Benthic Ecological Assessments for Proposed Salmon Farm Sites

Part 2: Assessment of Potential Effects

Prepared for Ministry for Primary Industries

December 2016

Prepared by:
Stephen Brown
Jeffrey Ren
Kevin Mackay
Brett Grant
Joanne O'Callaghan

For any information regarding this report please contact:

Stephen Brown
Marine Ecologist

+64-3-545 7741
stephen.brown@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 893
Nelson 7040

Phone +64 3 548 1715

NIWA CLIENT REPORT No: NEL2016-006
Report date: December 2016
NIWA Project: MPI16401

Quality Assurance Statement		
Ken Grange	Reviewed by:	
Ken Grange	Formatting checked by:	
Sean Handley	Approved for release by:	

22 December 2016 12.08 p.m.

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Executive summary

The Ministry for Primary Industries (MPI) engaged NIWA to undertake ecological benthic assessments at eight potential aquaculture farm sites in the Marlborough Sounds as part of the process to assess their suitability for relocation of existing salmon farms. This report comprises Part 2 of the assessment, presenting a modelled deposition footprint for each farm site, produced from hydrodynamic and particle tracking modelling (DEPOMOD) based on anticipated annual feed input scenarios and field measurement of currents, to forecast the intensity and extent of the deposition from the proposed farming activity. The results of the DEPOMOD footprint simulations are overlaid on maps depicting the location of notable ecological features identified in Part 1 of the study (Brown et al 2016), to enable an assessment of the potential effects of farm deposition on ecological features at each site.

A threshold depositional flux of approximately 13 kg m^{-2} yr^{-1} that equates to enrichment stage ES5, is currently considered to be the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. Initially, a single annual feed input scenario was proposed for the DEPOMOD simulations of deposition at each of the farm sites for the purpose of this assessment. For sites where that proposed feed input resulted in forecast deposition exceeding accepted limits of intensity, additional modelled scenarios using lower feed inputs were produced.

At all eight of the sites, communities of infauna living within the sediments beneath the cages and within the zone of maximum effects will be affected by the deposition. Enrichment-tolerant species (e.g. Capitellid polychaetes and nematodes) will become highly abundant, infaunal diversity will decrease significantly, and there is potential for the formation of bacterial mat (*Beggiatoa* sp.) and for some outgassing of H_2S gas from the sediment. Some of those effects may extend some way beyond the zone of maximum effects into the wider footprint. Infaunal assemblages at the sites mainly comprised taxa that are widespread and common in soft sediment habitats within the Marlborough Sounds so the effects on those infaunal communities are not considered to be ecologically significant in the context of the Marlborough Sounds geographic region. Notable or ecologically significant features identified in the survey were mainly either animals or plants living on the seabed surface (epibiota), or else substrata and habitats such as bedrock reef that support diverse communities of epibiota and fish. The effects of deposition from finfish farms on epibiota in New Zealand have not been widely studied or described so the predictions of effects on the notable features presented in this assessment are intended to indicate where the spatial extent of deposition from the farms could potentially affect the notable features identified, rather than to forecast the precise mechanism or degree of impact.

Summary of predicted effects at each site:

Blowhole Point North site (34): Using the proposed feed input level of **5000** tonnes per year, modelling indicated that the resulting deposition would produce enrichment within a small area beneath cages just exceeding the threshold (>ES5) deemed to be the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. Scallops, brachiopods, and small biogenic clumps would be displaced/excluded beneath the cage area and are likely to be affected within the wider footprint. The primary footprint extended 360 m to the southwest, but not as far as the extensive reef at Blowhole Point nor to inshore patch reef and kelp communities. An adjusted level of feed input of **4500** tonnes resulted in forecast enrichment of < ES5. Scallops, brachiopods and other epifaunal taxa considered sensitive to depositional effects would be displaced/ excluded beneath the cage area.

Blowhole Point South site (122): Using the proposed feed input of **5000** tonnes, the level of deposition predicted at this site would lead to moderate to high levels of enrichment (ES3 to 4) and would not exceed the acceptable limit of enrichment (stage ES 5) on the seabed beneath the site. The primary footprint extended over an area of ~20 Ha. Brachiopods (sparsely distributed), are likely to be displaced/excluded beneath the cages and effects may extend some way into the wider primary footprint. The primary footprint extends to the northeast over portions of the extensive reef at Blowhole Point. There is potential for some effects to diverse communities on that reef from low to moderate levels of deposition and elevated nutrient levels.

Waitata Reach mid channel site (125): Assuming a feed input of **12000** tonnes per year, the modelling indicated that a very small area (~0.018 Ha) in the center of the farm would be subject to a maximum rate of deposition of between 12 and 14 kg m^{-2} yr^{-1} and seabed enrichment would not be expected to exceed ES5. At this site, no ecological features of special significance are predicted to be affected as a result of the proposed farm activity.

Richmond South site (106): At the proposed feed input rate of **6500** tonnes, DEPOMOD indicated that an area of ~0.2 Ha on the seabed in the close vicinity of the cages is likely to be subjected to deposition of ~12 to 13 kg solids m^{-2} yr^{-1} leading to a level of enrichment in that zone characterised as enrichment stage ES4 to ES5. An area of ~26 Ha is forecast to be affected by the wider primary footprint within which deposition can be expected to decrease with distance from the cages to a level of ~1 kg solids m^{-2} yr^{-1} causing moderate enrichment and impacts associated with enrichment stage ES3 at the distal edges of the footprint. Scallops and other taxa sensitive to deposition (e.g. small sparsely distributed biogenic clumps) will be displaced beneath the cages and those effects may extend a short way into wider primary footprint.

Horseshoe Bay site (124): Modelling using a feed input level of **2500** tonnes predicted that an area of ~0.5 Ha in the vicinity of the cages would be subject to excessive enrichment > ES5, and the primary footprint (moderately enriched ES3 to ES4) would cover ~8 Ha. Effects from deposition would exclude most epibiota beneath the cages. Within the wider footprint scallops and other taxa considered to be sensitive to deposition such as small, scattered clumps of hydroids, sponges and bivalves may be displaced/excluded. Moderate depositional effects would extend to the reef area adjacent to Te Kaiangapipi headland, potentially affecting portions of a bedrock reef habitat and also a biogenic shell rubble habitat feature and associated communities. A reduction of feed input to **1500** tonnes would reduce the intensity of the deposition such that benthic enrichment would drop to an accepted level of less than ES5, and the wider deposition footprint (>1 kg solids m^{-2} yr^{-1}) would not be expected to extend as far as the reef area adjacent to Te Kaingapipi. Benthic taxa sensitive to the effects of deposition such as scallops would be displaced on the seabed below the cages but overall ecological effects would be unlikely to be significant under that feed input scenario.

Tipi Bay site (42): A feed input level of **2000** tonnes per year is expected to produce excessive enrichment directly impacting ecologically significant habitats and communities in the NE and SW ends of the embayment. A reduced feed input level of **1000** tonnes per year would reduce the enrichment to less than ES5 directly beneath the cage area, but moderate levels of deposition would still extend over, and potentially affect ecologically significant features. Inshore giant kelp (*Macrocystis)* stands and seagrass beds could be potentially affected by resuspended farm wastes and elevated nutrient levels.

Motukina site (82): At the proposed annual feed input level of **5000** tonnes, modelling indicated that an area of seabed of 1.2 Ha would become severely enriched (ES6 or 7) and ecologically significant habitats and communities would be directly impacted. A reduction of the feed input level to **1000** tonnes would reduce the expected enrichment stage beneath cages to ≤ ES5 but moderate levels of deposition would be expected to affect notable benthic habitats and communities at the eastern and western ends of the site. Macroalgal beds inshore of the farm could potentially be affected by resuspension of farm wastes and elevated nutrient levels within the embayment resulting from the farming activity.

Te Weka Bay site (47): Modelling indicated that a feed input level of **5000** tonnes at this site would produce excessive enrichment >ES5 over an area of 1.6 Ha. No particularly significant ecological features were identified in that zone, but moderate levels of deposition producing enrichment of ES3 to ES4 would extend over significant broken rock/cobble habitat to the northeast of the cage area. Reducing the feed level to **1800** tonnes per year would result in levels of deposition (< 13 kg solids m^{-2} yr^{-1}) and enrichment considered to be sustainable on the seabed beneath cages, but some of the ecologically significant habitat northeast of the cages would still lie within the primary footprint and be subject to moderate levels of deposition.

Far field and secondary effects beyond the primary deposition footprint should be considered in monitoring programmes if farms are established at the sites assessed here. Other effects to consider include:

- Cumulative effects of resuspended biodeposits and elevated nutrient levels beyond the primary deposition footprint, especially in quiescent areas adjacent to sites.
- Effects of colonisation of farm structures by fouling organisms and pest species, and potential for spread to adjacent natural habitats.
- Potential changes to benthic habitats and communities caused by aggregation of predators (seals, sharks, seabirds) attracted to the farm sites.

Monitoring:

If salmon farms are relocated to sites investigated in this assessment, it is recommended that a benthic monitoring plan for those sites is developed following the ‘Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Benthic environmental quality standards and monitoring protocol’ guidelines (Keeley *et al* 2015). Monitoring of effects to notable features and habitat types other than soft sediment habitat such as rocky or biogenic habitat that are located either within, or close to the ‘zone of effect’ of the primary depositional footprint is also recommended. It is possible that cumulative effects from low levels of waste particulates from the farm, and resuspension and dispersion of dissolved nutrients transported well beyond the predicted primary footprint could affect inshore habitats (e.g.patch reefs, kelp) and other notable features, and the possibility of such effects should be considered in the design of any monitoring program if a farm is established at any of the proposed sites.

1 Introduction

1.1 Background and Scope

The Ministry for Primary Industries has engaged NIWA to undertake ecological benthic assessments at eight potential aquaculture farm sites in the Marlborough Sounds (five in Pelorus Sound and three in Tory Channel) as part of the process to assess their suitability for relocation of existing salmon farms. The surveys and analyses at each site are designed to describe benthic ecological features, to predict the depositional footprint from the farming activity, and to identify benthic features that may be affected.

Part 1 of the assessment (Brown et al 2016), described the benthic ecological characteristics at all eight sites, and identified notable ecological features that would be considered to have significant ecological, scientific or conservation value in the context of the biogeographic region of the Marlborough Sounds (see Davidson et al 2011), including benthic resources that are likely to be of particular interest to local Tangata Whenua groups and also fishing interests (commercial and recreational). This report comprises Part 2 of the assessment, presenting a modelled deposition footprint for each of the eight potential farms in Pelorus Sound and Tory Channel (Figure 1-1, Table 1-1), and an assessment of the likely effects to habitats and communities at those sites.

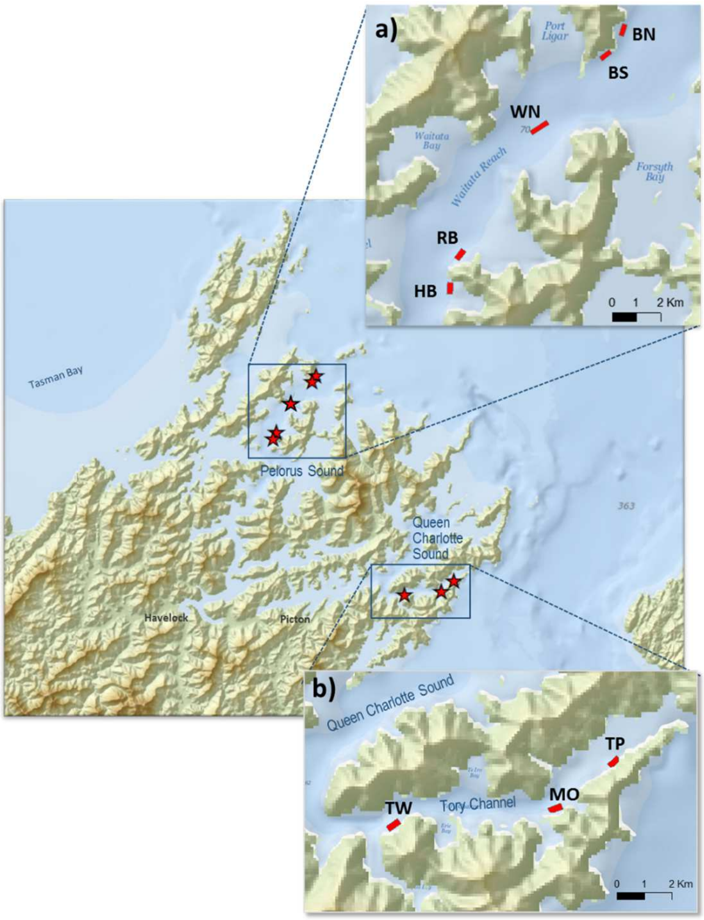


Figure 1-1: Map of proposed farm locations in Marlborough Sounds. a) Farm sites within Pelorus Sound (BN= Blowhole Point North, BS= Blowhole Point South, WN Waitata North, RB= Richmond Bay, HB= Horseshoe Bay); b) Farm sites within Tory Channel (TP = Tipi Bay, MO= Motukina, TW= Te Weka Bay).

Table 1-1: Location and size of the eight proposed farm sites.

Site	Ref No.	Total area (Ha)	Latitude °S	Longitude °E
Blowhole North	34	10	40° 55’ 54.43772 S	174° 01’ 01.84054 E
Blowhole South	122	10	40 ° 56’ 26.80217 S	174 ° 00’ 27.19076 E
Waitata Reach	125	16	40° 58’ 06.30473 S	173° 58’ 34.42026 E
Richmond South	106	11	41° 00’ 50.91566 S	173° 56’ 25.58251 E
Horseshoe Bay	124	11	41° 01’ 26.00837 S	173° 56’ 09.08216 E
Tipi Bay	42	9	41° 13’ 34.37781 S	174° 17’ 06.88767 E
Motukina	82	11	41° 14’ 31.19472 S	174° 15’ 38.51199 E
Te Weka Bay	47	12	41° 14’ 52.25166 S	174° 11’ 24.56129 E

1.2 Approach: Modelling and assessment

Part 1 of the assessment, comprising a benthic survey to describe the main benthic ecological features in the vicinity of each site, including the area within the farm boundaries and the adjacent embayment, is presented in detail in Brown et al (2016). Summarised results from that survey, including maps showing the location of notable ecological features are combined with 2-dimensional depictions of the modelled depositional footprint at each site to enable an assessment of potential effects in this, Part 2 of the study.

There are a number of modelling tools that can be used to predict aquaculture impacts. DEPOMOD was chosen to simulate depositional footprints in this study because it was developed specifically to predict organic deposition resulting from fish faeces and uneaten feed under finfish aquaculture sites (Cromey et al 2002), it is a relatively simple tool that can be easily applied to individual sites and requires less observational data than some other modelling tools, and it has been widely used internationally as a rapid assessment tool to delineate benthic footprints (e.g. Black et al 2008, Keeley et al 2013a). DEPOMOD simulations require particular parameters to be specified including feed input and current flow profiles, to forecast the magnitude and spatial extent of the benthic deposition from the proposed farming. For this study, two-dimensional depictions of the DEPOMOD footprint simulations are overlaid on maps showing the location of notable ecological features that were identified in Part 1 of the study (Brown et al 2016), to enable an assessment of the potential effects of farm deposition on significant ecological features at each site. The drawn boundaries of the notable features depicted in the maps are intended to indicate their location rather than to precisely define their extent. This is because ecological features usually do not have sharply defined boundaries, and also because the benthic sampling is not continuous across the seabed due to practical constraints of time and resources.

To translate the results of the depositional modelling into an assessment of the effects on the benthic habitats and biological communities, we used thresholds of depositional flux identified as causing discernible ecological effects, following recommendations in the ‘Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Benthic environmental quality standards and monitoring protocol’ (Keeley et al 2015). The guidelines and the research underpinning them largely consider benthic effects in terms of the depositional footprint over soft sediment habitat. While the methods used in developing those guidelines are not well proven where the deposition extends over other habitat types and substrata such as reef or coarse biogenic gravels, they are currently the best available tools for assessing salmon farm impacts in the Marlborough region.

Experimental work has indicated that sites with mean current speeds >~0.1 m s^{-1} can be broadly described as dispersive sites (where the magnitude of deposition directly below the farm will be lower but the spatial extent of the footprint will be greater), and those with lesser current speeds can be considered non-dispersive (greater intensity of deposition beneath the farm, but spatial extent of footprint less) (Cromey et al 2002, Keeley et al 2013a). In a study of multiple salmon farm sites in the Marlborough Sounds, Keeley et al (2013a) related the quantity of depositional flux to an index of enrichment stages (ES) that integrates a number of different chemical and ecological indicators of enrichment into a single index, with each stage characterised by observable environmental impacts (Appendix A). Seven enrichment stages (ES) are identified along the continuum from pristine unenriched conditions (ES = 1.0) to extremely enriched anoxic and azoic conditions (ES = 7.0). We *a priori* designated the outer edge of the benthic footprint as ES3 because this is the lowest level of enrichment that is clearly distinguishable from natural background levels (Keeley and Taylor 2011, Keeley et al 2015). Moderately enriched conditions designated as ES3 are produced by a deposition rate of ~0.4 kg solids m^{-2} yr^{-1} at non dispersive sites, and ~1 kg solids m^{-2} yr^{-1}at dispersive sites. ES3 at dispersive sites such those considered in this assessment is characterised by a measurable increase in infaunal abundance, reduced diversity of taxa and increased abundance of opportunistic species, especially Capitellid polychaete worms. An intermediate stage of high enrichment (ES4) is transitional between moderate effects (ES3) and peak abundance of macrofauna in ES5, and is characterised by major changes to the infaunal community. Rates of deposition of ~6 kg solids m^{-2} yr^{-1} at non-dispersive sites and ~13 kg solids m^{-2} yr^{-1} at dispersive sites will produce a state of very high enrichment designated as ES5 (Keeley et al 2013). At dispersive sites such as those considered in this assessment, ES5 is characterised by extremely high abundance of opportunistic macrofaunal species, significantly reduced faunal diversity and the possibility of bacterial mat (*Beggiatoa*) formation and some outgassing of hydrogen sulphide gas from the sediment. At ES5 the benthos is still considered biologically functional and is often associated with the greatest benthic biomass (Keeley et al. 2013a, 2015) and therefore the greatest waste assimilation capacity. ES5 is considered to be the upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds, and any increase in the rate of waste deposition will lead to ES6 marked by a decline in macrofaunal abundance, major changes in sediment chemistry, formation of bacterial mats and outgassing from the sediment resulting from a build-up of hydrogen sulphide gas. Continued high rates of deposition can then lead to enrichment stage ES7 at which point sediments become anoxic and devoid of macrofauna.

2 Methods

2.1 Current Measurements

A RD Instruments Acoustic Doppler Current Profiler (ADCP) was deployed at three sites in Pelorus Sound on 7 March, 2016. The three ADCPs were recovered on 12 April, 2016, and re-deployed at the three sites in Tory Channel on 13 April, then finally recovered on 28 May. A summary of locations for the eight current meter deployments is given in Table 2-1.

An ADCP uses the Doppler shift to measure currents in the ocean. Data measuring full water column currents were collected every 10 minutes with varying bin sizes dependent on site characteristics. Each depth measured is referred to as a bin, and the full column of bins is referred to as a profile. A well-known limitation of ADCPs is the loss of data near the surface due to the spreading of the

Table 2-1: Current meter deployment locations.

	Latitude (S)	Longitude (E)	Depth (m)
Blowhole Pt North	-40 55.921	174 01.012	51
Blowhole Pt South	-40 56.410	174 0.531	59
Waitata Reach	-40 58.215	173 58.364	64
Horseshoe Bay	-41 01.429	173 56.09	43.5
Richmond Bay	-41 00.831	173 56.412	50.3
Tipi Bay	-41 13.585	174 17.040	30
Motukina	- 41 14.522	174 15.640	30
Te Weka Bay	-41 14.864	174 11.408	30

acoustic beams on the instrument (~10% of the water depth). Therefore each profile from an ADCP provides current measurements from close to the seabed to within the top 10% of water depth where the instrument was deployed. ADCP observations at the Richmond South and Horseshoe Bay sites were collected by the Cawthron Institute during 2015 and those data were provided to NIWA for use in the modelling and assessment of potential depositional effects at those sites.

Two figures are included per site in the results section. The first figure is a current rose diagram which includes current magnitude and direction for all bins of quality-controlled observations. The second figure shows a different aspect of the ADCP data by including a) the relationship between current direction and magnitude, and b) the average magnitude and direction at each depth for the observation period. The second figure was used to identify depths of strong currents or dominant flow directions which is an important factor when evaluating footprints and material transport. This is particularly important when the contribution from estuarine flows are significant as can be the case for some areas in Pelorus Sound.

2.2 DEPOMOD

The model requires data on bathymetry, current velocities, and feed inputs. Bathymetry data were sourced from our own depth measurements at each site plus hydrographic soundings acquired from LINZ data service (https://data.linz.govt.nz/layer/3388-nz-bathymetric-data-index/). The current data were measured by an ADCP that was moored onsite for 34 days at the Pelorus Sound sites and 45 days at the Tory Channel sites. Time-series of ADCP data were extracted into 5 depth layers. The domain size for each farm varied according to farm size, feed inputs and local velocities at each site (Table 2-2). Nominal annual feed input figures were determined in consultation with the New Zealand King Salmon Company Ltd. NIWA has conducted experiments to measure size-specific and particle type-specific settling velocities for feed and faeces and the model's default settings have been improved by incorporating particle size classes and settling velocities based on those experimental data (Table 2-3). The following default parameters were set for the model: 3% for feed wastage rates, 10% for water content, 85% for digestibility. For the turbulence sub-model (random walk), horizontal and vertical dispersion coefficients were set at 0.1 $m^2 s^{-1}$ and 0.001 $m^2 s^{-1}$ respectively. Cage area dimensions used were those provided in the structure diagrams (as shown in the map figures in this report) and net depth was assumed to be 20 m. The number of loops to run the model was set to 10 and the bulk sediment density was assumed to be 1500 kg m^{-3}. The model was run using the scenario of continuous feed release. Default values of DEPOMOD were used for the simulations because the model was previously verified using those default values at NZ King

Salmon Ltd. Farms in the Marlborough Sounds by Keeley et al. (2013). In that study, the modelled deposition using default values reasonably matched (was close to) the observed deposition patterns.

Table 2-2: Key parameters used in DEPOMOD simulations.

Farm site	Annual feed usage scenarios (tonnes)	Domain size (m)	Grid cell size (m)
Blowhole Point North	5000, 4500	1000 x 1400	10 × 14
Blowhole Point South	5000	1400 x 1400	14 × 14
Waitata Reach	12000	2500 x 2500	24 × 24
Richmond Bay South	6500	2400 × 1000	24 × 10
Horseshoe Bay	2500, 1500	1000 × 1000	10 × 10
Tipi Bay	2000, 1000	1400 x 1000	14 × 10
Motukina	5000, 1000	1400 x 1000	14 × 10
Te Weka	5000, 1800	1400 x 1000	14 × 10

Table 2-3: Parameters for salmon feed and faeces used in DEPOMOD simulations.

Feed settling velocity (mm/s)	Feed (% of total volume)	Faeces settling velocity (mm/s)	Faeces (% of total volume)
<30	0.4	<5	0.6
20-30	4.5	5_10	12.6
30-40	14.2	10_15	31
40-50	17	15-20	29.4
50-60	24.6	20-25	15.5
60-70	16.2	25-30	8.9
>70	23.1	30-35	1.2
		>35	0.8

2.2.1 DEPOMOD assumptions and limitations

DEPOMOD includes an optional flow-related resuspension module, but a model verification study conducted by Keeley et al (2013a) in the Marlborough Sounds found that model results at high-flow sites (mean current velocities >15 cm s^{-1}) were unrealistic when resuspension was included in the model and were more consistent with the field survey data when resuspension was not included. Therefore we did not include resuspension in our model runs.

DEPOMOD was developed primarily in reference to low-flow sites (currents less than ~ 9 cm s^{-1}) with fairly uniform bathymetry, and is considered to be less accurate in predicting benthic depositional footprints at high-flow sites with complex bathymetry. One limitation is that the vertical profile of currents measured by the ADCP at a single position is assumed to be uniform throughout the entire modelled area. This limits the accuracy of the model at sites where currents are swift and bathymetry is complex and there is a greater likelihood for flow characteristics throughout the modelled area to vary from those measured at the position where the ADCP was deployed.

2.3 Linking predicted depositional flux to ecological effects

For this assessment we defined the outer extent of the deposition footprint as the point at which the enrichment stage was predicted to be ≥ enrichment stage ES3. At dispersive sites such as those considered in this assessment, ES3 is produced by a deposition rate of ~1 kg solids m^{-2} yr^{-1} and is characterised by a measurable increase in infaunal abundance, reduced diversity of taxa and increased abundance of enrichment-tolerant opportunistic species, especially capitellid polychaete worms. We also depicted the area where deposition of between 6 and 12 kg solids m^{-2} yr^{-1} was predicted in our maps of the depositional footprints. That level of deposition is expected to produce the 'high' enrichment stage ES4 exhibiting further reduced faunal diversity, elevated abundance, dominance of opportunistic species (but other taxa may still persist), and evidence of major sediment chemistry changes (approaching hypoxia). The other relevant threshold used in this assessment was the 'very high' enrichment category ES5, considered to be the upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. ES5 is produced at dispersive sites by a rate of deposition of ~13 kg solids m^{-2} yr^{-1} (Keeley et al 2013a), and is characterised by extremely high abundance of opportunistic macrofaunal species, significantly reduced faunal diversity and the possibility of bacterial mat formation and some outgassing of hydrogen sulphide gas from the sediment. Note that throughout this report figures for depositional flux reported as kg m^{-2} yr^{-1} pertain to the total solids rather than only the Carbon (C) component. For sites where the proposed feed input resulted in forecast deposition exceeding the accepted limits of intensity, additional modelled scenarios using successively lower feed inputs were produced until a level was reached that did not result in deposition producing enrichment exceeding ES5.

Research in New Zealand and overseas describing the ecological effects of deposition from finfish farms has mainly focussed on effects on the animals living within the sediments, the infauna. Most of the 'notable ecological features' identified in Part 1 of this assessment were either populations of animals or algae living on the seabed surface (epibiota), or else substrata and habitats such as bedrock reef that support diverse communities of epibiota and fish. The effects of deposition from finfish farms on epibiota in New Zealand have not been widely studied or described so the effects resulting from a given level of deposition cannot be precisely forecast. Thus the predictions of effects on the notable features presented in this assessment are necessarily general and are intended to indicate where the spatial extent of deposition from the farms could potentially affect the notable features identified, rather than to forecast the precise level of impact.

3 Results

3.1 Blowhole Point North (34)

3.1.1 Blowhole Point North, general site information

The proposed site is 10 Ha in area located between Blowhole Point and Mataka Point at the entrance to Pelorus Sound. The farm boundaries are positioned over a sloping seabed in depths between 28 and 80 m (Figure 3-1).

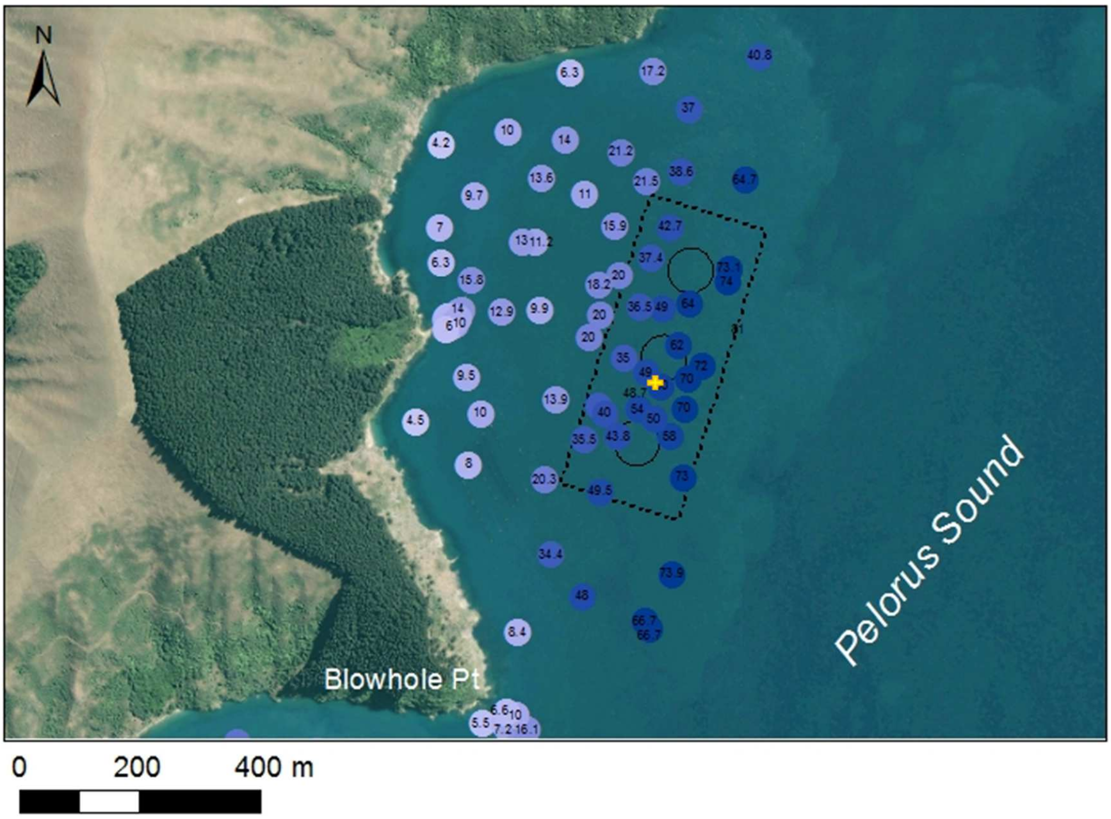


Figure 3-1: Station depths and ADCP position at Blowhole Point North site. Colour depicts depth from shallow (white) to dark blue (deep), central values are depths in metres. Yellow cross depicts ADCP position.

3.1.2 Currents at Blowhole Point North

The ADCP deployed at Blowhole Point North measured currents from 11m below the surface to 3m from the sea bed. The dominant direction of flow was to the south-west (Figure 3-2). Approximately 17% of profiles exceeded 0.2 m s^{-1} and 5% of profiles exceed 0.34 m s^{-1} over the 36-day ADCP deployment. Examining all of the observations by magnitude and direction, higher current speeds up to 0.65 m s^{-1} were associated with the flows towards the SW (Figure 3-3). Mean mid-water current speed was 0.13 m s^{-1}, and mean near-bottom current speed was 0.12 m s^{-1} so this site would be considered a relatively dispersive site in terms of transport of farm waste particles.

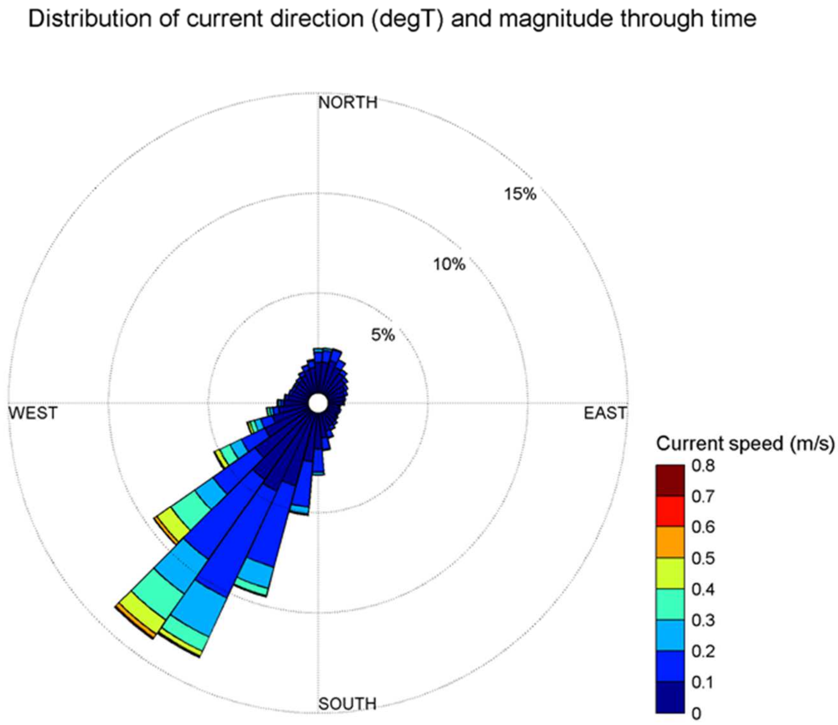


Figure 3-2: Current rose showing current directions and magnitudes for all bins at Blowhole Point North.

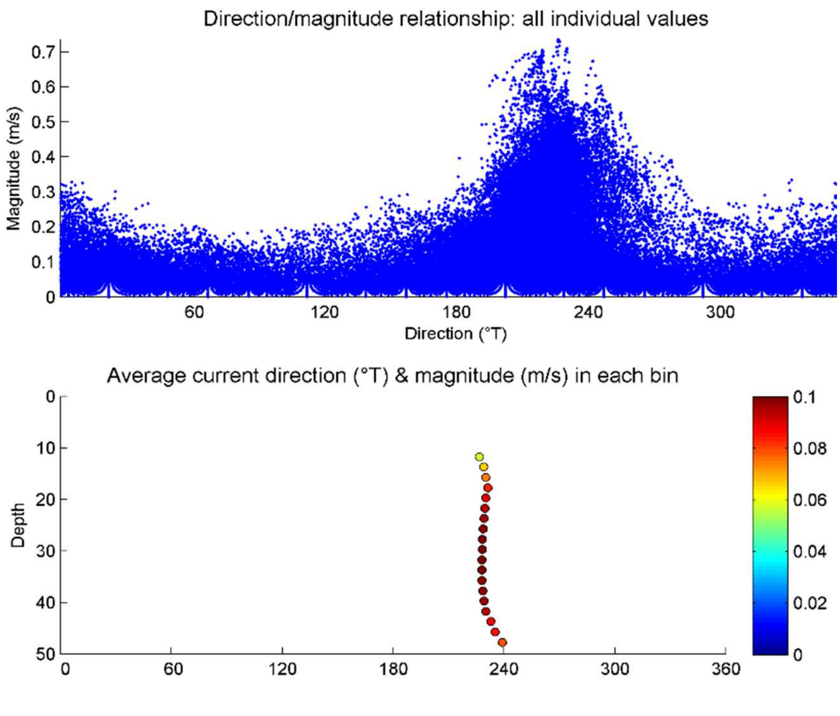


Figure 3-3: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at Blowhole Point North.

3.1.3 Habitats, communities and notable features at Blowhole Point North

The substratum beneath the cage area and the remainder of the proposed site was mainly sandy mud with a varying component of shell gravel. The sloping mud seabed and much of the surrounding embayment supported a fairly sparse faunal community typical of outer Marlborough Sounds deep mud habitat (Figure 3-4). Scallops (*Pecten novaezelandiae*), were noted as abundant throughout almost the entire length of the site at depths between 21 and approximately 45 m. At depths greater than 30 m, isolated small biogenic clumps composed of aggregations of hydroids, colonial ascidians, and macroalgae were present above the mud substratum. These types of associations are considered to have ecological value in supporting benthic biodiversity in the region (Davidson et al 2011), however the biogenic clumps found on the mud habitat within the site boundaries were relatively small and were sparsely distributed. A relatively diverse infaunal assemblage was dominated by polychaetes, small crustaceans, and bivalve taxa that are common and widespread within the outer Marlborough Sounds region (e.g. McKnight and Grange 1991).

Brachiopods (*Terebratella sanguinea* and *Calloria inconspicua*) were found in dredge and grab samples from within the southern half of the site. Diatom films were extensive over the shallow soft sediment habitat inshore of the site and beds of bladed and tufting red macroalgae were present in patches. A substantial bedrock reef extends to the southeast of Blowhole Point itself, providing habitat for a diversity of macroalgae, sessile and mobile fauna, and associated reef, demersal and pelagic fishes (Brown et al 2016). Fringing the shoreline were patches of shallow reef and kelp (e.g. *Carpophyllum* spp. and *Cystophora* sp.) communities. The presence in that reef habitat of paua (*Haliotis iris*), kina (*Evechinus chloroticus*) and high density patches of the anemone *Anthothoe albocincta* were notable features (Figure 3-4). The varied shoreline habitats and adjacent subtidal zone are also blue cod habitat.

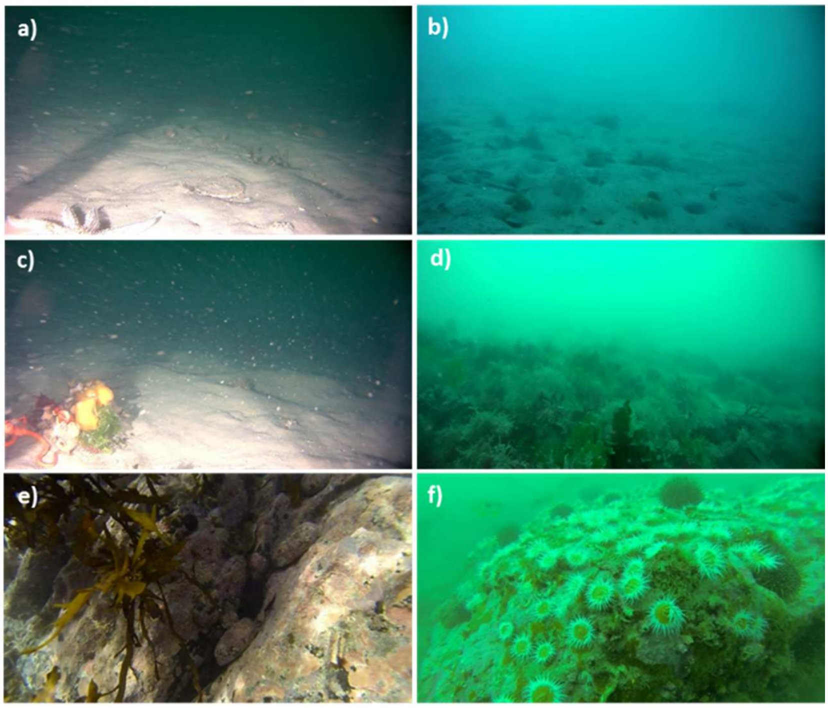


Figure 3-4: Main habitats and communities within the site and surrounding embayment... a) Mud habitat with scallop and starfish mid-site; b) Mud and scattered shell drop from mussel farm adjacent to the site; c) Isolated biogenic clump on mud d) Macroalgal bed close to shoreline; e) Shoreline reef community with *Carpophyllum maschalocarpum* and paua; f) Shoreline reef habitat with anemones (*Anthothoe albocincta*) and kina (*Evechinus chloroticus*).

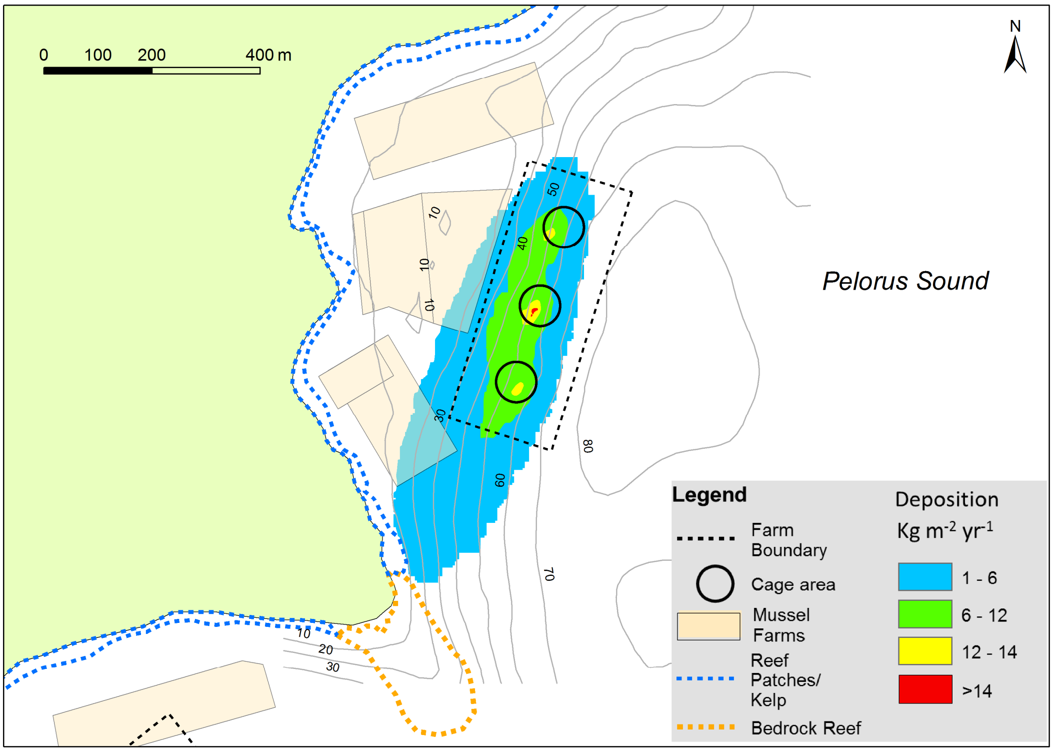
3.1.4 Predicted depositional effects at Blowhole Point North

At this site, for the initial proposed feed input of 5000 tonnes per year, the DEPOMOD simulation predicts that a small area (approximately 100 m^2) on the seabed beneath the cages would be subject to deposition greater than 13 kg solids m^{-2} yr^{-1} (Figure 3-5 a). Although that level of deposition could lead to enrichment exceeding enrichment stage ES5 (considered to be the maximum sustainable level beneath salmon farms in the Marlborough Sounds), only a small area would be affected.

An alternative lesser feed input scenario of 4500 tonnes per year was also modelled, and that predicted maximum rate of deposition between 12 and 14 kg solids m^{-2} yr^{-1} within a small area (~300 m^2) beneath the farm (Figure 3-5b). Within that zone, deposition is expected to induce conditions of high to very high enrichment designated as enrichment stages ES4 to ES5 (Keeley et al 2012, 2013), and characterised by very high abundance of enrichment-tolerant infauna (e.g. Capitellid worms), significantly reduced faunal diversity and possibly bacterial mat (*Beggiatoa*) formation and outgassing of hydrogen sulphide. In the immediate vicinity of the cages, conspicuous epibiota such as scallops, and the small biogenic clumps comprised of hydroids, sponges and macroalgae are expected to be displaced. Brachiopods will also be excluded there. Beyond that zone, an area of ~15 Ha is forecast to be affected by the wider primary footprint within which deposition can be expected at rates decreasing from ~12 kg m^{-2} yr^{-1} to ~1 kg m^{-2} yr^{-1} at the outer edge of the depositional footprint (Figure 3-5b). That zone extends approximately 360 m south of the cage area, almost to Blowhole Point, and is expected to cause effects ranging from ES4 (high enrichment) close to the cage area to enrichment stage ES3 (moderate enrichment) in the distal edges of the footprint. Within the wider footprint under moderately enriched conditions (ES3), infaunal abundance (particularly of opportunistic species) is expected to increase, and diversity may decrease. Scallops may be displaced from a large portion of the wider footprint, but other more enrichment tolerant epibiota (for example sea cucumbers *Australostichopus mollis*) may not be negatively affected.

Although the primary deposition footprint does not extend over the bedrock reef at Blowhole Point and the other notable features identified inshore of the site including macroalgal beds, small patch reef and kelp communities and the associated biota such as paua and kina, it is possible that temporal cumulative effects from low levels of waste particulates from the farm, and resuspension and dispersion of dissolved nutrients transported beyond the primary footprint could affect those features. If this site (34) and the Blowhole Point South site (122) were both developed, there would be the possibility of cumulative effects of low-moderate deposition from both farms having some effect on the reef community at Blowhole Point. The possibility of such effects should be considered in the design of any monitoring program if a farm is established on the site.

a)



b)

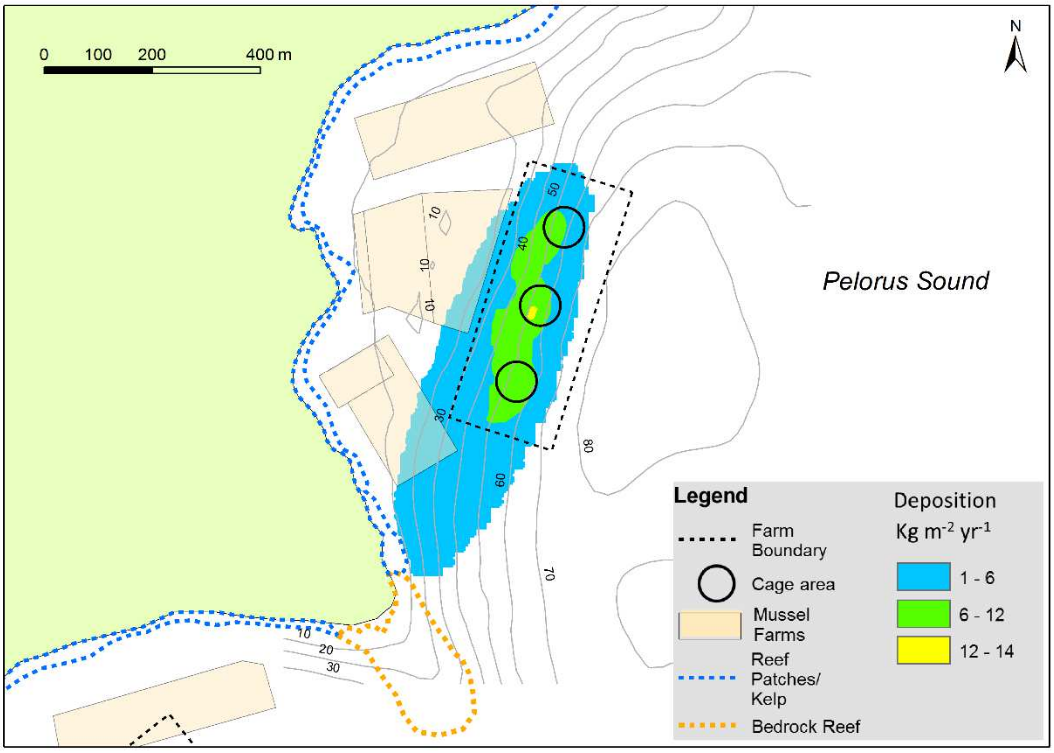


Figure 3-5: Predicted deposition footprint and notable ecological features at the Blowhole Point North site. Annual feed input scenarios of 5000 tonnes (a, above), and 4500 tonnes (b, below). Depth contour units are meters. Boundaries of notable ecological features are approximate.

3.2 Blowhole Point South (122)

3.2.1 Blowhole Point South, general site information

The proposed site at Blowhole Point South covers an area of 10 Ha located between Blowhole Point and West Entry Point at the entrance to Pelorus Sound. The farm boundaries are positioned over a sloping seabed in depths between 38 and 65 m (Figure 3-6).

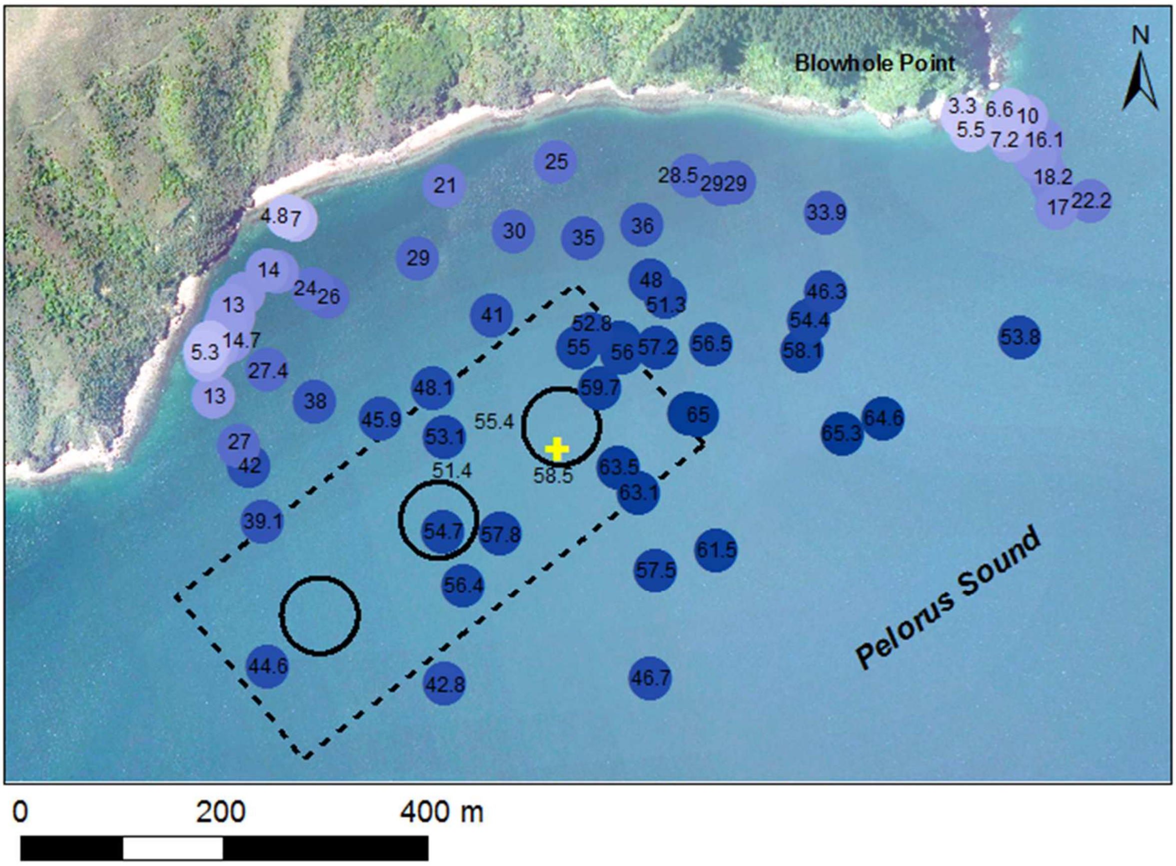


Figure 3-6: Station depths and ADCP position at Blowhole Point South. Colour depicts depth from shallow (white) to dark blue (deep), central values are depths in metres. Yellow cross depicts ADCP position.

3.2.2 Currents at Blowhole Point South

The ADCP profiles at Blowhole Point South span from 5m below the surface to 2m from the sea bed. Current speeds exceeded 0.2 ms^{-1} for 20% of the deployment and were directed towards the NE and ENE direction (Figure 3-7). The fastest currents of 0.38 ms^{-1} occurred for around 5% of the 36-day observation period. Any currents flowing towards the west (into the Bay) were weak at less than 0.1 ms^{-1} . The time-averaged profile showed weaker near-bed flows that increased towards the surface, where currents of 0.2 ms^{-1} were directed to the NE (Figure 3-8). Mean mid-water current speed from was 0.14 m s^{-1}, and the mean near-bottom current speed was 0.15 m s^{-1} so this site is considered to be a dispersive site in terms of transport of farm waste particles.

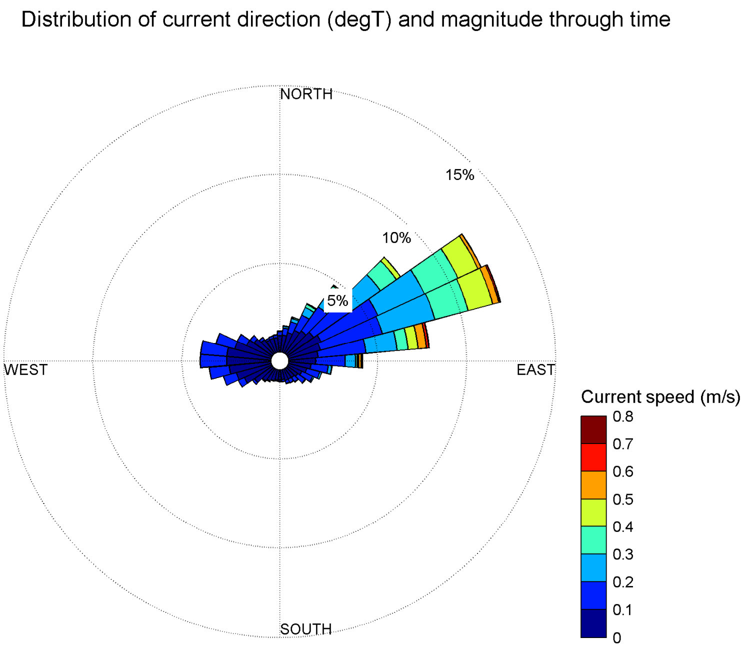


Figure 3-7: Current rose showing current directions and magnitudes for all bins at Blowhole Point South.

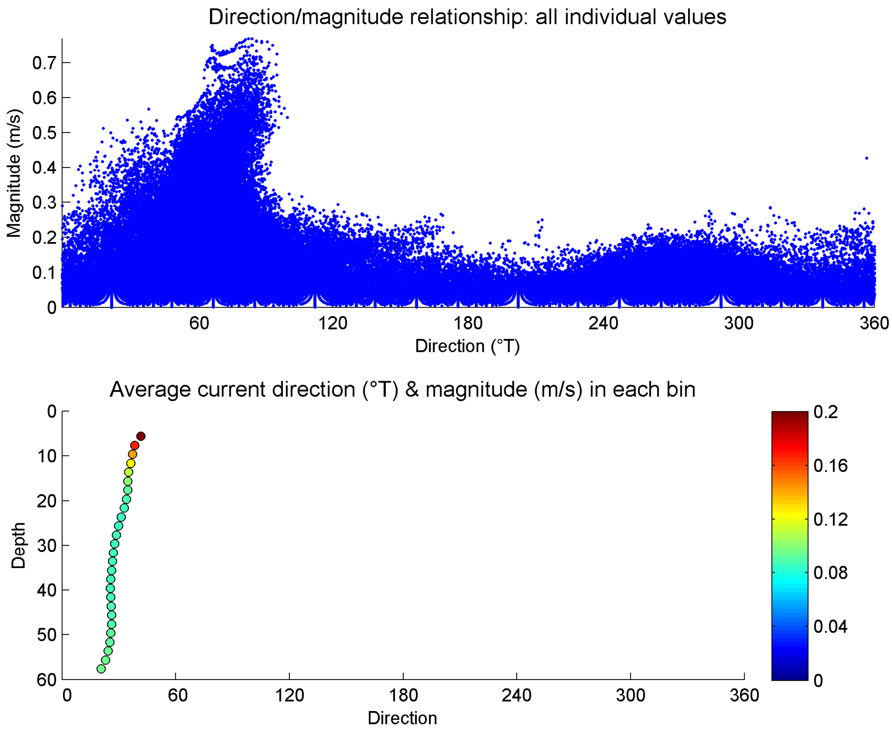


Figure 3-8: All observations of current magnitude and direction (top panel) and time-averaged profile of magnitude and direction (bottom panel) at Blowhole Point South.

3.2.3 Habitats, communities and notable features at Blowhole Point South

The cage area and most of the remainder of the site is situated over a sandy mud/shell gravel habitat (Figure 3-9 a, b) supporting a mixed community comprising rather sparsely distributed macroalgae and diverse invertebrates. Infaunal and epifaunal diversity at this site was relatively high. The northwest corner of the site overlaps an existing mussel farm and in that area the benthic community was influenced by mussels (Figure 3-9 c) and other biota dropping from the mussel farm structures. Brachiopods were sparse and widely dispersed at the site. The substratum inshore of the site was variable, with a range of different community types, including muddy sand with patches of shell hash (Figure 3-9d), and kelp communities on small patch reefs. Scallops were also noted as common inshore of the farm site. A significant reef extends for at least 200 m to the southeast of Blowhole Point into the channel, to approximately 60 m depth and it is approximately 350 m distant from the NE corner of the site. The reef provides habitat for a high diversity of macroalgae, and sessile and mobile fauna, and associated reef, demersal and pelagic fish species. A smaller inshore reef surveyed provided habitat for taxa that are all common and widespread in the outer Marlborough Sounds region.

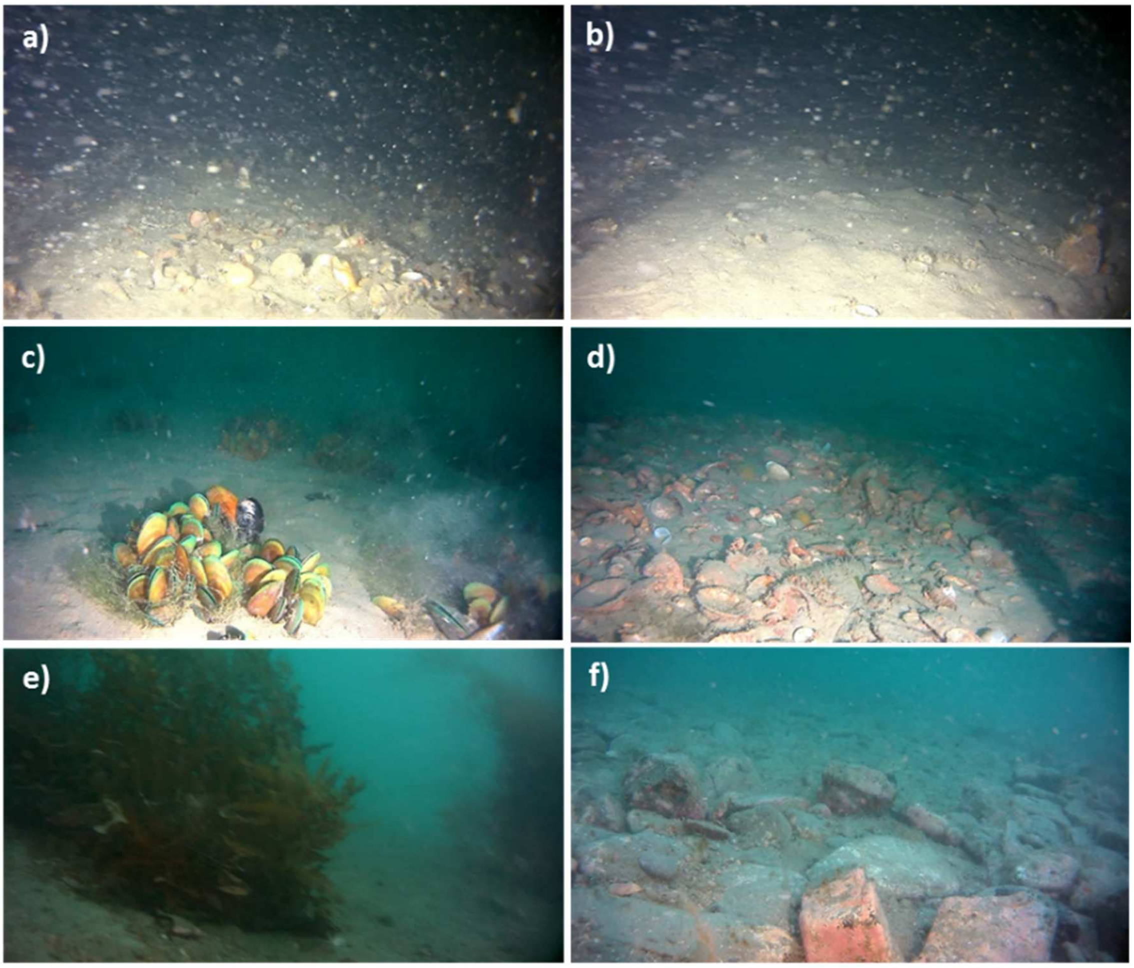


Figure 3-9: Habitat types at the Blowhole South site and surrounding embayment.

a) Mud and shell rubble habitat within the site boundaries; b) Sandy mud habitat within the proposed site; c) mussel drop from existing farm at the Northwest end of the site; d) Sandy mud and shell rubble habitat inshore of SW end of the site; e) kelp (*Carpophyllum maschalocarpum*) and sand near the shoreline; f) Inshore cobble habitat

3.2.4 Predicted depositional effects at Blowhole Point South

Modelling of deposition at this dispersive site using the proposed feed input scenario of 5000 tonnes per year forecast a maximum deposition intensity of ≤ 13 kg solids m^{-2} yr^{-1} (Figure 3-10). This level of deposition does not exceed the accepted upper threshold of ~13 kg solids m^{-2} yr^{-1}, and is likely to produce effects associated with enrichment stage ES4 (Keeley et al 2013). An area of ~20 Ha is forecast to be affected by the wider primary footprint within which deposition can be expected to decrease from ES4 (high enrichment) near the cages, to enrichment stage ES3 (moderate enrichment) where deposition of~1 kg solids m^{-2} yr^{-1} is expected at the distal edges of the footprint.

In the most highly impacted zone (ES4) on the sandy mud/shell gravel substratum in the immediate vicinity of the cages, conspicuous epibiota such as fan shells (*Talochlamys* sp.) and hermit crabs (*Pagurus* sp.) may be displaced, and the relatively diverse infaunal community will be modified. Faunal diversity will be reduced and opportunistic taxa especially nematodes and Capitellid polychaetes will become abundant. Scallops, brachiopods and hydroids may not persist in this zone.

Within the wider footprint under moderately enriched conditions (ES3) at a dispersive site such as this, infaunal abundance (particularly of opportunistic species) is expected to increase, and diversity may decrease slightly. The response of epibiota to moderate enrichment will vary according to the specific tolerance of each species. Epibiota in this area that are considered to be sensitive to elevated deposition such as hydroids, sponges and brachiopods may be affected over a period of time, while other taxa such as ophiuroids (*Ophiopsammus maculata*) may persist or even aggregate in moderately enriched zones.

The extensive reef projecting to the southeast of Blowhole Point provides habitat for a diversity of macroalgae, sessile and mobile fauna, and associated reef, demersal and pelagic fishes. The DEPOMOD simulation predicts that a low level of deposition (between 1 and 4 kg solids m^{-2} yr^{-1}) will extend over a portion of this reef, indicating that there is potential for some effect on communities inhabiting the reef. If this site (122) and the Blowhole Point North site (34) were both developed, there would be the possibility of additional cumulative effects from both farms on the reef community at Blowhole Point.

Far-field effects such as changes resulting from deposition of resuspended wastes, and elevated concentrations of dissolved nutrients could also potentially have negative effects on inshore habitats (e.g.patch reefs, kelp) and associated communities after a significant period of time (Keeley and Taylor 2011).

If a salmon farm is established at this site, it is recommended that a benthic monitoring plan is developed following the 'Best Management Practice guidelines for salmon farms in the Marlborough Sounds' (Keeley et al 2015) and potential effects to the Blowhole point reef as well as potential cumulative effects to inshore habitats should be considered as part of the monitoring plan.

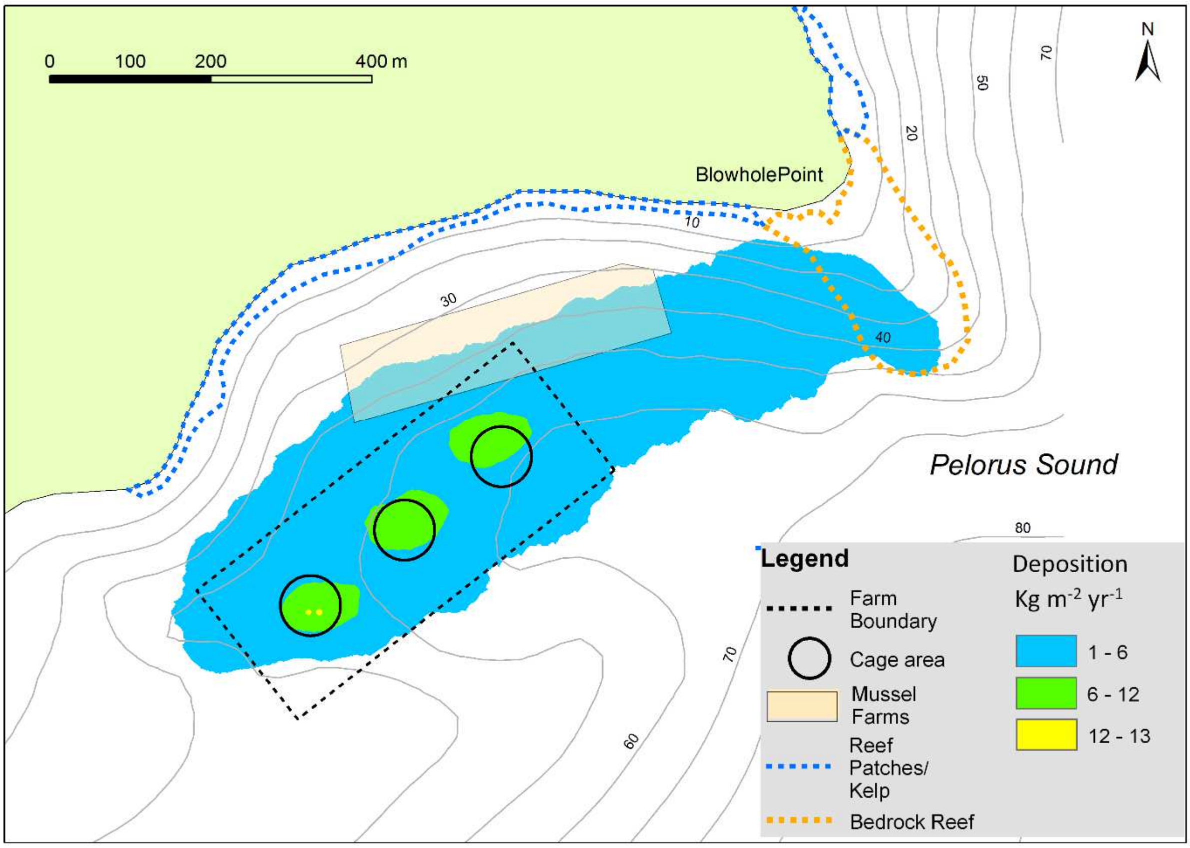


Figure 3-10: Predicted deposition footprint and notable ecological features at the Blowhole Point South site. Annual feed input scenario of 5000 tonnes. Depth contour units are meters. Boundaries of notable ecological features are approximate.

3.3 Waitata Reach Mid-Channel (125)

3.3.1 Waitata Reach general site information

Waitata Reach (125) is a deep site with an area of 16 Ha located in the centre of Waitata Reach between Burnt Point and Post Office Point. It is situated over an almost flat, sandy mud substratum where depths range from 61 to 64 m (Figure 3-11).

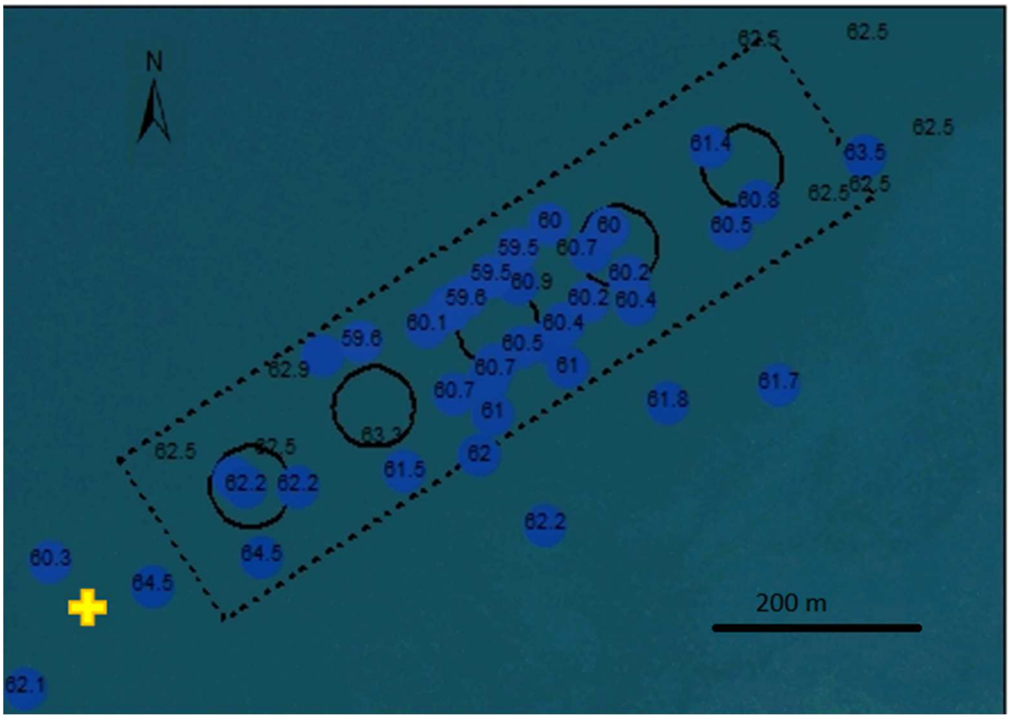


Figure 3-11: Station depths and ADCP position at mid Waitata Reach site. Central values are depths in meters. Yellow cross depicts ADCP position.

3.3.2 Currents at the mid Waitata Reach site

Current observations at the Waitata Reach site span from 5m below the surface down to 59 m. Figure 3-12 shows that the current flows were oriented in a NE/SW direction, with very few exceptions. Current speeds were greater than 0.2 ms^{-1} for 52% of the 36-day deployment, and 10 % of the currents exceeded 0.4 ms^{-1}.

Separating currents into associated depths showed the top 8m were directed out of Pelorus Sound (NE direction, Figure 3-13). A corresponding inflow was present in the lower 4 bins (SW direction, Figure 3-14). This two-layer flow is a typical estuarine flow that is set up by the density stratification in the system. While the strongest time-averaged flows were directed out of Pelorus Sound (Figure 3-15), a moderate average inflow (up to 0.1 ms^{-1}) in the lower water column would move any material below 30 to 40m into Pelorus Sound. This site exhibited the strongest current profiles with a mean mid-water current speed of of 0.24 m s^{-1}, and mean near-bottom current speed of 0.22 m s^{-1}.

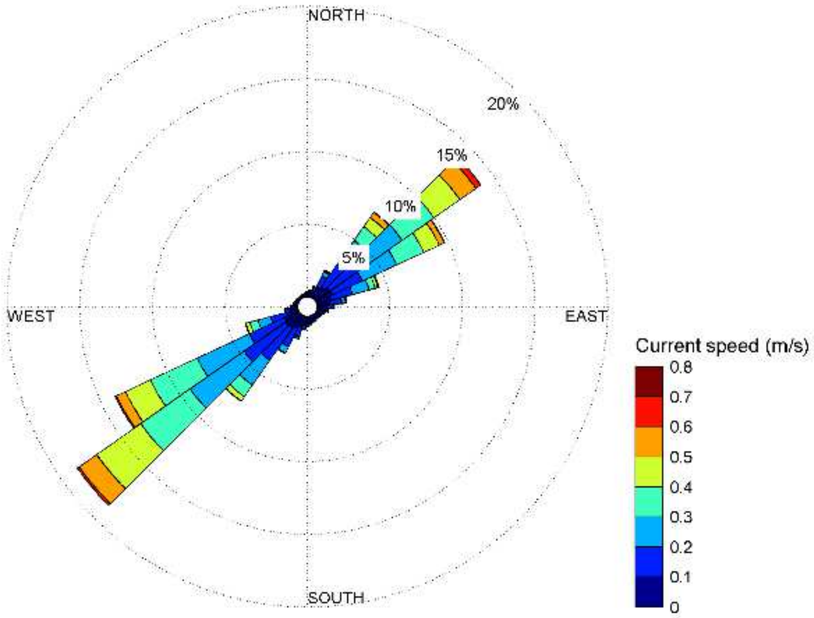


Figure 3-12: Current rose showing current directions and magnitudes for all bins at mid Waitata Reach.

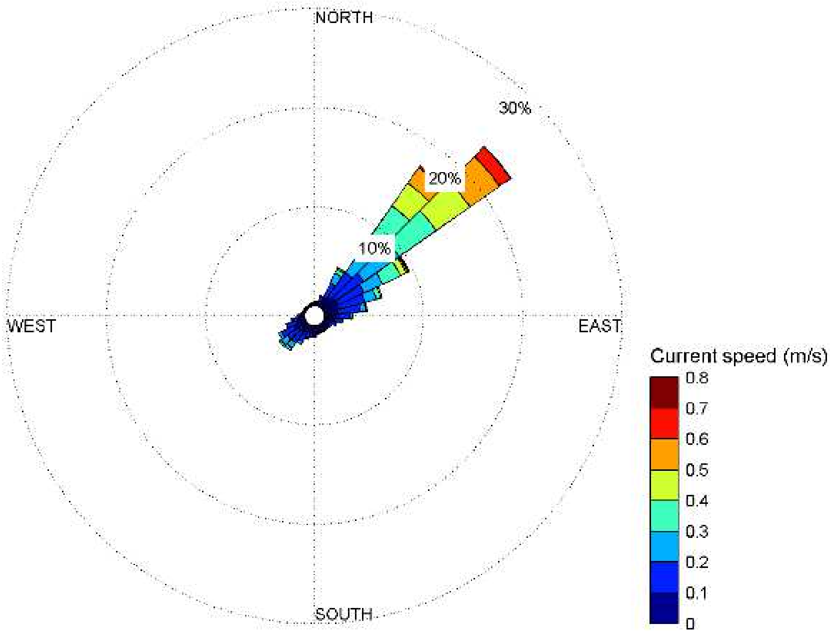


Figure 3-13: Current rose showing current directions and magnitudes for the top four bins at mid Waitata Reach.

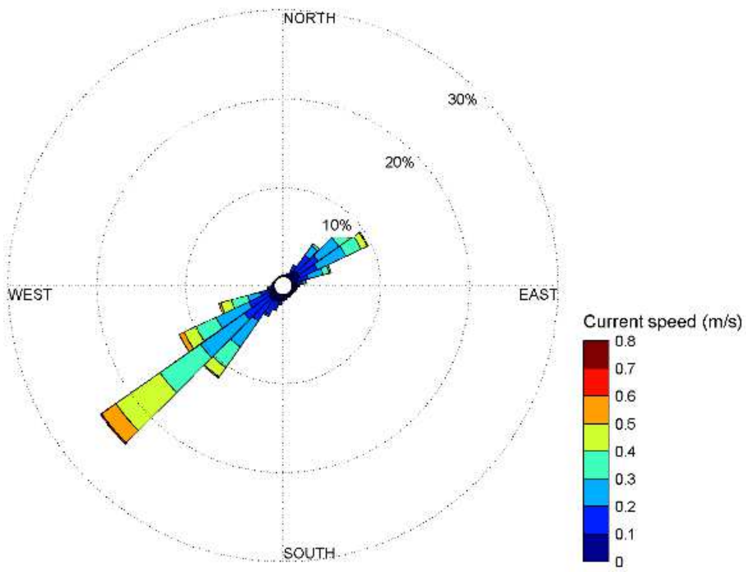


Figure 3-14: Current rose showing current directions and magnitudes for the lowest four bins at mid Waitata Reach.

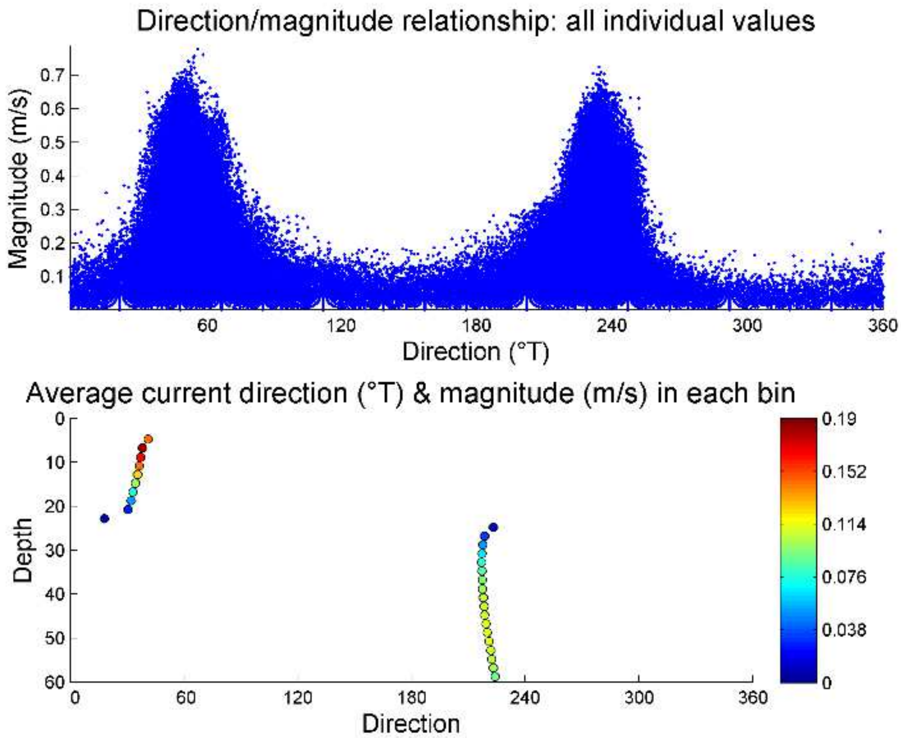


Figure 3-15: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at mid Waitata Reach.

3.3.3 Habitats, communities and notable features at mid Waitata Reach site

The habitat throughout this deep site was sandy mud (Figure 3-16) and the community sampled at that depth only comprised faunal taxa, with no macroalgae recorded from the grab, dredge or drop cam samples. The invertebrate community was sparse throughout the entire site except for zone of moderate densities near the centre of the site. The species assemblage sampled in the epibenthic sled tows comprised taxa that are known to be widespread and common in the Marlborough Sounds deep mud habitat (e.g. McKnight and Grange 1991). Fan shells were the most common taxon seen in drop cam images. Two scallops were recorded in epibenthic sled tow samples from within the southern site (118), but no scallops were sampled from within the northern site (125). Two brachiopods were noted in epibenthic sled tows from within the site.

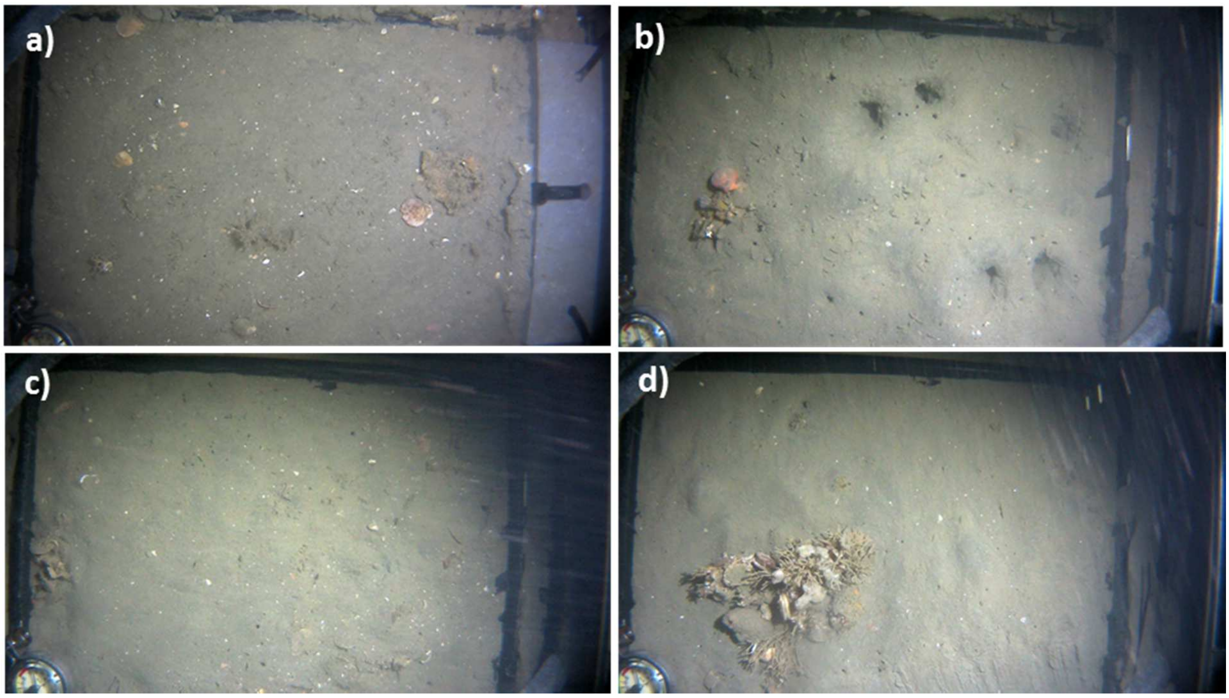


Figure 3-16: Benthic environment within the mid Waitata Reach site. a) Mud with fan shell; b) Mud with fan shell and infauna holes; c) Mud; d) Mud with small biogenic clump of bryozoans and solitary and colonial ascidians.

3.3.4 Predicted depositional effects at mid Waitata Reach

Currents measured at this site were the strongest of the five Pelorus Sound sites assessed, and this site is classified as dispersive. Using a proposed feed input of 12000 tonnes per year, the DEPOMOD simulation indicated that accepted enrichment levels of ES5 or less are expected beneath the cages and within the wider footprint. Under that scenario, a small area of <0.1 Ha on the seabed in the center of the farm is likely to be subjected to maximum deposition of between 12 and 14 kg solids $m^{-2}yr^{-1}$, producing enrichment stage ES5 (Figure 3-17). An area of ~45 Ha is forecast to be affected by the wider primary footprint within which deposition can be expected at rates decreasing from ~12 kg m^{-2} yr^{-1} directly beneath the cages, to ~1 kg m^{-2} yr^{-1} at the outer edge of the depositional footprint (Figure 3-17). That zone extends approximately 600 m to the northeast and 900 m to the southwest of the cage area, and is expected to cause impacts ranging from ES4 (high enrichment) close to the cage area to enrichment stage ES3 (moderate enrichment) toward the distal edges of the footprint.

At the seabed beneath the cages, the faunal assemblage will be modified such that some epifauna will be excluded and opportunistic species of infauna such as Capitellid polychaetes and nematodes will become abundant. Within the remainder of the footprint, elevated abundance of infauna (especially enrichment tolerant species) can be expected, and less sensitive epifaunal species will persist also. Diversity may not be affected outside of the farm site boundaries. Although the areal extent of the moderate effects footprint is predicted to be relatively extensive, there were no features of particular ecological, scientific or conservation value identified at this site by our benthic survey, and there are no shoreline habitats adjacent to the site, so in the context of the Pelorus Sound region the ecological effects from placement of a salmon farm at this site are expected to be minor.

If a salmon farm is to be established at this site, it is recommended that a benthic monitoring plan is developed following the recently developed 'Best Management Practice guidelines for salmon farms in the Marlborough Sounds' (Keeley et al 2015).

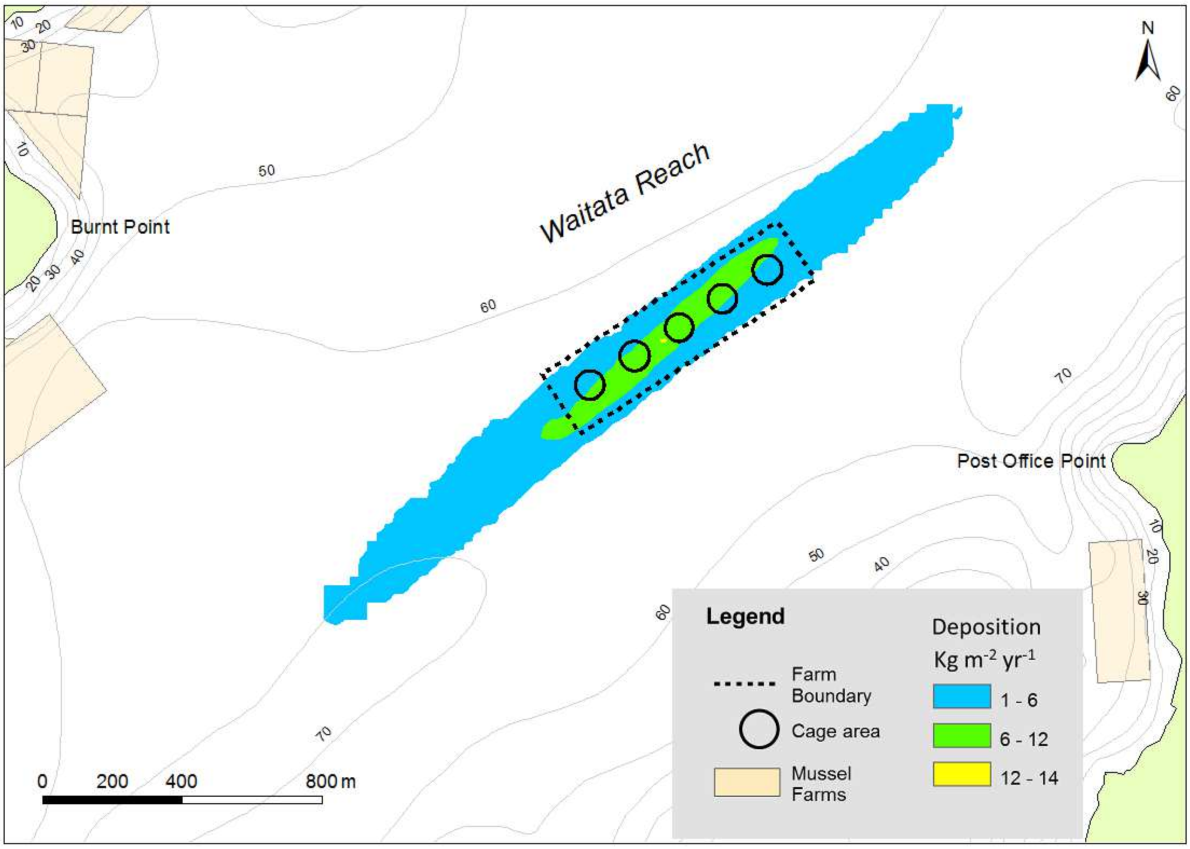


Figure 3-17: Predicted deposition footprint at the mid Waitata Reach site. Annual feed input scenario of 12000 tonnes. Depth contour units are meters.

3.4 Richmond Bay South (106)

3.4.1 Richmond South, general site information

The proposed 13.75 Ha site is located south of Richmond Bay on the east side of Waitata Reach, between The Reef and Te Kaiangapipi. The farm boundaries are positioned over a sloping seabed in depths between 30 and 56 m Figure (Figure 3-18).

Figure 3-18: Station depths and ADCP position at Richmond South. Blue shading depicts depth from shallow (white) to dark blue (deep), central values are depths in metres. Yellow cross depicts ADCP position.

3.4.2 Currents at Richmond South

Currents at the Richmond South site were directed along a NE/SW trajectory with stronger near-bed flows directed into Pelorus Sound (Figure 3-19). The mean mid-water current speed and near bottom current speed at Richmond South were both 0.18 ms^{-1} so this site is considered to be dispersive in terms of transport of farm waste.

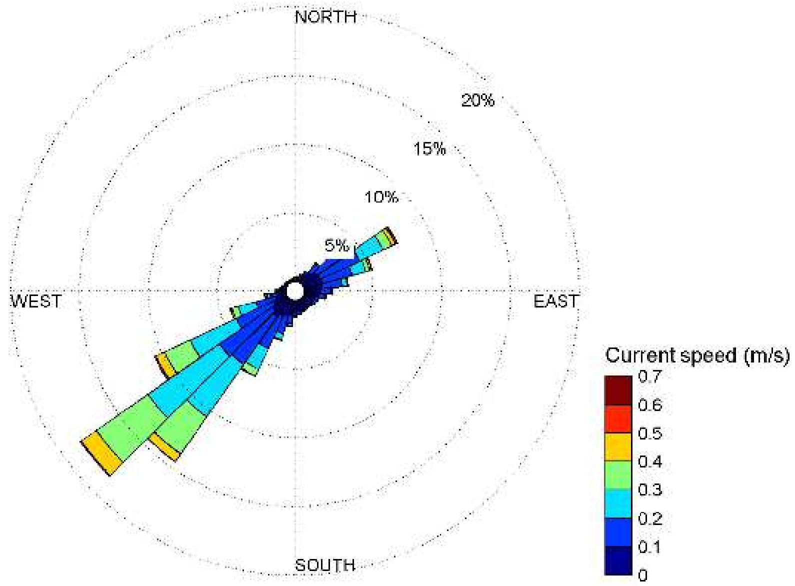


Figure 3-19: Current rose showing current directions and magnitudes for all bins at Richmond South.

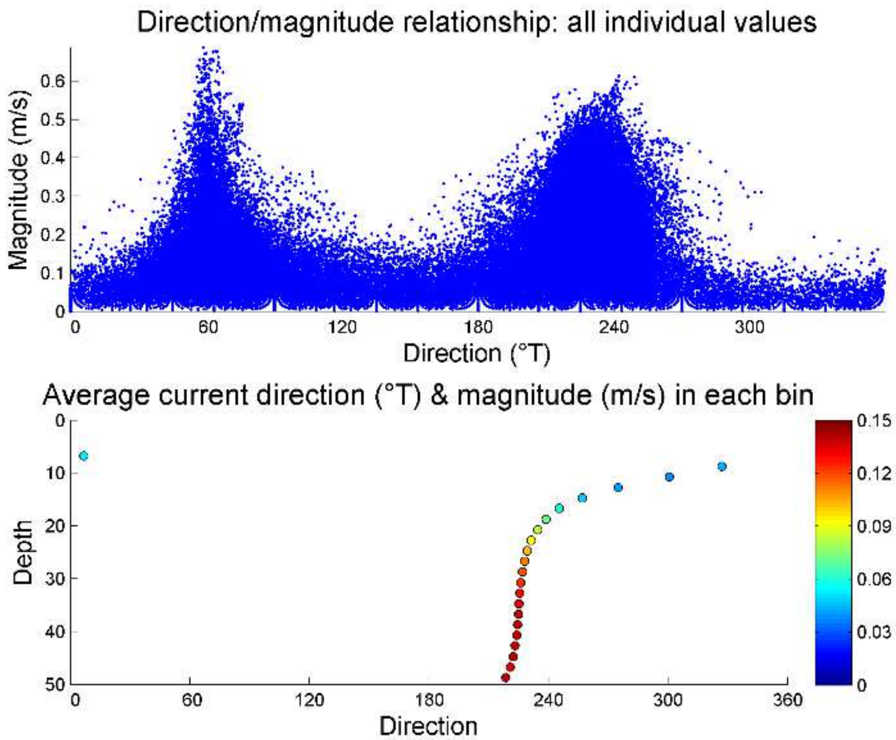


Figure 3-20: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at Richmond South.

3.4.3 Habitats, communities and notable features at Richmond South

The habitat throughout was homogenous mud with small polychaete worm tubes and uniformly distributed mounds and hollows (Figure 3-21 a,b). Scallops, feather hydroids and opalfish were common within the site. Small isolated biogenic clumps composed of hydroids, sponges, ascidians, bivalves (e.g. *Talochlamys* sp.) and red and green macroalgae occurred in a scattered distribution at depths less than ~40 m, and became larger and more common at shallower depths inshore of the farm site .The abundance of mobile epifauna including brittle stars, eleven arm starfish and several species of gastropods increased as the seabed profile shallowed to 25m. Infauna sampled from within the site comprised taxa that are common and widespread within the Marlborough Sounds region.

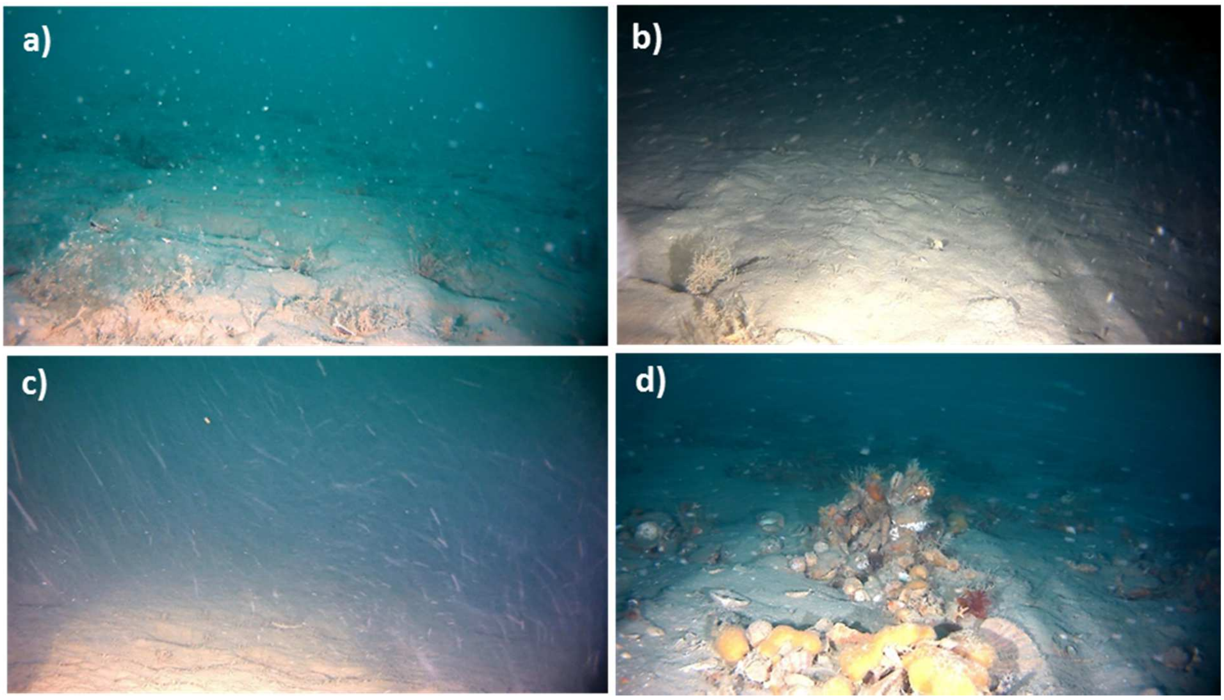


Figure 3-21: Benthic habitat at the Richmond South site. a) Mud habitat with hydroids and small mounds and hollows; b) Mud habitat with very sparse biota; c) Mud habitat with scallop; d) Biogenic clump inshore of the site.

Inshore of the site the shoreline comprised alternating cobble, sandy beach and reef habitat. Macroalgal stands of *Carpophyllum* and *Cystophora* were present in this zone. Patches of bedrock reef extended a short way from the shoreline, and these supported a diverse assemblage of encrusting and mobile fauna typical of the outer Marlborough Sounds including kina, sponges, small patches of *Galeolaria* tubeworms and reef fish including blue cod, terakihi and spotties. On the patches of sand substrate, kina and a single burrowing tube anemone (*Cerianthus*) were noted.

Large reefs extended out from 'The Reef' headland north of the site at the mouth of Richmond Bay, and south of the site from Te Kaiangapipi headland at the mouth of Horseshoe Bay. These large reefs were both more than 500 m away from the proposed farm boundaries, and were considered to be outside the influence of primary depositional effects from the proposed farm activity, so were not investigated during this survey.

3.4.4 Predicted depositional effects at Richmond South

Mean near-bed current speeds at this site are 0.18 ms^{-1}, so it can be considered a dispersive site where farm wastes sinking to the seabed are likely to be resuspended and transported by currents at times of high flow. Under initial proposed feed input scenario of 6500 tonnes per year, an area of 0.2 Ha on the seabed in the close vicinity of the cages is likely to be subjected to deposition at levels less than 13 kg solids m^{-2} yr^{-1} that would produce sustainable levels of enrichment of ES5 or less (Figure 3-22).

Under that scenario a total area of seabed of ~26 Ha extending approximately ~880 m in a WSW direction is forecast to be affected by the wider primary footprint (Figure 3-22 b). Deposition will decrease with distance from the cages to a level of ~1 kg solids m^{-2} yr^{-1} at the edge of the footprint and the enrichment status of the seabed will grade from ES4 (high enrichment) near the cage area, to moderate enrichment and impacts associated with enrichment stage ES3 at the distal edges of the footprint.

Within the area beneath the cages some epifauna will be excluded and opportunistic species of infauna (mostly Capitellid polychaetes and nematodes) will become abundant, scallops may be displaced, and the abundance of other taxa considered to be sensitive to elevated levels of deposition such as hydroids and sponges is expected to decrease. Within the wider footprint, elevated abundance of infauna (especially enrichment tolerant species) can be expected, and less sensitive epifaunal species such as sea cucumbers (*Australostichopus mollis*) and starfish (e.g. *Coscinasterias muricata* and *Patiriella regularis*) will persist also. Notable ecological features including patches of reef and cobble and kelp communities inshore of the site are beyond the predicted footprint of deposition and are unlikely to be affected directly, but if a farm is established at this site then monitoring of those communities to detect changes resulting from possible cumulative effects of elevated levels of dissolved nutrients and other potential far-field effects is recommended.

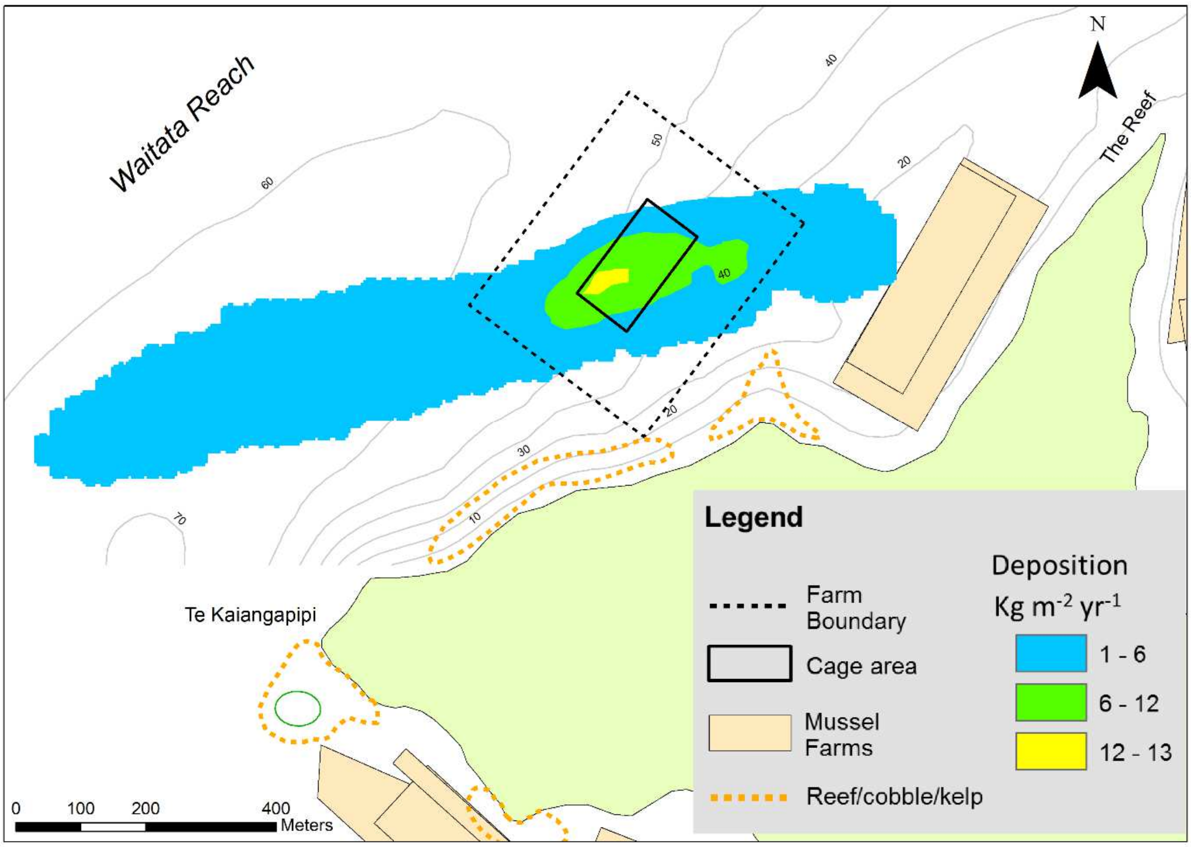


Figure 3-22: Predicted depositional footprint and notable ecological features at the Richmond South site. Annual feed input scenarios of 6500 tonnes. Depth contour units are meters. Boundaries of notable ecological features are approximate.

3.5 Horseshoe Bay (124)

3.5.1 Horseshoe Bay, general site information

The proposed 11 Ha site is located on the north side of Horseshoe Bay near Te Kaiangapipi headland. The farm boundaries are positioned over a seabed of variable bathymetry in depths between 18 and 45 m (Figure 3-23).

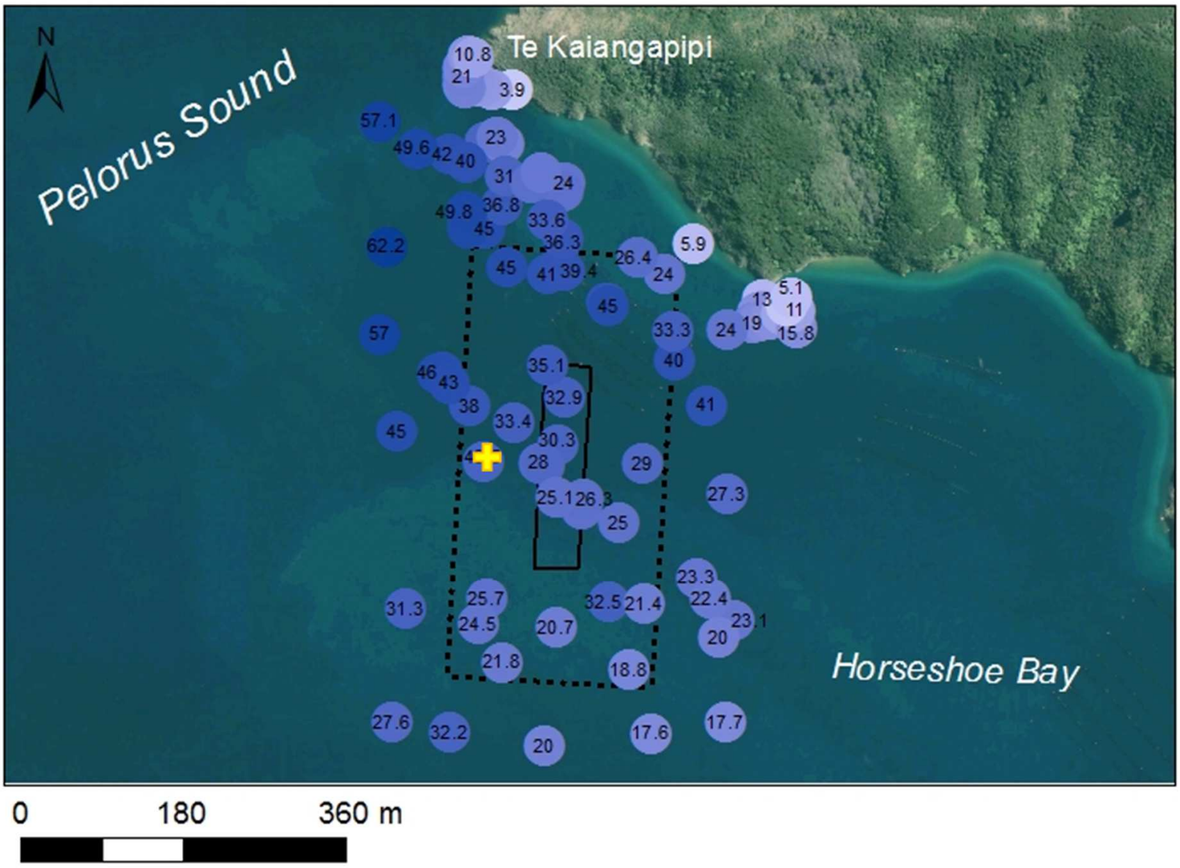


Figure 3-23: Station depths and ADCP position at Horseshoe Bay. Blue shading depicts depth from shallow (white) to dark blue (deep), central values are depths in metres. Yellow cross depicts ADCP position

3.5.2 Currents at Horseshoe Bay

The mean mid-water current speed was 0.11 m s^{-1} , the mean near-bottom current speed at this site was 0.12 m s^{-1} and more than 5% of the currents were measured above 0.25 m s^{-1}, even at the lowest recorded depth. Such moderate to high current speeds indicate that the site is considered to be relatively dispersive (compared to non-dispersive sites with mean current speeds <0.09 m s^{-1}), and that organic material from salmon farming would be likely to be resuspended periodically. The current rose plot for all measured depth bins in Horseshoe Bay (Figure 3-24) indicates a weak tidal signature with net movement of water to the northwest.

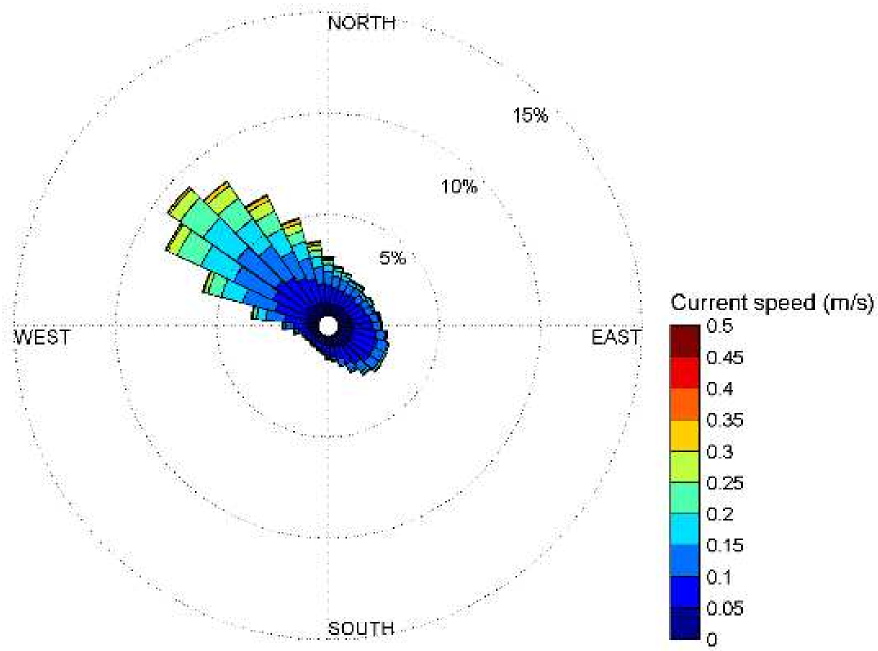


Figure 3-24: Current rose showing current directions and magnitudes for all bins at Horseshoe Bay.

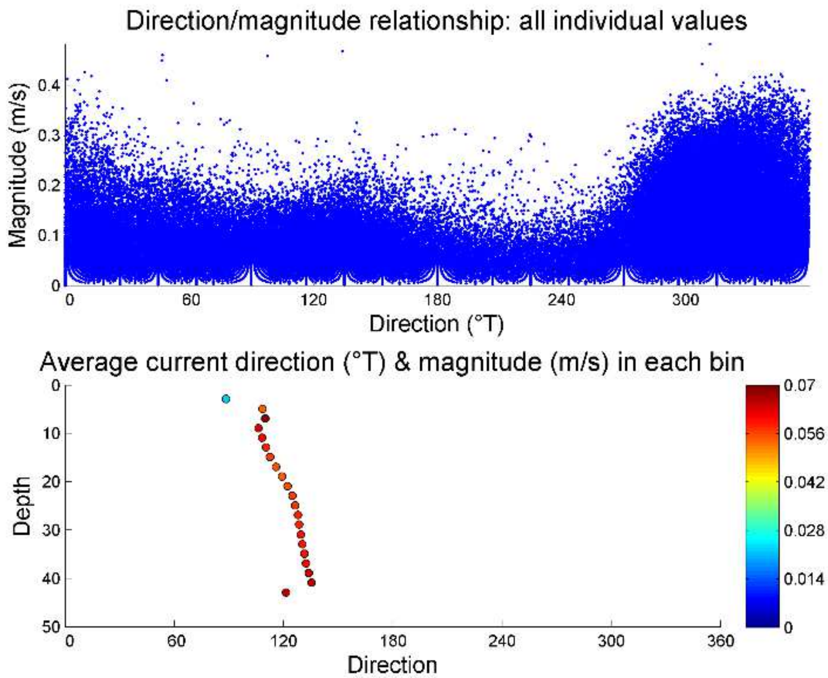


Figure 3-25: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at Horseshoe Bay.

3.5.3 Habitats, communities and notable features at Horseshoe Bay

Within the proposed farm site boundaries the substratum is mostly sandy mud supporting an infaunal community of common and widespread taxa, and there were no habitats or communities of particular ecological or conservation value (Figure 3-26 a). However, scallops were frequently noted in video transects (Figure 3-26 b), and found in epibenthic sled tow samples from within the site. In the northeast portion of the site, beneath an existing mussel farm, were aggregations of epibiota and debris that had dropped from mussel lines (Figure 3-26 d). Small biogenic clumps mostly comprised of hydroids and ascidians were present in a sparse distribution within the site (Figure 3-26 e, f)

There is extensive reef habitat extending south from Te Kaiangapipi headland supporting a reef community of diverse and notable taxa including kina (*Evechinus chloroticus*) and crayfish (*Jasus edwardsii*), and a range of associated fish species including terakihi (*Nemadactylus macropterus*), butterfly perch (*Caesioperca lepidoptera*), and kingfish (*Seriola lalandi*). A notable taxon seen at the base of the reef was the stony coral species *Culicea rubeola*. Near the base of the reef approximately 90 m to the northwest of the site boundary there was an area of biogenic habitat comprising whole-shell rubble and associated epifauna including brachiopods (Figure 3-26 c). There was an area of cobble and rock habitat approximately 40 m inshore of the northeast corner of the proposed farm boundary and that habitat supported a diverse community of macroalgae, epifauna including sponges, *Galeolaria* tubeworms (small patches) and kina, and fish including blue cod (*Parapercis colias*), snapper (*Pagrus auratus*) and tarakihi. With increasing depth the habitat changed to sand and shell rubble supporting scallops, horse mussels, schools of spotties (*Notolabrus celidotus*) plus sweep (*Scorpis lineolatu*) and blue moki (*Latridopsis ciliaris*).

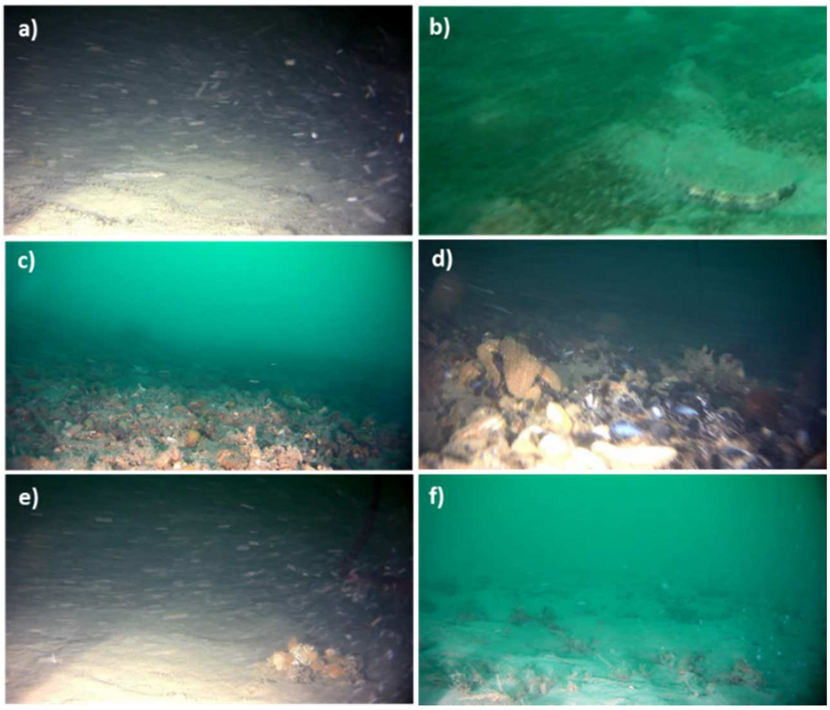


Figure 3-26: Habitats in the vicinity of the Horseshoe Bay site. a) Mud habitat, polychaete tubes, opalfish within the proposed site; b) mud with diatom mat and scallop at 23 m depth at south end of the site; c) Shell rubble and associated community including brachiopods at 30 m depth near base of the reef to the north of the site; d) Shell drop and starfish within the site beneath existing mussel farm lines; e) Mud habitat with isolated biogenic clump including brachiopods; f) Mud, hydroids and scattered small biogenic clumps within the site at ~28 m depth.

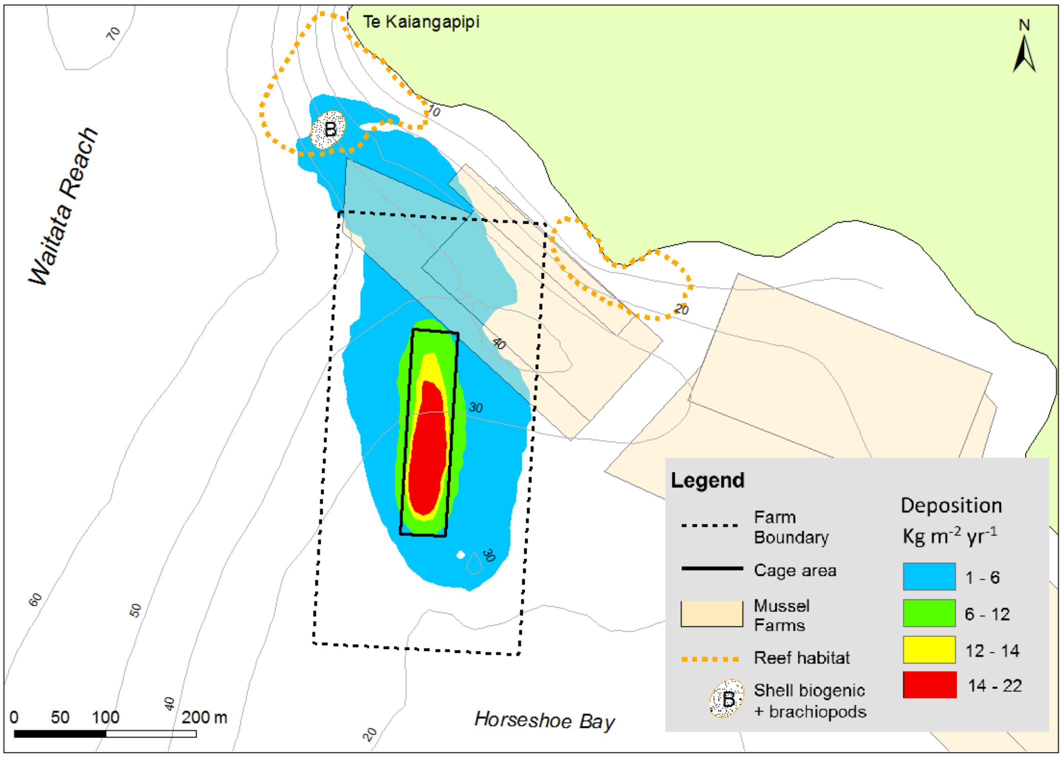
3.5.4 Predicted depositional effects at Horseshoe Bay

Assuming an annual feed input of 2500 tonnes, output from DEPOMOD simulations indicates that an area of ~0.5 Ha on the seabed in the close vicinity of the cages is likely to be subjected to deposition of >13 kg solids m^{-2} yr^{-1} (Figure 3-27 a), leading to enrichment exceeding the upper limit of enrichment recommended for salmon farms in the Marlborough Sounds (Keeley et al 2012, 2013, 2015). Beyond that zone, an area of ~8 Ha is forecast to be affected by the wider primary footprint, with deposition ranging from enrichment stage ES5 (very high enrichment) near the cage area, to ES3 (moderate enrichment) at the distal edges of the footprint where a predicted deposition rate of ~1 kg solids m^{-2} yr^{-1} is expected. Under that scenario, the primary footprint would also extend approximately 280 m to the North, over part of the reef area adjacent to Te Kaiangapipi, potentially affecting portions of the bedrock reef habitat and also the shell rubble habitat feature and associated communities.

Under a reduced feed input scenario of 1500 tonnes per year, deposition would not be expected to exceed 13 kg solids m^{-2} yr^{-1}, and the wider footprint would extend only ~ 210 m to the North (Figure 3-27 b). Within the area beneath the cages and extending some way into the wider footprint, scallops and other taxa such as hydroids and sponges that are considered to be sensitive to elevated levels of deposition may be displaced, and opportunistic infaunal species (particularly Capitellid polychaetes) will become more abundant. Under this latter scenario primary deposition is less likely to have any significant effect on the ecological features adjacent to Te Kaingapipi headland and the reef and cobble habitats inshore of the northeast corner of the proposed farm are not predicted to be affected by primary deposition.

If this site is utilised for relocation of a salmon farm, any monitoring program developed based on the 'Best Management Practice guidelines for salmon farms in the Marlborough Sounds' (Keeley et al 2015) should also consider the reef features adjacent to Te Kaingapipi, and the potential for cumulative effects to the reef and cobble habitats and associated communities inshore of the northeast corner of the proposed site.

a)



b)

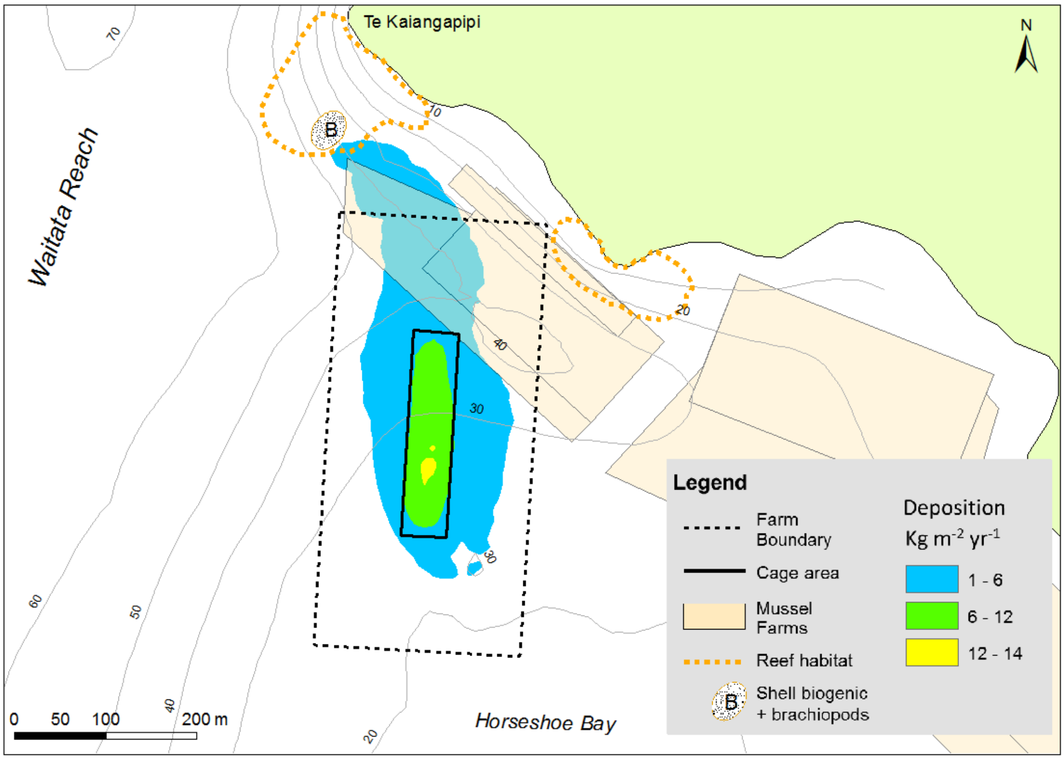


Figure 3-27: Predicted deposition footprint and notable ecological features at the Horseshoe Bay site. Annual feed input scenarios of 2500 tonnes (a, above), and 1500 tonnes (b, below). Depth contour units are meters. Boundaries of notable ecological features are approximate.

3.6 Tipi Bay (42)

3.6.1 Tipi Bay, general site information

The proposed site is 9 Ha in area located adjacent to the southeast shore of Tory Channel approximately 3 km southwest of the Tory Channel entrance. The farm boundaries are positioned over a sloping seabed in depths between 3 and 31 m (Figure 3-1).

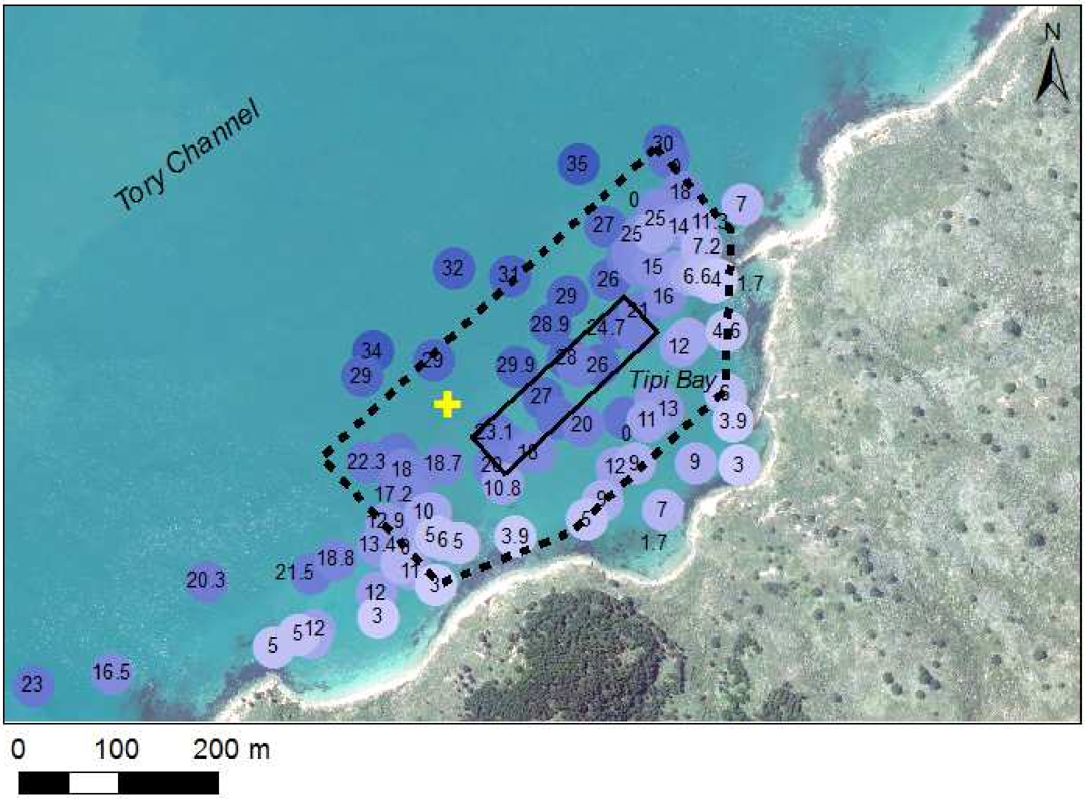


Figure 3-28: Station depths and ADCP position at Tipi Bay site. Colour depicts depth from shallow (pale blue) to deep (dark blue), central values are depths in metres. Yellow cross depicts ADCP position

3.6.2 Currents at Tipi Bay

The ADCP deployed at Tipi Bay reliably measured currents from 3m below the surface to 27m depth, at a location that was ~29.5m deep on average. The site was tidally-dominated with a higher proportion of flows recorded towards the North-East (Figure 3-29) than the reverse SW. Approximately 44% of profiles exceeded 0.2 ms^{-1} and 5% of profiles exceed 0.46 ms^{-1} over the 45-day ADCP deployment. Examining all of the observations by magnitude and direction, higher current speeds up to 1.0 ms^{-1} were associated with the flows towards the NE (Figure 3-30). The top 1% of current speed observations exceeded 0.62 ms^{-1}. Average currents were to the NE direction at all depths. The mean mid-water current speed was 0.22 ms^{-1} and mean near-bottom current speed was 17 ms^{-1}.

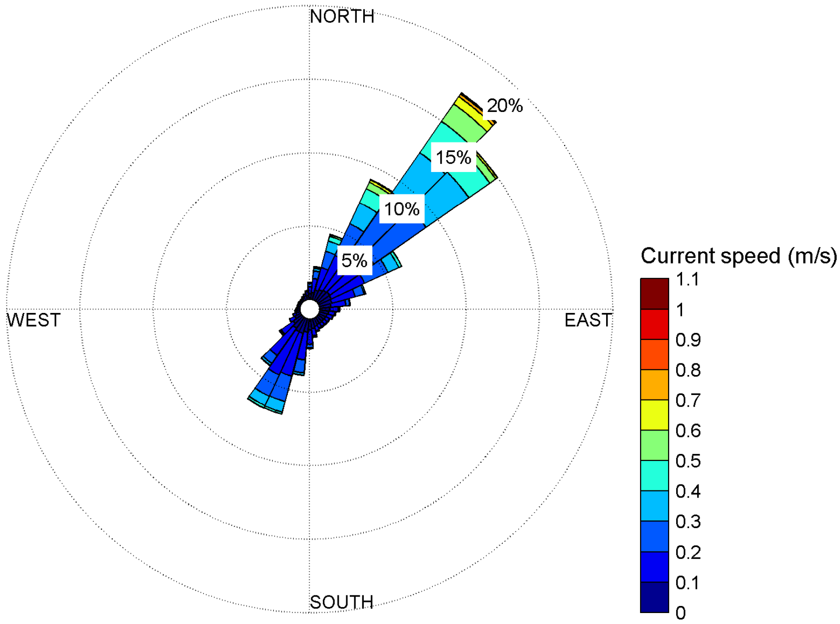


Figure 3-29: Current rose showing current directions and magnitudes for all bins at Tipi Bay.

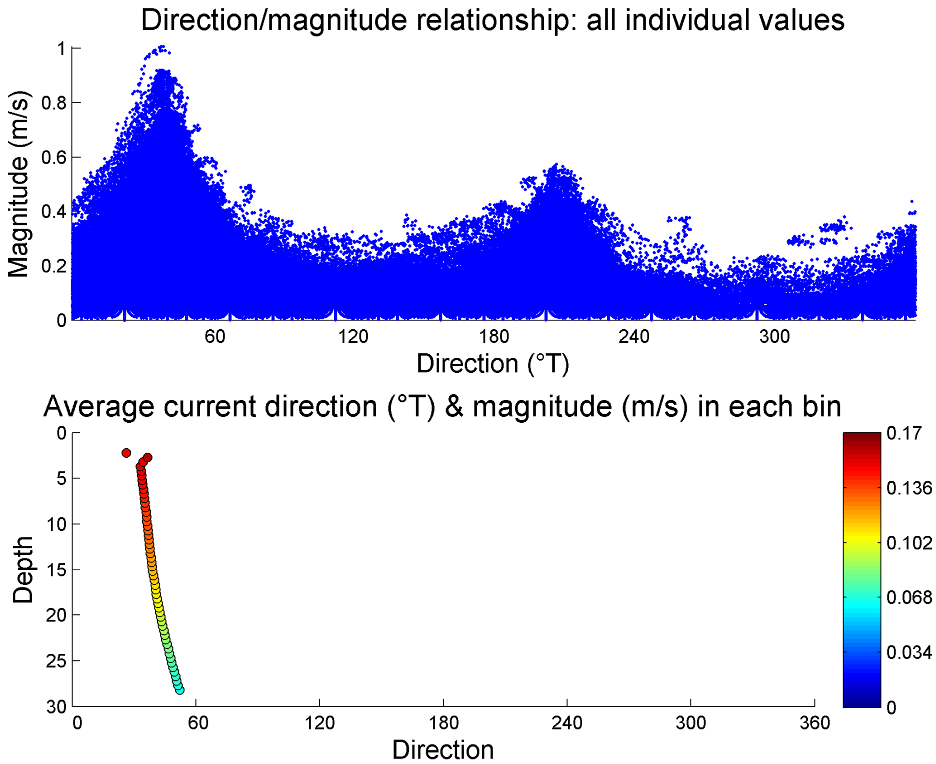


Figure 3-30: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at Tipi Bay.

3.6.3 Habitats and Communities at Tipi Bay

A wide range of habitat types and communities were seen at this site. In the vicinity of the offshore boundary in approximately 28 to 30 m depth, and throughout most of the offshore third of the site, the substratum was whole shell, shell hash and muddy sands that supported mainly ophiuroids and bryozoans (both branching and fluffy) (Figure 3-31 a). The seabed under the cage area consisted of muddy sand with shell hash that supported sparsely distributed ophiuroids and fluffy bryozoans (Figure 3-31 b). Further inshore, the sandy mud component of the sediment increased and the shell hash content decreased. Inshore of the central portion of the cage area between approximately 5 and 15 m depth there was a conspicuous diatom biofilm overlaying the soft muddy sand substratum and epibiota was scarce (Figure 3-31 c), except for scattered macroalgae, ophiuroids and a few kina (Figure 3-31 d).

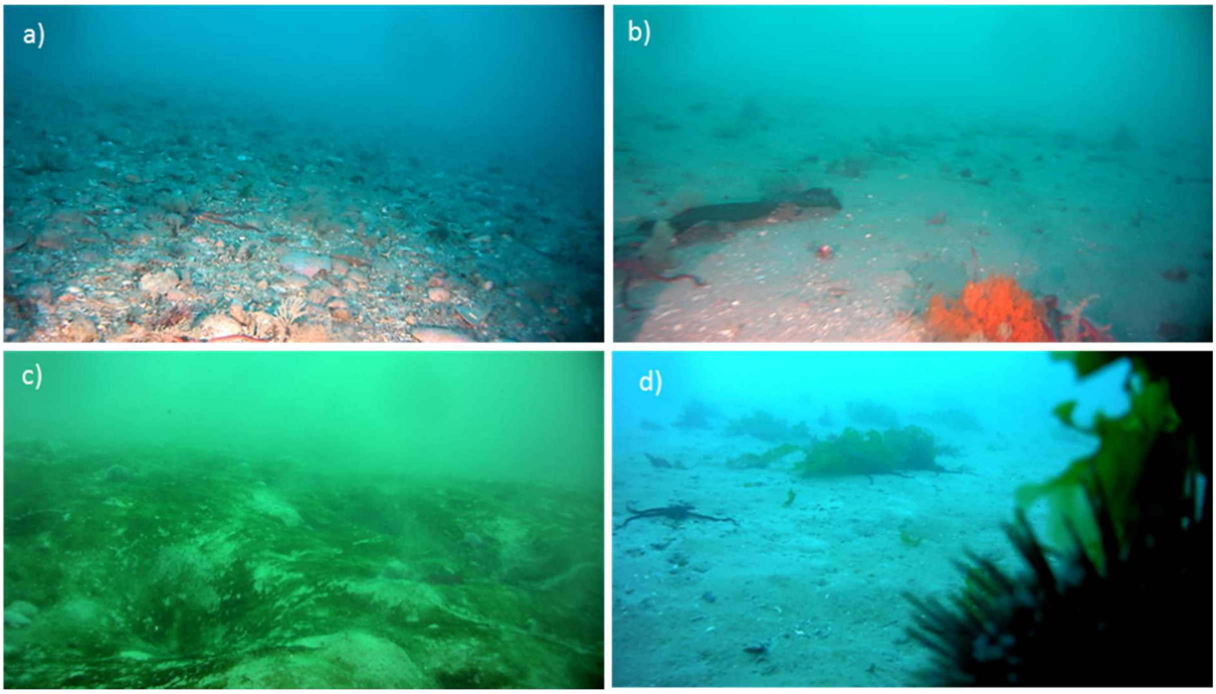


Figure 3-31: Most widespread habitats found within the proposed site. a) Shell hash habitat at offshore boundary of the site (~30m depth). b) Within cages boundary. c) Soft muddy sand inshore at 13 m depth. d) Inshore sandy habitat.

A rocky reef extends into the northeast end of the site to within 30-40 m of the cage area. The reef provided habitat for a diverse assemblage of macroalgae, molluscs, hydroids, ascidians, and bryozoans and associated fishes, including large schools of butterfly perch (*Caesioperca lepidoptera*) (Figure 3-32 a, b). In the vicinity of the southwest end of the cage area, broken rock patches support macroalgae and reef epifauna, including sponges, hydroids, bryozoans and ascidians (Figure 3-32 c). Inshore, patches of broken rock and low-relief reef fringed most of the shoreline adjacent to the inshore boundary of the site providing contiguous rocky-reef habitat for blue cod (*Parapercis colias*).

Beds of seagrass (*Zostera muelleri*) (Figure 3-32 d) were noted in the small embayment, 10 to 20 m inshore of the northeast corner of the site boundary and also in the next small embayment to the south.

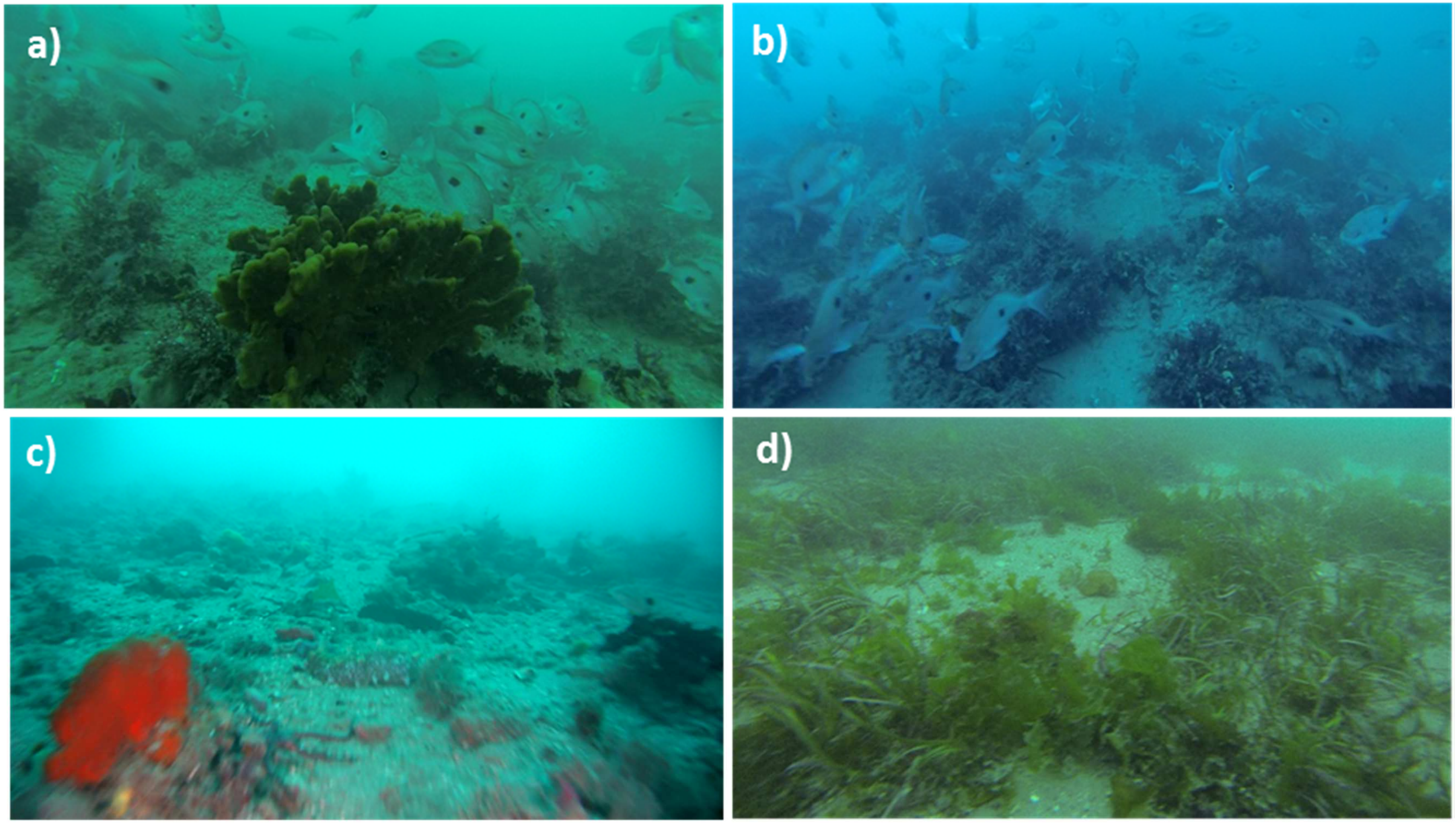


Figure 3-32: Reef, broken rock and seagrass habitat. a) Reef with sponge (*Crella incrustans*) and butterfly perch (*Caesioperca lepidoptera)* in the northeast end of the site, b) Reef and butterfly perch in the northeast end of the site, c) broken rock habitat in the vicinity of the southwestern end of the cage area, d) seagrass (*Zostera muelleri*) inshore of the site, northeast end.

3.6.4 Predicted depositional effects at Tipi Bay

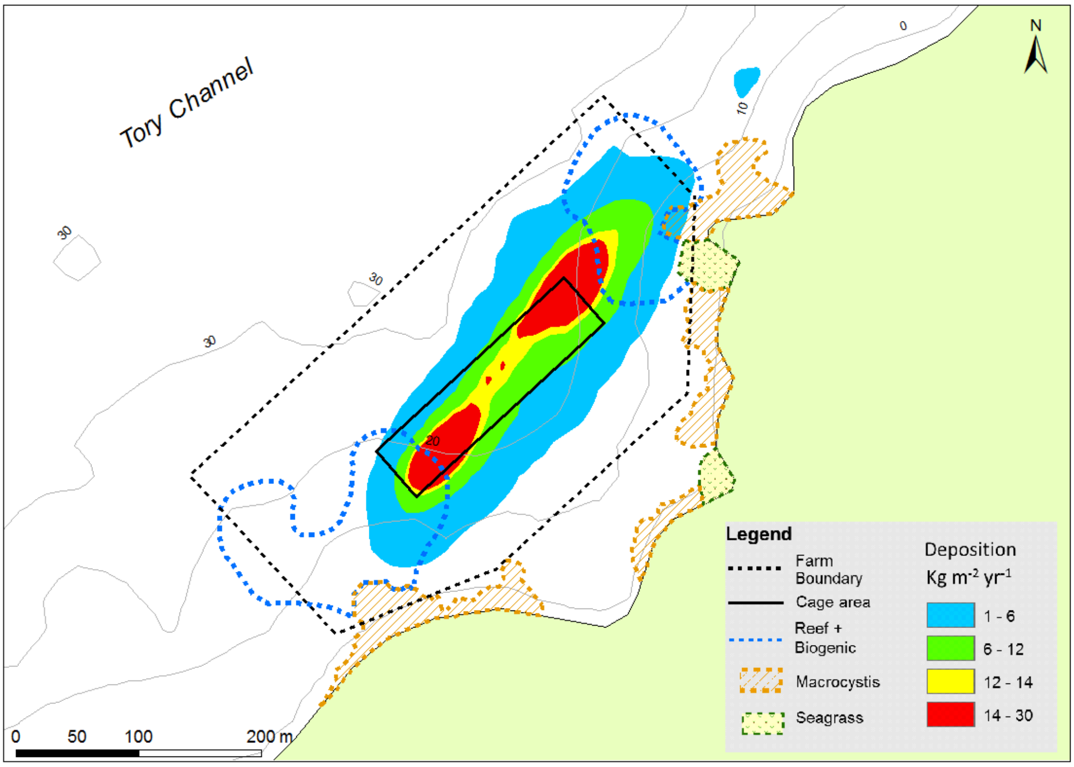
Modelling using the proposed feed input of 2000 tonnes per year forecast that an area of 0.25 Ha would be subject to deposition of between 14 and 30 kg solids m^{-2} yr^{-1} (Figure 3-33 a). That magnitude of deposition would lead to excessive build-up of organic matter and produce enrichment of ES6 or greater, considered to be unsustainable beneath salmon farms in the Marlborough Sounds. At that feed loading, the excessively enriched zone is predicted to extend ~ 45 m to the northeast of the cage area and would impinge on reef and broken rock habitat supporting a diverse epibiota of encrusting invertebrates, macroalgae and associated reef fishes at the northeast end of the embayment (Figure 3-33 a). Some of the taxa comprising that ecological feature are considered to be potentially sensitive or ecologically valuable taxa, in particular, large sessile suspension feeders (e.g. hydroids, sponges) and macroalgae (e.g. kelp) (Keeley 2013c, Roberts et al 2006). A similar notable feature of broken rock and associated communities would also be affected in the vicinity of the cage area at the southwestern end of the site (Figure 3-33 a). Under that scenario, the wider footprint producing enrichment stages ES3 and ES4 would extend over a significant portion of those ecological features, and also potentially impact giant kelp beds *(Macrocystis pyrifera*) to the northeast of the site. Kina (*Evechinus chloroticus*) and paua (*Haliotis iris*) resources would also be potentially affected by the deposition.

Modelling of an alternative scenario assuming a feed input of 1000 tonnes per year forecast a considerably lower magnitude of deposition up to a maximum of ~ 14 kg solids m^{-2} yr^{-1} beneath the cage area (Figure 3-33 b). Such a level of deposition is likely to produce very high enrichment that could remain sustainable around the level of enrichment stage ES5, but the wider primary footprint still spreads extensively over notable habitats and communities in the northeast and southwest portions of the site, potentially affecting notable ecological features including diverse communities of sponges, macroalgae, molluscs, hydroids, ascidians, bryozoans and associated fishes (Figure 3-33 b).

The potential for resuspension and wider dispersal of depositional material from the farm and subsequent accumulation in quiescent areas of the bay should also be considered, particularly in relation to the seagrass beds that are present in the small embayment 10 to 20 m inshore of the northeast corner of the site boundary and also in the next small embayment to the south (Figure 3-33). Elevated nutrient levels in those beds could lead to blooms of ephemeral macroalgae which could potentially impact the seagrass beds (e.g. Han and Liu 2014).

Even under a lower feed input scenario than has been modelled here, there is potential for significant detrimental effects to the notable features described above. If development of a salmon farm at this site was permitted, further detailed benthic surveys would be required to optimise placement of farm structures, comprehensive monitoring of potential effects to the notable reef and biogenic features, and the development of a very precautionary adaptive management plan would be necessary to avoid significant effects to those notable ecological features.

a)



b)

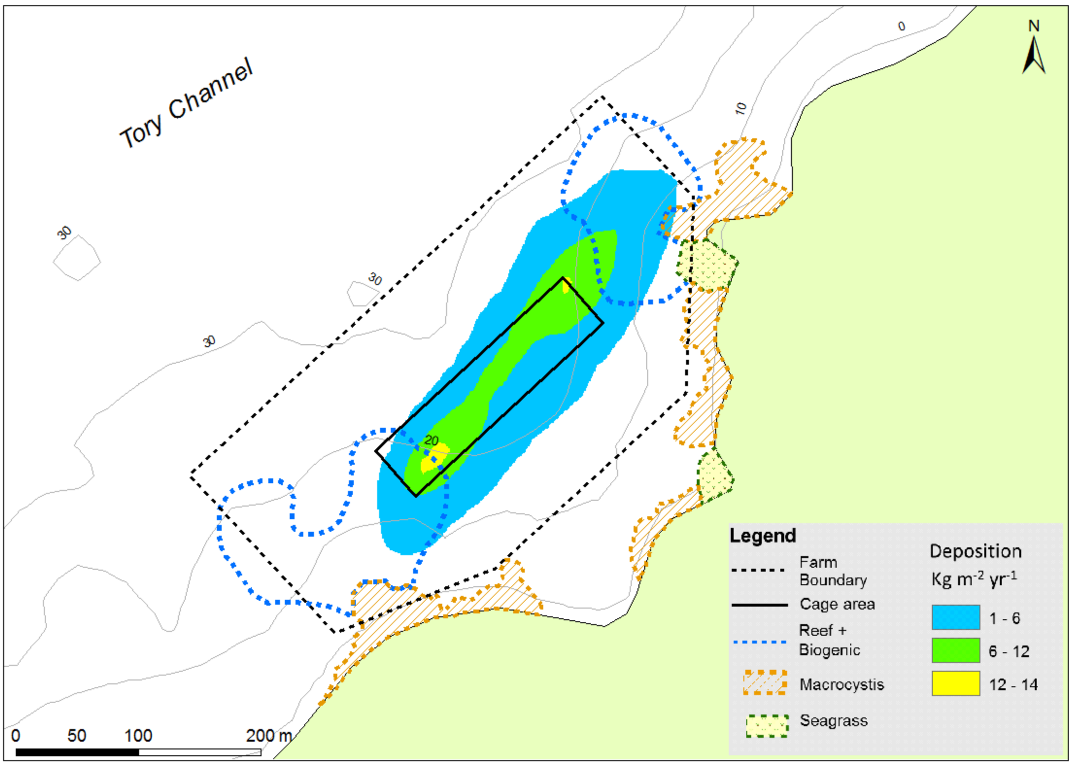


Figure 3-33: Predicted deposition footprint and notable ecological features at the Tipi Bay site. Annual feed input scenarios of 2000 tonnes (a, above), and 1000 tonnes (b, below). Depth contour units are meters. Boundaries of notable ecological features are approximate.

3.7 Motukina (82)

3.7.1 Motukina general site information

The proposed 11 Ha site at Motukina is located on the southern side of Tory Channel directly across the channel from Te Uira-Karapa point on the opposite shore. The farm is positioned over a sloping seabed and depths within the site range from 3 to 45 m (Figure 3-49).

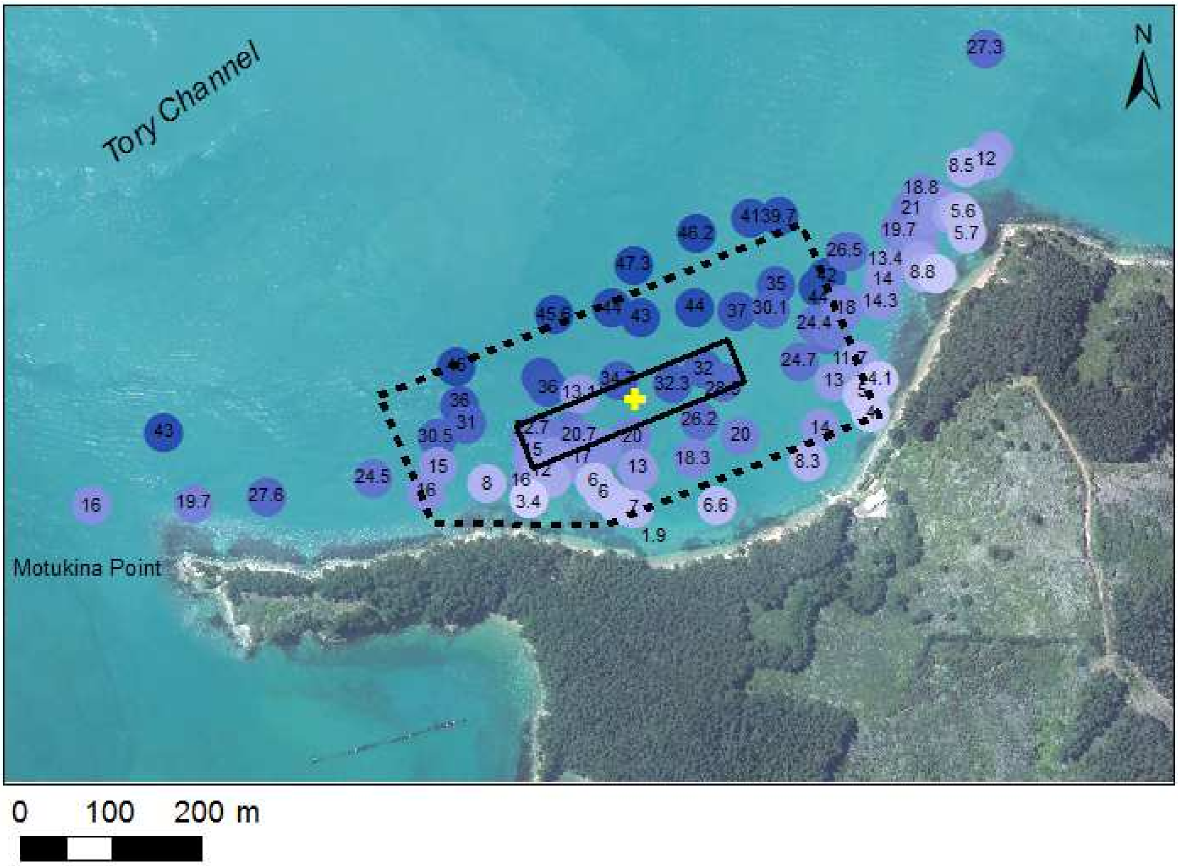


Figure 3-34: Station depths and ADCP position at Motukina site. Colour depicts depth from shallow (pale blue) to dark blue (deep), central values are depths in metres. Yellow cross depicts ADCP position

3.7.2 Currents at Motukina

The ADCP deployed at Motukina reliably measured currents from 3m below the surface to 27m depth, at a location that was ~30m deep. The dominant direction of flow was to the East (Figure 3-35), however there was a considerable range of flow directions during this deployment. Approximately 33% of profiles exceeded 0.2 ms^{-1} and 5% of profiles exceed 0.36 ms^{-1} over the 45-day ADCP deployment. Examining all of the observations by magnitude and direction, higher current speeds up to 0.75 ms^{-1} were associated with the flows towards the ENE (Figure 3-36) and the top 1% of observations exceeded 0.49 ms^{-1}. Average currents were to the N direction near the surface, and progressively shifted towards the NE lower in the water column. The mean mid-water current speed was 0.18 ms^{-1} and the mean near-bottom current speed was 0.16 ms^{-1}. The top four bins in the bottom panel of Figure 3-36, are low-quality observations due to the side-lobe effect and should be disregarded.

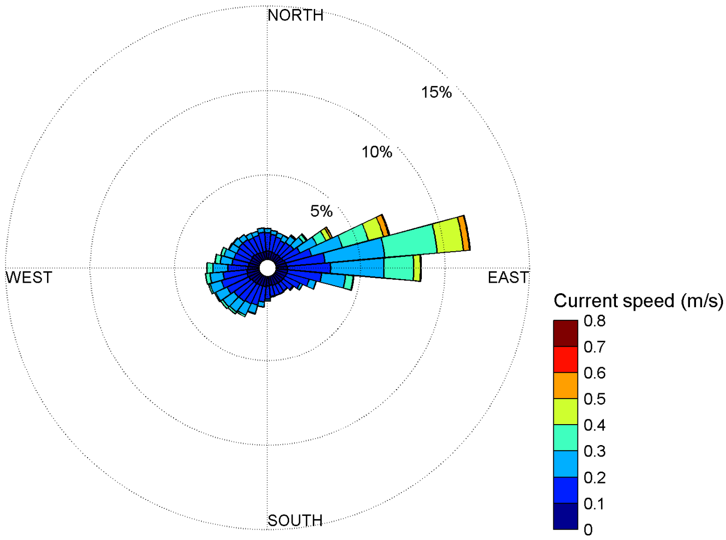


Figure 3-35: Current rose showing current directions and magnitudes for all bins at Motukina.

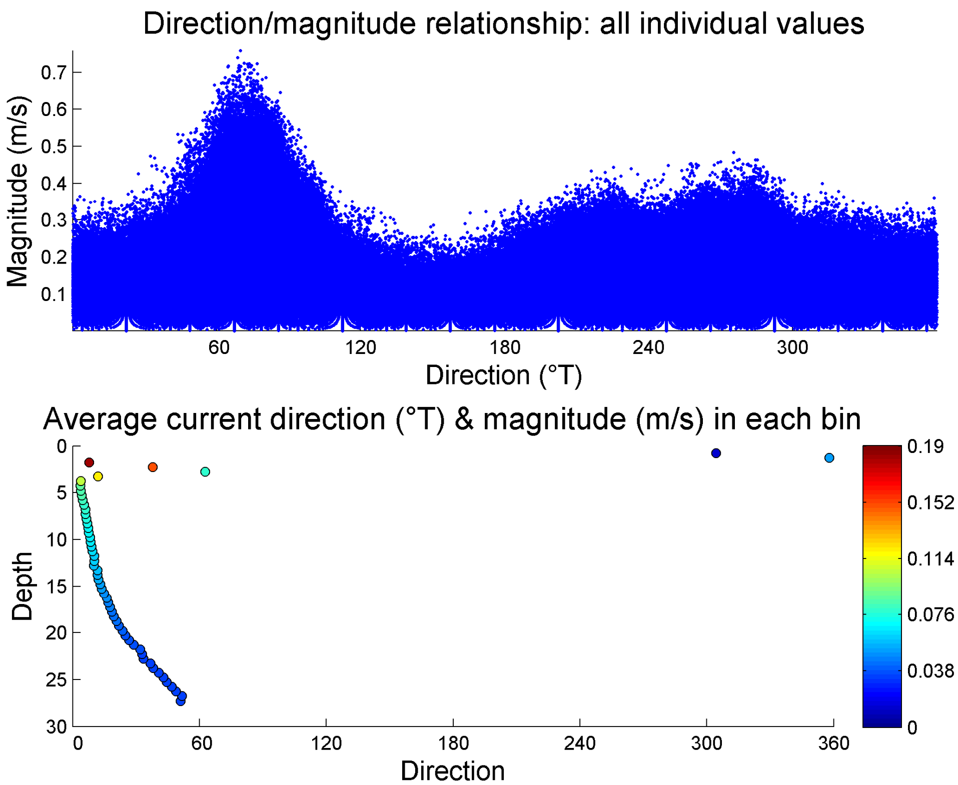


Figure 3-36: All observations of current magnitude and direction (top panel) and time-averaged profile of magnitude and direction (bottom panel) at Motukina.

3.7.3 Habitats and communities at Motukina

The substratum throughout most of the site including the cage area, in depths between ~18 and 40 m was composed of muddy sand, shell hash and calcareous gravel (Figure 3-37). In that zone, brittle stars (*Ophiopsammus maculata*) were the most common large-bodied epifaunal organism and scattered small biogenic clumps mostly comprising feather hydroids, various sponges, fluffy bryozoans, ascidians, and macroalgae were also present. The shell hash and gravel components increased with depth and proximity to the fast-flowing main channel. Inshore, in depths of 10m or less, the habitat was mostly sand and mud that supported assemblages dominated by infaunal burrowing organisms (Figure 3-37 a) or diverse macroalgal communities (Figure 3-37 b). Brittlestars (*Ophiopsammus maculata*) were common in these inshore habitats. Rocky reefs extend out from the headlands to the east, and to the west of the proposed site, and areas of broken reef, boulder and cobble lie inshore of the site, extended some of the way into the site in places, particularly near the eastern boundary, also in the vicinity of the southwest portion of the proposed cage area, and along the inshore boundary at the western end of the site.

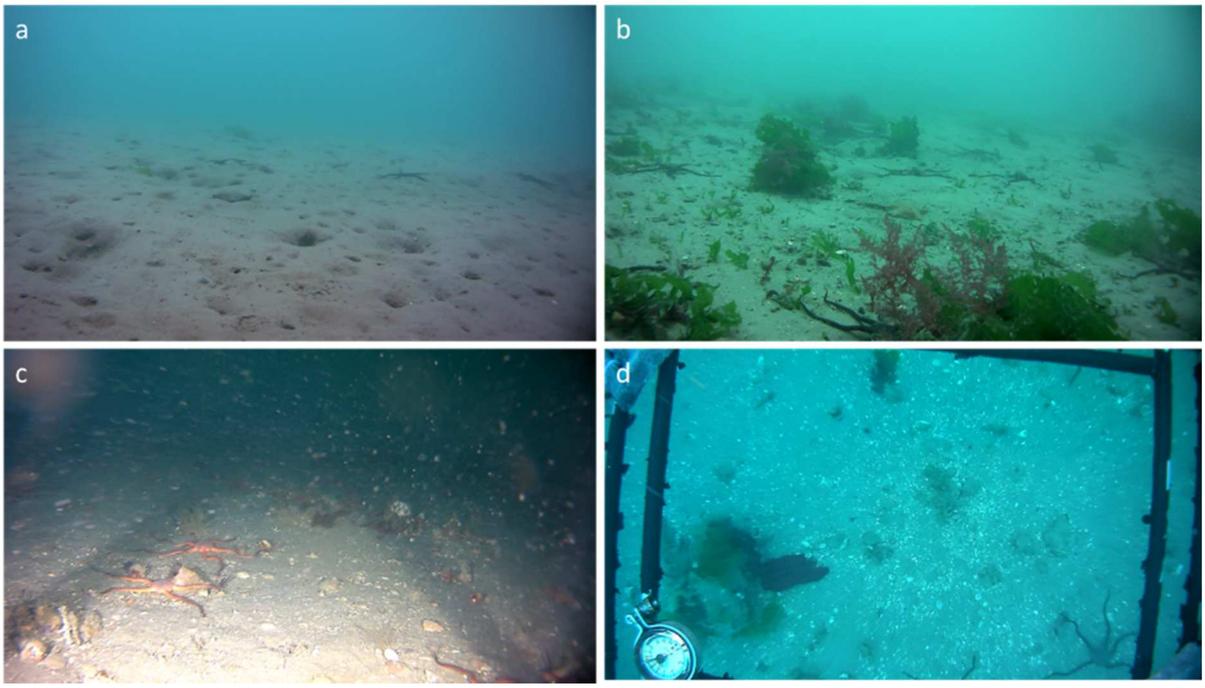


Figure 3-37: Soft sediment habitats at the Motukina site. a) Sandy mud substratum inshore of the site at <10m depth; b) sandy mud and algae, <10 m depth; c) outer boundary of cage area ~28m depth; d) near inner cage boundary, 19 m depth.

The broken reef, cobble and/or bedrock patches extending into the eastern and western portions of the proposed licence provided substratum for highly diverse biogenic aggregations formed by a range of invertebrate taxa including bryozoan corals (e.g. *Celleporaria agglutinans*), and various sponges, ascidians and hydroids, including tree hydroids (*Solanderia* sp.) (Figure 3-38). These areas also provided habitat for numerous reef fish including butterfly perch (*Caesioperca lepidoptera*), blue cod (*Parapercis colias*), Tarakihi (*Nemadactlylus macropterus*) and blue moki (*Latridopsis ciliaris*).

Some bedrock outcrops and broken reef substratum with stands of giant kelp (*Macrocystis pyrifera*) were present in the inshore portion of the proposed licence area. Patches of kelp occurred within the southwestern portion of the site and extended to just inside the southwestern portion of the proposed cage area (Figure 3-39a, b). Areas of macroalgal beds comprising a range of red and green algal taxa were present inshore at depths of 10-15 m. (Figure 3-39c, d).

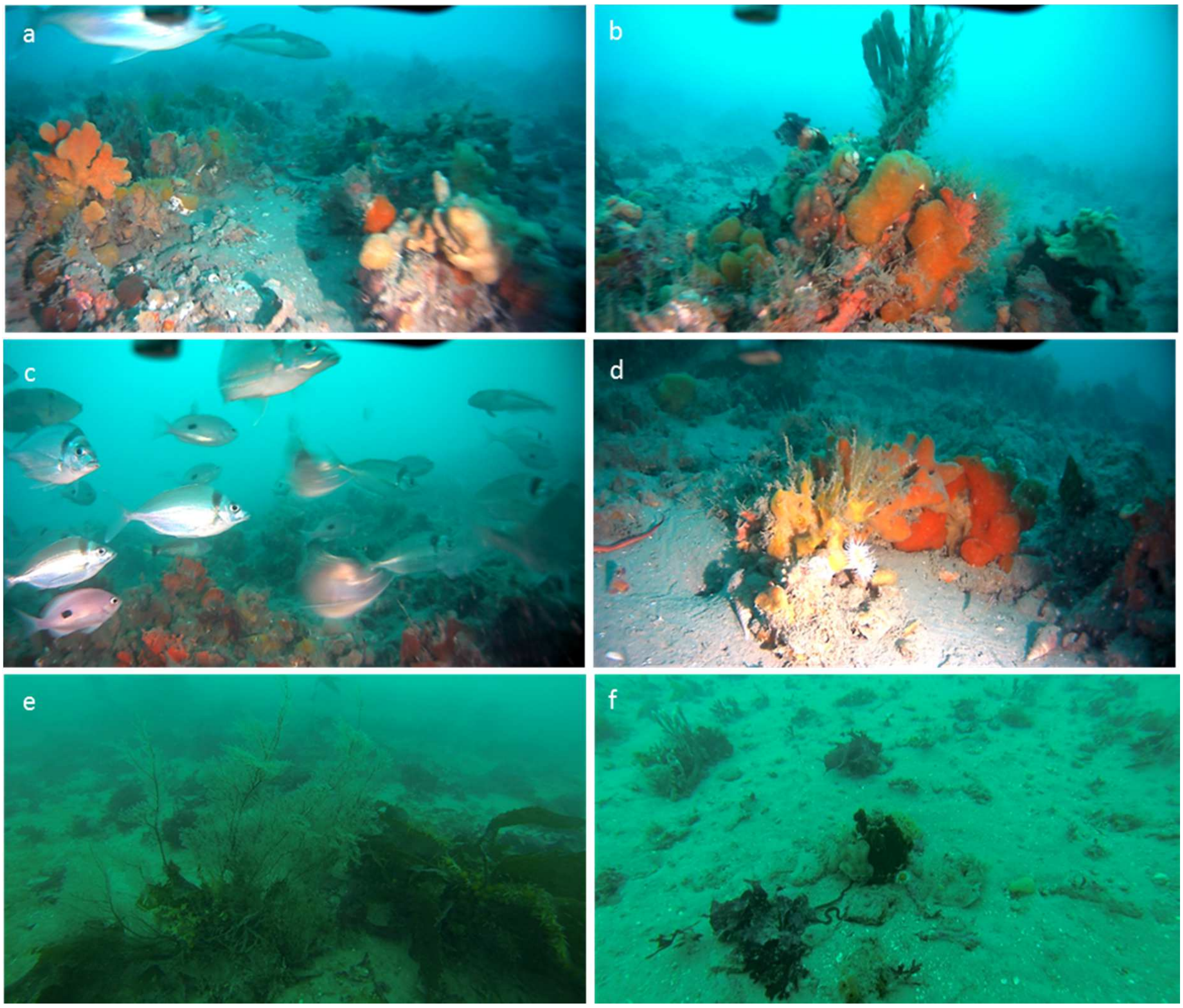


Figure 3-38: Biogenic aggregations on reef and broken rock. a), b), c), d) Broken rock/reef habitat close to the northeast boundary of the site with diverse invertebrate communities; e), f) in the vicinity of the southwest portion of the cage area

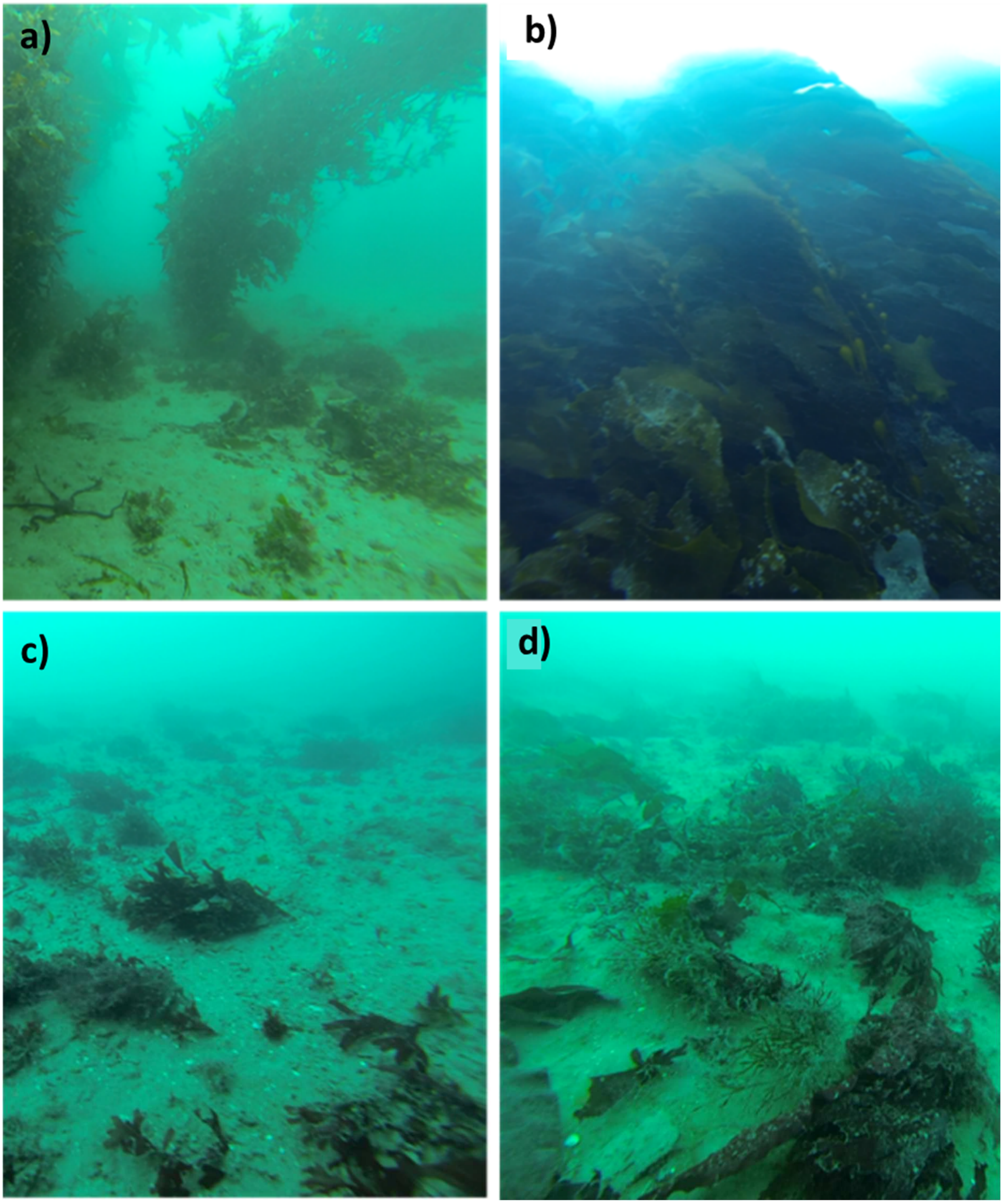


Figure 3-39: Kelp stands and algal beds. a) Carpophyllum sp. in the shallows in western dive transect. b) Bladder kelp (*Macrocystis pyrifera*) stand at 7 m depth inshore and 100 m east of the farm boundary. c), d) Algal beds at 14 m depth.

3.7.4 Predicted depositional effects at Motukina

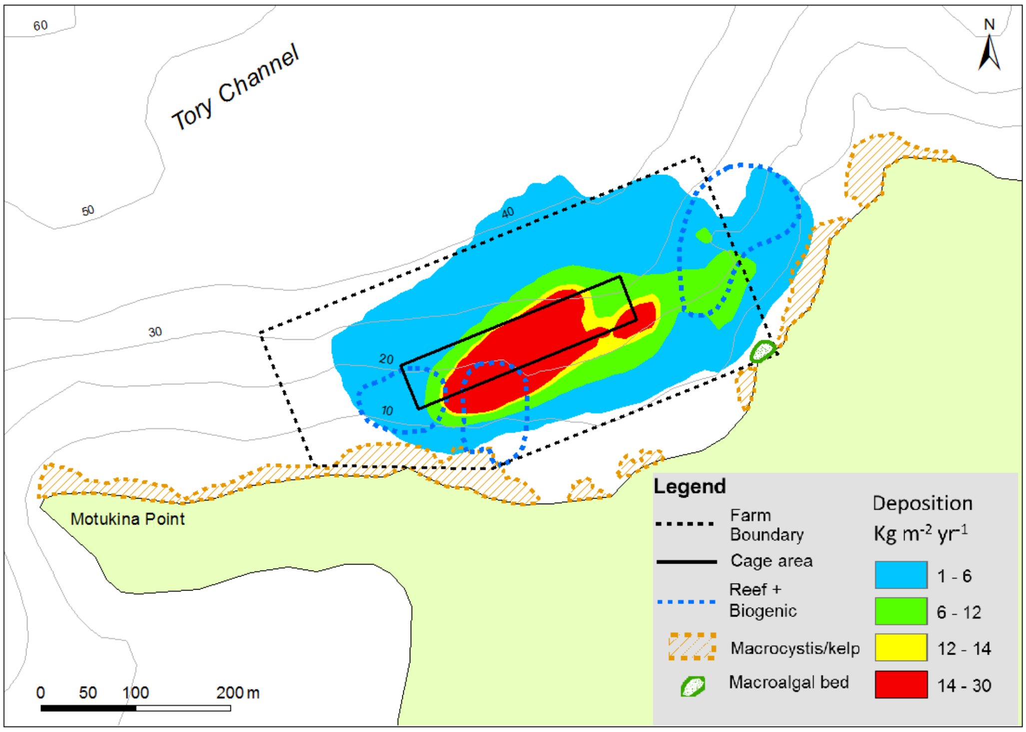
Assuming an annual feed input of 5000 tonnes at this site, the DEPOMOD simulation yielded an area of approximately 1.2 Ha in the vicinity of the cage area where deposition was greater than 13 kg solids m^{-2} yr^{-1} up to a maximum rate of 67 kg solids m^{-2} yr^{-1} (Figure 3-40 a). That forecast would result in unsustainable accumulation of organic matter producing azoic and anoxic benthic conditions associated with enrichment stages of ES6 or ES7. Under that scenario, reef and broken rock habitats supporting diverse epibiotic communities and associated fish populations are likely to be significantly impacted (Figure 3-40 a).

An alternative model implemented with a reduced feed input of 1000 tonnes predicted significantly lower maximum rates of deposition of ~ 13 kg solids m^{-2} yr^{-1} considered to be sustainable beneath salmon farms in the Marlborough Sounds (Figure 3-40 b). Under this scenario the wider footprint covered an area of ~3.8 Ha where deposition rates of 12 kg solids m^{-2} yr^{-1} beneath the cage area, decreasing to 1 kg solids m^{-2} yr^{-1} at the outer edges of the depicted footprint would be expected.

Under this reduced feed regime, broken rock/reef habitat and biogenic aggregations of bryozoans sponges, ascidians, hydroids, macroalgae and associated communities at the eastern and western ends of the site would be affected by moderate levels of deposition (Figure 3-40 b). While the level of susceptibility to the effects of deposition of each of the potentially affected species is not well documented, it is likely that conditions of chronically elevated organic deposition originating from the farming activity would have a detrimental effect on components of those benthic communities considered sensitive to deposition such as large sessile suspension feeders (bryozoans, hydroids, sponges) and cause change to those notable ecological features.

There is potential for giant kelp stands and macroalgal beds inshore of the farm to be affected by resuspension and dispersal of depositional material from the farm beyond the modelled primary footprint, and also elevated dissolved nutrient levels within the embayment that could lead to changes in the composition of those macroalgal communities by stimulating growth of epiphytic and 'nuisance' ephemeral algal taxa. If development of a salmon farm at this site was permitted, even under a lower feed input scenario than has been modelled here, comprehensive monitoring conditions to detect potential effects to the notable reef and biogenic features, and development of a very stringent adaptive management plan would be required. Development of such monitoring and management conditions to adequately safeguard the notable ecological features at this site would likely require considerable (and possibly prohibitive) additional expenditure of time and resources in terms of detailed surveys and experimental research.

a)



b)

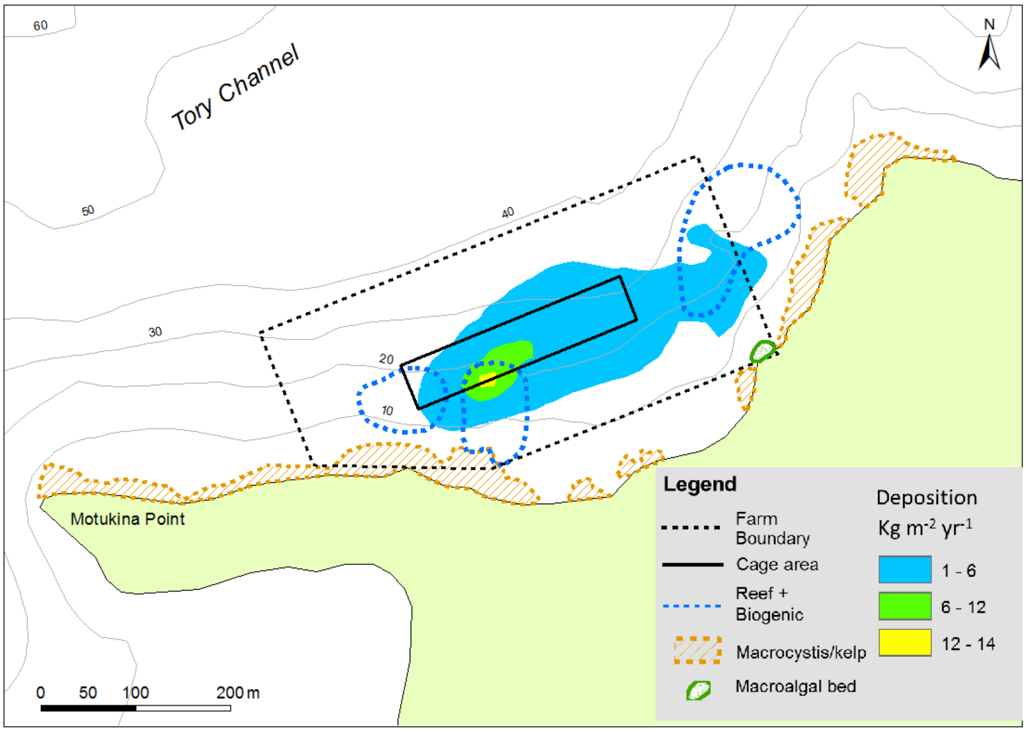


Figure 3-40: Predicted deposition footprint and notable ecological features at the Motukina site. Annual feed input scenarios of 5000 tonnes (a, above), and 1000 tonnes (b, below). Boundaries of notable ecological features are approximate.

3.8 Te Weka Bay (47)

3.8.1 Te Weka Bay general site information

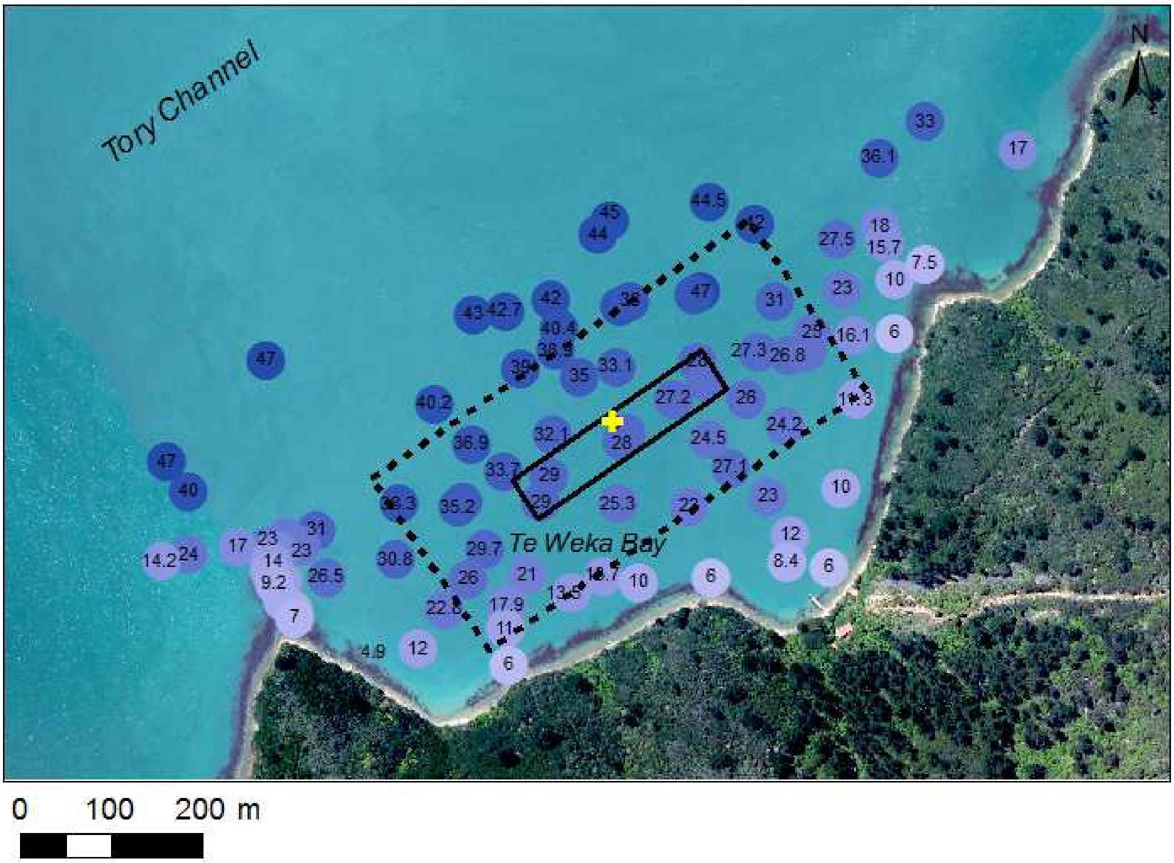


Figure 3-41: Station depths and ADCP position at the Te Weka Bay site. Colour depicts depth from shallow (pale blue) to deep (dark blue), central values are depths in metres. Yellow cross depicts ADCP position.

3.8.2 Currents at Te Weka

The ADCP deployed at Te Weka Bay reliably measured currents from 4m below the surface to 28m depth, at a location that was ~29.5m deep on average. The dominant direction of flow was to the North-East (Figure 3-42). Approximately 41% of profiles exceeded 0.2 ms^{-1} and 5% of profiles exceeded 0.36 ms^{-1} over the 45-day ADCP deployment. Examining all of the observations by magnitude and direction, higher current speeds up to 0.57 ms^{-1} were associated with the flows towards the NE, with the top 1% of observations exceeded 0.42 ms^{-1}. Average currents were to the NE direction at all depths. The mean mid-water current speed was 0.20 ms^{-1} and the mean near-bottom current speed was 0.16 ms^{-1}. At Te Weka Bay, the higher profile speeds were to the N-NE, and lower speeds towards the SW (Figure 3-43).

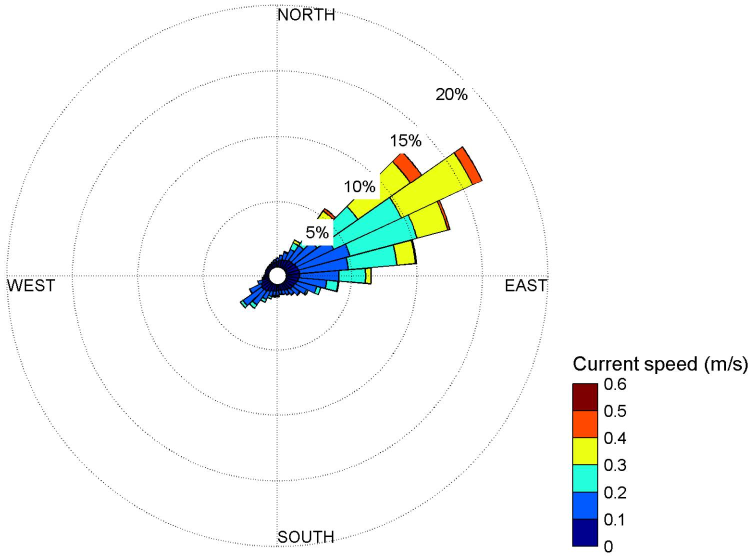


Figure 3-42: Current rose showing current directions and magnitudes for all bins at Te Weka Bay.

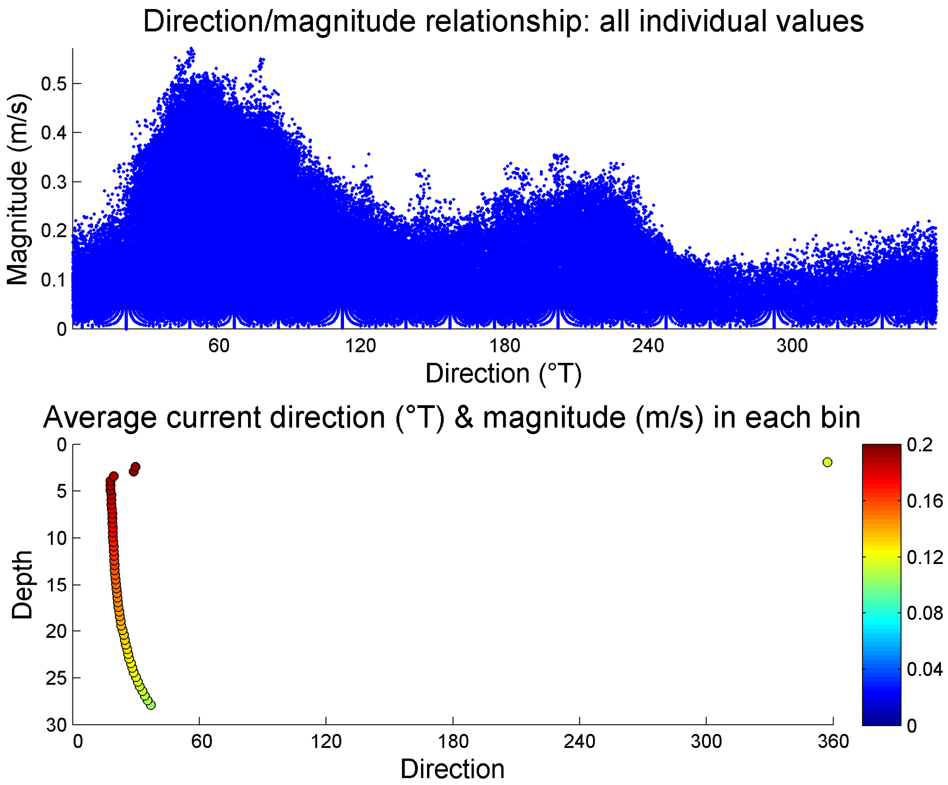


Figure 3-43: All observations of current magnitude and direction (top panel) and time-averaged profile magnitude and direction (bottom panel) at Te Weka Bay.

3.8.3 Habitats and communities at Te Weka

A diverse range of benthic habitats and communities were surveyed at the Te Weka site. From the low intertidal out to approximately 15 m depth the sediment is predominantly soft muddy sand (Figure 3-44 a,) and here biotic communities were dominated by polychaetes (densely distributed in places) and other infaunal organisms as well as patches of macroalgae. Epibiota was sparse and brittlestars (*Ophiopsammus maculata*) were the only conspicuous epifaunal organism. Further offshore in depths of approximately 12-16 m, along the southwest portion of the inshore boundary of the site, there were dense beds of red macroalgae (Figure 3-44 b), supporting patchy distributions of kina. Beneath most of the proposed cage area, and throughout much of the broader farm site (depths of ~25-35 m), the substratum was composed of varying ratios of sand, silt, shell hash and shell gravel, and biota was relatively sparse (Figure 3-44 c, d). In that zone, brittlestars (*O. maculata*) were the most common large-bodied epifaunal organism, along with small and sparsely distributed biogenic clumps comprised of aggregates of hydroids, sponges, fluffy bryozoans, ascidians, and algae. Occasional larger biogenic clumps and a few tree hydroids (*Solanderia* sp.) were also recorded in this zone (Figure 3-44 e), particularly where scattered broken rock substratum was found in the western side of the site.

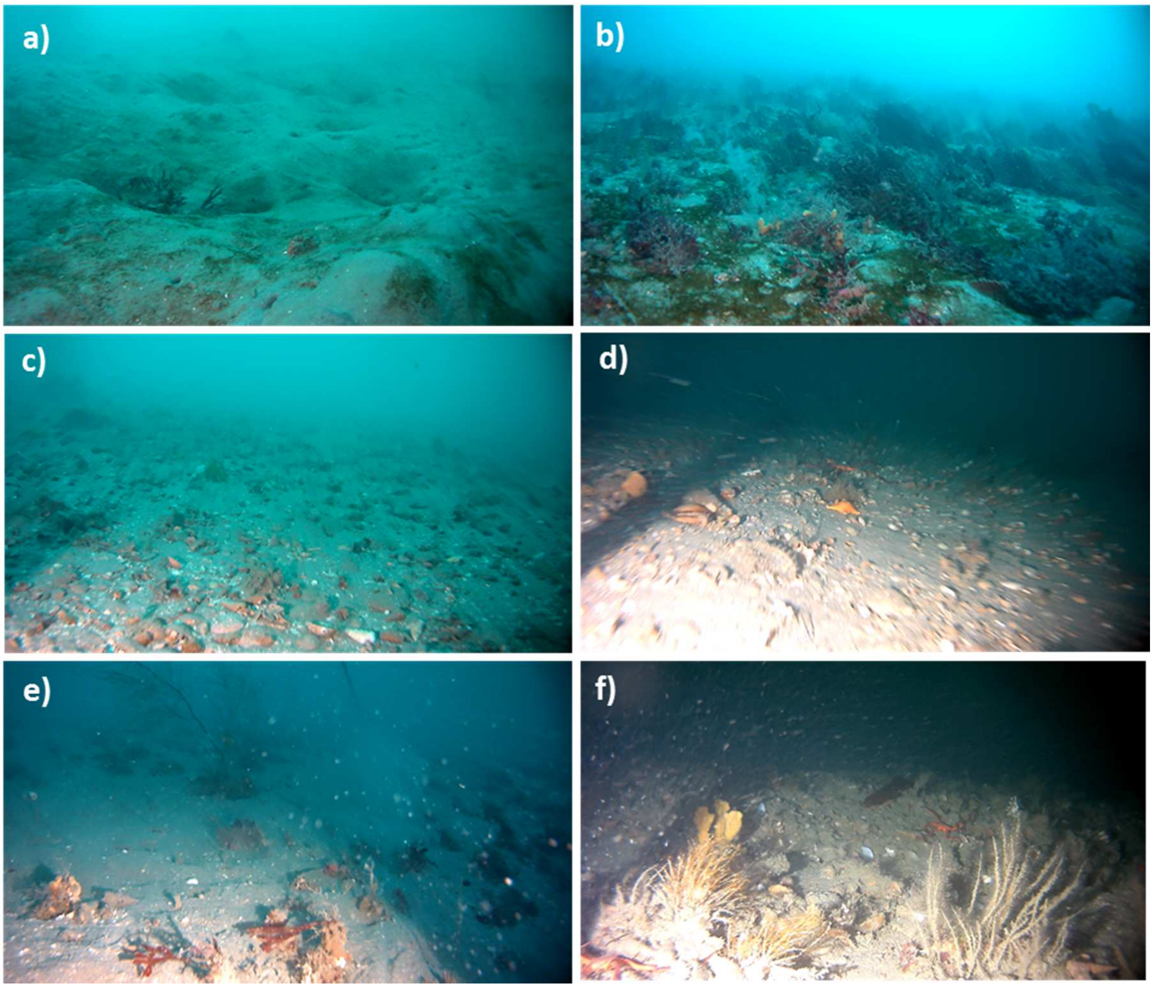


Figure 3-44: Habitats and communities at Te Weka. a) Sandy mud habitat with diatom mat inshore at ~8 m depth; b) Macroalgal bed inshore of the site at ~14 m depth; c), d) Muddy sand/shell rubble/shell hash habitat with sparse epifaunal community within the site at ~25 and ~30 m respectively; e) sand cobble and biogenic clumps including tree hydroids (*Solanderia* sp.) from video footage at the western end of site ~28 m depth; f) wave-like biogenic mounds with diverse biota at ~40 m depth near the offshore boundary of the site.

Stands and isolated individual sporophytes of kelp including giant kelp (*Macrocystis pyrifera*) grew on broken rock, cobble and low relief bedrock habitat along most of the shoreline adjacent to the proposed site.

A large bedrock reef extends out from the headland at Katoa point and at its closest point is approximately 100m from the western site boundary (250 m from the cage area boundary), and a smaller reef area lies approximately 60 m to the east of the site boundary (180 m from the cage area boundary). These reef habitats supported diverse communities including notable taxa such as bryozoan coral (*Celleporaria agglutinans*), clusters of the tubeworm (*Galeolaria hystrix*), tree hydroids (*Solanderia* sp.), kina, and scallops.

Further offshore, in the vicinity of the offshore cage boundary in the northeast portion of the site (depths of 35-45 m) there are areas of dense bivalve rubble comprising semi-consolidated aggregations of whole shell rubble and shell hash that form distinct wave-like biogenic mounds on the seabed. This shell hash/biogenic mound zone, supports a diverse epibenthic assemblage, of encrusting and erect epibenthos, including sponges, hydroids, ascidians and bryozoans, and mobile invertebrates including brittle stars, sea cucumbers and hermit crabs (Figure 3-44 f). This type of ecological feature is notable, and does not appear to have been observed or documented previously in Tory Channel.

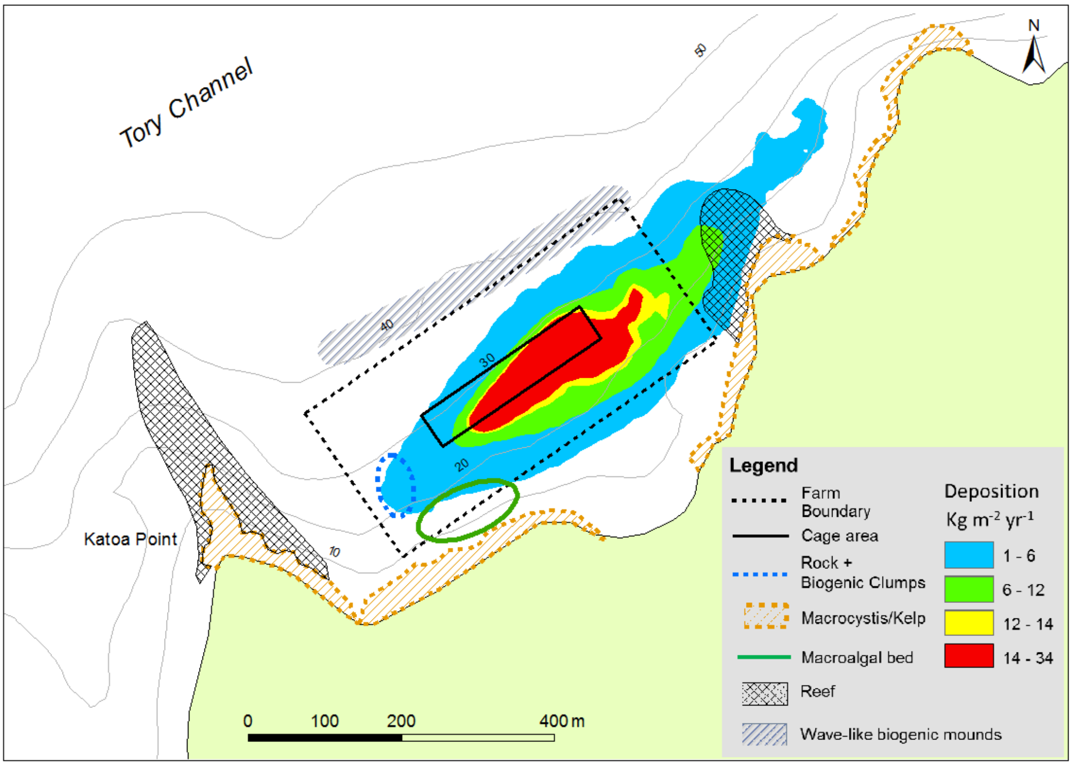
3.8.4 Predicted depositional effects at the Te Weka Bay site

Using the proposed feed input figure of 5000 tonnes per year, our modelling indicated that an area of ~1.6.Ha in the vicinity of the cages would be subject to deposition at a rate greater than 13 kg solids m^{-2} yr^{-1}, up to a maximum level of 34 kg solids m^{-2} yr^{-1} (Figure 3-45 a). The forecast rate of deposition within that zone would lead to excessive enrichment and detrimental effects associated with enrichment stage ES6. That level of enrichment is above the level of ES5, considered to be sustainable beneath salmon farms in the Marlborough Sounds. The primary footprint resulting from that feed loading was forecast to extend approximately 400 m to the northeast of the cage area, over rocky reef/broken rock/cobble habitat and associated communities. Notable broken rock habitat, tree hydroids, biogenic clumps, and a macroalgal bed at the southwest end of the site may also be affected by moderate levels of deposition (Figure 3-45a).

Modelling using a revised feed loading of 1800 tonnes per year resulted in a reduced level of deposition not exceeding ~13 kg solids m^{-2} yr^{-1} (Figure 3-45 b). However, moderate levels of deposition (ES3) would still be likely to extend approximately 240 m to the northeast of the cage area, over some of the reef/broken rock/cobble habitat located there and could negatively affect taxa that are sensitive to deposition such as suspension feeding and filter feeding hydroids, sponges and bryozoans over time.

There is potential for macroalgal beds, giant kelp stands inshore of the farm to be affected by resuspension and dispersal of depositional material beyond the modelled primary footprint. Influence from resuspended material and elevated dissolved nutrient levels within the embayment could lead to changes in the structure of those macroalgal communities and the possibility of such effects should be considered in the design of any monitoring program if a farm is established on the site.

a)



b)

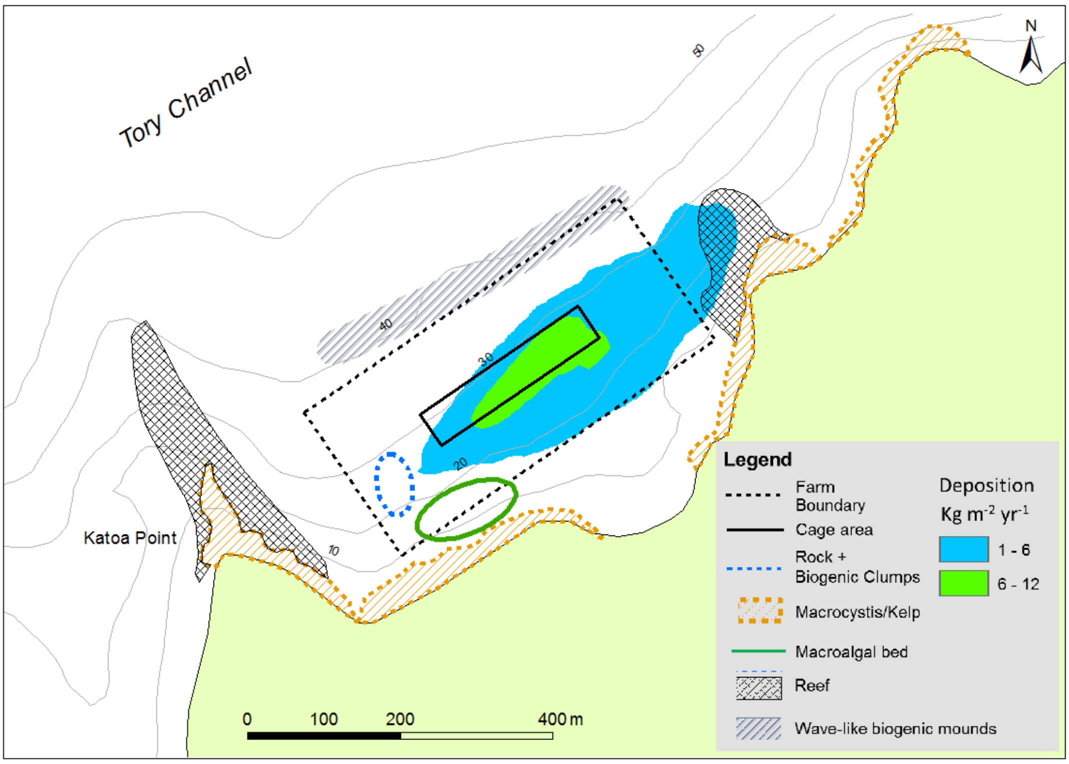


Figure 3-45: Predicted deposition footprint and notable ecological features at the Te Weka Bay site. Annual feed input scenarios of 5000 tonnes (a, above), and 1800 tonnes (b, below). Depth contour units are meters. Boundaries of notable ecological features are approximate.

4 Summary and Discussion

4.1 Summary assessment

Simulations of deposition using the initial proposed feed input values at all sites except the Blowhole Point South site resulted in maximum levels of deposition exceeding the threshold of approximately 13 kg m^{-2} yr^{-1} identified by Keeley et al (2013, 2015) as the rate of deposition that at high-flow or dispersive sites will lead to enrichment stage ES5, considered to be the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. Therefore, at those sites where acceptable limits were exceeded, alternative scenarios were modelled using successively reduced feed input figures to establish an approximate level of input that would be considered sustainable in terms of the function of the seabed community within the zone of maximum effect (ZME) (i.e. in the close vicinity of the cages). It is important to note that while the deposition associated with those reduced feed input levels is predicted to be sustainable for soft sediment communities within the ZME, notable ecological features located within the wider depositional footprint beyond the ZME may still be negatively affected by lower levels of biodeposition. A summary of the results of simulations using the initial proposed feed input levels and the corresponding sustainable feed input level are presented in Table 4.1.

Communities of infauna living within the sediments on the seabed beneath the cages and within the zone of maximum effect will be subject to significant changes at all eight of the sites. Enrichment-tolerant species such as Capitellid polychaetes and nematodes will become very abundant and diversity will be significantly reduced. Bacterial mat (*Beggiatoa* sp.) may form and outgassing of H2S gas from the sediment may occur. Noticeable changes to the infaunal community composition are likely to extend some way beyond the zone of maximum effects into the wider footprint. The infaunal species assemblage at all the sites largely comprised taxa that are widespread and common in muddy or soft-sediment habitats within the Marlborough Sounds (e.g. McKnight and Grange 1991), so the effects on these infaunal communities are not considered to be ecologically significant in the context of the Marlborough Sounds geographic region. Notable or ecologically significant features identified in Part 1 of this assessment were either populations of animals or algae living on the seabed surface (epibiota), or else substrata and habitats such as bedrock reef that support diverse communities of epibiota. The effects of deposition from finfish farms on epibiota in New Zealand have not been widely studied or described so effects to those features from a given level of deposition cannot be precisely forecast. The predictions of effects on the notable features presented in this assessment are intended to indicate where the spatial extent of deposition from the farms could potentially affect the notable features identified, rather than to forecast the precise level of impact. Effects to benthic features that are considered to be ecologically significant at each of the sites are summarised in Table 4-1.

In Tory Channel, the fast flowing tidal currents and close proximity to oceanic waters of Cook Strait have a strong influence on the structure of the marine environment such that the ecology of the channel is unique in the Marlborough Sounds Region (Hadfield *et al* 2014, Davidson *et al* 2011). The survey described in Part 1 of this assessment (Brown *et al* 2016) identified diverse habitats and communities within, and adjacent to all three of the proposed sites in Tory Channel. For example, the presence of habitat-forming biogenic aggregations comprised of epifaunal organisms including sponges, bryozoans, hydroids and ascidians, the stands of giant kelp *Macrocystis pyrifera,* and the adjacent rocky reef areas supporting diverse assemblages of invertebrates, macroalgae and fish were features of special ecological significance that are common to all three of the sites surveyed.

Table 4-1: Summary of main effects predicted at each of the proposed sites..

Site	Feed input (tonnes yr^{-1})	Approx. area of footprint ≥ES3 (Ha)	Approx. area of footprint >ES5 (Ha)	Main predicted effects, including effects on notable ecological features
Blowhole Pt North (34)	5000	16	0.01	ES5 predicted to be exceeded within a very small area beneath cages. Scallops, brachiopods, and small biogenic clumps displaced/excluded beneath cages and likely to be affected within the wider footprint. Primary footprint extends to southwest, but not as far as extensive reef at Blowhole Point nor to inshore patch reef and kelp communities.
	4500	15	0	Scallops, brachiopods, and small biogenic clumps displaced/excluded beneath cages. Note: Potential cumulative effect on the reef community at Blowhole Point if this site and site 122 Blowhole Pt Sth are both developed – suggest reef monitoring if sites approved..
Blowhole Pt South (122)	5000	20	0	Brachiopods (sparsely distributed) and small biogenic clumps, displaced/excluded beneath the cages. Low to moderate levels of deposition extend to the NE over a portion of the large reef at Blowhole Point. Potential for effects to diverse communities on that reef. Possibility of cumulative effects on the reef community at Blowhole Point if this site and site 34 Blowhole Pt Nth are both developed. Monitoring including reef and inshore monitoring recommended if site is approved.
Waitata Reach (125)	12000	45	0	Enrichment not expected to exceed ES5. No ecological features of special significance affected. Standard benthic monitoring protocol recommended.
Richmond South (106)	6500	26	0	Scallops and other taxa sensitive to deposition (eg small sparsely distributed biogenic clumps) displaced beneath the cages. Benthic monitoring including inshore habitats recommended if site approved.
Horseshoe Bay (124)	2500	8	0.5	Excessive enrichment and epibiota mostly excluded beneath cages. Within the wider footprint scallops and other taxa such as hydroids and sponges may be displaced/excluded. Moderate effects extend to the reef adjacent to Te Kaiangapipi, potentially affecting portions of the reef habitat and also the shell rubble habitat feature and associated communities.
	1500	5.5	0	Scallops and other taxa considered to be sensitive to deposition such as hydroids and sponges may be displaced/excluded beneath cages and some way into wider footprint. Benthic monitoring recommended including reef features at Te Kaingapipi and inshore of NE corner.

Site	Feed input (tonnes yr^{-1})	Approx. area of footprint ≥ES3 (Ha)	Approx. area of footprint >ES5 (Ha)	Main predicted effects, including effects on notable ecological features
Tipi Bay (42)	2000	4.25	0.25	Excessive enrichment and biodeposition directly affecting significant reef/broken rock and biogenic habitats and associated communities in NE and SW of embayment.
	1000	3.2	0	Moderate levels of deposition extend directly over, and may affect notable habitats and communities in NE and SW portions of the site. Inshore kelp stands and seagrass beds potentially affected by resuspended farm waste and elevated nutrient levels. Very stringent management plan and monitoring conditions and possibly further research recommended at this site even at reduced feed input levels.
Motukina (82)	5000	9.6	1.2	Severe enrichment beneath cage area. Direct impacts to significant ecological habitats and communities.
	1000	3.8	0	Moderate levels of deposition expected to affect notable benthic habitats and communities at the eastern and western ends of the embayment. Potential for resuspension and elevated nutrient levels to affect inshore macroalgal beds. Further surveys, research and comprehensive management/monitoring plan may be necessary to try to avoid or mitigate effects if this site was approved.
Te Weka Bay (47)	5000	11	1.6	Excessive enrichment beneath cages. Moderate depositional effects expected to extend over broken rock/reef/biogenic habitat to the northeast of the cage area.
	1800	6.5	0	Moderate deposition extends over, and potentially affects portions of reef/broken rock/cobble habitat to the northeast of the cages. Potential for resuspended biodeposits and elevated nutrient levels to affect inshore kelp stands and macroalgal beds. Comprehensive benthic monitoring including inshore macroalgal communities recommended if site was approved.

4.2 Limitations of DEPOMOD Version 2

DEPOMOD Version 2 was developed mainly in reference to low-flow sites with fairly uniform bathymetry, and is considered to be less accurate in predicting benthic depositional footprints at high-flow sites with complex bathymetry. For example, one limitation is that the vertical profile of currents are measured by the ADCP at a single position within the modelled area, and assumed to flow in the same manner throughout the entire modelled area or domain (ie there is vertical resolution but not horizontal resolution of current flows). At sites where currents are swift and bathymetry is complex (such as the sites in Tory Channel) there is a greater likelihood of complex flow characteristics such as eddies, vortices or other flow anomalies to manifest, and for flow characteristics to vary from those measured at the position where the ADCP was deployed. Thus there is increased potential for inaccuracy in the modelled pattern of deposition and for biodeposition to occur over ecological features outside of the modelled footprint at those sites. Of the sites considered in this assessment, the DEPOMOD predictions are likely to be most accurate at the Waitata mid-channel site where the bathymetry was relatively even and thus current profiles are likely to be more uniform in the horizontal dimension throughout the modelled area.

4.3 Effects beyond the predicted primary footprint

This study focussed on direct effects to the benthos from the deposition of farm wastes in the form of waste feed and salmon faeces. Other potential effects from establishment of finfish farms at these sites could influence the ecology of the marine environment beyond the predicted depositional footprint. Such potential effects include long term effects from transport of resuspended biodeposits and elevated levels of dissolved nutrients. For example, resuspension and transport of biodeposits and elevated nutrient levels beyond the primary footprint could cause increased turbidity, enhanced growth of ephemeral benthic algae and epiphytes (e.g. Schiel 2004) potentially leading to increased abundance of grazing invertebrates and grazing pressure changes or other flow-on effects that can affect kelp recruitment (e.g. Bergström et al 2003) or alter community structure. There is potential for such effects on notable features identified inshore of all of these sites (except for the Waitata Reach mid-channel site) including quiescent areas beyond the immediate footprint, macroalgal beds, and small patch reef and kelp communities. Those effects have not been documented so far in relation to salmon farms in the Marlborough Sounds, but the possibility of such effects should be considered in the design of monitoring programs if salmon farms are relocated to any of these sites.

4.4 Other potential effects

Settlement, growth and subsequent drop-off of fouling species on farm structures can contribute to deposition on the seabed beneath farms, and fouling taxa may also colonise habitats adjacent to farm structures causing changes to natural benthic communities. Similarly, there is a potential risk of pest species introduced by boat traffic visiting farms to become established on farm structures and subsequently spread to adjacent benthic habitats (Hewitt et al 2004, Forrest et al 2007). Finfish farms also attract and aggregate large predators (e.g. seals, sharks and seabirds) that could influence predator - prey dynamics or contribute to nutrient enrichment within embayments and lead in turn to changes in benthic community structure (e.g. Papastamatiou et al 2010), but no studies have been conducted in New Zealand to investigate the effects on benthic communities of predator aggregation around marine finfish farms.

4.5 Recommendations for monitoring

Collaborative efforts by industry, research providers, local authorities and central government have achieved significant progress in the understanding of benthic effects of finfish farms, resulting in improved management of those effects in the Marlborough Sounds. The culmination of that work to date has been the development of the 'Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Benthic environmental quality standards and monitoring protocol' (Keeley et al 2015). If salmon farms are relocated to sites investigated in this assessment, it is recommended that a benthic monitoring plan is developed following those recently developed guidelines. Given the uncertainties surrounding the prediction of effects, design of monitoring surveys should also consider: Monitoring of effects to notable features and habitat types other than soft sediment habitat such as rocky or biogenic habitat that are located either within, or near to the 'zone of effect' of the primary depositional footprint; cumulative effects from deposition of low levels of waste particulates from the farm, and resuspension and dispersion of dissolved nutrients transported beyond the predicted primary footprint that could negatively affect notable features identified in the site surveys (section 4.3 above); and biosecurity in terms of transport of marine pests via movement of farm structures and vessel movements (section 4.4 above).

5 Acknowledgements

The authors thank Matt McGlone (skipper of RV Ikatere), Dave Bremner, Fiona Elliot, Chris Healey, Andrew James, Erik Behrens for field deployment and recovery of ADCPs, Colin Sutton for additional field sampling, Julian Sykes and Jochen Bind for assistance with GIS expertise, and Simon Hoyle for additional modelling advice.

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Appendix A Description and main environmental characteristics of enrichment stages (ES) 1-7 for low flow (LF) and high flow (HF) sites

Reproduced from Keeley *et al* 2015.

ES	General description		Environmental characteristics
1.0	***Pristine end of spectrum.*** Clean unenriched sediments. Natural state, but uncommon in many modified environments	LF	Environmental variables comparable to an unpolluted / un-enriched pristine reference station.
		HF	As for LF, but infauna richness and abundances naturally higher (~2 × LF) and %organic matter (OM) slightly lower.
2.0	***Minor enrichment.*** Low-level enrichment. Can occur naturally or from other diffuse anthropogenic sources. 'Enhanced zone.'	LF	Richness usually greater than for reference conditions. Zone of 'enhancement' – minor increases in abundance possible. Mainly a compositional change. Sediment chemistry unaffected or with only very minor effects.
		HF	As for LF
3.0	***Moderate enrichment.*** Clearly enriched and impacted. Significant community change evident.	LF	Notable abundance increase; richness and diversity usually lower than reference station. Opportunistic species (i.e. Capitellid worms) begin to dominate.
		HF	As for LF
4.0	***High enrichment.*** Transitional stage between moderate effects and peak macrofauna abundance. Major community change.	LF	Diversity further reduced; abundances usually quite high, but clearly sub-peak. Opportunistic species dominate, but other taxa may still persist. Major sediment chemistry changes (approaching hypoxia).
		HF	As above, but abundance can be very high while richness and diversity are not necessarily reduced.
5.0	***Very high enrichment.*** State of peak macrofauna abundance. Currently considered to be the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds.	LF	Very high numbers of one or two opportunistic species (i.e. Capitellid worms, nematodes). Richness very low. Major sediment chemistry changes (hypoxia, moderate oxygen stress). Bacterial mat usually evident. Out-gassing occurs on disturbance of sediments.
		HF	Abundances of opportunistic species can be extreme (10 × LF ES5 densities). Diversity usually significantly reduced, but moderate richness can be maintained. Sediment organic content usually slightly elevated. Bacterial mat formation and out-gassing possible.
6.0	***Excessive enrichment.*** Transitional stage between peak abundance and azoic (devoid of any organisms).	LF	Richness and diversity very low. Abundances of opportunistic species severely reduced from peak, but not azoic. Total abundance low but can be comparable to reference stations. %OM can be very high (3–6 × reference).
		HF	Opportunistic species strongly dominate, with taxa richness and diversity substantially reduced. Total infauna abundance less than at stations further away from the farm. Elevated %OM and sulfide levels. Formation of bacterial mats and out-gassing likely.
7.0	***Severe enrichment.*** Anoxic and azoic; sediments no longer capable of supporting macrofauna with organics accumulating.	LF	None, or only trace numbers of infauna remain; some samples with no taxa. Spontaneous out-gassing; bacterial mats usually present but can be suppressed. %OM can be very high (3–6 × reference).
		HF	Not previously observed — but assumed similar to LF sites.