFDW	0.871	0.333	0.492	1											
logTN	0.853	0.226	0.348	0.903	1										
logTP	0.588	0.159	0.357	0.642	0.682	1									
logCd	0.296	-0.18	0.318	0.267	0.313	0.283	1								
logCr	0.349	-0.282	-0.2	0.14	0.381	0.612	0.345	1							
logCu	0.779	-0.042	0.14	0.688	0.759	0.776	0.333	0.729	1						
logPb	0.619	0.22	0.24	0.611	0.673	0.755	0.403	0.566	0.691	1					
logNi	0.31	-0.307	-0.288	0.008	0.241	0.49	0.304	0.949	0.63	0.442	1				
logZn	0.628	0.194	0.205	0.679	0.73	0.833	0.203	0.621	0.765	0.904	0.45	1			
logAbnEpi	0.126	-0.25	-0.382	0.036	0.018	-0.354	0.048	-0.075	-0.198	-0.066	-0.095	-0.094	1		
logDivEpi	0.179	0.15	-0.07	0.27	0.18	0.032	0.092	-0.018	-0.248	0.19	-0.067	0.249	0.579	1	
logAbnInf	-0.146	0.423	0.205	0.035	0.133	-0.087	-0.113	-0.254	-0.365	0.126	-0.348	0.117	0.287	0.443	1
logDivInf	-0.07	-0.078	0.073	-0.147	-0.201	-0.314	0.156	-0.293	-0.512	-0.259	-0.178	-0.335	0.48	0.788	0.361
B															
logTN	-0.626	-0.025	-0.244	0.936	1										
logTP	-0.891	-0.1	-0.224	0.849	0.796	1									
logCd	-0.689	-0.2	-0.212	0.816	0.88	0.791	1								
logCr	-0.738	-0.295	-0.398	0.528	0.572	0.817	0.686	1							
logCu	-0.755	-0.201	-0.297	0.81	0.826	0.92	0.854	0.867	1						
logPb	-0.401	0.155	-0.067	0.304	0.231	0.471	0.279	0.501	0.4	1					
logNi	-0.622	-0.337	-0.458	0.319	0.409	0.663	0.57	0.946	0.737	0.38	1				
logZn	-0.851	-0.032	-0.244	0.821	0.755	0.952	0.715	0.824	0.886	0.635	0.638	1			
logAbnEpi				-0.148	-0.031	-0.268	-0.101	-0.207	-0.279	-0.223	-0.236	-0.218			
logDivEpi				-0.212	-0.245	-0.257	-0.319	-0.263	-0.441	0.009	-0.309	-0.188			
logAbnInf				0.248	0.223	0.146	0.063	-0.026	-0.058	0.394	-0.161	0.269			
logDivInf				-0.153	-0.169	-0.143	-0.119	-0.261	-0.398	-0.303	-0.21	-0.241			

1 %Mud = % sediment <63 µm; Chl = chlorophyll *a*; Phaeo = phaeophytin; TN: = total nitrogen; TP = total phosphorus; AbnEpi = abundance of epifauna; DivEpi = diversity of epifauna; AbnInf = abundance of infauna; DivInf = diversity of infauna.

Multivariate analysis: environmental variables (PCA)

The physical and chemical data were examined using principle component analysis (PCA) to explore the similarity of the sites based on their physical and chemical properties. It was also possible from this analysis to determine which variables were most responsible for the observed differences.

The PCA plots generated for the normalised (to mud content) and un-normalised physical and chemical data are presented in Figure 13A and B (Part A Section 6). In the case of the un-normalised data, PCA1 (x-axis) and PCA2 (y-axis) together account for 75.5 % of the total sample variability (Table A63), suggesting that a two-dimensional ordination described the data adequately. On the PCA1 axis, the influence of most of the (transformed) variables was approximately equally weighted, with the strongest coefficients including mud content, organic content (AFDW), TN, TP, copper, lead and zinc (Table A64). This was not surprising given the co-linearity of these variables (Table A61, correlation matrix). The variables that did not feature strongly on PCA1 (chlorophyll *a*, phaeophytin, cadmium and nickel) were the dominant influencing factors on the PCA2 axis (Table A64).

The PCA generated four approximate groupings of sites from the un-normalised physical and chemical data. The first consisted of the single Kaikorai estuary site, suggesting conditions in the sediments were significantly different than those from sites in the other study estuaries. The second group contained the three sites from the Otamatea Arm. Group three included all sites from the Avon-Heathcote, Ohiwa, Ruataniwha and New River estuaries. Group four contained all sites from the Havelock and Waimea estuaries (which are also in close geographic proximity). Differences between these approximate groupings are further examined through PCA analyses of pairs of the groups.

A two-dimensional ordination (PCA1 and PCA2) of the normalised values accounted for a similar amount of variance to that of the un-normalised data (75.3 %) (Table A63). Chlorophyll *a*, phaeophytin and lead did not feature strongly on the PCA1 axis. However, PCA2 axis was most influenced by the photosynthetic pigments (chlorophyll *a* and phaeophytin), TN and lead.

Normalisation of the environmental data to mud content altered the PCA ordinations (Figure 13, Part A Section 6). The Kaikorai site was no longer considered distinct from the Otamatea sites, and the Ohiwa sites shifted from being more closely related to the New River and Avon-Heathcote estuaries to being more aligned with the Havelock and Waimea Estuary sites.

Table A63: Eigenvalues, percent variation and cumulative percent variation of un-normalised and normalised physical and chemical data explained by principal component (PC) axes 1:10.

PC	**Un-normalised**			**Normalised**		
	Eigenvalues	%Variation	Cum. % variation	Eigenvalues	%Variation	Cum. % variation
1	7.14	54.9	54.9	7.79	59.9	59.9
2	2.68	20.6	75.5	2.00	15.4	75.3
3	1.05	8.0	83.6	0.97	7.5	82.8
4	0.87	6.7	90.3	0.76	5.9	88.7
5	0.45	3.5	93.7	0.56	4.3	93.0
6	0.37	2.9	96.6	0.42	3.3	96.3
7	0.16	1.2	97.8	0.31	2.4	98.7
8	0.11	0.9	98.6	0.08	0.6	99.3
9	0.10	0.7	99.4	0.05	0.4	99.7
10	0.05	0.4	99.8	0.02	0.2	99.8

Table A64: Euginevectors of the transformed physical and chemical variables (Coefficients in the linear combinations of variables making up PC's)

	Un-normalised					**Normalised**				
Variable	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5
arcsin% Mud	-0.324	0.083	0.074	0.321	0.276	0.323	0.014	-0.244	-0.297	0.113
logChl a	-0.078	0.422	0.195	-0.598	0.245	0.107	-0.532	0.432	0.010	0.148
logPheao	-0.138	0.400	-0.450	-0.306	0.337	0.156	-0.462	0.025	0.420	-0.365
arcsinAFDW	-0.325	0.255	0.045	0.262	-0.028	0.297	-0.245	-0.391	-0.196	0.108
logTOC	-0.324	0.258	0.044	0.265	-0.034	0.294	-0.252	-0.401	-0.198	0.113
logTN	-0.345	0.101	0.076	0.192	0.008	-0.27	-0.344	-0.279	0.066	0.338
logTP	-0.334	-0.05	0.018	-0.197	0.011	-0.334	-0.192	-0.007	0.197	0.138
logCd	-0.155	-0.115	-0.835	0.047	-0.165	-0.227	0.046	-0.542	0.254	-0.547
logCr	-0.221	-0.465	0.012	-0.202	0.186	-0.336	0.030	-0.074	-0.239	0.025
logCu	-0.336	-0.162	0.066	0.149	0.268	-0.325	-0.127	-0.204	0.05	0.31
logPb	-0.320	-0.055	-0.010	-0.281	-0.552	-0.184	-0.340	0.146	-0.624	-0.522
logNi	-0.173	-0.499	0.012	-0.179	0.379	-0.301	0.168	0.008	-0.317	0.046
logZn	-0.333	-0.059	0.203	-0.235	-0.408	-0.326	-0.248	0.000	-0.039	0.062

Multivariate analysis: BIOENV procedure

The Pearson correlations (Tables A61 and A62) identified several variables that were highly correlated, and were therefore omitted from the BIOENV analyses. When comparing biotic assemblages to un-normalised environmental data, AFDW, TN, Cr and Zn were omitted from the BIOENV analysis. AFDW, TN, TP, Cr and Zn were omitted when the analysis was conducted on the normalised data set. The omitted variables and the corresponding surrogate and correlation coefficients are listed below (Table A65).

In general, the grouping of the physical and chemical variables did not explain the ordination of the biotic variable; *i.e.* no correlations (ρ) > 0.52 (Table A66). Un-normalised variables which best captured the pattern described by the ordination of infauna data included the mud content and lead, explaining approximately 50% of the pattern (ρ = 0.514). The next best result incorporated a third variable, TP content (ρ = 0.497). The normalised variables which best explained the ordination of the infauna data included a three- variable combination of mud content, lead and copper (ρ = 0.512). The second best result was a four- variable combination including cadmium concentrations (ρ = 0.487).

Table A65: Pearson product moment correlation coefficients for site-averaged physical and chemical data used in BIOENV procedure. **A** = a comparison with epifauna data: excluding sites Otamatea A, Kaikorai B and C, Ruataniwha A and B; **B** = a comparison with infauna data: excluding Ruataniwha sites A and B. Bolded figures indicate those left out of the procedure with suitable surrogate listed adjacent.

	Un-normalised			Normalised to mud content		
	Out	Surrogate	Correlation	Out	Surrogate	Correlation
A	**arcsin AFDW**	arcsin % Mud	0.880	**arcsin AFDW**	arcsin % Mud	0.880
	log TN	arcsin % Mud	0.855	**log TP**	arcsin % Mud	-0.896
	log Cr	log Ni	0.966	**log Zn**	arcsin % Mud	-0.894
	log Zn	log Pb	0.873	log TP	log TN	0.907
	`			**log TN**	log Cu	0.885
				log TN	log Zn	0.895
				log TP	log Cu	0.921
				log TP	log Zn	0.972
				log Cr	log Cu	0.861
				log Cr	log Ni	0.940
				log Zn	log Cu	0.894
B	**arcsin AFDW**	arcsin % Mud	0.869	**arcsin AFDW**	arcsin % Mud	0.869
	log TN	arcsin % Mud	0.852	**log TP**	arcsin % Mud	-0.893
	arcsin AFDW	log TN	0.902	**log Zn**	arcsin % Mud	-0.850
	log Cr	log Ni	0.949	log TP	log TN	0.870
	log Zn	log Pb	0.904	**log TN**	log Cu	0.865
				log TN	log Zn	0.862
				log Cr	log Cu	0.868
				log Cr	log Ni	0.945
				log Zn	log Cu	0.887

Epifauna data were not well predicted from any combination of the un-normalised environmental variables, with a three- variable combination of Chlorophyll *a*, TP and Pb only explaining 22.9 % of the observed pattern. The second best result was a similar combination, excluding TP (ρ = 0.211). Normalisation of environmental characteristics to 100% mud improved the explanation of differences in epifauna distributions, with copper accounting for as much as 50% of the pattern (ρ = 0.501). This relationship was only slightly worse with the inclusion of Cd (ρ = 0.493), and then Chlorophyll *a* (ρ = 0.484).

Table A66: The best correlations from the BIOENV procedure (Primer), indicating which variables, or combination of variables, best captured the patterns biotic (epifauna and infauna), as indicated by strength of correlation; ρ 0-1. Results were limited to four best combinations.

		Var. 1	Var. 2	Var. 3	Var. 4	Correlation
Infauna						
Un-normalised	1	asin %Mud	log Pb			0.514
(4 best results)	2	asin %Mud	log TP	log Pb		0.497
	3	asin %Mud	log Chl a	log TP	log Pb	0.496
	4	asin %Mud	log Chl a	log Pb		0.480
Normalised	1	asin %Mud	log Cu	log Pb		0.512
	2	asin %Mud	log Cd	log Cu	log Pb	0.487
	3	log Cu	log Pb			0.486
	4	asin %Mud	log Chl a	log Cu	log Pb	0.479
Epifauna						
Un-normalised	1	log Chl a	log TP	log Pb		0.229
	2	log Chl a	log Pb			0.211
	3	asin %Mud	log Chl a	log TP	log Pb	0.199
	4	asin %Mud	log Chl a	log Pb		0.194
Normalised	1	log Cu				0.501
	2	log Cd	log Cu			0.493
	3	log Chl a	log Cu			0.484
	4	log Chl a	log Cd	log Cu		0.468

The MDS ordination of infauna data from the reference estuaries was overlaid with the three variables that were found to best describe the infaunal assemblages, %Mud, lead and total phosphorus (TP) (Figure A31). The circles in the plots represent concentration of the variable, and are an alternative representation of the relationship between the biotic assemblages and other environmental characteristics.

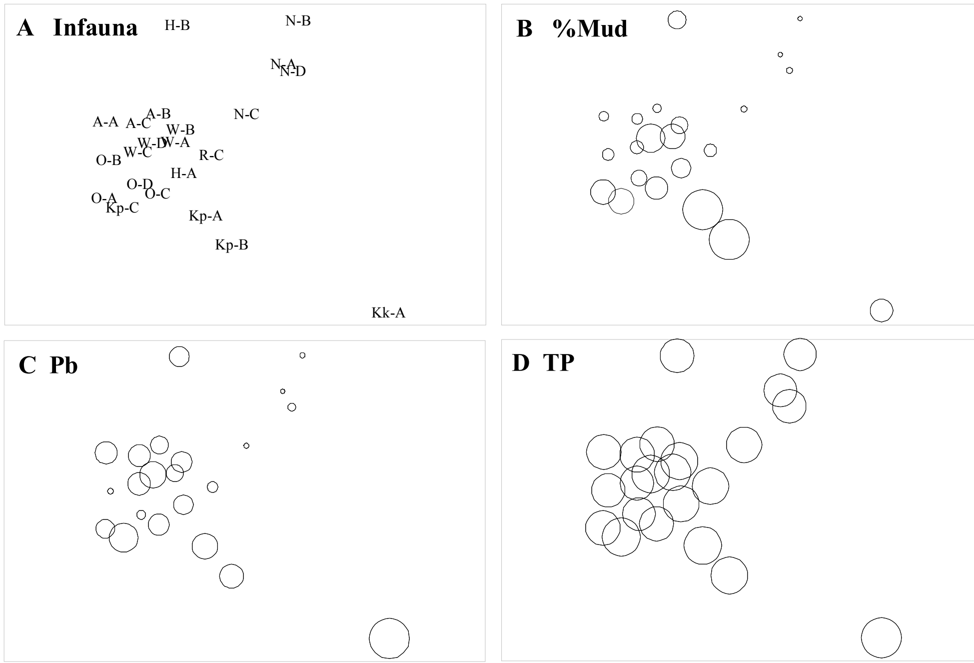


Figure A31: MDS ordination of the Bray-curtis similarities of infauna data (A), and the same ordination superimposed with circles of increasing size with increasing content of the environmental variables, %Mud (B), Lead, Pb (C) and total phosphorus, TP (D). Data were presented as un-normalised, raw data.

Step 3: Determining the optimum sample size

Analysis of precision and pooling of sites

The variability of the environmental characteristics between sites and between estuaries was examined. This served two purposes: i) it provided a comparison of sample variability between sites to determine if pooling sites was justified, based on similar within-site variation (*i.e.* although the sites may share a similar mean value, do they have similar spatial variability?), and ii) it allowed the identification of measures that were inherently less variable (more precise) on this spatial scale.

The variation between the relative measures of precision (coefficient of variation, CV) of each variable due to 'estuary' was examined using one-way ANOVAs (with site CV as 'replicate'). The results indicated that estuary was a significant source of variation for eight out of the 16 variables, despite the variation that may have been introduced by site (see Table A67). The variables that demonstrated significantly different variation in CV between estuaries included both nutrients (total nitrogen (TN) and total phosphorus (TP)), and all of the metal concentrations (Cd, Cr, Cu, Pb, Ni and Zn). CVs of sediment chlorophyll *a* concentrations and infauna abundances were also marginally significantly different ($P < 0.15$). The variability encountered between estuaries did not outweigh the variability within estuaries (between sites) for mud content (% mud), phaeophytin, organic content (AFDW), infauna abundance and diversity and epifauna abundance and diversity. Significant variation in means and CVs (Table A68) attributable to estuary indicated that the determination of optimum sample size should be addressed on an estuary by estuary basis.

Tests for homogeneity of CVs within estuaries identified significant differences between sites (Table A68). In general, the New River and Havelock estuaries had the least number of variables with significant variation in CV between sites, while the Waimea and Otamatea Arm estuaries experienced the most variation in CV. Significant variations in precision were more common for chemical variables than for physical and biological variables.

The significant differences in CVs and means between sites resulted in few occasions where all the sites within an estuary could be pooled for a particular variable. The estuaries which had some variables with similar CVs across all sites were the Avon-Heathcote, Havelock, New River, Ruataniwha and the Waimea (Table A68). In the Otamatea Arm, Site C was the least similar for all variables, suggesting that it was environmentally distinct from Sites A and B. In the estuaries with four sites (New River, Waimea, and Ohiwa), there were a number of occasions (13) where it was necessary to remove two sites to achieve similarity between those that remained.

Table A67: One-way ANOVAs with estuary as factor (for estuaries with >2 sites) and site as replicate comparing CVs between estuaries for each variable. Estuary *df* = 5, error *df* = 15.

Variable	MS	F-ratio	P	Sig.
% Mud	0.004	0.502	0.770	
Chl	0.015	2.132	0.126	
Phaeo	0.000	1.454	0.270	
AFDW	0.935	1.525	0.241	
TN	0.898	6.717	0.002	***
TP	0.861	26.678	0.000	***
Cd	0.000	6.987	0.001	***
Cr	0.000	18.392	0.000	***
Cu	0.004	15.584	0.000	***
Pb	0.015	6.71	0.002	***
Ni	0.000	25.325	0.000	***
Zn	0.935	15.73	0.000	***
AbndInf	0.898	1.634	0.211	
DivInf	0.861	2.665	0.065	
AbndEpi	0.000	0.646	0.669	
DivEpi	0.000	1.173	0.373	

Table A68: Test for inter-site homogeneity of coefficients of variation (Zar 1999) for each estuary. If significant variation was found using all sites, the test was run again after the site with the most different CV was removed. No significant variation existed between sites for variables at the two site level. Brackets indicate number of sites have been selectively reduced by one.

	New River				**Ohiwa**				**Waimea**				**Avon-Heathcote**		**Kaipara**		**Ruataniwha**		**Havelock**	
# sites:	4		(3)		4		(3)		4		(3)		3		3		3		2	
	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig	X^2	Sig
% Mud	5.170				5.631				41.711	***	2.439		5.126	*	21.407	***	5.441	*	0.270	
Chl a	13.900	***	10.650	***	2.887				3.532				0.710		9.474	***	118.700	***	0.003	
Phaeo	8.069	**	0.194		2.773				21.340	***	9.434	***	0.194		0.683		129.286	***	0.000	
AFDW	2.537				5.956				16.780	***	4.737	*	0.748		1.025		1.477		0.885	
TN	7.284	*	2.122		32.219	***	7.077	**	6.636	*	0.201		16.078	***	39.442	***	35.152	***	1.254	
DRP	0.925				8.797	**	3.844		15.287	***	1.658		6.267	**	48.804	***	0.478		0.069	
Cd	1.608				32.032	***	4.130		17.042	***	6.672	**	5.972	*	25.399	***	11.273	***	1.761	
Cr	1.289				14.581	***	7.388	**	13.346	***	1.278		9.634	***	26.135	***	2.090		0.095	
Cu	1.807				18.521	***	11.447	***	26.338	***	6.541	**	10.090	***	36.588	***	0.615		0.028	
Pb	1.000				36.781	***	17.316	***	103.697	***	0.572		3.607		45.160	***	10.284	***	2.502	
Ni	0.719				22.558	***	18.936	***	16.065	***	3.965		9.289	***	28.622	***	1.350		1.045	
Zn	1.845				16.924	***	8.088	**	21.402	***	7.876	**	7.171	**	25.921	***	0.285		0.078	
AbndC	17.764	***	6.068	**	2.529				5.214				1.482		1.766		6.810	**	1.908	
DivC	2.230				1.848				10.699	**	3.129		6.407	**	3.300		2.524		0.909	
AbndQ	6.708	*	2.349		7.182	*	3.503		4.630				8.515	**	129.544	***	4.989	*	0.893	
DivQ	29.666	***	0.846		2.944				10.178	**	1.091		18.170	***	130.441	***	5.142	*	0.105	

* Indicates significant correlation at $\alpha = 0.1$ level.
** Indicates significant correlation at $\alpha = 0.05$ level.
*** Indicates significant correlation at $\alpha = 0.01$ level.

Power analysis and sample size

Estimated 'actual' CV

The estimated mean (near "actual") CVs derived from computer-generated plots of CV against sample number (*n*) for all variables in each estuary are presented in Figure A32 and Table A69. Values in the table can be interpreted as the level of precision likely to result from sampling with the recommended numbers of replicates, with the 95% confidence intervals (CI) shown in brackets. Mean CVs for the measured variables were typically between 0.20 and 0.40 (mean = 0.293 ± 0.128 (95% CI)), and ranged from 0.10 (10 %) for mud content in the Otamatea Arm, to 0.75 (75 %) for epifauna abundance in the New River Estuary and lead concentrations in the Ohiwa Estuary. Lead concentrations also had the lowest level of precision on average; in part due to the disparity between samples which were below detection limits (allocated a value 0.5 × detection limit) and those that were within the detection limits. Animal abundance and diversity measures were also typically more variable, with CVs ranging between 25 and 50 %. Chlorophyll *a*, TN and cadmium had mean CVs in the order of 20 to 40 %, while organic content (AFDW), TP, chromium, copper, nickel and zinc were the least variable with CVs of around 15 to 30 %.

Recommended sample size

Variation in precision (CV) is an important factor in determining sample size. Therefore, the relationship between increased sample size (from real data) and CV was explored on multiple plots for each variable in each estuary. The point (*n*) at which substantial gains in CV were no longer attained for a further 5*n* increase in sample size was estimated for each variable and these are summarised in Figure A32. This point was defined as the cost benefit point (CBP) and assumes an approximately linear relationship between sampling cost and sample number (*n*). Over all variables and all estuaries, the mean number of samples at CBP was 8.0 (SD = 2.0). The maximum suggested sample size by this approach was 14 (for lead in the Ohiwa estuary) and the minimum was four, recorded on one occasion for each of: zinc, nickel, copper and mud content. Based on this analysis, copper and nickel consistently required seven samples to reach the optimal level of precision, represented by the CBP. The CBP for lead was, on average, notably higher than for the other physical and chemical variables, at approximately 11 (possibly due to some sample concentrations being lower than the analytical detection limit). Chlorophyll *a* concentrations and epifauna diversity were also notably above the mean value of eight, requiring between eight to 12, and seven to 12 samples, respectively. Abundance of infauna could be well assessed with eight to nine samples, while infauna diversity required seven to eight samples.

Table A69: Estimated mean (near "actual") coefficient of variation (± 95 % CI) from plots of CV against *n* for each variable in each estuary.

Variable	Avon-Heathcote	Havelock	Otamatea	New River	Ohiwa	Ruataniwha	Waimea
% Mud	0.32 (± 0.17)	0.19 (± 0.07)	0.1 (± 0.07)			0.22 (± 0.18)	0.62 (± 0.19)
Chl a	0.4 (± 0.25)		0.3 (± 0.14)		0.31 (± 0.18)		0.26 (± 0.16)
Pheao		0.3 (± 0.23)	0.22 (± 0.1)		0.25 (± 0.15)		
AFDW	0.23 (± 0.12)		0.23 (± 0.22)	0.35 (± 0.18)	0.19 (± 0.1)	0.2 (± 0.08)	
TN				0.2 (± 0.08)	0.41 (± 0.11)	0.25 (± -0.25)	0.23 (± 0.17)
TP	0.31 (± 0.11)			0.2 (± 0.1)	0.28 (± 0.13)	0.23 (± 0.09)	0.22 (± 0.08)
Cd	0.32 (± 0.14)				0.39 (± 0.13)		
Cr	0.3 (± 0.2)		0.19 (± 0.06)	0.2 (± 0.09)	0.3 (± 0.16)	0.22 (± 0.14)	0.21 (± 0.13)
Cu	0.28 (± 0.2)	0.14 (± 0.05)	0.12 (± 0.1)	0.2 (± 0.09)	0.22 (± 0.08)	0.21 (± 0.11)	0.21 (± 0.14)
Pb	0.28 (± 0.12)	0.3 (± 0.12)		0.56 (± -0.56)	0.75 (± 0.38)	0.46 (± 0.25)	
Ni	0.34 (± 0.24)			0.25 (± 0.14)	0.23 (± 0.15)	0.21 (± 0.12)	0.2 (± 0.13)
Zn	0.31 (± 0.19)		0.17 (± 0.12)	0.2 (± 0.1)	0.23 (± 0.11)	0.21 (± 0.11)	
AbndInf		0.46 (± 0.19)	0.49 (± 0.22)	0.75 (± -0.75)	0.22 (± 0.14)		0.49 (± 0.19)
DivEInf	0.22 (± 0.09)		0.25 (± 0.1)	0.27 (± 0.13)	0.19 (± 0.1)	0.31 (± 0.2)	0.28 (± 0.13)
AbndEpi	0.38 (± 0.16)			0.23 (± 0.12)	0.2 (± 0.1)	0.53 (± 0.24)	0.45 (± 0.15)
DivEpi	0.2 (± 0.08)				0.28 (± 0.12)	0.46 (± 0.06)	0.41 (± 0.21)

Table A70: Mean values for each variable in each estuary with corresponding minimum detectable difference (bracketed); based on the recommended sample size (CBP), mean (near actual) CV and actual mean values ($\alpha = 0.05$, $\beta = 0.10$, using a two-tailed test) (Zar 1999).

Variable	Avon-Heathcote	Havelock	Otamatea	New River	Ohiwa	Ruataniwha	Waimea
% Mud	5 (± 2)	19 (± 4)	56 (± 14)			12 (± 4)	24 (± 20)
Chl a	56 (± 30)		53 (± 21)		30 (± 10)		19 (± 7)
Pheao		27 (± 11)	149 (± 44)		43 (± 13)		
AFDW	20 (± 8)		11 (± 3)	40 (± 27)	13 (± 3)	13 (± 3)	
TN				17104 (± 5026)	3919 (± 2147)		2355 (± 669)
TP	6736 (± 2791)			17397 (± 5112)	1815 (± 523)	5192 (± 1755)	2241 (± 659)
Cd	2 (± 1)				1 (± 0)		
Cr	319 (± 158)		41 (± 10)	735 (± 196)	47 (± 15)	273 (± 80)	357 (± 100)
Cu	64 (± 35)	57 (± 12)	26 (± 7)	255 (± 75)	24 (± 6)	80 (± 22)	50 (± 17)
Pb	127 (± 47)	31 (± 13)			16 (± 11)	53 (± 24)	
Ni	137 (± 112)			335 (± 112)	23 (± 8)	156 (± 44)	391 (± 129)
Zn	777 (± 580)		106 (± 27)	1150 (± 307)	174 (± 59)	428 (± 120)	
AbndInf		42 (± 24)	14 (± 8)		62 (± 18)		22 (± 14)
DivInf	6 (± 2)		3 (± 1)	3 (± 1)	5 (± 2)	3 (± 1)	4 (± 2)
AbndEpi	322 (± 164)			89 (± 27)	97 (± 26)	46 (± 25)	59 (± 36)
DivEpi	13 (± 4)				15 (± 5)	9 (± 4)	11 (± 5)

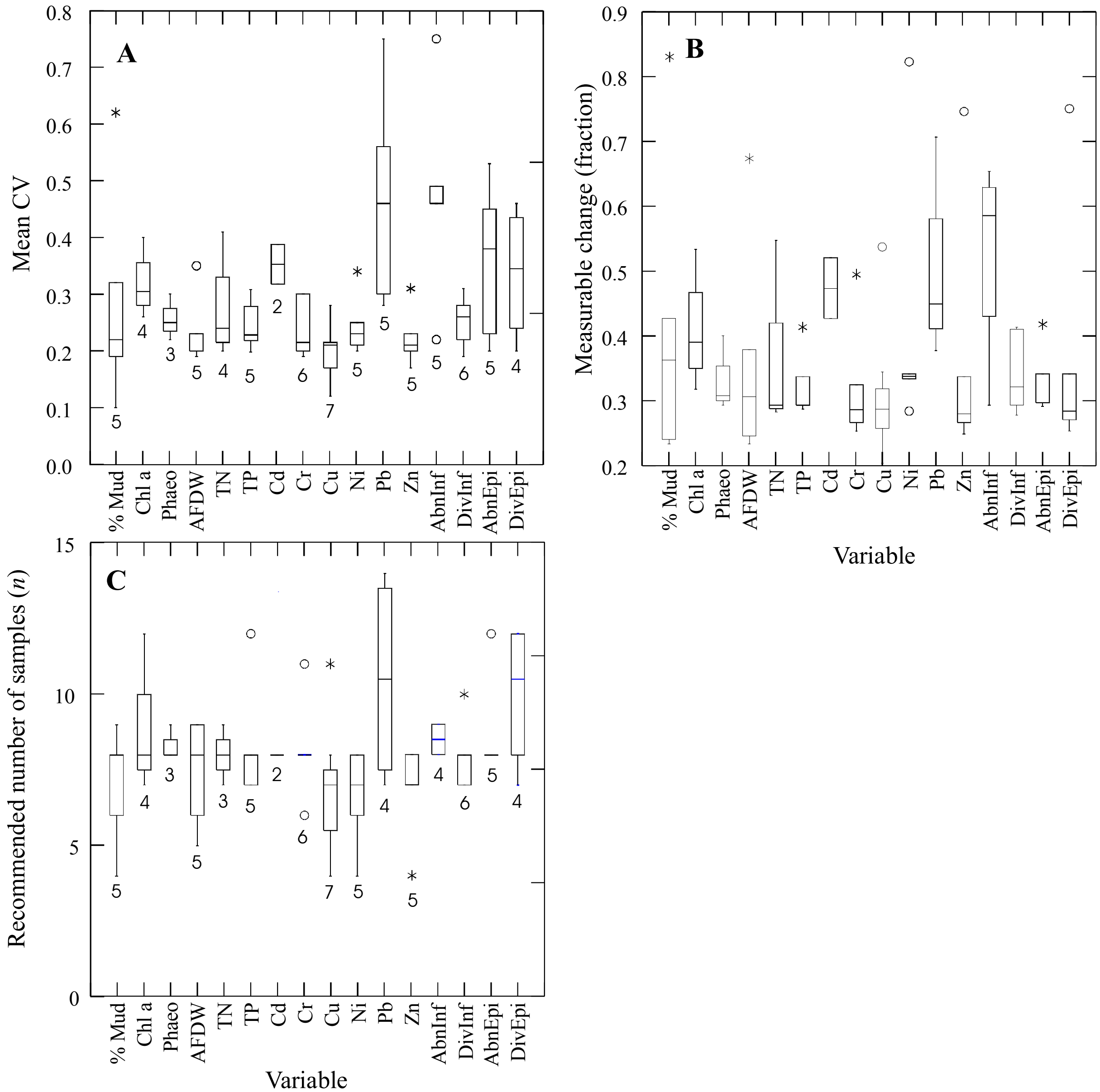


Figure A32: Box and whisker plots of recommended number of samples at CBP (a), mean (near actual) CV (b) and fraction of measurable change (c) for all variables. Boxes represent a summary of the range of values estimated for individual estuaries (see Table A70). The length of the box shows the range in which 50% of the values fall, with the box edges at the first and third quartiles. Values between the inner and outer fences are plotted with * and the values beyond the outer fences ('far outside values') are depicted in open circles. Number of values used in each instance indicated below each box.

Exploring sample size and effect size

The influence of CV level on the ability to detect change was explored by plotting the outputs from two power analysis/sample number estimation models (Figure A33). The first was a G*Power model, which is a shareware computer program, and the other was an iterative test described in Zar (1999). Each model represented a means of exploring the number of samples required, and/or the power of the test to detect a specified difference between two means (*i.e.* a t-test). On each occasion, the output was derived from a selection of the original data, representing a wide range of sample precisions.

Figure A33a shows the relationships between sample size (*n*) and the size of the measurable change (proportional to the mean = percent change/effect size) for four variables from the Waimea estuary with differing CVs. The importance of precision was very apparent, *e.g.* when a sample size of 10 was selected, the measurable change one can expect to detect increased from around 15 % with a CV = 0.08, up to a 98 % with a CV of 0.58 (Power = 0.8, $\alpha = 0.05$). Under theses circumstances, estimates in the present study with CVs above 0.6 could only detect changes that represent greater than a two-fold increase in the given variable. A similar, but less conservative trend was apparent using the iterative test (Zar 1999), where the range of CV values (from 0.08 to 0.58) translated to an expected measurable change of between 10 and 57 %, respectively, despite using a slightly higher power of 0.9 ($\alpha = 0.05$).

Figure A33c and d show the required '*n*', given the observed CV and a specified effect size (% measurable change). Using a CV of 0.3 (approximate mean overall CV for this data), the G*Power model determined that approximately five samples would be required in order to detect a 100 % change in the mean, and as many as 63 samples to detect a 20 % change. The less conservative estimate from the t-test model determined that less than three samples were necessary to detect a 100 % change, and 25 samples to detect a 20 % change.

The recommended sample numbers (Figure A33) and the expected CVs were related to the actual mean values (averaged across estuary) to obtain estimates of the minimum detectable differences for each variable in each of the estuaries. Examples of the estuary means, along with the corresponding likely minimum detectable difference are presented in Table A70. The relative minimum levels of detectable change (measurable change = minimum detectable difference/mean value x 100) associated with each variable are compared in Figure A33.

The size of the detectable change was between 25 and 50% for most means using the CBP sample number according to the iterative test described in Zar (1999) (α = 0.05 and β = 0.1). The less variable measures, such as AFDW, TP, copper, nickel and zinc had slightly lower ranges of estimated minimum detectable differences of between 25 and 35%. Inherently more variable measures, such as Chlorophyll *a*, total nitrogen (TN), cadmium, lead and infaunal abundance would require a change in the order of 30 to 65 % before a difference could be confidently detected. However, as noted earlier, a large degree of the variability encountered in the cadmium, lead, and to a lesser degree TN data, was likely to be attributable to samples being below the detection limits on several occasions.

In some instances (*e.g.* nickel and zinc in the Avon-Heathcote estuary), this method resulted in selecting a low CBP (four) with a relatively high mean CV (>0.3), which translated into a large relative level of detectable change. This occurred when the plots showed little discernable reduction in CV_{95} with increasing sample number, suggesting additional sampling would not omprove the level of precision, but at the same time demonstrated considerable variability about the mean (CV_{mean}). In such cases, it was suggested that sample size should be increased slightly in order to increase the power of detection, despite the fact the precision is unlikely to be improved.

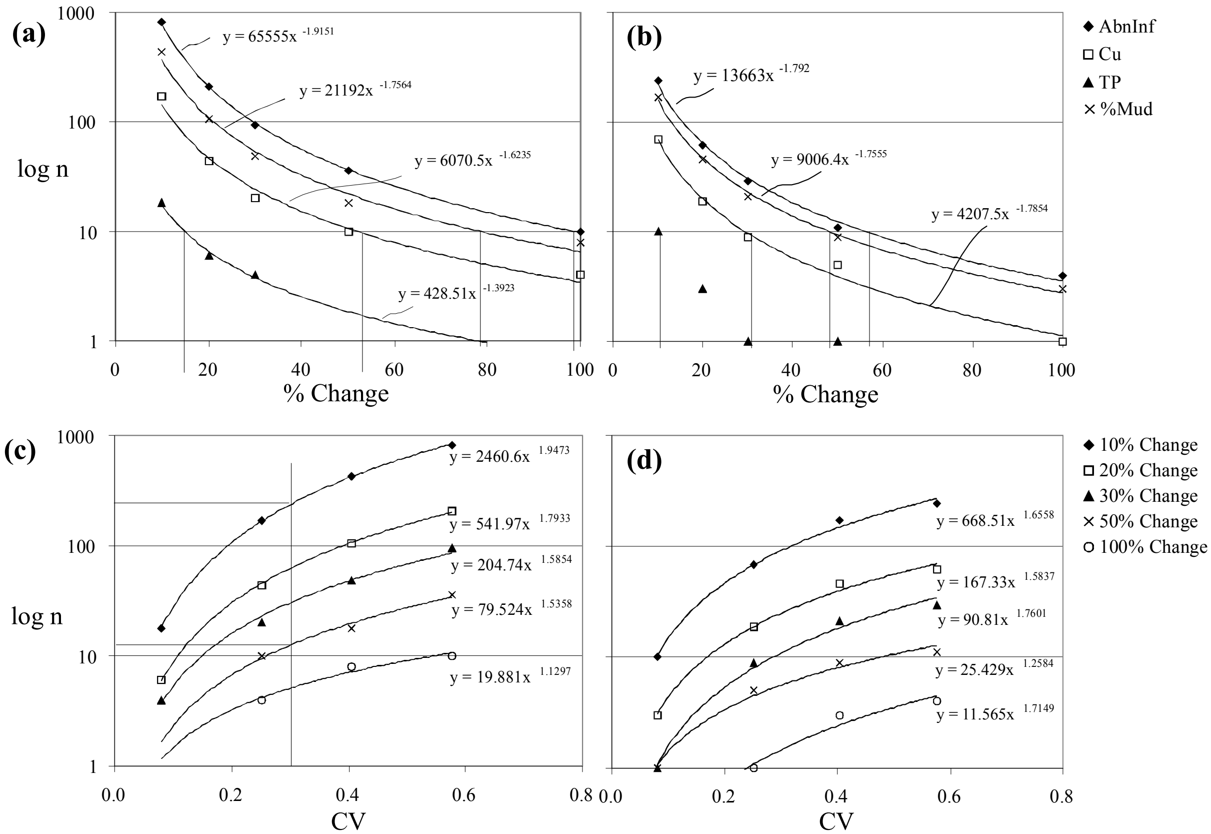


Figure A33: Performance summary of the G*Power model ($\alpha = 0.05$ and $\beta = 0.20$) and formular for predicting *n* for a t-test (Zar 1999, $\alpha = 0.05$ and $\beta = 0.10$) comparing samples size (*n*) in relation to minimum detectable change (% change) for a range of variables with differing CVs (G*Power: a, Zar: b), and sample size plotted against CV for five different levels of minimum detectable change (G*Power: c, Zar: d).