CAWTHRON

Report No. 1987
August 2011

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

RESEARCH BASED SOLUTIONS

CAWTHRON

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

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Issue date: 12 August 2011

Recommended citation:
Atalah J, Taylor D, Keeley N, Goodwin E, Forrest R, Dunmore R 2011. Assessment of Effects of Farming Salmon at Tapipi, Pelorus Sound: Deposition and Benthic Effects. Prepared for The New Zealand King Salmon Company Limited. Cawthron Report No. 1987. 47 p.

EXECUTIVE SUMMARY

Overview of purpose and scope

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

Proposal

The Tapipi application is a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. The site would be used for farming salmon fed at an initial feed level rate of 3000 tonnes per annum (t yr^{-1}). NZ King Salmon have applied for an option to increase the feed discharge at 1000 t yr^{-1} increments if it is considered environmentally appropriate up to a maximum of 5000 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 Tapipi Site were characterised using a range of remote and diver operated sampling techniques; including depth profiling, sediment grab sampling and video transects. The intertidal region of the shoreline was also surveyed. Water currents were characterised using an ADCP (Acoustic Doppler Current Profiler) current meter and these data were then used to predict depositional patterns.

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

Summary of findings

The Tapipi Site is located in 50 to 60 m water depth in a region of high velocity water currents. The seabed immediately beneath the proposed site was dominated by soft sediments, which are well represented in the Marlborough Sounds region. Infauna and epibiota communities were generally considered representative of current-swept locations in Central and Outer Pelorus Sound. Infaunal communities within the study area were species-rich (a total of 110 different taxa) and were numerically dominated by various species of polychaetes, nematodes, cumaceans, isopods, amphipods and ostracods. Few epibiota were present on the soft sediments, with the exception of the occasional tubeworm mound, sea cucumber, snake tail star and scallop. Cobble and boulder habitats are located well inshore of the site and were characterised by a relatively diverse community of invertebrates, seaweed and fish. Sand content around the cobbles increased with water depth, and some ecologically important species were found; including several species of sponges, burrowing anemones, tubeworms and horse mussels. The intertidal region of the coastline inshore of the Tapipi Site was characteristic of the wider Pelorus and Marlborough Sounds.

The site is situated on the eastern side of Waitata Reach and is in close proximity to the larger water bodies of the Cook Strait and the Tasman Sea. The average current velocity at the Tapipi Site was *ca.* 16 cm s^{-1}, with maximum velocities of 40 to 50 cm s^{-1} recorded throughout the water column. Currents flowed predominantly to the northeast (out of the Sound) and ran parallel to the coastline. Depositional modelling indicated that dispersal of the footprint through resuspension will be considerable due to the high water current velocities. Under a no-resuspension scenario, the maximum predicted depositional flux ranged from 6 to 10 kg m^{-2} yr^{-1} when 3000 and 5000 t yr^{-1} feed loading scenarios were modelled, respectively, with the majority of flux directly beneath the 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. 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 Tapipi, resuspension is predicted to prevent excessive accumulation of organic biodeposits beneath the farm. This is clearly demonstrated by the fact that when resuspension is modelled, we predict little or no net flux to the seabed. However, while the accumulation of organic material within the sediments is likely to be minimal at high-flow sites, sediment chemistry and composition will be significantly altered (*i.e.* sulphide levels elevated, redox levels reduced).

Directly beneath the farm cages (ca. 0 to 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 21 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 on-going monitoring.

The recommended initial feed level (RIFL) of 3000 t yr^{-1} is considered an appropriate starting point for this site; although modelling suggests that adverse environmental effects are unlikely if feed usage is increased to the predicted sustainable feed level (PSFL) of 4000 t yr^{-1}. The maximum conceivable feed level (MCFL) for the Tapipi Site was estimated to be 5000 t yr^{-1}. Any increases from the RIFL should be undertaken in 1000 t yr^{-1} increments based on favourable environmental monitoring results. If initial feed levels prove to be too high, permitted feed levels should be adjusted accordingly.

Environmental monitoring

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

Conclusions

The Tapipi Site is situated in a relatively high-flow area where wastes will largely be dispersed and assimilated by the environment. The site bathymetry is suited to cage farming and the site has limited propensity for adverse biological effects due to the considerable distance to any notable ecological habitats.

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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 off Tapipi Point along Waitata Reach, Pelorus Sound (Figure 1); hereafter referred to as the 'Tapipi Plan Change Site' or 'Tapipi Site'. 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 (Keeley & Taylor 2011) that accompanies the NZ King Salmon application.

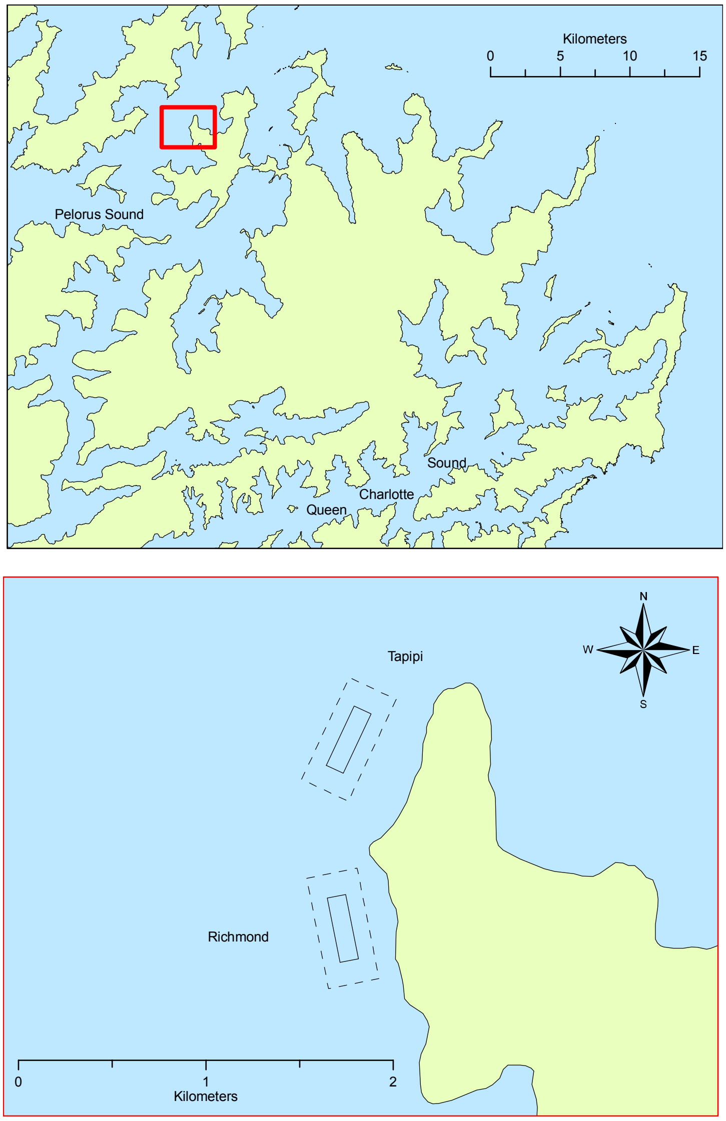

Figure 1. Location of the study area off Tapipi Point, with an expanded map of the proposed Tapipi Site. The dashed black rectangle indicates the Plan Change Site and the solid black rectangle indicates the proposed Cage Area Boundary (a 3.5 ha area within which 1.5 ha of cage structures will be placed). One of the other proposed sites, the Richmond Site, is shown to the south (see Atalah *et al.* 2011).

1.2. Description of proposed activities at the Tapipi Site

NZ King Salmon seeks approval for a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. They also seek approval for the use of an initial maximum of 3000 tonnes of feed per annum (t yr^{-1}) with the option to increase the feed discharge at 1000 t yr^{-1} increments if it is considered environmentally appropriate to a maximum of 5000 t yr^{-1}. Fish would be on-grown in large sea cages (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 Richmond, south of the proposed Tapipi Site (Figure 1).

1.3. Potential environmental issues and scope of this report

The selection of the Tapipi Site is the culmination of an extensive site selection process undertaken as part of 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 existing physical (*e.g.* water currents) and ecological characteristics of the aquatic environment at the Tapipi Site and the wider Pelorus Sound.

- The likely effects of the installation of farm structures on the benthic environment.
- The likely effects of farm wastes on the seabed; including habitats inshore of the Tapipi Site.
- A recommended approach to managing the magnitude and spatial extent of seabed impacts.

1.4. Structure of this report

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

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

2. EXISTING KNOWLEDGE OF MARINE ENVIRONMENTS IN THE STUDY AREA

2.1. Outer Pelorus Sound and Waitata Reach marine environments

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

Waitata Reach is located in the Outer Pelorus Sound north of Maud Island, bordering Tawhitinui Reach in the southwest and connecting with the Cook Strait in the northeast. The Reach is approximately 12 km long and 2 to 4 km wide and water depths are generally 45 to 60 m, but achieves greater than 80 m in the Outer Reach. Waitata Reach contains several medium-to-large bays; including Waitata Bay, Port Ligar and Forsyth Bay. The dominant deep subtidal habitat in Waitata Reach is soft sediment, and the coastline is characterised by narrow rocky reefs, boulders and cobbles. Soft sediment areas support epibiota such as echinoderms (*e.g.* sea stars, snake tail stars, cushion stars), hydroid trees, bryozoan corals, tunicates (*e.g.* saddle squirts) and bivalves (*e.g.* mussels, horse mussels, scallops) (Roberts & Asher 1993; Forrest 1995; Forrest & Roberts 1995; Davidson 2001). A wide range of biota have been observed on hard substrata; including numerous species of macroalgae (*e.g.* *Carpophyllum* sp., *Undaria pinnatifida*, *Caulerpa* sp., *Cystophora* sp., *Codium* sp.), sponges, hydroids, ascidians, echinoderms (*e.g.* kina, sea stars, snake tail stars, cushion stars), crustaceans, molluscs (*e.g.* mussels, limpets) and various fish species (*e.g.* triplefins, blue cod, spotties, butterfly perch) (Roberts & Asher 1993; Forrest 1995; Forrest & Roberts 1995; Davidson 2001). No known sites with high ecological value have been documented within the vicinity of the present study area (Davidson *et al.* in press.).

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

2.2. The Tapipi Site study area

The proposed Tapipi Site is a 16.5 ha area situated on the eastern side of the Waitata Reach, north of Tapipi Point (Figure 1). Ketu and Richmond Bays are to the north and south of the site, respectively. The site is somewhat exposed to the prevailing northwest winds in the outer Sounds, but exposed to some attenuated sea-swell action that enters the outer Sounds from the Cook Strait (Roberts & Asher 1993).

3. SEABED CHARACTERISTICS

3.1. Site bathymetry

Water depths at the Tapipi Site ranged from a 50 to 55 m along the inshore boundary, to 60 m along the seaward boundary (Figure 2). Inshore of the site, in depths of up to 40 m, the seabed was steeply sloping, but the gradient progressively lessened with increasing depth. At approximately 60 m depth the seabed was relatively flat (Figure 2).

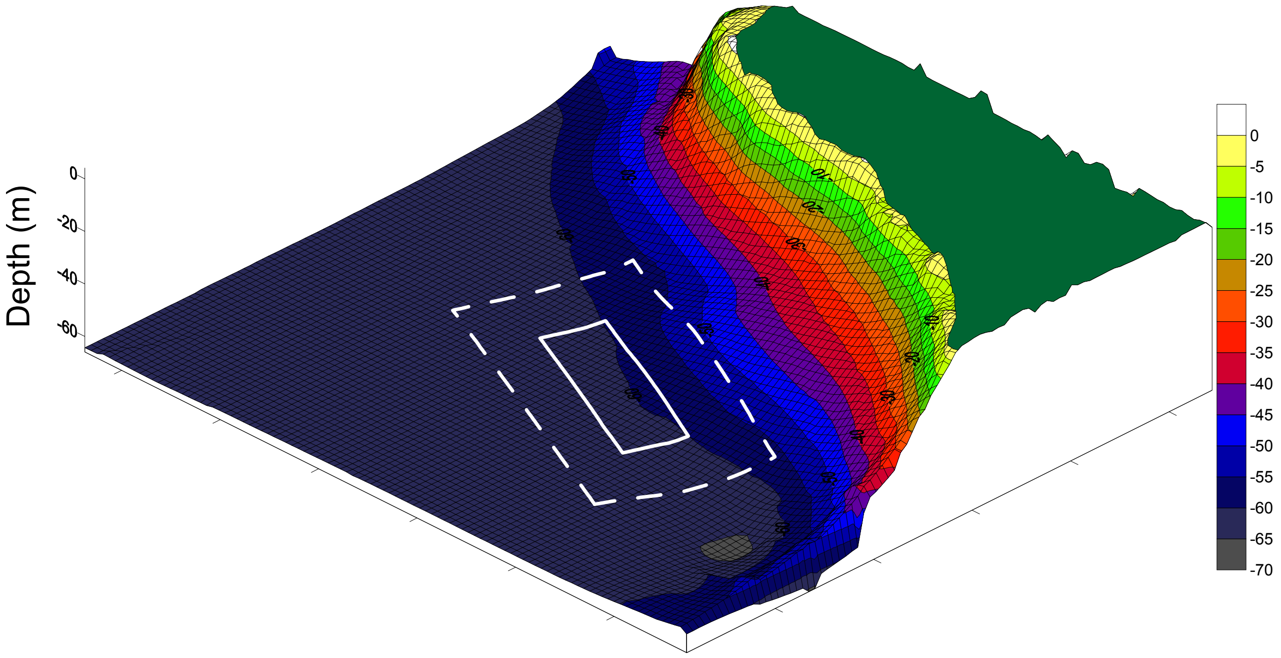

Figure 2. 3-D bathymetry map of the Tapipi Site with proposed locations of the Cage Area Boundary (solid white line) and Plan Change Site Boundary (dashed white line) overlaid onto the seafloor.

3.2. Sediment physical and chemical properties

The dominant substrate beneath the Tapipi Site was mud (Figure 3). On average, sediments from the study area contained 47% silt and clay (<63 µm), 37% sand (2 mm and >63 µm) and 16% gravel (>2 mm). Sediments sampled from the shallower stations (Stations 1, 4 and 7) had higher sand and gravel content compared to deeper stations, which had higher content in the silt and clay fraction. These results are consistent with observations made from video footage and drop-camera images (see Section 3.4). Sediments were well oxygenated, with no evidence of an apparent Redox Potential Discontinuity (aRPD) layer, and were characterised by a fairly uniform light grey/brown colour (Appendix 4). Sediment organic content was similar between sampling stations (average of 4.1% AFDW, SE of 0.2%), with levels suggesting a productive benthic environment (Figure 3).

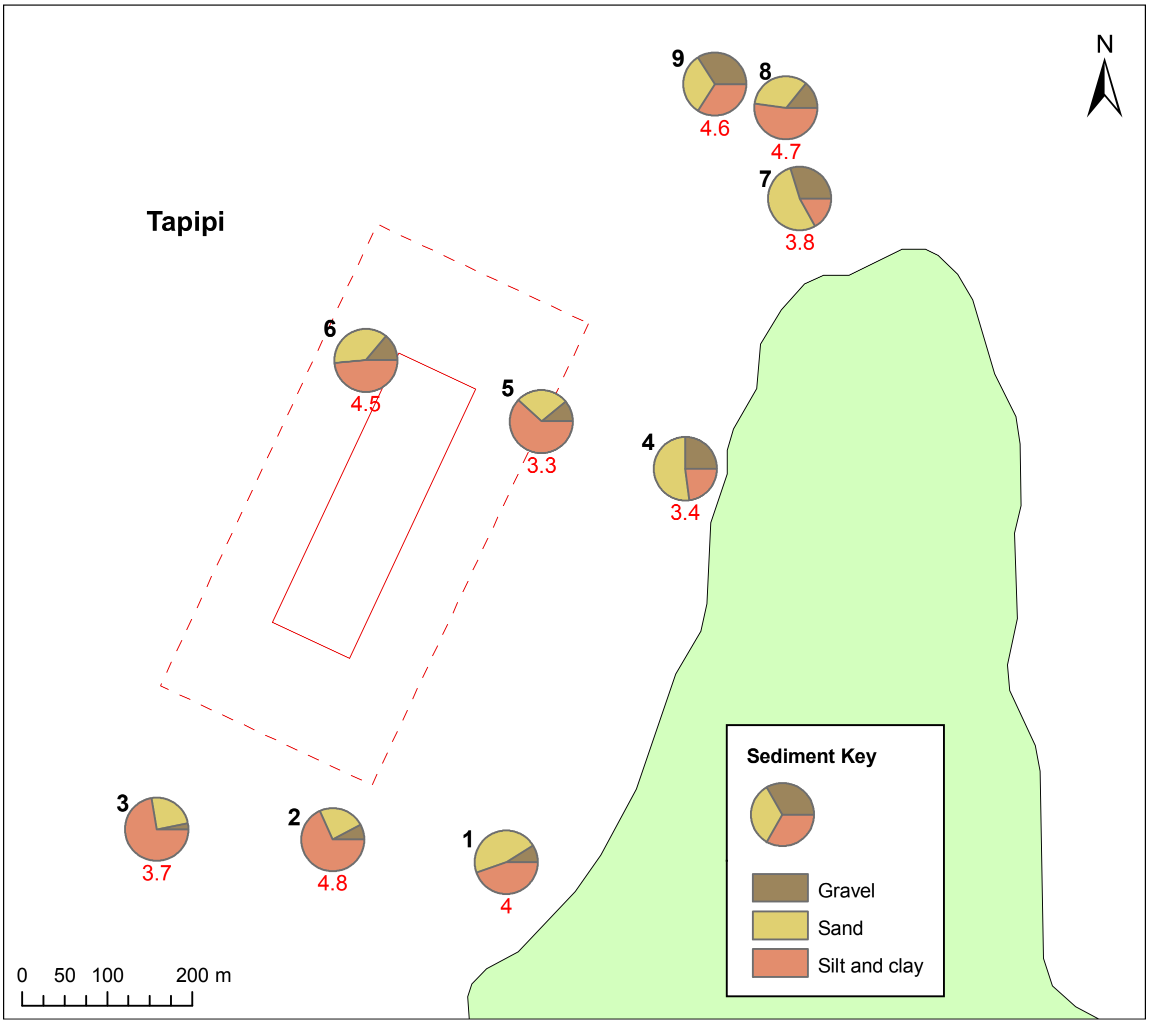

Figure 3. Grain size composition (% wet weight) and organic content (in red: %AFDW) of sediments collected from the Tapipi Site. Black numbers indicate sampling stations, the red box indicates the proposed Cage Area Boundary and the red dashed line indicates the Plan Change Site.

3.3. Sediment biological properties

Sediments sampled beneath and adjacent to the Tapipi Site contained infaunal communities that were representative of those commonly found under moderate-to-high-flow areas throughout the Marlborough Sounds region, and are therefore considered indicative of natural conditions. The site was characterised by high taxa richness (a total of 110 taxa recorded), ranging between 29 and 54 taxa per core (Table 1). Refer to Appendix 5 for the complete species list. Infaunal abundance ranged between 116 and 305 individuals per core. Numerically dominant taxa included various species of polychaetes, nematodes, cumaceans, isopod, amphipods and ostracods (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.

Table 1. Average and relative abundances of the 15 most commonly occurring infaunal taxa collected from sediments within and adjacent to the Tapipi Site.

		Grab station										
Taxa	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Average Abund.**	**Relative Abund (%)**
Prionospio multicristata	Polychaete	12	64	8	4	11	47	16	13	8	20	11
Paraonidae	Polychaete	13	50	23	2	35	32	1	15	9	20	11
Sphaerosyllis sp.	Polychaete	12	35	5	10	12	13	26	41	16	19	10
Cirratulidae	Polychaete	7	16	11	2	11	19	2	16	2	10	5
Heteromastus filiformis	Polychaete	8	2	1	4	4	31	2	21	10	9	5
Nematoda	Nematode	6	12	2	15	4	16	13	7	3	9	5
Lumbrineridae	Polychaete	2	7	8	7	5	4	4	9	10	6	3
Cumacea	Cumacean	1	14	4	1	9	0	13	0	1	5	3
Terebellidae	Polychaete	2	0	2	2	1	2	24	3	2	4	2
Asellota	Isopod	8	19	5	0	5	0	1	0	0	4	2
Maldanidae	Polychaete	5	8	4	8	6	0	3	1	1	4	2
Neanthes cricognatha	Polychaete	0	0	0	0	0	0	1	15	13	3	2
Aoridae	Amphipod	4	1	0	8	1	1	5	7	2	3	2
Euphilomedes agilis	Ostracod	3	4	1	4	1	0	6	4	5	3	2
Armandia maculata	Polychaete	5	6	3	0	1	3	0	4	2	3	1
Total abundance		**140**	**305**	**116**	**122**	**148**	**206**	**215**	**225**	**146**		
Total richness		**45**	**54**	**32**	**38**	**36**	**29**	**49**	**36**	**40**		

3.4. Subtidal habitats and conspicuous epibiota

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

Habitats in the vicinity of the proposed farm are represented diagrammatically in Figure 7. Shallow areas inshore of the Tapipi Site were characterised by a fringe of boulders and cobbles mixed with sand habitats. With greater depth and distance from shore, sand and shell habitats increased, eventually grading to mud and silt mixed with shells in deeper parts of the study area, including beneath the Cage Area Boundary (Figure 7). No reef habitats were found in the immediate vicinity of the Tapipi Site.

The combination of hard substrates and strong currents act to produce a diverse biota inhabiting the shallow rocky habitats (*i.e.* boulders and cobbles). These habitats supported a range of macroalgae (encrusting coralline algae, red filamentous, sea lettuce, *Carpophyllum* sp.), hydroids, white striped anemones, vase sponges, kina, cushion stars, snake tail stars and various fish species (*e.g.* blue cod, spotty, triplefins). Sand content around the cobbles increased with depth and scallops, hydroids, snake tail stars, 11-arm sea stars, tubeworms, orange finger sponges, sea cucumbers and red filamentous algae were present in this habitat. Silt, sand and shell habitats were characterised by the presence of tubeworm mounds, bryozoans, diatoms mats, hydroids, grey sponges, anemones, 11-arm sea stars and snake tail stars.

Sandy-mud substrates containing shells material observed directly beneath the Tapipi Site had a few epibiota present in low abundance. The inshore edge of the farm had a seabed dominated by soft sediments interspersed with shell material. Turret shells were abundant and sea cucumbers, snake tail stars and 11-arm sea stars were common. Hydroids, ascidians and sponges were occasionally observed. Further offshore, the substrate was muddier, with tube holes present but few epibiota observed. Sea cucumbers, 11-arm sea stars, scallops, ascidians, sponges and bryozoans were less common in muddy areas. Overall, habitats and epibiota resembled those previously described for the area by Davidson (2001).

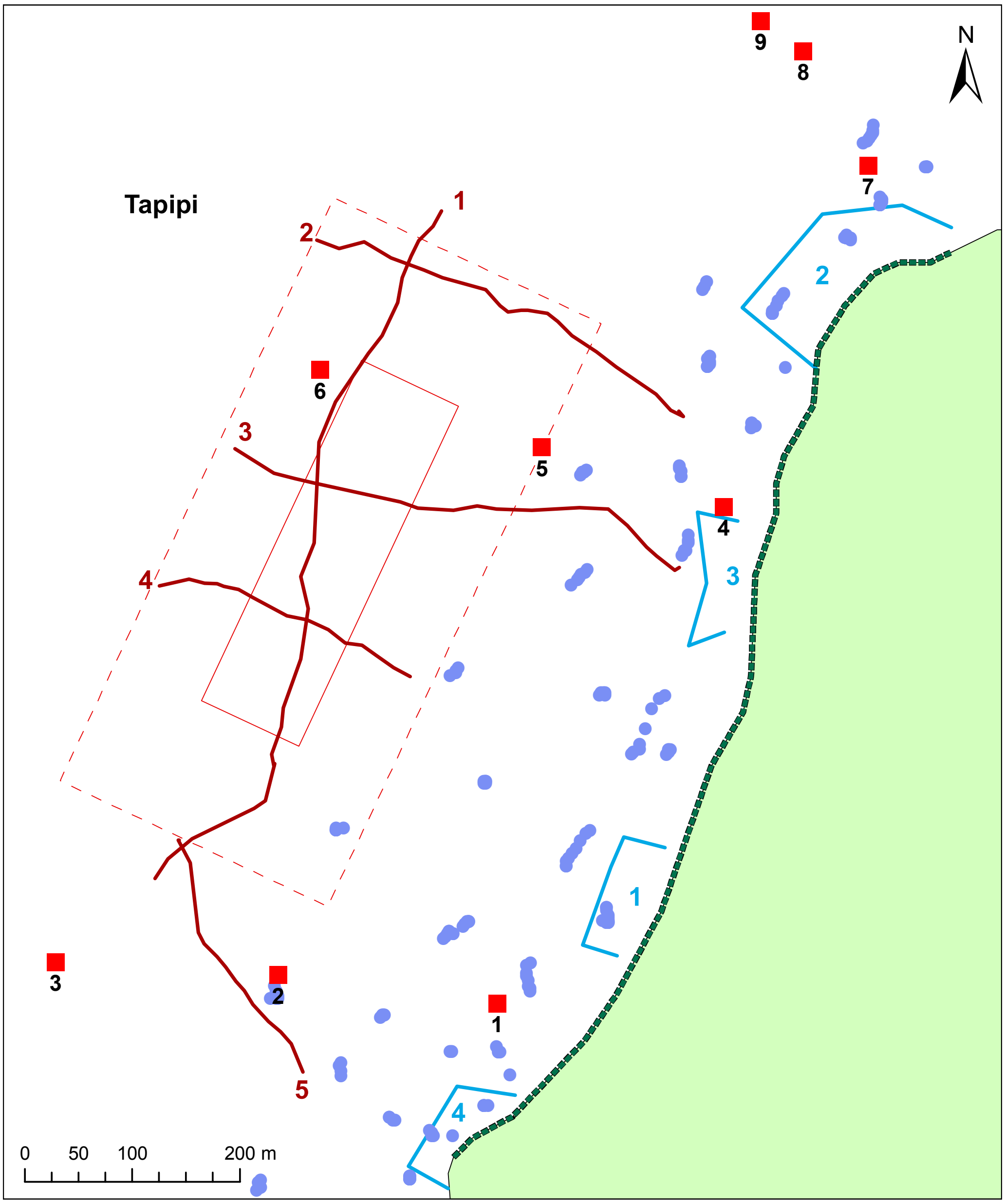

Figure 4. Sampling locations beneath and adjacent to the Tapipi Plan Change Site: sediment grab (red squares) and drop-camera stations (purple circles), dive (blue lines) and video sled transects (brown lines), and the intertidal survey transect (green dashed line) are shown.

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

Seabed habitat	**Conspicuous epibiota**
Cobble and sand	Tubeworms mounds, ascidians (saddle squirts, encrusting ascidians), kina (*Evechinus chloroticus*), 11-arm sea stars (*Coscinasterias calamaria*), cushion stars (*Patiriella* sp.), snake tail stars (*Ophiopsammus maculata*), calcareous tubeworms (*Galeolaria hystrix*), hydroids, barnacles, sea lettuce (*Ulva* sp.), flap jack (*Carpophyllum flexuosum*), red algae, coralline algae, vase sponge (*Ancorina alata*), white striped anemones (*Actinothoe albocincta*), various reef fish; including triplefin (Tripterygiidae), blue cod (*Parapercis colias*) and spotties (*Notolabrus celidotus*).
Sand and Shell	Small hydroids, sea stars, cushion stars, snake tail stars, red algae, turret shells (*Maoricolpus roseus*), sea cucumbers (*Stichopus mollis*), scallops (*Pecten novaezelandiae*) and horse mussels.
Mud and shell	Small hydroids, echinoderms (11-arm sea stars, cushion stars, snake tail stars), red algae, scallops, turret shells, sea cucumbers, tubeworm mounds.

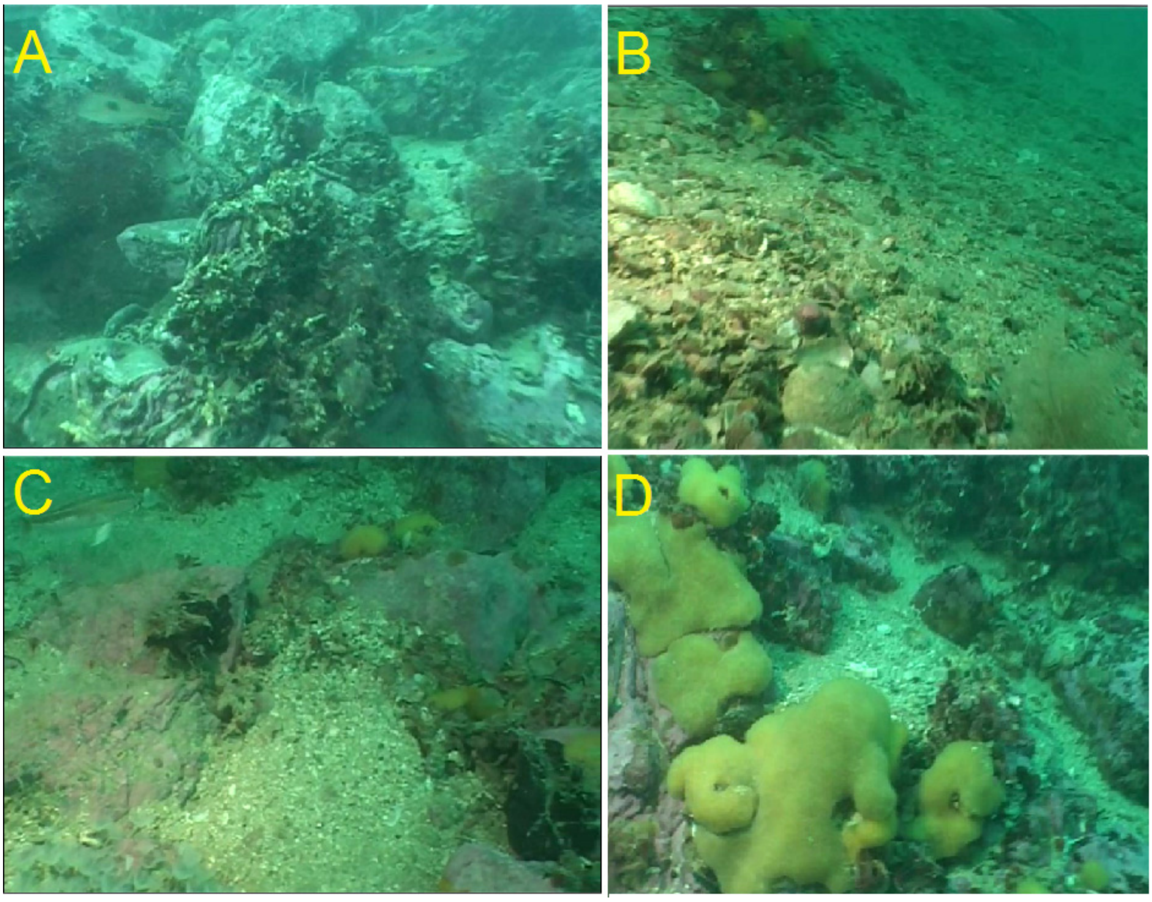

Figure 5. Images obtained from video footage showing different habitat types: (A) cobbles and sand, (B) shallow pebble and sand with hydroids, (C&D) boulders and sand with a compound ascidian.

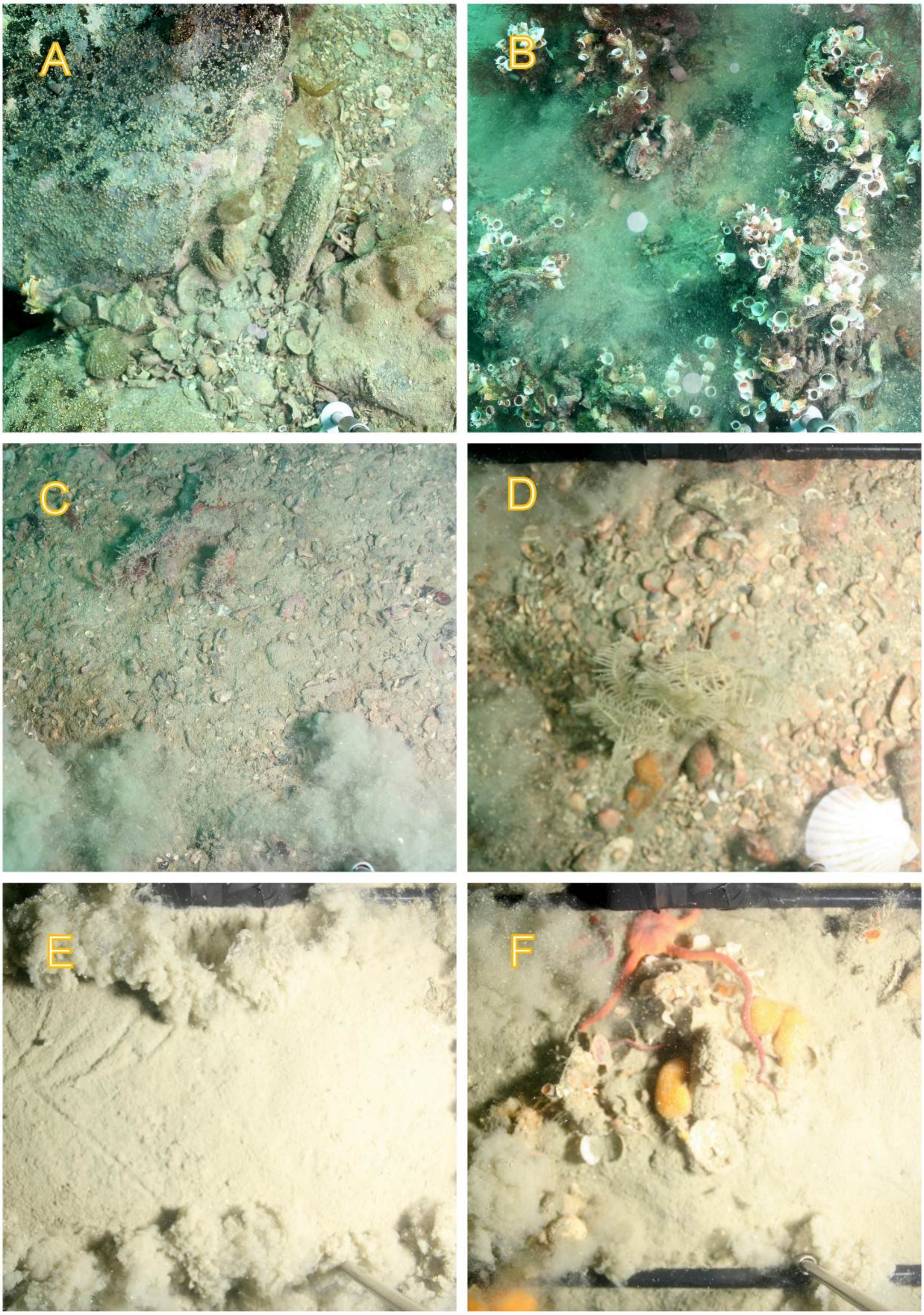

Figure 6. Examples of drop-camera images: (A & B) cobbles and sand habitat, (C) pebbles and sand, (D) shell and sand, and (E) mud and (F) mud with shell.

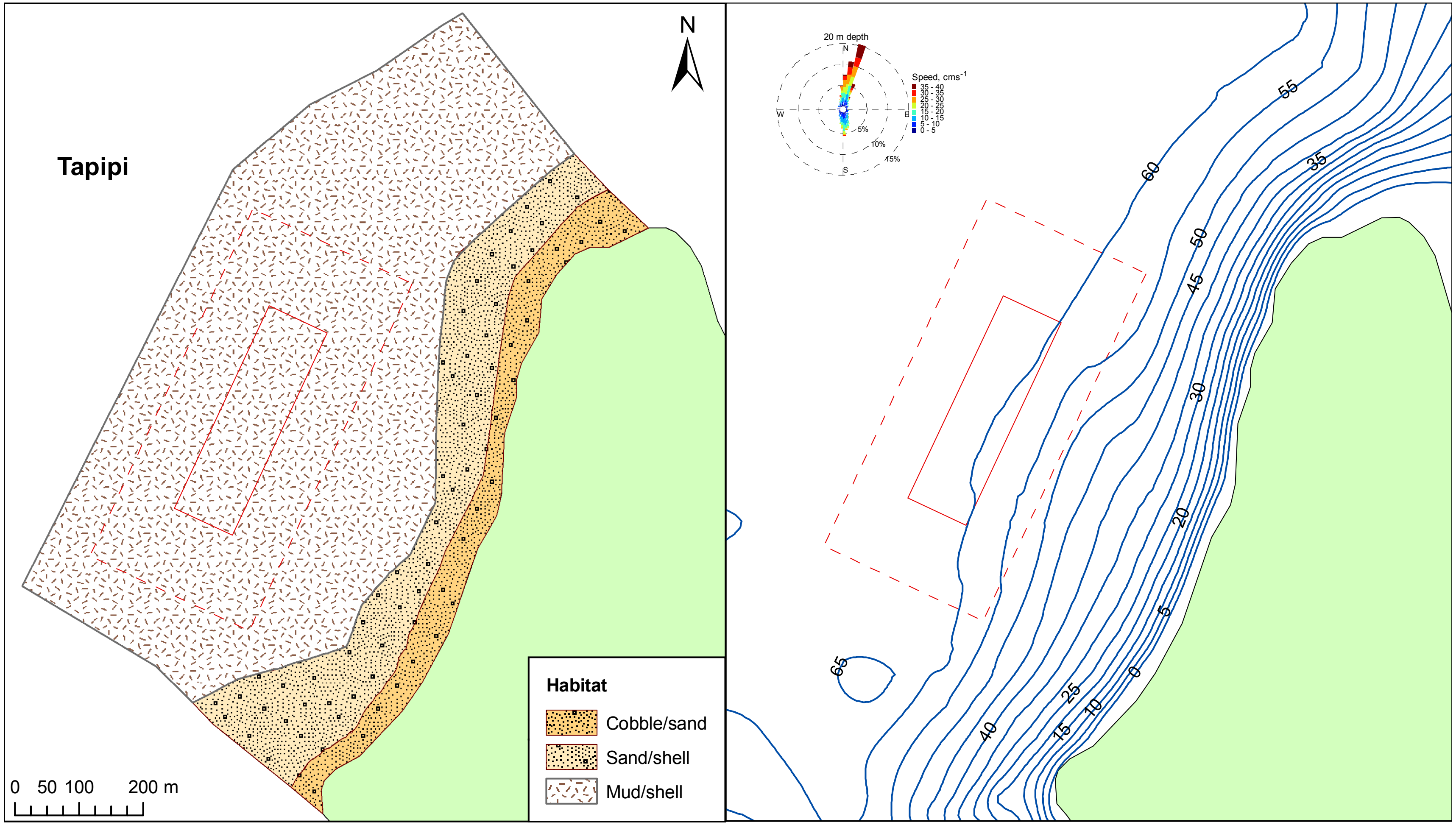

Figure 7. Left panel: Map of seabed habitats observed beneath and adjacent to the Tapipi Plan Change Site. Right panel: Bathymetric contour lines at the Tapipi Site with the 20 m depth current rose inset. The solid red rectangle indicates the proposed Cage Area Boundary and the red dashed line indicates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

3.5. Intertidal habitats

The intertidal region of the coastline inshore of the Tapipi Site was characteristic of the wider Pelorus and Marlborough Sounds (Figure 8). The upper and mid shore was dominated by barnacles, with the small periwinkles common but patchy in its distribution. The mid-shore had a variety of grazing and predatory gastropods present, with whelks, limpets, chitons and snails common. The low-shore had patches of the blue mussel, the seaweeds Neptune's necklace, encrusting coralline algae and brown encrusting algae. There was variety of invertebrate fauna underneath the cobbles; including porcelain crabs, top shells and limpets. A full list of taxa and relative abundance scores can be found in Appendix 8.

Figure 8. The intertidal zone inshore of the proposed Tapipi Site; showing the cobble substrate extending from the high shore into the immediate subtidal.

4. WATER CURRENTS

Graphs of current speed (cm s^{-1}) and direction at surface, mid-water and bottom depths are shown in Figure 9, and flow charts of the entire water column are presented in Appendix 9. Average water velocities were approximately 16 cm s^{-1} and maximum water velocities were in the order of 40 to 50 cm s^{-1}, decreasing in speed with depth (Table 3). The predominant direction of flow was to the northeast (out of the Sound), running parallel to the coastline. Water currents were primarily unidirectional (to the northeast), however, limited tidal reversal (water flow back the other way) was seen at depths greater than 16 m. Therefore, water currents predominantly move along the eastern coastline of Waitata Reach and out of the Pelorus Sound.

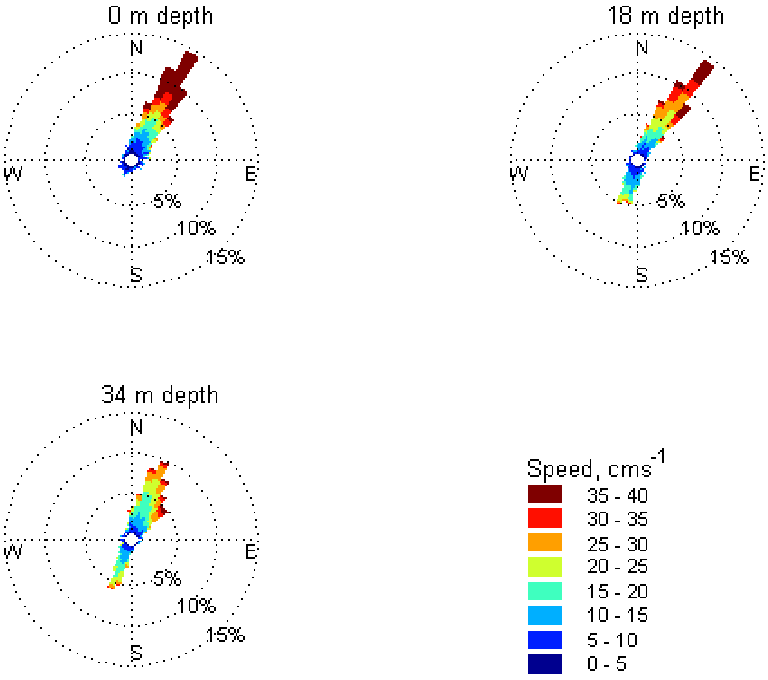

Figure 9. Mean current speed and direction measured at surface (0 m depth), mid-water (18 m depth) and near-seabed (34 m depth) at the Tapipi Site.

Table 3. Depth-averaged current speeds (cm s^{-1}) collected between 20 October 2010 to 24 November 2010 by an ADCP deployed at the Tapipi Plan Change Site (see Appendix 2 for sampling details).

Depth (m)	Average	1st percentile	99th percentile	Std. Dev.	Std. Error
0	16.58	1.19	52.90	13.79	0.34
2	15.85	0.90	51.96	13.28	0.33
4	15.36	0.91	51.13	12.81	0.32
6	15.11	1.06	49.79	12.40	0.31
8	15.08	1.19	48.54	11.99	0.30
10	15.23	1.05	46.75	11.58	0.29
12	15.47	1.33	45.01	11.10	0.27
14	15.78	1.47	44.39	10.71	0.27
16	16.03	1.56	43.52	10.48	0.26
18	16.35	1.71	43.70	10.31	0.26
20	16.64	1.44	44.05	10.23	0.25
22	16.94	1.36	43.34	10.12	0.25
24	17.15	1.44	42.92	10.02	0.25
26	17.26	1.77	42.27	9.89	0.25
28	17.23	1.66	41.76	9.78	0.24
30	17.00	1.74	41.08	9.57	0.24
32	16.54	1.63	39.46	9.08	0.23
34	15.77	1.61	36.25	8.26	0.20

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

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

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

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 Tapipi 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 nematodes. ES 5 has traditionally been the recommended upper level of acceptable impacts in New Zealand, because the benthos is still considered biologically functional and associated with the greatest biomass - and is therefore thought to have greatest waste assimilation capacity. Stages beyond ES 5 (*i.e.* ES 6-7) are characterised by extremely impacted sediments and the collapse of the infauna population, at which point organic accumulation of waste material is thought to greatly increase.

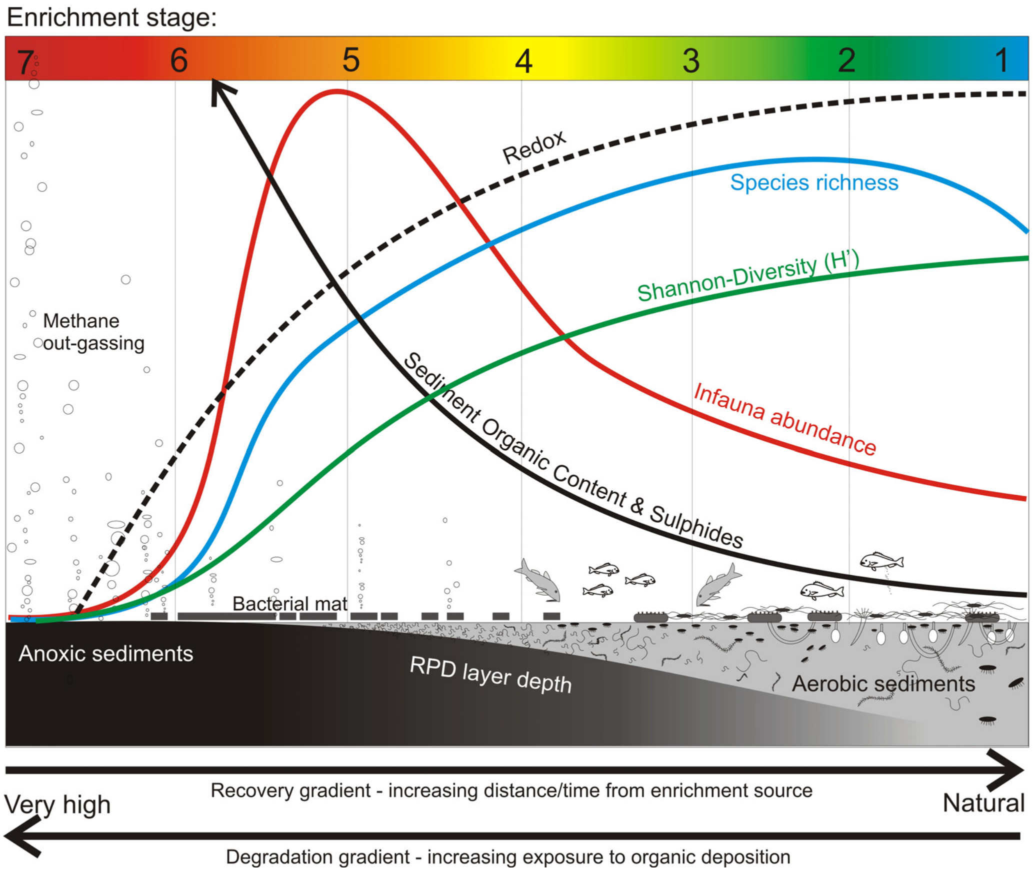

Figure 10. Graphical representation of typical enrichment gradient indicating approximate boundaries of proposed seven impact stages in relation to some frequently adopted environmental indicator variables.

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

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

Predicted depositional footprint at the Tapipi Site

NZ King Salmon proposes to place eight cages (40 x 40 m) in two rows of four cages. The depositional footprint was modelled in DEPOMOD at seven theoretical levels of annual feed loading under the ‘no-resuspension’ and ‘resuspension’ scenarios. These feed loadings were selected based on predictive modelling undertaken in the Benthic Report (Keeley & Taylor 2011), and include three feed usage thresholds developed for the various NZ King Salmon sites (including the Tapipi Site). These are as follows (refer to Keeley & Taylor 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 (3000, 4000 and 5000 t yr^{-1}, respectively), while footprints for other feed usage levels (2000 t yr^{-1} and > 5000 t yr^{-1}) are provided in Appendix 10. When no-resuspension was assumed in the model, the maximum depositional flux was 6 kg m^{-2} yr^{-1} at the RIFL (*i.e.* 3000 t yr^{-1}). Depositional flux increased with increasing feed input (Figure 11), reaching 8 to 10 kg m^{-2} yr^{-1} at the MCFL (5000 t yr^{-1}). Effects of the prevailing current moving northward and southward across the site was evident in the elliptical shape of deposition (Figure 11). 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 the seven feed loadings (without resuspension in the model) was estimated to increase from 18 to 31 ha for feeding loads of 2000 to 8000 t yr^{-1}, respectively, with most of this area exposed to relatively low depositional rates of 0.5 to 4 kg m^{-2} yr^{-1} (Figure 12). In contrast, when resuspension was added to the model, the total area affected by deposition rates was negligible, as the re-suspension scenarios involved no net depositional flux or, any that 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.

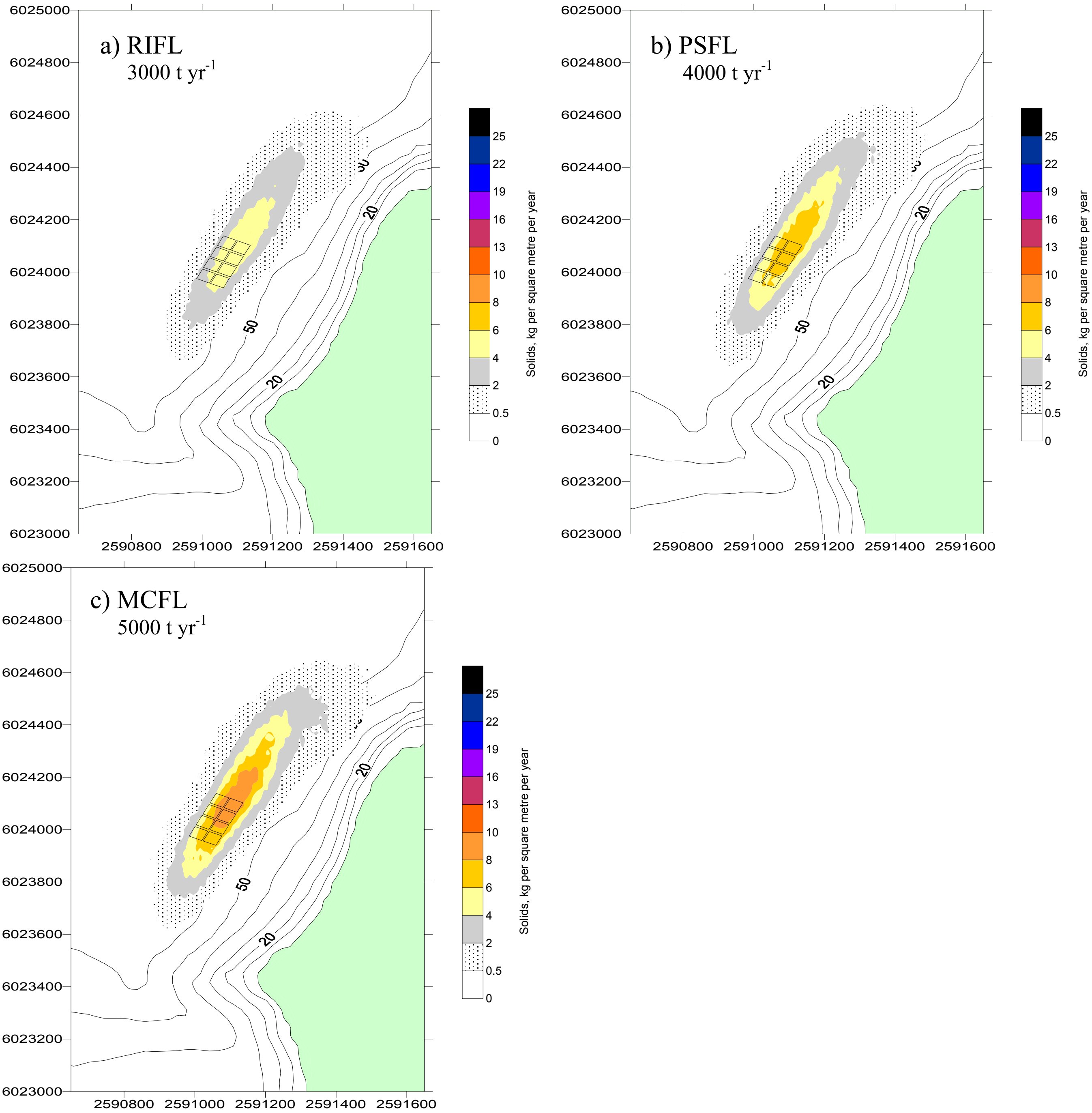

Figure 11. Predicted depositional footprints modelled under 'no-resuspension' scenarios at the Tapipi Site for three different feed levels: a) Recommended Initial Feed Level (RIFL, 3000 t yr^{-1}), b) Predicted Sustainable Feed Level (PSFL, 4000 t yr^{-1}), and c) Maximum Conceivable Feed Level (MCFL, 5000 t yr^{-1}).

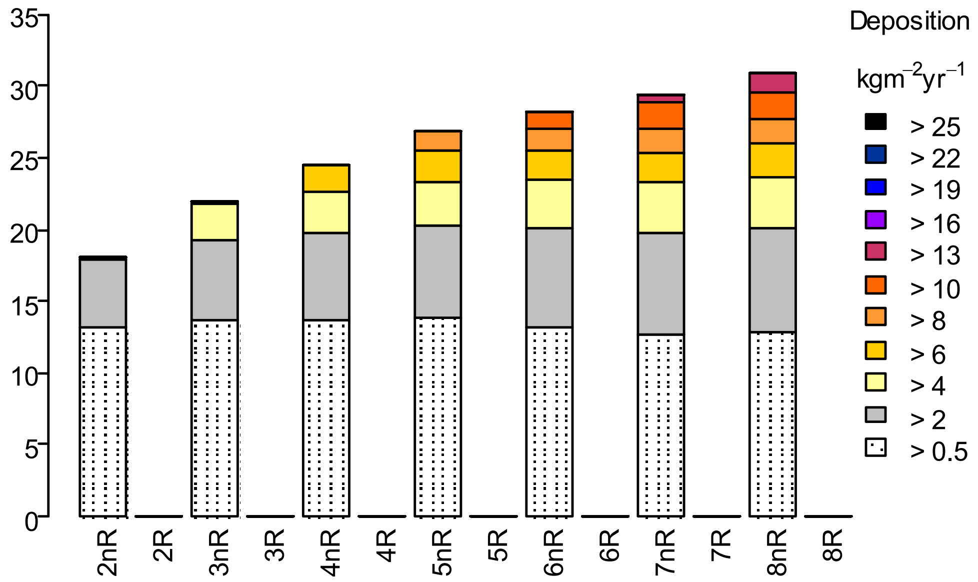

Figure 12. Summary of the total area affected by differing amounts of depositional flux for each of the modelled feed level scenarios (2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}), with resuspension (R) and without resuspension (nR) in the model.

5.2.2. Magnitude and significance of seabed effects

As described in Section 3.4, the substratum within the boundaries of the Tapipi Site was mostly soft sediments (mud and to a lesser degree, mud/shell). The infaunal communities associated with these substrata were dominated by polychaetes, ostracods, bivalves, cumaceans, nematodes and amphipods that are common to the Marlborough Sounds region. Notable ecological habitats observed at the site were inshore of the Cage Area Boundary.

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 Tapipi, resuspension is predicted to prevent excessive accumulation of organic biodeposits beneath the farm. This is clearly demonstrated by the fact that when resuspension is modelled, we predict little or no net flux to the seabed (Section 5.2.1). However, while the accumulation of organic material within the sediments is likely to be minimal at high-flow sites, sediment chemistry and composition will be significantly altered (*i.e.* sulphide levels elevated, redox levels reduced).

The predicted footprint for the Maximum Conceivable Feed Level (5000 t yr^{-1}) under no-resuspension is overlaid on the habitat map created for the study area (Figure 13). This figure helps to visualise the spatial scale of the area that could be impacted under a worst-case scenario, as well as the key habitats that could be affected. Directly beneath the farm cages (*ca.* 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected (*i.e.* ES 5 impacts are likely to occur). This is also likely to result in the displacement of most epibiota. It is anticipated that a further 21 ha of seabed will be moderately impacted (*i.e.* ES score >3); however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions (*i.e.* ES score <3) within 500 m (refer the Benthic Report, Keeley & Taylor 2011). Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.

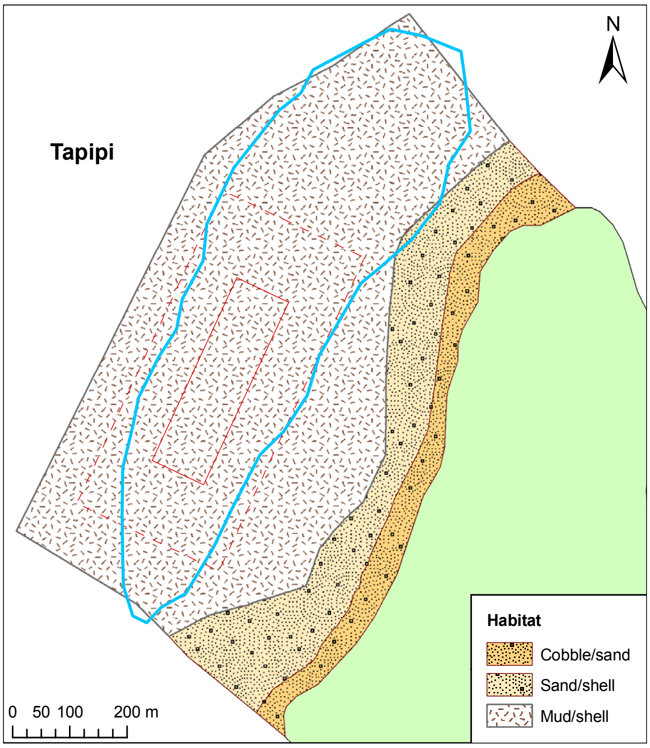

Figure 13 . Predicted depositional footprint for the Maximum Conceivable Feed Level (MCFL, 5000 t yr^{-1}) under a 'no-resuspension' scenario, overlaid onto the habitat map created for the Tapipi Plan Change Site. The blue line indicates the 0.5 kg m^{-2} yr^{-1} deposition area and no deposition greater than 10 kg m^{-2} yr^{-1} was seen.

6. MANAGEMENT OF BENTHIC EFFECTS

It is proposed that the Tapipi 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) 5000 t yr^{-1}, dependant on the outcome of the environmental monitoring results.

Under the Zones concept, compliance is assessed with reference to predefined Environmental Quality Standards including site-specific constraints on the spatial extent and magnitude of effects. The EM-AMP also encompasses the procedures for monitoring copper and zinc in sediments, and the strategy for local and regional monitoring of the water column and potential wider ecological effects. The ecological attributes at this site which warrant special consideration under the wider ecological monitoring programme include reef and tubeworm mound habitats identified inshore and alongshore 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 in the study area, with silt/clay being the most widespread. The sediment was well oxygenated with moderate organic content. A rich infaunal community was found at the site comprising a total of 110 taxa. Taxa were typical of moderate-to-high-flow areas throughout the Marlborough Sounds.
2. The seabed beneath the Tapipi Site was dominated by soft sediments. Few epibiota were present in this soft sediment habitat.
3. Areas inshore of the site were characterised by boulder and cobble habitats and had a relatively diverse community of taxa; including some ecologically significant species such as sponges, scallops, burrowing anemones, tubeworms and horse mussels.
4. Intertidal communities were characteristic of rocky shore habitats throughout the Outer Pelorus Sounds.
5. The proposed site overlies water depths of 50 to 60 m. Water current velocities at the site were high (average 16 cm s^{-1}, maximum 40-50 cm s^{-1}) and the predominant direction of flow was northeast, out to of the Sounds. Near-bed water velocities were often above the resuspension threshold used in the depositional modelling for the site.
6. At feed levels of up to 5000 t yr^{-1}, depositional modelling indicated that depositional flux will 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 8000 t yr^{-1}. When resuspension was not considered, the depositional footprint (deposition > 0.5 kg m^{-2} yr^{-1}) affected an area of 18 to 31 ha at feed loadings of up to 8000 t yr^{-1}, however, most this area was exposed to relatively low depositional rates of 0.5 to 4 kg m^{-2} yr^{-1}.
7. The Recommended Initial Feed Level (RIFL) is 3000 t yr^{-1}. It is possible that feed could be increased in 1000 t yr^{-1} increments to a predicted sustainable feed level of 4000 t yr^{-1}. The maximum conceivable feed level for the Tapipi Plan Change Site was estimated to be 5000 t yr^{-1}.
8. Directly beneath the farm cages (*ca*. 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected. Epibiota observed beneath the site will also be displaced. It is anticipated that a further 21 ha of seabed will be low-to-moderately impacted; however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within 500 m. Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.
9. It is proposed that the Tapipi 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 programme include reef and tubeworm habitats identified inshore and alongshore of the proposed farm.

10. The Tapipi Site is situated in a high-flow area where wastes will tend to be dispersed and assimilated. The bathymetry of the area is suited to cage farming and has limited propensity for adverse biological effects.

8. ACKNOWLEDGEMENTS

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

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10. APPENDICES

Appendix 1. Approach to assessing seabed characteristics

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

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

Purpose	Sampling technique	Date
Site bathymetry	Depth profiling	20 November 2010
Characterisation of subtidal habitats	Video transects (diver-collected)	16 March 2011
	Video sled transects	21 May 2011 24 May 2011
	Drop-camera photography	29 February 2011
	Sediment grab samples	23 February 2011
Characterisation of intertidal habitats	Intertidal shoreline survey	29 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 Tapipi 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 105 ºC, for gravel (≥2 mm), sand (≥63 µm - <2 mm) and silt/clay (<63 µm) size classes. Organic content was assessed by measuring the Ash Free Dry Weight (AFDW) following drying at 105°C, then ashing at 550°C to a constant weight (method modified from that of Luczak *et al.* 1996).

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

Table 1-2. Grab sample locations.

Station	NZMG-E	NZMG-N	Latitude	Longitude
1	2591216	6023620	-40 59.40	173 57.92
2	2591012	6023647	-40 59.39	173 57.78
3	2590804	6023659	-40 59.38	173 57.63
4	2591427	6024083	-40 59.15	173 58.07
5	2591257	6024139	-40 59.12	173 57.95
6	2591051	6024211	-40 59.08	173 57.80
7	2591561	6024401	-40 58.98	173 58.16
8	2591501	6024508	-40 58.92	173 58.12
9	2591461	6024536	-40 58.90	173 58.09

Subtidal habitats

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

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

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

Table 1-3. Dive transect start locations.

Dive transect	NZMG-E	NZMG-N	Latitude	Longitude
1	2591372	6023766	-40 59.32	173 58.03
2	2591638	6024343.2	-40 59.01	173 58.22
3	2591440	6024070.1	-40 56.39	173 58.43
4	2591233	6023534.7	-40 57.94	173 57.94

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	2591164	6024359	-40 59.00	173 57.88	2590898	6023739	-40 59.34	173 57.70
2	2591049	6024332	-40 59.02	173 57.80	2591391	6024167	-40 59.10	173 58.04
3	2590973	6024138	-40 59.12	173 57.75	2591384	6024026	-40 59.18	173 58.04
4	2590901	6024009	-40 59.19	173 57.70	2591135	3023926	-63 38.59	176 57.43
5	2591035	6023557	-40 59.43	173 57.79	2590918	6023773	-40 59.32	173 57.71

Intertidal habitats

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

Appendix 2. Approach to assessing water currents

An Acoustic Doppler Current Profiler (ADCP) was deployed for 35 days approximately halfway up the eastern (seaward) edge of the Site, in *ca*. 30 m water depth. Water currents (speed and direction) were characterised at 3, 11, 18, 25, 32 m depth intervals (bins) through the water column (Table 2-1).

Table 2-1. ADCP deployment details.

Particulars	**Tapipi Plan Change Site**
Device:	RD Instruments ADCP
Logging depth:	Vertical profile @ 1.1 m intervals
Averaging interval:	5 minutes
Sampling frequency:	30 minutes
Deployment period:	20/10/10 to 24/11/10
Mooring location:	2591250 E, 6023929 N

Appendix 3. Approach to assessing depositional footprints

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

DEPOMOD also allows the user to predict the influence of resuspension on the footprint. This prediction is based on default resuspension and deposition velocity thresholds (9.5 cm s^{-1} and 4.5 cm s^{-1} near-bed current speed, respectively), and was not specifically calibrated for the sediments present at the Site. Thus, it should be considered an approximation only. The no-resuspension output represents a scenario where there is a one way flux to the sediment and thus can be treated as a worst case scenario with regard to seabed impacts. In the case of Tapipi, 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 Tapipi salmon farm layout was modelled at seven theoretical feed loadings (2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}). Cage dimensions were based on blocks of 40 m x 40 m x 20 m deep cages; *i.e.* similar to those used by NZ King Salmon elsewhere in the Marlborough Sounds. A summary of the detailed input parameters and settings used are provided in Table 3-1.

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

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

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

1. Grid Generation	
Major grid size	i=99 @ 22.7 m, j=99@ 34.6 m (2247 x 3425 m)
Minor grid size	i=99@ 10 m, j=99@ 20 m (990 x 1980 m)
Position on grid	i=7, j=34
Cage configuration	2 rows of 4
Total number cages	8
Spacing between cage centres (m)	45 m
Cage orientation (deg T)	67°
Depth under cages (m)	16 m
2. Particle tracking	
Type of feed release	Continuous
Food loading	2000, 3000, 4000, 5000, 6000, 7000 and 8000 t yr^{-1}
Cage dimensions	40 x 40 m 20 m deep
Source of velocity data	RD Instruments ADCP
Current depth bins used:	1, 9, 17, 27, 35 m
Instrument sampling period (min)	5 min every 30
Time step used in model (seconds)	1800
Length of velocity record (steps)	1630
Random walk model	On: Kx=0.1, Ky=0.1, Kz=0.001

Table 3-2. Average feed rates for the twelve months preceding the annual monitoring for each of the six modelled scenarios (two annual periods for each of three existing salmon farm sites).

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

Appendix 4. Photographs of sediment cores collected from grab stations

Appendix 5. Infaunal count data

	Grab Station								
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Hydroida (thecate)	0	0	0	0	0	1	0	0	0
ANTHOZOA UNID.	0	0	0	0	0	0	2	0	0
Edwardsia sp.	0	0	0	0	0	1	0	0	0
NEMERTEA	1	1	0	0	0	1	1	1	2
NEMATODA	6	12	2	15	4	16	13	7	3
Sipuncula	0	1	0	0	0	3	0	0	0
Leptochiton inquinatus	0	0	0	0	0	1	4	0	10
GASTROPODA UNID. JUV.	0	0	0	0	0	0	1	0	0
Amalda mucronata	1	0	0	0	0	0	0	0	0
Caecum digitulum	0	0	0	0	0	0	2	1	0
Crepidula monoxyla	2	0	0	0	0	0	0	0	0
Tanea zelandica	1	0	0	0	0	0	0	0	0
Turbonilla sp.	0	0	0	0	0	0	0	0	1
Myadora antipodum	0	1	0	0	0	0	0	0	0
Arthritica bifurca	0	1	0	1	3	0	1	0	0
Chlamys sp.	0	0	0	0	0	0	0	1	0
Corbula zelandica	1	5	2	0	0	0	3	0	3
Dosina zelandica zelandica	1	2	0	0	0	0	0	0	3
Felaniella zealandica	0	0	0	0	0	0	3	0	0
Gari stangeri	0	0	8	0	0	0	5	0	3
Glycymeris modesta	0	0	1	0	0	0	0	0	0
Leptomya retiaria retiaria	0	0	0	0	0	0	0	1	0
Limaria orientalis	0	0	0	9	0	0	2	0	0
Maorithyas marama	8	0	0	0	1	0	0	0	0
Melliteryx parva	0	0	0	0	0	0	0	0	2
Nemocardium pulchellum	1	0	0	1	0	0	0	0	0
Notocallista multistriata	1	1	0	0	0	0	0	0	0
Nucula gallinacea	0	0	1	0	0	0	1	1	1
Nucula nitidula	0	0	0	0	0	0	0	0	6
Pleuromeris zelandica	0	1	0	0	0	0	0	0	1
Tawera spissa	0	1	0	2	0	0	1	0	5
Theora lubrica	0	1	1	0	0	0	0	0	0
Venericardia purpurata	1	1	0	0	0	0	0	0	0
OLIGOCHAETA	0	1	0	2	0	0	0	0	0
Ampharetidae	2	3	2	0	2	0	9	0	0
Amphinomidae	0	0	0	0	0	1	0	0	0
Neanthes cricognatha	0	0	0	0	0	0	1	15	13
Leitoscoloplos kerguelensis	0	1	1	0	0	0	0	0	0
Paraonidae	13	50	23	2	35	32	1	15	9
Aricidea sp.	0	1	0	0	0	1	0	0	1
Cossura consimilis	0	0	5	0	3	0	0	0	0

	Grab Station								
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Boccardia sp.	0	0	0	0	0	0	9	0	0
Paraprionospio pinnata	1	0	2	0	3	2	0	0	0
Prionospio aucklandica	0	0	0	0	0	0	0	0	1
Prionospio multicristata	12	64	8	4	11	47	16	13	8
Prionospio yuriel	0	2	3	0	2	0	1	1	0
Spiophanes kroyeri	0	0	0	0	1	0	0	0	0
Capitella capitata	0	1	0	0	0	0	0	0	0
Capitellethus zeylanicus	1	0	0	0	0	0	0	2	0
Heteromastus filiformis	8	2	1	4	4	31	2	21	10
Maldanidae	5	8	4	8	6	0	3	1	1
Armandia maculata	5	6	3	0	1	3	0	4	2
Scalibregma inflatum	1	0	0	0	1	0	0	10	1
Phyllodocidae	1	0	0	0	0	0	0	0	0
Polynoidae	0	0	0	0	0	1	0	0	1
Sigalionidae	1	1	1	0	0	0	1	0	0
Hesionidae	2	2	2	1	3	1	1	0	2
Syllidae	1	2	0	1	1	8	1	4	3
Sphaerosyllis sp.	12	35	5	10	12	13	26	41	16
Nereidae (juvenile)	0	0	0	0	0	0	1	0	0
Glyceridae	0	1	1	1	0	2	0	3	1
Goniada sp.	2	5	0	8	0	0	0	2	0
Aglaophamus sp.	0	0	0	0	0	0	0	1	0
Eunicidae	0	1	0	0	0	0	0	0	1
Lumbrineridae	2	7	8	7	5	4	4	9	10
Dorvilleidae	0	4	1	0	6	0	3	3	4
Cirratulidae	7	16	11	2	11	19	2	16	2
Flabelligeridae	1	1	0	1	0	0	1	3	1
Terebellidae	2	0	2	2	1	2	24	3	2
Sabellidae	0	0	0	2	0	0	1	1	0
Pomatoceros terraenovae	0	0	0	0	0	0	0	5	0
Spirorbidae	0	0	0	0	0	0	0	20	0
Cumacea	1	14	4	1	9	0	13	0	1
Tanaid sp.	5	4	2	0	2	2	0	0	0
Anthuridea	1	1	0	0	1	1	1	1	3
Munna schauinslandii	1	0	0	0	0	0	2	0	0
Asellota	8	19	5	0	5	0	1	0	0
Gnathiidea	0	2	3	0	0	0	1	0	0
Aoridae	4	1	0	8	1	1	5	7	2
Corophiidae	0	0	0	1	0	0	0	0	0
Dexaminidae	1	1	0	2	3	0	0	1	0
Lysianassidae	0	0	0	1	0	0	0	0	0
Melitidae	1	0	0	3	0	0	1	0	0
Oedicerotidae	0	0	1	0	2	0	0	0	0

	Grab Station								
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Phoxocephalidae	5	1	0	2	1	1	7	0	0
Ampelisca sp.	1	2	1	1	0	3	4	3	2
Alpheus sp.	0	0	0	0	0	0	0	1	0
Ebalia laevis	0	0	0	1	0	0	0	0	0
Pagurus sp.	1	0	0	1	1	0	0	0	0
Petrolisthes elongatus	1	2	0	0	0	0	0	0	0
Upogebia sp.	0	0	0	0	1	0	0	0	0
Bradleya opima	0	1	0	0	2	0	0	0	0
Cymbicopia hispida	0	3	0	0	0	0	0	0	0
Cypridinoides concentrica	0	0	1	0	0	0	0	0	0
Diasterope grisea	0	2	0	0	0	0	0	0	0
Euphilomedes agilis	3	4	1	4	1	0	6	4	5
Neonesidea sp.	3	0	0	0	0	0	1	0	0
Parasterope quadrata	0	0	0	1	0	0	1	0	1
Scleroconcha arcuata	0	1	0	3	1	0	0	0	0
Trachyleberis lytteltonsis	0	0	0	0	1	0	0	0	0
COPEPODA	0	1	0	6	0	0	2	0	0
Phoronus sp.	0	0	0	1	0	0	0	0	0
BRYOZOA (ENCRUSTING)	0	0	0	1	0	6	10	0	1
Waltonia inconspicua	0	1	0	0	0	1	1	0	0
Ophiuroidea	0	1	0	0	1	0	9	1	2
Trochodota dendyi	1	0	0	1	0	0	4	2	0
Cystodytes dellechiajei	0	0	0	0	0	1	0	0	0
Eugyra brewinae	0	1	0	0	0	0	0	0	0
Pareugyriodes filholi	0	0	0	1	0	0	0	0	0
OSTEICHTHYES EGGS	0	1	0	0	0	0	0	0	0
Total abundance	**140**	**305**	**116**	**122**	**148**	**206**	**215**	**225**	**146**
Total richness	**45**	**54**	**32**	**38**	**36**	**29**	**49**	**36**	**40**

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 structure. SIMPROF test showed no significant distinction among stations, with all stations sharing at least 50% of similarity, indicative of homogeneous infaunal communities at the Site. The relative abundance and presence/absence of a variety of other invertebrates (summarised in Figure 6-1) were also influential in characterising the communities.

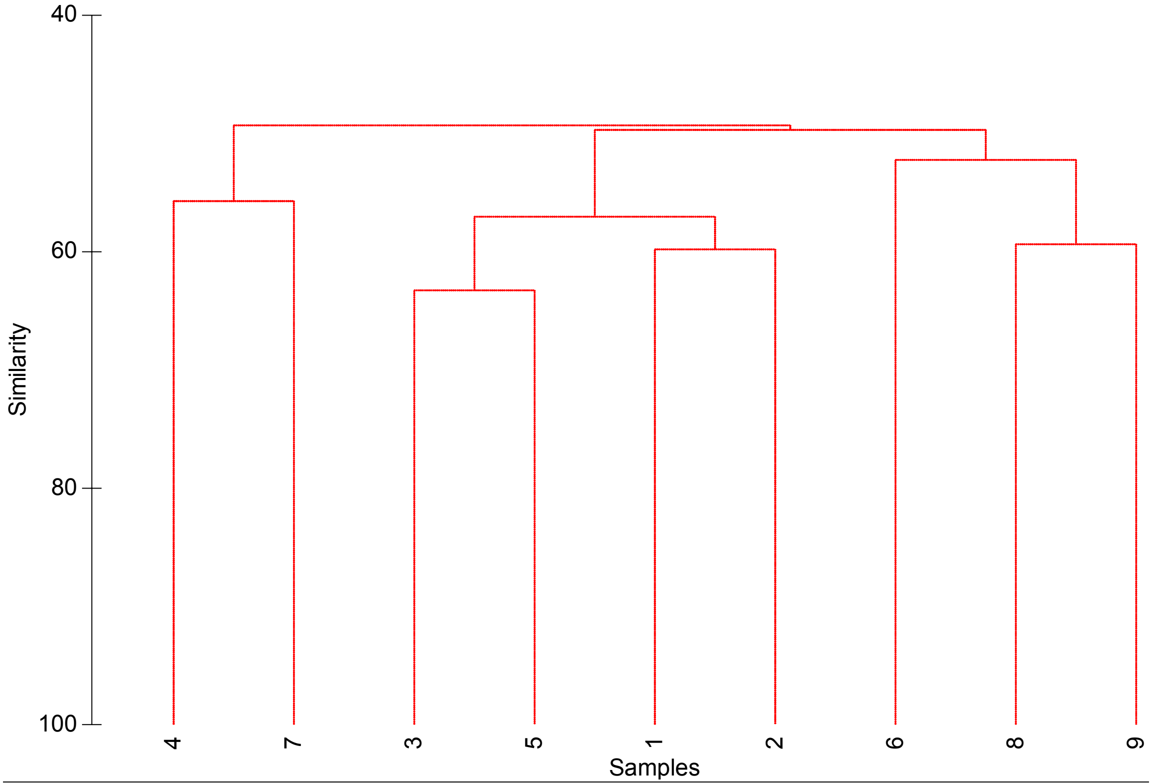


Figure 6-1. Dendrogram showing similarity (%) of infaunal assemblages collected from the Tapipi study area. The analysis was performed on the basis of Bray-Curtis similarity of the fourth-root transformed count data.

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

X = taxa present in transect.

		Dive transect				Video sled transect				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Porifera										
Ancorina alata / Geodia regina	Vase sponge	X	X	X	X	X	X	X		X
Axinella sp.	Antler sponge	X	X	X	X	X				
Callyspongia sp.	Erect sponge					X	X	X		X
Hydrozoa										
Hydroida (thecate)	Feather hydroid	X	X	X	X	X	X	X	X	X
Scyphozoa										
Aurelia aurita	Moon jellyfish		X		X			X		
Anthozoa										
Actinothoe albocincta	White striped anemone		X	X	X			X		
Cerianthus sp.	Tube anemone	X		X	X					
Gastropoda										
Nudibranchia unid.	Nudibranch				X					
Maoricolpus roseus	Turret shell					X	X	X	X	X
Bivalvia										
Atrina zelandica	Horse mussel			X	X					
Pecten novaezelandiae	Scallop		X		X	X	X	X	X	X
Modiolarca impacta	Nesting mussel	X								
Cephalopoda										
Octopodidae sp.	Octopus				X					
Polychaeta: Serpulidae										
Galeolaria hystrix	Tubeworm	X					X			
Polychaeta: Sabellidae		X	X	X	X					
Echinoidea										
Evechinus chloroticus	Sea urchin (kina)	X	X	X	X		X			X
Asteroidea										
Coscinasterias calamaria	11-arm sea star	X	X	X	X	X	X	X	X	X
Pentagonaster pulchellus	Biscuit star		X							
Patiriella sp.	Cushion star	X	X	X	X	X		X	X	X
Ophiuroidea										
Ophiopsammus maculata	Snake tail star	X	X	X	X	X	X	X	X	X
Holothuroidea										
Stichopus mollis	Sea cucumber			X	X	X	X	X	X	X
Ascidiacea										
Cnemidocarpa bicornuta	Solitary ascidian	X	X	X	X					
Aplidium phortax	Colonial ascidian	X	X	X	X	X	X	X	X	X
Colonial ascidian (unid.)	Unidentified sea squirt	X								
Osteichthyes										

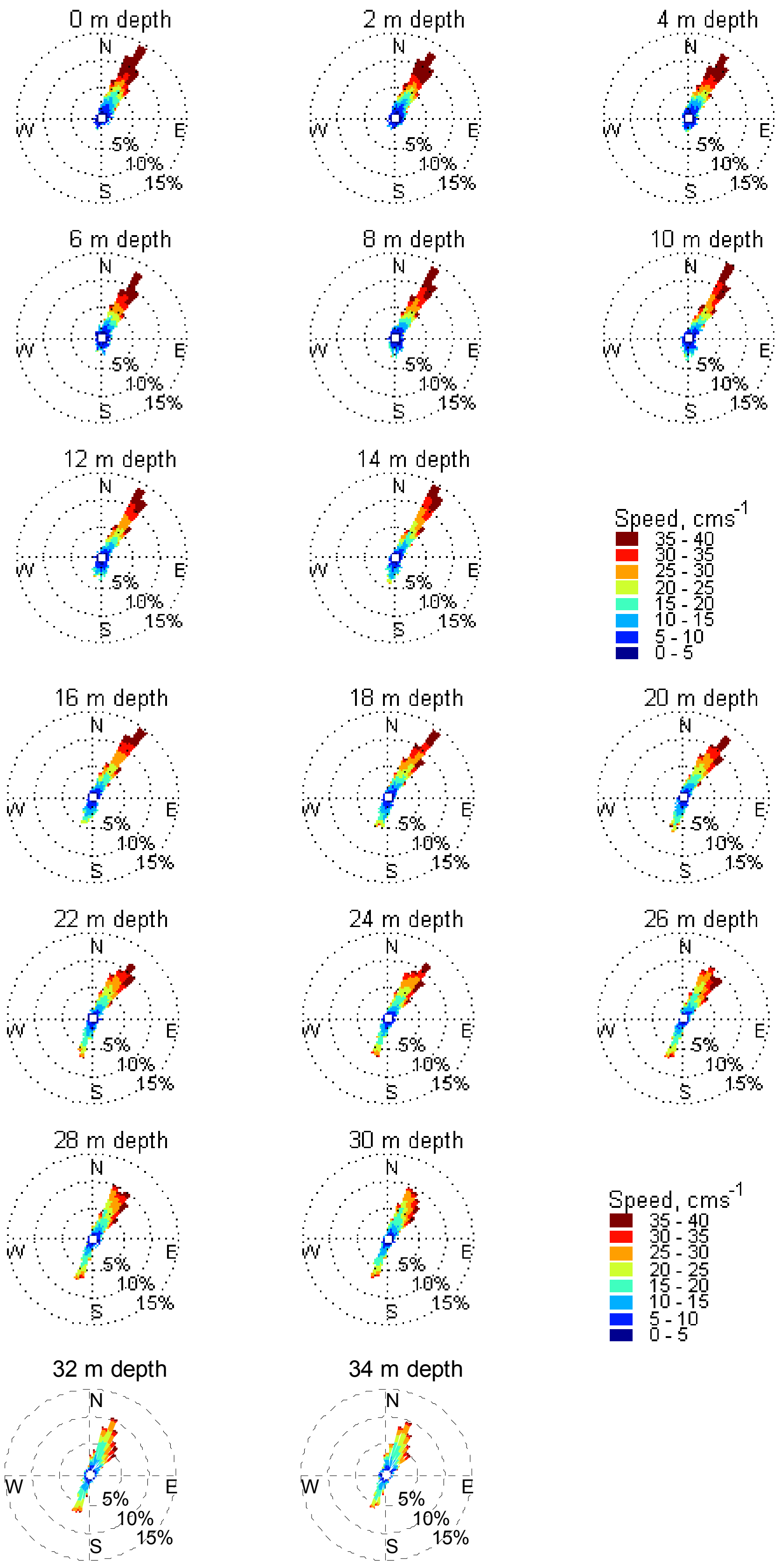
		Dive transect				Video sled transect				
Taxa	**Common name**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Parapercis colias	Blue cod	X	X	X	X			X	X	
Notolabrus celidotus	Spotty	X	X	X	X					
Parika scaber	Leatherjacket				X					
Tripterygiidae sp.	Unidentified Triplefin	X	X	X	X					X
Chelidonichthys kumu	Red Gurnard					X			X	
Syngnathidae sp.	Pipe fish					X				X
Zeus faber	John Dory							X		
Synodus sp.	Lizard fish		`							X
Nemadactylus macropterus	Tarakihi									X
Chondrichthyes										
Cewphaloscyllium isabellum	Carpet shark									X
ALGAE										
Chlorophyta										
Algae (green filamentous)	Green alga	X	X	X	X					
Caulerpa geminata	Sea rimu			X	X					
Phaeophyta										
Carpophyllum sp.	Flapjack	X	X	X	X					
Ralfsia verrucosa	Brown encrusting algae	X	X	X	X					
Rhodophyta										
Algae (red filamentous)	Red alga	X	X	X	X					
Corallina (encrusting)	Pink paint	X	X	X	X		X	X	X	

Appendix 8. Relative abundance and tidal height distribution of conspicuous intertidal and immediate subtidal 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	Description	Tidal zone	Replicate 1	2	3
Anthozoa					
Actinia tenebrosa	Waratah anemone	L-M	R		R
Polyplacophora					
Sypharochiton pelliserpentis	Snakeskin chiton	L-M	C	C	O
Gastropoda					
Cellana radians	Radiate limpet	L-M	A	A	A
Cellana ornata	Ngakihi, Ornate limpet	L-M	A	A	A
Haustrum haustorium	Brown whelk	L-M	O	O	O
Haustrum scobina	Oyster borer	L-M	C	C	C
Austrolittorina spp.	Banded periwinkle	H	A	A	A
Melagraphia aethiops	Spotted top shell	L-M	C	C	C
Diloma sp.	Top shell	L-M	A	A	
Bivalvia					
Mytilus galloprovincialis	Blue mussel	L	O	O	O
Decapoda					
Petrolisthes elongates	Half crab	M	C	C	C
Cirripedia					
Chamaesipho sp.	Brown and column barnacles	H	A	A	A
Epopella plicata	Common barnacle	H	A	A	A
Elminius modestus	Barnacle				
Unid. barnacle	Unidentified barnacle	H	O		
Asteroidea					
Patiriella regularis	Cushion Star	M		R	
ALGAE					
Chlorophyta					
Ulva sp.	Sea lettuce	L		R	R
Phaeophyta					
Brown encrusting algae	Brown alga	L	O	O	O
Hormosira banksii	Neptunes' Necklace	L	C	O	C
Scytothamnus australis	Brown alga	L		O	
Rhodophyta					
Unid. red algae	Unidentified red algae	L-M	O	O	O
Ceramium sp.	Red alga	L			O
Laurencia thyrsifera	Red alga	L	O	O	
Corallina officinalis	Pink turf	L	O		O
Encrusting coralline algae	Paint	L			O

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



Appendix 10. Predicted depositional footprints for four levels of food usage at the Tapipi Site: (a) 2000 t yr^{-1}, (b) 6000 t yr-1, (c) 7000 t yr^{-1}, and (d) 8000 t yr^{-1} under 'no-resuspension' scenarios