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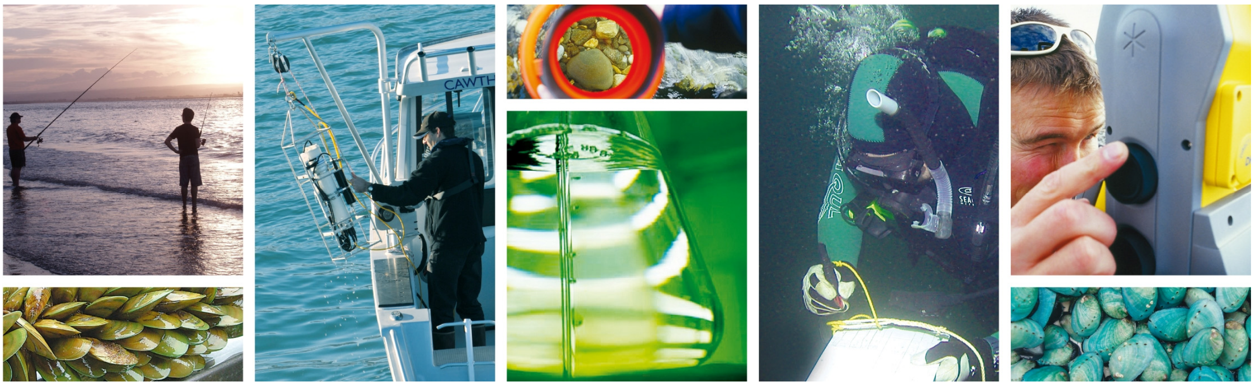
# Assessment of Effects of Farming Salmon at Ngamahau, Queen Charlotte Sound: Deposition and Benthic Effects.



RESEARCH BASED SOLUTIONS

# Assessment of Effects of Farming Salmon at Ngamahau, Queen Charlotte Sound: Deposition and Benthic Effects.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# EXECUTIVE SUMMARY


**Overview of purpose and scope**

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

**Proposal**

The Ngamahau application is a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. The site would be used for farming salmon fed at an initial feed level rate of 1500 tonnes per annum (t $yr^{-1}$). NZ King Salmon have applied for an option to increase the feed discharge at 500 t $yr^{-1}$ increments if it is considered environmentally appropriate up to a maximum of 4000 t $yr^{-1}$.

**Assessment approach**

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

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

**Summary of findings**

The proposed Ngamahau Site was located in 5 to 40 m water depth in a region of relatively high water currents. Within Ngamahau Bay, and parts of the small inlets inshore of the proposed site, the benthos was characterised by mud. The mud zone ranged from areas of bare mud to mud covered with various species of algae. The seabed beneath the proposed site ranged from pebbles to sand to mud with varying levels of associated biodiversity. Infaunal (within sediment) communities within the study area were species-rich (a total of 118 different taxa) and were numerically dominated by various species of polychaetes, nematodes, cumaceans, isopods, amphipods and ostracods. Epibiota biodiversity of the predominant substratum beneath the proposed site was greatest in the

pebble/shell/sand area with biogenic clumps of species such as sponges, ascidians and bryozoans rated as abundant to common. Biogenic clumps became less common in the sand/shell habitat and were seen only occasionally in mud/shell habitats beneath the site.

The habitats inshore and to the north of the proposed Ngamahau Site were often characterised by hard or coarse substrata and supported a relatively diverse flora and fauna. Inshore of the proposed site cobbles appeared at depths of 15 to 18 m and increased in size with depth. The inshore boundary of the proposed site partially extends onto this reef/cobble/sand area (distance of up to 40 m). A large reef was observed from the headland north of the site to depths of 40 m. A small reef area is located within the northern corner of the proposed site at a depth of approximately 18 m. These reef areas supported a diverse array of fish, invertebrates and macroalgae.

Tree hydroid patches were regularly observed across most habitat types. These areas were associated with high biodiversity. The only observed tree hydroids within the proposed site were those associated with the small reef area in the northern corner. Other ecologically significant species observed inshore of the Ngamahau Site were *Cerianthus* anemones, and the kelp, *Macrocystis pyrifera*. Juvenile crayfish and paua were also observed on reef approximately 175 m to the east of the proposed Cage Area Boundary. The intertidal and shallow subtidal areas inshore of the proposed farm were characteristic of many areas in the Tory Channel region of the Marlborough Sounds.

The site is situated on the southern side of Arapawa Island, within the high energy Tory Channel area, and is in close proximity to the much larger water bodies of the Cook Strait. The average current velocity at the Ngamahau Site was *ca.* 22 cm $s^{-1}$, with maximum velocities of 55 to 64 cm $s^{-1}$ throughout the water column. Currents flowed predominately to the northeast (towards Cook Strait), and ran parallel to the coastline, with tidal reversal increasing with depth. Depositional modelling indicated that dispersal of the footprint will be considerable due to the high water current velocities. Under a no-resuspension scenario, the maximum depositional flux ranged from 19 to 22 kg $m^{-2}yr^{-1}$, when feed loadings of up to 4000 t $yr^{-1}$ were modelled, with the majority of flux directly beneath cages. The effect of the prevailing current is evident by the elliptical shape of deposition predicted for the site. When resuspension was considered in the model, net depositional flux reaching the seabed did not exceed 0.5 kg $m^{-2}$ $yr^{-1}$ for any of the feed loadings modelled, even at the highest level modelled (8000 t $yr^{-1}$ of feed). As the prevailing near-bottom current conditions regularly exceeded the resuspension threshold, the resuspension scenario is considered the most appropriate estimate for the site.

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

Directly beneath the farm cages (*ca.* 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected. Epibiota observed beneath the site will also be displaced. It is anticipated that a further 14.6 ha of seabed will be low-to-moderately impacted; however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within 500 m. The boundaries of the proposed site were chosen to minimise potential effects to ecologically sensitive habitats in the vicinity of the proposed farm. Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.

The recommended initial feed level (RIFL) of 1500 t $yr^{-1}$ is considered an appropriate starting point for this site; although modelling suggests that adverse environmental effects are unlikely if feed usage is increased to the predicted sustainable feed level (PSFL) of 2500 t $yr^{-1}$. The maximum conceivable feed level (MCFL) for the Ngamahau Site was estimated to be 4000 t $yr^{-1}$. Any increases from the RIFL should be undertaken in 500 t $yr^{-1}$ increments based on favourable environmental monitoring results. If initial feed levels prove to be too high, permitted feed levels should be adjusted accordingly.

**Environmental monitoring**

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

**Conclusions**

The Ngamahau Site is situated in a high-flow where wastes will be dispersed and assimilated by the environment. The bathymetry and physical attributes of the site are suited to cage farming, but there are notable ecological habitats in this area. The location of the proposed site has been chosen to minimise potential effects to ecologically sensitive habitats in the vicinity of the proposed farm.

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# 1. INTRODUCTION

## 1.1. Background

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

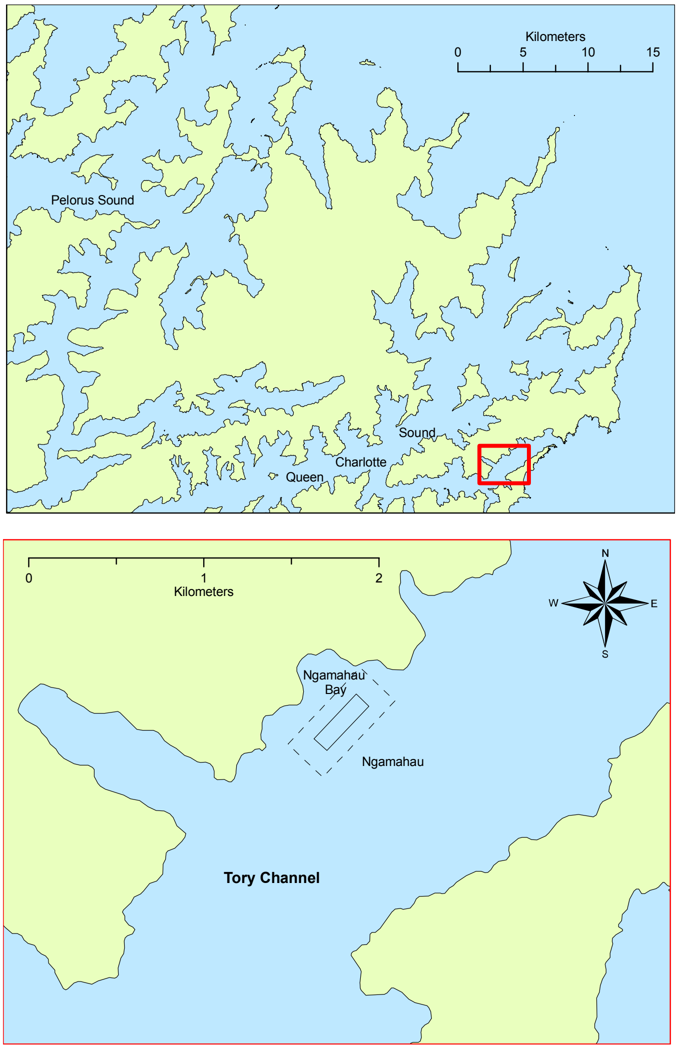


**Figure 1.** Location of the study area in Queen Charlotte Sound, with an expanded map of the proposed Ngamahau Site. The dashed black rectangle indicates the Ngamahau Plan Change Site and the solid black rectangle indicates the Cage Area Boundary (a 3.5 ha area within which 1.5 ha of cage structures will be placed).

## 1.2. Description of proposed activities at the Ngamahau Site

NZ King Salmon seeks approval for a 16.5 hectare (ha) area with a 3.5 ha area for cage structures within which there will be 1.5 ha of cages. They also seek approval for the use of an initial maximum of 1500 tonnes of feed per annum (t $yr^{-1}$) with the option to increase the feed discharge at 500 t $yr^{-1}$ increments if it is considered environmentally appropriate to a maximum of 4000 t $yr^{-1}$. Fish would be on-grown in large sea cages (40 x 40 m) from smolt reared in land-based hatcheries and fed a pelleted diet until they reached a mean harvestable size of approximately 3.5 kg.

## 1.3. Potential environmental issues and scope of this report

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

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

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

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

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

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

## 1.4. Structure of this report

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

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

# 2. EXISTING KNOWLEDGE OF MARINE ENVIRONMENTS IN THE STUDY AREA

## 2.1. Tory Channel and the Queen Charlotte Sound marine environments

The Ngamahau study area is situated on the eastern side of Arapawa Island in Tory Channel; including Ngamahau Bay area is approximately 800 m long and 600 m wide. Water depths at the Ngamahau study area vary widely, with a relatively shallow area of up to 15 m depth within the bay, and deeper water of up to 55 m offshore.

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

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

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

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

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

## 2.2. The Ngamahau Site study area

The site is situated near Ngamahau Bay on the eastern side Arapawa Island, Queen Charlotte Sound, approximately 4.5 km from the entrance of Tory Channel into Cook Strait (Figure 1). Tory Channel is characterised by strong tidal currents ranging from 1 to 7 knots (Davidson *et al.* 2005). The study area is sheltered from most wind directions including the prevailing northwest winds, but strong wind gusts eddy into the Sound and some northerly winds reach the study area. The Ngamahau study area is directly sheltered from most wave action, although some attenuated sea-swell action enters Tory Channel from Cook Strait.

# 3. SEABED CHARACTERISTICS

## 3.1. Site bathymetry

Water depths at the study area ranged from 5 to 20 m along the inshore boundary of the proposed site, to depths of 35 to 40 m along the seaward boundary. Inshore of the site, in depths of 5 to 30 m, the seabed was steeply sloping, whereas offshore of the site the seabed was relatively flat (Figure 2).

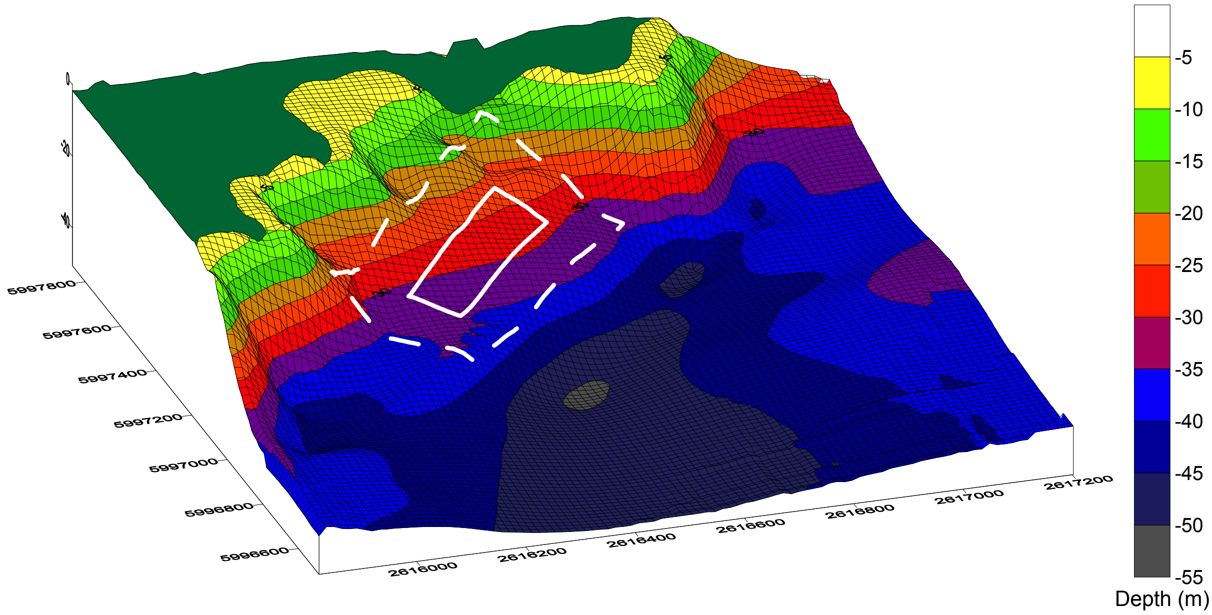


**Figure 2.** 3-D bathymetry map of Ngamahau Site with proposed locations of the Cage Area Boundary (solid white line) and Plan Change Site Boundary (dashed white line) overlaid onto the seafloor.

## 3.2. Sediment physical and chemical properties

Sediments sampled from beneath and adjacent to the proposed site contained varying amounts of silt and clay (<63 µm), sand (<2 mm and >63 µm) and gravel-sized (>2 mm) components (Figure 3). Sediments sampled from the Ngamahau study area primarily contained sand (50-78 % ww; Figure 3). Gravel components were highest in sediments from Stations 2, 3 and 5 (17-31 % ww). Stations closer to the shore (1, 4, 7 and 8) contained higher proportions of silt and clay, with Stations 1 and 4 (inshore of proposed site) containing almost no gravel. These results were consistent with observations made from video footage and drop-camera images (see Section 3.3.4). Sediment cores were characterised by a fairly uniform light grey/brown colour and appeared well oxygenated, with no evidence of an apparent Redox Potential Discontinuity (aRPD) layer or sulphide odours (Appendix 4). Sediment organic content was relatively similar between stations (average 2.7 % AFDW; range 2.3-3.2 %) but slightly lower in sediments containing more gravel (stations 2, 3 and 5; 2.3-2.4 % AFDW).

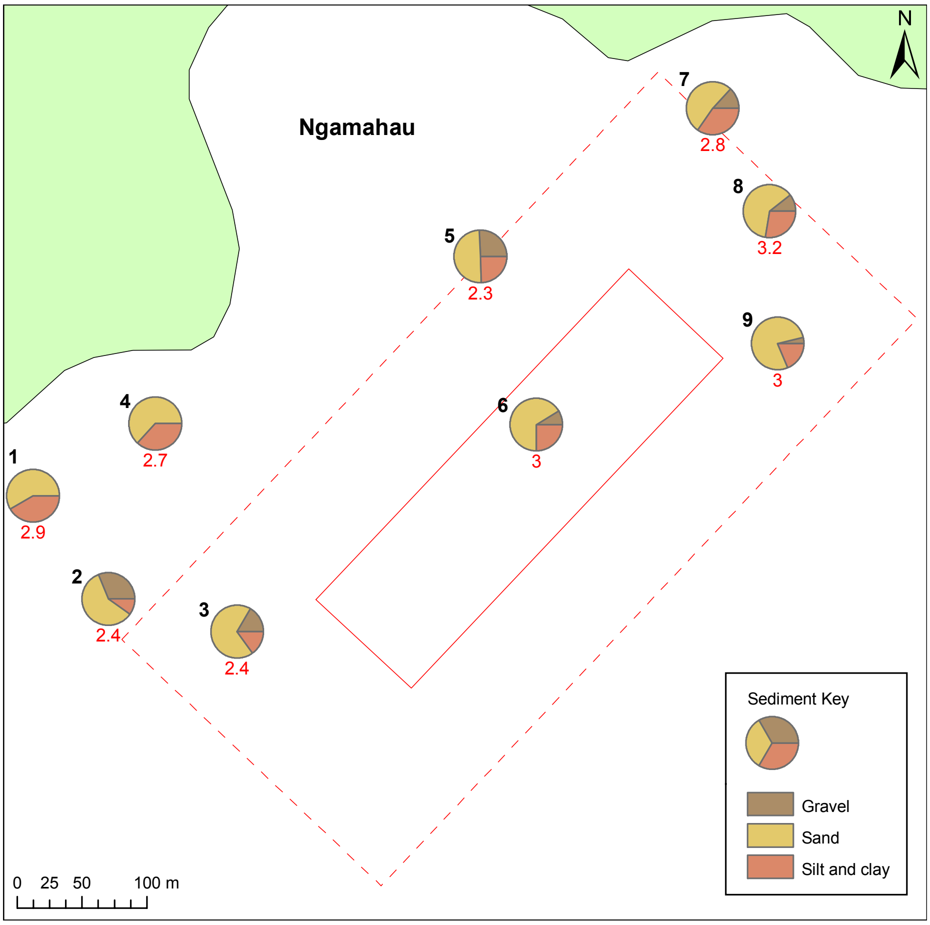


**Figure 3.** Grain size composition (% wet weight) and organic content (in red: %AFDW) of sediments collected from within and adjacent to the proposed Ngamahau Site. Black numbers indicate station number, the solid red line indicates the proposed Cage Area Boundary and the red dashed line indicates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

## 3.3. Sediment biological properties

Sediments sampled from the Ngamahau study area contained infaunal communities representative of those commonly found in deep, high-flow areas throughout the Marlborough Sounds region, and are therefore considered indicative of natural or pre-farm conditions. The site was characterised by high taxa richness (a total of 118 taxa recorded), and ranged between 24 and 62 taxa per sediment core (Table 1). Refer to Appendix 5 for the complete species list. Infaunal abundance ranged between 53 and 337 individuals (average of 180).

Patterns in infaunal community composition were further explored using multivariate statistical techniques, and the reader is referred to Appendix 6 for a summary of these analyses. In addition to being distinguished by the lowest total abundance and taxa richness, multivariate analysis showed the infaunal community at Station 4 was different to the other stations due to the dominance of *Capitella capitata* polychaetes and absence of a number of species, including Aoridae amphipods, *Sphaerosyllis* polychaetes and nematodes (see Appendix 6). The dominant taxa at the other stations were amphipods of the family Aoridae, various species of polychaetes, the ascidian *Oligocarpa megalorchis*, cumaceans, nematodes and tanaids (Table 1).

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

| | Grab Station | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **Ave. abund.** | **Rel. abund. (%)** |
| Amphipoda: Aoridae | 50 | 145 | 7 | 0 | 17 | 7 | 27 | 7 | 24 | 32 | 19 |
| Polychaeta: Syllidae: *Sphaerosyllis* sp. | 2 | 5 | 36 | 0 | 33 | 16 | 1 | 16 | 29 | 15 | 9 |
| Polychaeta: Paraonidae | 1 | 5 | 15 | 1 | 20 | 5 | 4 | 13 | 34 | 11 | 7 |
| Polychaeta: Capitellidae: *Heteromastus filiformis* | 4 | 1 | 31 | 6 | 8 | 16 | 1 | 7 | 17 | 10 | 6 |
| Ascidiacea: *Oligocarpa megalorchis* | 0 | 0 | 0 | 0 | 30 | 33 | 0 | 0 | 5 | 8 | 5 |
| Cumacea | 4 | 12 | 20 | 1 | 10 | 0 | 2 | 3 | 16 | 8 | 3 |
| Nematoda | 1 | 1 | 38 | 0 | 15 | 3 | 4 | 0 | 6 | 8 | 5 |
| Polychaeta: Sabellidae: *Euchone pallida* | 4 | 12 | 20 | 1 | 10 | 0 | 2 | 3 | 16 | 8 | 5 |
| Tanaidacea: *Tanaid* sp. | 2 | 1 | 0 | 1 | 12 | 8 | 2 | 16 | 13 | 6 | 4 |
| Polychaeta : Spionidae: *Spiophanes kroyeri* | 3 | 0 | 5 | 0 | 0 | 4 | 5 | 16 | 9 | 5 | 3 |
| Polychaeta: Syllidae | 0 | 2 | 12 | 0 | 4 | 3 | 2 | 3 | 8 | 4 | 2 |
| Polychaeta: Capitellidae: *Capitella capitata* | 0 | 1 | 3 | 16 | 4 | 0 | 0 | 0 | 0 | 3 | 2 |
| Polychaeta: Maldanidae | 1 | 8 | 2 | 0 | 2 | 2 | 0 | 4 | 9 | 3 | 5 |
| Polychaeta: Oweniidae: *Myriochele* sp. | 8 | 0 | 0 | 1 | 1 | 0 | 5 | 5 | 5 | 3 | 2 |
| Polychaeta: Spionidae: *Prionospio multicristata* | 8 | 6 | 5 | 1 | 2 | 0 | 0 | 3 | 6 | 3 | 2 |
| **Total abundance** | **145** | **205** | **261** | **53** | **223** | **140** | **78** | **178** | **337** | | |
| **Taxa richness** | **37** | **23** | **44** | **24** | **45** | **33** | **27** | **47** | **62** | | |

## 3.4. Subtidal habitats and conspicuous epibiota

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

Habitats in the study area are represented diagrammatically in Figure 7. The benthic habitats within the proposed site were primarily characterised by sand/shell and mud/shell (Figure 7). Areas of pebble/sand/shell, reef/cobbles/sand and mud were also present within the site, and characterised the areas inshore and north of the site. Beneath the proposed site, the substratum graded west to east from pebbles and dead shells overlying sand (western corner; Figure 6C) to areas of sparse pebbles and more sand (Figure 6D) and finally to areas of finer sediment (mud) with shells (Figure 6E). Biodiversity in these three zones was patchy, with species such as snake tail stars and cushion stars common throughout, but other species, such as sponges, ascidians, hydroids, and bryozoans, concentrated in clumps. The abundance of these clumps and, therefore, the biodiversity of the area, also graded west to east with biogenic clumps abundant to common in pebble/shell/sand areas, common to occasional in sand/shell areas and occasional in mud/shell areas. A tongue of mud extended into the mud/shell habitat at the northern end of the Cage Area Boundary. The mud zone contained relatively few epibiota and ranged from areas of bare mud to mud covered with various species of algae.

Within Ngamahau Bay, and parts of the small inlets inshore of the proposed site, the benthos was characterised by mud (Figure 7). The mud zone ranged from areas of bare mud to mud covered with various species of algae. Bare mud areas contained few epibiota with generally only a film of benthic diatoms and the occasional snake tail star and red algae present (Figure 5H; Figure 6F). Mud habitat, supporting green (*Ulva* sp.), brown (*Ecklonia radiata* and *Undaria pinnatifida*) and red algae, snake tail stars and small fish, was observed along the coastline to the south of Ngamahau Bay, to depths of 15 to 18 m (Figure 5G). Large *M. pyrifera*, *E. radiata* and *Carpophyllum flexuosum* were common down to 14 m (Figure 5A). Similar mud habitat was observed along parts of the coastline of Ngamahau Bay.

The habitats inshore and to the north of the proposed Ngamahau farm Site were often characterised by hard or coarse substrata and supported a relatively diverse flora and fauna (Table 2). To the south of Ngamahau Bay cobbles appeared at depths of 15 to 18 m and increased in size with depth. The cobble area was dominated by green (*Ulva* sp.), brown (*M. pyrifera, E. radiata*, *U. pinnatifida*, *C. flexuosum* and *Marginariella boryana*) and red algae with sponges, hydroids, kina, sea cucumbers, sea stars and fish common (Figure 5E,F; Figure 6A,B). Amongst the cobble and large macroalgae areas, diverse patches of reef were also observed, characterised by sponges, hydroids, ascidians, fish and red algae (Figure 5C). Two burrowing *Cerianthus* anemones were noted during dive and video transects (one at 19 m, the other at an unknown depth). The inshore boundary of the proposed site partially extends into this reef/cobble/sand area (distance of 40 m; depth of 20 m) (Figure 7).

A large reef was observed extending from the headland north of the proposed site (20 m from proposed site, 175 m from proposed Cage Area) (Figure 7). The reef extended to depths of 40 m and shallower areas of the reef were dominated by brown algae (*M. pyrifera, E. radiata* and *C. flexuosum*). The reef was characterised by sponges, hydroids, *Caulerpa* algae, red algae, ascidians and various fish species. High densities of juvenile crayfish (*Jasus edwardsii*) filled crevices in the reef from 10 to 16 m water depth (Figure 5B) and several paua (*Haliotis iris*) were observed. Cobbles with coarse sandy patches were also observed in this area.

A small reef area sits within the northern corner of the proposed site at a depth of approximately 18 m. Ascidians, sponges, hydroids, algae (red, *Ulva* sp., *U. pinnatifida*), sea urchins, snake tail stars, fish (tarakihi, spotties, blue cod) and duck's bill limpets (*Scutus breviculus)* were noted in this area and large tree hydroids were common (Figure 5, D).

Patches of tree hydroids were regularly observed in dive and video footage, and dropcam images (Figure 5D; Figure 7). As habitat-forming species, tree hydroids represent areas of high biodiversity. High numbers of fish were seen in the vicinity of tree hydroid zones and the substratum surrounding them was reef-like with high diversity and abundance of sponges, ascidians, smaller hydroids, kina, sea stars, snake tail stars, sea cucumbers, anemones, fanworms and algae. The only observed tree hydroids within the proposed site are those associated with the small reef area in the northern corner. The tree hydroid zones shown in Figure 7 represent only those observed during dive and video transects or drop-camera images. There are likely to be more of these features in this part of the study area. Tree hydroid patches do not appear to be limited to a particular substratum type and were observed in all habitat types, except mud.

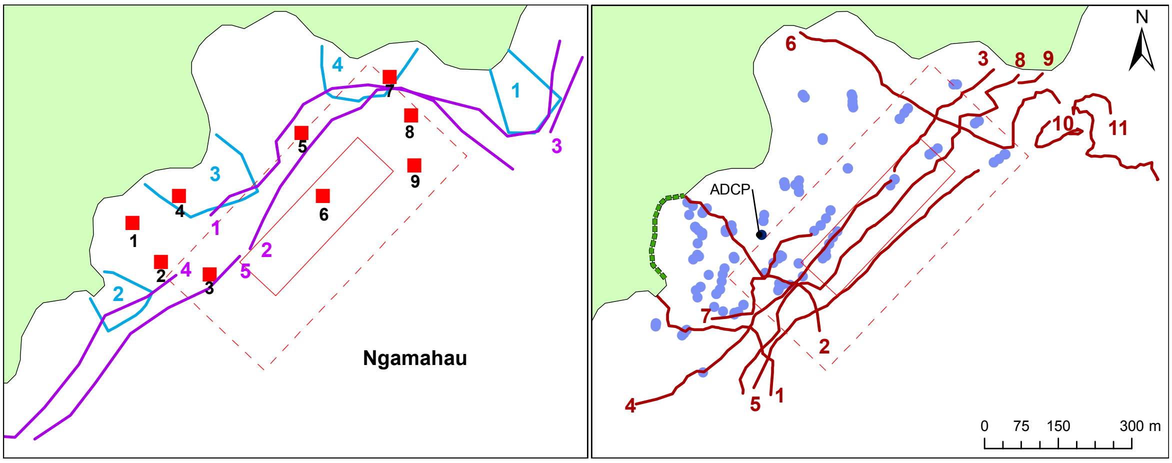


**Figure 4.** Sampling locations beneath and adjacent to the Ngamahau Plan Change Site. Left: dive transects (blue lines), side scan sonar transects (purple lines), sediment grab sampling stations (red squares). Right: intertidal survey (green dashed line), drop camera locations (purple circles), video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

**Table 2.** Conspicuous epibiota associated with seabed habitats identified from video and drop-camera images within and adjacent to the Ngamahau Site.

| Seabed habitat | Conspicuous epibiota |
|---|---|
| Mud | Encrusting coralline algae, red algae, green algae (*Ulva* sp.), brown algae (*M. pyrifera, U. pinnatifida, E. radiata, C. flexuosum, Marginariella boryana*), encrusting sponge, feather hydroids, colonial ascidians (orange, white), bryozoans (branching, bushy), snake tail stars (*Ophiopsammus maculata*), sea urchins (*Evechinus chloroticus*), sea stars (*Coscinasterias calamaria* , *Patiriella* sp., unidentified sp.), sea cucumbers (*Stichopus mollis*), sea anemones (*Anthothoe albocincta*), fanworm, Duck's bill limpet (*S. breviculus*), camouflage crab, fish (*Latridopsis ciliaris, Notolabrus celidotus, Parapercis colias, Nemadactylus macropterus*) |
| Mud/shell | Encrusting coralline algae, red algae, brown algae (*U. pinnatifida*), sponges (various species of encrusting and erect), feather hydroids, tree hydroid, solitary and colonial ascidians (orange, white, *Oligocarpa megalorchis, Cnemidocarpa* sp., *Pyura* sp.), bryozoans (branching, bushy, strawberry), snake tail stars (*O. maculata*), sea urchins (*E. chloroticus*), sea stars (*C. calamaria* , *Patiriella* sp.), sea cucumbers (*Ocnus brevidentis* , *S. mollis*), sea anemones (*A. albocincta*), fanworms, brachiopods, scallops (*Pecten novaezelandiae* ), fish (Pleuronectidae sp., |

| | |
|---|---|
| | *P. colias, N. celidotus, Caesioperca lepidoptera,* unidentified fish). |
| Sand/shell | Encrusting coralline algae, red algae, green algae (*Ulva* sp.), brown algae (*U. pinnatifida),* sponges (various species of encrusting and erect), feather hydroids, solitary and colonial ascidians (orange, white, grey, *O. megalorchis, Cnemidocarpa* sp., *Pyura* sp.), bryozoans (branching, bushy), snake tail stars (*O. maculata*), sea stars (*Patiriella* sp*.),* sea cucumbers (*S. mollis*), sea anemones (*A. albocincta*), fanworms, scallops (*P. novaezelandiae* ), fish (*P. colias, Hemerocoetes monopterygius*, unidentified fish). |
| Pebble/shell/sand | Encrusting coralline algae, red algae, green algae (*Ulva* sp.), brown algae (*U. pinnatifida, C. flexuosum*), sponges (various species of encrusting and erect), feather hydroids, calcareous tubeworms, solitary and colonial ascidians (orange, white, grey, *O. megalorchis, Cnemidocarpa* sp.), bryozoans (encrusting, branching, bushy, strawberry), snake tail stars (*O. maculata*), sea urchins (*E. chloroticus*), sea stars (*C. calamaria , Patiriella* sp*., Pentagonaster pulchellus* , unidentified sp.), sea cucumbers (*S. mollis*), sea anemones (*A. albocincta, Cerinathus* sp.), fanworms, brachiopods, scallops (*P. novaezelandiae* ), Cook's turban (*Cookia sulcata*), hermit crab, fish (*Cephaloscyllium isabellum* , Pleuronectidae sp., *P. colias, C. lepidoptera,* unidentified triplefins, unidentified fish). |
| Reef/cobble/sand | Encrusting coralline algae, red algae, green algae (*Ulva* sp., *Caulerpa* sp.), brown algae (*M. pyrifera, U. pinnatifida, E. radiata, C. flexuosum, M. boryana*), sponges (various species of encrusting and erect), feather hydroids, calcareous tubeworms, solitary and colonial ascidians (orange, white, grey, *O. megalorchis, Cnemidocarpa* sp., *Pyura* sp.), bryozoans (encrusting, branching, bushy), snake tail stars (*O. maculata*), sea urchins (*E. chloroticus*), sea stars (*C. calamaria , Patiriella* sp*.,* unidentified sp.), sea cucumbers (*S. mollis*), sea anemones (*A. albocincta*), fanworms, brachiopods, nudibranch, Cook's turban (*C. sulcata*), Duck's bill limpet (*S. breviculus*), crayfish (*Jasus edwardsii*), fish (*C. lepidoptera, Helicolenus* sp., *N. macropterus, N. celidotus, N. fucicola, Parika scaber*, *Odax pullus*, *Pseudolabrus miles*, unidentified triplefins, unidentified fish). |
| Observed tree hydroid zones | Encrusting coralline algae, red algae, brown algae (*U. pinnatifida*), sponges (various species of encrusting and erect), feather hydroids, tree hydroids, calcareous tubeworms, solitary and colonial ascidians (orange, white, grey, *O. megalorchis, Cnemidocarpa* sp., *Pyura* sp., *Ciona intestinalis*), bryozoans (encrusting, bushy), snake tail stars (*O. maculata*), sea urchins (*E. chloroticus*), sea stars (*C. calamaria , Patiriella* sp*.,* unidentified sp.), Duck's bill limpet (*S. breviculus*), fish (*P. colias, N. macropterus, N. celidotus, C. lepidoptera, P. miles, Helicolenus* sp., unidentified triplefins, unidentified fish). |

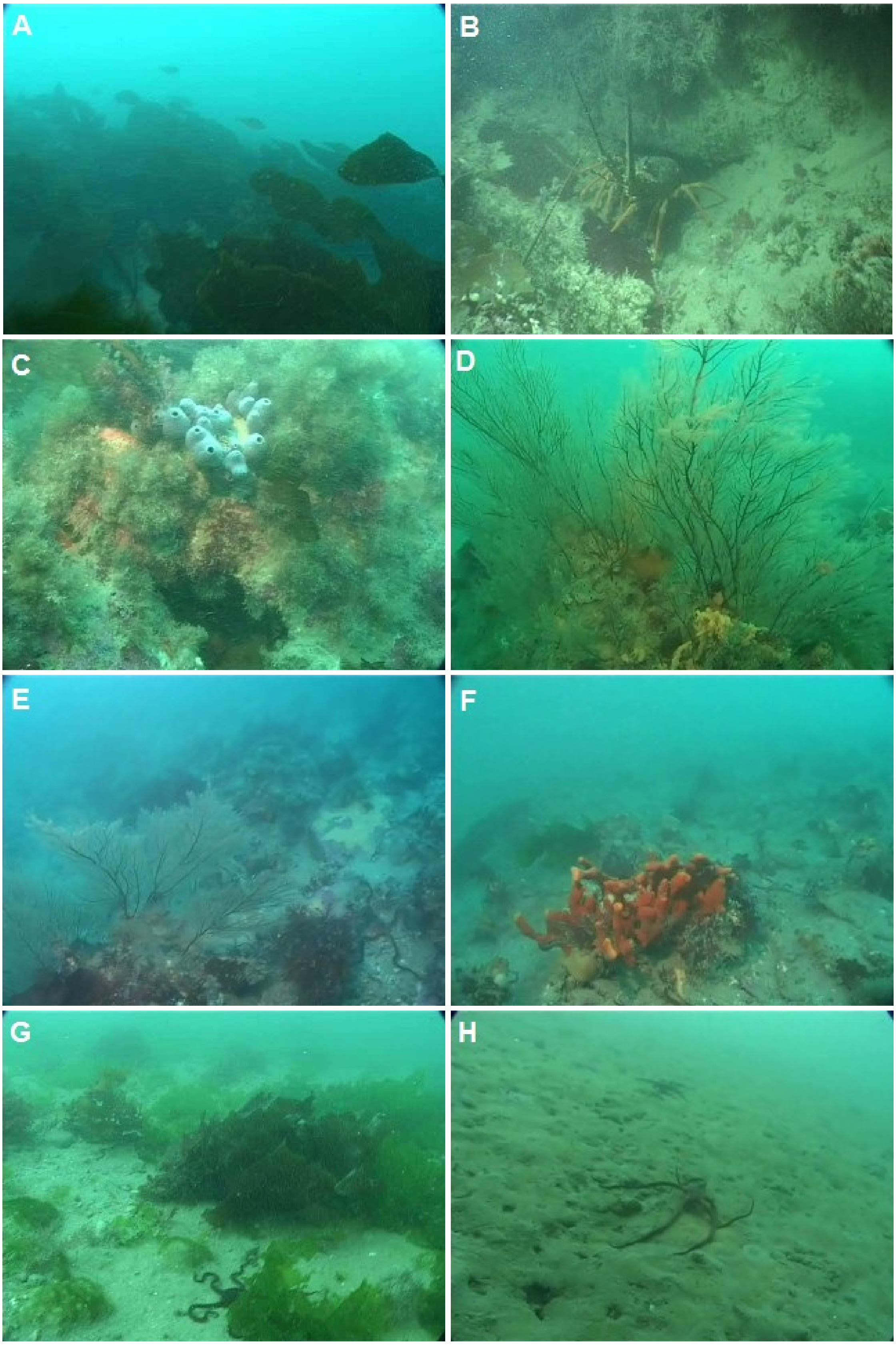


**Figure 5.** Images obtained from dive transect video footage. (A) *Macrocystis pyrifera* from Transect 2, (B, C) reef habitat from transects 1 and 2, (D) tree hydroid zone from transect 4, (E) cobble habitat from transect 2, (F) cobble/sand habitat from transect 2, (G) mud habitat from transect 3 and (H) mud habitat from Transect 1.

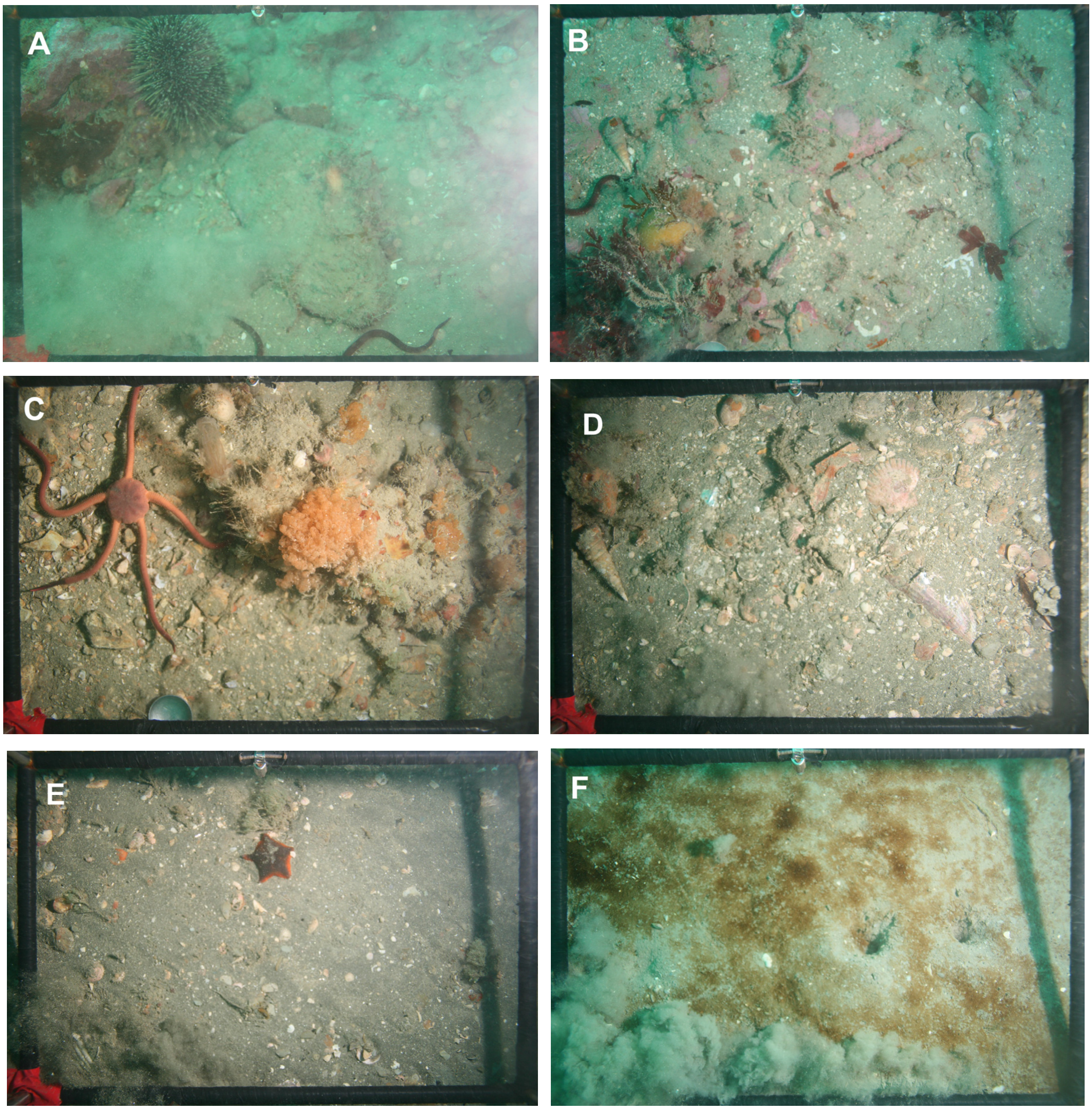


**Figure 6.** Examples of drop-camera images. (A & B) cobble/sand habitat, (C) pebble/shell/sand habitat, (D) sand/shell (E) mud/shell habitat, (F) mud habitat.

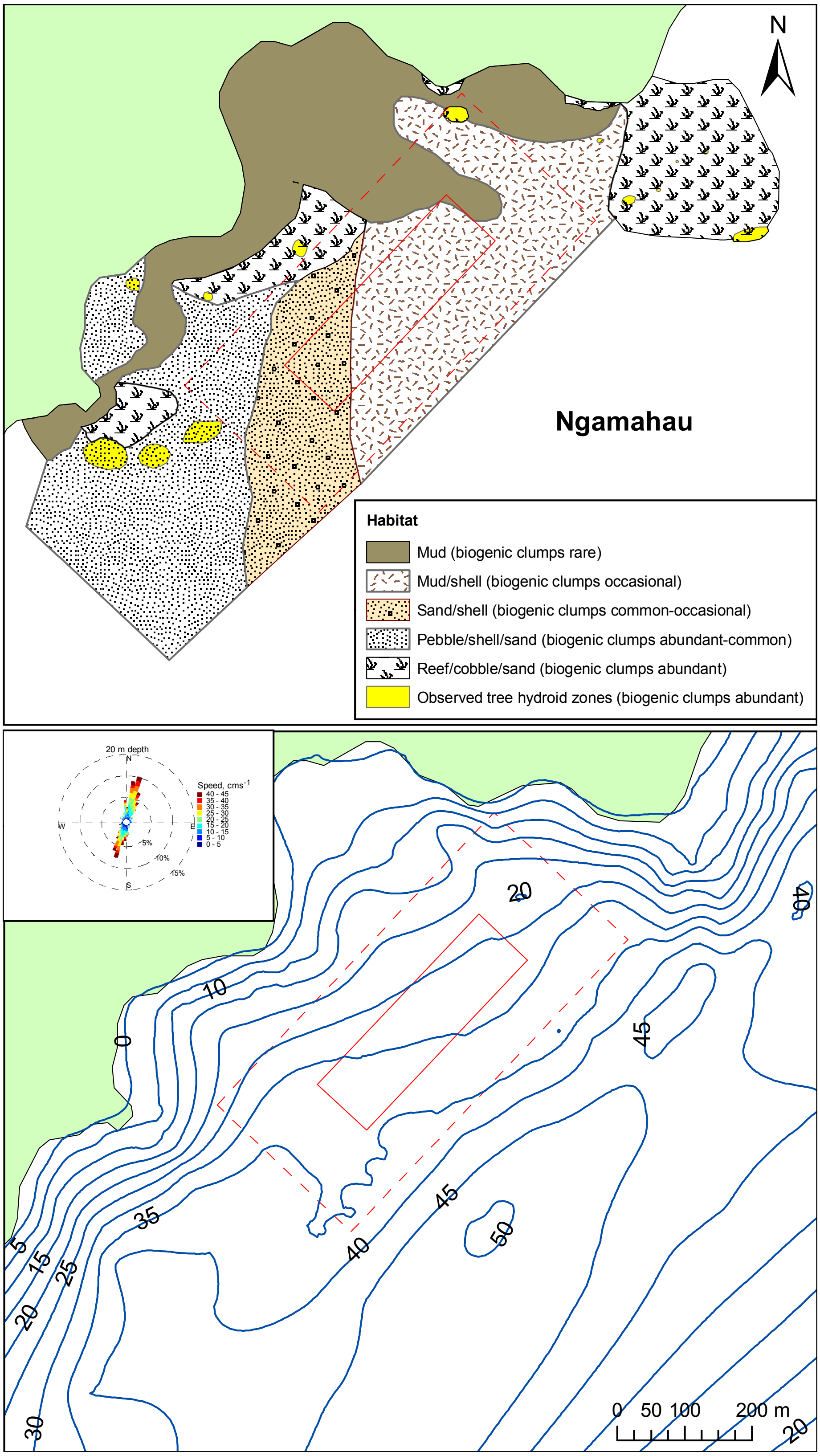


**Figure 7.** Top: Map of seabed habitats observed beneath and adjacent to the proposed Ngamahau Plan Change Site. Bottom: Bathymetric contour lines at the proposed Ngamahau Site with the 20 m depth current rose in inset. The solid red rectangle indicates the proposed Ngamahau Cage Area Boundary and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

## 3.5. Intertidal habitats

The intertidal region inshore of the proposed Ngamahau Site was characteristic of areas in the outer Marlborough Sounds (Davidson & Abel 1998; Davidson *et al.*2010a), and consisted primarily of a narrow (5 m) intertidal zone of rocky reef and large cobbles, with a small pebble beach situated at the northern end of the bay. The reef extended out 5 m wide and beyond this the substrate was characterised by cobbles, with sand below the pebble beach. The reef areas had barnacles (*Chamaesipho* sp.) common from the high to low shore. Sea anemones and various mobile gastropods were common on the mid-shore while lower down blue mussels (*Mytilus galloprovincialis*) and chitons (*Sypharochiton pelliserpentis*) were frequently observed. The low shore and immediate subtidal had a relatively diverse array of seaweed, with a number of brown and red taxa present that are generally indicative of a high energy environment (*e.g. Xiphophora gladiata*, *Gigartina* sp.). The pebble beach appeared relatively depauperate of conspicuous seaweeds and invertebrates. A full list of taxa and relative abundance scores is presented in Appendix 8.

# 4. WATER CURRENTS

Flow charts of current speed (cm $s^{-1}$) and direction (true) at surface, mid-water and near-seabed depths are shown in Figure 8, and flow charts of the entire water column are presented in Appendix 9. Average water velocities were *ca.* 22 cm $s^{-1}$ and maximum water velocities were in the order of 60 cm $s^{-1}$ throughout most of the water column (Table 3). Current speed decreased slightly with depth, with mean surface current speeds of 23 cm $s^{-1}$ (maximum 61-64 cm $s^{-1}$) and mean near-seabed current speeds of 21 to 22 cm $s^{-1}$ (maximum 55 -58 cm $s^{-1}$) (Table 3). The predominant direction of flow was to the northeast (toward Cook Strait), running parallel to the coastline, with tidal reversal (water flow back the other way) increasing with depth.

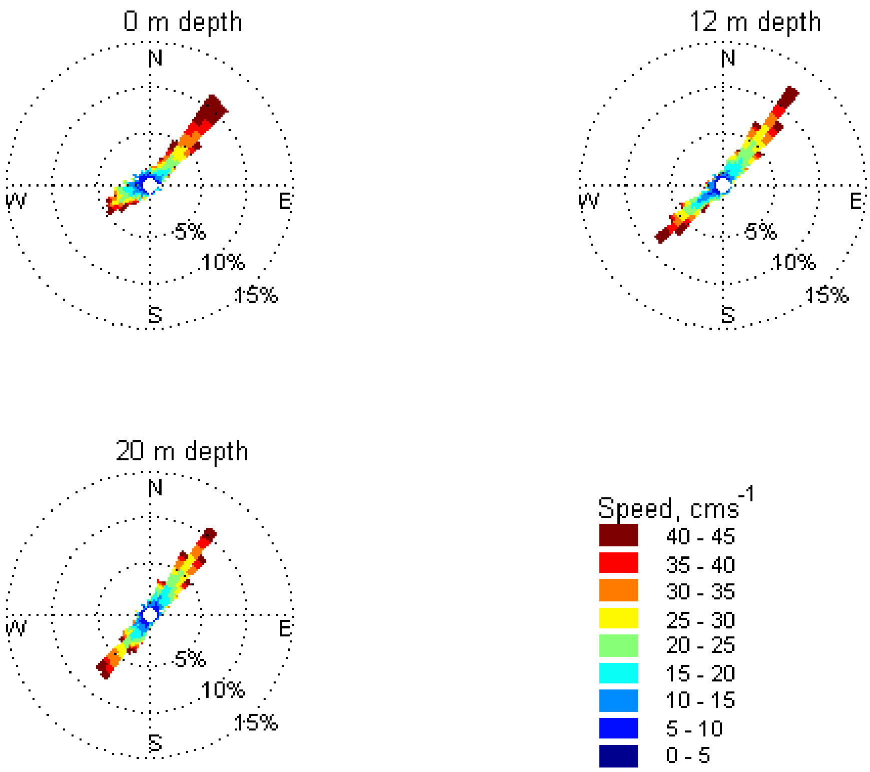


**Figure 8.** Mean current speed and direction measured at 0 m (surface), 12 m (mid-water) and 20 m (near-seabed) depths at the Ngamahau study area.

**Table 3.** Depth-averaged current speeds (cm $s^{-1}$) collected between 6 January 2011 to 11 February 2011 by an ADCP deployed at the Ngamahau Site (see Appendix 2 for sampling details).

| Water depth (m) | Average (cm $s^{-1}$) | $1^{st}$ Percentile (cm $s^{-1}$) | $99^{th}$ Percentile (cm $s^{-1}$) | Standard deviation |
|---|---|---|---|---|
| 0 | 23.0 | 3.0 | 61.5 | 13.5 |
| 2 | 23.1 | 2.9 | 63.5 | 13.4 |
| 4 | 22.8 | 2.8 | 62.9 | 13.1 |
| 6 | 22.6 | 2.7 | 62.4 | 12.8 |
| 8 | 22.5 | 2.9 | 62.8 | 12.6 |
| 10 | 22.4 | 3.2 | 63.8 | 12.4 |
| 12 | 22.3 | 3.3 | 62.6 | 12.2 |
| 14 | 22.1 | 2.4 | 61.2 | 12.1 |
| 16 | 21.8 | 2.9 | 59.8 | 12.0 |
| 18 | 21.6 | 2.5 | 58.0 | 11.8 |
| 20 | 21.1 | 3.1 | 54.6 | 11.5 |

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

# 5. ASSESSMENT OF BENTHIC EFFECTS

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

## 5.1. Benthic impacts associated with the initial site development

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

Substrata beneath the proposed farm were dominated by sand/shell and mud/shell with areas of pebble/sand/shell, reef/cobble/sand and mud also present (Figure 7). The inshore boundary of the proposed site overlies areas of reef/cobble/sand at depths of 20 m (distance of 40 m). A small reef area, with tree hydroids, was also noted in the northern corner of the proposed site. These reef/cobble areas may be impacted by the initial installation of anchoring structures. Fine-scale changes in hydrodynamics are expected due to the presence of ropes and other farm structures (Plew 2009), and are not predicted to have significant ecological effects (the Water Column Report, Gillespie *et al.* 2011). Risks associated with marine pests colonising farm structures are addressed separately in the Biosecurity Report (Forrest 2011). Benthic effects associated with fouling taxa (*e.g.* drop-off to the seabed) are likely to be minimal and can be managed through regular maintenance.

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

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

## 5.2. Benthic impacts arising from farm operations

### *5.2.1. Spatial extent of deposition*

**Background**

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

New Zealand and overseas studies have shown that benthic effects tend to be most evident directly beneath the cages, and exhibit a strong gradient of decreasing impact with increasing distance (Figure 9). High levels of organic enrichment directly beneath finfish farms are typically manifested via a suite of different ‘indicators’. Typical changes in infauna along an enrichment gradient from a finfish farm are depicted in Figure 9 and described in Table 5, and range from pristine natural conditions (Enrichment Stage (ES) 1) to extremely enriched conditions (ES 7). An important feature along the gradient is the stage of greatly enhanced seabed productivity, which defines ES 5 and is evidenced by extreme proliferation of one or a few enrichment-tolerant ‘opportunistic’ species such as the marine polychaete worm *Capitella capitata* and nemotodes. ES 5 has traditionally been the recommended upper level of acceptable impacts in New Zealand, because the benthos is still considered biologically functional and associated with the greatest biomass - and is therefore thought to have greatest waste assimilation capacity. Stages beyond ES 5 (*i.e.* ES 6 - 7) are characterised by extremely impacted sediments and the collapse of the infauna population, at which point organic accumulation of waste material is thought to greatly increase.

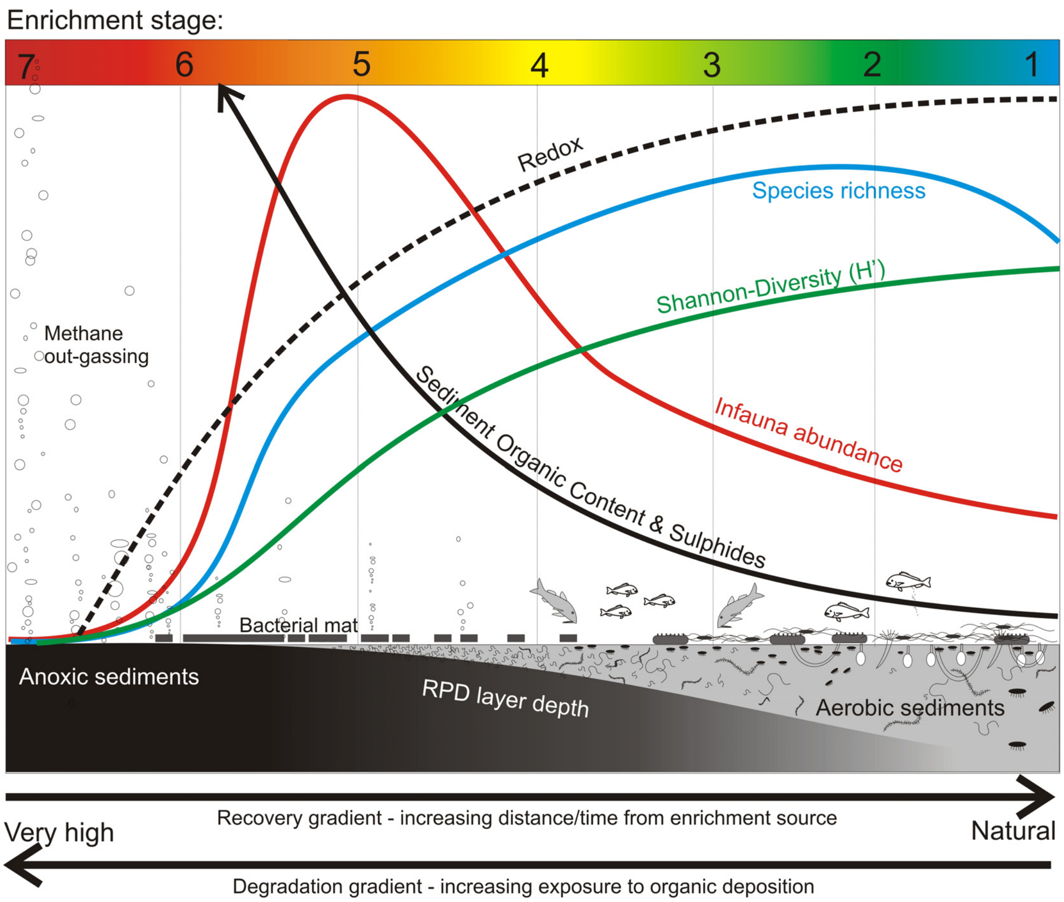


**Figure 9.** Graphical representation of typical enrichment gradient indicating approximate boundaries of proposed seven impact stages in relation to some frequently adopted environmental indicator variables.

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

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

### Predicted depositional footprint at the Ngamahau Site

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

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

Figure 10 shows the predicted depositional footprints close to the RIFL (1500 t yr$^{-1}$), PSFL (2500 t yr$^{-1}$) and MCFL (4000 t yr$^{-1}$ ) feed levels (*i.e.* 2000, 3000, 4000 t yr$^{-1}$, respectively), while footprints for feed usage levels greater than 4000 t yr$^{-1}$ are provided in Appendix 10. When no-resuspension was assumed in the model, the maximum depositional flux was 8 to 10 kg m$^{-2}$ yr$^{-1}$ at 2000 t yr$^{-1}$. Depositional flux increased with increasing feed input (Figure 11), reaching 19 to 22 kg m$^{-2}$ yr$^{-1}$ at the MCFL (4000 t yr$^{-1}$). When resuspension was included in the model, the depositional flux beneath the cages was considerably reduced due to particles being resuspended and transported by the currents after they had originally settled. In fact, net depositional flux reaching the seabed did not exceed 0.5 kg $m^{-2}$ $yr^{-1}$ for any of the feed loadings modelled, and therefore diagrammatic representation of the depositional footprints are not provided in this report. Thus, under the resuspension scenarios, DEPOMOD predicts that most of the organic particulates being discharged from the farm will be diluted, dispersed and exported from the area.

The overall area directly affected by deposition across the seven feed loadings (without resuspension in the model) was estimated to increase from 12 to 18 ha for feeding loads of 2000 to 8000 t $yr^{-1}$, respectively, with most of this area exposed to relatively low depositional rates of 0.5 to 4 kg $m^{-2}$ $yr^{-1}$ (Figure 11). In contrast, when resuspension was added to the model, the total area affected by deposition rates was negligible, as the resuspension scenarios involved no net depositional flux or, any that was predicted was less than 0.5 kg $m^{-2}$ $yr^{-1}$. In reality, the area affected by deposition is likely to be somewhere between these two ranges.

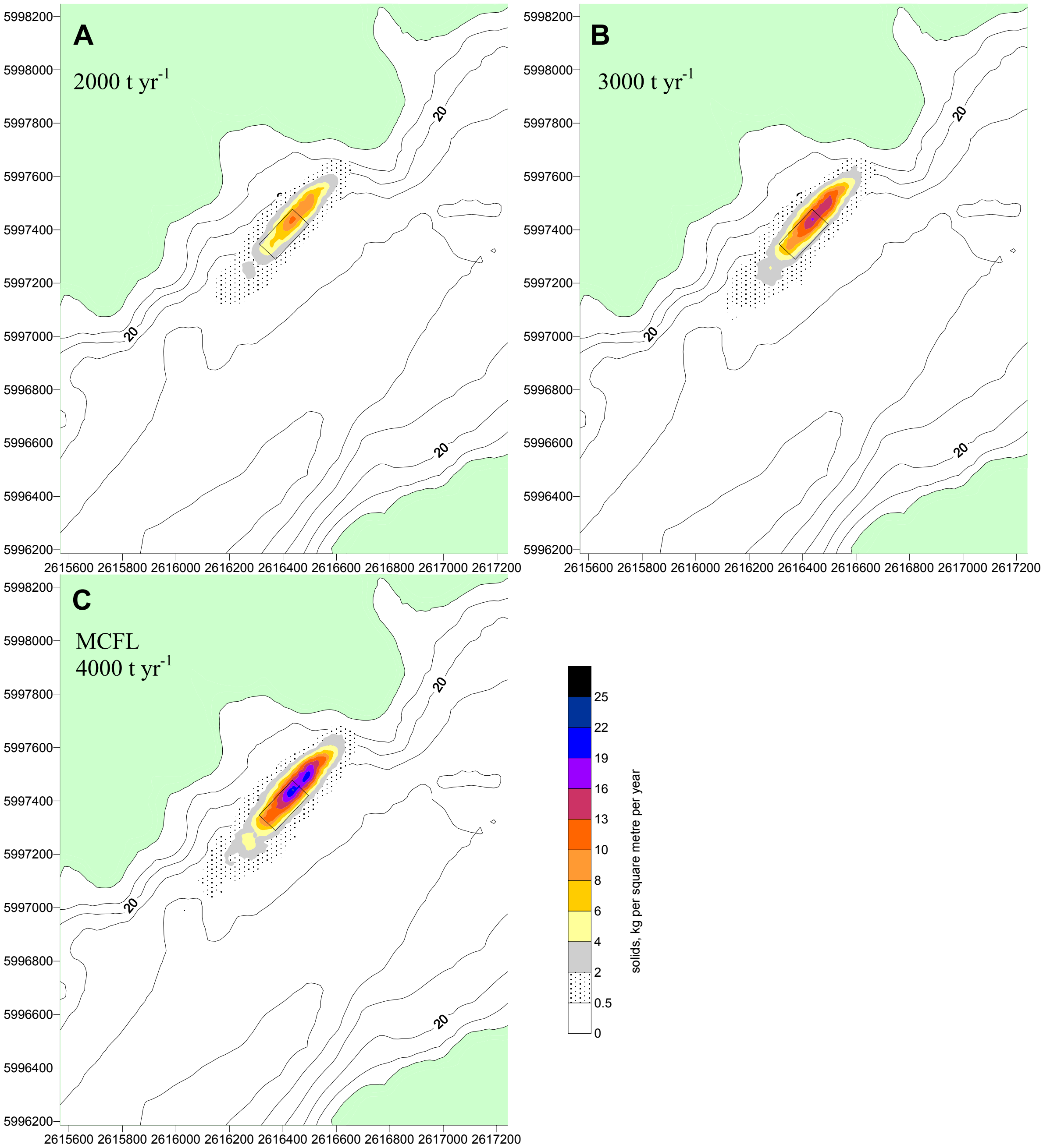


**Figure 10.** Predicted depositional footprints modelled with no-resuspension at the Ngamahau Site for three feed usage levels: (A) 2000 t yr$^{-1}$ (NB. Recommended Initial Feed Level, RIFL, 1500 t yr$^{-1}$), (B) 3000 t yr$^{-1}$ (NB. Predicted Sustainable Feed Level, PSFL, 2500 t yr$^{-1}$), (C) Maximum Conceivable Feed Level (MCFL, 4000 t yr$^{-1}$).

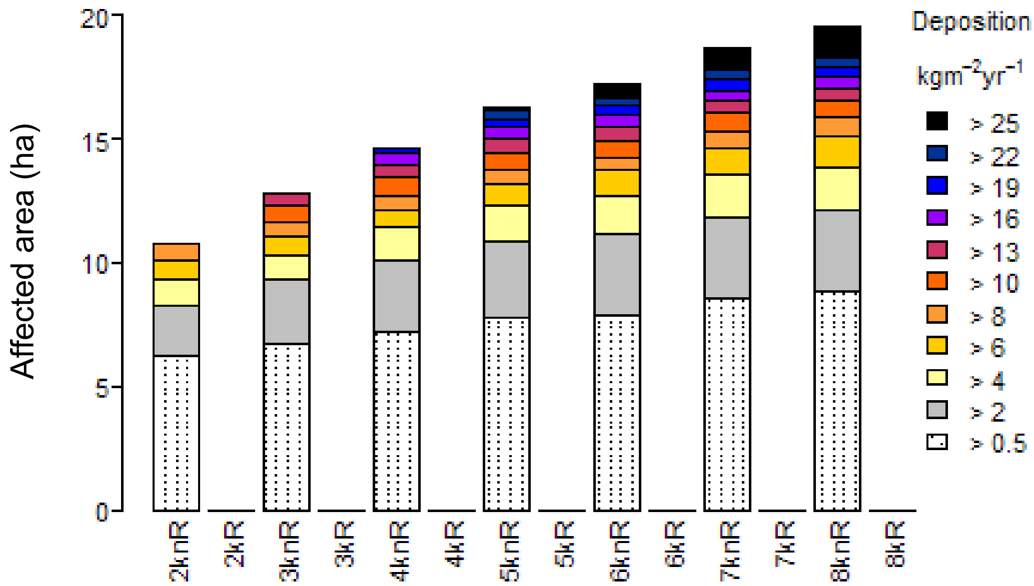


**Figure 11.** Summary of the total area affected by differing amounts of depositional flux for each of the modelled feed level scenarios at Ngamahau, with resuspension (R) and no-resuspension 'nR' included in the model.

### *5.2.2. Magnitude and significance of seabed effects*

As described in Section 3.4, the substratum within the boundaries of the Ngamahau Site was mostly soft sediments (sand/shell and mud/shell with areas of pebble/sand/shell and mud). The infaunal communities associated with these substrata were dominated by polychaetes, amphipods, nematodes and ascidians; taxa that are well represented and widespread in the Marlborough Sounds region (see Section 3.3). Epibiota were patchy, with species such as snake tail stars and cushion stars common throughout, but other species, such as sponges, ascidians, hydroids, and bryozoans, concentrated in clumps. Davidson *et al.* 2010b notes the occurrence of biogenic clumps in various locations in the Marlborough Sounds and describes such structures as clumps formed by combinations of species often living in association, where no one species of biogenic habitat former dominates. Biogenic patches of biodiversity are important in attracting and supporting the biodiversity of the area (Davidson *et al.* 2010b). The abundance of these biogenic clumps was rated as occasional to common in the dominant substrata (sand/shell and mud/shell) beneath the proposed site. Other notable ecological habitats, including reef and the kelp, *M. pyrifera*, were observed inshore of the site.

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

The predicted depositional footprint for the MCFL (4000 t $yr^{-1}$), under no-resuspension is overlaid on the habitat map created for the study area (Figure 12). This figure helps to visualise the spatial scale of the area that could be impacted under a worst-case scenario, as well as the key habitats that could be affected. Directly beneath the farm cages (*ca*. 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected (*i.e.* ES 5 impacts are likely to occur, refer Figure 9. This is also likely to result in the displacement of most epibiota. It is anticipated that a further 14.6 ha of seabed will be moderately impacted (*i.e.* ES 3 score or more); however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions (*i.e.* ES score <3) within 500 m (refer the Benthic Report, Keeley & Taylor 2011). Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring (see Section 6).

There are, however, some notable areas over which deposition may occur. The depositional footprint extends to the south over the pebble/shell/sand substrata, a habitat in which biogenic clumps were rated as common to abundant. As mentioned earlier, these biogenic clumps are important in attracting and maintaining biodiversity. In addition, the depositional modelling indicated that low levels of deposition (0.5 kg $m^{-2}$ $yr^{-1}$) may affect the reef/cobble/sand area along the inshore boundary of the farm and a tree hydroid patch to the south of the proposed site. Due to the regular occurrence of tree hydroid patches in the area, it should be assumed that other tree hydroid patches are present at the study area and that these may also fall within the depositional footprint of the farm. Tree hydroids are more likely to be present in near-shore areas where cobbles or other hard structures provide attachment surfaces and away from muddy areas that may clog their filter feeding structures. Increased sedimentation derived from the salmon farm could potentially smother tree hydroid communities.

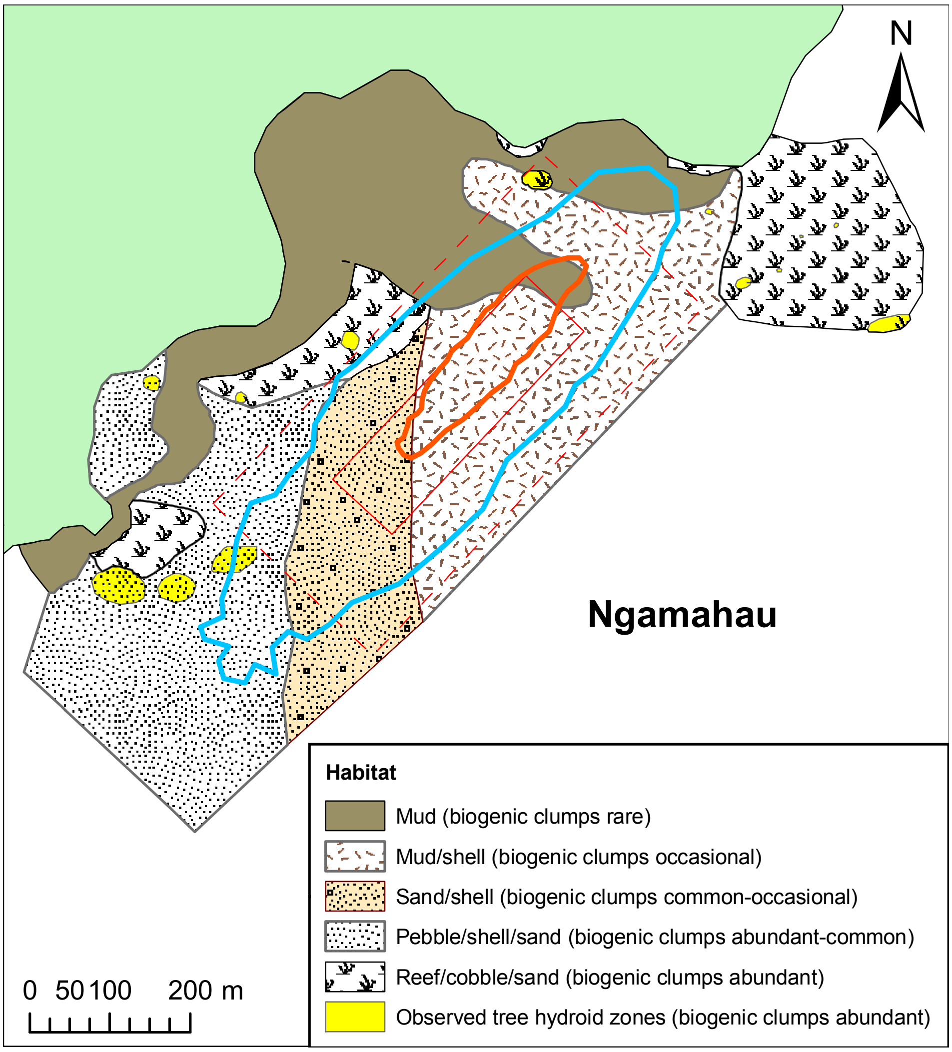


**Figure 12 .** Predicted depositional footprint for the Maximum Conceivable Feed Level (MCFL, 4000 t $yr^{-1}$) under a 'no-resuspension' scenario, overlaid onto the habitat map created for the Ngamahau Plan Change Site. The blue line indicates the 0.5 kg $m^{-2}$ $yr^{-1}$ deposition area. The orange line indicates the >10 kg $m^{-2}$ $yr^{-1}$ deposition area.

# 6. MANAGEMENT OF BENTHIC EFFECTS

It is proposed that the Ngamahau Plan Change site will be monitored under NZ King Salmon's Environmental Monitoring and Adaptive Management Plan (EM-AMP, Keeley 2011) and as outlined in Section 6 of Keeley & Taylor (2011) – the Benthic Report. Under which, the primary depositional footprint and associated ecological effects will be monitored and managed using staged development and the Zones concept. In terms of staged development for this site, the recommended initial feed level (RIFL) is 1500 t $yr^{-1}$, and that may be increased by 500 t $yr^{-1}$ after three years of operation up to a maximum (MCFL) 4000 $t{\cdot}yr^{-1}$, dependant on the outcome of the environmental monitoring results. Under the Zones concept, compliance is assessed with reference to predefined Environmental Quality Standards including site-specific constraints on the spatial extent and magnitude of effects. The EM-AMP also encompasses the procedures for monitoring copper and zinc in sediments, and the strategy for local and regional monitoring of the water column and potential wider ecological effects. The ecological attributes at this site which warrant special consideration under the wider ecological monitoring programme include tree hydroid and reef habitats identified inshore and alongshore of the proposed farm.

# 7. SUMMARY AND RECOMMENDATIONS

The main findings of our benthic assessment are as follows:

1. A range of substratum types were observed at the study area, with sand being the most widespread. The sediment was well oxygenated with low organic content, and a rich infaunal (*i.e.* within sediment) community was present, with a total of 118 taxa. The species were typical of deep high-flow areas throughout the Marlborough Sounds.
2. The seabed beneath the Ngamahau Site primarily ranged from pebbles to sand to mud. Within Ngamahau Bay, and parts of the small inlets inshore of the proposed site, the benthos was characterised by mud.
3. Areas inshore and to the north of the proposed site were often characterised by hard or coarse substrata and supported a relatively diverse flora and fauna. The proposed site extends into this reef/cobble/sand area. A large reef was observed 20 m northeast of the site and a small reef area was noted in the northern corner of the proposed site.
4. Tree hydroid patches were regularly observed across most habitat types. The only observed tree hydroids within the proposed site were those associated with the small reef area in the northern corner.
5. Biogenic clumps were rated as occasional to common beneath the proposed Cage Area Boundary.
6. Intertidal areas inshore of the proposed site were characteristic of areas in the outer Marlborough Sounds. Some seaweed taxa indicative of a relatively high energy environment were present (*e.g. Xiphophora gladiata*, *Gigartina* sp.).
7. The proposed site overlies water depths of 5 to 40 m. Water current velocities at the site were strong (average 22 cm $s^{-1}$; maximum *ca.* 60 cm $s^{-1}$) and the predominant direction of flow was northeast (toward the Cook Strait), running parallel to the coastline, with tidal reversal increasing with depth. Near-bed water velocities were consistently above the resuspension threshold used in the depositional modelling for the study area.
8. At feed levels of up to 4000 t $yr^{-1}$, depositional modelling indicated that depositional flux would be moderate (19-22 kg $m^{-2}$ $yr^{-1}$, without resuspension in the model). When resuspension was considered, deposition was not detectable above predicted background levels (<0.5 kg $m^{-2}$ $yr^{-1}$), even under extreme feed loadings of up to 8000 t $yr^{-1}$. When resuspension was not considered, the depositional footprint (deposition >0.5 kg $m^{-2}$ $yr^{-1}$) affected an area of 15 ha at feed loadings of up to 4000 t $yr^{-1}$, however, most of this area was exposed to relatively low depositional rates of less than 4 kg $m^{-2}$ $yr^{-1}$ and the footprint extended to the northeast, away from potentially sensitive inshore communities.
9. Given the proposed cage configuration, our estimates suggest an initial feed level of 1500 t $yr^{-1}$, with 2500 t $yr^{-1}$ sustainable in the long term, depending on the outcome of continued environmental monitoring. The maximum conceivable feed level for the Ngamahau Site is 4000 t $yr^{-1}$.
10. The depositional footprint primarily extends over soft sediment habitats, common throughout Queen Charlotte Sound, however, low levels of deposition have the potential

to affect the reef/cobble/sand habitat inshore of the proposed site, biogenic clumps in the pebble/shell/sand habitat and some tree hydroids.

11. Directly beneath the farm cages (*ca*. 0-2 ha), infaunal communities will become highly enriched, infauna diversity will be significantly reduced and a high abundance of opportunistic taxa such as nematodes and *Capitella capitata* are expected. Epibiota observed beneath the site will also be displaced. It is anticipated that a further 14.6 ha of seabed will be low-to-moderately impacted; however the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within 500 m. Importantly, depositional flux is not predicted to have noticeable effects on ecologically important species and habitats observed inshore of the farm. Far-field effects are more difficult to predict due to the processes of diffusion and dilution, and therefore will require ongoing monitoring.
12. It is proposed that the Ngamahau Plan Change site will be monitored under NZ King Salmon's Environmental Monitoring and Adaptive Management Plan (EM-AMP, Keeley 2011) and as outlined in Section 6 of Keeley & Taylor (2011) – the Benthic report. The ecological attributes at this site which warrant special consideration under the wider ecological monitoring programme include hydroid and *M. pyrifera* habitats identified inshore and alongshore of the proposed farm.
13. The Ngamahau study area is situated in a high-flow area where wastes will be dispersed and assimilated. The bathymetry of the area is suited to cage farming, but there are notable ecological habitats in this area. The location of the proposed site has been chosen to minimise potential effects to ecologically sensitive habitats in the vicinity of the proposed farm.

# 8. ACKNOWLEDGEMENTS

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# 10. APPENDICES

## Appendix 1. Approach to assessing seabed characteristics

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

**Table 1-1.** Seabed sampling undertaken at the Ngamahau study area.

| Purpose | Sampling Technique | Date |
|---|---|---|
| Study area bathymetry | Depth profiling | 20 December 2010 |
| | | 22 June 2011 |
| | Side scan sonar | 22 June 2011 |
| Assess subtidal habitats | Video transects (diver-collected) | 31 May 2010 |
| | | 2 June 2010 |
| | | 17 June 2011 |
| | Video sled transects | 22 May 2011 |
| | | 17 June 2011 |
| | Drop camera photography | 16 February 2011 |
| | | 25 March 2011 |
| | Sediment grab samples | 17 February 2011 |
| Assess intertidal habitats | Intertidal shoreline survey | 25 March 2011 |

### *Site bathymetry*

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

### *Sediment physical, chemical and biological properties*

Sediment grab samples were collected using a 0.01 $m^2$ van Veen grab sampler from nine sampling stations within and adjacent to the Ngamahau Site (Figure 4; Table 1-2). The following sub-samples were collected to characterise the physical, chemical and biological properties of the sediments:

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

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

**Table 1-2.** Grab sample locations

| Station | Depth (m) | Lat | Long | NZMG-E | NZMG-N |
|---|---|---|---|---|---|
| 1 | 10 | -41 13.41056 | 174 15.88689 | 2616029 | 5997370 |
| 2 | 20 | -41 13.45292 | 174 15.9295 | 2616087 | 5997291 |
| 3 | 30 | -41 13.46566 | 174 16.00065 | 2616186 | 5997266 |
| 4 | 10 | -41 13.37989 | 174 15.95394 | 2616123 | 5997426 |
| 5 | 15 | -41 13.30862 | 174 16.1317 | 2616374 | 5997554 |
| 6 | 30 | -41 13.37801 | 174 16.16382 | 2616417 | 5997425 |
| 7 | 15 | -41 13.24569 | 174 16.25845 | 2616553 | 5997668 |
| 8 | 20 | -41 13.28803 | 174 16.29062 | 2616596 | 5997589 |
| 9 | 35 | -41 13.34291 | 174 16.29615 | 2616603 | 5997487 |

### *Subtidal habitats*

Drop camera still photos and video transects were used to identify the approximate distribution of habitats and associated biota beneath and adjacent to the proposed Ngamahau Site (Figure 4). More than 100 images of the seabed were taken using a 10 mega-pixel Canon digital camera inside an underwater housing, mounted on a frame. The camera triggered remotely when a sensor on the frame came into contact with the seabed, allowing a pseudo-random array of seabed photos to be taken beneath and adjacent to the proposed farm. Additional photographs were taken along transects extending perpendicular to the coastline (*i.e.* from the shallow subtidal to the farm boundary) to help delineate habitat changes with depth. Epibiota and substratum type were noted for each image.

Four transects inshore of the proposed farm were surveyed by divers and recorded on underwater video cameras (Figure 4; Table 1-3). These transects extended from the shoreline down to 20 to 25 m water depth. Divers filmed down the depth profile, before returning to the shoreline on a reciprocal heading several metres up-current. Notes were made describing the dominant features, including encounters of pelagic species (*e.g.* fish) (see Appendix 7 for species list).

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

**Table 1-3.** Dive transect start locations

| Dive transect | Latitude | Longitude | NZMG-E | NZMG-N |
|---|---|---|---|---|
| 1 | -41 13.95361 | 174 16.34547 | 2616655 | 5996356 |
| 2 | -41 13.90736 | 174 15.83278 | 2615940 | 5996452 |
| 3 | -41 13.78546 | 174 15.91133 | 2616053 | 5996676 |
| 4 | -41 14.01923 | 174 16.17637 | 2616417 | 5996238 |

**Table 1-4.** Video sled transect start and end locations

| Video sled transect | Start | | | | End | | | |
|---|---|---|---|---|---|---|---|---|
| | NZMG-E | NZMG-N | Latitude | Longitude | NZMG-E | NZMG-N | Latitude | Longitude |
| 1 | 2616184 | 5997021 | -41 13.59805 | 174 16.00149 | 2615948 | 5997227 | -41 13.48860 | 174 15.83048 |
| 2 | 2616284 | 5997154 | -41 13.52541 | 174 16.07167 | 2616012 | 5997424 | -41 13.38167 | 174 15.87423 |
| 3 | 2616640 | 5997683 | -41 13.23682 | 174 16.32089 | 2616438 | 5997477 | -41 13.34970 | 174 16.17850 |
| 4 | 2615910 | 5997002 | -41 13.61046 | 174 15.80562 | 2616429 | 5997458 | -41 13.36003 | 174 16.17226 |
| 5 | 2616148 | 5997087 | -41 13.56267 | 174 15.97504 | 2616610 | 5997478 | -41 13.34781 | 174 16.30156 |
| 6 | 2616245 | 5997758 | -41 13.19940 | 174 16.03748 | 2616773 | 5997616 | -41 13.27197 | 174 16.41676 |
| 7 | 2616066 | 5997175 | -41 13.51577 | 174 15.91545 | 2616268 | 5997348 | -41 13.42073 | 174 16.05820 |
| 8 | 2616689 | 5997673 | -41 13.24184 | 174 16.35606 | 2616128 | 5997022 | -41 13.59794 | 174 15.96141 |
| 9 | 2616740 | 5997675 | -41 13.24035 | 174 16.39253 | 2616691 | 5997656 | -41 13.25100 | 174 16.35767 |
| 10 | 2616754 | 5997578 | -41 13.29265 | 174 16.40356 | 2616820 | 5997556 | -41 13.30401 | 174 16.45101 |
| 11 | 2616877 | 5997593 | -41 13.28357 | 174 16.49141 | 2616973 | 5997458 | -41 13.35575 | 174 16.56151 |

### *Sidescan sonar imagery*

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

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

| Sidescan Sonar transect | Start | | | | End | | | |
|---|---|---|---|---|---|---|---|---|
| | NZMG-E | NZMG-N | Latitude | Longitude | NZMG-E | NZMG-N | Latitude | Longitude |
| 1 | 2616192 | 5997383 | -41 13.40241 | 174 16.00346 | 2616896 | 5997741 | -41 13.20347 | 174 16.50346 |
| 2 | 2616271 | 5997316 | -41 13.43799 | 174 16.06068 | 2616802 | 5997480 | -41 13.34521 | 174 16.43893 |
| 3 | 2616881 | 5997553 | -41 13.30515 | 174 16.49469 | 2616942 | 5997708 | -41 13.22093 | 174 16.53672 |
| 4 | 2616116 | 5997265 | -41 13.46676 | 174 15.95030 | 2615708 | 5996908 | -41 13.66282 | 174 15.66204 |
| 5 | 2616247 | 5997298 | -41 13.4479 | 174 16.04369 | 2615834 | 5996934 | -41 13.64779 | 174 15.75194 |

### *Intertidal habitats*

An intertidal subtidal survey was undertaken at mid tide along the coastline inshore of the Ngamahau Site using snorkelling gear (Figure 4). Substratum type, biota and general observations were recorded, and photographs of the general habitats were taken. A complete list of taxa can be found in Appendix 8.

## Appendix 2. Approach to assessing water currents

An ADCP (Acoustic Doppler Current Profiler) meter was deployed for 36 days at the southern end of the western (landward) edge of the site, in *ca.* 20 m water depth (Figure 4). Water currents (speed and direction) were characterised at 2 m depth intervals (bins) through the water column (Table 2-1). Reflection of an unknown cause caused the ADCP output to report currents for almost 40 m of water column. Prior to analysis, the reflected current data was removed by deleting the current layers reported as being between 25 m and 40 m above the (bottom-mounted upward facing) ADCP meter. The remaining depth values were corrected to account for this.

**Table 2-1.** ADCP deployment details.

| Particulars | Ngamahau |
|---|---|
| Device: | RD Instruments ADCP |
| Logging depth: | Vertical profile @ 2 m intervals |
| Averaging interval: | 5 minutes |
| Sampling frequency: | 37 minutes |
| Deployment period: | 06/01/11 to 11/02/11 |
| Mooring location: | 2616166.60 E 5996528.00 N |

## Appendix 3. Approach to assessing depositional footprints

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

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

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

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

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

**Table 3-1.** DEPOMOD parameters and settings used to estimate flux to the seabed environment from the Ngamahau Site

| **Grid Generation** | |
|---|---|
| Major grid size | i=99 at 17.1 m<br>j=99 at 21.0 m<br>(1674 x2062 m) |
| Minor grid size | i=99 at 13.0 m<br>j=99 at 13.0 m<br>(1287 x 1287 m) |
| Position on grid | i = 11, j = 26 |
| Minor grid origin NZMG | 2615755, 5996732 |
| Cage configuration | 2 rows of 4 |
| Total number cages | 8 |
| Spacing between cage centres (m) | 42 |
| Cage orientation (deg T) | 45º |
| Depth under cages (m) | 4 |
| **Particle tracking** | |
| Type of feed release | Continuous |
| Food loading (t $yr^{-1}$) | 2000, 3000, 4000, 5000, 6000, 7000, 8000 |
| Cage dimensions (m) | 40 x 40 x 20 deep |
| Source of velocity data | RD Instruments ADCP |
| Current depth bins used (m) | 1, 5, 11, 15, 21 |
| Instrument sampling period (min) | 5 min every 37 |
| Time step used in model (sec) | 1800 |
| Length of velocity record (hrs) | 1329 |
| Random walk model | On: Kx = 0.1, Ky = 0.1, Kz = 0.001 |

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

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

# Appendix 4. Photographs of sediment cores collected from grab stations

# Appendix 5. Infaunal count data

| | | | | | | Station | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | **Common name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Anthozoa** | | | | | | | | | | |
| *Edwardsia* sp. | Red striped anemone | | | | | | | | | 1 |
| **Nemertea** | Ribbon worm | 1 | 1 | 2 | | | | 1 | 1 | 2 |
| **Nematoda** | Roundworm | 1 | 1 | 38 | | 15 | 3 | 4 | | 6 |
| **Sipuncula** | Peanut worm | | | | | 5 | | | 1 | |
| **Polyplacophora** | | | | | | | | | | |
| *Ischnochiton maorianus* | Variable chiton, active chiton | | | | | 1 | | | | |
| *Leptochiton inquinatus* | | | | | | | | | | 1 |
| **Gastropoda** | | | | | | | | | | |
| Gastropoda (white rissoid like) | Unidentified gastropod | | 1 | | | | | | | |
| Unidentified juvenile gastropod | Unidentified juvenile gastropod | 1 | | | | | | | | |
| *Crepidula monoxyla* | | | | | | | | | | 1 |
| *Tanea zelandica* | Moon shell | 1 | | | | | | | | |
| *Zeacolpus* sp. | | | | | | | | | | 1 |
| **Opisthobranchia** | | | | | | | | | | |
| Unidentified opisthobranchia | Unidentified opisthobranchia | | | | | | | | | 1 |
| *Philine auriformis* | White slug | 1 | | | | | | | | |
| **Bivalvia** | | | | | | | | | | |
| *Arthritica bifurca* | Bivalve | 1 | | | | 2 | | | | |
| *Corbula zelandica* | Bivalve | | | | | 7 | 1 | | 1 | 1 |
| *Dosinia lambata* | Bivalve | | | | 1 | | | | | |
| *Ennucula strangei* | Bivalve | | | | | 1 | | | | |
| *Felaniella zealandica* | Bivalve | | | | | | | | 1 | |
| *Gari stangeri* | Bivalve | | | | | | | 1 | | |
| *Maorithyas marama* | Bivalve | 1 | | | | 2 | 2 | 1 | 2 | 4 |
| *Nemocardium pulchellum* | Purple cockle | | | 5 | | 1 | 1 | 1 | | 1 |
| *Nucinella maoriana* | Bivalve | | | | | | | | 5 | |
| *Nucula gallinacea* | Nut shell | 1 | | | | | | | | |
| *Nucula nitidula* | Nut shell | | | | | | | | | 5 |
| *Ostrea chilensis* | Flat oyster, dredge oyster | | | 1 | | | | | | |
| *Pleuromeris* sp. | Bivalve | | | | | 3 | | | | |
| *Pleuromeris zelandica* | Bivalve | | | | | 1 | | | | |
| *Scalpomactra scalpellum* | Bivalve | | | | | | | | | 1 |
| *Tawera spissa* | Morning Star | 1 | 1 | 1 | | 1 | 1 | | | 3 |
| *Theora lubrica* | Bivalve | 2 | | | | 2 | | | 6 | |
| **Oligochaeta** | Oligochaete worm | | | 3 | | | | | | 7 |
| **Polychaeta** | | | | | | | | | | |
| Ampharaetidae: | Polychaete | 1 | | 5 | | 1 | 3 | | 4 | 9 |
| Orbiniidae: | | | | | | | | | | |
| *Leitoscoloplos kerguelensis* | Polychaete | 1 | | | | | | | | |
| Paraonidae: | | 1 | 5 | 15 | 1 | 20 | 5 | 4 | 13 | 4 |
| *Aricidea* sp. | Polychaete | 10 | | | | | | 1 | | 2 |
| Cossuridae: | | | | | | | | | | |
| *Cossura consimilis* | Polychaete | | | | 1 | | | | 1 | |
| Spionidae: | | | | | | | | | | |
| *Boccardia* sp. | Polychaete | | | | | | | 1 | | 2 |
| *Paraprionospio pinnata* | Polychaete | | | 1 | | | | | | 1 |
| *Prionospio multicristata* | Polychaete | 8 | 6 | 5 | 1 | 2 | | | 3 | 6 |
| *Prionospio yuriel* | Polychaete | 1 | | 1 | | | | | 3 | |
| *Spio* sp. | Polychaete | | | 2 | | | | | 1 | |
| *Spiophanes kroyeri* | Polychaete | 3 | | 5 | | | 4 | 5 | 16 | 9 |
| Magelonidae: | | | | | | | | | | |
| *Magelona dakini* | Polychaete | | | | | | | | | 1 |
| Chaetopteridae: | Polychaete | | | | | | | | | |
| *Phyllochaetopterus socialis* | Parchment worm | | | | | | | | 1 | 1 |
| Capitellidae: | | | | | | | | | | |
| *Capitella capitata* | Polychaete | | 1 | 3 | 16 | 4 | | | | |
| *Capitellethus zeylanicus* | Polychaete | 1 | | | | | | | | |
| *Heteromastus filiformis* | Polychaete | 4 | 1 | 31 | 6 | 8 | 16 | 1 | 7 | 7 |

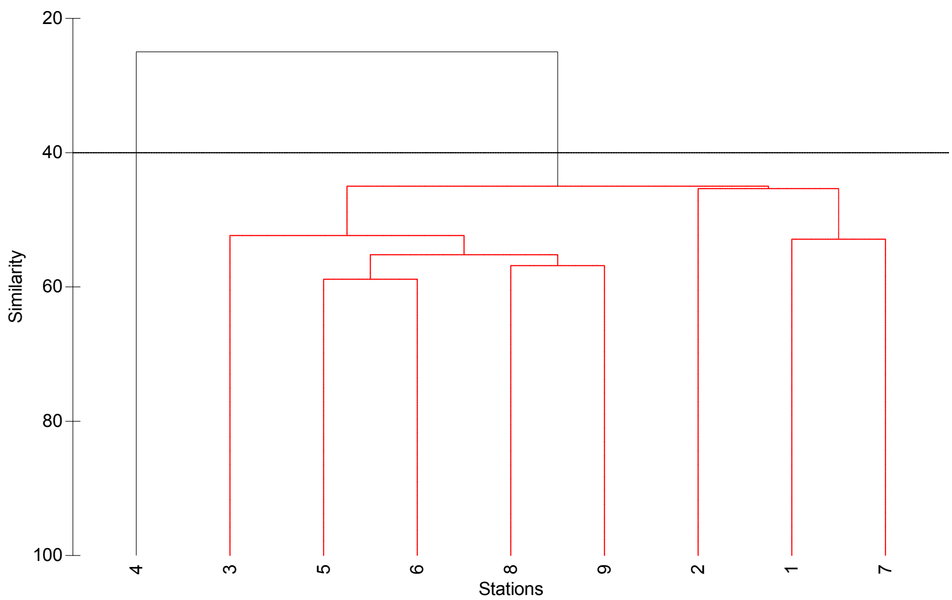
| Taxa | Common name | Station 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Maldanidae: | Bamboo worm | 1 | 8 | 2 | | 2 | 2 | | 4 | 9 |
| Opheliidae: | | | | | | | | | | |
| *Armandia maculata* | Polychaete | | | | | | | | | 1 |
| Phyllodocidae: | Paddle worm | | | 3 | | | | | | |
| Aphroditidae: | | | | | | | | | | |
| *Aphrodita australis* | Sea mouse | | | | | | | | 1 | |
| Polynoidae: | Scale worm | | | | | 1 | | 1 | 1 | 1 |
| Hesionidae: | Polychaete | | | 3 | | | | | | |
| Syllidae: | | | 2 | 12 | | 4 | 3 | 2 | 3 | 8 |
| *Sphaerosyllis* sp. | Polychaete | 2 | 5 | 36 | | 33 | 16 | 1 | 16 | 9 |
| Nereidae: | Rag worm | | | | 1 | 1 | | | | |
| *Platynereis australis* | Polychaete | | | | 6 | | | | | |
| Glyceridae: | | | 2 | | | 1 | | | | |
| Goniadidae: | | | | | | | | | | |
| *Goniada* sp. | Polychaete | | 3 | | | | | | 2 | 2 |
| Nephtyidae: | | | | | | | | | | |
| *Aglaophamus* sp. | Polychaete | | | | | | | 2 | | 3 |
| Eunicidae: | Polychaete | | | | | | 1 | | | |
| Lumbrineridae: | Polychaete | | 1 | 3 | 1 | 4 | 2 | 1 | 1 | 2 |
| Dorvilleidae: | Polychaete | | 1 | 1 | | | 1 | | | |
| Oweniidae: | | | | | | | | | | |
| *Myriochele* sp. | Polychaete | 8 | | | 1 | 1 | | 5 | 5 | 5 |
| Cirratulidae: | Polychaete | 1 | 1 | 12 | | 6 | 5 | | 5 | 6 |
| Flabelligeridae: | Polychaete | | | 1 | | | | | | |
| Pectinariidae: | | | | | | | | | | |
| *Pectinaria australis* | Polychaete | 1 | | | | | | 1 | | 1 |
| Terebellidae: | | 2 | | 4 | | | | | 3 | 2 |
| Sabellidae: | Umbrella worm | | | 1 | | | 2 | 1 | 2 | 3 |
| *Euchone pallida* | Sandy tubeworm | 4 | 12 | 20 | 1 | 10 | | 2 | 3 | 6 |
| Serpulidae: | Fanworm | | | | | | | | | |
| *Pomatoceros terraenovae* | Polychaete | | | 1 | | | | | | |
| Spirorbidae: | Polychaete | | | 4 | 1 | 3 | | | | |
| **Crustacea** | | | | | | | | | | |
| *Nebalia* sp. | Crustacean | | | | 1 | 1 | | | | |
| Notostraca | Tadpole shrimp | | | 1 | | | | | | |
| **Cumacea** | Cumacean | 1 | | 3 | | 3 | 6 | 1 | 13 | 3 |
| **Tanaidacea** | | | | | | | | | | |
| *Tanaid* sp. | Tanaid shrimp | 2 | 1 | | 1 | 12 | 8 | 2 | 16 | 3 |
| **Isopoda** | | | | | | | | | | |
| *Natatolana pellucida* | Fish lice | | | 2 | | | | | | |
| *Anthuridea* | Isopod | 1 | | 8 | 1 | 3 | 2 | | 2 | 2 |
| *Munna schauinslandii* | Isopod | 3 | | | | | 1 | | | 2 |
| *Paramunna serrata* | Isopod | | | | | | | | 2 | |
| Asellota | Isopod | | | | | 1 | | | 6 | 1 |
| Gnathiidea | Isopod | | | | | 1 | | | | |
| Valvifera | Isopod | | | | | | | | | 1 |
| **Amphipoda** | | | | | | | | | | |
| Aorida | Amphipod | 50 | 145 | 7 | | 17 | 7 | 27 | 7 | 4 |
| Corophiidae | Amphipod | | | | | 1 | | | 1 | |
| Lysianassidae | Amphipod | | | | | 1 | 1 | | | 7 |
| Melitidae | Amphipod | | | | 2 | 3 | 5 | | 1 | 5 |
| Oedicerotidae | Amphipod | 9 | | | | | | | | |
| Phoxocephalidae | Amphipod | 8 | | 1 | | 2 | 3 | 4 | 2 | 2 |
| *Ampelisca* sp. | Amphipod | | | 1 | | | | | | 1 |
| Amphipoda indeterminata | Amphipod | | | | | | | | 2 | |
| **Decapoda** | | | | | | | | | | |
| *Halicarcinus cookii* | Pill-box crab | | | | 1 | | | | | |
| *Halicarcinus tongi* | Pill-box crab | | | | | | | | | 1 |
| *Macrophthalmus hirtipes* | Stalk-eyed mud crab | | | | 4 | | | | | |
| *Pagurus* sp. | Hermit crab | | | | | | | | | 1 |
| *Pinnotheres novaezelandiae* | Mussel pea crab | | | 2 | | | | | | |
| **Ostracoda** | | | | | | | | | | |

| Taxa | Common name | Station 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Cymbicopia hispida* | Ostracod | 1 | | | | | 1 | | 1 | 1 |
| *Cypridinoides reticulata* | Ostracod | | | | | | | 1 | 1 | |
| *Diasterope grisea* | Ostracod | | | 1 | | 2 | | | | |
| *Euphilomedes agilis* | Ostracod | 6 | 1 | | | 1 | 1 | 5 | | 1 |
| *Neonesidea* sp. | Ostracod | | | | | | 1 | | 1 | |
| *Parasterope quadrata* | Ostracod | 3 | 1 | 1 | | 1 | | 1 | 1 | |
| *Phylctenophora zealandica* | Ostracod | | | | | | 1 | | | |
| *Scleroconcha arcuata* | Ostracod | 1 | | | | | | | 1 | |
| *Trachyleberis lytteltonsis* | Ostracod | | | | | | | 1 | | |
| **Pycnogonida** | | | | | | | | | | |
| Pycnogonidae | Sea spider | | | | | | | | | 3 |
| **Phoronida** | | | | | | | | | | |
| *Phoronus* sp. | Phoronid | | | 1 | | | 1 | | | 1 |
| **Bryozoa** | | | | | | | | | | |
| Bryozoa (encrusting) | Bryozoan | | 1 | 3 | 1 | 1 | | | 1 | 5 |
| Bryozoa (erect) | Bryozoan | | | 1 | | | | | 1 | 2 |
| Bryozoa (solid stalked) | Bryozoan | | | 1 | | | | | | 1 |
| **Ophiuroidea** | Brittle star | | 4 | 7 | | | 1 | | 6 | 5 |
| **Holothuroidea** | | | | | | | | | | |
| *Trochodota dendyi* | Sea cucumber | | | | 1 | 1 | | | 1 | |
| **Chaetognatha** | Arrow worm | | | | | | | | | 2 |
| **Ascidiacea** | | | | | | | | | | |
| *Eugyra brewinae* | Sea squirt | | | | 1 | | | | | |
| *Oligocarpa megalorchis* | Solitary sea squirt | | | | | 30 | 33 | | | 5 |
| **Chlorophyta** | | | | | | | | | | |
| *Ulva* sp. | Sea lettuce | | | | 1 | | | | | |
| **Phaeophyta** | | | | | | | | | | |
| *Halopteris novae zelandiae* | Brown alga | | | | 1 | | | | | 1 |
| **Rhodophyta** | | | | | | | | | | |
| *Corallina* (encrusting pink) | Paint | | | | 1 | | | | | |
| | **Taxa Abundance** | **145** | **205** | **261** | **53** | **223** | **140** | **78** | **178** | **337** |
| | **Taxa Richness** | **37** | **23** | **44** | **24** | **45** | **33** | **27** | **47** | **62** |

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

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

The results of the multivariate (Figure 6-1) show the relative similarity of the samples in terms of infaunal assemblage structure. SIMPROF test showed, at a 40% similarity level, the samples resolved into two groupings (Group 1: Station 4; Group 2: all other stations). The dominance of *Capitella capitata* polychaetes and absence of a number of species at Station 4 (Group 1), including Aoridae amphipods, *Sphaerosyllis* sp. polychaetes and nematodes, were the strongest determining features separating the two groups. Station 4 (outside site) had the lowest total abundance and taxa richness. The abundance and presence or absence of a variety of other invertebrates (summarised in Figure 6-1) were also influential in characterising the communities and are summarised.




| Group | Station | Key distinguishing characteristics |
|---|---|---|
| 1 | 4 | Community dominated by *Capitella capitata* polychaetes, with *Heteromastus filiformis* and *Platynereis australis* polychaetes also common. Absence of many taxa. Lowest taxa richness of all study areas. |
| 2 | All other stations | Community dominated by Aoridae amphipods and *Sphaerosyllis* sp. and Paraonidae polychatetes. No *Platynereis australis* or *Macrophthalmus hirtipes*. |

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

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

X = taxa present in transect.

| Taxa | Common name | Dropcam images | Dive transect | | | | Video sled transect | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Porifera** | | | | | | | | | | | | | | | | | |
| Antler sponge | Antler sponge | | | X | | X | X | X | | X | X | X | X | X | | X | X |
| Encrusting orange sponge | Encrusting orange sponge | X | X | X | X | X | X | | X | | X | X | X | X | | X | X |
| Encrusting red sponge | Encrusting red sponge | X | | | | | | X | | X | X | X | | | | | X |
| Encrusting yellow sponge | Encrusting yellow sponge | X | X | | X | | | | | X | | | | X | | X | X |
| Erect orange sponge | Erect orange sponge | | | | | | | | | | | | | X | | X | |
| Erect red sponge | Erect red sponge | | | | | | | | | | | | | | | | X |
| Erect yellow sponge | Erect yellow sponge | | | | | | | | | | | | | | | | X |
| Finger sponge | Finger sponge | X | | X | X | X | | | | X | | | | X | | X | |
| Grey vase sponge | Grey vase sponge | | X | X | | X | X | | | | | X | | | | X | X |
| Lobed Sponge | Lobed sponge | | X | X | X | X | X | X | X | | | X | X | | | X | X |
| **Hydrozoa** | | | | | | | | | | | | | | | | | |
| Hydroida (thecate) | Feather hydroid | X | X | X | X | X | X | | X | X | | X | X | | | X | |
| Tree hydroid | Tree hydroid | X | | X | X | X | X | | X | | | X | X | | | X | X |
| **Anthozoa** | | | | | | | | | | | | | | | | | |
| *Anthothoe albocincta* | White striped anemone | X | | | | X | X | X | X | X | | | | | | | |
| *Cerianthus* sp. | Tube anemone | | | | X | | X | | | | | | | | | | |
| **Bryozoa** | | | | | | | | | | | | | | | | | |
| Encrusting bryozoan | Encrusting bryozoan | X | | | | | X | X | | | | | | | | X | X |
| Branching bryozoan | Branching bryozoan | X | | X | X | | X | X | X | | X | X | X | | | X | X |
| Bushy orange bryozoan | Bushy orange bryozoan | X | | | | | X | X | X | X | X | | X | X | | X | X |
| Strawberry bryozoan | Strawberry bryozoan | X | | | | | | | | | | | | | | | |
| **Brachiopoda** | Brachiopod | X | | | | | | | | | | | | | | | |
| **Crustacea** | | | | | | | | | | | | | | | | | |
| *Jasus edwardsii* | Crayfish | | X | | | | | | | | | | | | | | |
| Camouflage crab | Camouflage crab | X | | | | | | | | | | | | | | | |
| Paguroidea sp. | Hermit crab | X | | | | | | | | | | | | | | | |

| Taxa | Common name | Dropcam images | Dive transect | | | | Video sled transect | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Gastropoda** | | | | | | | | | | | | | | | | | |
| *Cookia sulcata* | Cook's turban | | | | X | | | X | | | | | | | | X | |
| *Scutus breviculus* | Duck's bill limpet | | | | X | X | | | | | | | | | | | |
| Nudibranchia | White nudibranch | | | X | | X | | | | | | | | | | | |
| **Bivalvia** | | | | | | | | | | | | | | | | | |
| *Pecten novaezelandiae* | Scallop | X | | | | | X | X | X | X | X | | | X | | | |
| **Polychaeta: Serpulidae** | | | | | | | | | | | | | | | | | |
| *Galeolaria hystrix* | Tubeworm | X | | X | X | | | | | | | | | | | X | X |
| Fanworm | Fanworm | | | | | X | X | X | X | | X | | | | | | |
| **Echinoidea** | | | | | | | | | | | | | | | | | |
| *Evechinus chloroticus* | Sea urchin (kina) | X | | X | X | X | X | X | X | X | | X | X | X | | X | X |
| **Asteroidea** | | | | | | | | | | | | | | | | | |
| *Coscinasterias calamaria* | Eleven arm star | | | X | X | X | X | X | X | | | X | X | X | | X | X |
| *Patiriella* sp. | Cushion star | X | | X | X | | X | X | X | X | X | X | X | X | | X | X |
| *Pentagonaster pulchellus* | Biscuit star | X | | | | | | | | | | | | | | | |
| Unidentified sea star | Unidentified sea star | X | | | | | X | X | X | X | X | | X | X | | | |
| **Ophiuroidea** | | | | | | | | | | | | | | | | | |
| *Ophiopsammus maculata* | Snake tail star | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X |
| **Holothuroidea** | | | | | | | | | | | | | | | | | |
| *Ocnus brevidentis* | Burrowing sea cucumber | X | | | | | | | | | | | | | | | |
| *Stichopus mollis* | Sea cucumber | | | X | X | | X | X | X | X | X | X | X | X | X | X | X |
| **Ascidiacea** | | | | | | | | | | | | | | | | | |
| *Ciona intestinalis* | Sea squirt | X | | | | | | | | | | | | | | | |
| *Cnemidocarpa* sp. | Sea squirt | X | | X | | | X | | X | X | | X | | | | | |
| *Oligocarpa megalorchis* | Sea squirt | X | X | | | | | | | | | | | | | | |
| *Pyura* sp. | Sea tulip | | | X | | | | | | X | | X | X | | | X | |
| Grey colonial ascidian | Grey colonial ascidian | X | | | | | X | | X | | | X | X | | | X | X |
| Orange colonial ascidian | Orange colonial ascidian | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| White colonial ascidian | White colonial ascidian | X | | X | X | X | X | X | X | X | | | X | | | X | X |
| **Chondrichthyes** | | | | | | | | | | | | | | | | | |

| Taxa | Common name | Dropcam images | Dive transect | | | | Video sled transect | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| *Cephaloscyllium isabellum* | Carpet shark | | | | | | X | | | | | | | | | | |
| **Osteichthyes** | | | | | | | | | | | | | | | | | |
| *Caesioperca lepidoptera* | Butterfly perch | | | X | | | X | | | | X | | X | | | X | |
| *Helicolenus* sp. | Sea perch | | X | | | | | | | | | | X | | | X | |
| *Hemerocoetes monopterygius* | Opalfish | | | | | | | | | | X | | | | | | |
| *Latridopsis ciliaris* | Blue moki | | X | | | X | | | | | | | | | | | |
| *Nemadactylus macropterus* | Tarakihi | | | | X | X | | | | | | | | X | | | |
| *Notolabrus celidotus* | Spotty | | X | X | X | X | | | | | | X | | | | | |
| *Notolabrus fucicola* | Banded wrasse | | X | | X | | | | | | | | | | | | |
| *Odax pullus* | Butterfish | | X | | | | | | | | | | | | | | |
| *Parapercis colias* | Blue cod | | X | | | X | X | X | X | | X | X | X | X | | X | X |
| *Parika scaber* | Leatherjacket | X | | | | | | | | | | | | | | | |
| *Pseudolabrus miles* | Scarlet wrasse | | | | | | | | | | | | X | | | X | |
| Pleuronectidae sp. | Flatfish | | | | | | X | | | | X | | | | | | |
| Tripterygiidae sp. | Unidentified triplefin | | X | X | X | X | X | | | | | | | | | X | X |
| Unidentified fish | Unidentified fish | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| **ALGAE** | | | | | | | | | | | | | | | | | |
| **Chlorophyta** | | | | | | | | | | | | | | | | | |
| *Caulerpa* sp. | Sea rimu | | X | | | | | | | | | | | | | | |
| *Ulva* sp. | Sea lettuce | X | | X | X | X | X | X | X | X | X | X | X | X | X | | X |
| **Phaeophyta** | | | | | | | | | | | | | | | | | |
| *Carpophyllum flexuosum* | Flapjack | X | X | X | X | X | X | X | | | | X | X | X | X | X | |
| *Ecklonia radiata* | Paddle weed | | X | X | X | | | | | | | | | | | | |
| *Macrocystis pyrifera* | Bladder kelp | X | X | X | X | X | X | | | | | | | | | | |
| *Marginariella boryana* | Brown alga | | | X | X | | | | | | | | | | | | |
| *Undaria pinnatifida* | Wakame | | | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| **Rhodophyta** | | | | | | | | | | | | | | | | | |
| *Corallina* (encrusting pink) | Paint | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| *Corallina officinalis* (turfing pink) | Turf | | | X | X | X | X | | | | | X | | | | X | X |
| Red bushy | Red alga | | | | | | | | | | | | | X | X | X | X |

| Taxa | Common name | Dropcam images | Dive transect | | | | Video sled transect | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Red filamentous | Red alga | | X | X | X | X | X | | X | | X | X | | | | | |
| Red foliose | Red alga | X | X | X | X | X | X | X | X | X | X | X | | X | X | | X |

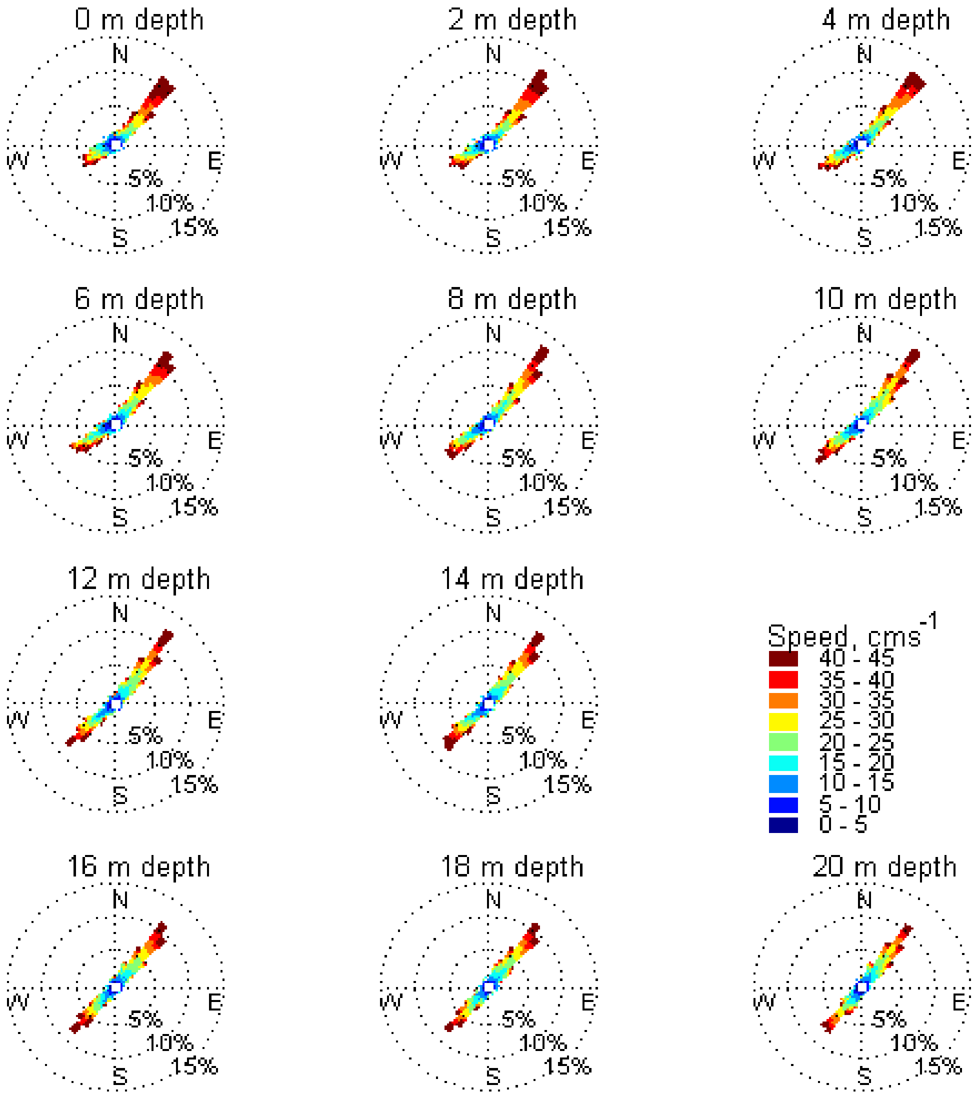
# Appendix 8. Relative abundance and tidal height distribution of conspicuous intertidal and immediate subtidal epibiota observed during the intertidal survey

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

| Taxa | Common Name | Tidal zone | Relative abundance |
|---|---|---|---|
| **Anthozoa** | | | |
| *Actina tenebrosa* | Waratah anemone | M | C |
| *Actinothoe* sp. | White striped anemone | M | C |
| *Anthopleura aureoradiata* | Mud flat anemone | M | C |
| *Isactinia olivacea* | Olive anemone | M | C |
| *Oulactis mucosa* | Common anemone | M | C |
| *Phlyctenactis tuberculosa* | Wandering anemone | S | R |
| **Asteroidea** | | | |
| *Patiriella* sp. | Cushion star | S | R |
| **Bivalvia** | | | |
| *Aulacomya atra maoriana* | Ribbed mussel | L | O |
| *Mytilus galloprovincialis* | Blue mussel | L-M | C |
| **Cirripedia** | | | |
| *Chamaesipho* sp. | Brown and column barnacles | L-H | A |
| **Gastropoda** | | | |
| *Cellana denticulata* | Dentate limpet | M | O |
| *Cellana ornata* | Ornate limpet, Ngakihi | M | C |
| *Cellana radians* | Radiate limpet | L-M | C |
| *Haliotis iris* | Black-foot paua | S | O |
| *Melagraphia aethiops* | Spotted top shell | L-M | C |
| *Risellopsis varia* | Rissoidae limpet | M | R |
| *Siphonaria* sp. | Siphonated limper | M | C |
| *Turbo smaragdus* | Cat's eye, Ataata | L | C |
| **Polyplacophora** | | | |
| *Sypharochiton pelliserpentis* | Snakeskin chiton | L-M | C |
| **Urochordata** | | | |
| *Cnemidocarpa* sp. | Solitary ascidian | S | R |
| **ALGAE** | | | |
| **Chlorophyta** | | | |
| *Cladophora* sp. | Green alga | S | R |
| *Ulva* sp. | Sea lettuce | S | A |
| **Phaeophyta** | | | |
| *Carpophyllum flexuosum* | Flapjack | S | C |
| *Cystophora scalaris* | Zig-zag weed | S | C |
| *Halopteris* sp. | Brown alga | S | O |
| *Hormosira banksii* | Neptune's necklace | L | C |
| *Macrocystis pyrifera* | Bladder kelp | S | A |
| *Scytosiphon lomentaria* | Brown alga | S | O |
| *Undaria pinnatifida* | Wakame | S | O |

| Taxa | Common Name | Tidal zone | Relative abundance |
|---|---|---|---|
| *Xiphophora gladiata* | Brown alga | S | C |
| **Rhodophyta** | | | |
| Corallina (Encrusting Pink) | Paint | S | C |
| *Corallina officinalis* (Turf) | Turf | S | C |
| *Champia* sp. | Red alga | S | O |
| *Cladhymenia* sp. | Red alga | S | O |
| *Echinothamnion* sp. | Red alga | S | O |
| *Gigartina circumcincta* | Red alga | S | O |
| *Gigartina* sp. | Red alga | S | R |
| *Pterocladia* sp. | Agar weed | S | O |
| Unidentified fine red algae | Red alga | S | R |

# Appendix 9. Flow charts of current speed (cm s$^{-1}$) and direction (true) at the ADCP deployment site at Ngamahau, Tory Channel



# Appendix 10. Predicted depositional footprints for five levels of feed usage at the Ngamahau Site: (a) 5000, (b) 6000, (c) 7000 and (d) 8000 t $yr^{-1}$ under 'no-resuspension' scenarios