Report No. 1988
August 2011

Assessment of Effects of Farming Salmon at Kaitira, Pelorus Sound: Deposition and Benthic Effects

RESEARCH BASED SOLUTIONS

Assessment of Effects of Farming Salmon at Kaitira, Pelorus Sound: Deposition and Benthic Effects

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Reviewed by: Joanne Ellis

Approved for release by: Rowan Strickland

Issue date: 12 August 2011

Recommended citation:
Atalah J, Taylor D, Keeley N, Forrest R, Goodwin E, Dunmore R 2011. Assessment of Effects of Farming Salmon at Kaitira, Pelorus Sound: Deposition and Benthic Effects. Prepared for The New Zealand King Salmon Company Limited. Cawthron Report No. 1988. 49 p.

EXECUTIVE SUMMARY

Overview of purpose and scope

In January 2011, The New Zealand King Salmon Company Limited (NZ King Salmon) commissioned Cawthron Institute (Cawthron) to undertake a comprehensive assessment of the likely effects of a proposed salmon farm on the aquatic environment at Post Office Point, (hereafter referred to as the Kaitira Site), along Waitata Reach in the Pelorus Sound. This report assesses potential impacts to the seabed and inshore habitats and provides recommendations for appropriate environmental monitoring to assess the level and extent of impacts against predefined environmental criteria, and to facilitate appropriate management responses. This information will form a part of NZ King Salmon's Plan Change and resource consent applications, and is presented as a supplement to the Benthic Report.

Proposal

The Kaitira application is a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. The site would be used for farming salmon fed at an initial feed level rate of 3000 tonnes per annum (t yr^{-1}). NZ King Salmon have applied for an option to increase the feed discharge at 1000 t yr^{-1} increments if it is considered environmentally appropriate up to a maximum of 6000 t yr^{-1}.

Assessment approach

During the initial stages of this project, an extensive site selection process was undertaken to ensure that the proposed farm site was sufficiently distanced from ecologically sensitive habitats (*e.g.* rocky reef). Seabed habitats and communities at the Kaitira Site were characterised using a range of remote and diver operated sampling techniques; including depth profiling, sediment grab sampling and video transects. The intertidal region of the shoreline was also surveyed. Water currents were characterised using an ADCP (Acoustic Doppler Current Profiler) current meter and these data were then used to predict depositional patterns.

The likely degree and spatial extent of farm-related sedimentation was determined using a peer-reviewed deposition model (DEPOMOD). The Kaitira Site was modelled based on one cage configuration (two rows of four cages) at seven theoretical feed loadings (2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}), under 'resuspension' and 'no-resuspension' scenarios. Potential environmental effects associated with farm deposition were predicted in a separate report (the Benthic Report) by comparing the results to those calculated for existing farms with known historical feed inputs and measured ecological responses. We provide a summary of these findings in this report.

Summary of findings

The Kaitira Site is located in 30 to 65 m water depth in a region of high water currents. The seabed immediately beneath the proposed site was dominated by soft sediments, which are well represented in the Marlborough Sounds region. Seabed communities were generally considered representative of current-swept locations in central and outer Pelorus Sound. Infaunal (within sediment) communities within the study area were species-rich (a total of 114 different taxa) and were numerically dominated by various species of polychaetes, cumaceans, nematodes and amphipods. In contrast, few epibiotic (upon sediment) taxa were observed inhabiting the soft sediment habitats at the site. Shallow inshore areas of the site were characterised by reef, boulders and cobble habitats. These habitats supported a relatively diverse community of invertebrates, algae and fish. With increasing water depth and distance from shore, the sand content increased and the cover of cobbles declined. This habitat supported some ecologically significant species; including sponges, scallops (*Pecten novaezelandiae*), burrowing anemones (*Cerianthus* sp.), lamp shells (*e.g. Waltonia inconspicua*) and the occasional horse mussel (*Atrina zelandica*). The intertidal zone was characteristic of the wider Pelorus Sound. It consisted of steep, narrow (<4 m wide) cobble, boulder and rocky substrata, dominated by barnacles, grazer and predatory gastropods, patches of blue mussels and a range of macroalgae; including a fringe of *Carpophyllum flexuosum* along the sub-littoral fringe.

The average current velocity at the site was *ca*. 19 cm s^{-1}, with maximum velocities ranging between 43 and 56 cm s^{-1} recorded throughout the water column. Currents flowed predominantly to the southwest (into the Sound) and northeast (out of the Sound), and ran parallel to the coastline. Modelling indicated that dispersal of the footprint through resuspension will be considerable due to the high water current velocities. Under a no-resuspension scenario, the maximum predicted depositional flux ranged from 6 to 13 kg m^{-2} yr^{-1} when 3000 and 6000 t yr^{-1} feed loading scenarios were modelled, respectively. The effect of the prevailing current is evident by the elliptical shape of deposition predicted for the site. When resuspension was considered, net depositional flux reaching the seabed did not exceed 0.5 kg m^{-2} yr^{-1} for any of the feed loadings modelled. As the prevailing near-bottom currents regularly exceeded the resuspension threshold, the resuspension scenario is considered the most appropriate scenario for the site.

Depositional modelling indicates there will be relatively low rates of deposition consistent with the high flows observed in this area, and that the degree of deposition and subsequent organic enrichment will be determined by the feed regime. At high flow sites such as Kaitira, resuspension is predicted to prevent excessive accumulation of organic biodeposits beneath the farm. This is clearly demonstrated by the fact that when resuspension is modelled, we predict little or no net flux to the seabed. However, while the accumulation of organic material within the sediments is likely to be minimal at high flow sites, sediment chemistry and composition will be significantly altered (*i.e.* sulphide levels elevated, redox levels reduced).

Directly beneath the farm cages (*ca*. 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected. Epibiota observed beneath the site will also be displaced. It is anticipated that a further 23 ha of seabed will be low-to-moderately impacted; however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within 500 m. Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.

The Recommended Initial Feed Level (RIFL) of 3000 t yr^{-1} is considered an appropriate starting point for this site; although modelling suggests that adverse environmental effects are unlikely if feed usage is increased to a Predicted Sustainable Feed Level (PSFL) of 4000 t yr^{-1}. The maximum conceivable feed level (MCFL) for the site was estimated to be 6000 t yr^{-1}. Any increases from the RIFL should be undertaken in 1000 t yr^{-1} increments based on favourable environmental monitoring results. If initial feed levels prove to be too high, permitted feed levels should be adjusted accordingly.

Environmental monitoring

NZ King Salmon proposes to operate an Environmental Monitoring and Adaptive Management Plan (EM-AMP) which will specify the environmental monitoring and reporting requirements for the site. If monitoring identifies that impacts are exceeding allowable limits to identified habitats/communities, then it is recommended that NZ King Salmon should implement changes to farm management practices to ensure impacts are reduced or mitigated.

Conclusions

The Kaitira Site is situated in a high-flow area where wastes will tend to be dispersed and assimilated by the receiving environment. During our field surveys, small patches of notable biological features (*i.e.* rocky reefs) were recorded close to the Kaitira Site. These features are, however, located outside the application area and are at a sufficient distance from cages to minimise the chance of any detectable adverse impacts.

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1. INTRODUCTION

1.1. Background

In January 2011, The New Zealand King Salmon Company Limited (NZ King Salmon) commissioned Cawthron Institute (Cawthron) to undertake comprehensive environmental impact assessments associated with the development of salmon farms at eight proposed locations in the Pelorus and Queen Charlotte Sounds. This report relates to a proposed site in the Outer Pelorus Sound (Figure 1); hereafter referred to as the 'Kaitira Plan Change Site' or 'Kaitira Site'. This information will form a part of the company's Plan Change and resource consent applications, and is presented as a supplement to the Benthic Report (Keeley and Taylor 2011) that accompanies the NZ King Salmon application.

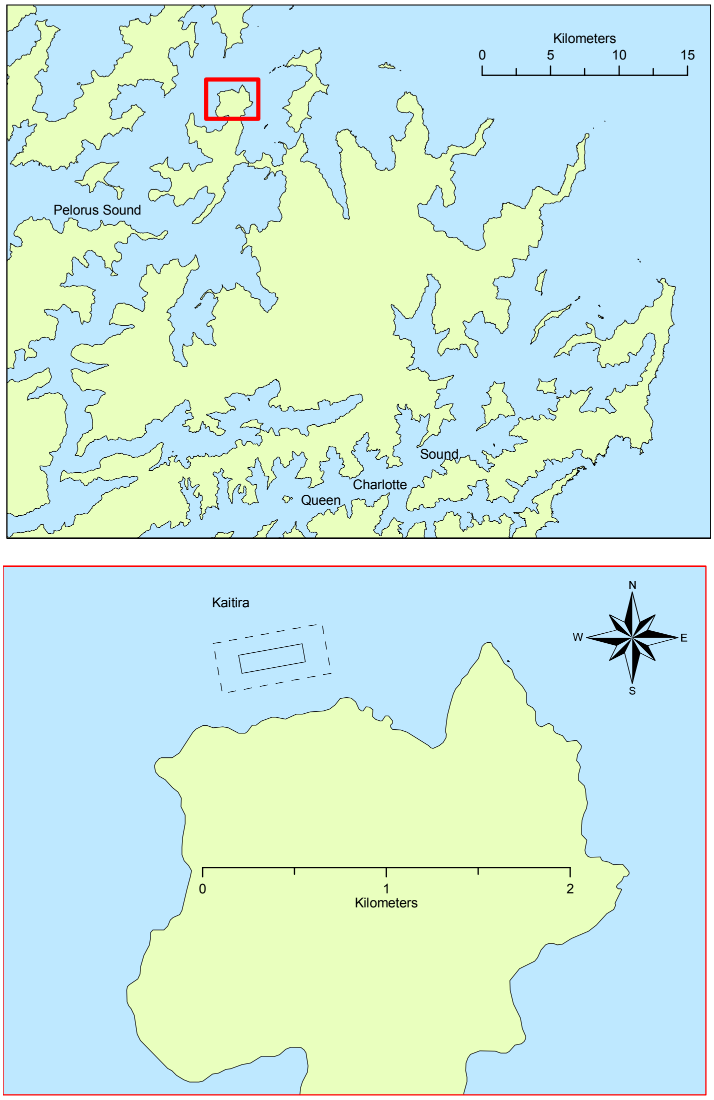

Figure 1. Location of the study area in the Outer Pelorus Sound with an expanded map of the proposed Kaitira Site. The dashed black rectangle indicates the Kaitira Plan Change Site and the solid black rectangle indicates the Cage Area Boundary (a 3.5 ha area within which all cage structures will be placed).

1.2. Description of proposed activities at the Kaitira Site

NZ King Salmon seeks approval for a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. They also seek approval for the use of an initial maximum of 3000 tonnes of feed per annum (t yr^{-1}) with the option to increase the feed discharge at 1000 t yr^{-1} increments if it is considered environmentally appropriate to a maximum of 6000 t yr^{-1}. Fish would be on-grown in large sea cages (*ca.* 40 x 40 m) from smolt reared in land-based hatcheries and fed a pelleted diet until they reached a mean harvestable size of approximately 3.5 kg.

1.3. Potential environmental issues and scope of this report

The selection of the Kaitira Site is the culmination of an extensive site selection process undertaken as part of the NZ King Salmon Plan Change application. Considerable effort was made to position proposed farms in deep, high-flow sites away from sensitive habitats of ecological significance and over more common silt-mud habitats. However, despite careful placement, the operation of any salmon farm has the potential to impact the aquatic environment in a number of ways. The key risks to consider are:

1. Effects on the seabed and inshore environments associated with the dispersion of wastes generated by the farming operation.
2. The accumulation of copper and zinc (used in antifouling paints and feed, respectively) within sediments beneath the farm.
3. Effects to the water column environment associated with the installation of farm structures and dispersion of farm generated wastes.
4. Biosecurity risks associated with the application.
5. Effects to wild fish and the environment from escapees and disease transfer.
6. Effects to marine mammals and seabirds.
7. Other issues relating to user-perceived values of the coastal environment (*e.g.* social, recreational and navigational aspects).

Issues 2-7 are addressed by the various reports that accompany the broader Plan Change AEE document. The present report addresses Issue 1 and is limited to an assessment of the effects of farm wastes on the benthic environment.

The nature and severity of benthic impacts depend on the characteristics of the waste generated, farm management (*e.g.* stocking density), the pattern of waste dispersion and dilution, and the sensitivity of the receiving environment. To this end, we present information on the following:

- The existing physical (*e.g.* water currents) and ecological characteristics of the aquatic environment at the Kaitapeha Site and the wider Queen Charlotte Sound.
- The likely effects of the installation of farm structures on the benthic environment.

- The likely effects of farm wastes on the seabed environments; including habitats inshore of the proposed site.
- A recommended approach to managing the magnitude and spatial extent of seabed impacts.

1.4. Structure of this report

In Section 2 of this report, we provide existing background information that details the physical and biological habitats along Waitata Reach and the Outer Pelorus Sound region. Section 3 summarises the seabed characteristics; including site bathymetry, sediment properties (*e.g.* grain size, organic content), and biological communities (*i.e.* infauna and epiobiota). Section 4 provides data on water currents, and these data were then used to predict the spatial extent and magnitude of deposition under varying feed loadings (Section 5). In Section 6, we provide information on monitoring available to manage seabed impacts, and finally in Section 7 we provide a summary of the main report findings and site-specific recommendations for the development of this salmon farm site. In order to improve the readability of this document, methods used to underpin the environmental assessments are included in the appendices, as follows:

- Approach to assessing seabed characteristics (Appendix 1)
- Approach to assessing water currents (Appendix 2)
- Approach to assessing depositional footprints (Appendix 3)

2. EXISTING KNOWLEDGE OF MARINE ENVIRONMENTS IN THE STUDY AREA

2.1. Outer Pelorus Sound and Waitata Reach marine environments

Pelorus Sound is large (56 km long with a surface area of 290 km^2) and complex, containing many coves, bays, lesser sounds and islands. The Sound has a high silt loading (contributed to by the Pelorus and Kaituna Rivers, which enter the head of the Sound at Havelock); consequently, inner areas can be dominated by fine sediment. More exposed areas are characterised by rocky foreshores and cobble intertidal zones, with cobbles and sand sloping to mud. The subtidal slope generally flattens out at 35 to 40 m depth (Davidson *et al.* 1990). There are few published studies on the subtidal macrobiota of the Marlborough Sounds. Most of the literature has focussed on the effects of mussel farms on nutrients and plankton, and descriptive accounts of subtidal habitats are lacking. In our assessments, most of the information on subtidal biota in Pelorus Sound has been sourced from unpublished reports for marine farm consents. The physical oceanography of Pelorus Sound has been described by Heath (1976a,b), who found that circulation was mainly tidal, and that salinities were lower than those in Queen Charlotte Sound due to the high inflows from the Pelorus and Kaituna Rivers. Current speeds were slow near high tide, and outgoing flows were stronger and lasted for a shorter time than incoming flows (Heath 1976a).

Waitata Reach is located in the Outer Pelorus Sound north of Maud Island, bordering Tawhitinui Reach in the southwest and connecting with Cook Strait in the northeast. The Reach is approximately 12 km long and 2 to 4 km wide with water depths of 45 to 60 m, but achieves greater then 80 m depth in the Outer Reach. Waitata Reach contains several medium-to-large bays; including Waitata Bay, Port Ligar and Richmond Bay. The dominant deep subtidal habitat in Waitata Reach is soft sediment, and the coastline is characterised by narrow rocky reefs, boulders and cobbles. Soft sediment areas support epibiota such as echinoderms (*e.g.* snake tail stars, cushion stars), hydroid trees, bryozoan corals, tunicates (*e.g.* saddle squirts) and bivalves (*e.g.* mussels, horse mussels, scallops) (Roberts & Asher 1993; Forrest 1995; Forrest & Roberts 1995; Davidson 2001). A wide range of biota have been observed on hard substrata; including numerous species of macroalgae (*e.g. Carpophyllum* sp., *Undaria pinnatifida*, *Caulerpa* sp., *Cystophora* sp., *Codium* sp.), sponges, hydroids, ascidians, echinoderms (*e.g.* kina, sea stars, snake tail stars, cushion stars), crustaceans, molluscs (*e.g.* mussels, limpets) and various fish species (*e.g.* triplefins, blue cod, spotties, butterfly perch) (Roberts & Asher 1993; Forrest 1995; Forrest & Roberts 1995; Davidson 2001). Recognised areas of ecologically significance in the region include a burrowing anemone habitat at Oke Rock, a red algae bed in Harris Bay, a high current habitat at Paparoa, and bird breeding and roosting habitats at Duffers Reef and Bird Island (Davidson *et al.* 1995, Davidson *et al.* in prep.). However, there are no known sites with high ecological value documented in the immediate vicinity of the present study area.

Waitata Reach is utilised by a wide range of economic sectors. At present, portions of the coastline are occupied by marine farms. Most are mussel farms, but salmon farms are located at Wahinau Bay (currently fallowed to measure and assess environmental recovery) and Forsyth Bay (operational). The area is also regularly used by both commercial and recreational fishers. The surrounding land supports forestry and farming, as well as some tourism (*e.g.* holiday accommodation). Much of the landscape surrounding Waihinau Bay and Waitata Bay is part of the Te Kopi Wildlife Sanctuary which aims to enhance the biodiversity and wildlife values of the area.

2.2. The Kaitira Site study area

The Kaitira Site is a 16.5 ha area situated in the outer Pelorus Sound, on the eastern side of the Waitata Reach, between Post Office Point and Wynens Bay (Figure 1). The site is somewhat sheltered from southeasterly winds, but is exposed to wind from most other directions. Strong wind gusts eddy into the Sound and some northerly winds reach the site. The site is exposed to localised wave action, although some attenuated ocean-swell can enter the outer Sounds from Cook Strait (Roberts & Asher 1993).

3. SEABED CHARACTERISTICS

3.1. Site bathymetry

Water depths at the Kaitira Site ranged from 30 to 55 m along the inside boundary of the farm, to 60 to 65 m along the seaward boundary (Figure 2). Inshore of the site in depths of 35 to 50 m, the seabed was steeply sloping, but the gradient progressively lessened with increasing depth and became relatively flat at 60 m. No significant depressions or reef structures were apparent, however inshore areas of rocky reef were observed (Figure 2).

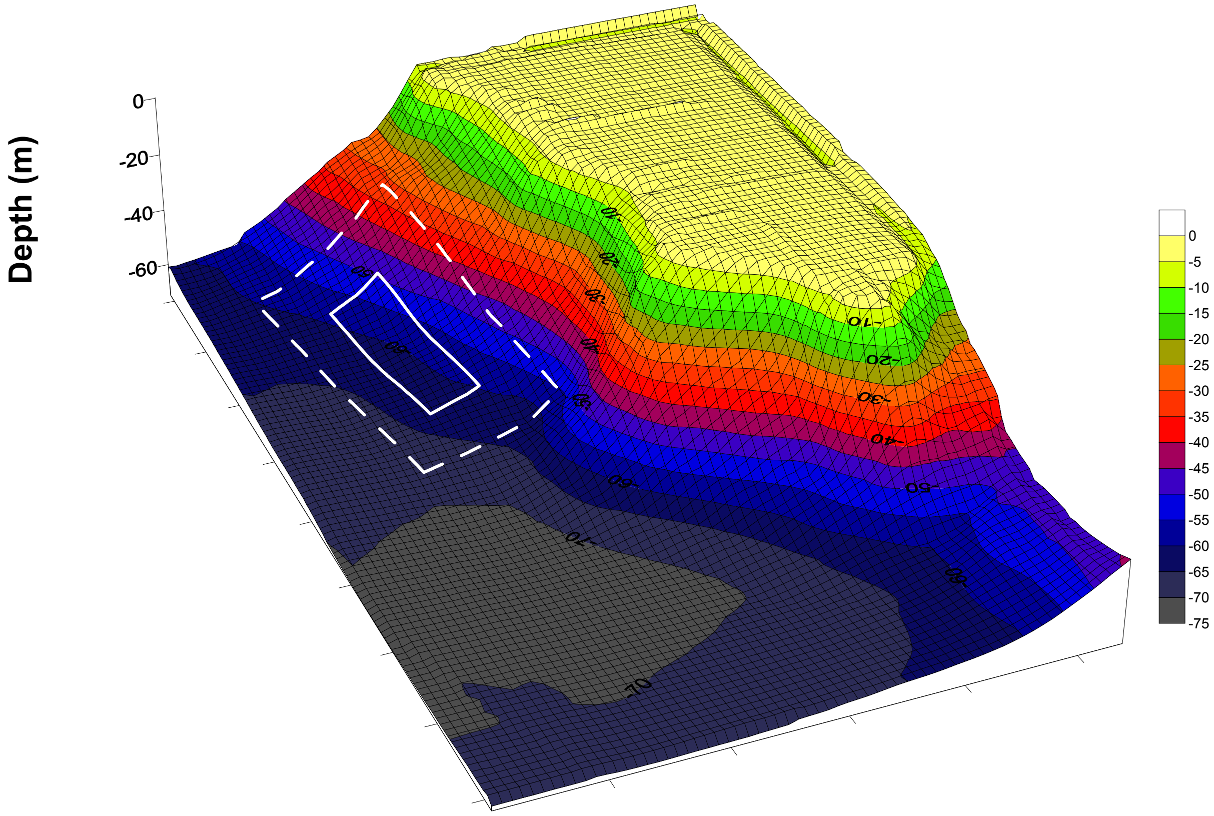

Figure 2. 3-D bathymetry map of Kaitira Site with proposed locations of the Cage Area Boundary (solid white line) and Plan Change Site Boundary (dashed white line) overlaid onto the seafloor.

3.2. Sediment physical and chemical properties

Sediments sampled from beneath and adjacent to the proposed site contained varying amounts of silt and clay (<63 µm), sand (<2 mm and >63µm) and gravel-sized (>2 mm) components (Figure 3). On average, sediments contained 57% silt/clay, 35% sand and 8% gravel. These results were consistent with observations made from video footage and drop-camera images (see Section 3.4). Sediment cores were characterised by a fairly uniform light grey/brown colour and appeared well oxygenated, with no evidence of a Redox Potential Discontinuity (aRPD) layer. Photographs of the sediment cores are presented in Appendix 4. Sediment organic content was similar between sampling stations (average 4.8% AFDW, SE 0.2%), with levels suggesting a productive benthic environment (Figure 3).

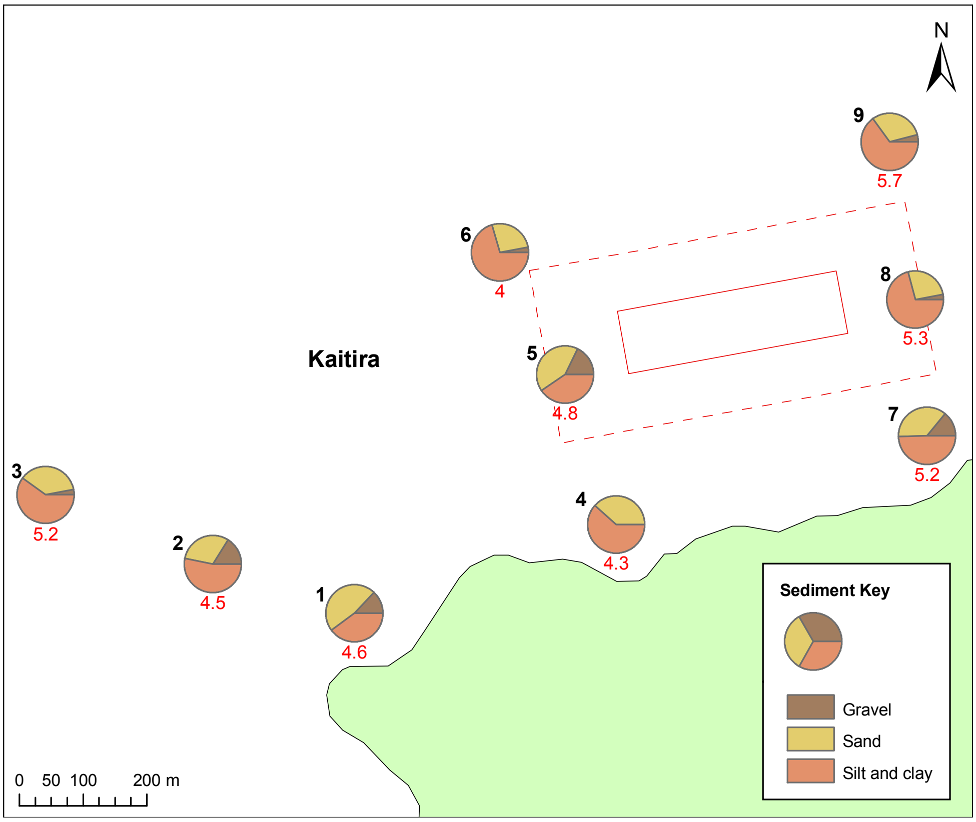

Figure 3. Grain size composition (% wet weight) and organic content (in red: %AFDW) of sediments collected from the Kaitira Site. Black numbers indicate station number, the red boxes indicate the proposed Cage Area Boundary and the red dashed line indicates Plan Change Site.

3.3. Sediment biological properties

Sediments sampled from beneath and adjacent to the proposed Kaitira Site contained infaunal communities representative of those commonly found under high-flow sites throughout the Sounds region, and are therefore considered indicative of natural conditions. The site was characterised by high taxa richness (a total of 114 taxa recorded), and ranged between 26 and 57 taxa per core (Table 1). Refer to Appendix 5 for the complete species list. Infaunal abundance ranged between 93 and 310 individuals per sediment core (average of 208). Numerically dominant taxa included various species of polychaetes, nematodes, ostracods and amphipods (Table 1). Patterns in infaunal community composition were explored using multivariate statistical techniques, and the reader is referred to Appendix 6 for a summary of these analyses.

Table 1. Average and relative abundances (%) of the 15 most common infaunal taxa collected from sediments at the Kaitira Site.

Taxa	Description	1	2	3	4	5	6	7	8	9	Average Abund.	Relative Abund. (%)
Paraonidae	Polychaete	4	28	39	18	27	19	24	14	38	23	21
Prionospio multicristata	Polychaete	42	79	5	5	12	21	17	2	6	21	18
Cirratulidae	Polychaete	11	17	15	12	2	13	19	11	23	14	12
Sphaerosyllis sp.	Polychaete	0	32	0	5	20	8	20	1	8	10	9
Lumbrineridae	Polychaete	13	4	3	7	9	5	14	0	9	7	6
Cumacea	Cumacean	0	15	6	4	4	1	12	10	4	6	5
Heteromastus filiformis	Polychaete	9	20	0	2	3	8	6	1	5	6	5
Dorvilleidae	Polychaete	1	1	0	10	4	1	33	0	3	6	5
Maldanidae	Polychaete	6	3	4	5	1	6	5	8	11	5	5
Nematoda	Polychaete	5	15	0	4	9	1	2	0	5	5	4
Asellota	Isopod	0	1	8	2	7	4	8	5	6	5	4
Spirorbidae	Polychaete	38	0	0	0	0	0	0	0	0	4	4
Melitidae	Amphipod	8	14	11	0	2	1	2	0	0	4	4
Cossura consimilis	Polychaete	0	0	10	6	1	3	4	3	5	4	3
Prionospio yuriel	Polychaete	0	20	0	3	0	2	1	0	6	4	3
Total infaunal abundance		**272**	**326**	**144**	**145**	**167**	**211**	**291**	**106**	**208**		
Taxa richness		**46**	**44**	**33**	**35**	**42**	**40**	**58**	**27**	**44**		

3.4. Subtidal habitats and conspicuous epibiota

Video and drop-camera images were collected from beneath and adjacent to the Kaitira Site to identify conspicuous epibiota and assist in developing a habitat map of the study area (Figure 4). Habitat types and the associated conspicuous epibiota are summarised in Table 2, and examples from video footage and drop-camera images are shown in Figures 5 and 6. A full list of observed taxa is presented in Appendix 7.

Habitats in the study area are represented diagrammatically in Figure 7. Shallow intertidal/subtidal areas inshore of the Kaitira Site were characterised by a narrow fringe of rocky reef. Cobbles and boulders, with 'pockets' of sand interspersed, were widespread immediately below the shallow reefs. Pebbles mixed with sand and shell habitats were present between depths of 6 and 11 m, while deeper areas were dominated by silt/mud habitats, and mud and shell habitats (Figure 7). Communities inhabiting the shallow, current-swept hard-substrate habitats (*i.e.* reef, boulders and cobbles) were relatively diverse, and supported a range of biota; including algae (encrusting coralline and brown algae, red filamentous, sea lettuce, *C. flexuosum*), sea cucumbers, hydroids, anemones, vase sponges, kina, Cook's turban shell, cushion stars, snake tail stars and various fish species (*e.g.* blue cod, spotties, triplefins). Sand content around the pebbles increased with depth (>9 m), and some scallops, sea stars, hydroids, snake stars, tubeworms, sea cucumbers and red filamentous algae were present in this habitat.

The deep muddy substrata under and around the proposed Plan Change Site supported a sparse and relatively low diversity of epibiota. Turret shells, sea cucumbers, snake tail stars and cushion stars were common, while hydroids, ascidians and sponges, diatom mats and worm mounds were less abundant in this habitat. Inshore of the Cage Area Boundary, the muddy seabed had a greater amount of shell material, thus supported a higher abundance of similar epibiota. Of special ecological interest, lamp shells (brachiopods) were observed in low densities at a depth of approximately 20 m; however were well below limits that would trigger further investigation (DoC 1995). In general, habitats and epibiota observed beneath and adjacent to the site resembled those described for the wider area by Davidson (2001).

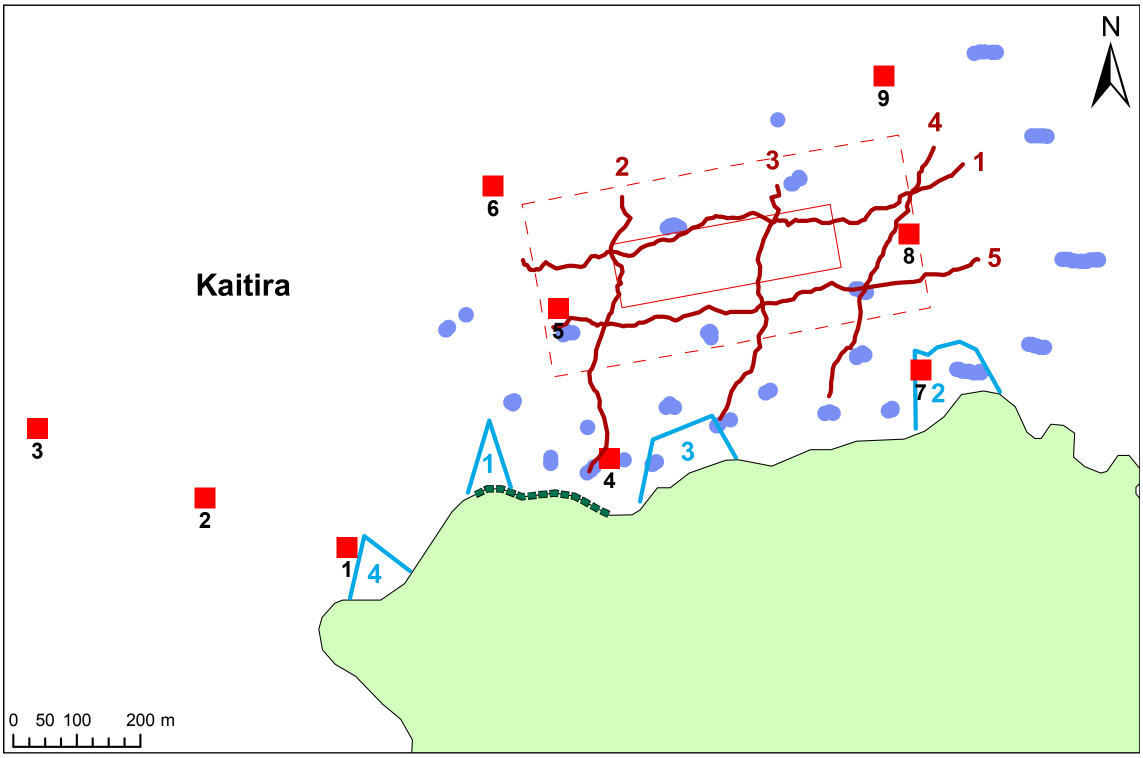

Figure 4. Sampling locations beneath and adjacent to the Kaitira Plan Change Site: sediment grab (red squares) and drop-camera stations (purple circles), dive (blue lines) and video sled transects (brown lines) and the intertidal survey transect (green dashed line) are shown.

Table 2. Conspicuous epibiota associated with seabed habitats identified from video and drop-camera images collected from beneath and adjacent to the Kaitira Site. Refer to Figures 5 & 6 for representative photographs.

Seabed habitat	**Conspicuous epibiota**
Reef, boulders or cobble mixed with sand	Tubeworms (*Galeolaria hystrix*), saddle squirts (*Cnemidocarpa bicornuta*), encrusting ascidians (*Aplidium phortax*), kina (*Evechinus chloroticus*), 11-arm sea stars (*Coscinasterias calamaria*), cushion stars (*Patiriella* sp.), sea star (*Astrotole scabra*), snake tail stars (*Ophiopsammus maculata*), calcareous tubeworms, hydroids, barnacles, Cook's turban (*Cookia sulcata*), red filamentous algae, *Carpophyllum flexuosum*, encrusting coralline algae, vase sponge (*Ancorina alata* or *Geodia regina)*), erect sponges, striped anemone (*Actinothoe albocincta*) and various reef fish; including triplefin (Tripterygiidae sp.), blue cod (*Parapercis colias*) and spotties (*Notolabrus celidotus*).
Pebble and sand	Small hydroids, 11-arm sea stars, cushion stars, snake tail stars, red algae, scallops (*Pecten novaezelandiae*), turret shells (*Maoricolpus roseus*) and sea cucumbers (*Stichopus mollis*).
Sand and shell	Cushion stars, scallops, snake tail stars, hydroids, brachiopods and sea cucumbers.
Mud	Low densities of hydroids, snake tail stars, whelks, scallops and encrusting ascidians.

Figure 5. Images obtained from video footage: (A) Shallow cobble habitat with kina, (B) reef habitat, (C&D) cobbles and sand habitat with tubeworms and sponge, respectively, (E&F) pebble and sand habitat.

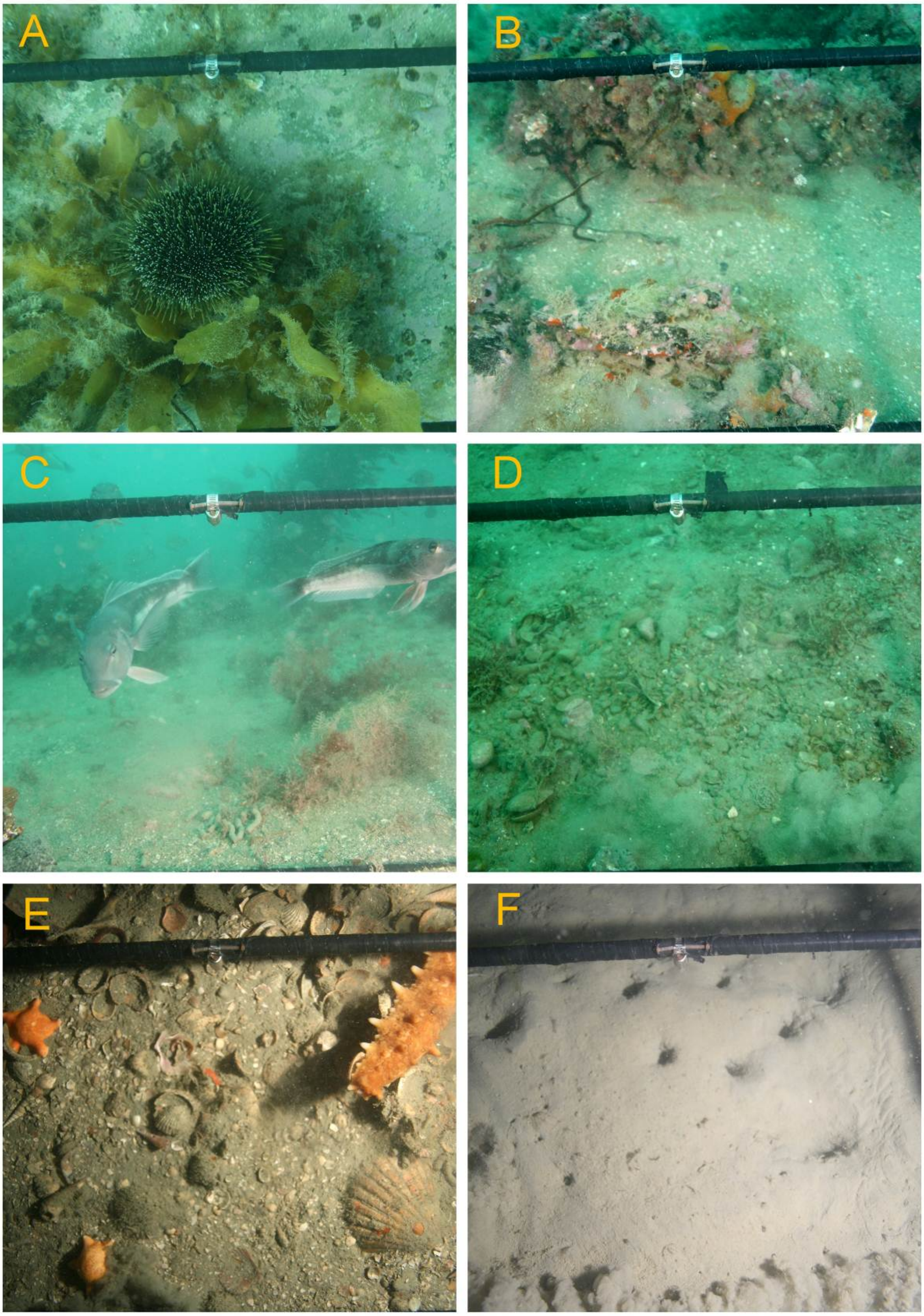

Figure 6. Examples of drop-camera images: (A) Reef habitat with kina and *Carpophyllum* sp., (B&C) cobble and sand habitat, (D) pebble, sand and shell habitat, (E) mud with shell habitat and (F) mud and silt habitat.

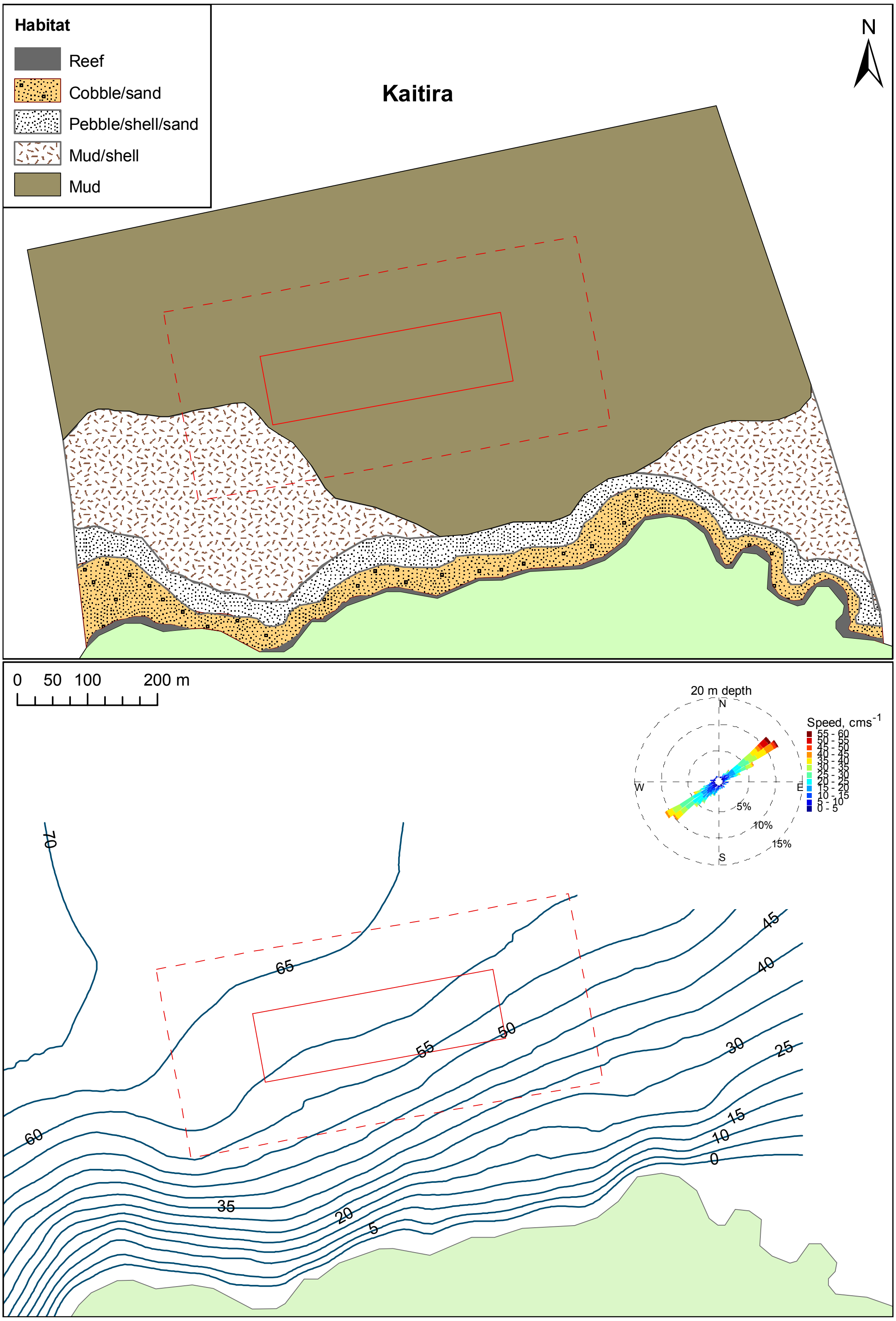

Figure 7. Top: Map of seabed habitats observed beneath and adjacent to the Kaitira Plan Change Site. Bottom: Bathymetric contour lines at the Kaitira Site with the 20 m depth current rose inset. The solid red rectangle indicates the proposed Cage Area Boundary and the red dashed line indicates the Kaitira Plan Change Site.

3.5. Intertidal habitats

The intertidal region inshore of the Kaitira Site was characteristic of the wider Pelorus and Marlborough Sounds, and consisted of steep, narrow (<5 m wide) cobble, boulder and rocky reef habitats (Figure 8). The upper and mid shores were dominated by barnacles, with the small periwinkles common but patchy in distribution. The mid shore also had a variety of grazing and predatory gastropods present; including limpets and whelks. The low shore had patches of the blue mussel and a range of macroalgae; including encrusting coralline algae, Neptune's necklace and filamentous red algae. Cat's eye snails and chitons were also common on the low-shore. The immediate subtidal had cobbles encrusted with coralline and brown algae, patches of mussels, and a conspicuous fringe of the *Carpophyllum* algae. Additionally, underneath the cobbles there was a variety of invertebrates; including porcelain crabs. A full list of taxa and relative abundance scores can be found in Appendix 8.

Figure 8. The intertidal zone inshore of the proposed Kaitira Site; showing the reef and boulders extending from the high shore into the immediate subtidal.

4. WATER CURRENTS

Flow charts of current speed (cm s^{-1}) and direction (true) at surface, mid-water and near-seabed are shown in Figure 9, and flow charts of the entire water column are presented in Appendix 9. Average water velocities were above 19 cm s^{-1} within each depth interval, with the highest flows observed mid-water (20-24 m depth). Current directions differed throughout the water column, with surface waters (0 m) moving predominantly towards the northeast, with only limited tidal reversal evident. Mid-water currents (24 m) showed a more balanced tidal reversing signal than those near the surface, with flows predominately moving northeast and southwest. These directions correspond with water moving in and out of the Pelorus Sound and therefore waste particulates would likely be transported along the main channel on the flooding tide, and towards the open sea during the ebb (see Section 5.2.1). Near-seabed water currents (44 m) were predominantly moving towards the southwest (into the Pelorus Sound), with only limited tidal reversing.

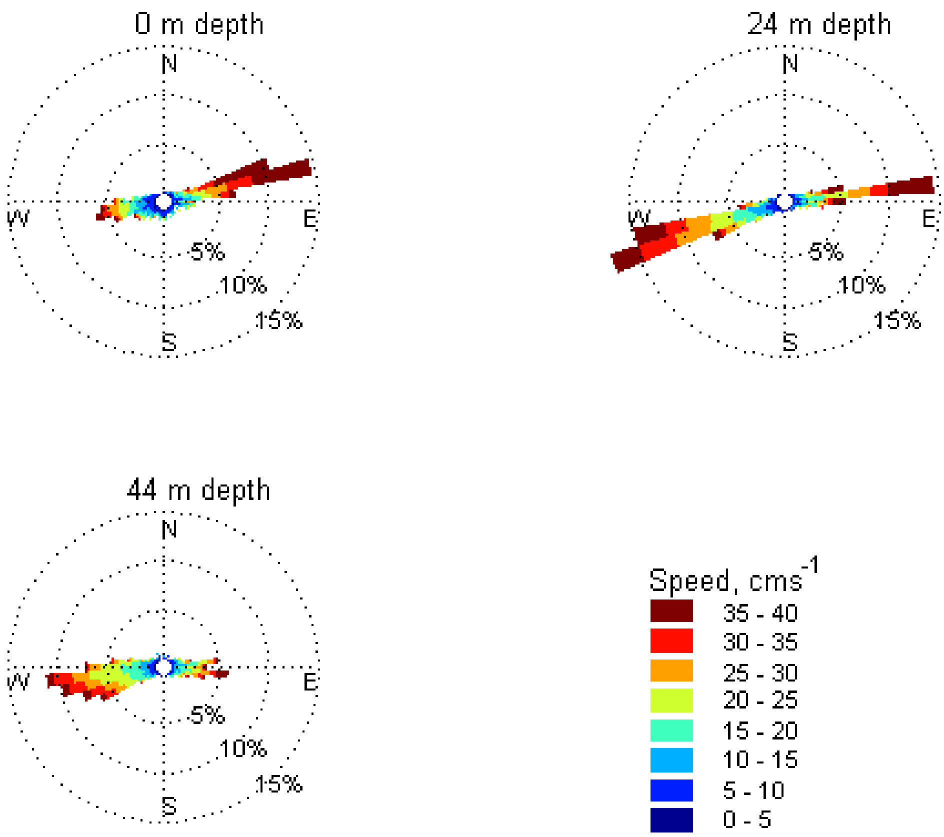

Figure 9. Mean current speed and direction measured at surface (0 m depth), mid-water (24 m depth) and near-seabed (44 m depth) at the Kaitira Site.

Table 3. Depth-averaged current speed (cm s^{-1}) collected between 8 November 2010 to 9 December 2010 by an ADCP deployed at the Kaitira Site (see Appendix 2 for sampling details).

Depth (m)	Average (cm s^{-1})	1^{st} percentile (cm s^{-1})	99^{th} percentile (cm s^{-1})	Std. Dev	Std. Error
0	19.26	1.51	56.62	13.23	0.34
4	19.86	1.75	55.67	12.54	0.33
8	20.71	1.47	54.59	12.23	0.32
12	21.36	2.29	54.15	12.17	0.32
16	21.66	2.32	54.86	12.26	0.32
20	21.70	1.69	56.13	12.47	0.32
24	21.69	1.65	54.97	12.55	0.33
28	21.62	1.58	53.99	12.43	0.32
32	21.53	1.64	53.59	12.14	0.32
36	21.35	1.50	53.14	11.72	0.30
40	20.85	1.44	49.84	11.08	0.29
44	19.60	1.64	43.96	9.92	0.26

Note: The 1^{st} and 99^{th} percentiles are the values below which 1% and 99% of the observations may be found, respectively.

5. ASSESSMENT OF BENTHIC EFFECTS

Benthic impacts can potentially occur at the Kaitira Site during initial development (*i.e.* during the installation of anchors, warps and cage structures) and from discharges associated with farm operation. The following section of this report provides an assessment of the likely effects that may result from both of these processes. In relation to ongoing farm discharges, modelling results and associated discussion have been extracted from a broader benthic assessment report (the Benthic Report) that considers all eight proposed farm sites being applied for by NZ King Salmon (Keeley & Taylor 2011).

5.1. Benthic impacts associated with the initial site development

NZ King Salmon are applying for consent that allows for the installation of cages using an anchoring system similar to that currently used on other salmon farms. This consists of block and spiral anchors and anchor warps, which will attach to the cage structures. Effects arising from the installation of anchoring structures can include: the destruction/displacement of species and/or habitats, the short-term resuspension of sediments, changes to hydrodynamics in the region and an increase in the surface area available for colonisation by fouling organisms (Table 4).

Substrata beneath the Plan Change Site were dominated by sand and mud, with shell interspersed. Areas of hard substrata (and associated biota) are located well inshore of the proposed farm area, and are therefore highly unlikely to be affected during the initial site development. Fine-scale changes in hydrodynamics are expected due to the presence of ropes and other farm structures (Plew 2009), and are not predicted to have significant ecological effects (see the Water Column Report - Gillespie *et al.* 2011). Risks associated with marine pests colonising farm structures are addressed separately in the Biosecurity Report (Forrest 2011) accompanying the application. Benthic effects associated with fouling taxa (*e.g.* drop-off to the seabed) are likely to be minimal and can be managed through regular maintenance.

Table 4. Summary of potential environmental impacts associated with the installation of anchoring systems at the Kaitira Site.

Potential impact	Environmental implications	Options to avoid, remedy or mitigate
1. Destruction/ displacement of species and/or habitat	The installation of each spiral anchor is likely to result in the displacement of epifaunal and infaunal taxa in a small area (approx. 1 m^2).	Areas to be used for anchorage are characterised by soft sediments, thus sensitive habitats (*e.g.* reefs) are unlikely to be affected.
2. Short-term resuspension of sediments	There will be small-scale resuspension and settlement of fine particulates onto similar sediments, which will likely occur over a relatively short time frame (hours to days) with minimal impact.	Use of experienced and qualified personnel to install anchors and structures to minimise the amount of seabed disturbance.
3. Effects on hydrodynamics	Due to the diameter (approx. 40 mm) of the warps, the anchoring systems are not expected to significantly alter the hydrodynamics at the site.	Periodically maintain warps to manage the amount of fouling organisms attached.
4. Increased surface area for colonisation	Colonisation of the anchor warps by algae is expected to occur, based on observations at other farm sites. Introduced fouling species may also colonise the anchor warps (*e.g. Didemnum vexillum* and *Undaria pinnatifida*). Some drop-off to the seabed is expected, which may result in the colonisation of the seabed.	Periodic maintenance of warps to manage the amount of fouling organisms attached. Routine monitoring for introduced fouling species. The invasive species *Undaria pinnatifida* is already present on reef habitat near the site.

5.2. Benthic impacts arising from farm operations

5.2.1. Spatial extent of deposition

Background

Deposition of farm waste is the primary driver of seabed impacts and particle tracking models have become an accepted and useful tool to predict and manage their extent (Henderson *et al.* 2001). For this assessment, DEPOMOD v2.2 was used to predict the likely degree and spatial extent of deposition to the seabed. DEPOMOD was selected from a number of analogous particle tracking models because it is widely used and published, and designed specifically for managing fish farm wastes (Cromey & Black 2005; Cook *et al.* 2006; Magill *et al.* 2006). It is notable among fish farm impact models in that a number of processes it simulates have been validated against field measurements (Cromey *et al.* 2002 a,b,c; Chamberlain & Stucchi 2007). DEPOMOD is used as a regulatory tool in Scotland for discharge consents of in-feed chemotherapeutants (SEPA 2003), and in setting biomass limits (SEPA 2005). Similar modelling approaches have been used in France, Norway, Ireland, Canada, Australia, Chile and South Korea (Henderson *et al.* 2001; C Cromey, pers. comm.). DEPOMOD also allows the user to predict the influence of resuspension on the footprint. This prediction is based on default resuspension and deposition velocity thresholds (9.5 cm s^{-1} and 4.5 cm s^{-1} near-bed current speed, respectively), and was not specifically calibrated for the sediments present at the Kaitira Site. Thus, it should be considered an approximation only. The no-resuspension output represents a scenario where there is a one way flux to the sediment and thus can be treated as a worst-case scenario with regard to seabed impacts.

New Zealand and overseas studies have shown that benthic effects tend to be most evident directly beneath the cages, and exhibit a strong gradient of decreasing impact with increasing distance (Figure 10). High levels of organic enrichment directly beneath finfish farms are typically manifested via a suite of different 'indicators'. Typical changes in infauna along an enrichment gradient from a finfish farm are depicted in Figure 10 and described in Table 5, and range from pristine natural conditions (Enrichment Stage (ES) 1) to extremely enriched conditions (ES 7). An important feature along the gradient is the stage of greatly enhanced seabed productivity, which defines ES 5 and is evidenced by extreme proliferation of one or a few enrichment-tolerant 'opportunistic' species such as the marine polychaete worm *Capitella capitata* and nematodes. ES 5 has traditionally been the recommended upper level of acceptable impacts in New Zealand, because the benthos is still considered biologically functional and associated with the greatest biomass - and is therefore thought to have greatest waste assimilation capacity. Stages beyond ES 5 (*i.e.* ES 6-7) are characterised by extremely impacted sediments and the collapse of the infauna population, at which point organic accumulation of waste material is thought to greatly increase.

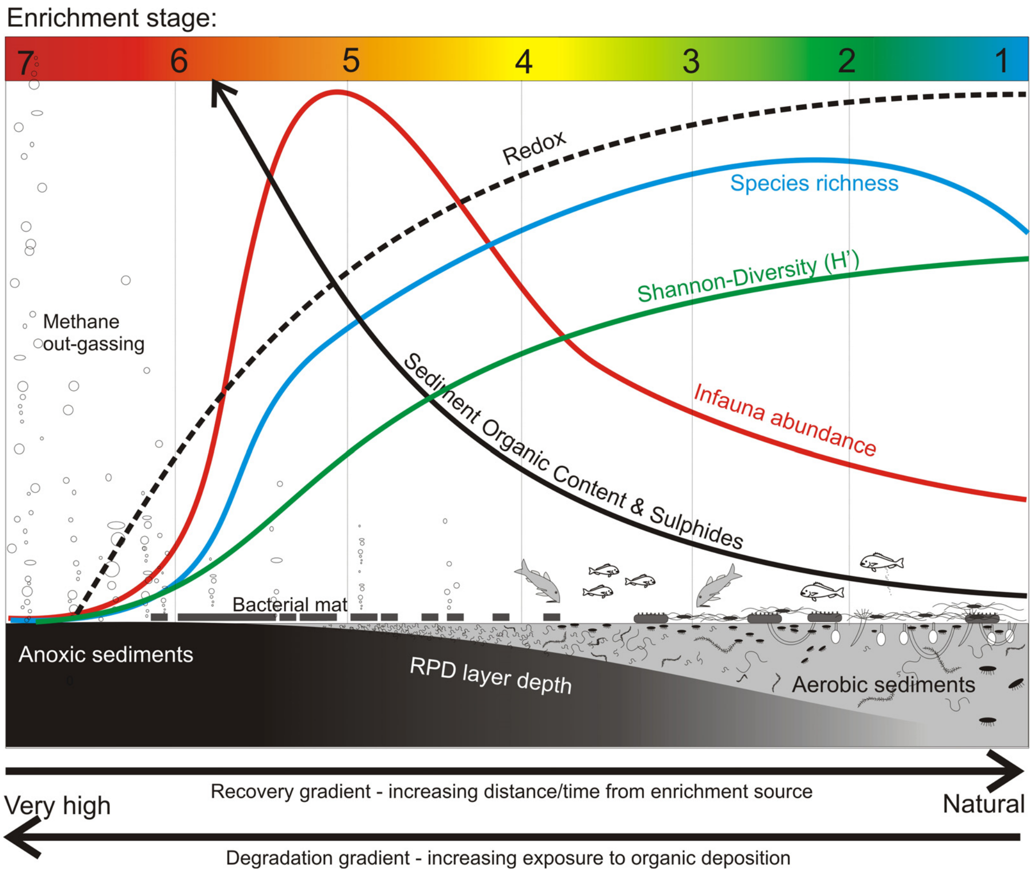

Figure 10. Graphical representation of typical enrichment gradient indicating approximate boundaries of proposed seven impact stages in relation to some frequently adopted environmental indicator variables.

Table 5. General description and main environmental characteristics of enrichment stages (ES) 1-7. Refer to the Benthic Report (Keeley & Taylor 2011) for further background to typical benthic effects associated with salmon farming.

ES	**General description**
1	***Natural/pristine conditions*** – Environmental variables comparable to unpolluted/ un-enriched pristine reference site.
2	***Minor enrichment/enhanced zone*** - This can also occur naturally or from other diffuse anthropogenic sources. Taxa richness usually greater than for reference conditions. Minor increases in animal abundance possible.
3	***Moderate enrichment*** – This is typically coupled with a significant change in community composition. Notable abundance increase, richness and diversity usually lower than reference. Opportunistic species (*e.g.* capitellids) begin to dominate.
4	***High enrichment*** – A transitional stage between moderate effects and peak macrofauna abundance. A major change in community composition is evident. Opportunistic species dominate, but other taxa may still persist. Major sediment chemistry changes (approaching hypoxia).
5	***Very high*** – Sediments are highly enriched and macrofauna are at peak abundance. Total abundances can be extreme. Diversity usually significantly reduced, but moderate richness can be maintained. Sediment organic content usually slightly elevated. Beggiatoa (bacterial mat) formation and out-gassing possible.
6	***Excessive enrichment*** - Transitional stage between peak abundance and azoic conditions (no infauna present). This has not previously been observed at high-flow salmon sites in the Marlborough Sounds.
7	***Severe enrichment*** - Anoxic and azoic; sediments no longer capable of supporting macrofauna. Organic material accumulating in the sediments. This has not previously been observed at high-flow salmon sites in the Marlborough Sounds.

Predicted depositional footprint at the Kaitira Site

NZ King Salmon proposes to place eight cages (40 x 40 m) in two rows of four cages. The depositional footprint was modelled in DEPOMOD at seven theoretical levels of annual feed loading: 2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}, under 'no-resuspension' and 'resuspension' scenarios. These feed loadings were selected based on predictive modelling undertaken by in the Benthic Report (Keeley & Taylor 2011), and include three feed usage thresholds developed for the various NZ King Salmon sites (including the Kaitira Site). These are as follows (refer to the Benthic Report for full description and the approach for their determination):

- Recommended Initial Feed Level (**RIFL**): 75% of the PSFL.
- Predicted Sustainable Feed Level (**PSFL**): The level at which flux to the seabed exceeds 10 kg m^{-2} yr^{-1}.
- Maximum Conceivable Feed Level (**MCFL**): A less conservative estimate of the site feed loading capacity.

Figure 11 shows the predicted depositional footprints for the RIFL, PSFL and MCFL feed levels (*i.e.* 3000, 4000 and 6000 t yr^{-1}, respectively), while footprints for feed usage levels of 2000, 5000 and greater than 6000 t yr^{-1} are provided in Appendix 10. When no-resuspension was assumed in the model, the maximum depositional flux was 6 kg m^{-2} yr^{-1} at 3000 t yr^{-1} (*i.e.* the RIFL) and this increased with increasing feed input (Figure 11), reaching 13 kg m^{-2} yr^{-1} at feed loadings of 6000 t yr^{-1} (the MCFL). The effect of the prevailing current is evident in the elliptical shape of deposition (Figure 11). When resuspension was included in the model, the depositional flux beneath the cages was reduced considerably due to particles being resuspended and transported by the currents after they had originally settled. In fact, net depositional flux reaching the seabed did not exceed 0.5 kg m^{-2} yr^{-1} for any of the feed loadings modelled, and therefore diagrammatic representation of the depositional footprints are not provided in this report. Thus, under resuspension scenarios, DEPOMOD predicts that most of the organic particulates discharged from the farm will be diluted, dispersed and exported from the area.

The overall area directly affected by deposition across the six feed loadings without resuspension in the model was estimated to range from 16-34 ha for feeding loads of 2000 to 8000 t yr^{-1}, respectively, with most of this area exposed to relatively low depositional rates of 0.5 to 4 kg m^{-2} yr^{-1} (Figure 12). In contrast, when resuspension was added to the model, the total area affected by deposition rates was negligible, as the re-suspension scenarios involved no net depositional flux or, any that is predicted is less than 0.5 kg m^{-2} yr^{-1}. In reality, the area affected by deposition is likely to be somewhere in between these two ranges.

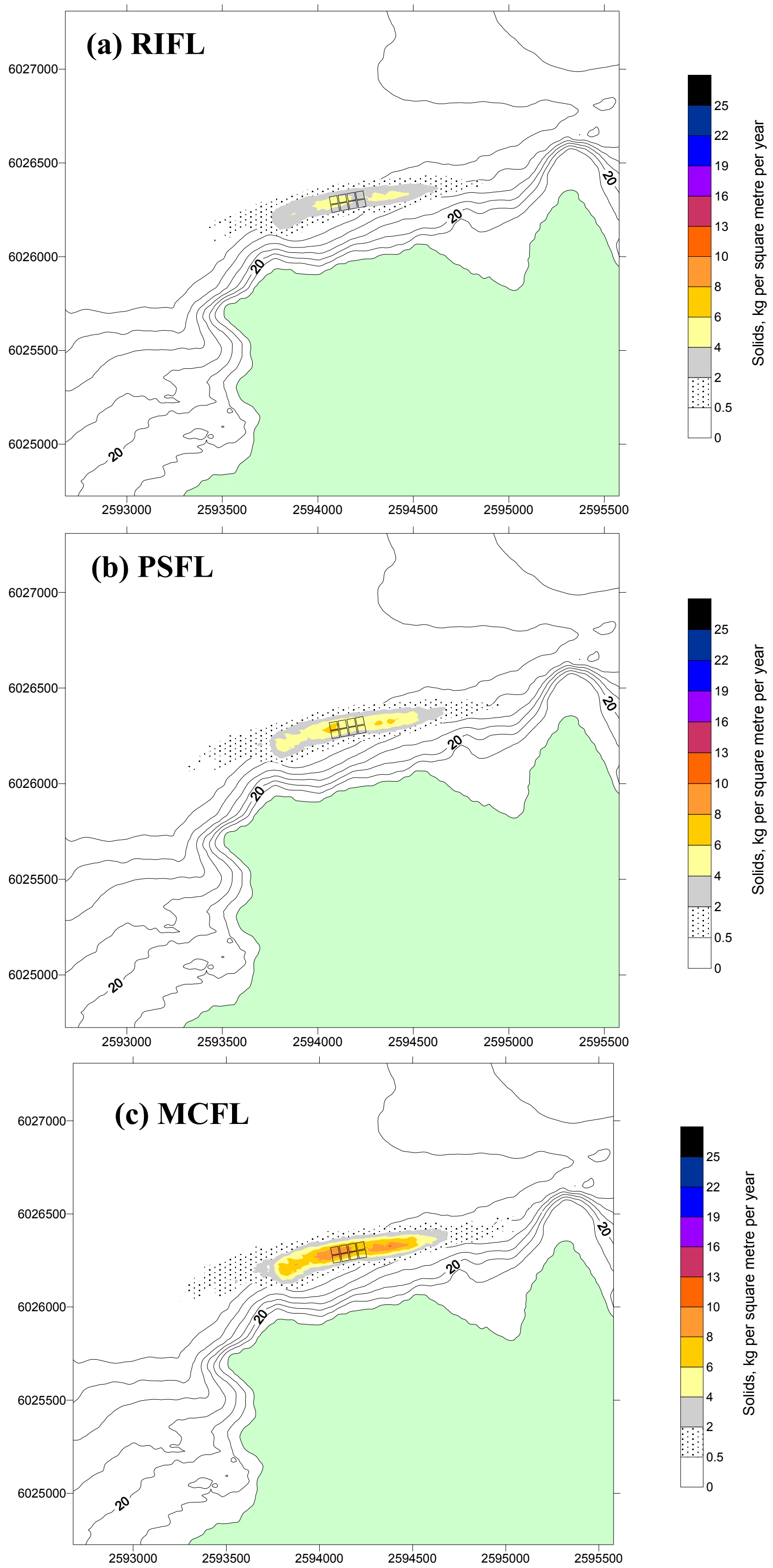

Figure 11. Predicted depositional footprints modelled under 'no-resuspension' scenarios at the Kaitira Site for three feed usage levels: (a) the Recommended Initial Feed Level (RIFL, 3000 t yr^{-1}), (b) the Predicted Sustainable Feed Level (PSFL, 4000 t yr^{-1}), and (c) the Maximum Conceivable Feed Level (MCFL, 6000 t yr^{-1}).

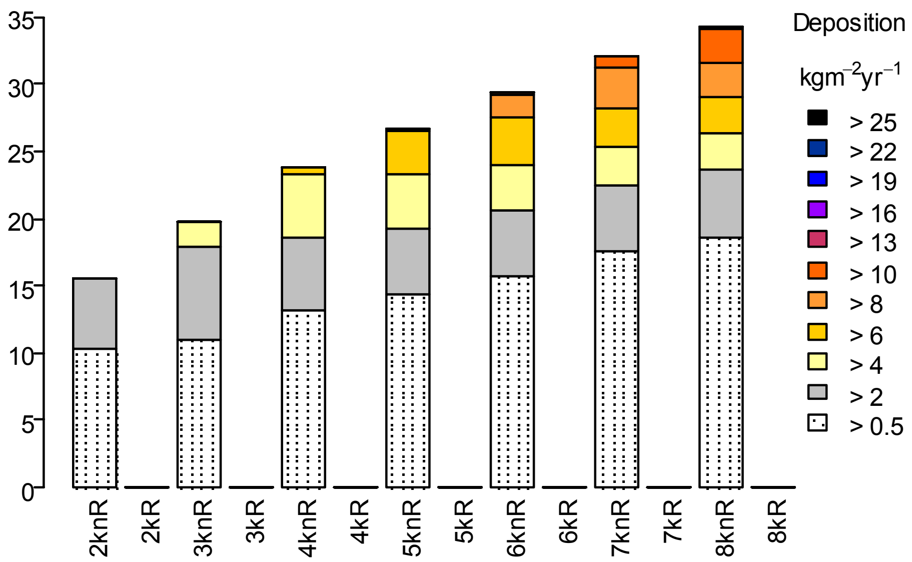

Figure 12. Summary of the total area affected by differing amounts of depositional flux for each of the modelled feed levels (2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}); with resuspension (R) and without resuspension (nR) included in the model.

5.2.2. *Magnitude and significance of seabed effects*

As described in Section 3.4, the substratum within the boundaries of the Kaitira Site was mostly soft sediments (mud and to a lesser degree mud with shell material). The infaunal communities associated with these substrata were dominated by polychaetes, ostracods, bivalves, cumaceans, nematodes and amphipods; taxa that are well represented and widespread in the Marlborough Sounds region. The majority of notable ecological habitats in the study area were located inshore of the proposed site.

Depositional modelling indicates there will be relatively low rates of deposition consistent with the high flows observed in this area, and that the degree of deposition and subsequent organic enrichment will be determined by the feed regime. At high-flow sites such as Kaitira, resuspension is predicted to prevent excessive accumulation of organic biodeposits beneath the farm. This is clearly demonstrated by the fact that when resuspension is modelled, we predict little or no net flux to the seabed (Section 5.2.1). However, while the accumulation of organic material within the sediments is likely to be minimal at high-flow sites, sediment chemistry and composition will be significantly altered (*i.e.* sulphide levels elevated, redox levels reduced).

The predicted footprint for the Maximum Conceivable Feed Level (6000 t yr^{-1}) under no-resuspension is overlaid on the habitat map created for the study area (Figure 13). This figure helps to visualise the spatial scale of the area that could be impacted under a worst-case scenario, as well as the key habitats that could be affected. Directly beneath the farm cages (*ca.* 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and

Capitella capitata are expected (*i.e.* ES 5 impacts are likely to occur). This is also likely to result in the displacement of most epibiota. It is anticipated that a further 23 ha of seabed will be moderately impacted (*i.e.* ES score >3), however, the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions (*i.e.* ES score <3) within 500 m (refer the Benthic Report, Keeley & Taylor 2011). Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.

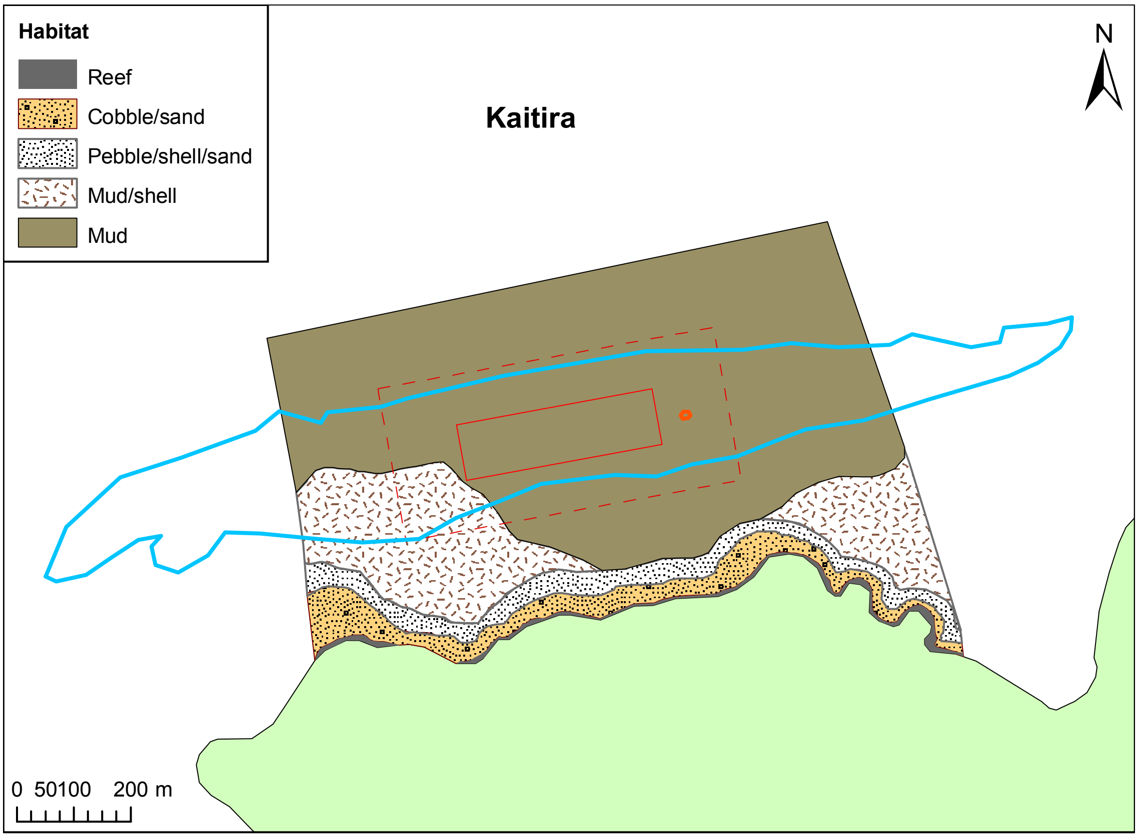

Figure 13. Predicted depositional footprint for the Maximum Conceivable Feed Level (MCFL, 6000 t y^{-1}), under 'no-resuspension' scenario, overlaid onto the habitat map created for the Kaitira Site. The blue and orange lines indicate the 0.5 kg m^{-2} yr^{-1} and 10 kg m^{-2} yr^{-1} deposition area, respectively.

6. MANAGEMENT OF BENTHIC EFFECTS

It is proposed that the Kaitira Plan Change site will be monitored under NZ King Salmon's Environmental Monitoring and Adaptive Management Plan (EM-AMP, Keeley 2011) and as outlined in Section 6 of Keeley & Taylor (2011) – the Benthic Report. Under which, the primary depositional footprint and associated ecological effects will be monitored and managed using staged development and the Zones concept. In terms of staged development for this site, the recommended initial feed level (RIFL) is 3000 t yr^{-1}, and that may be increased by 1000 t yr^{-1} after three years of operation up to a maximum (MCFL) 6000 t·yr^{-1}, dependant on the outcome of the environmental monitoring results. Under the Zones concept, compliance is assessed with reference to predefined Environmental Quality Standards including site-specific constraints on the spatial extent and magnitude of effects. The EM-AMP also encompasses the procedures for monitoring copper and zinc in sediments, and the strategy for local and regional monitoring of the water column and potential wider ecological effects.

7. SUMMARY AND RECOMMENDATIONS

The main findings of our benthic assessment are as follows:

1. The seabed beneath the Plan Change Site at Kaitira was dominated by silt/clay. Few epibiota were present in this soft sediment. The sediment was well oxygenated with moderate organic content, and a rich infaunal (*i.e.* within sediment) community was present, with a total of 114 taxa. The species were typical of deep high-flow areas throughout the Marlborough Sounds.
2. Areas inshore of the application were characterised by reef, boulder and cobble habitats and had a relatively diverse community of invertebrate, seaweed and fish. Some ecologically significant species, such as various sponges, scallops, *Cerianthus* anemones, lamp shells and horse mussels were present.
3. The intertidal zone inshore of the site was characteristic of the Outer Pelorus Sounds. It consisted of steep, narrow (<4 m wide) cobble, boulder and rocky reef habitats.
4. The Kaitira study area is subjected to high velocity water currents, with average water velocities approximately 19 cm s^{-1} and maximum water velocities in the order 43 to 56 cm s^{-1} throughout most of the water column. Near-seabed water velocities were often above the resuspension threshold.
5. At feed levels of up to 6000 t yr^{-1}, depositional modelling indicated that depositional flux would be moderate (13 kg m^{-2} yr^{-1}, without resuspension in the model). When resuspension was considered, deposition was not detectable above predicted background levels (<0.5 kg m^{-2} yr^{-1}), even under extreme feed loadings of up to 8000 t yr^{-1}. When resuspension was not considered, the depositional footprint (deposition >0.5 kg m^{-2} yr^{-1}) affected an area of 23 ha at feed loadings of up to 6000 t yr^{-1}, however, most of this area was exposed to relatively low depositional rates of less than 4 kg m^{-2} yr^{-1} and the footprint extended away from potentially sensitive inshore communities.
6. Given the proposed cage configuration, our estimates suggest an initial feed level of 3000 t yr^{-1}, with 4000 t yr^{-1} sustainable in the long term, depending on the outcome of continued environmental monitoring. The maximum conceivable feed level for the Kaitira Site is 6000 t yr^{-1}.
7. The depositional foot print primarily extends over soft sediment habitats, common throughout Pelorus Sound.
8. Directly beneath the farm cages (*ca*. 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected. Epibiota observed beneath the site will also be displaced. It is anticipated that a further 23 ha of seabed will be low-to-moderately impacted; however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within 500 m. Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.

9. It is proposed that the Kaitira Plan Change site will be monitored under NZ King Salmon's Environmental Monitoring and Adaptive Management Plan (EM-AMP, Keeley 2011) and as outlined in Section 6 of Keeley & Taylor (2011) – the Benthic Report.
10. The Kaitira Site is situated in a high-flow area where wastes will tend to be dispersed and assimilated. The site bathymetry is suited to cage farming. No species of communities regarded as having high ecological or conservation values were found within the application area.

8. ACKNOWLEDGEMENTS

Thanks to Rob Davidson (Davidson Environmental Limited) and Grant Hopkins (Cawthron Institute) for providing invaluable input into earlier drafts, and to Joanne Ellis for the final review of this document.

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10. APPENDICES

Appendix 1. Approach to assessing seabed characteristics

The seabed beneath and adjacent to the Kaitira Site was characterised over five days using a range of sampling techniques; including depth profiling, sediment grab sampling and video transects (refer Tables 1-1 to 1-4). Sufficient sampling was undertaken to permit delineation of the major habitats to assess potential effects.

Table 1-1. Seabed sampling undertaken at the proposed Kaitira Site.

Purpose	Sampling technique	Date
Site bathymetry	Depth profiling	8 November 2010
Characterisation of subtidal habitats	Video transects (diver-collected)	9 December 2010
	Drop-camera photography	3 March 2011
	Sediment grab samples	23 February 2011
	Benthic video sled	21 / 24 May 2011
Characterisation of intertidal habitats	Intertidal shoreline survey	3 May 2011

Site bathymetry

Depth profiling at the proposed site was undertaken to assist in characterising the seabed; in particular, to locate any significant structures on the seabed such as reefs. Continuous depth readings were taken from a Lowrance LC100-x depth sounder within and adjacent to the prospective farm area, and sent to a PC via a RS232 serial output. The PC simultaneously collected separate RS232 serial output of latitude and longitude from a GPS, and both data streams were incorporated using communications software. Depths were standardised to chart datum and plotted in 3-D using Surfer v7 surface mapping software. The 2-D graduated colour contour map was gridded using the natural neighbour method (Sibson 1981), while the 3-D wire frame plot used the kriging method (Matheron 1973), over a grid spacing of 10 x 10 m.

Sediment physical, chemical and biological properties

Sediment grab samples were collected using a 0.01 m^2 van Veen grab sampler, from nine sampling stations within and adjacent to the Kaitira Site (Table 1-2). The following sub-samples were collected from each grab sample to characterise the physical, chemical and biological properties of the sediments:

- **Sediment core samples:** A single 63 mm diameter core was photographed and the top 25 mm was collected for analyses of sediment grain size and organic matter content. Grain size was determined gravimetrically after separation of fractions by wet sieving and drying at 105 ºC, for gravel (≥2 mm), sand (≥63 µm - <2 mm) and silt/clay (<63 µm) size classes. Organic content was assessed by measuring the Ash Free Dry Weight (AFDW) following drying at 105 °C, then ashing at 550 °C to a constant weight (method modified from that of Luczak *et al.* 1996).

- **Macrofaunal core samples:** A single 130 mm diameter core, approximately 100 mm deep was gently sieved through a 0.5 mm mesh and animals retained were preserved with 40% formalin in sea water, and transported back to Cawthron for identification and counting. Infauna data were analysed to ascertain levels of abundance (taxa density) and taxa richness (diversity).

Table 1-2. Grab sampling locations.

Station	NZMG-E	NZMG-N	Latitude	Longitude
1	2593561	6025837	-40 58.19	173 59.58
2	2593338	6025914	-40 58.15	173 59.42
3	2593076	6026023	-40 58.09	173 59.23
4	2593973	6025976	-40 58.11	173 59.87
5	2593892	6026211	-40 57.98	173 59.81
6	2593790	6026403	-40 57.88	173 59.74
7	2594461	6026115	-40 58.03	174 00.22
8	2594443	6026329	-40 57.92	174 00.20
9	2594403	6026576	-40 57.78	174 00.17

Subtidal habitats

Drop-camera still photos and video transects were used to identify the approximate distribution of habitats and associated biota beneath and adjacent to the proposed Kaitira Site (Figure 4). More than 160 images of the seabed were taken using a 10 mega-pixel Canon digital camera inside an underwater housing, mounted on a frame. The camera triggered remotely when a sensor on the frame came into contact with the seabed, allowing a pseudo-random array of seabed photos to be taken beneath and adjacent to the proposed farm. Additional photographs were taken along transects extending perpendicular to the coastline (*i.e.* from the shallow subtidal to the farm boundary) to help delineate habitat changes with depth. Epibiota and substratum type were noted for each image.

Four transects inshore of the proposed farm were surveyed by divers and recorded on underwater video cameras (Figure 4; Table 1-3). These transects extended from the shoreline down to 25 to 30 m water depth. Divers filmed down the depth profile, before returning to the shoreline on a reciprocal heading several metres up-current. Notes were made describing the dominant features, including encounters of pelagic species (*e.g.* fish) (see Appendix 7 for species list).

Video footage was also obtained using a video sled, which was necessary to obtain footage of habitats below 30 m. An underwater video camera and light was attached to a sled and tethered via cables to a VCR and television on the boat. Five transects were undertaken by lowering the sled and camera to the seabed and towing it in the desired direction. GPS positions were recorded for each transect (Table 1-4; Table 1-4), along with observations of conspicuous epibiota and substratum type (see Appendix 7 for species list).

Table 1-3. Dive transect start locations.

Dive transect	NZMG-E	NZMG-N	Latitude	Longitude
1	2593819	6025931	-40 58.14	173 59.76
2	2594586	6026080	-40 59.01	173 58.22
3	2594171	6025977	-40 58.11	174 00.01
4	2593661	6025800	-40 58.21	173 59.65

Table 1.4. Video sled transect start and end locations.

Video sled transect	Start				End			
	NZMG-E	NZMG-N	Latitude	Longitude	NZMG-E	NZMG-N	Latitude	Longitude
1	2594527	6026436	-40 57.86	174 00.26	2593836	6026286	-40 57.94	173 59.77
2	2593992	6026385	-40 57.89	173 59.88	2593941	6025957	-40 58.12	173 59.85
3	2594236	6026402	-40 57.88	174 00.05	2594151	6026041	-40 58.07	173 59.10
4	2594483	6026463	-40 57.84	174 00.23	2594317	6026075	-40 58.05	174 00.11
5	2594551	6026289	-40 57.94	174 00.28	2593885	6026181	-40 57.10	173 59.81

Intertidal habitats

An intertidal survey was undertaken at low tide along the coastline inshore of the proposed Kaitira Site. Substratum type, biota and general observations were recorded, and photographs of the general habitats were taken. A complete list of taxa can be found in Appendix 8.

Appendix 2. Approach to assessing water currents

An Acoustic Doppler Current Profiler (ADCP) was deployed for 35 days approximately halfway up the eastern (seaward) edge of the site, in *ca*. 32 m water depth. Water currents (speed and direction) were characterised at 3, 11, 18, 25, 32 m depth intervals (bins) through the water column (Table 2-1).

Table 2-1. Acoustic Doppler Current Profiler (ADCP) meter deployment details.

Particulars	**Kaitira Site**
Device:	RD Instruments ADCP
Logging depth:	Vertical profile @ 1.1 m intervals
Averaging interval:	5 minutes
Sampling frequency:	30 minutes
Deployment period:	6/1/11 to 11/2/11
Mooring location:	2594375 E, 6026396 N

Appendix 3. Approach to assessing depositional footprints

Deposition of farm waste is the primary driver of seabed impacts and particle tracking models have become an accepted and useful tool to predict and manage their extent (Henderson *et al.* 2001). For this assessment, DEPOMOD v2.2 was used to predict the likely degree and spatial extent of deposition to the seabed. DEPOMOD was selected from a number of analogous particle tracking models because it is widely used and published, and designed specifically for managing fish farm wastes (Cromey & Black 2005; Cook *et al.* 2006; Magill *et al.* 2006). It is notable among fish farm impact models in that a number of processes it simulates have been validated against field measurements (Cromey *et al.* 2002 a,b,c; Chamberlain & Stucchi 2007). DEPOMOD is used as a regulatory tool in Scotland for discharge consents of in-feed chemotherapeutants (SEPA 2003), and in setting biomass limits (SEPA 2005). Similar modelling approaches have been used in France, Norway, Ireland, Canada, Australia, Chile and South Korea (Henderson *et al.* 2001; C Cromey, pers. comm.).

DEPOMOD also allows the user to predict the influence of resuspension on the footprint. This prediction is based on default resuspension and deposition velocity thresholds (9.5 cm s^{-1} and 4.5 cm s^{-1} near-bed current speed, respectively), and was not specifically calibrated for the sediments present at the site. Thus, it should be considered an approximation only. The no-resuspension output represents a scenario where there is a one way flux to the sediment and thus can be treated as a worst-case scenario with regard to seabed impacts. In the case of Kaitira, the near-bed velocities periodically exceeded the resuspension threshold, so there was considerable difference in the resuspension/no-resuspension outputs. The predicted depositional footprints were presented using Surfer 9.0™, where sediment flux (in kg m^{-2} yr^{-1}) was overlaid with the bathymetric contours and simulated cage positions. The sediment flux categories (and keys) are standardised among outputs to facilitate comparisons.

The Kaitira proposed salmon farm layout was modelled at seven theoretical feed loadings (2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}). Cage dimensions were based on blocks of 40 m x 40 m x 20 m deep cages; *i.e.* similar to those used by NZ King Salmon elsewhere in the Marlborough Sounds. A summary of the detailed input parameters and settings used are provided in Table 3-1.

Bathymetry data (and subsequent grid files) were obtained from a medium resolution bathymetric survey. The model used actual current data collected with an ADCP that was deployed at the south-eastern edge of the site. Current data from four depth strata evenly distributed through the water column were used to account for possible vertical structuring in the water column.

Outputs from this model were validated for New Zealand conditions by predicting the depositional footprint for two selected annual periods at three existing Marlborough Sounds salmon farms (Table 3-2; also see Keeley *et al.* 2008) and comparing the results to observed ecological responses. All three of these farms have been in operation for more than 10 years and the corresponding seabed conditions have been documented as part of NZ King Salmon's annual monitoring programme. The models for the existing sites were configured using actual site parameters (position, cage number, size, *etc.*) and feeding regimes for selected years. Further details relating to the model validation procedures are described in the Benthic Report (Keeley & Taylor 2011).

Table 3-1. DEPOMOD parameters and settings used to estimate depositional flux to the seabed environment at Kaitira, Pelorus Sound.

1. Grid Generation	
Major grid size	i=99 @ 29.6 m, j=99@ 26.4 m (2930 x 2614 m)
Minor grid size	i=99@ 25 m, j=99@ 10 m (2475 x 990 m)
Position on grid	i=8, j=39
Minor grid origin NZMG	2592914, 6025805
Cage configuration	2 rows of 4
Total number cages	8
Spacing between cage centres (m)	46 m
Cage orientation (deg T)	79º
Depth under cages (m)	26 m
2. Particle tracking	
Type of feed release	Continuous
Food loading	2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}
Cage dimensions	40 m x 40 m 20 m deep
Source of velocity data	RD Instruments ADCP
Current depth bins used:	1, 13, 21, 33, 45 m
Instrument sampling period (min)	5 min every 30
Time step used in model (seconds)	1800
Length of velocity record (steps)	1334
Random walk model	On: Kx=0.1, Ky=0.1, Kz=0.001

Table 3.2. Average feed rates for the twelve months preceding the annual monitoring for each of the six modelled scenarios (two annual periods for each of three existing salmon farm sites).

Farm	Year	Monitoring date	No. cages	Feed/farm/yr	Feed/cage/day
Te Pangu	2005	10 Oct 05	20	2104 t	288 kg
	2008	18 Nov 08	20	4120 t	564 kg
Ruakaka	2004	27 Nov 04	18	2509 t	382 kg
	2007	17 Oct 07	18	3280 t	499 kg
Otanerau	2005	12 Oct 05	22	2238 t	278 kg
	2008	21 Nov 08	22	2135 t	265 kg

Appendix 4. Photographs of sediment cores collected from grab stations

Appendix 5. Infaunal count data

	Grab station								
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
ANTHOZOA UNID.	0	0	1	0	0	0	1	0	0
Edwardsia sp.	1	0	0	0	0	0	1	0	0
NEMERTEA	2	0	1	1	0	1	1	1	1
NEMATODA	5	15	0	4	9	1	2	0	5
PRIAPULA	0	0	0	1	0	1	0	0	1
Sipuncula	0	0	0	0	2	1	0	0	1
Cadulus teliger	0	0	0	0	0	0	0	2	0
Leptochiton inquinatus	4	0	0	0	0	0	1	0	0
GASTROPODA (WHITE RISSOID LIKE)	0	0	0	0	0	0	0	0	6
GASTROPODA UNID. JUV.	0	0	0	0	0	2	0	0	0
Amalda mucronata	0	0	0	0	0	1	0	0	1
Maoricolpus roseus roseus	1	0	0	0	0	0	0	0	0
Tonna sp.	0	0	0	0	1	0	0	0	0
Turbonilla sp.	0	0	0	0	0	0	1	0	0
Zeacolpus sp.	0	0	0	0	0	0	1	0	0
Zegalerus tenuis	0	0	0	0	0	1	3	0	0
Philine auriformis	0	0	0	0	0	0	1	0	2
Arthritica bifurca	0	2	0	0	0	0	5	0	2
Corbula zelandica	4	1	0	0	0	6	0	0	0
Dosina zelandica zelandica	0	3	0	0	0	0	1	0	0
Ennucula strangei	1	1	1	11	0	0	0	4	3
Felaniella zealandica	4	0	0	0	0	0	0	0	0
Gari stangeri	6	1	0	0	0	0	0	0	0
Hiatella arctica	0	0	0	0	0	0	2	0	0
Limaria orientalis	1	0	0	0	0	0	0	0	0
Maorithyas marama	0	1	0	1	1	1	1	2	4
Melliteryx parva	0	0	0	0	0	20	0	0	1
Nemocardium pulchellum	0	1	0	0	0	0	3	0	0
Notocallista multistriata	0	0	0	1	0	0	0	0	0
Nucula gallinacea	1	0	0	0	0	0	0	0	0
Ostrea chilensis	1	0	0	0	0	0	0	0	0
Pleuromeris zelandica	0	0	0	0	1	0	0	0	0
Serratina charlottae	0	0	0	0	0	0	1	0	0
Tawera spissa	0	1	0	2	0	0	0	0	0
Theora lubrica	0	0	0	3	0	0	13	0	0
Thracia sp.	0	0	0	1	0	0	1	0	0
OLIGOCHAETA	0	12	0	0	4	0	0	0	0
Ampharetidae	0	0	3	0	1	6	2	6	10
Leitoscoloplos kerguelensis	2	0	0	0	0	0	0	0	1
Scoloplos cylindrifer	0	0	0	0	1	0	0	0	0
Paraonidae	4	28	39	18	27	19	24	14	38

CAWTHRON

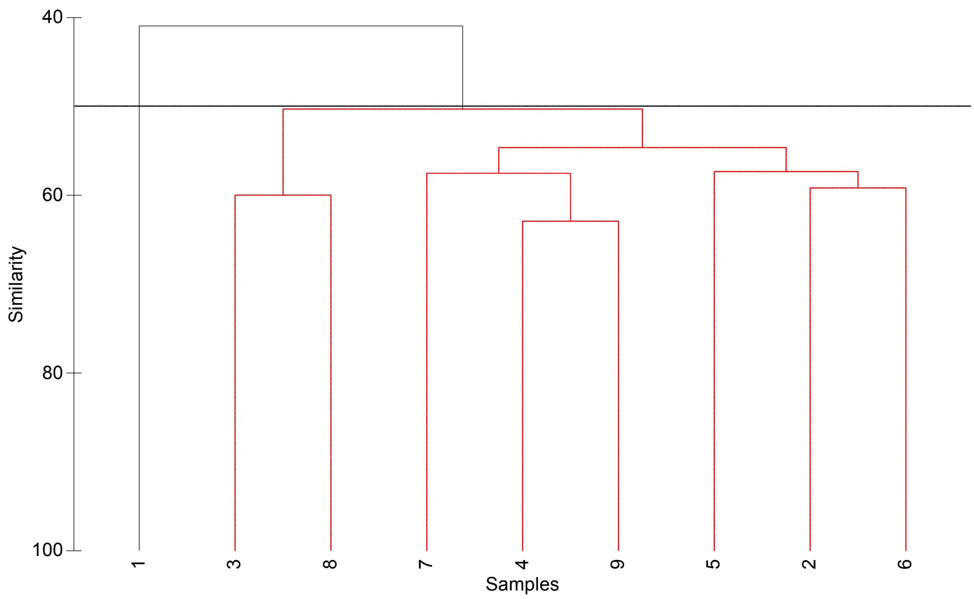
Taxa	Grab station 1	2	3	4	5	6	7	8	9
Aricidea sp.	0	1	0	0	1	3	0	0	0
Cossura consimilis	0	0	10	6	1	3	4	3	5
Boccardia sp.	12	1	0	0	0	0	0	0	0
Paraprionospio pinnata	1	1	2	5	4	2	2	2	3
Prionospio multicristata	42	79	5	5	12	21	17	2	6
Prionospio yuriel	0	20	0	3	0	2	1	0	6
Spio sp.	1	0	0	0	0	0	0	0	0
Spiophanes kroyeri	0	0	1	0	0	0	1	4	9
Capitella capitata	0	0	2	0	0	0	1	0	0
Capitellethus zeylanicus	0	1	1	0	1	1	1	2	0
Heteromastus filiformis	9	20	0	2	3	8	6	1	5
Maldanidae	6	3	4	5	1	6	5	8	11
Armandia maculata	1	5	2	0	0	1	1	0	1
Scalibregma inflatum	3	0	0	1	2	0	0	0	0
Phyllodocidae	0	0	0	0	0	0	1	0	1
Polynoidae	0	0	0	0	0	0	1	0	0
Sigalionidae	1	0	1	2	1	0	1	1	0
Hesionidae	0	2	0	1	3	2	1	0	1
Syllidae	3	3	0	0	4	3	0	0	0
Sphaerosyllis sp.	0	32	0	5	20	8	20	1	8
Glyceridae	6	2	1	0	1	17	1	0	0
Goniada sp.	0	3	3	0	3	11	3	0	1
Aglaophamus sp.	4	2	1	0	0	0	1	0	0
Onuphis aucklandensis	0	0	0	0	0	0	0	0	1
Lumbrineridae	13	4	3	7	9	5	14	0	9
Dorvilleidae	1	1	0	10	4	1	33	0	3
Cirratulidae	11	17	15	12	2	13	19	11	23
Flabelligeridae	1	0	1	2	1	0	0	2	2
Sternaspis scutata	0	0	0	0	0	0	0	1	1
Terebellidae	4	2	1	3	0	0	6	0	5
Sabellidae	1	0	0	0	1	0	0	0	0
Euchone pallida	2	0	0	0	0	0	0	0	0
Pomatoceros terraenovae	4	0	0	0	0	0	0	0	0
Spirorbidae	38	0	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	1	0	0	0
Cumacea	0	15	6	4	4	1	12	10	4
Tanaid sp.	1	2	0	0	0	3	3	0	0
Natatolana pellucida	0	0	0	0	1	0	0	0	0
Anthuridea	1	0	0	0	0	0	0	0	0
Asellota	0	1	8	2	7	4	8	5	6
Gnathiidea	0	0	1	0	0	0	0	0	0
Aoridae	0	0	6	1	3	0	5	0	1
Caprellidae	0	0	0	0	1	0	0	0	0

Taxa	Grab station 1	2	3	4	5	6	7	8	9
Corophiidae	0	0	0	0	0	0	1	0	0
Dexaminidae	0	3	0	0	0	0	2	0	7
Liljeborgiidae	0	0	0	0	0	0	0	0	1
Lysianassidae	1	0	1	0	0	0	0	0	0
Melitidae	8	14	11	0	2	1	2	0	0
Oedicerotidae	0	0	0	0	0	0	2	1	0
Phoxocephalidae	0	0	0	3	0	0	3	3	2
Ampelisca sp.	1	2	14	1	1	3	2	2	1
Ebalia laevis	0	1	1	0	0	0	0	0	0
Liocarcinus corrugatus	0	1	0	0	0	0	0	0	0
Nectocarcinus antarcticus	1	0	0	0	0	0	0	0	0
Pagurus sp.	0	1	0	0	0	0	0	0	0
Upogebia sp.	0	0	0	0	0	1	0	0	1
Cymbicopia hispida	0	1	0	1	0	0	0	0	0
Cypridinoides concentrica	0	0	1	0	0	0	0	0	0
Diasterope grisea	0	0	2	0	3	0	1	1	0
Euphilomedes agilis	1	1	1	2	2	3	6	1	0
Parasterope quadrata	0	0	0	0	0	0	1	0	0
Scleroconcha arcuata	0	1	0	0	0	0	0	0	0
Trachyleberis lytteltonsis	0	0	0	0	0	0	0	3	0
COPEPODA	0	0	0	1	1	0	0	0	0
Pycnogonidae	0	0	0	0	0	0	1	0	0
BRYOZOA (ENCRUSTING)	10	0	0	0	0	5	2	0	0
BRYOZOA (SOLID STALKED)	2	0	0	0	0	0	0	0	0
Echinocardium cordatum	0	0	0	1	0	0	0	0	0
Ophiuroidea	3	2	0	0	4	0	1	0	1
Pentadactyla longidentis	0	0	0	0	0	0	0	0	1
Eugyra brewinae	0	0	0	0	1	0	0	0	0
Pareugyriodes filholi	0	0	0	0	0	1	0	0	0
OSTEICHTHYES EGGS	0	0	0	0	1	0	0	0	0
Taxa abundance	**230**	**310**	**150**	**128**	**152**	**190**	**257**	**93**	**202**
Taxa Richness	**45**	**43**	**32**	**34**	**41**	**39**	**57**	**26**	**43**

Appendix 6. Methods and results of multivariate analyses of infaunal data

Infauna data were analysed to ascertain levels of abundance (taxa density) and taxa richness (diversity). The infaunal assemblages were visualised using dendrograms from hierarchical cluster analysis using the group average mode based on Bray-Curtis similarities (Clarke & Warwick 1994). The SIMPROF test was used to detect any station grouping pattern at significance level of 5%. Abundance data were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each group (areas) were identified using analysis of similarities (SIMPER; Clarke & Warwick 1994; Clarke & Gorley 2001). All multivariate analyses were performed with PRIMER v6 software.

The results of the multivariate analyses (Figure 6-1) show the relative similarity of the samples in terms of infaunal assemblage composition. Station 1 was distinct from the other stations, sharing a 50% similarity. At a 55% similarity level, the samples resolved into three groupings. The presence of Spirorbids and *Boccardia* sp. polychaetes and the absence of cumaceans at Station 1 were the strongest determining features separating this station. At all other stations, communities were dominated by Paraonidae, Cirratulidae, *Sphaerosyllis* sp. and *Prionospio multicristata* polychaetes. While cumaceans were common, Spirorbid polychaetes were absent from these stations.



Station	Key distinguishing characteristics
1	Community dominated by *Prionospio multicristata* and Spirorbidae. Lumbrineridae, *Boccardia* sp. and Cirratulidae polychaetes common. Cumacea, Sphaerosyllis sp. and Asellota absent.
All other stations	Communities dominated by Paraonidae, Cirratulidae, *Sphaerosyllis* sp. and *Prionospio multicristata* polychaetes, and Cumacean common. No Spirorbidae.

Figure 6-1. Dendrogram showing similarity (%) of infaunal assemblages collected from the Kaitira study area. The black horizontal line indicates groups of samples separated by SIMPROF test (at $P > 0.05$). The analysis was performed on the basis of Bray-Curtis similarity of the fourth-root transformed count data.

Appendix 7. Conspicuous epibiota observed along dive and video sled transects

X = taxa present in transect.

		Dive transect				Video Sled				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Porifera										
Ancorina alata / Geodia regina	Vase sponge	X	X	X	X					
Sponge (unid.)	Unidentified sponge				X			X		
Callyspongia sp.	Erect sponge					X	X	X	X	X
Hydrozoa										
Hydroida (thecate)	Feather hydroid	X	X	X	X	X	X	X	X	X
Anthozoa										
Actinothoe albocincta	White striped anemone	X								
Cerianthus sp.	Tube anemone		X							
Phlyctenactis tuberculosa	Wandering anemone	X					X			
Bivalvia										
Pecten novaezelandiae	Scallop	X		X		X	X			
Atrina zelandica	Horse mussel									
Gastropoda										
Cookia sulcata	Cook's turban	X								
Maoricolpus roseus	Turret shell					X	X			
Nudibranchia (unid.)	Nudibranch					X				
Polychaeta: Serpulidae										
Pomatoceros sp.	Polychaete	X			X					
Polychaeta: Sabellidae	Tubeworm	X	X		X					
Echinoidea										
Evechinus chloroticus	Sea urchin (kina)	X	X	X	X					
Asteroidea										
Coscinasterias calamaria	11-arm sea star	X		X		X				
Patiriella sp.	Cushion star	X	X	X		X	X		X	
Ophiuroidea										
Ophiopsammus maculata	Snake tail star	X	X	X		X	X	X		X
Holothuroidea										
Stichopus mollis	Sea cucumber	X	X	X	X	X			X	
Ascidiacea										
Cnemidocarpa bicornuta	Solitary ascidian		X		X					
Aplidium phortax	Colonial ascidian				X	X	X	X		
Colonial ascidian (unid.)	Unidentified sea squirt				X					
Osteichthyes										
Parapercis colias	Blue cod	X	X	X	X					
Notolabrus celidotus	Spotty	X	X	X						
Tripterygiidae sp.	Unidentified triplefin	X			X	X				
Peltorhamphus novaezeelandiae	Sole					X	X	X		
Synodus sp.	Lizard fish					X		X	X	X

		Dive transect				Video Sled				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Scorpaena papillosus	Scorpion fish					X				
Zeus faber	John dory					X				
Chelidonichthys kumu	Gurnard					X				
Chondrichthyes										
Dipturus nasutus	Rough skate									X
ALGAE										
Chlorophyta										
Algae (green filamentous)	Green algae	X	X	X	X					
Phaeophyta										
Carpophyllum spp.	Brown algae	X	X	X	X					
Undaria pinnatifida	Wakame			X						
Colpomenia sp.	Bubble alga			X						
Ralfsia verrucosa	Brown alga	X	X							
Rhodophyta										
Algae (red filamentous)	Red alga	X		X						
Corallina (encrusting)	Pink paint	X	X		X		X			
Algae (brown filamentous)	Algal mat	X		X				X	X	

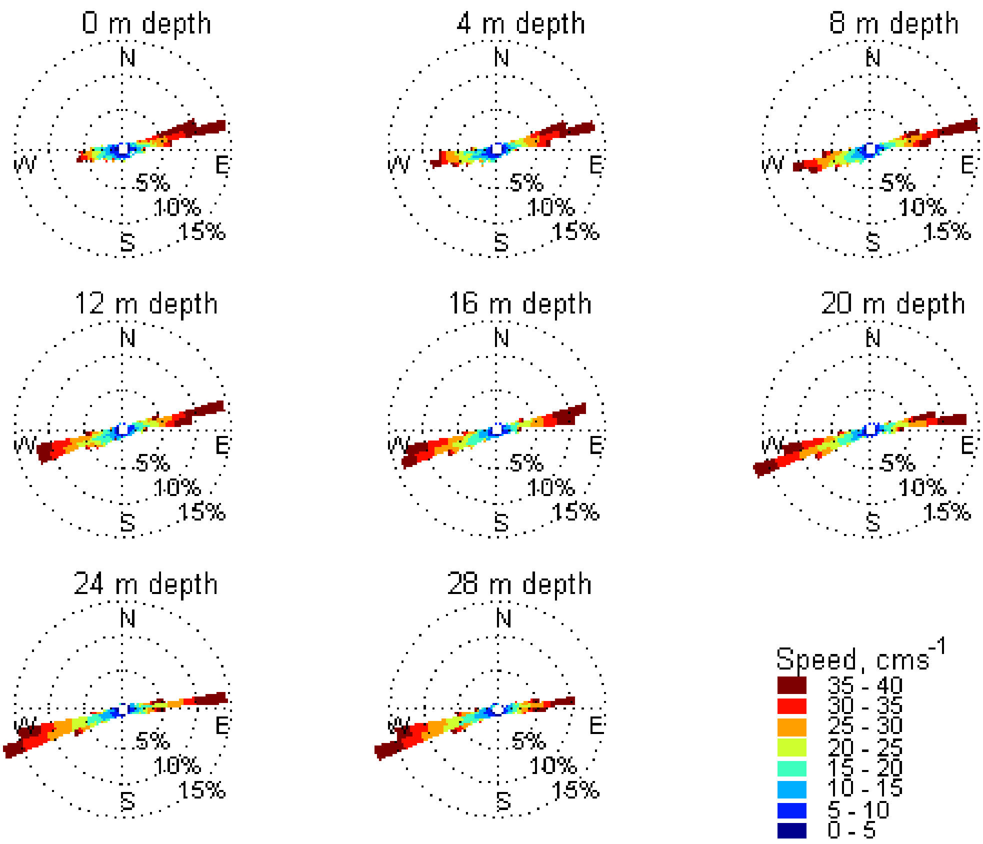
Appendix 8. Relative abundance and tidal height distribution of conspicuous intertidal and immediate subtidal epibiota observed during the intertidal survey.

Relative abundance code: A = abundant, C = common, O = occasional, R = rare. Tidal height code: H = high shore, M = mid shore, L = low shore, S = subtidal.

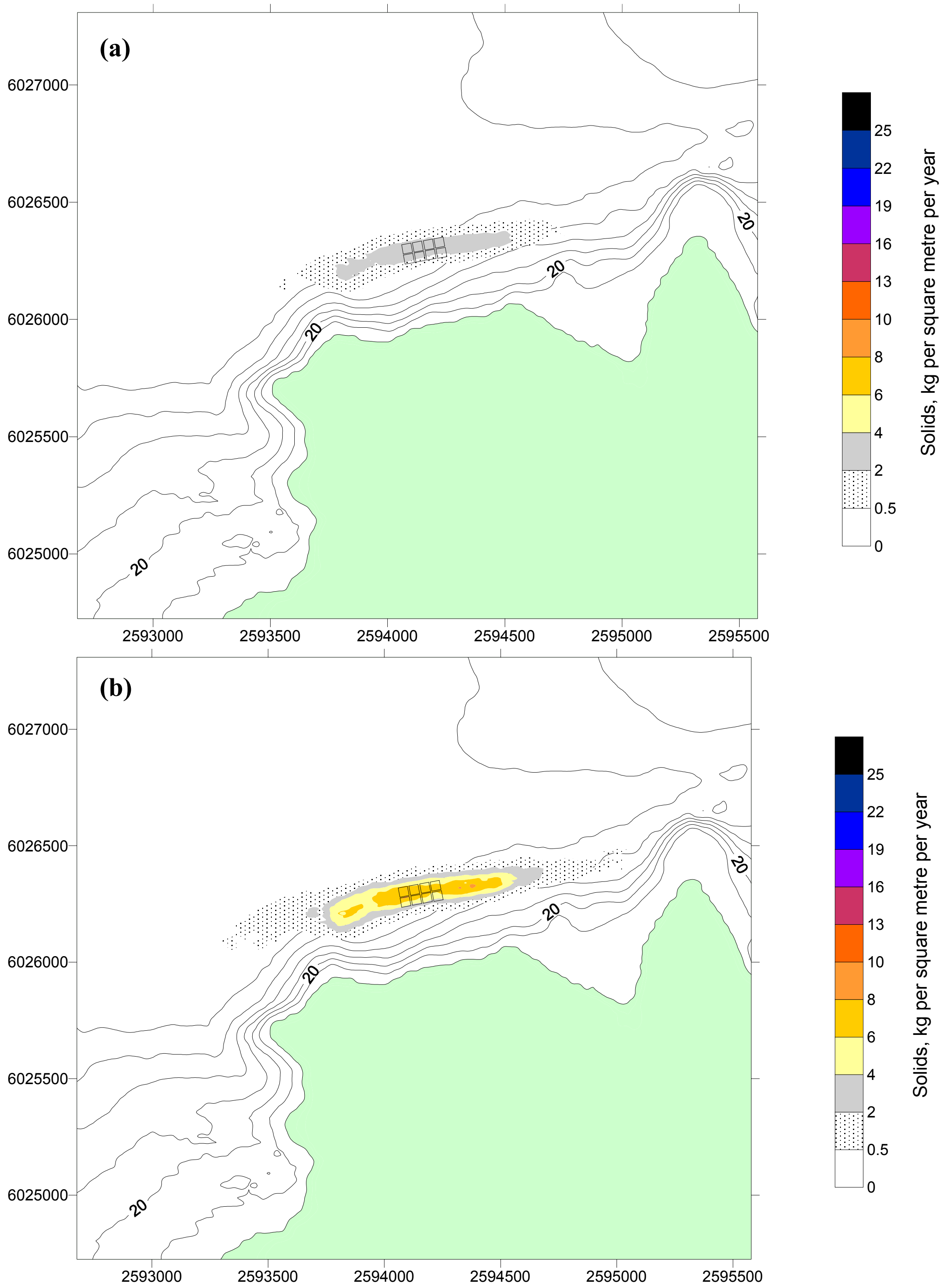
Taxa	Description	Tidal zone	Relative abundance
Anthozoa			
Actina tenebrosa	Waratah anemone	H	C
Oulactis sp.	Anemone	M	R
Polyplacophora			
Sypharochiton pelliserpentis	Snakeskin chiton	L - M	C
Gastropoda			
Cellana radians	Radiate limpet	L - M	A
Cellana ornata	Ornate limpet	M	A
Cominella maculosa	Spotted whelk	L	R
Haustrum haustorium	Brown whelk	L - M	O
Haustrum scobina	Oyster borer	L - M - H	O
Austrolittorina unifasciata	Periwinkle	H	C
Melagraphia aethiops	Spotted top shell	M	C
Turbo smaragdus	Cat's eye	L	C
Bivalvia			
Mytilus galloprovincialis	Blue mussel	L - M	C
Aulacomya atra maoriana	Ribbed mussel	M	R
Perna canaliculus	Green-lipped mussel	L	R
Polychaeta			
Serpulidae	Fan worm	M	C
Decapoda			
Petrolisthes elongatus	Porcelain crab	H	C
Cirripedia			
Austrominius modestus	Estuarine barnacle		
Chamaesipho spp.	Column barnacle	L - M	A
Epopella plicata	Common barnacle	M - H	O
Unid. barnacle	Unidentified barnacle	L	O
Asteroidea			
Coscinasterias calamaria	11-arm sea star		
Patiriella regularis	Cushion star	L	R
ALGAE			
Chlorophyta			
Codium adhaerens	Green pillow alga	L	O
Phaeophyta			
Carpophyllum maschalocarpum	Flapjack	S	A
Carpophyllum flexuosum	Flapjack	S	A
Colpomenia sp.	Brown bubble alga	L	C
Hormosira banksii	Neptune's necklace	L	C
Splachnidium rugosum	Dead man's fingers	L	C

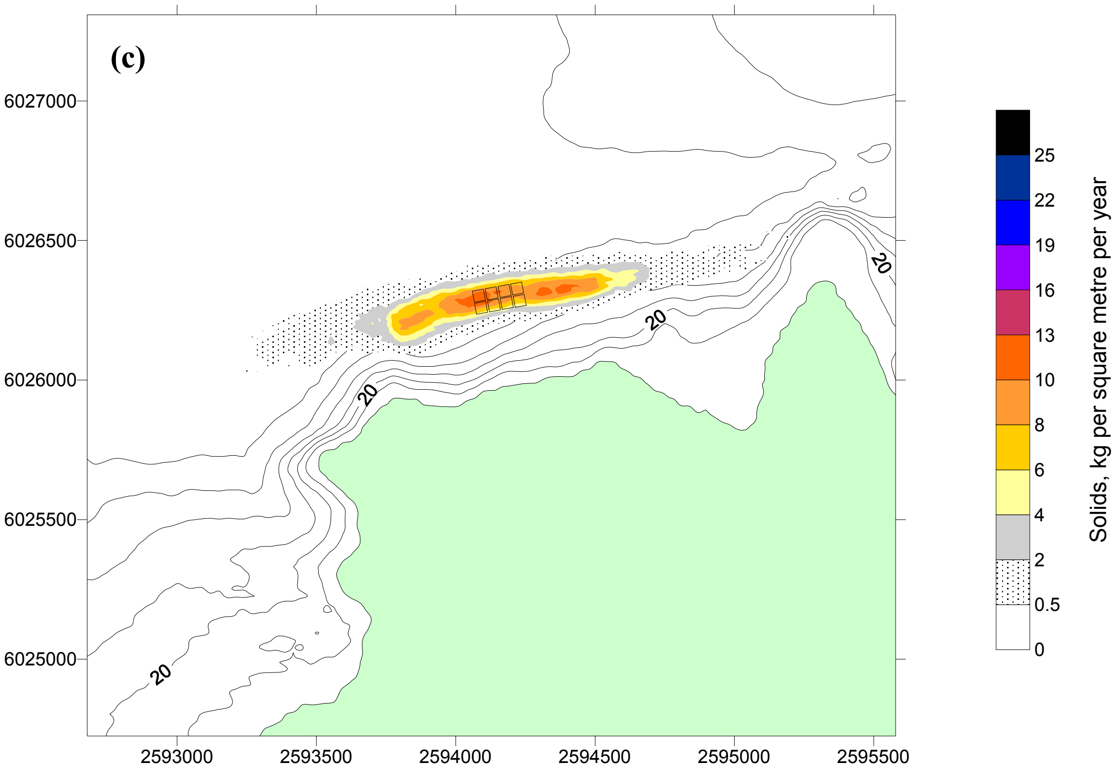
Taxa	Description	Tidal zone	Relative abundance
Cystophora scalaris	Zig-zag weed	S	C
Ecklonia radiata	Kelp	S	O
Scytothamnus australis	Brown alga	L	R
Rhodophyta			
Corallina (encrusting)	Pink paint	S - L - M	A
Porphyra sp.	Karengo	H	R
Corallina officinalis	Pink turf	M	A
Gelidium sp.	Red alga	L	R
Laurencia sp.	Red alga	L	R
Glossophora kunthii	Red alga	L - M	R

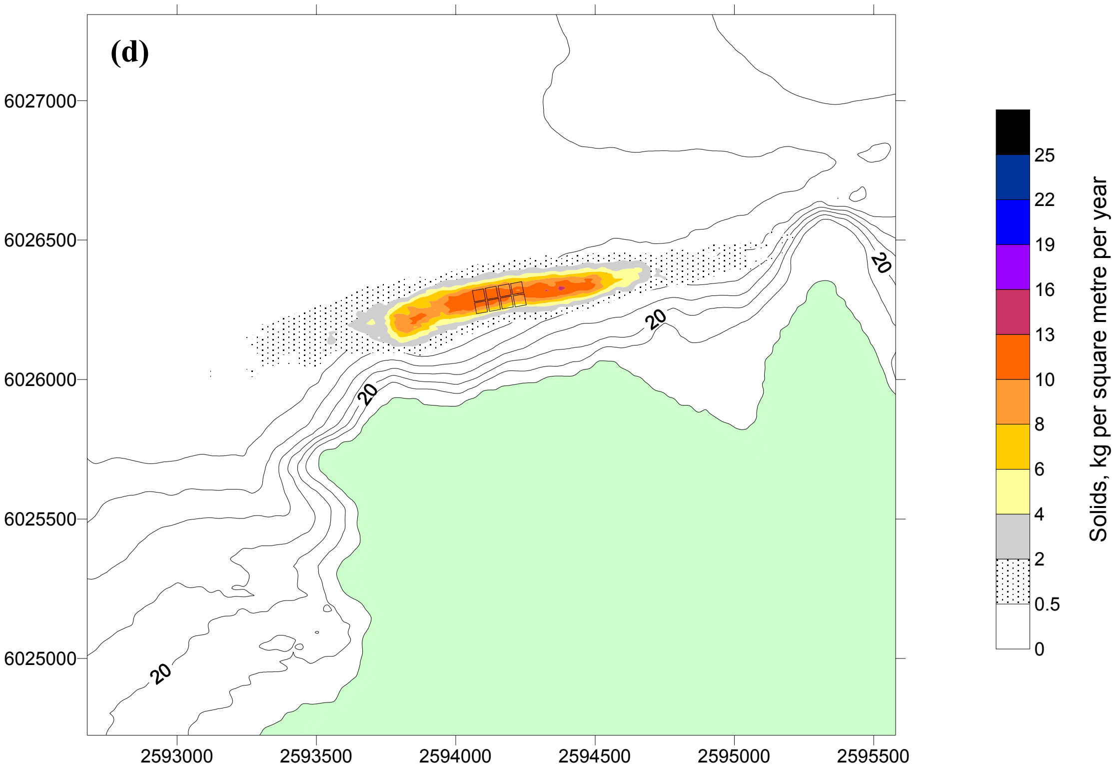
Appendix 9. Flow charts of current speed (cm s^{-1}) and direction (true) at the ADCP deployment site at Kaitira, Waitata Reach



Appendix 10. Predicted depositional footprints for four levels of feed usage at the Kaitira Site: (a) 2000 t yr^{-1}, (b) 5000 t yr^{-1}, (c) 7000 t yr^{-1}, and (d) 8000 t yr^{-1} under 'no-resuspension' scenarios




(c)
6027000
6026500
6026000
6025500
6025000
2593000
2593500
2594000
2594500
2595000
2595500
20
20
20
20
25
22
19
16
13
10
8
6
4
2
0.5
0
Solids, kg per square metre per year


(d)
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6026500
6026000
6025500
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2593000
2593500
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2594500
2595000
2595500
20
20
20
20
25
22
19
16
13
10
8
6
4
2
0.5
0
Solids, kg per square metre per year