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Assessment of Effects of Farming Salmon at Ruaomoko, Queen Charlotte Sound: Deposition and Benthic Effects

RESEARCH BASED SOLUTIONS

Assessment of Effects of Farming Salmon at Ruaomoko, Queen Charlotte Sound: Deposition and Benthic Effects

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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 Ruaomoko, in Queen Charlotte Sound, Marlborough. 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 Ruaomoko application is a 14.1 hectare (ha) area with a 2.1 ha area for cage structures within which there will be 0.7 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 Ruaomoko Site were characterised using a range of remote and diver operated sampling techniques; including depth profiling, sediment grab sampling and video transects. The intertidal regions of the shoreline were 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-derived sediment deposition was determined using a peer-reviewed deposition model (DEPOMOD). The Ruaomoko site was modelled based on one cage configuration (one row of four cages) at 14 theoretical feed loadings (500-6500 t yr^{-1}). It was also modelled in conjunction with the neighbouring proposed Kaitapeha site (two rows of four cages) at five theoretical feed loadings (4000–12000 t yr^{-1}). Potential environmental impacts associated with farm deposition were then 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 proposed Ruaomoko Site is located in 5 to 70 m water depth in a region of high water currents. Infaunal (within sediment) communities within the study area were species-rich (a total of 128 different taxa) and were numerically dominated by various species of polychaetes, amphipods and ophiuroids. The seabed beneath the proposed site was dominated by shell hash while inshore areas were characterised by reef, cobble, tubeworm mounds and sand habitats. Few epibiota were present in the shell hash habitat but communities in reef areas were very diverse with a number of ecologically significant species observed (scallops, *Cerianthus* species, horse mussels, tree hydroids). The southern reef extended up to 70 m into the site boundary, and a small area of reef was observed in the southeast corner of the Cage Area boundary. Tubeworm mounds, interspersed with sand patches, were common near reef areas. A band of *Macrocystis pyrifera* and *Carpophyllum flexuosum* algae fringed the coastline and the intertidal was characteristic of the Marlborough Sounds.

The site is situated on the southwestern side of Arapawa Island and has very fast currents, with average water velocities *ca.* 30 cm s^{-1} and maximum water velocities in the order of 70 cm s^{-1}. Currents flowed predominantly to the southwest (into Tory Channel), and ran parallel to the coastline, with limited tidal reversal, which decreased with depth. Depositional modelling indicated that dispersal of the footprint will be considerable due to the high water current velocities. Under a no-resuspension scenario, the maximum depositional flux was 10 kg $m^{-2}yr^{-1}$, when feed loadings of up to 6000 t yr^{-1} were modelled, with the majority of flux directly beneath cages. The effect of the prevailing current is evident by the elliptical shape of deposition predicted for the site. When resuspension was considered in the model, net depositional flux reaching the seabed did not exceed 0.5 kg m^{-2} yr^{-1} for any of the feed loadings modelled, even at the highest level modelled (6500 t yr^{-1} of feed). As the prevailing near-bottom current conditions regularly exceeded the resuspension threshold, the resuspension scenario is considered the most appropriate estimate 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 Ruaomoko, 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).

When the cumulative deposition effects of the neighbouring proposed Kaitapeha Site were taken into account, maximum depositional flux was 10 to 13 kg m^{-2} yr^{-1} at a combined feed loading of up to 8000 t yr^{-1}. Without resuspension in the model, the area affected by deposition (>0.5 kg m^{-2} yr^{-1}), across combined feed loadings of 4500 to 8000 t yr^{-1}, was estimated to be 31 to 42 ha for the two farms.

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 36 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. The boundaries of the proposed site were chosen to minimise potential effects to ecologically sensitive habitats in the vicinity of the proposed farm. 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.

When the proposed Ruaomoko Site is considered on its own, 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 the predicted sustainable feed level (PSFL) of 4000 t yr^{-1}. The maximum conceivable feed level (MCFL) for the Ruaomoko Site was estimated to be 6000 t yr^{-1}. Any increases from the RIFL should be based on favourable environmental monitoring results. If initial feed levels prove to be too high, permitted feed levels should be adjusted accordingly. When considered together, the combined RIFL for the Ruaomoko and Kaitapeha Sites is 4500 t yr^{-1}, the combined PSFL is 6000 t yr^{-1} and the combined MCFL is 8000 t yr^{-1}. Any increases from the combined RIFL should be undertaken in 1500 t yr^{-1} increments (1000 t yr^{-1} at Ruaomoko and 500 t yr^{-1} at Kaitapeha) and should also be based on favourable environmental monitoring results.

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 Ruaomoko Site is situated in a high-flow area where wastes will be dispersed and assimilated. The bathymetry of the area is suited to cage farming, but there are notable reef areas inshore and south of the site.

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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 establishment of salmon farms at eight proposed locations in the Marlborough Sounds. This report relates to a proposed site at Ruaomoko, Queen Charlotte Sound (Figure 1); hereafter referred to as the 'Ruaomoko Plan Change Site' or 'Ruaomoko Site'. Information provided in this report will form a part of the NZ King Salmon's Plan Change and resource consent applications, and is presented as a supplement to the Benthic Report (Keeley & Taylor 2011) that accompanies the NZ King Salmon Plan Change application.

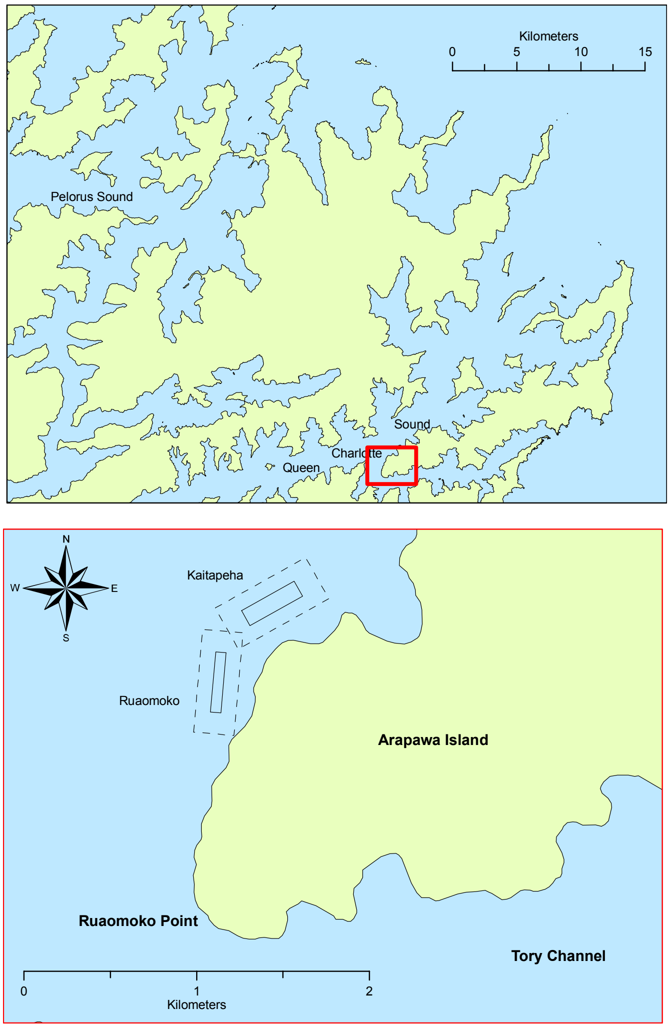

Figure 1. Location of the study area in Queen Charlotte Sound, with an expanded map of the proposed Ruaomoko Site. The dashed black rectangle indicates the Ruaomoko Plan Change Site and the solid black rectangle indicates the Cage Area Boundary (a 0.7 ha area within which all cage structures will be placed). One of the other proposed sites, the Kaitapeha Site, is shown to the north (see Clark *et al.* 2011).

1.2. Description of proposed activities at the Ruaomoko Site

NZ King Salmon seeks approval for a 14.1 hectare (ha) area with a 2.1 ha area for cage structures within which there will be 0.7 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. NZ King Salmon are also applying for a salmon farm at Kaitapeha, north of the proposed Ruaomoko Site (Figure 1).

1.3. Potential environmental issues and scope of this report

The selection of the Ruaomoko 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 Ruaomoko 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 at and around the Ruaomoko headland and the wider Queen Charlotte 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. Tory Channel and Queen Charlotte Sound marine environments

The Ruaomoko study area is located on the western side of Arapawa Island, just north of Ruaomoko Point, near the entrance to the Tory Channel (Figure 1). Tory Channel, one of two main entrances to the Queen Charlotte Sound, is approximately 15.5 km long, and relatively narrow (0.8-1.3 km wide in most areas). Water depths along the channel are in the 30-50 m depth range; but reach more than 60 m in places. The dominant feature of the Tory Channel marine environment is the strong water currents that carry nutrient-rich oceanic water from the Cook Strait, with water residence times likely to be considerably shorter than those of the wider Queen Charlotte Sound area (Gibbs 1991; Davidson 2001).

Significant water currents play an important role in structuring the marine environment, and as such, the ecology of the channel is relatively unique compared to the wider Marlborough Sounds region. Seabed and water column environments in the channel have been generally described during various ecological assessments (*e.g.* Gillespie & Asher 1995, 2000) and annual seabed monitoring at the NZ King Salmon Te Pangu Bay and Clay Point sites (*e.g.* Brown 2000; Hopkins 2005; Hopkins *et al.* 2006 a-d; Keeley *et al.* 2006; Dunmore *et al.* 2011). Intertidal and shallow subtidal investigations have also been undertaken to assess the ecological impacts of ferry wakes (*e.g.* Gillespie 1996; Davidson & Richards 2005). The coastline along the channel is dominated by bedrock, boulders and cobbles (refer Table 1), with limited areas of sandy beaches found in the upper areas of the bays. Kelp beds (predominately *Macrocystis pyrifera*) occur commonly in the rocky areas, and sea lettuce (*Ulva* sp.) has been observed in the inner areas of some bays (*e.g.* Gillespie 1991). Subtidal communities have been found to be diverse, with shallow regions containing numerous species of macroalgae, sponges, tunicates, echinoderms (*e.g.* kina, sea stars, snake tail stars), crustaceans (*e.g.* crabs, crayfish), molluscs (*e.g.* mussels, limpets) and various fish species (*e.g.* triplefins, blue cod, butterfish).

Ecological investigations undertaken in deeper areas of Tory channel [*e.g.* monitoring at the NZ King Salmon Te Pangu Bay salmon farm site and Gillespie (1991)] have consistently found sandy substrata (with varying amounts of mud-sized particles) supporting epibiota such as echinoderms (*e.g.* kina, sea stars, snake tail stars), tree hydroids (Brown 2000), bryozoan corals (Gillespie 1991), sponges, tunicates (*e.g.* saddle squirts) and bivalves (*e.g.* mussels, horse mussels). Rocky reef areas have also been observed at depth (>30 m), and have been found to support a diverse range of epibiota. Biota such as kelp and tree hydroids are not commonly found throughout the Marlborough Sounds, and are recognised by the Department of Conservation as having special ecological value (Department of Conservation 1995).

Sheltered areas of the Tory Channel are also characterised by sandy mud substrata, while areas exposed to greater currents are dominated by sands, gravels and cobbles. The seabed slopes up to a variety of shoreline habitats, from sheltered gravel and cobble beaches to exposed bedrock reefs and sheer cliff faces. There are few published studies on the subtidal macrobiota of the Marlborough Sounds (see Davidson 2002; Davidson *et al.* in press). Most of the literature has focussed on the effects of mussel farms on nutrients and plankton, and descriptive accounts of subtidal habitats are limited. While very little published information was found relating specifically to the subtidal biota in the Tory Channel area of Queen Charlotte Sound, there are known biogenic habitats in the vicinity of the present application area (Davidson *et al*. in press). These biogenic habitats are present at other locations along the Tory Channel and are regarded as biologically significant in the Marlborough Sounds.

Queen Charlotte Sound is utilised by a number of economic sectors. At present, two NZ King Salmon farms operate in the Tory Channel area, at Te Pangu and Clay Point. Queen Charlotte Sound, including Tory Channel, is also commercially and recreationally fished. The catchments support forestry and some farming. A number of mainland protected and unprotected natural areas with important terrestrial habitats also exist in the region (Davidson *et al.* 1995).

2.2. The Ruaomoko Site study area

The Ruaomoko Site is situated on the western side of Arapawa Island to north of Ruaomoko Point, where Tory Channel joins Queen Charlotte Sound (Figure 1). The Ruaomoko study area is approximately 1 km long and 0.4 km wide. The coastline slopes steeply down to 60 m and then flattens out to approximately 65 to 70 m. Ruaomoko is sheltered from easterly wind directions by Arapawa Island, but is exposed to most of other winds. Strong wind gusts eddy into the Sound and some northerly winds reach the study area. The site is exposed to localised wave action, although some attenuated ocean-swell can enter Tory Channel and the Outer Queen Charlotte Sound from Cook Strait.

3. SEABED CHARACTERISTICS

3.1. Site bathymetry

The coastline at the Ruaomoko study area was dominated by a cobble shoreline, which dropped steeply down to 60 m before flattening out at approximately 65 to 70 m depth (Figure 2). The proposed Cage Area boundary is positioned over water depths of 40 to 65 m while the site boundary extends into areas as shallow as 5 m.

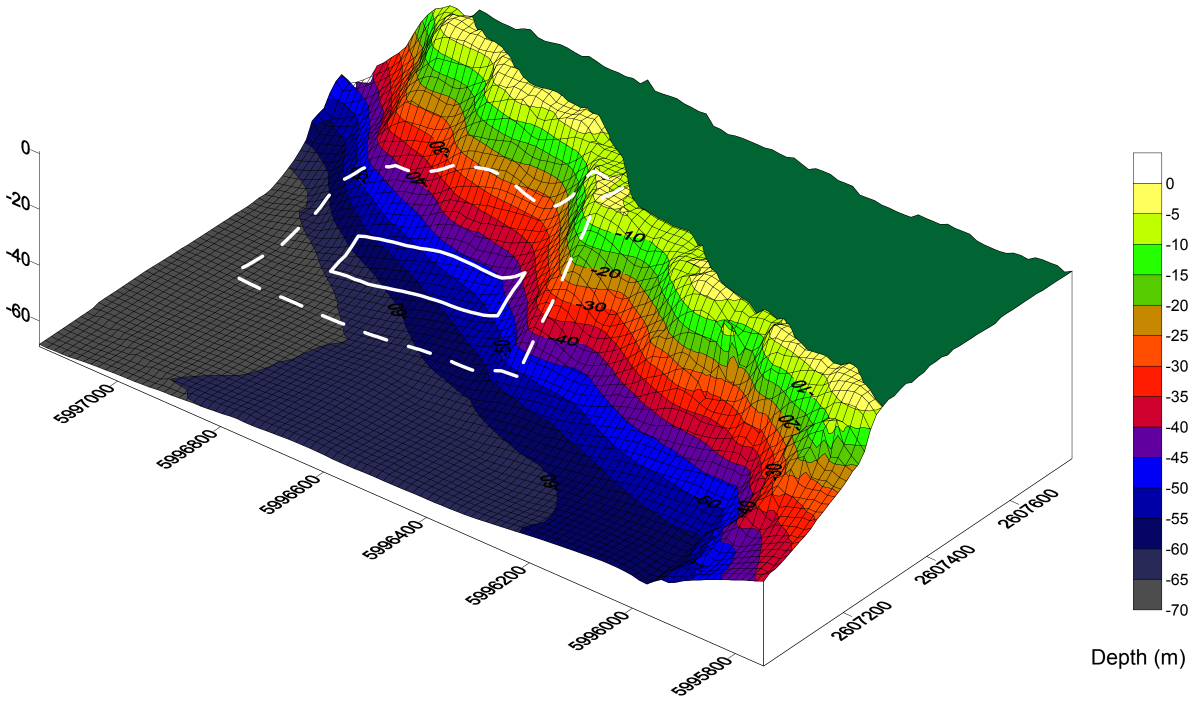

Figure 2. 3-D bathymetry map of Ruaomoko Site with proposed locations of the Cage Area Boundary (solid white line) and Plan Change Site Boundary (dashed white line) overlaid onto the seafloor.

3.2. Sediment physical and chemical properties

Sediments sampled from beneath and adjacent to the proposed site (see Appendix 1 for methods) contained varying amounts of silt and clay (<63 µm), sand (<2 mm and >63 µm) and gravel-sized (>2 mm) components (Figure 3). Sediments from beneath the proposed site (Stations 1, 2 and 5) primarily contained sand components (40-51% ww) except Station 6, which was mostly silt and clay (44% ww) (Figure 3). Sediments to the south of the site (Stations 7, 8 and 9) were predominantly sand (36-47% ww) while samples from stations offshore (Stations 3 and 4) of the site were principally composed of silt and clay components (46-54 % ww). The amount of gravel in the sediment ranged from 15 to 33 % ww and was lowest at stations furthest from the shore (Stations 3, 4, 7 and 8; 15-21 % ww). These results were consistent with observations made from video footage and drop-camera images (see Section 3.3.4). Sediment cores were characterised by a fairly uniform light grey/brown colour and appeared well oxygenated, with no evidence of an apparent Redox Potential Discontinuity (aRPD) layer or sulphide odours (Appendix 4). Sediment organic content was moderate (average of 4.3 % AFDW) and relatively similar between stations.

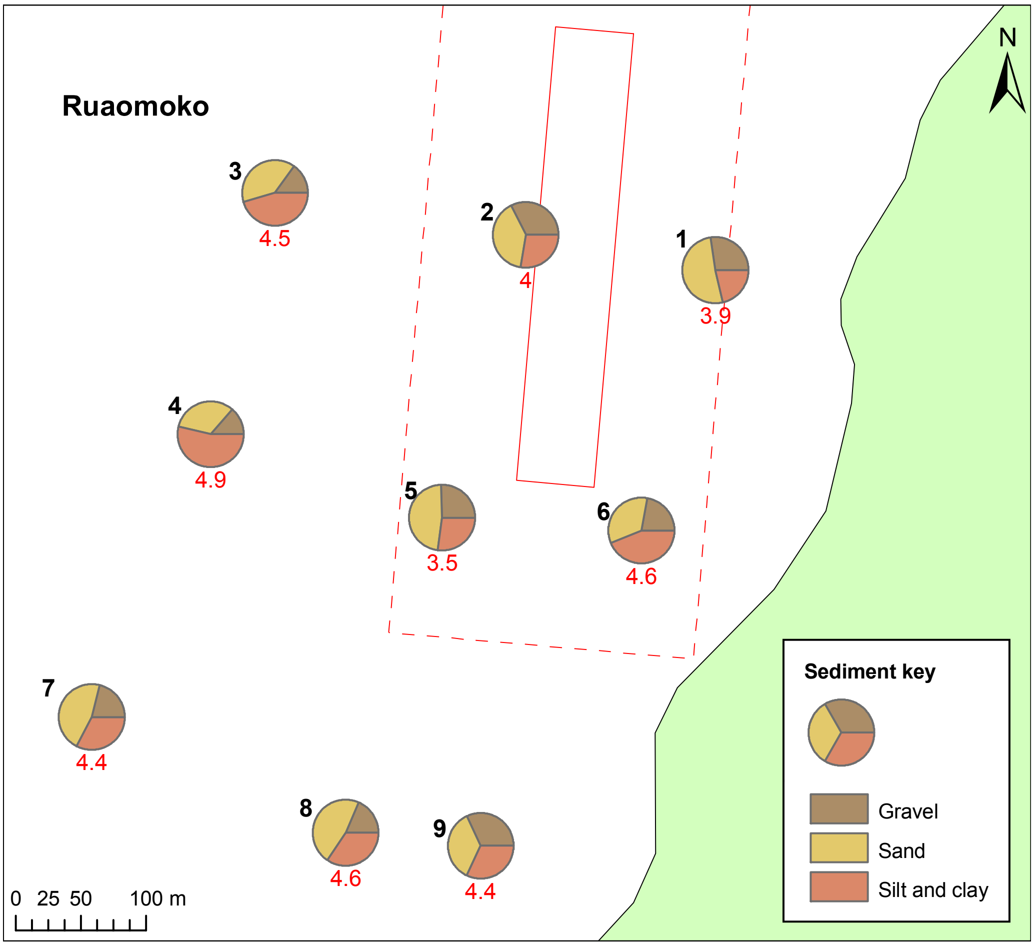

Figure 3. Grain size composition (% wet weight) and organic content (in red: %AFDW) of sediments collected from within and adjacent to the proposed Ruaomoko Site. Black numbers indicate station number, the red rectangle indicates the proposed Cage Area Boundary and the red dashed line indicates the Plan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

3.3. Sediment biological properties

Sediments sampled from the Ruaomoko study area contained infaunal communities representative of those commonly found in deep, high-flow areas throughout the Marlborough Sounds region, and are therefore considered indicative of natural or pre-farm conditions. The site was characterised by high taxa richness (a total of 128 taxa recorded), and ranged between 44 and 70 taxa per sediment core (Table 1). Refer to Appendix 5 for the complete species list. Infaunal abundance ranged between 159 and 451 individuals (average = 267). Numerically dominant taxa included various species of polychaetes and bivalves, amphipods from the families Aoridae and Phoxocephalidae, ophiuroids, nematodes, cumaceans and tanaids (Table 1).

Patterns in infaunal community composition were further explored using multivariate statistical techniques, and the reader is referred to Appendix 6 for a summary of these analyses. Samples resolved into three distinctive groups (Group 1: Stations 1 and 8; Group 2: Station 9; Group 3: Stations 2, 3, 4, 5, 6 and 7). The presence of the polychaete *Cossura consimilis*, the higher abundance of the bivalve *Venericardia purpurata* and the absence of several taxa, including polychaetes, bivalves and amphipods, at Stations 1 and 8 (Group 1) was the strongest determining feature separating this group from Group 3. Station 9 (Group 2) had the highest taxa abundance and richness with several taxa, including polychaetes, amphipods and bivalves, exclusively found at this station.

Table 1. Average and relative abundances (%) of the 15 most commonly occurring infaunal taxa collected from sediments within and adjacent to the proposed Ruaomoko Site.

	Grab station										
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Ave. abund.**	**Rel. abund. (%)**
Polychaeta: Capitellidae: *Heteromastus filiformis*	18	61	43	56	42	28	54	40	40	42	16
Polychaeta: Syllidae: *Sphaerosyllis* sp.	16	23	33	30	53	22	24	17	49	30	11
Amphipoda: Aoridae	14	33	12	17	28	2	3	15	10	15	6
Polychaeta: Cirratulidae	5	15	15	18	16	3	8	10	2	10	4
Ophiuroidea	9	5	4	3	5	11	7	9	39	10	4
Nematoda	7	0	5	0	20	7	2	9	24	8	3
Polychaeta: Lumbrineridae	10	10	5	14	3	5	2	7	15	8	3
Polychaeta: Syllidae	3	6	10	14	7	3	2	2	16	7	3
Bivalvia: *Nucula nitidula*	6	4	1	2	0	10	14	6	18	7	3
Bivalvia: *Tawera spissa*	2	1	3	1	4	18	5	4	20	6	2
Polychaeta: Spionida: *Prionospio multicristata*	5	8	5	7	7	4	13	2	4	6	2
Cumacea	4	8	2	5	27	4	3	0	2	6	2
Tanaidacea: *Tanaid sp.*	1	3	1	3	9	3	2	2	21	5	2
Amphipoda: Phoxocephalidae	0	2	2	3	3	13	6	7	8	5	2
Bivalvia: *Nemocardium pulchellum*	0	5	7	1	16	0	6	0	8	5	2
Total abundance	**159**	**285**	**232**	**245**	**336**	**257**	**206**	**236**	**451**		
Taxa richness	**44**	**56**	**51**	**46**	**54**	**62**	**48**	**53**	**70**		

3.4. Subtidal habitats and conspicuous epibiota

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

Habitats in the study area are represented diagrammatically in Figure 7. The benthic habitats within the proposed site were primarily characterised by shell hash, while those inshore of the site were composed of reef, cobbles, tubeworms mounds and sand. The shell hash habitat was composed of dead shells overlying soft sediment with a low number of epifaunal taxa. Snake tail stars, sea cucumbers, sea urchins (*Evechinus chloroticus*), sea stars (*Patiriella* sp., *Coscinasterias calamaria*) and scallops were commonly noted in shell hash areas and fish (blue cod, butterfly perch, sea perch, spotties, opalfish), fanworms, colonial ascidians and sponges were occasionally observed (Figure 6G,H). A burrowing *Cerianthus* anemone was recorded in shell hash habitat in video sled transect one.

Reef and large reef outcrops amongst cobble and sand were observed inshore of the proposed site and generally extended from the coastline to the inside boundary of the site. To the south of the Cage Area, the reef extended up to 70 m into the site boundary (85-100 m from the Cage Area) and down to depths of 55 m. Shallower reef areas (<8 m) were relatively barren with few epibiota (Figure 5D; Figure 6E,F), while deeper areas were very diverse and characterised by large sponges, ascidians, hydroids, sea anemones, fish, sea urchins, sea stars and bryozoans (Figure 5A,B; Figure 6A,B). At least 12 species of fish were seen, with butterfly perch and spotties abundant and blue cod common. *M. pyrifera* and *Carpophyllum flexuosum* algae fringed the coastline down to 6 m depth, with small *Undaria pinnatifida* seen to depths of 10 to 12 m.

A small area of reef was observed in the southeast corner of the Cage Area boundary, in 45 m of water (Figure 7). Species observed included encrusting and erect sponges, sea stars (*Patiriella* sp., *C. calamaria*), sea urchins (*E. chloroticus*), colonial and solitary ascidians, hydroids and snake tail stars. Dropcam images and video sled footage inshore and to the south of this small reef area showed shell hash substratum, suggesting this patch of reef does not directly connect to larger reef areas nearby.

Areas of tubeworm mounds interspersed amongst sand, and sometimes cobble, were common near reef areas (Figure 5C; Figure 6C,D). The tubeworm mounds were not solely one species of tubeworm but tubeworms interspersed amongst a number of other species (*eg*. sponges, bryozoans, ascidians) to form biogenic clumps. Areas of sand and gravel amongst the tubeworm mounds/biogenic clumps supported large numbers of snake tail stars and, in some places scallops. Sand habitat was seen in northern areas, extending into the site. Species of significance included burrowing *Cerianthus* anemones (seen at 7, 14 and 18 m depth), horse mussels (seen at 8 and 24 m depth) and large tree hydroids (seen at 13 m depth).

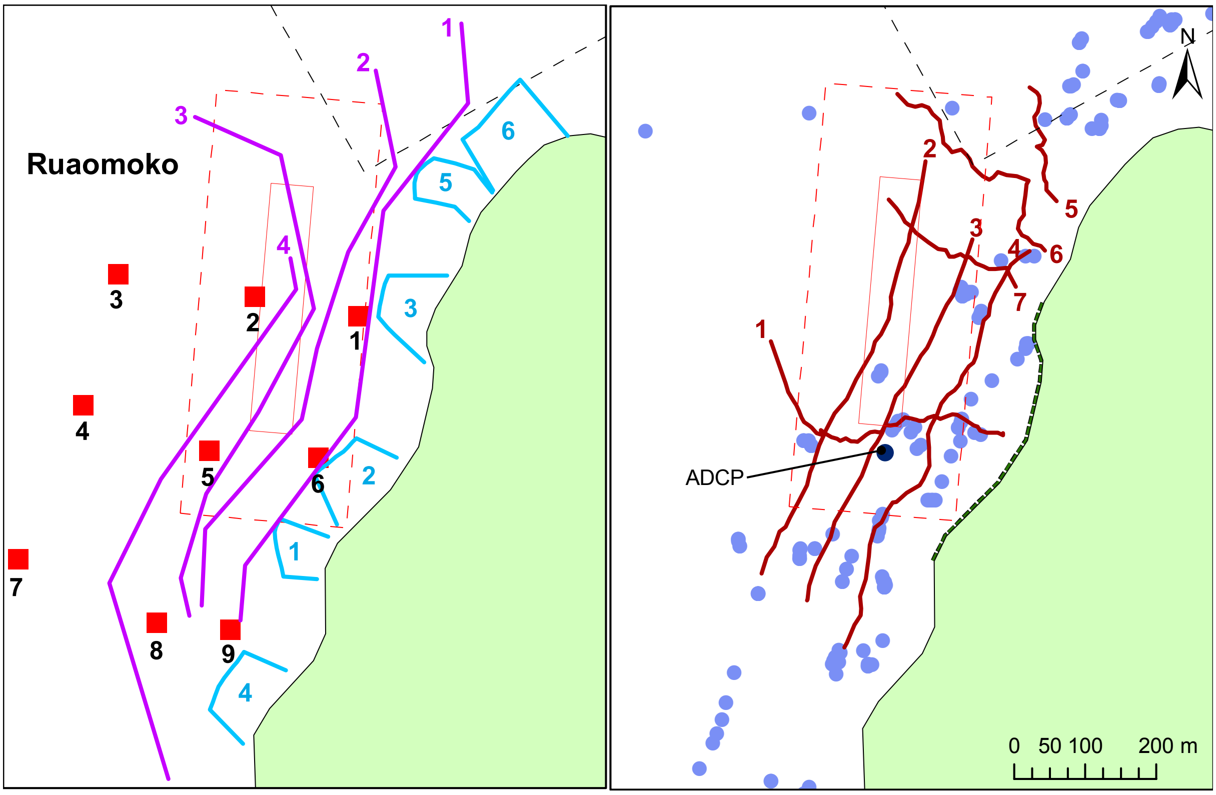

Figure 4. Sampling locations beneath and adjacent to the Ruaomoko Plan Change Site. Left: dive transects (blue lines), side scan sonar transects (purple lines), sediment grab sampling stations (red squares). Right: intertidal survey (green dashed line), drop camera locations (purple circles), video sled transects (brown lines), ACDP location (dark blue circle, labelled on map). Part of the proposed Kaitapeha Site is also shown (black dashed line).

Table 2. Conspicuous epibiota associated with seabed habitats identified from video and drop-camera images within and adjacent to the Ruaomoko Site. Refer to Figure 5 and Figure 6 for representative photographs.

Seabed habitat	**Conspicuous epibiota**
Shell hash	Red algae, sponges (encrusting orange/yellow, finger), hydroids, colonial and solitary ascidians (orange, *Cnemidocarpa* sp.), snake tail stars (*Ophiopsammus maculata*), sea urchins (*Evechinus chloroticus, Pseudechinus albocinctus*), sea stars (*Patiriella* sp., *Coscinasterias calamaria,* unidentified sp.), sea cucumbers (*Stichopus mollis, Oncus brevidentis*), sea anemones (*Anthothoe albocincta, Cerianthus* sp.), fish (*Parapercis colias, Caesioperca lepidoptera, Helicolenus* sp., *Notolabrus celidotus, Hemerocoetes monopterygius*), fanworms and scallops (*P. novazelandiae*).
Sand	Colonial ascidians (orange, grey), snake tail stars (*O. maculata*), sea urchins (*E. chloroticus*), sea stars (*Patiriella* sp., *C. calamaria*), sea anemones (*A. albocincta, Cerianthus* sp.), fish (*Nemadactylus macropterus*, *P. colias, C. lepidoptera,* unidentified fish sp.), scallops (*P. novazelandiae*).
Tubeworm mounds (biogenic clumps) amongst cobble/sand	Encrusting coralline algae, sponges (various species of encrusting and erect), hydroids, calcareous tubeworms, colonial and solitary ascidians (orange, grey), snake tail stars (*O. maculata*), bryozoans (branching, encrusting), sea urchins (*E. chloroticus*), sea stars (*Patiriella* sp., *C. calamaria, Pentagonaster pulchellus*), sea cucumbers (*S. mollis*), sea anemones (*A. albocincta, Cerianthus* sp.), fish (*C. lepidoptera, N. celidotus, Pseudolabrus miles, Latridopsis ciliaris, Parika scaber*, unidentified triplefin, unidentified fish sp.), fanworms, nudibranch, scallops (*P. novazelandiae*).
Reef/reef outcrops amongst cobble/sand	Encrusting coralline algae, red algae, green algae (*Ulva* sp.), brown algae (*Undaria pinnatifida, Macrocystis pyrifera, Carpophyllum flexuosum*), sponges (various species of encrusting and erect), hydroids, tree hydroid, calcareous tubeworms, colonial and solitary ascidians (orange, white, grey, *Oligocarpa megalorchis, Cnemidocarpa* sp., *Pyura* sp.), snake tail stars (*O. maculata*), bryozoans (bushy, branching, encrusting), sea urchins (*E. chloroticus, P. albocinctus*), sea stars (*Patiriella* sp., *C. calamaria,* unidentified sp.), sea cucumbers (*S. mollis, O. brevidentis*), sea anemones (*A. albocincta, Cerianthus* sp.), fish (*P. colias, C. lepidoptera, N. celidotus, N. macropterus, Congiopodus leucopaecilus, P. miles, L. ciliaris, Pseudophycis bachus, N. fucicola, Arripis trutta*, *Helicolenus* sp., *P. scaber*, unidentified triplefin, unidentified fish sp.), fanworms, nudibranch, hermit crab, scallops (*P. novazelandiae*), horse mussel (*Atrina zelandica*), nesting mussel (*Modiolarca impacta*).

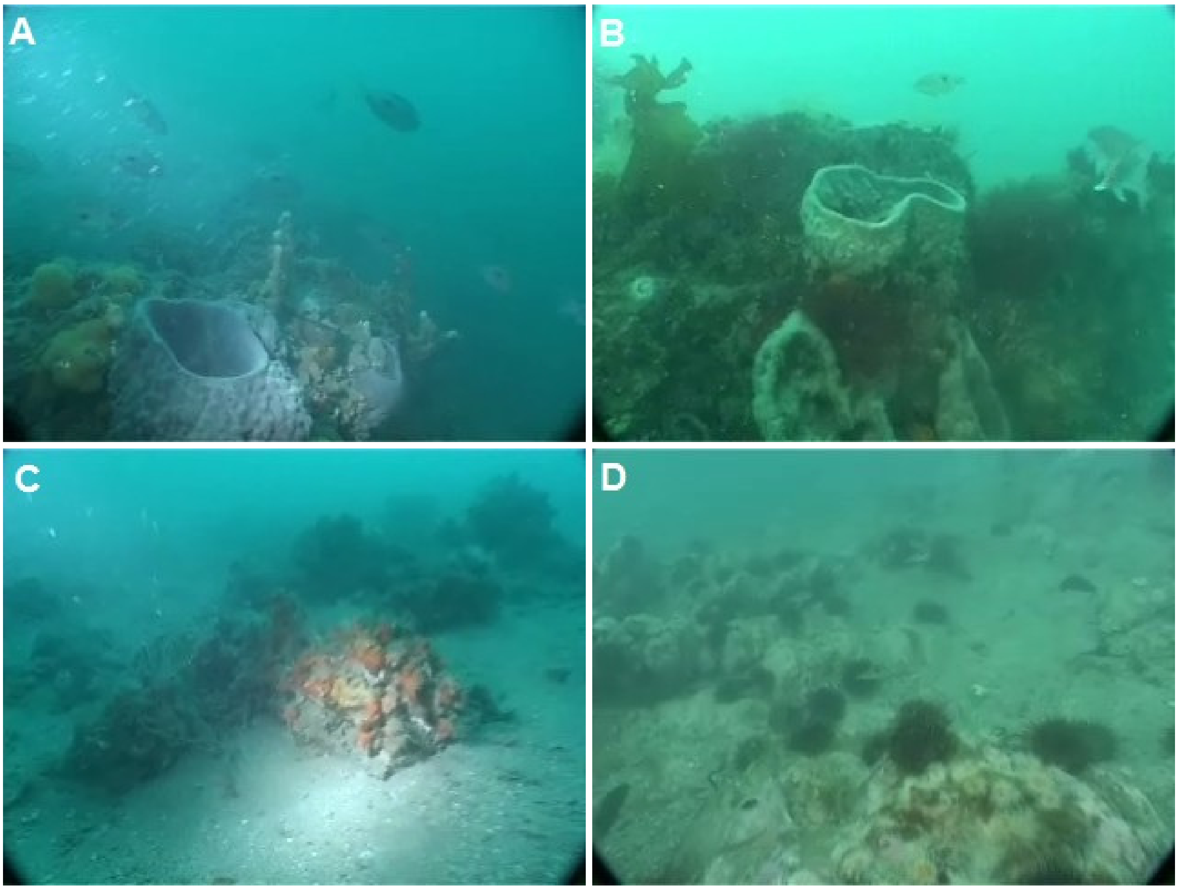

Figure 5. Images obtained from video footage of Dive Transect 3: (A & B) reef habitat, (C) tubeworm mounds (biogenic clumps) interspersed with sand, (D) reef covered with sand and sea urchins.

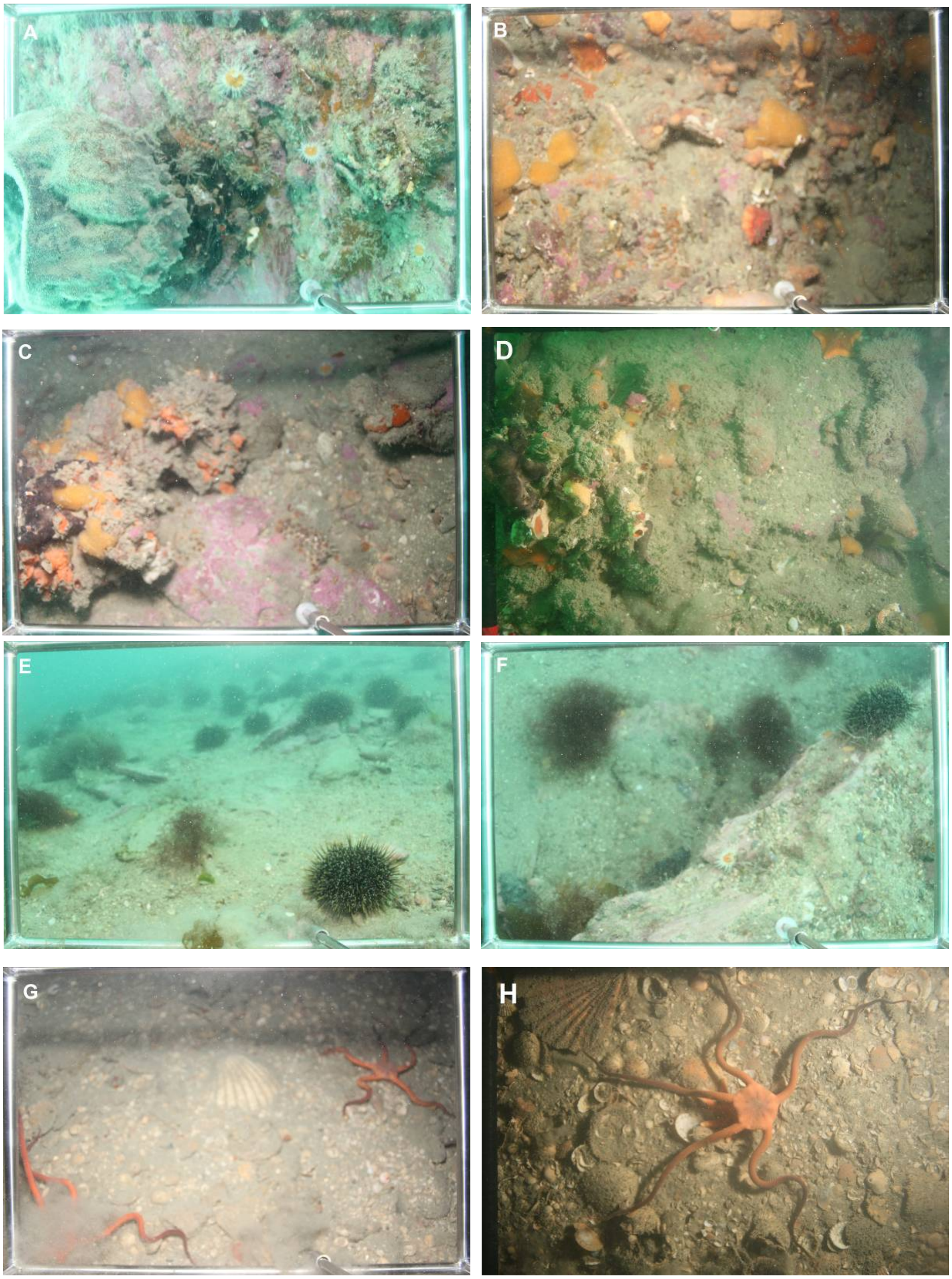

Figure 6. Examples of drop-camera images: (A & B) reef habitat, (C & D) tubeworm mounds (biogenic clumps), (E & F) sand covered reef with sea urchins, (G & H) shell hash and snake tail stars.

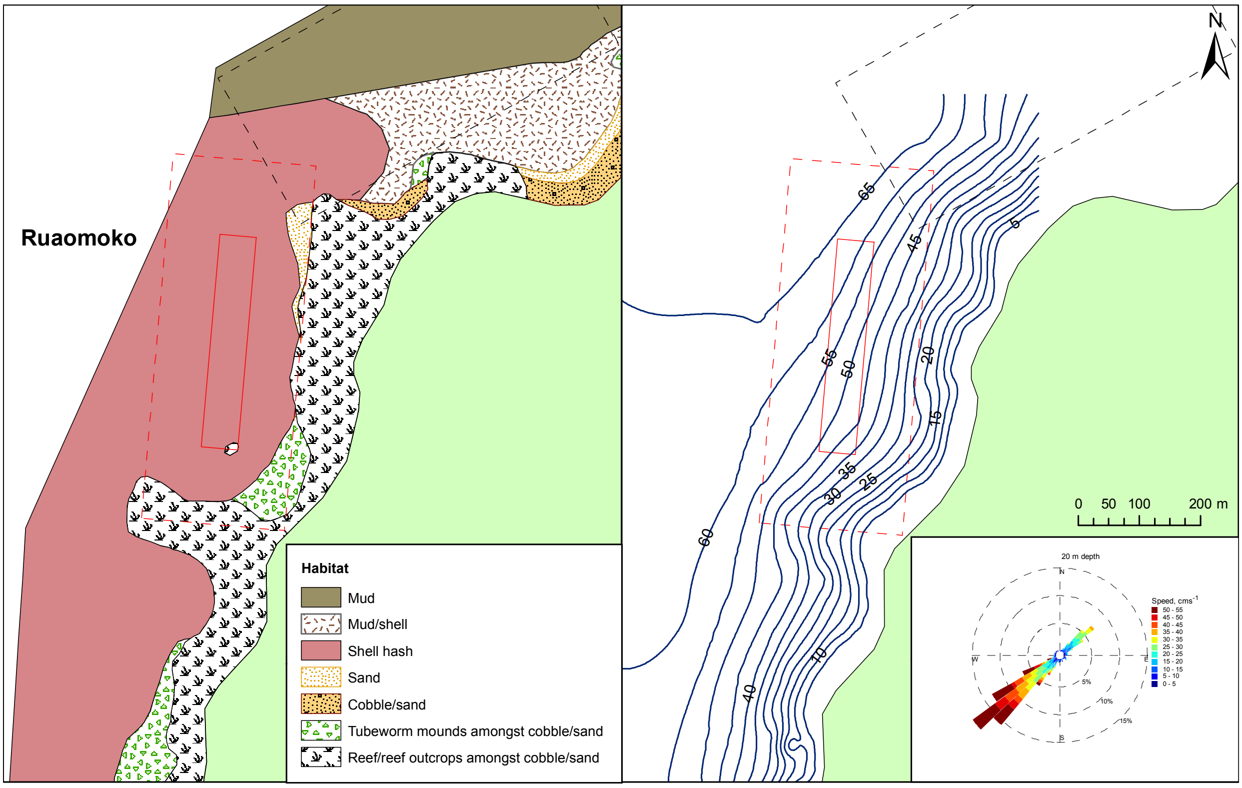

Figure 7. Left: Map of seabed habitats observed beneath and adjacent to the proposed Ruaomoko Plan Change Site. Right: Bathymetric contour lines at the Ruaomoko Site with the 20 m depth current rose inset. The solid red rectangle indicates the proposed Ruaomoko Cage Area Boundary and the dashed red rectangle indicates the Ruaomoko Plan Change Site. Part of the neighbouring proposed Kaitapeha Site is also shown (black dashed line).

3.5. Intertidal habitats

The intertidal region inshore of the proposed Ruaomoko Site was characteristic of many areas in the Marlborough Sounds (Davidson & Abel 1998; Davidson *et al.* 2010), and consisted of a narrow (5-10 m) intertidal area of cobble beach with rocky boulder/reef areas at either end (Figure 8). Cobble areas were dominated by bare space and appeared relatively depauperate of conspicuous seaweeds and invertebrates. Most of the invertebrates occupied the rocky reef. Littorinid snails, *Austrolittorina cincta* and *A. antipodum,* were present in the upper intertidal, and the mid shore was occupied by sea anemones, limpets, chitons and various mobile gastropods and crabs. Patches of barnacles (*Chamaesipho* sp.) and blue mussels (*Mytilus galloprovincialis*) were common in the mid to low shore. A full list of taxa and relative abundance scores is presented in Appendix 8.

Figure 8. Intertidal zone inshore of the proposed Ruaomoko Site; showing rocky boulder substratum and cobble beach. A fringe of giant kelp, *Macrocystis pyrifera*, is present in the foreground.

4. WATER CURRENTS

Flow charts of current speed (cm s^{-1}) and direction (true) at surface, mid-water and near-seabed depths are shown in Figure 9, and flow charts of the entire water column are presented in Appendix 9. Average water velocities were approximately 30 cm s^{-1} and maximum water velocities were in the order of 70 cm s^{-1} throughout most of the water column (Table 3). Current speeds decreased with depth, with mean surface current speeds of 31 cm s^{-1} (maximum 74 cm s^{-1}) and mean near-seabed current speeds of 27 cm s^{-1} (maximum 66 cm s^{-1}). The predominant direction of flow was to the southwest (into Tory Channel), running parallel to the coastline, with some tidal reversal (water flow back the other way).

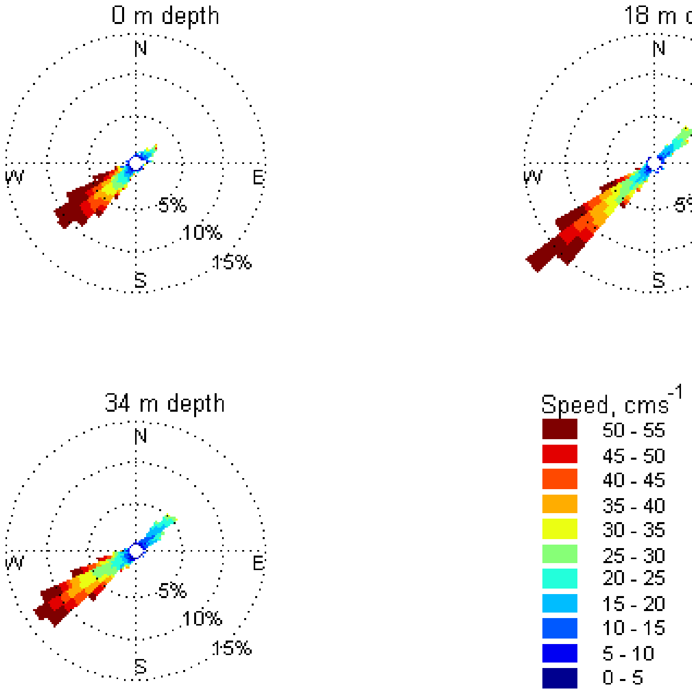

Figure 9. Mean current speed and direction measured at 0 m (surface), 18 m (mid-water) and 34 m (near-seabed) depths at the Ruaomoko Site.

Table 3. Depth-averaged current speeds (cm s^{-1}) collected between 6 February 2011 to 28 March 2011 by an ADCP deployed at the Ruaomoko Site (see Appendix 2 for sampling details).

Water depth (m)	Average (cm s^{-1})	1st Percentile (cm s^{-1})	99th Percentile (cm s^{-1})	Standard deviation
0	31.4	2.6	74.0	18.6
2	29.5	2.5	73.5	17.9
4	29.6	2.6	72.2	17.9
6	29.7	1.9	71.3	17.8
8	29.8	1.8	72.5	17.7
10	29.8	2.1	71.8	17.5
12	29.8	2.0	71.4	17.3
14	29.9	2.3	71.0	17.2
16	30.0	2.6	71.2	17.1
18	30.1	2.6	70.4	17.0
20	30.2	3.1	70.4	16.9
22	30.2	2.7	70.8	16.7
24	30.2	2.8	70.7	16.7
26	29.9	2.3	71.5	16.6
28	29.6	2.5	70.0	16.4
30	29.2	2.5	69.8	16.3
32	28.5	2.6	68.9	16.1
34	26.9	1.9	66.3	15.9

Note: The 1st and 99th 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 Ruaomoko Site during initial development (*e.g.* 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- Keeley & Taylor 2011) that considers all eight proposed farm sites being applied for by NZ King Salmon in their Plan Change and resource consent applications.

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 proposed farm were dominated by shell hash (Figure 7). The southern boundary of the proposed site overlies reef (5-55 m depth) and the inshore boundary overlies areas of tubeworm mounds interspersed with sand and cobbles. These reef and tubeworm mound areas may be impacted by the initial installation of anchoring structures. Due to the patchy nature of tubeworm mounds, it may be possible to avoid negatively affecting sensitive habitats but the southern reef appears to be fairly solid. 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 (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). 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 Ruaomoko 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).	Where possible, anchor sites should be placed away from sensitive habitats.
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.

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 Ruaomoko Site (*i.e.* 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 nemotodes. 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.

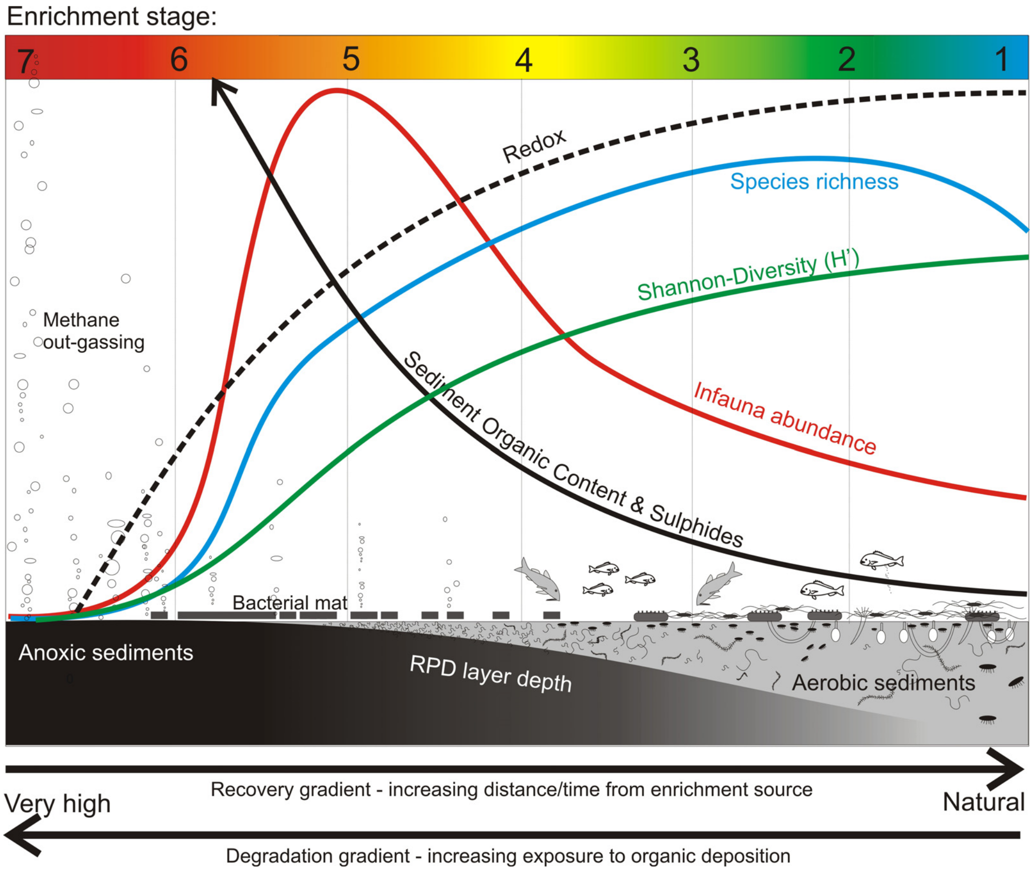

Figure 10. Graphical representation of typical enrichment gradient indicating approximate boundaries of proposed seven impact stages in relation to some frequently adopted environmental indicator variables.

Table 5. General description and main environmental characteristics of enrichment stages (ES) 1-7. Refer to 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*** - 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 enrichment*** – 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 Ruaomoko Site

NZ King Salmon propose to place four 40 x 40 cages in one row. The depositional footprint was modelled in DEPOMOD at 14 theoretical levels of annual feed loading, under 'no-resuspension' and 'resuspension' scenarios. These feed loadings were selected based on predictive modelling undertaken by Keeley & Taylor (2011), and include three feed usage thresholds developed for the various NZ King Salmon sites (including the Ruaomoko Site). These are as follows (refer Keeley & Taylor 2011 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, 6000 t yr^{-1}, respectively), while footprints for the other feed usage levels between 500 and 6500 t yr^{-1} are provided in Appendix 10. Under the modelled no-resuspension scenarios, maximum depositional flux at a feed loading of 3000 t yr^{-1} was 4 to 6 kg m^{-2} yr^{-1} and this increased with food input, reaching 10 kg m^{-2} yr^{-1} at feed loadings of 6000 t yr^{-1}. These relatively low rates of deposition are consistent with the high flows and, therefore, high dispersal potential (the particulates are spread further across the seabed), observed in this area.

When resuspension was included in the model, the depositional flux beneath the cages was considerably reduced 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 the resuspension scenarios, DEPOMOD predicts that most of the organic particulates being discharged from the farm will be diluted, dispersed and exported from the area.

The overall area directly affected by deposition across feed loadings of 3000 to 6000 t yr^{-1} (without resuspension in the model), was estimated to be 25 to 37 hectares (Figure 12). Most of this area, however, was exposed to relatively low depositional rates of 0.5 to 4 kg m^{-2} yr^{-1}. The effects of the prevailing current moving southwest across the study area can be seen in the elliptical shape of deposition, to the southwest of the cages (Figure 11). In contrast, when resuspension was added to the model, the total area affected by deposition rates was negligible, as the resuspension scenarios involved no net depositional flux or, any that was predicted was less than 0.5 kg m^{-2} yr^{-1}. In reality, the area affected by deposition is likely to be somewhere between these two ranges.

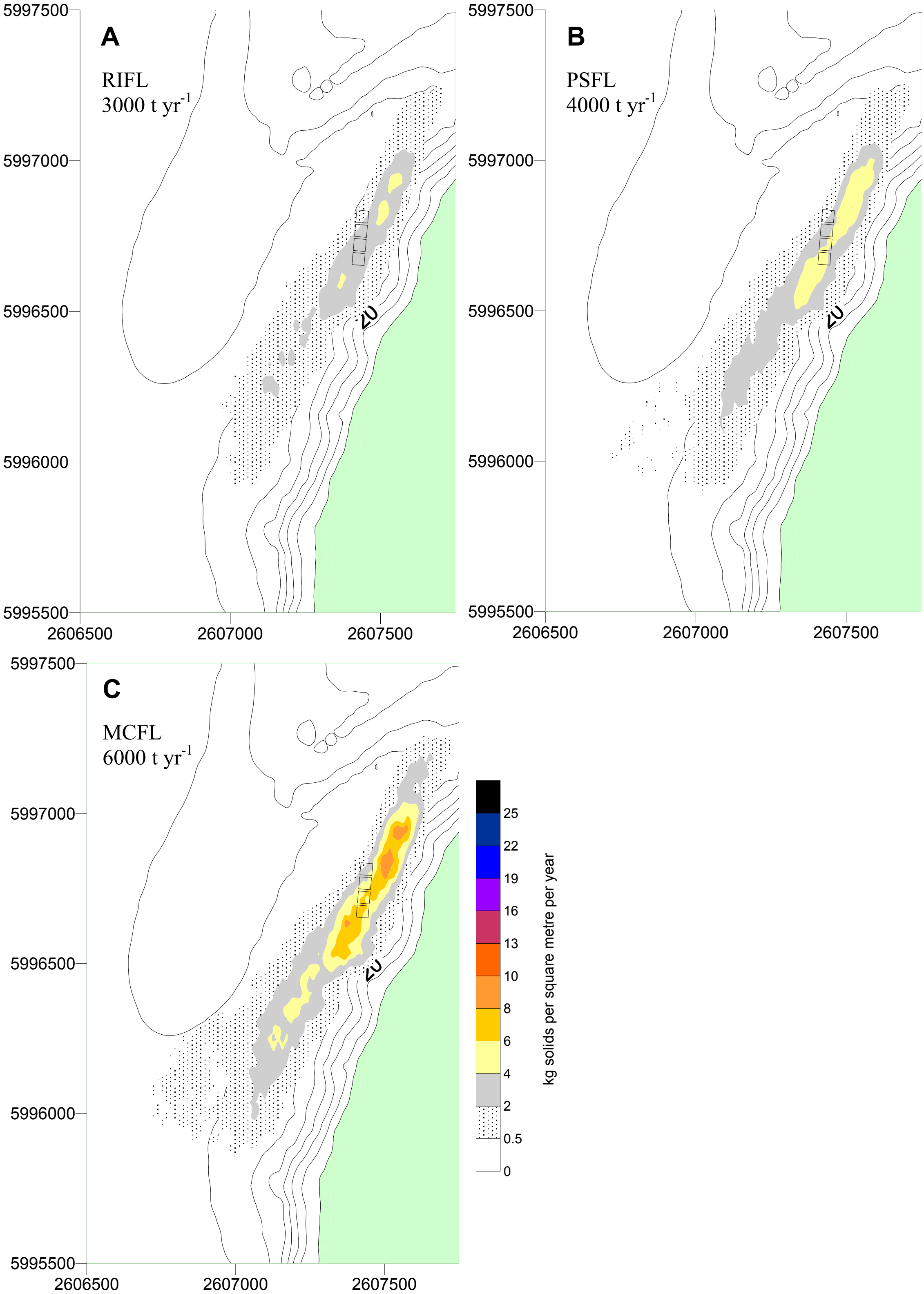

Figure 11. Predicted depositional footprints modelled with no-resuspension at the Ruaomoko Site for three feed usage levels: (A) Recommended Initial Feed Level (RIFL, 3000 t yr^{-1}), (B) the Predicted Sustainable Feed Level (PSFL, 4000 t yr^{-1}), (C) Maximum Conceivable Feed Level (MCFL, 6000 t yr^{-1}).

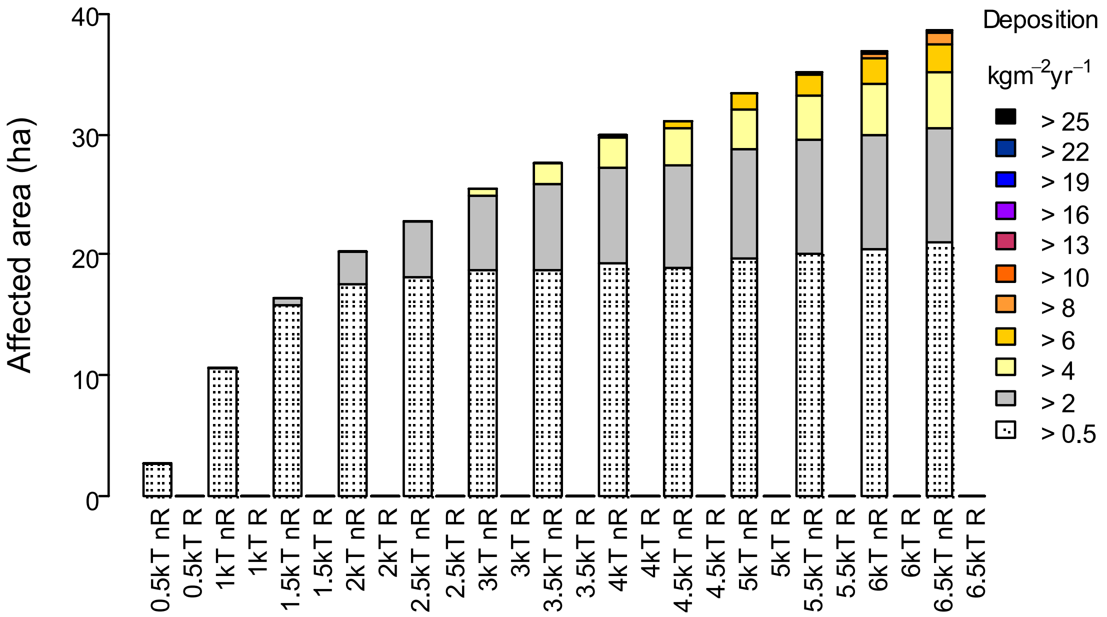

Figure 12. Summary of the total area affected by differing amounts of depositional flux for each of the modelled feed level scenarios at Ruaomoko, with resuspension (R) and no-resuspension 'nR' included in the model.

The proposed site at Ruaomoko cannot be considered solely on its own due to the likely presence of the proposed Kaitapeha Site to the north (distance of 200 m between Cage Area Boundaries). NZ King Salmon propose to place eight 40 x 40 m cages in two rows at Kaitapeha. The depositional footprint from these two cage configurations was modelled at five levels of feed loading (at a 1:1 ratio of feed at each site), under no-resuspension and resuspension scenarios.

Figure 13 shows the predicted depositional footprints close to the combined RIFL (4500 t yr^{-1}), PSFL (6000 t yr^{-1}) and MCFL (8000 t yr^{-1}) feed levels (*i.e.* 4000, 6000, 8000 t yr^{-1}, respectively), while footprints for the other feed usage levels are provided in Appendix 10. Under the modelled no-resuspension scenarios, maximum depositional flux at a feed loading of 4000 t yr^{-1} was 4 to 6 kg m^{-2} yr^{-1} and this increased with food input, reaching 8 to 10 kg m^{-2} yr^{-1} at feed loadings of 8000 t yr^{-1}. These relatively low rates of deposition are consistent with the high flows and, therefore, high dispersal potential (the particulates are spread further across the seabed), observed in this area.

Without resuspension in the model, the overall area directly affected by deposition greater than 0.5 kg m^{-2} yr^{-1}, across combined feed loadings of 4000 to 12000 t yr^{-1}, was estimated to be 31 to 50 hectares for the two farms (Figure 14). Most of this area, however, was exposed to relatively low depositional rates of 0.5 to 4 kg m^{-2} yr^{-1}. As seen for the Ruaomoko Site when considered on its own, due to the high current flows in this area, when resuspension was included in the model almost no accumulation of deposits was predicted. Again, no figures of the resuspension scenarios are shown because the predicted deposition rates were not above background levels of deposition.

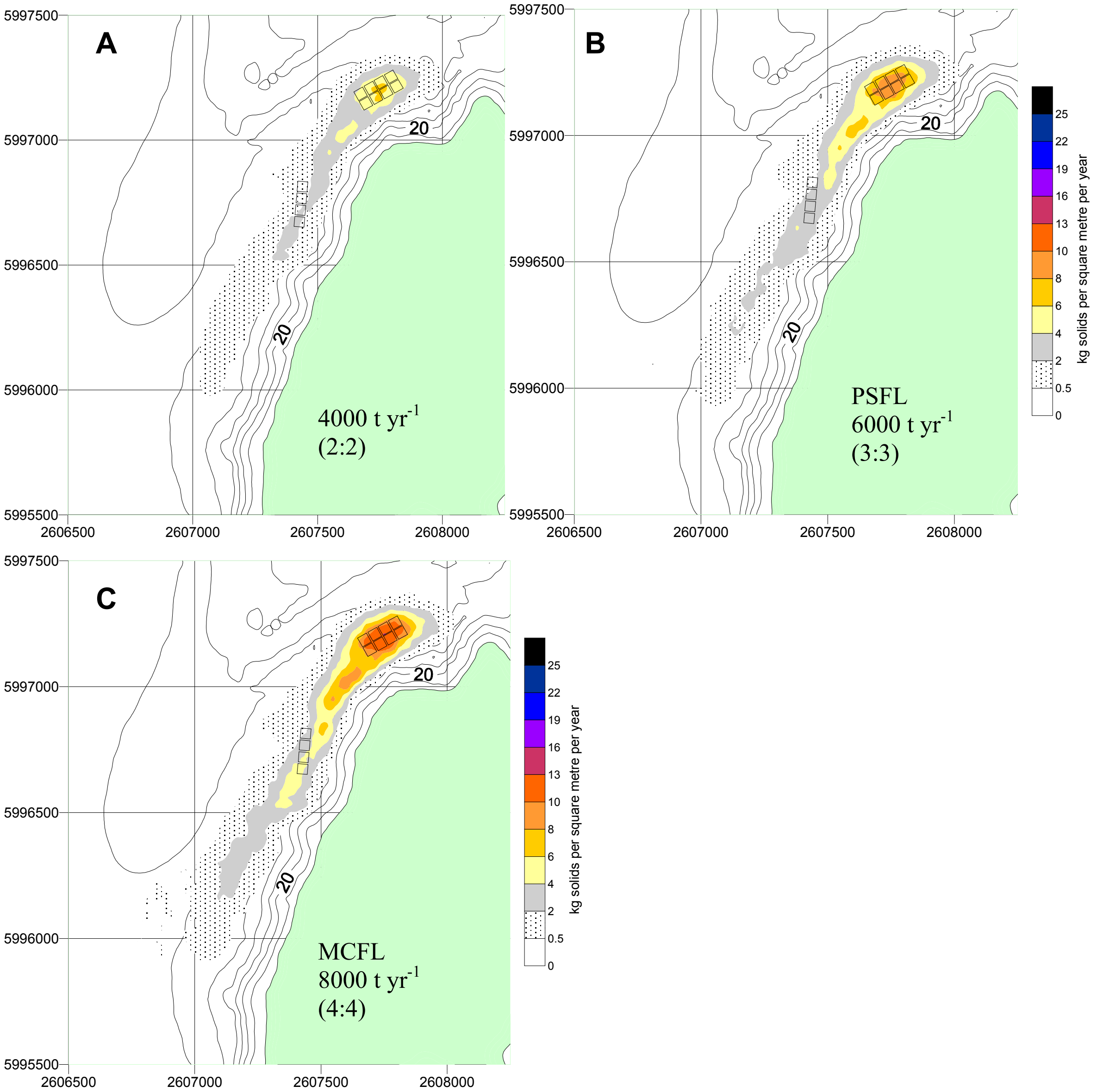

Figure 13. Predicted depositional footprints modelled with no-resuspension at the Ruaomoko and Kaitapeha Sites for three feed usage levels (total feed across both sites): (A) 4000 t yr^{-1} (NB. Recommended Initial Feed Level, RIFL, 4500 t yr^{-1}), (B) Predicted Sustainable Feed Level (PSFL, 6000 t yr^{-1}), (C) Maximum Conceivable Feed Level (MCFL, 8000 t yr^{-1}).

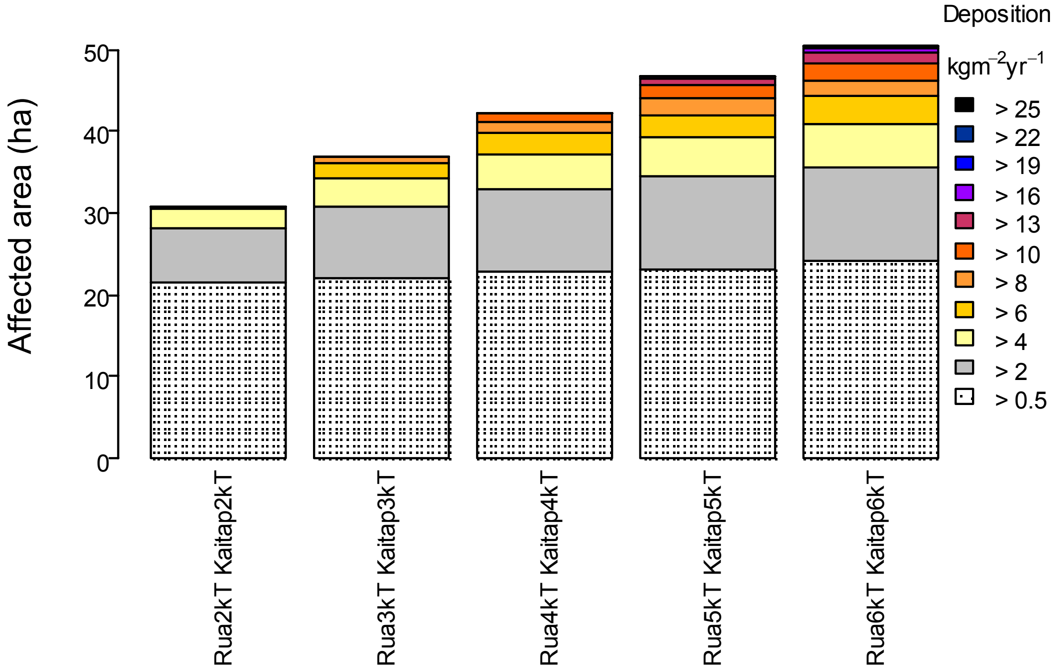

Figure 14. Summary of total area predicted to be affected by differing levels of sedimentation, for each of the combined modelled scenarios at Ruaomoko and Kaitapeha. NB. No-resuspension scenarios with the numbers denoting how many thousand tonnes per year of feed loading per site.

5.2.2. Magnitude and significance of seabed effects

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 Ruaomoko, resuspension is predicted to reduce 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 depositional modelling of the Ruaomoko Site (under MCFL 6000 t yr^{-1}), indicates the spread of waste particulates beyond the site will primarily be away from inshore habitats and out into the main channel (up to 880 m from the Cage Area). While some highly localised changes in benthic community structure will occur directly adjacent to the farm, the majority of effects will, therefore, be spread over a large area of more common soft-bottom mud/shell hash habitat, in the main channel. The infaunal communities associated with this substratum were dominated by polychaetes and amphipods; taxa that are well represented and widespread in the Marlborough Sounds region (see Section 3.3). Epibiota were sparse with only snake tail stars, sea cucumbers, sea urchins, sea stars and scallops commonly noted.

The predicted depositional footprint for the MCFL (6000 t yr^{-1}), under no-resuspension was overlaid on the habitat map created for the study area (Figure 15). This figure helps to visualise the spatial scale of the area that could be impacted under a worst-case scenario, in addition to 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, refer Figure 10). This is also likely to result in the displacement of most epibiota. It is anticipated that a further 36 ha of seabed will be moderately impacted (*i.e.* ES 3 score or more); 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 (see Section 6).

While, the footprint is primarily confined to shell hash habitats, low levels of deposition (<8 kg m^{-2} yr^{-1} under MCFL) are expected to extend onto the ecologically sensitive reefs inshore and to the south of the site (Figure 15). The small reef area in the southeast corner of the Cage Area is expected to be affected by less than 4 kg m^{-2} yr^{-1} deposition under MCFL. Monitoring of rocky reefs at two other NZ King Salmon farms in Queen Charlotte Sound (Te Pangu and Clay Point) indicate that the reef communities near the farms (90-200 m from cages) remained healthy and diverse after 18 and three years of operation, respectively (Dunmore *et al.* 2011). Potentially enrichment-sensitive organisms (*e.g.* cup sponges, thecate tree hydroids) were still present in similar volumes and appeared to remain healthy and unaffected. This data suggests that reef communities near Ruaomoko, which are located a minimum distance of 75 to 110 m from the Cage Area (except for the small reef area), may also remain healthy after farm operation commences. While occasional observations of ecologically important species (*Cerianthus* sp., horse mussels, tree hydroids) were noted at Ruaomoko, they primarily occurred inshore of this depositional footprint and it is assumed they will be largely unaffected by the operation of a salmon farm at the site.

The degree of enrichment will be determined by the feed regime. Increased sedimentation derived from the salmon farm may result in respiratory problems in some fauna, including scallops. In extreme cases the animals can be buried on the sea-floor, which may eventually decimate their populations. For detailed background information on the impacts of salmon farms on the seabed refer to the Benthic Report (Keeley & Taylor 2011).

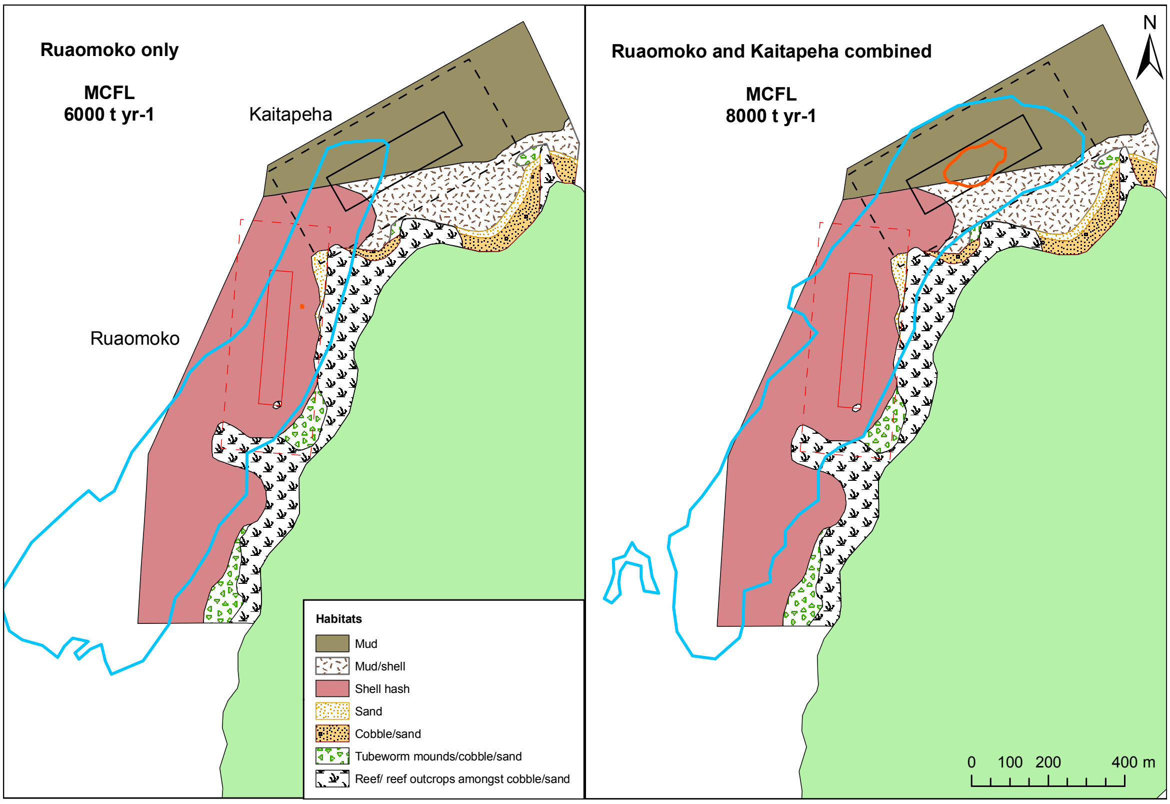

Figure 15. Predicted depositional footprint for the Maximum Conceivable Feed Level (MCFL) under a 'no-resuspension' scenario, overlaid onto the habitat map created for the Ruaomoko Plan Change Site. The blue line indicates the 0.5 kg m^{-2} yr^{-1} deposition area and the orange line indicates the >10 kg m^{-2} yr^{-1} deposition area. Left: Predicted depositional footprint for the Ruaomoko Site only (MCFL, 6000 t yr^{-1}). Right: Predicted combined depositional footprint for the Ruaomoko and Kaitapeha Sites (MCFL, 8000 t yr^{-1}).

6. MANAGEMENT OF BENTHIC EFFECTS

It is proposed that the Ruaomoko 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. When considered together, the combined RIFL for the Ruaomoko and Kaitapeha Sites is 4500 t yr^{-1}, the combined PSFL is 6000 t yr^{-1} and the combined MCFL is 8000 t yr^{-1}. Any increases from the combined RIFL should be undertaken in 1500 t yr^{-1} increments (1000 t yr^{-1} at Ruaomoko and 500 t yr^{-1} at Kaitapeha.

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. The ecological attributes at this site which warrant special consideration under the wider ecological monitoring program include reef and tubeworm mound habitats identified inshore and south of the proposed farm.

7. SUMMARY AND RECOMMENDATIONS

The main findings of our benthic assessment are as follows:

1. A range of substratum types were observed at the study area, with sand and silt/clay being the most widespread. The sediment was well oxygenated with moderate organic content. A rich infaunal (*i.e.* within sediment) community was found at the site comprising a total of 128 taxa. Taxa were typical of deep high-flow areas throughout the Marlborough Sounds.
2. The seabed beneath the proposed Ruaomoko Site was dominated by shell hash and inshore areas were largely characterised by reef, cobble, tubeworm mounds and sand. Shell hash habitats were characterised by relatively sparse epifaunal communities containing species that are common in the Marlborough Sounds. The inshore communities were diverse. The southern reef extended up to 70 m into the site boundary and a small area of reef was observed in the southeast corner of the Cage Area Boundary.
3. A number of ecologically significant species were observed (scallops, *Cerianthus* species, horse mussels, tree hydroids).
4. A band of *M. pyrifera* and *C. flexuosum* algae fringed the coastline and the intertidal area inshore of the site was characteristic of the Tory Channel region of the Marlborough Sounds.
5. The proposed site overlies water depths of 5 to 70 m. Water current velocities at the study area were high (average 30 cm s^{-1}; maximum 70 cm s^{-1}) and the predominant direction of flow was offshore towards the main channel in the southwest, with limited tidal reversal. Near-bed water velocities were consistently above the resuspension threshold used in the depositional modelling for the study area.
6. At feed levels of up to 6000 t yr^{-1}, depositional modelling indicated that depositional flux would be low (10 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 6500 t yr^{-1}. When resuspension was not considered, the depositional footprint (deposition >0.5 kg m^{-2} yr^{-1}) affected an area of 25 to 37 ha at feed loadings of 3000 to 6000 t yr^{-1}, however, most of this area was exposed to relatively low depositional rates of less than 2 kg m^{-2} yr^{-1} and the footprint extended to the northeast, away from potentially sensitive inshore communities.
7. When the cumulative deposition effects of the neighbouring proposed Kaitapeha Site were taken into account, maximum depositional flux was 10 to 13 kg m^{-2} yr^{-1} at a combined feed loading of up to 8000 t yr^{-1} (MCFL). Without resuspension in the model, the area affected by deposition (>0.5 kg m^{-2} yr^{-1}), across combined feed loadings of 4000 to 8000 t yr^{-1}, was estimated to be 31 to 50 ha for the two farms.
8. When the proposed Ruaomoko Site is considered on its own, 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 Ruaomoko Site is 6000 t yr^{-1}.

9. When considered together, the recommended combined initial feed level for the Kaitapeha and Ruaomoko sites is 4500 t yr^{-1}, the combined predicted sustainable feed level is 6000 t yr^{-1} and the combined maximum conceivable feed level is 8000 t yr^{-1}.
10. The depositional footprint primarily extends over soft sediment habitats, common throughout Queen Charlotte Sound, however, low levels of deposition have the potential to affect the southern reef area.
11. 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 36 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.
12. It is proposed that the Ruaomoko 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. The ecological attributes at this site which warrant special consideration under the wider ecological monitoring program include reef and tubeworm habitats identified inshore and south of the proposed farm.
13. The Ruaomoko study area is situated in a high-flow area where wastes will be dispersed and assimilated. The bathymetry of the area is suited to cage farming, but there are notable ecological habitats in this area. The location of the proposed site has been chosen to minimise potential effects to ecologically sensitive habitats in the vicinity of the proposed farm.

8. ACKNOWLEDGEMENTS

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10. APPENDICES

Appendix 1. Approach to assessing seabed characteristics

The seabed beneath and adjacent to the Ruaomoko Site was characterised over nine days using a range of sampling techniques; including depth profiling, sediment grab sampling, video transects and side-scan sonar (refer Tables 1-1 to 1-5). Sufficient sampling was undertaken to allow delineation of the major habitats to assess potential effects.

Table 1-1. Seabed sampling undertaken at the Ruaomoko study area.

Purpose	**Sampling Technique**	**Date**
Study area bathymetry	Depth profiling	25 March 2011
	Side scan sonar	22 June 2011
Assess subtidal habitats	Sediment grab samples	17 February 2011
	Drop camera photography	17 February 2011
		25 March 2011
	Video transects (diver-collected)	3 February 2010
		25 March 2011
		17 June 2011
	Video sled transects	22 May 2011
		17 June 2011
Assess intertidal habitats	Intertidal shoreline survey	25 March 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 Ruaomoko Site (Table 1-2). The following sub-samples were collected to characterise the physical, chemical and biological properties of the sediments:

- **Sediment core samples:** Two 63 mm diameter cores were photographed and the top 25 mm of each was collected for analyses of sediment grain size and organic matter content. The two samples were combined for each station. Grain size was determined gravimetrically after separation of fractions by wet sieving and drying at 105ºC, 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 sample locations.

Station	Depth (m)	Latitude	Longitude	NZMG-E	NZMG-N
1	25	-41 13.82002	174 09.81934	2607541	5996730
2	55	-41 13.80638	174 09.71470	2607395	5996758
3	65	-41 13.79040	174 09.57641	2607202	5996790
4	60	-41 13.89092	174 09.54279	2607153	5996604
5	50	-41 13.92437	174 09.67078	2607331	5996540
6	20	-41 13.92861	174 09.78056	2607484	5996530
7	60	-41 14.00910	174 09.47940	2607061	5996387
8	50	-41 14.05578	174 09.62001	2607257	5996298
9	25	-41 14.06038	174 09.69441	2607361	5996288

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 Ruaomoko Site (Figure 4). More than 100 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.

Six 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 20 to 25 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).

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. Seven 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 (Figure 4; Table 1-4), along with observations of conspicuous epibiota and substratum type.

Table 1-3. Dive transect start locations.

Dive transect	Latitude	Longitude	NZMG-E	NZMG-N
1	-41 14.02275	174 09.78071	2607482	5996356
2	-41 13.97077	174 09.79125	2607498	5996452
3	-41 13.84883	174 09.88000	2607625	5996676
4	-41 14.08694	174 09.73818	2607421	5996238
5	-41 13.72331	174 09.95007	2607726	5996907
6	-41 13.67326	174 10.03651	2607848	5996998

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	2607263	5996685	-41 13.84658	174 09.62085	2607593	5996554	-41 13.91498	174 09.85826
2	2607481	5996939	-41 13.70778	174 09.77444	2607250	5996355	-41 14.02496	174 09.61469
3	2607549	5996829	-41 13.76672	174 09.82415	2607316	5996319	-41 14.04393	174 09.66226
4	2607629	5996813	-41 13.77479	174 09.88155	2607366	5996253	-41 14.07923	174 09.69868
5	2607666	5996883	-41 13.73671	174 09.90736	2607628	5997043	-41 13.65054	174 09.87864
6	2607650	5996812	-41 13.77518	174 09.89659	2607445	5997034	-41 13.65672	174 09.74777
7	2607610	5996763	-41 13.80194	174 09.86843	2607430	5996887	-41 13.73624	174 09.73844

Sidescan sonar imagery

Sidescan sonar outputs were used to depict the topography of the nearshore seabed and enable the detection of any low resolution changes in substratum texture inshore of the prospective farm site. A Tritech™ sonar 'fish' was towed at a speed of approximately 2.5 knots, and had a swathe width set to 60 m (30 m either side of the 'fish'). GPS positions were simultaneously logged with the sidescan sonar output to an onboard computer using Tritech™ software, allowing the relocation of any areas of interest for later verification. Four sidescan sonar transects were carried out (Figure 4; Table 1-5).

Table 1-5. Sidescan sonar transect start and end locations

Sidescan Sonar transect	Start				End			
	NZMG-E	NZMG-N	Latitude	Longitude	NZMG-E	NZMG-N	Latitude	Longitude
1	2607685	5997141	-41 13.59718	174 09.91849	2607375	5996304	-41 14.05161	174 09.70463
2	2607562	5997074	-41 13.63427	174 09.83112	2607320	5996324	-41 14.04120	174 09.66508
3	2607310	5997011	-41 13.67011	174 09.65138	2607302	5996306	-41 14.05105	174 09.65237
4	2607445	5996811	-41 13.77720	174 09.74990	2607272	5996079	-41 14.17391	174 09.63306

Intertidal habitats

An intertidal subtidal survey was undertaken at mid tide along the coastline inshore of the Ruaomoko 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 ADCP (Acoustic Doppler Current Profiler) meter was deployed for 40 days south of the Cage Area, in *ca.* 34 m water depth (Figure 4). Water currents (speed and direction) were characterised at 2 m depth intervals (bins) through the water column (Table 2-1).

Table 2-1. ADCP deployment details.

Particulars	**Ruaomoko**
Device:	RD Instruments ADCP
Logging depth:	Vertical profile @ 2 m intervals
Averaging interval:	5 minutes
Sampling frequency:	30 minutes
Deployment period:	16/02/11 to 28/03/11
Mooring location:	2607424.57 E 5996528.01 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 v 2.2 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 Ruaomoko, 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^{TM}, where sediment flux (in kg/m^2/yr) was overlaid with the bathymetric contours and simulated cage positions. The sediment flux categories (and keys) are standardised among outputs to facilitate comparisons.

The proposed Ruaomoko 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.

The Ruaomoko Site was also modelled in conjunction with the neighbouring proposed Kaitapeha Site. The same cage configuration (1 row of 4 cages) was used for Ruaomoko but the Kaitapeha Site was modelled based on a cage configuration of two rows of four 40 m x40 m x 20 m deep cages. The deposition was modelled at five theoretical feed loadings (at a 1:1 ratio of feed at each site), 4000, 6000, 8000, 10000, 12000 t yr^{-1}. A summary of the detailed input parameters and settings used are provided in Table 3-2.

Bathymetry data (and subsequent grid files) were obtained from a medium resolution bathymetric survey. The model used actual current data collected with an ADCP meter that was deployed south of the Cage Area. 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 3-3; also 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 flux to the seabed environment from the Ruaomoko Site

Grid Generation	
Major grid size	i=99 at 24.8 m j=99 at 31.0 m (2431 x 3034 m)
Minor grid size	i=99 at 15 m j=99 at 26 m (1485 x 2574 m)
Position on grid	i = 16, j = 9
Cage configuration	1 row of 4
Total number cages	8
Spacing between cage centres (m)	47
Cage orientation (deg T)	5°
Depth under cages (m)	30
Particle tracking	
Type of feed release	Continuous
Food loading (t yr^{-1})	2 000, 3000, 4000, 5000, 6000, 7000, 8000
Cage dimensions (m)	40 x 40 x 20 deep
Source of velocity data	RD Instruments ADCP
Current depth bins used (m)	1, 9, 17, 25, 33
Instrument sampling period (min)	5 min every 30
Time step used in model (sec)	900
Length of velocity record (hrs)	1153
Random walk model	On: Kx = 0.1, Ky = 0.1, Kz = 0.001

Table 3-2. DEPOMOD parameters and settings used to estimate flux to the seabed environment from the Ruaomoko and Kaitapeha Sites.

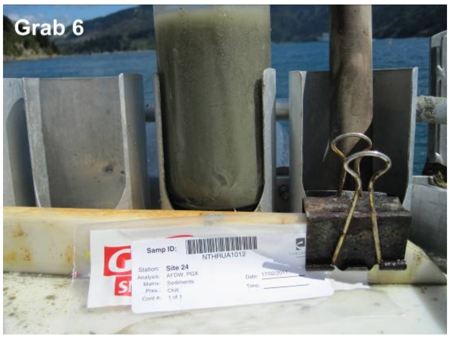
Grid Generation	
Major grid size	i=99 at 24.8 m j=99 at 31.0 m (2455 x 3069 m)
Minor grid size	i=99 at 18.0 m j=99 at 26.0 m (1782 x 2574 m)
Position on grid	i = 5, j = 14
Minor gird origin in NZMG	2606382, 5995478
Cage configuration	2 rows of 4 and 1 row of 4
Total number cages	12
Spacing between cage centres (m)	47
Cage orientation (deg T)	5° and 61°
Depth under cages (m)	30
Particle tracking	
Type of feed release	Continuous
Food loading (t yr^{-1})	2000, 4000, 6000, 8000, 10000, 12000 (total divided between two farms)
Cage dimensions (m)	40 x 40 x 20 deep
Source of velocity data	RD Instruments ADCP
Current depth bins used (m)	1, 11, 19, 29, 39
Instrument sampling period (min)	5 min every 30
Time step used in model (sec)	1800
Length of velocity record (hrs)	1725
Random walk model	On: Kx = 0.1, Ky = 0.1, Kz = 0.001

NB: The Kaitapeha current data was used for this scenario, swung 18 degrees anticlockwise, to better match the Ruaomoko currents.

Table 3-3. 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

						Station				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Hydrozoa										
Hydroida (thecate)	Feather hydroid	1				1			1	
Anthozoa										
Unidentified anthozoa	Unidentified anemone			1					1	
Edwardsia sp.	Red striped anemone				1	1				
Platyhelminthes	Flatworm									2
Nemertea	Ribbon worm	2		1		1	1	1	2	1
Nematoda	Roundworm	7		5		20	7	2	9	24
Priapula	Priapularin			1						
Sipuncula	Peanut Worm	1	1	3	1		3	2		1
Polyplacophora										
Ischnochiton maorianus	Variable chiton, active chiton						1			
Leptochiton inquinatus				2	2	1	4	3	4	13
Gastropoda										
Gastropoda (white rissoid like)	Unidentified gastropod	2								
Unidentified gastropod.	Unidentified gastropod									1
Caecum digitulum			1							1
Maoricolpus roseus roseus	Turret shell						1		1	
Micrelenchus sp.	Small top shell		1							
Notoacmea sp.	Limpet								1	
Sigapatella novaezelandiae								1		
Tanea zelandica	Moon shell									3
Turbonilla sp.					3				1	2
Zeacolpus sp.							1			
Zegalerus tenuis			2	7	2	1			3	1
Opisthobranchia										1
Bivalvia										
Modiolus areolatus	Hairy mussel								1	
Unidentified juvenile bivalve	Bivalve									6
Arthritica bifurca	Bivalve		3							
Borniola reniformis	Bivalve						2	2		3
Chlamys sp.	Fan scallop		1			2	2			1
Corbula zelandica	Bivalve	1	3				2	2		
Dosina zelandica zelandica	Bivalve			4	3					1
Dosinia greyi	Bivalve		1							
Hiatella arctica	Bivalve					1		1		
Leptomya retiaria retiaria	Bivalve			1						
Limaria orientalis	File shell					1	2		1	15
Mactra ordinaria	Bivalve								2	
Maorithyas marama	Bivalve		1	1	2			1	1	
Melliteryx parva	Bivalve				3			1		1
Nemocardium pulchellum	Purple cockle		5	7	1	16		6		8
Nucinella maoriana	Bivalve				1					
Nucula nitidula	Nut shell	6	4	1	2		10	14	6	18
Ostrea chilensis	Flat oyster, dredge oyster		1							
Pleuromeris zelandica	Bivalve						3			2
Ruditapes largillierti	Bivalve	2	1			2	6		1	1
Soletellina sp.	Sunset shell		2		4	13	2	3		1
Tawera spissa	Morning star	2	1	3	1	4	18	5	4	20
Theora lubrica	Bivalve	1	1	2			7		1	
Venericardia purpurata	Bivalve	1					4	1	11	
Oligochaeta	Oligochaete worm		3				2		1	
Polychaeta										
Ampharetidae:	Polychaete worm			4	1	1	1	3		1
Amphinomidae:	Polychaete worm		1							
Chrysopetalidae:	Polychaete worm									
Chrysopetalum sp.	Polychaete worm					1				3
Orbiniidae:	Polychaete worm									
Leitoscoloplos kerguelensis	Polychaete worm					2	2			1

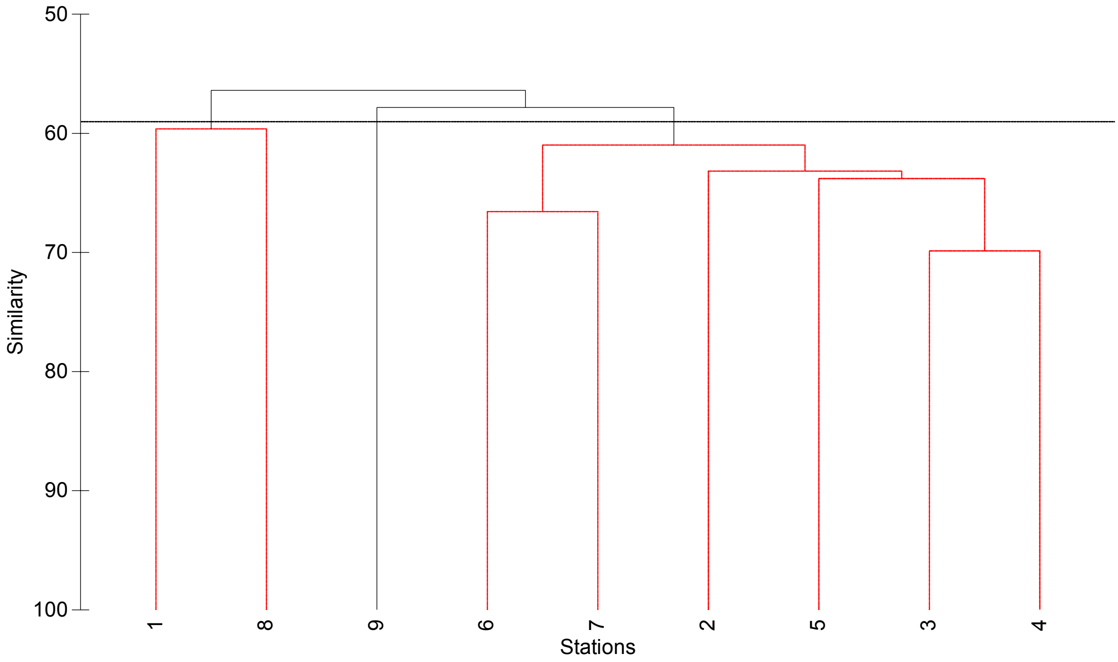
						Station				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Orbinia papillosa	Polychaete worm									1
Paraonidae:	Polychaete worm		4	2	2	6	2	4	3	5
Cossuridae:	Polychaete worm									
Cossura consimilis	Polychaete worm	1							1	
Spionidae:	Polychaete worm									
Boccardia sp.	Polychaete worm							2		
Paraprionospio pinnata	Polychaete worm			1						
Prionospio aucklandica	Polychaete worm	1								
Prionospio multicristata	Polychaete worm	5	8	5	7	7	4	13	2	4
Prionospio yuriel	Polychaete worm	1	1	4						
Spiophanes kroyeri	Polychaete worm			1	1					
Capitellidae	Polychaete worm									
Capitellethus zeylanicus	Polychaete worm									1
Heteromastus filiformis	Polychaete worm	18	61	43	56	42	28	54	40	40
Maldanidae:	Bamboo worm	3		2	1	2			1	
Opheliidae:	Polychaete worm									
Armandia maculata	Polychaete worm		1	4	2	2	6	1	5	3
Scalibregmidae:	Polychaete worm									
Scalibregma inflatum	Polychaete worm		3			1	1	1		1
Phyllodocidae:	Paddle worm	7	2	1				1	1	0
Polynoidae:	Scale worm					1				5
Hesionidae:	Polychaete worm	1	1	3		1	2		3	4
Syllidae:	Polychaete worm	3	6	10	14	7	3	2	2	16
Sphaerosyllis sp.	Polychaete worm	16	23	33	30	53	22	24	17	49
Nereidae:(juvenile)	Rag worm						1			
Glyceridae:	Polychaete worm	1	8	4	5	1	2	3	3	3
Goniadidae:	Polychaete worm									
Goniada sp.	Polychaete worm	2	2		3	4	2			1
Onuphidae:	Polychaete worm									
Onuphis aucklandensis	Polychaete worm			2						
Eunicidae:	Polychaete worm	1				1	1		1	
Lumbrineridae:	Polychaete worm	10	10	5	14	3	5	2	7	15
Dorvilleidae:	Polychaete worm	1	2	2	3	2	11	1	5	14
Cirratulidae:	Polychaete worm	5	15	15	18	16	3	8	10	2
Flabelligeridae:	Polychaete worm	1	1				1			1
Pectinariidae:	Polychaete worm									
Pectinaria australis	Polychaete worm			1	2					
Terebellidae:	Polychaete worm		2	2	1	1	1		1	3
Sabellidae:	Umbrella worm	1	14		6	12	1	3	4	
Euchone pallida	Sandy tubeworm	7	5	2	4	3	1	1	1	1
Serpulidae:	Fanworm									
Pomatoceros terraenovae	Polychaete worm						1			
Spirorbidae:	Polychaete worm						5			2
Hirudinea:	Leech									1
Crustacea										
Nebalia sp.	Crustacean									2
Cumacea	Cumacean	4	8	2	5	27	4	3		2
Tanaidacea										
Tanaid sp.	Tanaid shrimp	1	3	1	3	9	3	2	2	21
Isopoda										
Natatolana pellucida	Fish lice		3							
Sphaeromatidae	Isopod		1							
Anthuridea	Isopod	3	1	3	3		4	1	3	6
Munna schauinslandii	Isopod		3	2		2		1		1
Paramunna serrata	Isopod		2	1	1	5				
Asellota	Isopod	2		1			1			15
Amphipoda										
Aoridae	Amphipod	14	33	12	17	28	2	3	15	10
Caprellidae	Amphipod					3				
Corophiidae	Amphipod					1			1	1
Liljeborgiidae	Amphipod		2		1	1	1	1		
Lysianassidae	Amphipod	2	1		2		1		5	1

						Station				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Melitidae	Amphipod	1	3	5	2	3	4	1	6	2
Oedicerotidae	Amphipod			9						
Phoxocephalidae	Amphipod		2	2	3	3	13	6	7	8
Ampelisca sp.	Amphipod	1	1	1	2	1	4	2		
Amphipoda indeterminata	Amphipod		1						5	
Decapoda										
Munida sp.	Krill - red swimming crab						1			
Nectocarcinus antarcticus	Hairy red swimming crab						1			
Pagurus sp.	Hermit crab	1				1	6	2		
Ostracoda										
Bradleya opima	Ostracod		3		4			1		
Cymbicopia hispida	Ostracod			1		1				1
Cypridinoides concentrica	Ostracod									1
Diasterope grisea	Ostracod		1				2	1	4	1
Euphilomedes agilis	Ostracod		8		1	7	6	4	2	6
Neonesidea sp.	Ostracod			1	1	2	2	1		10
Parasterope quadrata	Ostracod	1					4	1	5	2
Ponticocythereis militaris	Ostracod									1
Scleroconcha arcuata	Ostracod	1								
Scleroconcha sculpta	Ostracod								1	
Pycnogonida										
Pycnogonidae	Sea spider						2		2	
Phoronida										
Phoronus sp.	Phoronid	7		1	1	2				
Bryozoa (encrusting)		1								
Echinoidea										
Pseudechinus albocinctus	Pink urchin					1	1		2	
Asteroidea										
Coscinasterias calamaria	Eleven arm star									1
Patiriella regularis	Cushion star									3
Ophiuroidea	Snake tail star	9	5	4	3	5	11	7	9	39
Holothuroidea										
Trochodota dendyi	Sea cucumber		2			1			8	12
Ascidiacea										
Aplidium sp.	White compound ascidian			1				1		
Eugyra brewinae	Sea squirt									1
	Taxa Abundance	**159**	**285**	**232**	**245**	**336**	**257**	**206**	**236**	**451**
	Taxa Richness	**44**	**56**	**51**	**46**	**54**	**62**	**48**	**53**	**70**

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 compositon. At a 59% similarity level, the samples resolved into three distinctive groups (Group 1: Stations 1 and 8; Group 2: Station 9; Group 3: Stations 2, 3, 4, 5, 6 and 7). The presence of the polychaete *Cossura consimilis*, the higher abundance of the bivalve *Venericardia purpurata* and the absence of several taxa, including polychaetes, bivalves and amphipods, at Stations 1 and 8 (Group 1) was the strongest determining feature separating this group from Group 3. Station 9 (Group 2) had the highest taxa abundance and richness with several taxa, including polychaetes, amphipods and bivalves, exclusively found at this station. This difference in community composition caused the separation from all the other sampling stations. The abundance and presence or absence of a variety of other invertebrates (summarised in Figure 6-1) were also influential in characterising the communities and are summarised in the figure below.



Group	Station	Key distinguishing characteristics
1	1 and 8	Community dominated by *Heteromastus filiformis*, *Sphaerosyllis* sp. and *Aoridae* sp. The polychaete *Cossura consimilis* present. Absence of the bivalves *Nemocardium pulchellum*, *Soletellina* sp. and the polychaete Ampharetidae.
2	9	High taxa richness. Community dominated by *Sphaerosyllis* sp., *Heteromastus filiformis*, Ophiuroidea, Nematoda, *Tanaid* sp. and *Tawera spissa*. Several taxa exclusively found at this station.
3	All other stations	Community dominated by *Heteromastus filiformis*, *Sphaerosyllis* sp. and Cirratulidae polychaetes. No *Cossura consimilis* polychaetes.

Figure 6-1. Dendrogram showing similarity (%) of infaunal assemblages collected from the Ruaomoko study area. The analysis was performed on the basis of Bray-Curtis similarity of the fourth-root transformed count data.

Appendix 7. Conspicuous epibiota observed in dropcam images and video footage

X = taxa present in transect

Taxa	Common name	Dropcam images	Dive transect						Video sled transect						
			1	2	3	4	5	6	1	2	3	4	5	6	7
Porifera															
Antler sponge	Antler sponge	X	X		X	X	X	X						X	X
Encrusting orange sponge	Encrusting orange sponge	X	X	X	X	X	X			X	X			X	
Encrusting yellow sponge	Encrusting yellow sponge	X	X	X	X	X	X	X		X	X	X		X	
Erect orange sponge	Erect orange sponge	X					X	X					X	X	
Erect yellow sponge	Erect yellow sponge	X													
Finger sponge	Finger sponge		X	X	X	X			X	X	X	X			
Grey vase sponge	Grey vase sponge	X	X	X	X	X	X	X		X		X	X	X	X
Hydrozoa															
Bushy tree hydroid	Bushy tree hydroid		X	X	X	X	X							X	X
Hydroida (thecate)	Feather hydroid	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tree hydroid	Tree hydroid					X		X							
Anthozoa															
Anthothoe albocincta	White striped anemone	X	X	X	X	X	X	X	X			X	X		
Cerianthus sp.	Tube anemone		X		X	X			X						
Bryozoan															
Branching bryozoan	Branching bryozoan		X	X	X	X	X								
Encrusting bryozoan	Encrusting bryozoan					X	X	X		X	X	X			
Orange bushy bryozoan	Orange bushy bryozoan	X			X										
Crustacea															
Paguroidea sp.	Hermit crab													X	
Gastropoda															
Nudibranchia	White nudibranch	X			X	X						X			
Nudibranchia	Pink/white nudibranch													X	
Bivalvia															
Atrina zelandica	Horse mussel			X		X	X								

Taxa	Common name	Dropcam images	Dive transect						Video sled transect						
			1	2	3	4	5	6	1	2	3	4	5	6	7
Modiolarca impacta	Nesting mussel					X									
Pecten novaezelandiae	Scallop		X	X					X	X				X	X
Polychaeta: Serpulidae															
Galeolaria hystrix	Tubeworm	X	X	X	X	X		X			X	X		X	X
Fanworms	Fanworms							X			X	X		X	
Echinoidea															
Evechinus chloroticus	Sea urchin (kina)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pseudechinus albocinctus	Sea urchin	X							X	X					
Asteroidea															
Coscinasterias calamaria	Eleven arm star	X		X	X	X	X	X	X	X	X	X	X	X	X
Patiriella sp.	Cushion star	X	X	X	X	X	X		X	X	X	X	X	X	X
Pentagonaster pulchellus	Biscuit star													X	
Unidentified sea star	Unidentified sea star		X	X	X				X	X					
Ophiuroidea															
Ophiopsammus maculata	Snake tail star	X		X	X	X			X	X	X	X	X	X	X
Holothuroidea															
Ocnus brevidentis	Burrowing sea cucumber	X													
Stichopus mollis	Sea cucumber			X	X	X	X	X	X	X	X	X	X	X	X
Ascidiacea															
Cnemidocarpa sp.	Sea squirt	X				X			X		X				
Oligocarpa megalorchis	Sea squirt	X	X	X				X					X		
Pyura sp.	Sea tulip			X											
Grey colonial ascidian	Grey colonial ascidian	X			X	X	X	X			X	X		X	X
Orange colonial ascidian	Orange colonial ascidian	X	X	X	X	X	X	X	X	X	X	X	X	X	X
White colonial ascidian	White colonial ascidian	X			X	X	X			X		X			
Osteichthyes															
Arripis trutta	Kahawai					X									
Caesioperca lepidoptera	Butterfly perch		X		X	X	X			X	X	X	X	X	X
Congiopodus leucopaecilus	Southern pigfish				X										
Helicolenus sp.	Sea perch									X	X			X	

Taxa	Common name	Dropcam images	Dive transect						Video sled transect						
			1	2	3	4	5	6	1	2	3	4	5	6	7
Hemerocoetes monopterygius	Opalfish										X				
Latridopsis ciliaris	Blue moki		X	X		X	X								X
Nemadactylus macropterus	Tarakihi		X		X	X						X	X		X
Notolabrus celidotus	Spotty		X	X	X	X	X			X	X	X	X		
Notolabrus fucicola	Banded wrasse		X			X									
Parapercis colias	Blue cod	X	X	X	X	X	X	X		X	X	X	X	X	X
Parika scaber	Leatherjacket										X	X	X		X
Pseudolabrus miles	Scarlet wrasse		X			X						X	X	X	X
Pseudophycis bachus	Red cod					X									
Tripterygiidae sp.	Unidentified triplefin		X	X	X	X	X	X							
Unidentified fish	Unidentified fish		X	X	X	X	X	X	X	X	X	X	X	X	X
ALGAE															
Chlorophyta															
Ulva sp.	Sea lettuce	X		X	X	X									
Phaeophyta															
Carpophyllum flexuosum	Flapjack			X		X									
Macrocystis pyrifera	Bladder kelp		X	X	X	X									
Undaria pinnatifida	Wakame					X	X	X							
Rhodophyta															
Corallina (encrusting pink)	Paint	X	X	X	X	X	X	X	X	X	X	X	X	X	
Corallina (turfing pink)	Turf		X	X	X	X	X	X		X	X	X	X	X	
Red filamentous	Red alga			X	X	X									
Red foliose	Red alga	X	X	X	X										

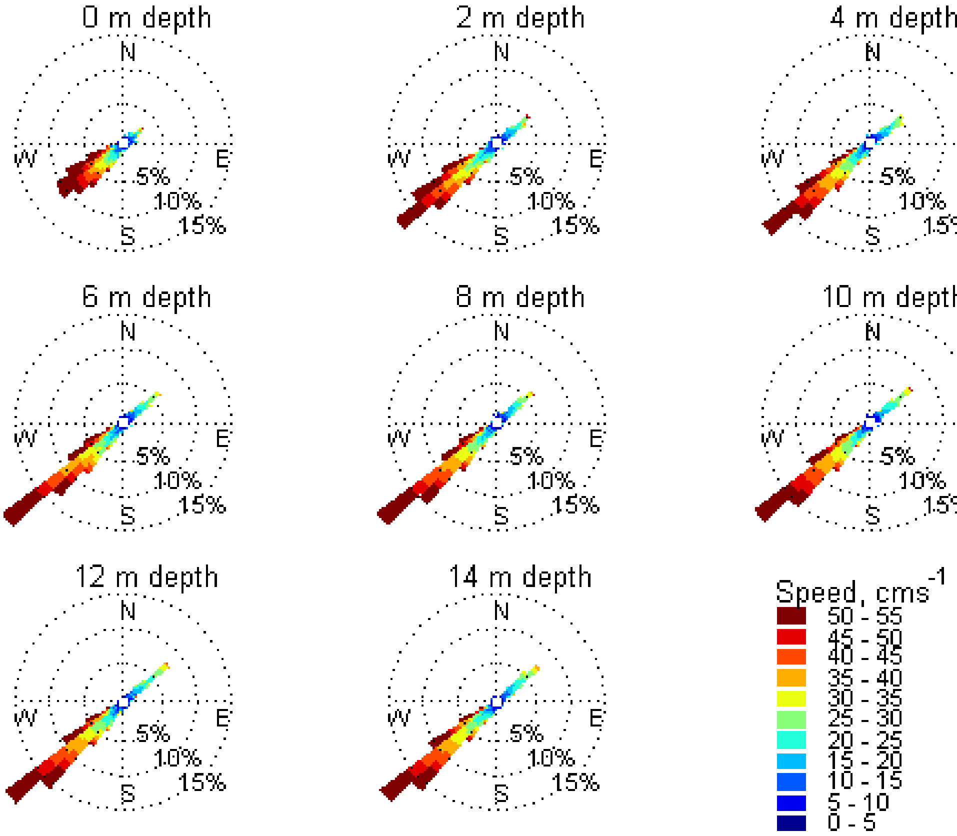
Appendix 8. Relative abundance and tidal height distribution of conspicuous intertidal epibiota observed during the intertidal survey

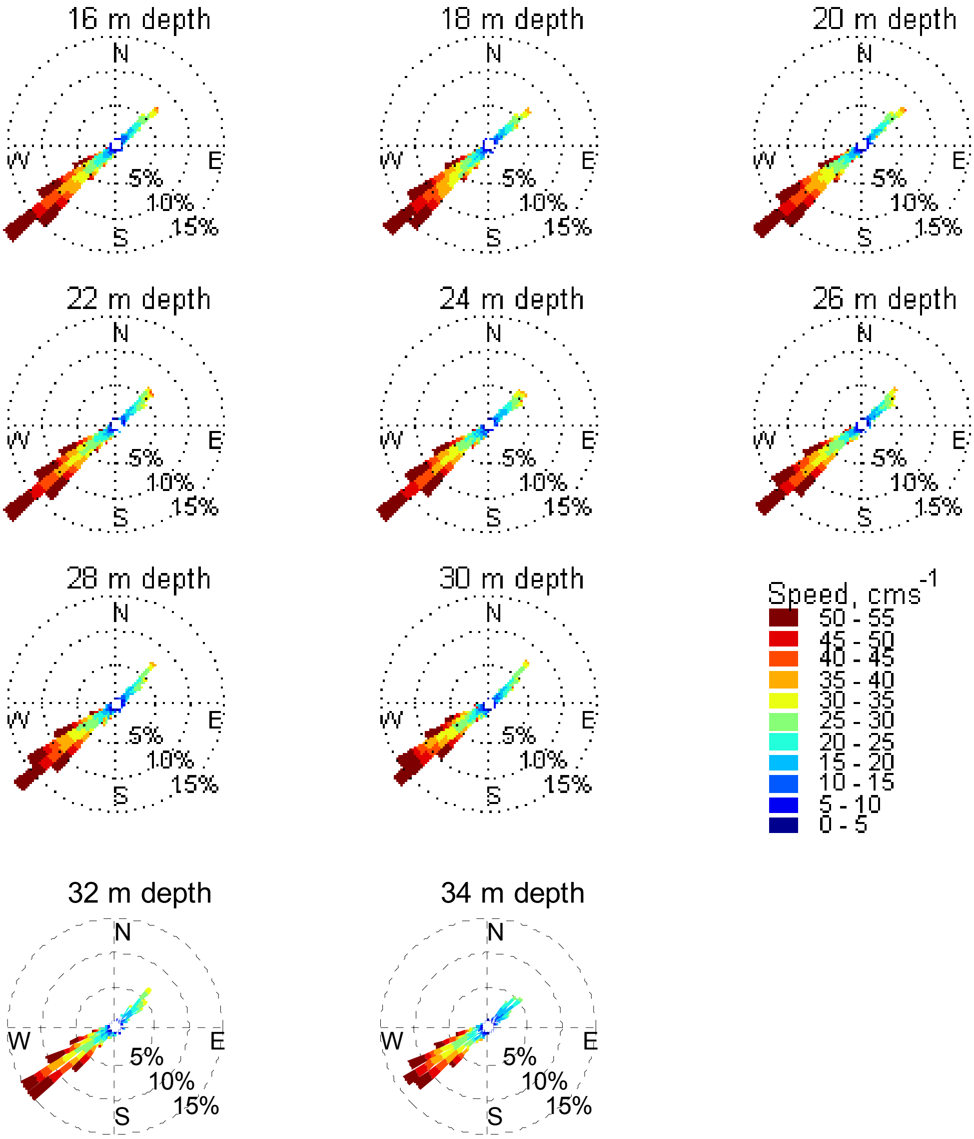
Tidal height code: H = high shore, M = mid shore, L = low shore, S = subtidal.
Relative abundance code: A = abundant, C = common, O = occasional, R = rare.

Taxa	Common Name	Tidal zone	Relative abundance
Anothoza			
Actina tenebrosa	Waratah anemone	M	C
Anthopleura aureoradiata	Mud flat anemone	M	O
Oulactis mucosa	Common anemone	M	C
Bivalvia			
Aulacomya atra maoriana	Ribbed mussel	L	O
Mytilus galloprovincialis	Blue mussel	L-M	C-A
Perna canaliculus	Green-lipped Mussel	L	O
Cirripedia			
Chamaesipho sp.	Brown and column barnacles	L-M	C
Epopella plicata	Plicate barnacle	M	O
Decapoda			
Heterozius rotundifrons	Big-handed crab	M	O
Petrolisthes novaezelandiae	Red false crab	L-M	C
Gastropoda			
Atalacmea fragilis	Fragile limpet	M	R
Austrolittorina antipodum	Banded periwinkle	H	C
Austrolittorina cincta	Brown periwinkle	H	C
Cellana ornata	Ornate limpet, Ngakihi	M	C
Cellana radians	Radiate limpet	L	C
Cominella maculosa	Spotted whelk	L	O
Diloma bicanaliculata	Knobbed top shell	M-L	C
Diloma sp.	Top shell	M	C
Haustrum haustorium	Brown whelk	M	O
Haustrum scobina	Oyster borer	M	C
Melagraphia aethiops	Spotted top shell	M	C
Notoacmea sp.	Limpet	H	R
Siphonaria sp.	Siphonated limpet	M	O
Turbo smaragdus	Cat's eye, Ataata	L-M	O
Polychaeta			
Serpulidae sp.	Fan worms	M	C
Polyplacophora			
Sypharochiton pelliserpentis	Snakeskin chiton	L-M	C
ALGAE			
Chlorophyta			
Ulva sp.	Sea lettuce	M	O
Phaeophyta			
Carpophyllum flexuosum	Flapjack	S	C-A
Cystophora scalaris	Brown alga	S	C-A
Hormosira banksii	Neptune’s necklace	L	R

Taxa	Common Name	Tidal zone	Relative abundance
Macrocystis pyrifera	Bladder kelp	S	A
Scytothamnus australis	Brown alga	M	O
Splachnidium rugosum	Dead man's fingers	S	O
Rhodophyta			
Porphyra sp.	Red alga	M	O

Appendix 9. Flow charts of current speed (cm s^{-1}) and direction (true) at the ADCP deployment site at Ruaomoko, Queen Charlotte Sound

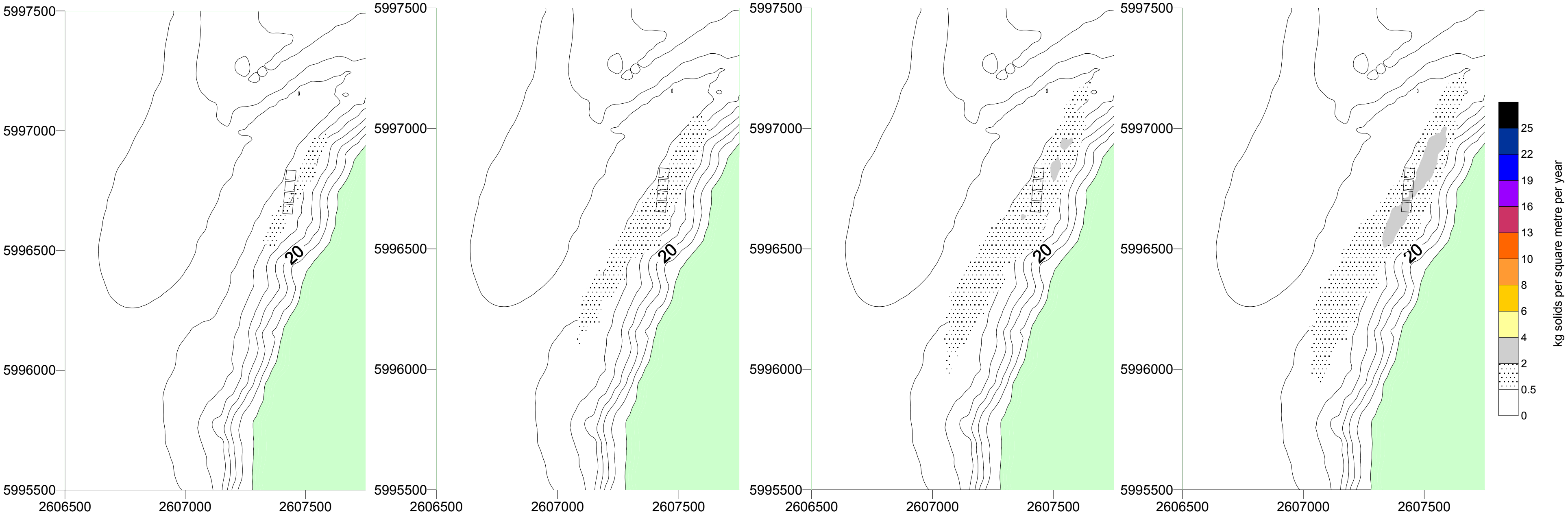


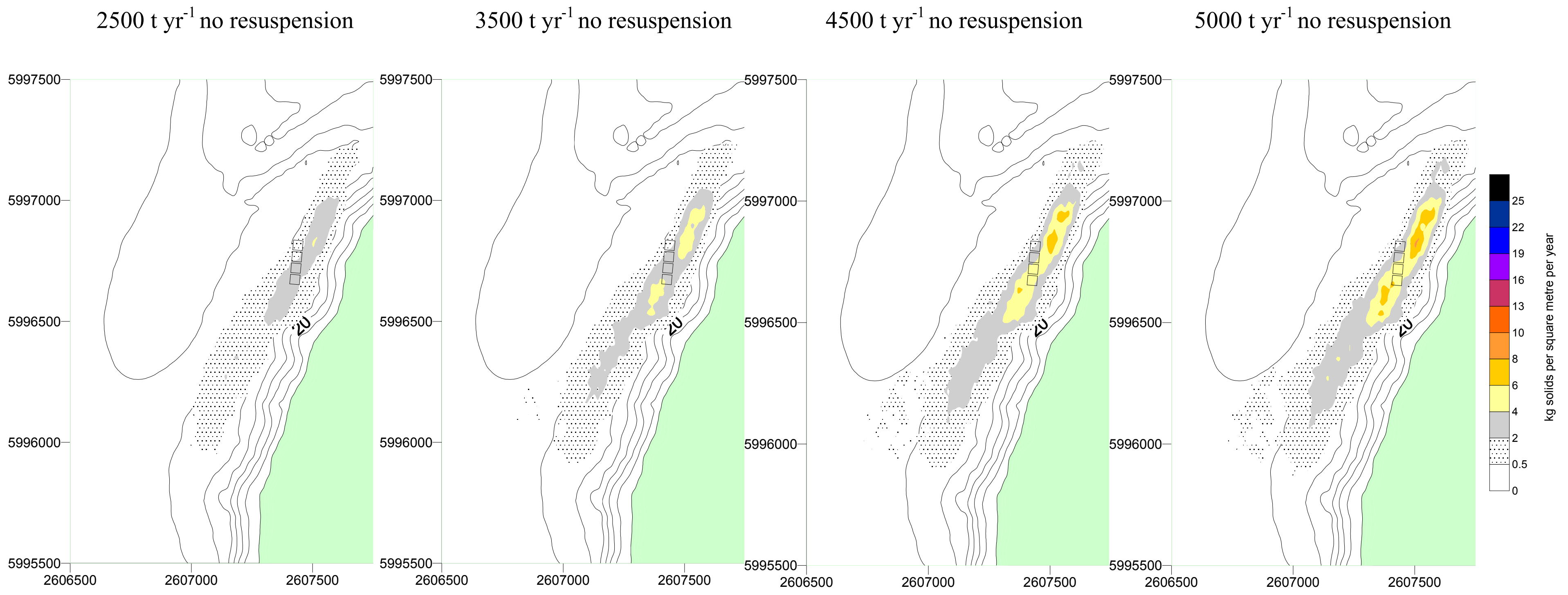

16 m depth
18 m depth
20 m depth
22 m depth
24 m depth
26 m depth
28 m depth
30 m depth
32 m depth
34 m depth
N
E
S
W
5%
10%
15%
Speed, cms^{-1}
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5

Appendix 10. Predicted depositional footprints for ten different feed usage levels at the Ruaomoko Site and five different feed usage levels at the combined Kaitapeha and Ruaomoko Sites under ‘no-resuspension’ scenarios

Ruaomoko predicted depositional footprints

500 t yr^{-1} no resuspension | 1000 t yr^{-1} no resuspension | 1500 t yr^{-1} no resuspension | 2000 t yr^{-1} no resuspension



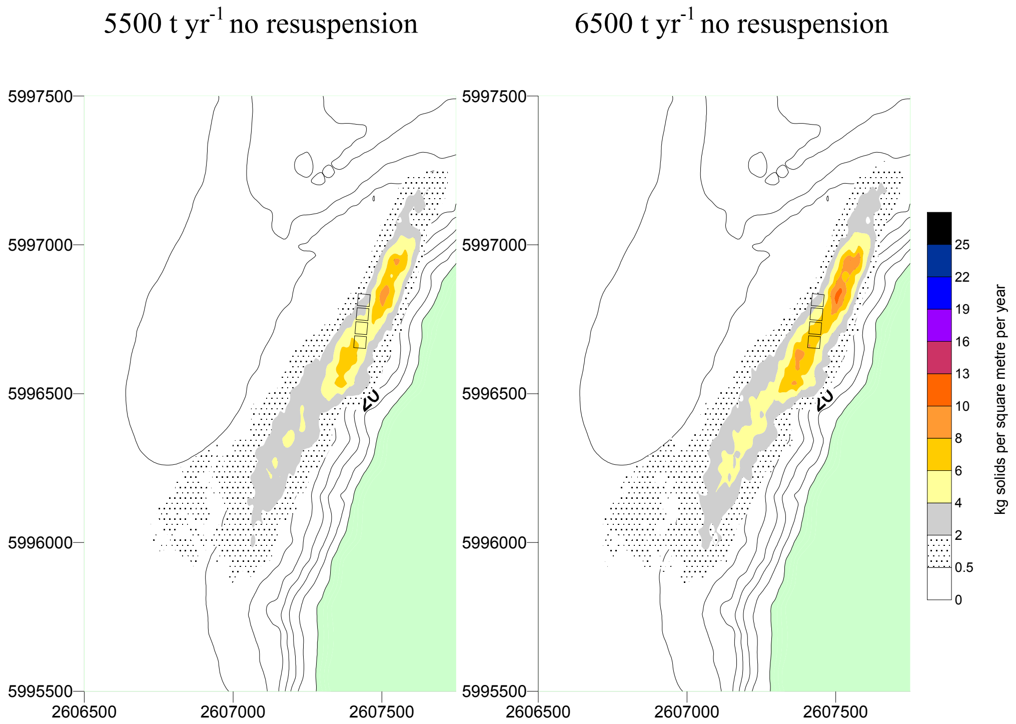


2500 t yr^{-1} no resuspension

3500 t yr^{-1} no resuspension

4500 t yr^{-1} no resuspension

5000 t yr^{-1} no resuspension



Note: 3000, 4000 and 6000 t yr^{-1} no-resuspension scenarios are shown in main body of report

Ruaomoko and Kaitapeha combined depositional footprints