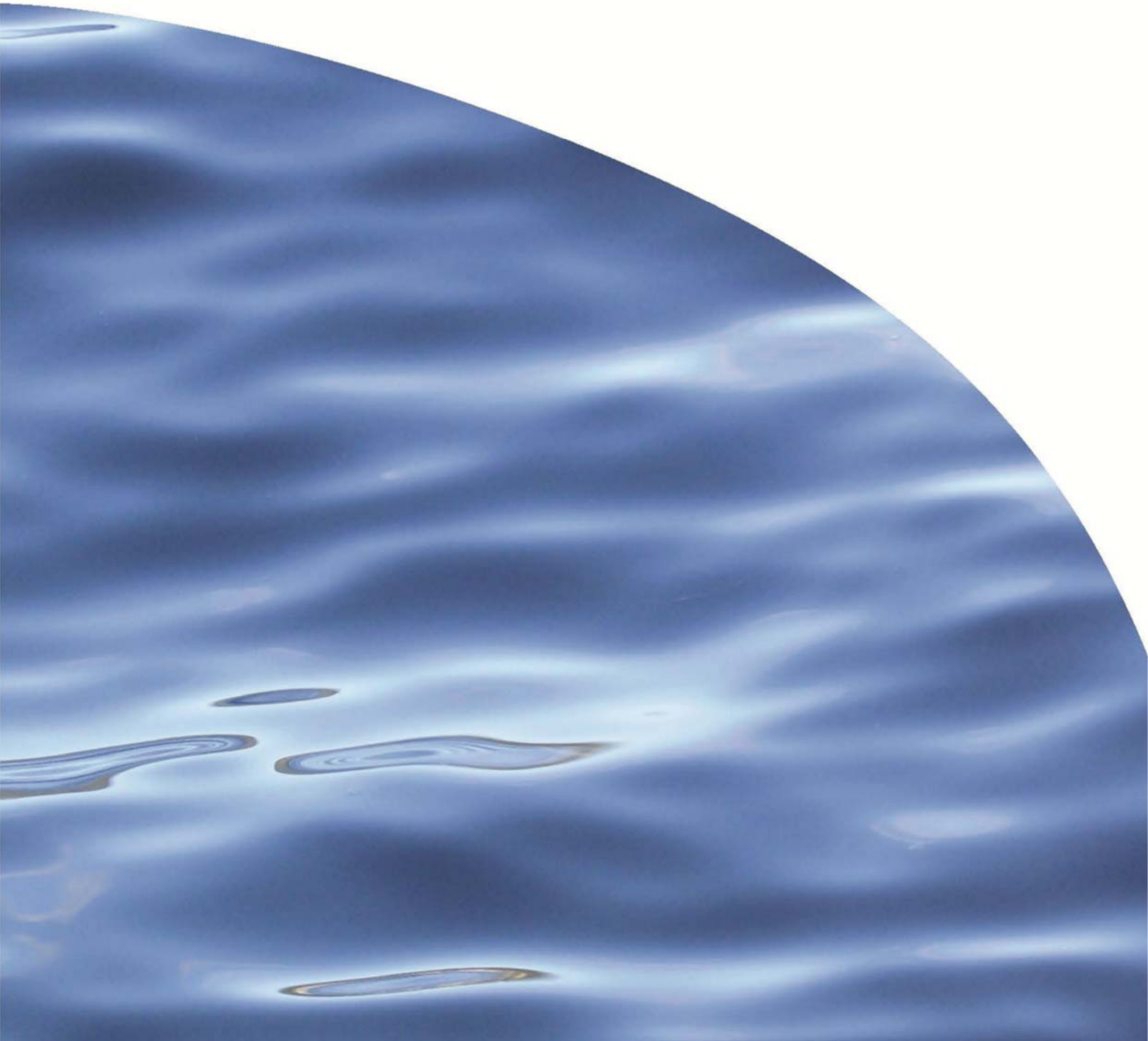
REPORT NO. 3000

NGAMAHAU BAY SALMON FARM: ANNUAL MONITORING REPORT (2016–2017)



NGAMAHAU BAY SALMON FARM: ANNUAL MONITORING REPORT (2016–2017)

DEANNA ELVINES, BEN KNIGHT, ANNA BERTHELSEN, LAUREN FLETCHER

Prepared for The New Zealand King Salmon Co. Ltd

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Grant Hopkins

APPROVED FOR RELEASE BY:
Chris Cornelisen

ISSUE DATE: 09 May 2017

RECOMMENDED CITATION: Elvines D, Knight B, Berthelsen A, Fletcher L 2017. Ngamahau Bay salmon farm: annual monitoring report (2016–2017). Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 3000. 38 p. plus appendices.

EXECUTIVE SUMMARY

Overall, the results of the 2016-17 Ngamahau Bay salmon farm annual monitoring are as follows, with key findings italicised:

- *No biological effects are expected from copper or zinc in the sediments.*

  A slight elevation in zinc concentrations is evident.

- *The levels of enrichment within all monitoring zones were within the EQS.*

  Moderate levels of enrichment were observed beneath the pens, and at the 75 N station. The 300 S station showed a fertilisation effect (minor enrichment), while the 300 N station did not show any signs of enrichment.

- *No chlorophyll-a (Chl-a) results exceeded the water quality standards (WQS), nor did dissolved oxygen (DO) saturations beside the net pens.*

  Reduced DO saturations and elevated total nitrogen (TN) and Chl-*a* concentrations were evident at the net pen station on some sampling occasions. While these changes in TN and DO are likely to be farm-related, the same cannot be said for Chl-*a*. With one exception, Chl-*a* concentrations were less than half the WQS in all samples throughout the year.

- *With two exceptions, TN concentrations were within the TN WQS.*

  The two exceedances occurred at the near-field reference station on two isolated occasions. The frequency at which these ‘exceedances’ occurred is in line with that observed in baseline data.

- *DO saturations outside of 250 m from the net pens were often below the ‘first step’ threshold for the DO WQS in 14 samples, and were often (marginally) lower than the 1.2% threshold second-step WQS which considers reference DO saturations.*

  There is no evidence to suggest the lower DO saturations were farm-related.

- *Elevated concentrations of TN, PN, NH_4-N, NO_3-N and urea-N were evident ≤ 250 m of the farm, but beyond 250 m were similar to reference concentrations.*

  The high current flows and associated mixing/dilution appear to be the primary ameliorating factor at the NGA farm site.

- *Obvious changes in silicate, phosphorus and chlorophyll-a concentrations, as well as phytoplankton biomass and community composition were not evident around the farm site.*

Based on the results of the 2016-17 Ngamahau Bay salmon farm annual monitoring, we recommend the following:

- Because the current WQS do not capture the full spectrum of natural DO fluctuations in Tory Channel, we recommend revision of the DO WQS for the area.
- We recommend exclusion of the following parameters from fine-scale water column monitoring (condition 65e):
  - Chlorophyll-*a*

  - Phytoplankton biomass and community composition
  - Silicate (DRSi).

  Results from these parameters are not expected to, and have not shown, localised farm effects. As such, they do not provide useful information on farm-specific near-farm mixing properties (Condition 43d, 55e and 65e).

- Because phosphorus is ubiquitous in Pelorus Sound, we recommend fine-scale sampling of this nutrient is limited only to near-bed samples around the net pen where potential farm-related effects are likely to be detected.
- Concentrations of DRSi should continue to be monitored at the reference station/s. However, as the salmon farm is not a source of silicate, and concentrations do not appear to be affected by the farm, we recommend this nutrient (DRSi), as well as phosphorus (TP and DRP), are not continued in full-suite monitoring (as part of condition 65c). Flexibility to exclude these nutrients appears to be provided for under Condition 62c and 65c. We also recommend phytoplankton biomass and composition is excluded from ongoing full-suite sampling by the same rationale.
- In lieu of the water column sampling as above, we recommend:
  - Ongoing inclusion of urea-N and PN in fine-scale monitoring for the next monitoring year, including measuring these nutrients also at 500 m and reference stations.
  - A one-off sampling study to investigate diel variation in nutrient (and DO) concentrations around the net pens. This would provide valuable information on the full amount of variability (e.g. episodic emissions from the fish) occurring at the site, allowing a more meaningful estimate of effects to the wider system. Data collected using this technique would better align with achieving the objectives in conditions 43d, 55e and 65e.
  - A physical mixing study using an artificial dye tracer. This would be more suited to determining near-farm mixing properties than the current nutrient tracking method, and thus better aligns with achieving the objectives in conditions 43d, 55e and 65e. The study could be done under a range of mixing conditions (slack tide vs. running tide, low- vs. moderate-wind) as a one-off at each farm site. Results could be used to apply context to results from future net pen samples, thereby reducing sampling effort and the need for repeated fine-scale measurements around every farm. The study would utilise fine-scale nutrient results collected to date to validate the completed ‘dispersion’ model.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

The New Zealand King Salmon Co. Limited (NZ King Salmon) is the largest finfish farming company in New Zealand and has a long history in the Marlborough Sounds. NZ King Salmon has 11 consented farms in the region (Figure 1): Te Pangu Bay (TEP), Ruakaka Bay (RUA), Otanerau Bay (OTA), Waihinau Bay (WAI), Forsyth Bay (FOR), Clay Point (CLA), Marine Farm Licence 48 (MFL-48), Marine Farm Licence 32 (MFL-32), Waitata Reach (WTA), Ngamahau Bay (NGA) and Kopaua (Richmond) Bay (KOP).

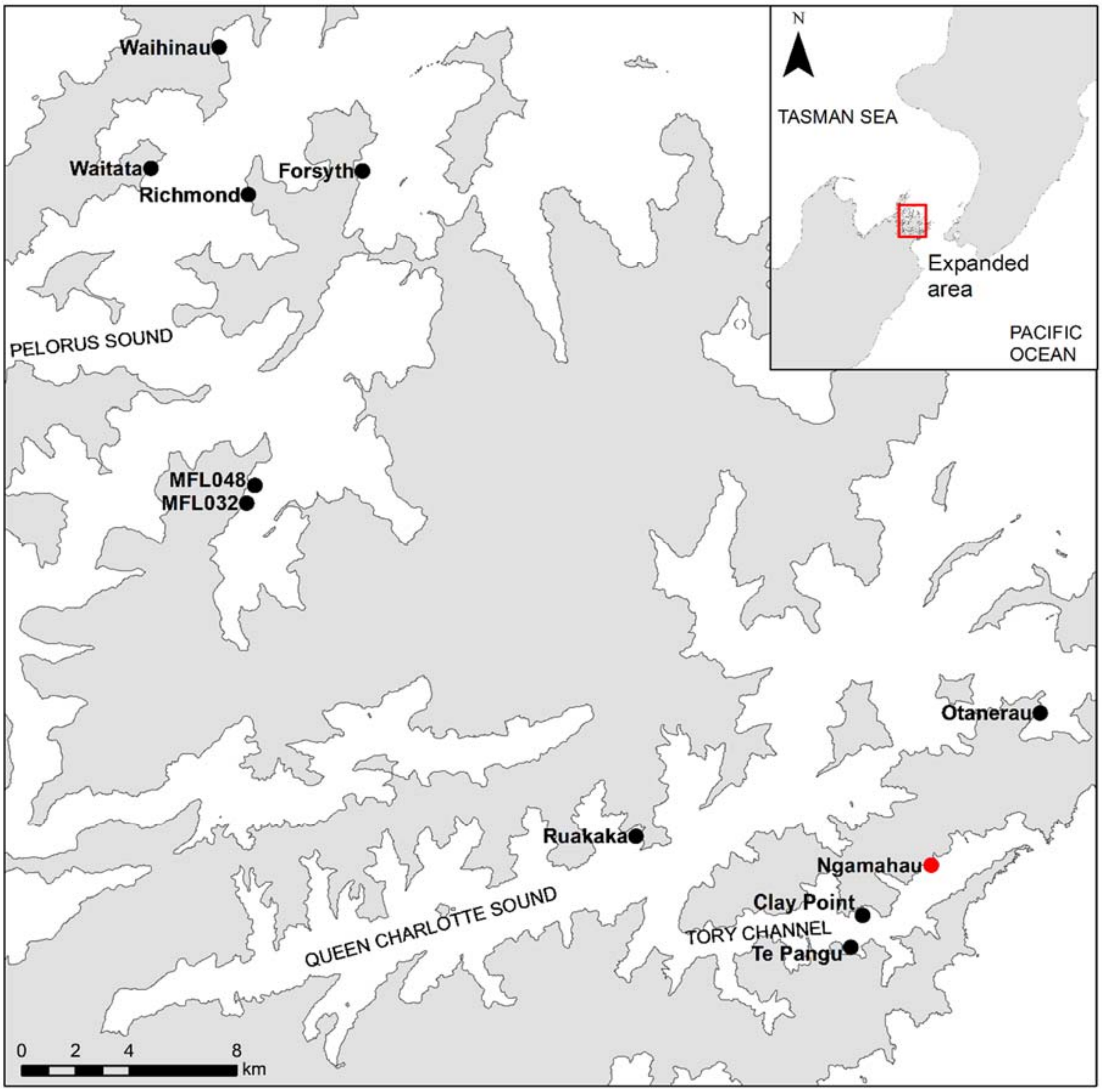


Figure 1. Map of the Marlborough Sounds area showing the location of the Ngamahau Bay salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

NZ King Salmon is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The current monitoring programme is conducted under a marine environmental monitoring adaptive management plan (MEMAMP) (Elvines et al. 2016b). The MEMAMP is prepared by Cawthron Institute (Cawthron) on behalf of NZ King Salmon, and approved by Marlborough District Council (MDC) prior to implementation.

This report presents the 2016-2017 monitoring results for the Ngamahau Bay salmon farm (NGA), and includes an assessment of:

- depositional effects on soft sediment habitats
- effects on water quality.

Results from reef habitat monitoring are reported separately in Dunmore (2017), attached as Part 2 of this report.

1.1. Site details and history of feed usage

Ngamahau was established in November 2015, and this is the second annual monitoring report for this site. Water depth at the farm site is *c.* 30–35 m, with the net pens extending from the surface to a depth of *c.* 20 m. It is a high-flow site, with average current velocity of 22 cm/sec, and maximum velocity up to 64 cm/sec. A total of 1,300 tonnes of feed was used over the 12 month period prior to the benthic monitoring survey in January 2017 (Figure 2). November had the highest monthly feed input (167 tonnes), while January had the lowest (66 tonnes). Nitrogen input correlated with feed input (average 6.98% of feed), and ranged from 5.3–11.4 tonnes per month, totalling 90.8 tonnes for this period.

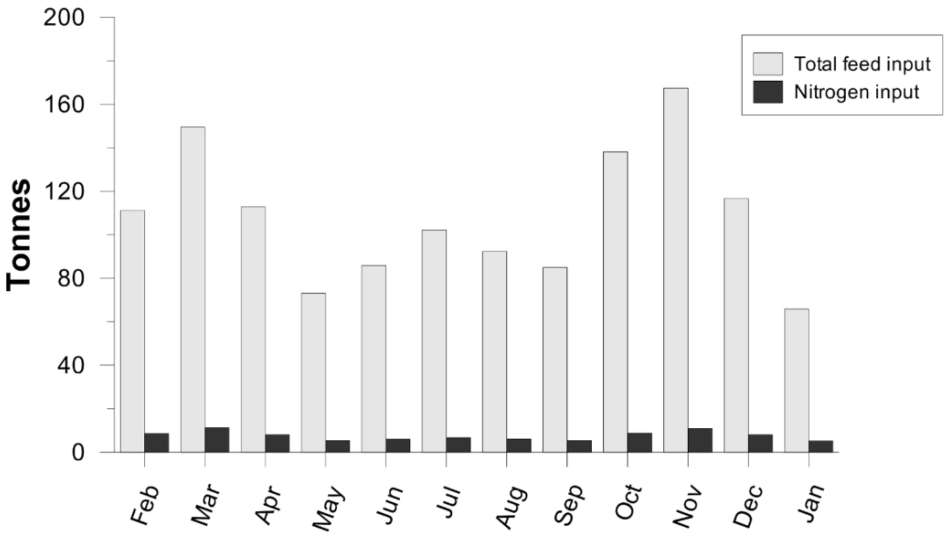


Figure 2. Monthly feed and nitrogen inputs at the Ngamahau Bay salmon farm for the 12 months leading up to the January 2017 benthic monitoring. Data provided by NZ King Salmon.

2. METHODS

Detailed methodology and rationale for the sampling approach can be found in the most recent MEMAMP (Elvines et al. 2016b); copies are held by MDC and NZ King Salmon. The MEMAMP is modified annually to accommodate the most relevant and effective sampling methods. Further rationale and details related to the general monitoring procedures can be found in the Best Management Practice guidelines (BMP; MPI 2015).

2.1. Soft-sediment habitats

2.1.1. Sampling locations

Annual benthic monitoring at NGA was undertaken on 24 January 2017. Sampling stations at the NGA farm are described and named as follows (also see Figure 3):

- Three net pen stations, within the zone of maximal effect (ZME), beneath the edge of the net pens; **Pen 1**, **Pen 2** and **Pen 3**.
- Two stations to monitor the outer limit of effects (OLE, Zone 3–4 boundary), set at 300 m, in opposing directions (north and south) along the predominant depositional axis (**300 N** and **300 S**).
- Three reference or ‘control’ stations, one near-field (**TC-Ctl-1**) and two far-field; **TC-Ctl-3** and **TC-Ctl-6**.
- In addition, although not a requirement under the BMP, one station at the Zone 2–3 boundary along the north transect was sampled to monitor the enrichment footprint in the early stages of operation; **75 N**.

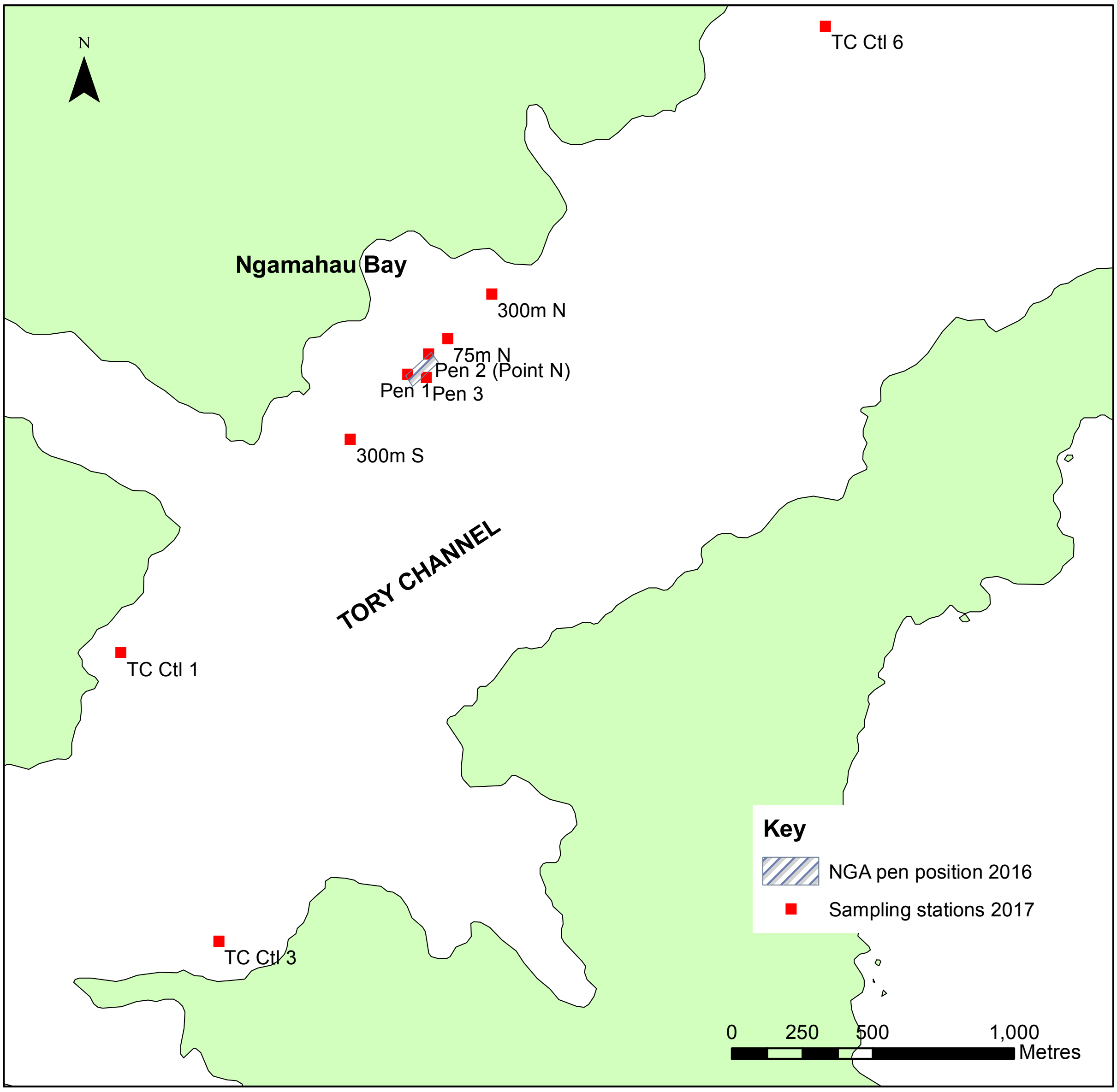


Figure 3. Soft sediment sampling locations for the Ngamahau Bay salmon farm site. 'TC-Ctl' = Tory Channel Control. Position accuracy is ± 5 m.

2.1.2. Environmental variables

Standard benthic monitoring

Three replicate sediment grab samples were collected at each sampling station using a van Veen grab. Each grab sample was examined for sediment colour, odour, texture and bacterial mat coverage. The top 30 mm of one sediment core (63 mm diameter) was analysed for organic content as % ash-free dry weight (AFDW), redox potential (Eh_{NHE}, mV), and total free sulphides (µM). In addition, composited triplicate samples from the pen stations were analysed for total recoverable copper and zinc concentrations. Laboratory analytical methods for sediment samples can be found in Appendix 1.

A separate core (130 mm diameter, approx. 100 mm deep) was collected from each grab for macrofauna[1] identification and enumeration, and sieved through 0.5 mm mesh. Raw macrofauna data were further analysed to calculate the total abundance (N/core), total number of taxa (S/core), Shannon-Weiner diversity index (H'), Pielou's evenness index (J'), Margalef richness index (d), AMBI biotic coefficient (BC) and mAMBI ecological quality ratio (EQR). Refer to MPI (2015) for an explanation of each of the biotic indices.

Two additional replicate samples ('d' and 'e' replicates) were collected from each pen station to determine the redox potential (measured in the field), and to obtain organic content and macrofauna samples for archive purposes.

Video footage was taken at each station to qualitatively assess bacterial mat coverage, general seabed condition and presence of sediment out-gassing. The sea surface was also scanned for visible sediment out-gassing as this could provide further evidence of particularly enriched conditions. General observations of epibiota were also made.

2.1.3. Assessment of Enrichment Stage

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to Enrichment Stage (ES). The ES assessment references a selection of informative chemical and biological indicator variables[2].

For each indicator variable (raw data), an equivalent ES score was calculated using previously described relationships (MPI 2015). Average ES scores were then calculated for the sediment chemistry variables (redox and sulphides), the macrofauna composition variables (abundance, richness, evenness, diversity and biotic indices), and organic content (% AFDW). The overall ES for a given sample was then calculated by determining the weighted average[3] of those three groups of variables. Finally, the overall ES for the sampling station was calculated from the average of the replicate samples with the degree of certainty reflected in the associated 95% confidence interval.

2.2. Water column

2.2.1. Sampling stations and frequency

Three 'types' of water column monitoring were undertaken under the NGA consent during the months of 2016. The types were:

---

[1] The term 'macrofauna' describes the animals buried in the sediment.

[2] There are risks associated with placing emphasis on any individual indicator variables of ES. This is particularly true for chemical indicators, which tend to be more spatially and temporally variable. As such, the derived overall ES value is considered a more robust measure of the general seabed state.

[3] Weighting used in the current assessment is the same as that used in previous years: organic loading = 0.1, sediment chemistry = 0.2, macrofauna composition = 0.7).

- **Routine monitoring.** This was undertaken on a monthly basis. Sampling typically occurred in the third or fourth week of each month, however this was not always possible due to weather or logistical issues. Routine monitoring was undertaken at three stations in vicinity of NGA (NZKS18 – NZKS20) and at two reference stations (NZKS21 and NZKS22; Table 1, Figure 4).
- **Full-suite monitoring.** This measured a larger suite of analytes, but at the same stations as routine sampling, and only during February, March, July and August 2016.
- **Fine-scale monitoring.** This was just in proximity of the farm, undertaken in March and August during the anticipated periods of diatom maxima in the Marlborough Sounds. The timing of this component coincided with full-suite monitoring for these months, because the same suite of analytes were measured.

As well as sampling the routine and full suite monitoring stations (Table 1), sampling was also conducted at two additional stations in these months, located 100 m and 250 m downstream of the net pens. These two additional stations, the net pen station, and the station 500 m downstream, constitutes the sampling stations for the fine-scale monitoring. In addition, because the routine monitoring stations were sampled on the same day, these data are used for comparison to reference conditions as required.

Table 1. Sampling stations for water column monitoring for the routine, full-suite and fine-scale monitoring components.

Description	**Station name**
a) Routine and full-suite sampling stations	
Beside net pen (downstream)*	NZKS18
500 m (up & downstream)*	NZKS19/20
Near-field reference stations	NZKS21**(QCS3)
Far-field reference stations	NZKS22
b) Fine-scale sampling stations	
100 m (downstream)	NGA100
250 m (downstream)	NGA250

* Locations changed depending on the state of tide at the time of sampling.
**Also MDC state of environment monitoring stations. Hereafter referred to only using NZKS21.

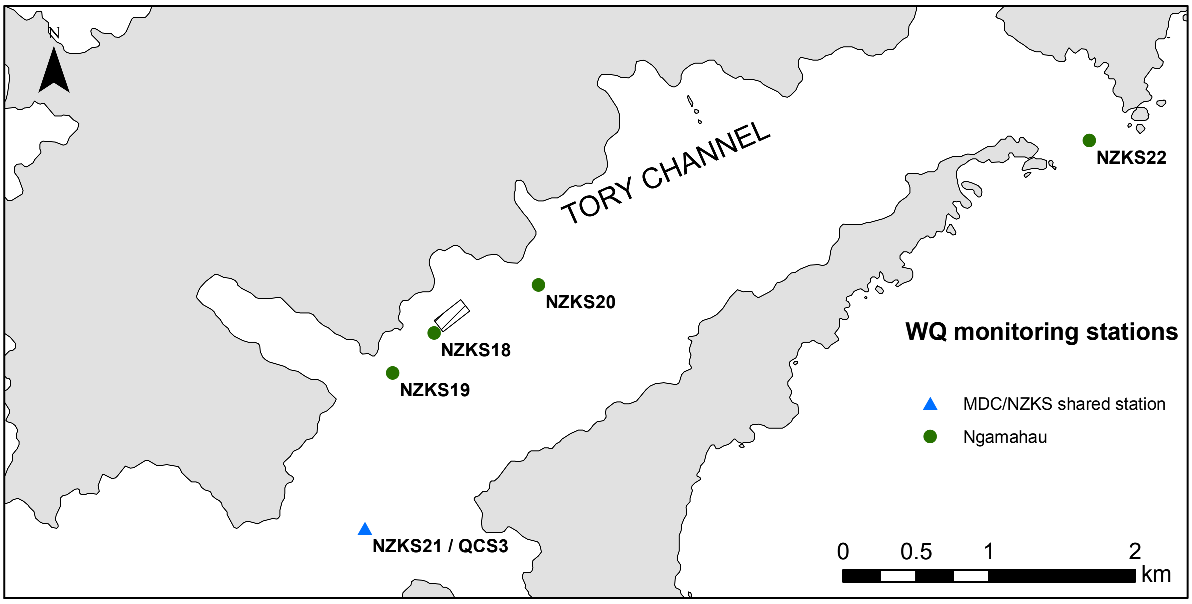


Figure 4. NZKS and MDC routine and full-suite water-quality monitoring stations in Tory Channel.

2.2.2. Sample collection

On all sampling occasions, water column depth profile data were collected at each station using a conductivity-temperature-depth (CTD) instrument with an attached dissolved oxygen (DO) sensor. Parameters measured included salinity, temperature, turbidity[4] and DO. In addition, single, surface-integrated samples were taken over the upper 15 m of the water column (obtained using a weighted hose) and analysed for total nitrogen (TN) and chlorophyll-*a* (Chl-*a*).

During full-suite and fine-scale monitoring (February, March, July and August), additional nutrients (NH_4-N, NO_3-N, NO_2-N, DRP, Si, and TP) and phytoplankton composition and biomass were also analysed.

For the fine-scale monitoring (March and August), variations to the sampling procedure were as follows:

- In addition to the surface integrated samples, a single near-bed water sample was collected from the 'fine-scale' monitoring stations, using a van Dorn sampler.
- Surface-integrated samples were collected in triplicate (as opposed to single samples) from the Pen station, and the 100 m, 250 m and 500 m downstream stations. Additional 500 m or reference stations were also sometimes sampled in triplicate, but not consistently. Triplicate samples were taken from a single, well-mixed, bucket of seawater comprised from two deployments from the 15 m hose sampler. The triplicates are therefore 'pseudo-replicates', with the variability

---

[4] Turbidity was used as a proxy for clarity, as turbidity data show the water column profile rather than just surface characteristics.

between the triplicates representing that introduced by transit times to the laboratory, rather than 'water parcel' or 'spatial' variability at the sampling station.

- With the exception of phytoplankton, a full-suite of parameters were analysed from all samples taken from the fine-scale monitoring stations. Phytoplankton was analysed only from single, 15 m depth integrated samples during these months (i.e. was not analysed from near-bed samples, nor in triplicate).

Routine and full suite samples were collected by Marlborough District Council (MDC) staff, coinciding with wide-scale state of the environment monitoring in Queen Charlotte Sound (led by MDC). Cawthron staff performed all additional sampling requirements related to fine-scale monitoring.

2.2.3. Sample analysis

Samples were analysed for nutrients using routine methods (Appendix 1). In addition, the remaining sample was filtered and archived for future analysis on nutrients, in case follow-up was required (i.e. if thresholds were exceeded).

Algal taxonomic composition (species abundance) was determined from a subsample of the 15 m depth integrated sample, which was then preserved with Lugol's acidified iodine solution. Algal taxonomic composition was determined by a modified Utermöhl method based on published Intergovernmental Oceanographic Commission (IOC) methods (Karlson et al. 2010). For this process, each sample is analysed using inverted light microscopy to identify and enumerate all taxa detected in the sample to the finest practicable taxonomic level by IANZ accredited staff. Sample bio-volume was estimated for recorded species and used to estimate cell carbon content (biomass) (Appendix 1).

3. COMPLIANCE FRAMEWORK

The environmental monitoring results from soft sediment habitats and water column monitoring are used to determine whether the farms are compliant with the respective environmental quality standards (EQS: water or benthic) specified in the consent conditions.

3.1. Soft sediment habitats

3.1.1. Enrichment

The EQS (benthic) are based on a seabed impact ‘zones concept’; an approach that provides an upper limit to the spatial extent and magnitude of seabed impacts (see Keeley 2012). The EQS in the consent conditions (Table 2) set precise parameters for the allowable environmental states within the zones. It should also be noted that best management practice guidelines—benthic (BMP; MPI 2015) exist for salmon farming in the Marlborough Sounds. Reference to the BMP is made within the consent conditions for this site, and will be referenced within this document where BMP principles apply.

Table 2. Environmental quality standards (EQS) for each zone at the Ngamahau Bay salmon farm (consent U140296).

Zone	**Compliance Monitoring Location**	**EQS**
Zones 1 & 2 Beside and beneath the net pens (ZME as per the BMP)	Measured beneath the edge of the net pens	ES ≤ 5 No more than one replicate core with no taxa (azoic) No obvious spontaneous out-gassing (H_2S/methane) Bacteria mat (*Beggiatoa*) coverage not greater than localised/patchy in distribution
Zone 3 Near to the net pens	Measured at the Zone 2/3 boundary	ES ≤ 4.0 Infauna abundance is not significantly higher than at corresponding ‘Pen’ station Number of taxa > 75% of number at relevant / appropriate reference station(s).
Zone 4 Outside the footprint area (OLE as per the BMP)	Measured at the Zone 3/4 boundary stations	ES < 3.0 Conditions remain statistically comparable with relevant appropriate reference station(s).

3.1.2. Copper and zinc

Compliance for copper and zinc levels follows the decision hierarchy in the BMP (MPI 2015), as shown in Figure 5. The BMP guidelines state that the ANZECC (2000) ISQG-Low criteria for copper and zinc are the most appropriate trigger values for sediments beneath farms (Table 3). Therefore these guideline thresholds should be used to trigger further action if exceeded.

Table 3. ANZECC (2000) Interim Sediment Quality Guideline concentrations for copper and zinc (mg/kg).

	ISQG-Low	ISQG-High
Copper	65	270
Zinc	200	410

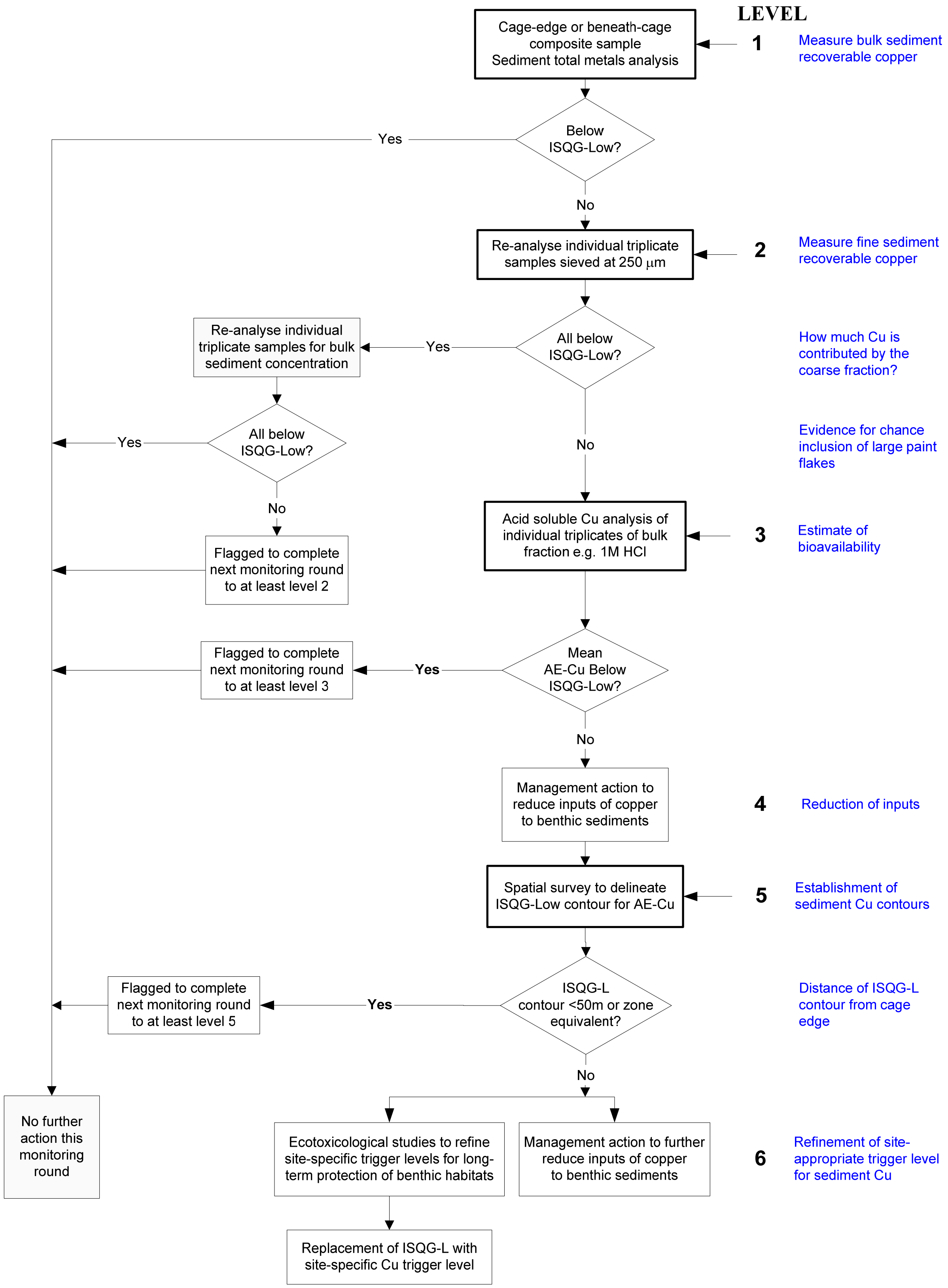


Figure 5. Decision response hierarchy for metals tiered monitoring approach (from MPI 2015). Copper is used in this example.

3.2. Water column

3.2.1. Assessing performance against the water quality objectives

Condition 43 of the NGA consent (number U140296) states water quality objectives as follows:

> 43. The marine farm shall be operated at all times in such a way as to achieve the following Water Quality Objectives in the water column:
>   a. *To not cause an increase in the frequency, intensity or duration of phytoplankton blooms (i.e. chlorophyll-a concentrations ≥ 5 mg/m3) [Note: water clarity as affected by chlorophyll-a concentrations is addressed by this objective];*
>   b. *To not cause a change in the typical seasonal patterns of phytoplankton community structure (i.e. diatoms vs. dinoflagellates), and with no increased frequency of harmful algal blooms (HABs) (i.e. exceeding toxicity thresholds for HAB species);*
>   c. *To not cause reduction in dissolved oxygen concentrations to levels that are potentially harmful to marine biota;*
>   d. *To not cause elevation of nutrient concentrations outside the confines of established natural variation for the location and time of year, beyond 250 m from the edge of the net pens;*
>   e. *To not cause a statistically significant shift, beyond that which is likely to occur naturally, from a oligotrophic/mesotrophic state towards a eutrophic state;*
>   f. *To not cause an obvious or noxious build-up of macroalgal (e.g. sea lettuce) biomass [Note: to be monitored in accordance with Condition 65h].*

These water quality objectives cannot be fully met by the current annual monitoring/reporting, due to implicit timescales for some objectives exceeding the time-series of farm-related water column data that are available to date. However, these objectives can be fully assessed in future reporting, when appropriate time scales of data are available.

3.2.2. Compliance with water quality monitoring conditions

Conditions 65c and 65e (Appendix 2) prescribe in part the locations, frequency and analytes to be sampled for ‘routine’, ‘full suite’ and ‘fine-scale’ monitoring. In addition, there are water quality standards (WQS) that set specific limits for Chl-*a*, dissolved oxygen and total nitrogen. The current WQS are discussed and specified in the MEMAMP, and are summarised in Table 4. A hierarchy of response to breaches of the WQS is presented in Figure 6.

Although results are not always explicitly interpreted for ‘compliance’, the objectives for each monitoring component are described as follows:

- **Routine monitoring, and full suite monitoring (as per Condition 65c)**

  To determine compliance with the WQS in Condition 44 (see Table 4).

- **Fine-scale monitoring (as per Condition 65e, also see Condition 55e)**

  To quantify the localised effect of the marine farm on surrounding water quality for the purpose of obtaining information regarding marine farm specific, near-farm mixing properties in order to provide a context for evaluating compliance with the WQS in Condition 44. (from permit)

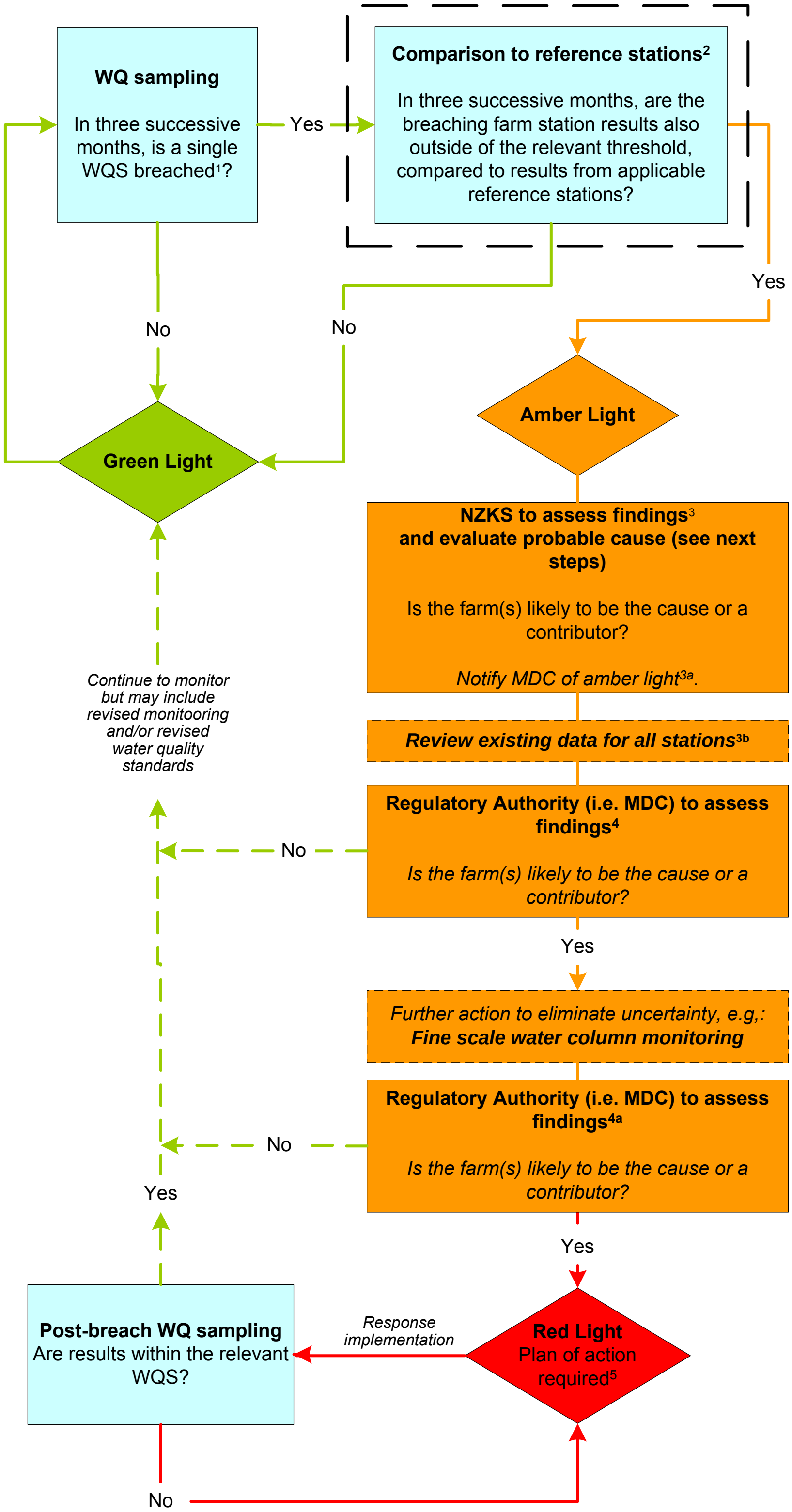
As above, the objective for monitoring data collected in February, March July and August (for full-suite monitoring) is to determine compliance with WQS (Condition 65c). However, WQS only exist for TN, Chl-*a* and DO. As such, discussion of results from other parameters is limited to spatial patterns.

Table 4. Water quality standards for chlorophyll-*a* (Chl-*a*), total nitrogen (TN) and dissolved oxygen (DO) at the Ngamahau salmon farm site 2016–2017. The second step threshold takes into account reference values (see note 2 in Figure 6). Further discussion of the WQS and how they are applied can be found in the MEMAMP (Elvines et al. 2016b).

	Chl-a	TN	DO	
WQS	≤ 3.5 mg/m^3	≤ 300 mg TN/m^3	> 90%	> 70%
Second step threshold	n/a	To be determined	≤1.2% lower than applicable reference stations (e.g. far-field, upstream 500 m)	
Sample	0-15 m depth integrated sample	0-15 m depth integrated sample	All depths, bin mean of 1 m.	All depths, bin mean of 1 m.
Location	All stations	Stations > 250 m from farm[5] (Stations < 250 m may exceed these levels)	Stations > 250 m from farm	Stations < 250 m from farm
Tolerance	Three consecutive months: at any one station, or at any station within the same sound for three consecutive months			

---

[5] We interpret that this does not include far-field reference stations which should, by definition, be unlikely to be affected by the salmon farms. TN concentrations > 300 mg/m^3 are noted as ‘historically rare’ in the baseline report of Morrisey et al. (2015). Consequently, the potential for wider enrichment, i.e. an increase in the number of samples > 300 mg TN/m^3 will still be considered in the annual report.



[1] This could be the same station that has 3 successive months breaching the WQS, or different stations that breach the same WQS in three successive months (within the same sound).

[2] For example, dissolved oxygen saturations at farm stations that are ≤1.2% lower than DO saturations from applicable reference stations would not be considered to breach DO WQS.

[3] via science providers: to review WQ data, and may draw on a range of monitoring data to determine likely cause

[3a] All amber lights must be reported within 2 working days to MDC

[3b] Report findings within 20 days of any breach.

[4] First Level Response
Where uncertainty exists, MDC may request continued monitoring, more analyses, more frequent and/or more detailed monitoring.

[4a] Reporting timeframe to be agreed upon by MDC.

[5] Second level response:
NZKS to propose a mitigation response. Plan of action required as soon as practicable to achieve full compliance, with clear time frames. This may include reduced stocking to achieve compliance.

Figure 6. Flow diagram illustrating the response regime for water quality monitoring against the water quality standards (WQS; Table 4) as specified in the current MEMAMP (Elvines et al. 2016b).

4. RESULTS

4.1. Soft-sediment habitats

4.1.1. Qualitative description

Video footage of the seabed at the Pen stations showed predominantly dark grey sandy sediment with small rocks and cobble. There was also considerable amount of shell hash (e.g. mussels. cockles, scallops), including whole empty shell debris. Diatom mats were present over some areas of substrate at Pen 2. No *Beggiatoa*-like bacterial coverage or outgassing was seen. Epifauna observed at Pen 1 included snake stars (*Ophiopsammus maculata*), a hermit crab (*Pagurus* sp.) and several unidentified solitary stalked ascidians. A higher diversity of epifauna was recorded at Pen 2 and included eleven-armed sea stars (*Coscinasterias muricata*), green-lipped mussels (*Perna canaliculus*), saddle sea squirts (*Cnemidocarpa* sp.), anemones (*Actinothoe albocincta*) and drift macroalgae (*Ulva* sp.). Snake stars and saddle sea squirts were also observed at Pen 3, along with another species of sea star (apricot sea star; *Sclerasterias mollis*) and an unidentified grey sponge. Several light brown-red globules, resembling feed pellets or fish faeces, were also evident on the surface of the sediment at this station. Blue cod (*Parapercis colias*) were observed at Pen 1 and Pen 2, as well as a small surface-dwelling fish (likely opalfish; *Hemerocoetes monopterygius*) and triple fin at Pen 3.

Substrate at the 75 N station was sandy with shell hash and some larger rocks. Epifauna included snake stars (abundant), eleven-armed and apricot sea stars, cushion stars (*Patiriella regularis*), scallops (juvenile and adult; *Pecten novaezelandiae*), cockles, and a species of unidentified fanworm. Attached and drift macroalgae (e.g. *Ulva* spp.) were also observed. Further from the farm structures, at the OLE, the sediment was finer but shell hash was still prevalent (more so at 300 S). Snake stars were again abundant, and other epifauna included saddle sea squirts, fanworms and cushion stars at both stations. Eleven-armed sea stars were observed at 300 N, and sea cucumbers (*Australostichopus mollis)* and scallops at 300 S. Drift macroalgae (*Ulva* sp., *Caulerpa brownii*, and an unidentified red foliose) were also common.

Substrates at the reference stations were predominantly sandy sediments with fine-to medium-sized shell hash common. The outer reference stations (TC-Ctl-3 and TC-Ctl-6) had substantial amounts of larger shell debris and small cobble present. Occasional burrow holes were observed at TC-Ctl-1 only. Epifaunal diversity was lower at this inner reference station (TC-Ctl-1), although snake stars were common, and a hermit crab, an unidentified anemone and drift macroalgae (*Ulva* sp.) were also noted. TC-Ctl-3 and TC-Ctl-6 had occasional reef-like structures present which were colonised by a variety of sessile invertebrate species (colonial ascidians, anemones, sponges, hydroids, encrusting bryozoans, saddle sea squirts, fanworms) and algae (*Ulva* sp., pink coralline algae, unidentified red foliose). A range of mobile epifauna including eleven-armed sea stars, cushion stars and snake stars were also noted at both stations. A single kina (*Evechinus chloroticus*), apricot sea star and sea cucumber were observed at TC-Ctl-3. Blue cod were common at both outer reference stations, with and spotted wrasse (*Notolabrus celidotus*) also observed at TC-Ctl-3. Representative images of the seabed and conspicuous taxa at each station are provided in Appendix 3.

4.1.2. Assessment of seabed enrichment

This section discusses the Enrichment Stage (ES) calculated for each station (Table 5). Discussion is provided on results of individual variables (Figure 7) where relevant.

Mean overall ES scores across the three Pen stations were 2.7 and 3.2 (Table 5) indicating moderate enrichment levels. The scores were well within the consented EQS (ES ≤ 5) for this zone (Table 2). Sediment chemistry (organic content, redox and sulphides) at all three Pen stations was comparable to control stations. Macrofauna communities at Pen 1 and Pen 3 had high total abundances (1,008–2,116 individuals per core), and marginally elevated taxa richness (average 52 taxa per core at both stations), in comparison to reference (Appendix 4 and Appendix 5) and baseline conditions (130–180 individuals per core and 30–40 taxa per core; Morrisey et al. 2015). Changes in community composition, as shown by the elevated AMBI scores, were evident as higher densities of enrichment tolerant taxa (e.g. Nematoda, *Capitella capitata*), and reductions in more sensitive taxa (e.g. Ampharetidae). Enrichment at Pen 2 was the highest (ES 3.2), due to lower redox values and deteriorations in macrofaunal communities, including reduced (although still similar to reference) taxa richness from that previously recorded at this station in response to progressing levels of enrichment. Total abundances were variable, and compositional changes were more apparent at this station (as indicated by the relatively lower AMBI and higher mAMBI scores).

At 75 N (Zone 2/3 boundary) the overall ES of 3.1 was similar to beneath the pens, indicating the same level of (moderate) enrichment at this station. Average abundances were lower than the Pen station averages, and the average taxa richness was within reference station taxa richness values. As such, the station was within the EQS for this zone boundary. With the exception of sulphides the observed changes at this station were also similar to changes beneath the pens. Sulphides were elevated (352–595 Eh_{NHE}, mV) compared to reference (40–475 Eh_{NHE}, mV) and Pen stations.

At 300 N and 300 S overall ES scores were both ES 2.0; within the range of average ES scores from the reference stations (overall ES 1.9 – 2.2), and well below the allowable ES (< 3.0). As such, these stations were within the EQS for this zone. Sediment chemistry and macrofauna communities at 300 N were comparable to reference stations, while taxa richness and total abundance were elevated at 300 S, indicating a ‘fertilisation’ effect here.

Table 5. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each Ngamahau Bay salmon farm sampling station, January 2017. The allowable ES (EQS) for each zone (Table 2) is also shown. Full breakdowns of indicator variable contributions are provided in Appendix 4 and Appendix 5.

Station	Summary of indicator variables		ES (95%CI)
Pen 1	Organic matter (%OM), redox potential and total free sulphides normal compared to reference. Total abundance very high (~5x ref). Taxa richness slightly elevated (5–53 taxa per core), compositional changes indicated by biotic indices.	Organic loading:	2.0 (0)
		Sediment chemistry:	2.5 (0)
		Macrofauna:	2.8 (0.1)
		Overall:	**2.7 (0.1)**
Pen 2	%OM normal. Redox and sulphides variable but generally within range of reference. Total abundance variable (318–1,696 per core), taxa richness slightly reduced and compositional changes indicated by biotic indices.	Organic loading:	2.0 (0)
		Sediment chemistry:	3.1 (0.7)
		Macrofauna:	3.3 (0.3)
		Overall:	**3.2 (0.3)**
Pen 3	%OM, redox and sulphides normal compared to reference. Total abundance high (1,008–2,116 individuals per core). Taxa richness elevated (42–58 taxa per core) and compositional changes indicated by biotic indices.	Organic loading:	2.0 (0)
		Sediment chemistry:	2.8 (0.1)
		Macrofauna:	2.8 (0.3)
		Overall:	**2.7 (0.2)**
		Zone 1 & 2 EQS	**≤ 5.0**
75 N	%OM and redox normal compared to controls. Sulphides elevated (352–595) compared to reference (40–475). Total abundance and AMBI score elevated. *C. capitata* variable but more abundant (7–146) compared to reference (0–4).	Organic loading:	2.0 (0)
		Sediment chemistry:	3.2 (0.4)
		Macrofauna:	3.2 (0.2)
		Overall:	**3.1 (0.2)**
		Zone 3 EQS	**≤ 4.0**
300 N	%OM, redox and sulphides normal compared to controls. All macrofauna measures normal compared to reference.	Organic loading:	1.7 (0.7)
		Sediment chemistry:	2.5 (0.7)
		Macrofauna:	1.9 (0.2)
		Overall:	**2.0 (0.3)**
300 S	%OM and redox normal, and sulphides marginally lower compared to reference. Total abundance (431–937 individuals per core) and taxa richness (54–58 taxa per core) elevated.	Organic loading:	2.0 (0)
		Sediment chemistry:	2.2 (0.2)
		Macrofauna:	1.9 (0.3)
		Overall:	**2.0 (0.2)**
		Zone 4 EQS	**< 3.0**
TC-Ctl-1	Normal reference conditions.	Organic loading:	1.7 (0.7)
		Sediment chemistry:	2.5 (1.1)
		Macrofauna:	2.0 (0.2)
		Overall:	**2.1 (0.4)**
TC-Ctl-3	Normal reference conditions.	Organic loading:	1.3 (0.7)
		Sediment chemistry:	3.1 (0.2)
		Macrofauna:	2.0 (0.3)
		Overall:	**2.2 (0.2)**
TC-Ctl-6	Normal reference conditions.	Organic loading:	1.7 (0.7)
		Sediment chemistry:	1.9 (0.3)
		Macrofauna:	1.9 (0.1)
		Overall:	**1.9 (0.1)**

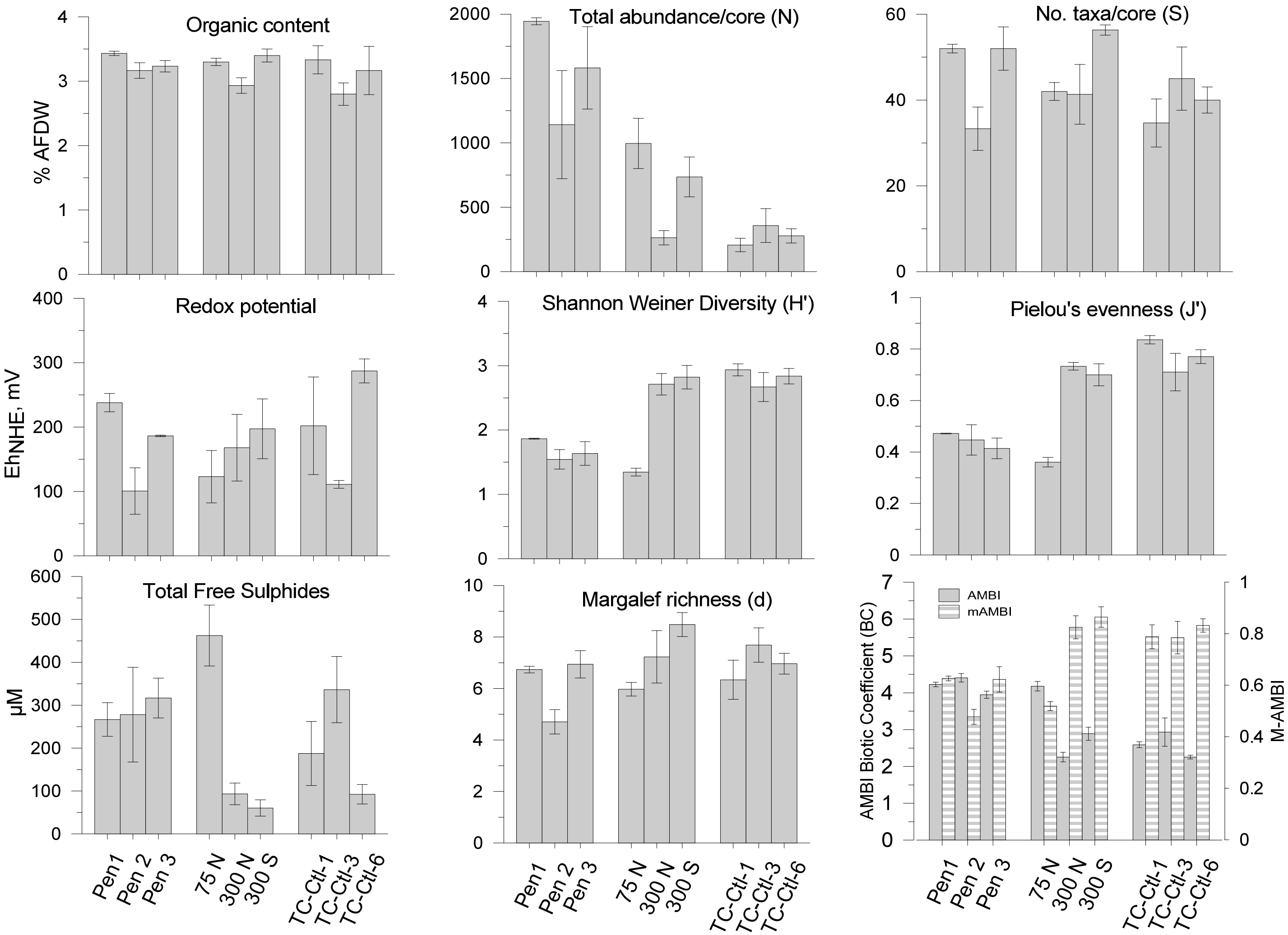


Figure 7. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh$_{NHE}$, mV), total free sulphides (µM) and macrofauna statistics determined at the Ngamahau Bay salmon farm monitoring stations, January 2017. TC-Ctl = Tory channel control. Error bars = ± 1 SE, n = 3.

4.1.3. Copper and zinc concentrations

Total recoverable copper and zinc concentrations were below the ANZECC (2000) ISQG-Low trigger level (65 mg/kg and 200 mg/kg respectively) for possible biological effects (Table 6). Concentrations were similar to that recorded at the Tory Channel control station during the baseline survey in 2013 (Morrisey et al. 2015), and the 2016 monitoring results (Elvines et al. 2016b) (Appendix 6).

Table 6. Total recoverable copper and zinc concentrations (mg/kg dry weight) in Ngamahau Bay pen samples, January 2017.

Sample	**Total recoverable copper**	**Total recoverable zinc**
Pen 1	4.2	29
Pen 2	4.1	30
Pen 3	4.5	33
ANZECC ISQG-Low	**65**	**200**
ANZECC ISQG-High	**270**	**410**

4.2. Water column

4.2.1. Dissolved oxygen

A side-by-side comparison of data from the two CTD instruments (Seabird 19 CTD: Cawthron Institute, YSI EXO Sonde CTD: Marlborough District Council; MDC) used in March[6] and August shows discrepancies between DO results from these two instruments (Appendix 7). However, because the Cawthron CTD was recording lower DO values consistently, compared to the MDC CTD, these more conservative results are used for compliance purposes. While data from the MDC instrument are not presented in Figure 8 for the months of March and August when both instruments were used, the minimum DO saturations from these data are still presented in Table 7.

Beside the net pens, minimum DO saturations were within the DO WQS in all months (i.e. > 70%; Table 7). On a number of occasions (February, March, April and August), minimum DO at 500 m and near-field reference stations breached the ‘first step’ DO WQS (> 90%; WQS [1], Table 7). However, concurrent reductions in DO were also observed at the far-field reference station, indicating these were most likely channel-wide reductions. Only six of the 14 low DO saturations did not breach the second step DO WQS threshold[7]. It appears that the current WQS of > 90 % for stations > 250 m from the farm are not appropriate for Tory Channel, as they do not capture the full

---

[6] In March, this was due to a faulty membrane, however discrepancies are still evident post-calibration, as shown in the August data comparison.

[7] The second step WQS threshold is calculated by subtracting 1.2% from the average of applicable reference station DO saturations (also see Table 4).

spectrum of natural DO fluctuations in this area. Although implementation of the second step WQS has reduced the occurrence of ‘false breaches’, we recommend the DO WQS are revised for Tory Channel.

Over the months sampled, changes in the minimum DO saturation around the farm generally followed natural changes in the region based on the reference values. Near-bed DO saturation was reasonably similar across all sampling stations (Figure 8), with the exception of March when the 250 m and 500 m upstream stations had lower DO saturations compared to all other stations. Dissolved oxygen saturations during full suite and fine-scale sampling showed no obvious reductions at the pen station, although on one sampling occasion, a reduced DO (by less than 5% compared to reference) was evident at 250 m downstream of the farm, in the surface 7 m of water. In August, large fluctuations in DO were apparent in the surface 10 m at the 500 m upstream and near-field reference. The cause for this is unknown, but could be related delays in the stabilisation of the sampling instrument prior to casting.

It is worth noting that reductions of DO also occur in the absence of photosynthetic oxygen production during dark hours, and these (and other) diel changes in DO are unable to be captured using the current method that employs only single point in time sampling.

Table 7. Minimum dissolved oxygen (DO) saturation (%) (1 m depth binned downcast data) at all stations. Both the first step (WQS [1]) and second step (WQS [2]; see Table 4) WQS are shown where applicable. Underlined values indicate those below the WQS (1), bolded values indicate those also below the WQS (2). NF = near-field, FF = far-field, ref = reference.

Month	**NZKS18**	**NZKS19**	**NZKS20**	**NZKS21**	**NZKS22**	**WQS (2)**
	Net pen	**500 m north**	**500 m south**	**NF-ref**	**FF ref**	
Jan*	90.2	89.4	89.3	88.5	88.7	**≥ 87.6**
Feb*	86.9	**86.6**	87.2	**86.5**	88.1	**≥ 87.0**
Mar*	77.7	**77.9**	**77.0**	78.5	78.9	**≥ 78.0**
Apr	90.6	89.8	90.3	89.6	90.5	**≥ 89.4**
May	92.7	93.6	92.7	91.8	95.0	
Jun	93.7	94.2	94.2	93.2	95.2	
Jul	95.2	94.4	94.5	94.5	96.0	
Aug	87.8	89.3	**79.8**	**87.7**	89.6	**≥ 88.5**
Sep	95.2	95.6	94.3	94.4	95.5	
Oct	93.4	94.9	93.4	93.6	94.7	
Nov	92.8	91.9	91.8	90.9	92.6	
Dec	94.5	92.2	92.5	91.7	93.3	
WQS (1)	**> 70%**	**> 90%**			**n/a**	

*Note the Jan, Feb and Mar data have already been presented in the previous monitoring report (Elvines et al. 2016a), and the values presented here vary from that report; due to different data processing (i.e. minimum DO and 1m depth binning).

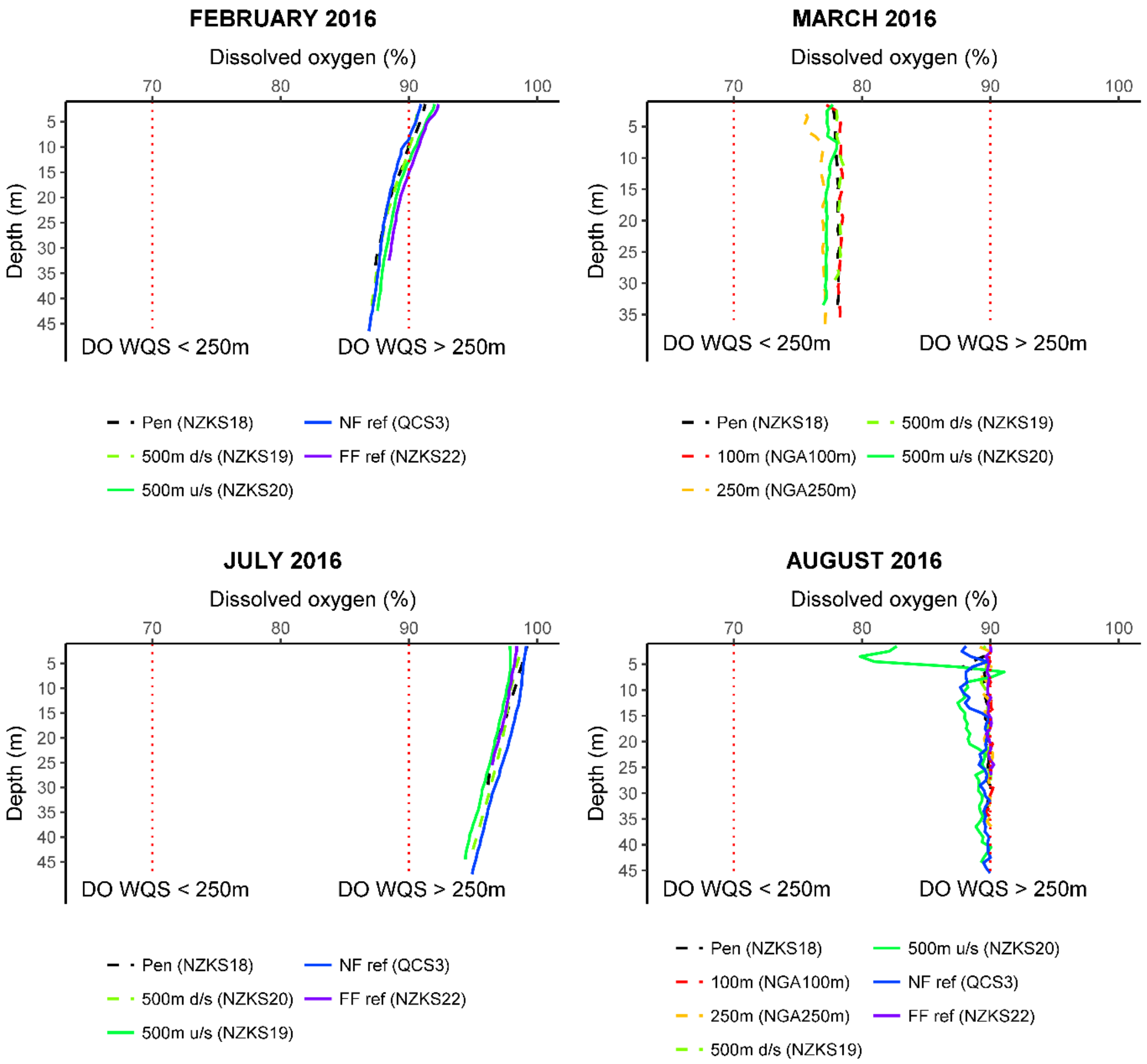


Figure 8. Dissolved oxygen (% saturation) (1 m binned depth binned downcast data) at routine and fine-scale sampling stations in February, March, July and August 2016.
D/s = downstream, u/s = upstream, NF near-field, FF = far-field, ref = reference.

4.2.2. Salinity, temperature, and turbidity

As with DO, discrepancies were also observed between the salinity and turbidity data in March and August collected using the two different CTD instruments (Figure A7.1 in Appendix 7), with the Cawthron CTD having more reasonable readings (i.e. positive turbidity and near oceanic salinities along Tory Channel). Despite the apparent problems with the MDC data, results are still presented for February and July (Figure 9) to infer relative differences between water column profiles across sampling stations[8]. However, the data are not presented in Figure 10 for March and August

---

[8] We consider this acceptable because salinity, temperature and turbidity data are used only for context / comparability purposes.

when both instruments were used as they do not provide an accurate comparison among stations.

Overall, water column profile data indicate a generally well mixed water body in this area, owing to the high tidal currents experienced in this channel. The near-field and 500 m upstream stations showed a colder layer in the deeper (*c.* > 30 m) part of the water column profile in one or more months (February, July and August), with concurrent reductions in salinity at these depths. Slight haloclines were also apparent higher up in the profile at some stations, at around 10 m depth in most months. Turbidity showed no strong trends throughout the stations and months sampled. The only notable points were the increase in turbidity with depth at the net pen and 500 m station in July, and the increase in near-bed turbidity at the 500 m upstream station in March (Figure 9; Figure 10).

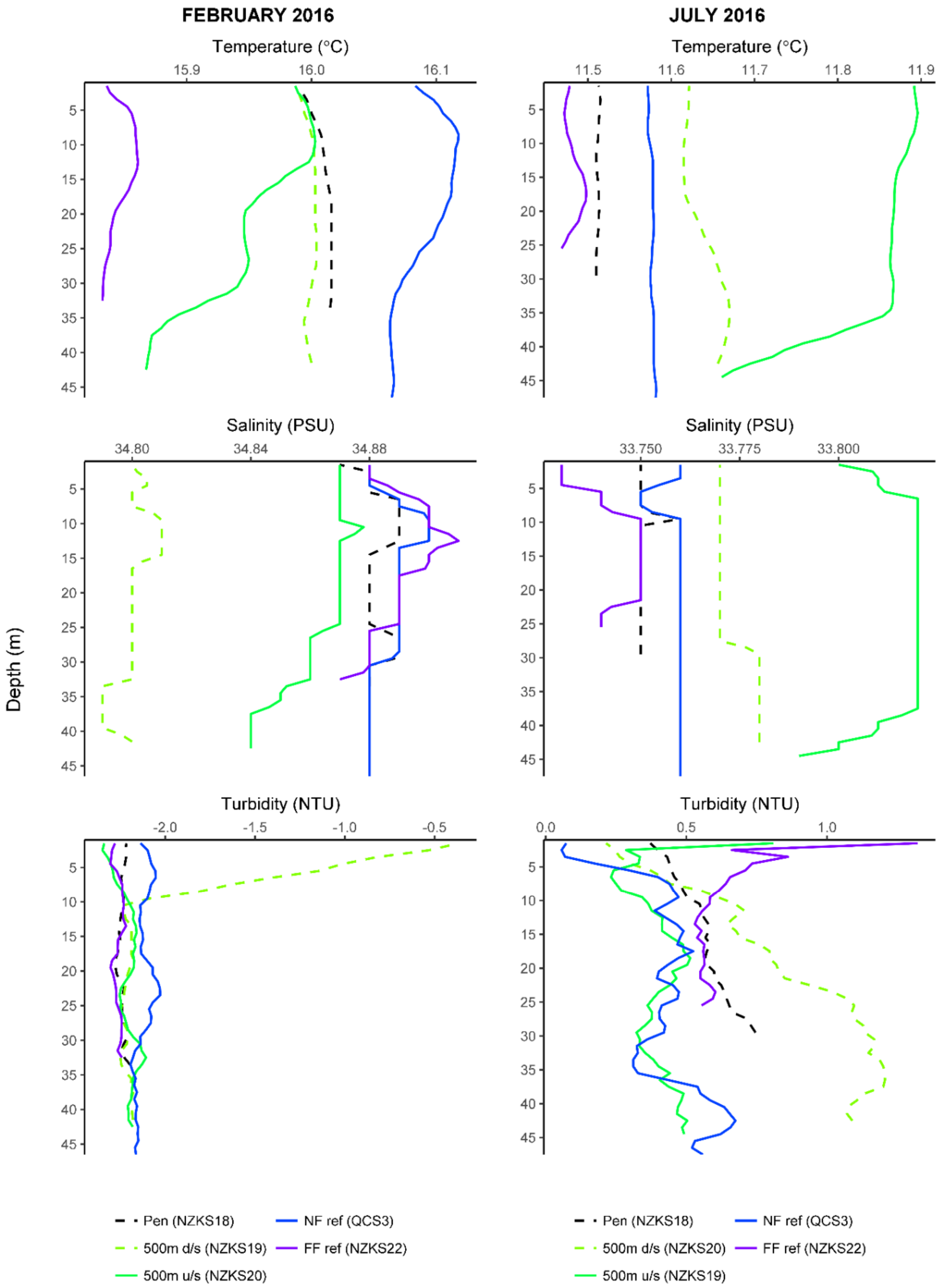


Figure 9. Water column profile salinity (PSU), temperature (°C), and turbidity (NTU) (1 m depth binned downcast data) at routine sampling stations in February and July 2016. All data were collected using MDC's YSI EXO Sonde CTD.

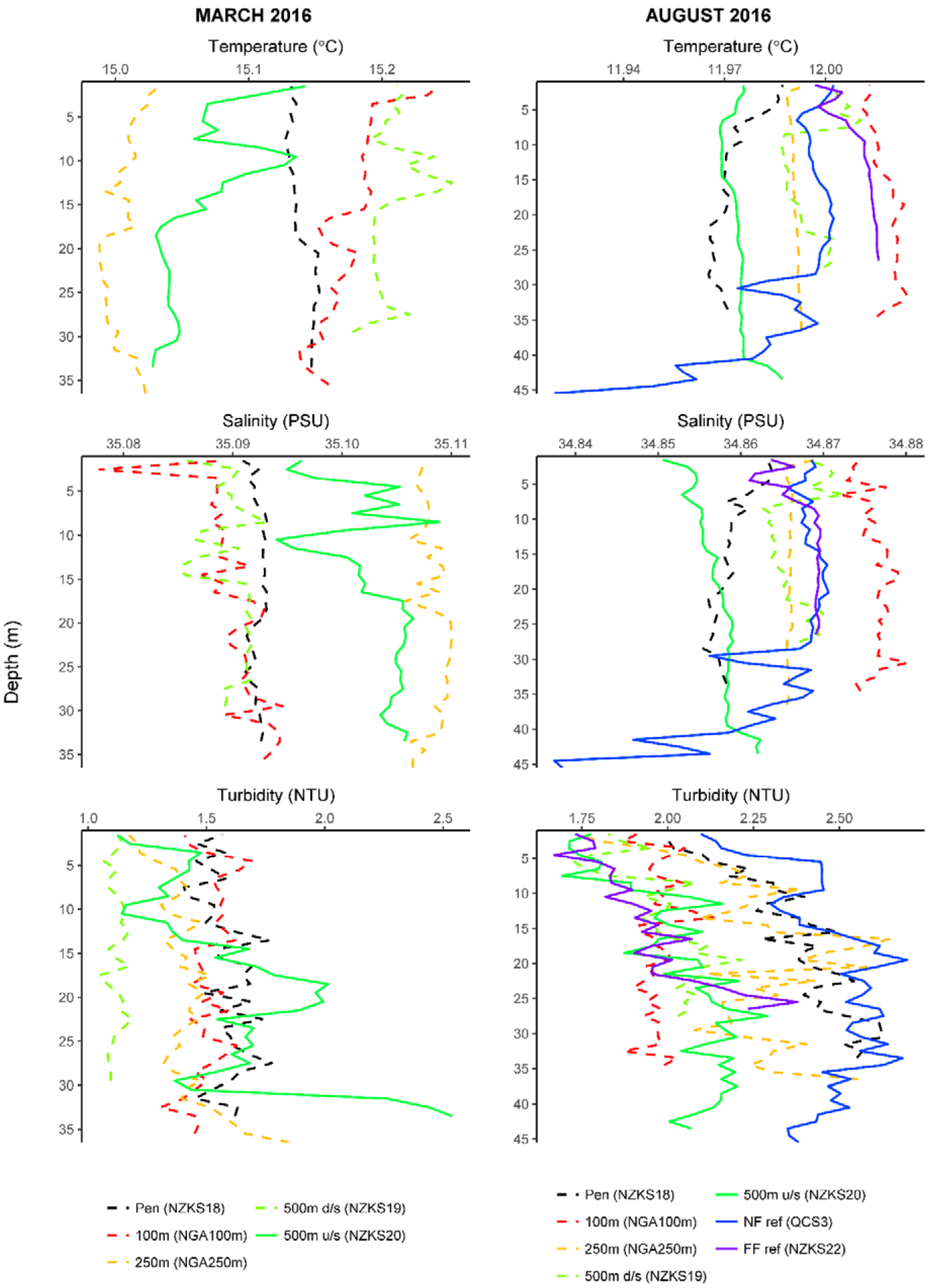


Figure 10. Water column profile salinity (PSU), temperature (°C), and turbidity (NTU) (1m depth binned downcast data) at fine-scale sampling stations (dashed lines) and routine / reference stations (solid lines) in March and August 2016. Data were collected using Cawthron's Seabird 19 CTD).

4.2.3. Nutrients

Nitrogen

All total nitrogen (TN) results from stations > 250 m from the farm were generally within the TN WQS (i.e. ≤ 300 mg-N/m^3) (Table 8). The exception was the near-field reference (NZKS21) which had high TN concentrations on several sampling occasions (January, July, August and November); two of which exceeded 300 mg-N/m^3. Morrisey et al. (2015) showed that background concentrations of TN > 300 mg/m^3 do occur on an annual basis, albeit on 'rare' occasions, and as well as NZKS21, the far-field reference (NZKS22) also often had TN concentrations higher than that recorded at net pen stations.

Although there is no TN threshold beside the net pen, it is worth noting that all results except one sample (in March) were < 300 mg-N/ m^3. As expected, elevated TN concentrations attributable to farming operations were recorded beside the net pen (e.g. March; [Figure 11]), but not on all sampling occasions. The highest net pen concentration of TN was 359 mg-N/ m^3. Interestingly, on some sampling occasions (e.g. January, August, November and December), TN concentrations beside the net pen were actually lower than those recorded at all other sampling stations in that month.

While the farm undoubtedly has localised effects on TN concentrations such as those observed in the fine-scale March sampling (Figure 11), natural variability appears to explain larger fluctuations of TN in the wider area, often exceeding increases in TN attributable to the farm. This has potential to mask smaller increases in TN concentrations around the farm. Because TN exceeded the WQS on only two isolated incidences (and only at the NF-ref), a second-step WQS threshold has not been determined for this nutrient (see Knight et al. 2016).

Looking at concentrations of other nitrogen forms (that have no associated WQS), nitrate (NO_3-N) had a slight peak at 250 m downstream of the net pens in surface samples in March (Figure 11), but the peak was more pronounced in near-bed samples. No peaks were observed outside of 250 m from the net pens. There were no trends observed in nitrite (NO_2-N) concentrations. Slightly elevated surface concentrations of ammonium (NH_4-N) were apparent beside the net pen in the March (23 mg/m^3) and July (11.9 mg/m^3) (Figure 11, Appendix 8), although elevated concentrations (22.9 mg/m^3) were also observed in March at the 500 m upstream station. Other nitrogen analytes, PN and urea (which are not required to be measured under the consent), also showed decreases associated with distance from the net pens, reaching similar levels to reference within 250 m (discussed in Appendix 10). Because urea-N is thought to be less susceptible to phytoplankton uptake as other forms of nitrogen (e.g. ammonium), but showed a similar rate of reduction in concentrations as other nitrogen species, it is likely that physical dispersal (rather than biological activity) is the primary ameliorating factor for marine-farm related nutrients in the water column at NGA.

Increases of nitrogen are well documented around finfish farms (e.g. Buschmann et al. 2007; Wang et al. 2012), and the expected amount of total dissolved nitrogen (TDN) loading from a farm can be estimated (Knight 2016, Appendix 9). Using the month of March at NGA, the average daily feed volume of 4.8 tonnes[9] would result in a total daily load of 410 kg TDN, with an estimated increase of about 25 mg TDN/m^3 beside the net pen (see assumptions in Appendix 9). The observed increase in TDN[10] beside the net pen in March was about 55 mg/m^3 (Figure 11, Appendix 8). Because theoretical assumptions (e.g. an even distribution of fish in the net pen and consistent excretion of nutrients through time) are unlikely to be met, periodic increases of observed dissolved nitrogen could easily deviate from the theoretical estimation.

Table 8. Surface integrated results for total nitrogen (mg/m^3) for all months. Underlined values indicate those above the WQS. NF = near-field, FF = far-field, ref = reference.

	NZKS18	**NZKS19**	**NZKS20**	**NZKS21 (QCS-3)**	**NZKS22**
Month	**Net pen**	**500 m north**	**500 m south**	**NF ref**	**FF ref**
Jan	195.0	219.0	222.0	281.0†	207.0
Feb	212.0	216.0	209.0	231.0	208.0
Mar	358.7*	201.0	240.0*	219.0	283.0*†
Apr	190.0	195.0	172.0	179.0	177.0
May	286.0	264.0	225.0	225.0	184.0
Jun	224.0	235.0	225.0	218.0	254.0
Jul	225.0	213.0	175.3	301.0	229.0
Aug	183.7*	164.3*	163.3*	247.8*	166.0
Sep	256.0	188.0	194.0	261.0	174.0
Oct	191.0	176.0	154.0	209.0	171.0
Nov	200.0	180.0	180.0	310.0	188.0
Dec	211.0	258.0	225.0	232.0	241.0
WQS	**n/a**	**300 mg-N/m^3**			**n/a**

* Mean value across triplicate samples.

†Incorrect values were reported in the previous report (Elvines et al. 2016a).

---

[9] 150 tonnes for the month of March

[10] Increase is relative to average TDN concentrations at > 250 m from the farm (Appendix 8).

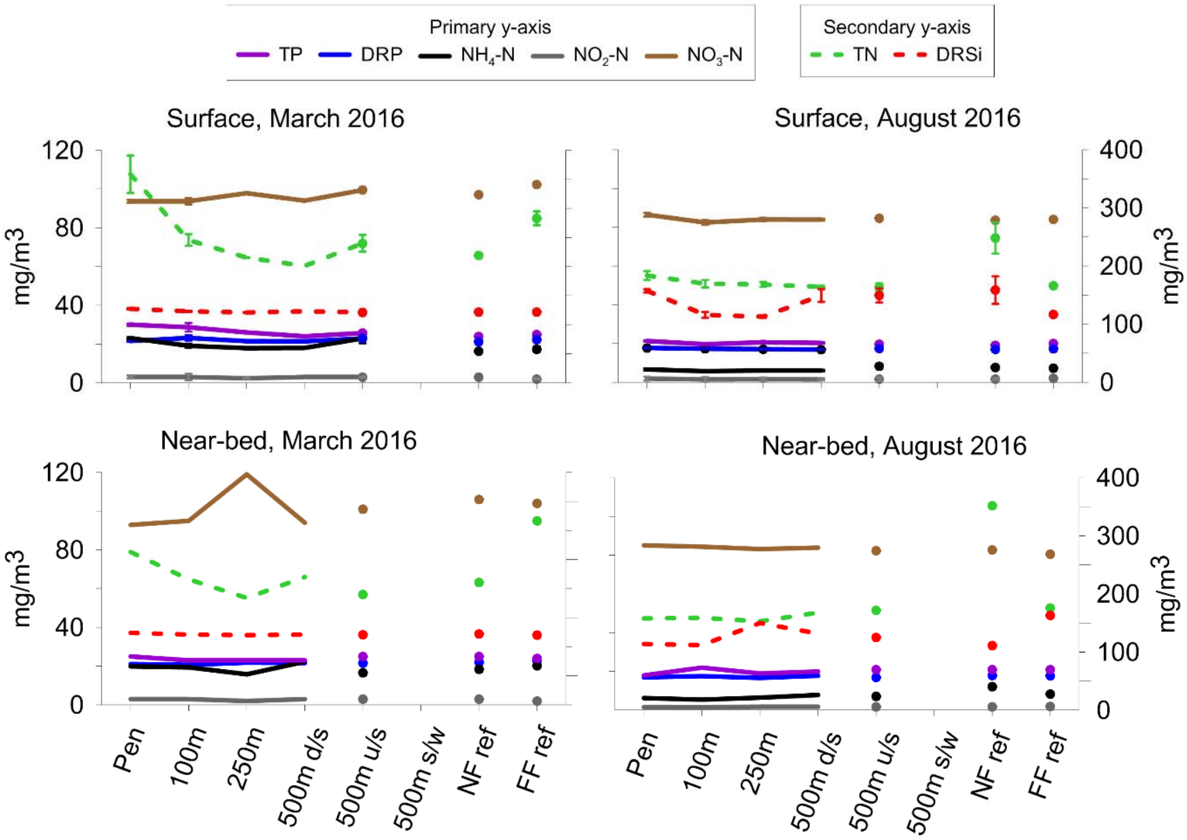


Figure 11. Concentrations (mg/m^3) of nutrients in integrated surface (mean ±SE) and near-bed fine-scale station samples, as well as reference sites for comparison. Note: triplicate samples were taken only for surface integrated samples. d/s = downstream, u/s = upstream, s/w = seaward, NF = near-field, FF = far-field, ref = reference.

Silicate and phosphorus

The 2016 monitoring results show that surface concentrations of phosphorus (dissolved reactive phosphorus: DRP, and total phosphorus: TP) and silicate (dissolved reactive silica: DRSi) are not obviously elevated around the farm (Figure 11, Appendix 8). While the net pen station in August had higher DRSi concentrations than 100 and 250 m downstream, all concentrations were comparable with reference concentrations. Similarly, there do not appear to be large differences in concentrations of phosphorus and silicate in near-bed water samples either in vicinity of the farm or at reference stations.

Changes in these nutrients (i.e. phosphorus and silicate concentrations) can enhance or alter phytoplankton abundance or composition. Silicate is not a by-product of salmon farming, but wide-scale monitoring of silicate (and elemental ratios) is important for understanding potential effects on diatoms. Natural silicate and phosphorus concentrations in Tory Channel are at levels that do not appear to limit diatom growth (see Appendix 8) although silicates are generally lower when compared to concentrations observed in Pelorus Sound (e.g. Elvines et al. 2017). In this context, we recommend silicate sampling focuses only on wide-scale changes.

Periodic increases in phosphorus from the farm are not likely to increase phytoplankton growth because phosphorus is non-limiting, however it is also a component of salmon feed and benthic-pelagic coupling effects from accumulations on the seabed can occur. As such, we recommend only measuring this nutrient (particularly DRP, the bioavailable form) from near-bed samples around the net pen.

Short time-scales for tidal flushing in Tory Channel also make it difficult for phytoplankton to respond measurably to localised increases in nutrients in the main channel area. Therefore, if localised increases in nutrients associated with salmon farms do result in compositional changes to phytoplankton communities, they are likely to occur in other areas of Queen Charlotte Sound that have high connectivity with the farms.

Summary and limitations

Overall, based on the 2016 monitoring results it appears that near-farm mixing properties (and concurrent unmeasured biological factors) were sufficient to reduce farm-related nutrient concentrations to reference levels in proximity to the farm. There were no elevated nutrient concentrations clearly attributable to farm-related effects at stations > 250 m from the farm, consistent with the WQO. However, we note the following limitations (also see Appendix 10) with the existing monitoring approach:

- Nutrient leachate rates from finfish farms are highly variable, occurring as ‘pulses’ of nutrients within a single 24 hr period (Karakassis et al. 2001). Diel patterns in nutrient ‘pulses’ from finfish farms can be related to (but not necessarily coincide with) feed consumption among other factors (Merino et al. 2007 and references therein). This presents an obvious limitation with the current single point-in-time sampling method.
- In order to use nutrient parameters to understand near-farm mixing properties, consideration must be given to biological activity/uptake, which also influences nutrient concentrations/availability. Understanding near-field mixing properties at each farm would be more effective if the *physical* near-field dilution around the farm was quantified.

4.2.4. Chlorophyll-a

In all cases, Chl-*a* concentrations (max. 1.71 mg/m^3) were within the Chl-*a* WQS (i.e. < 3.5 mg/m^3), and ranged from 0.16–1.71 mg/m^3 (Table 9). Concentrations were generally similar in both the surface integrated and the near-bed samples on both fine-scale sampling occasions. In March, Chl-*a* concentrations were elevated in surface and near-bed samples at the net pen station, and marginally elevated at the 100 m downstream station (Figure 12). Given the time-scale of response time for phytoplankton growth (days), it is unlikely to be farm-related.

Table 9. Surface integrated results for chlorophyll-*a* (mg/m^3) from all sampled months in 2016. No values were above the associated WQS. NF = near-field, FF = far-field, ref = reference.

Month	NZKS18	NZKS19	NZKS20	NZKS21 (QCS-3)	NZKS22
	Net pen	**500 m north**	**500 m south**	**NF ref**	**FF ref**
Jan	0.71	0.79	0.38	0.60	0.43
Feb	0.39	0.38	0.39	0.40	0.34
Mar	1.71*	0.52	0.34*	0.39	0.38*
Apr	1.03	0.82	1.13	1.50	1.11
May	0.29	0.24	0.26	0.40	0.22
Jun	0.76	0.45	0.44	0.50	0.43
Jul	0.40	0.30	0.34	0.30	0.34
Aug	0.32*	0.30*	0.32*	0.26*	0.16
Sep	0.74	0.76	0.78	0.80	0.83
Oct	0.59	0.64	0.54	0.80	0.44
Nov	0.77	0.76	0.54	0.60	0.48
Dec	0.90	0.81	0.46	0.60	0.39
WQS			**≤ 3.5 mg/m^3**		

* Mean value across triplicate samples.

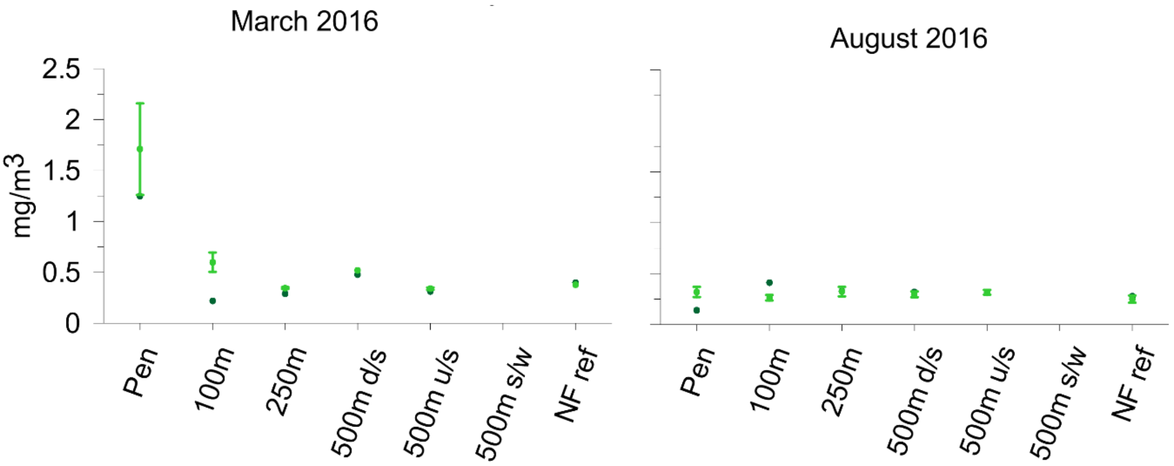


Figure 12. Chlorophyll-*a* (Chl-*a*) concentrations in integrated surface (mean ±SE; light green) and near-bed (dark-green) samples.

4.2.5. Phytoplankton biomass and composition

Estimated phytoplankton biomass values in February, March, July and August (refer Appendix 11) were in the range of 1 to 10 mg C/m^3, with the highest biomass estimates occurring in March. However, biomass estimates in general for all Tory Channel stations were low compared to biomass estimates recorded in other regions of the Marlborough Sounds (e.g. Pelorus Sound, Elvines et al. 2017). The variation in phytoplankton collected over the 2016 sites around the farms is consistent with that presented in the baseline report (Morrisey et al. 2015).

Diatoms were generally the dominant group of phytoplankton, typically accounting for > 70% of the biomass across most sampling months and stations (Table 10). In July, dinoflagellates were seen to represent a slightly higher proportion of the total biomass in the farm samples (NZKS18 and 20) and at the far field station (NZKS22).

While characterisation of the phytoplankton communities interacting with the farm may provide a more comprehensive record for the region, a farm-related effect would be most likely to manifest at some distance from the farm[11]. As such, we question the utility of small spatial-scale phytoplankton data from around the farm.

---

[11] Based on the mechanistic linkage between nitrogen released from the salmon farm and the time scales required for a phytoplankton response (e.g. 1-2 days, see Buschmann et al. 2007).

Table 10. Phytoplankton composition (as a percentage of total phytoplankton biomass; see Appendix 11) recorded in 2016. NF = near-field, FF = far-field, ref = reference, d/s = downstream.

	NZKS18	NGA100	NGA250	NZKS19	NZKS20	NZKS21	NZKS22
	Net pen	100 m d/s	250 m d/s	500 m south	500 m north	(QCS-3) NF ref	FF ref
Feb 2016							
Diatom	74.6%	-	-	100.0%	58.5%	30.0%	67.1%
Dinoflagellate	0.0%	-	-	0.0%	38.0%	7.6%	11.7%
Other	25.4%	-	-	0.0%	3.4%	62.4%	21.3%
Mar 2016							
Diatom	91.3%	99.4%	97.7%	98.4%	78.8%	70.9%	88.5%
Dinoflagellate	8.4%	0.6%	2.3%	1.0%	6.7%	0.0%	0.0%
Other	0.3%	0.0%	0.0%	0.6%	14.5%	29.1%	11.5%
July 2016							
Diatom	47.8%	-	-	100.0%	58.2%	20.5%	74.2%
Dinoflagellate	29.8%	-	-	0.0%	40.7%	7.1%	25.8%
Other	22.4%	-	-	0.0%	1.1%	72.4%	0.0%
August 2016							
Diatom	100.0%	32.1%	95.7%	100.0%	100.0%	100.0%	92.3%
Dinoflagellate	0.0%	0.0%	4.3%	0.0%	0.0%	0.0%	7.7%
Other	0.0%	67.9%	0.0%	0.0%	0.0%	0.0%	0.0%

5. SUMMARY OF FINDINGS

Overall, the results of the 2016-17 Ngamahau Bay salmon farm annual monitoring are as follows, with key findings italicised:

- *No biological effects are expected from copper or zinc in the sediments.*

  A slight elevation in zinc concentrations is evident.
- *The levels of enrichment within all monitoring zones were within the EQS.*

  Moderate levels of enrichment were observed beneath the pens, and at the 75 N station. The 300 S station showed a fertilisation effect (minor enrichment), while the 300 N station did not show any signs of enrichment.
- *No chlorophyll-a (Chl-a) results exceeded the water quality standards (WQS), nor did dissolved oxygen (DO) saturations beside the net pens.*

  Reduced DO saturations and elevated total nitrogen (TN) and Chl-*a* concentrations were evident at the net pen station on some sampling occasions. While these changes in TN and DO are likely to be farm-related, the same cannot be said for Chl-*a*. With one exception, Chl-*a* concentrations were less than half the WQS in all samples throughout the year.
- With two exceptions, TN concentrations were within the TN WQS.

  The two exceedances occurred at the near-field reference station on two isolated occasions. The frequency at which these ‘exceedances’ occurred is in line with that observed in baseline data.
- *DO saturations outside of 250 m from the net pens were often below the ‘first step’ threshold for the DO WQS in 14 samples, and were often (marginally) lower than the 1.2% threshold second-step WQS which considers reference DO saturations.*

  There is no evidence to suggest the lower DO saturations were farm-related.
- *Elevated concentrations of TN, PN, NH_4-N, NO_3-N and urea-N were evident ≤ 250 m of the farm, but beyond 250 m were similar to reference concentrations.*

  The high current flows and associated mixing/dilution appear to be the primary ameliorating factor at the NGA farm site.
- *Obvious changes in silicate, phosphorus and chlorophyll-a concentrations, as well as phytoplankton biomass and community composition were not evident around the farm site.*

6. RECOMMENDATIONS

Based on the results of the 2016-17 Ngamahau Bay salmon farm annual monitoring, we recommend the following:

- Because the current WQS do not capture the full spectrum of natural DO fluctuations in Tory Channel, we recommend revision of the DO WQS for the area.
- We recommend exclusion of the following parameters from fine-scale water column monitoring (condition 65e):
  - Chlorophyll-*a*
  - Phytoplankton biomass and community composition
  - Silicate (DRSi).

  Results from these parameters are not expected to, and have not shown, localised farm effects. As such, they do not provide useful information on farm-specific near-farm mixing properties (Condition 43d, 55e and 65e).
- Because phosphorus is ubiquitous in Pelorus Sound, we recommend fine-scale sampling of this nutrient is limited only to near-bed samples around the net pen where potential farm-related effects are likely to be detected.
- Concentrations of DRSi should continue to be monitored at the reference station/s. However, as the salmon farm is not a source of silicate, and concentrations do not appear to be affected by the farm, we recommend this nutrient (DRSi), as well as phosphorus (TP and DRP), are not continued in full-suite monitoring (as part of condition 65c). Flexibility to exclude these nutrients appears to be provided for under Condition 62c and 65c. We also recommend phytoplankton biomass and composition is excluded from ongoing full-suite sampling by the same rationale.
- In lieu of the water column sampling as above, we recommend:
  - Ongoing inclusion of urea-N and PN in fine-scale monitoring for the next monitoring year, including measuring these nutrients also at 500 m and reference stations.
  - A one-off sampling study to investigate diel variation in nutrient (and DO) concentrations around the net pens. This would provide valuable information on the full amount of variability (e.g. episodic emissions from the fish) occurring at the site, allowing a more meaningful estimate of effects to the wider system. Data collected using this technique would better align with achieving the objectives in conditions 43d, 55e and 65e.
  - A physical mixing study using an artificial dye tracer. This would be more suited to determining near-farm mixing properties than the current nutrient tracking method, and thus better aligns with achieving the objectives in conditions 43d, 55e and 65e. The study could be done under a range of mixing conditions (slack tide vs. running tide, low- vs. moderate-wind) as a one-off at each farm site. Results could be used to apply context to results from future

net pen samples, thereby reducing sampling effort and the need for repeated fine-scale measurements around every farm. The study would utilise fine-scale nutrient results collected to date to validate the completed ‘dispersion’ model.

7. REFERENCES

ANZECC 2000. Australian and New Zealand guidelines for fresh and marine water quality 2000 Volume 1. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Buschmann A, Costa-Pierce BA, Cross S, Iriarte JL, Olsen Y, Reid G 2007. Nutrient Impacts of farmed Atlantic salmon (*Salmo salar*) on pelagic ecosystems and implications for carrying capacity, Report for World Wildlife Fund Salmon Aquaculture Dialogue by the Technical working Group on Nutrients and Carrying Capacity.

Cornet-Barthaux V, Armand L, Queguiner B 2007. Biovolume and biomass estimates of key diatoms in the Southern Ocean. Aquatic Microbial Ecology 48 (3): 295-308.

Dunmore R 2017. Reef environmental monitoring results for the New Zealand King Salmon Company Ltd salmon farms: 2016. Prepared for New Zealand King Salmon Limited. Cawthron Report No. 3009. XX p. plus appendices.

Elvines D, Knight B, Taylor D. 2016a. Environmental impacts of the Ngamahau Bay Salmon Farm: annual monitoring 2015 - 2016. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2808. 30 p. plus appendices

Elvines D, Taylor D, Knight B, Dunmore R 2016b. Marine Environmental Monitoring – Adaptive Management Plan 2016 – 2017, for salmon farms Ngamahau, Kopaua, and Waitata - updated. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2862a. 31 p. plus appendices.

Elvines D, Knight B, Berthelsen A, Fletcher L 2017. Waitata Reach salmon farm: annual monitoring report (2016–2017). Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2999. 39 p. plus appendices.

Hillebrand H, Dürselen CD, Kirschtel D, Pollingher D, Zohary T 1999. Biovolume calculation for pelagic and benthic microalgae. Journal of Phycology, 35: 403-424.

Karlson B, Cusack C, Bresnan E 2010. Microscopic and molecular methods for quantitative phytoplankton analysis. UNESCO. 113 p.

Keeley N 2012. Assessment of enrichment stage and compliance for salmon farms–2011. Prepared for New Zealand King Salmon Company Limited. Report No. 2080. 15 p.

Keeley N, Macleod C, Forrest B 2012. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators (12) 154-166.

Karakassis I, Tsapakis M, Hatziyanni E, Pitta P 2001. Diel variation of nutrients and chlorophyll in sea bream and sea bass cages in the Mediterranean. Fresenius Environmental Bulletin 10 (3): 278-283.

Knight B 2012. Statement of evidence of Benjamin Robert Knight in Relation to Water Column Effects for the New Zealand King Salmon Co. Limited., in the matter of a Board of Inquiry appointed under section 149J of the Resource Management Act 1991 to consider The New Zealand King Salmon Co. Limited's private plan change requests to the Marlborough Sounds Resource Management Plan and resource consent applications for marine farming at nine sites located in the Marlborough Sounds, dated 21 June 2012, 54p.

Knight B 2016. Peer review of the Marlborough Sounds Biophysical Model Predictions. Prepared for Ministry for Primary Industries. Cawthron Report No. 2923. 19 p.

Knight B, Elvines D, Taylor D 2016. 2015/2016 Annual Water Quality Recommendations for Ngamahau and Te Pangu Salmon Farms. Prepared for NZ King Salmon Limited. Cawthron Report No. 2876. 14 p.

Menden-Deuer S, Lessard EJ 2000. Carbon to volume relationships for dinoflagellates, diatoms, and other protist plankton. Limnology and Oceanography 45 (3): 569-579.

Merino GE, Piedrahita RH, Conklin DE 2007. Ammonia and urea excretion rates of California halibut (*Paralichthys californicus*, Ayres) under farm-like conditions. Aquaculture 271 (1): 227-243.

Morrisey D, Stenton-Dozey J, Broekhuizen N, Anderson T, Brown S, Plew D 2015. Baseline monitoring report for new salmon farm sites, Marlborough Sounds. NIWA Client Report No. NEL-2014-020. Prepared for the New Zealand King Salmon. 247 p.

Ministry of Primary Industries (MPI). 2015. Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Part 1: Benthic environmental quality standards and monitoring protocol (Version 1.0 January 2015). Prepared for the Ministry for Primary Industries by the Benthic Standards Working Group (Keeley, N., Gillard, M., Broekhuizen, N., Ford, R., Schuckard, R., & Urlich, S.).

Rott E 1981. Some results from phytoplankton counting intercalibrations. Schweizerische Zeitschrift für Hydrologie 43: 1.

Twomey J, Pierhler M, Paerl H 2005. Phytoplankton uptake of ammonium, nitrate and urea in the Neuse River estuary, NC, USA. Hydrobiologia 533: 123–134.

Wang X, Olsen LM, Reitan KI, Olsen Y 2012. Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. Aquaculture Environment Interactions 2.3: 267-283.

Zeldis JR, Howard-Williams C, Carter CM, Schiel DR 2008. ENSO and riverine control of nutrient loading, phytoplankton biomass and mussel aquaculture yield in Pelorus Sound, New Zealand. Marine Ecology Progress Series 371: 131–142.

8. APPENDICES

Appendix 1. Laboratory analytical methods for sediment samples (March 2017) processed by Hill Laboratories (a), Cawthron Institute (b), and NIWA (c).

Analyte	Method	Default detection limit
Sediment samples		
Organic matter (as ash-free dry weight) [a]	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 22nd ed. 2012. Calculation: 100 – Ash (dry wt).	0.04 g/100 g
Total recoverable copper & zinc [a]	Dried sample. Nitric/ hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2.	0.2 - 2 mg/kg (Cu) 0.4 - 4 mg/kg (Zn)
Total zinc [c]	Pressed Powder / X-ray fluorescence spectrometry	
Total free sulphides [b]	Cawthron Protocol 60.102. Sample solubilised in high pH solution with chelating agent and anti-oxidant. Measured in millivolt (mV) using a sulphide specific electrode and calibrated using a sulphide standard.	
Water samples		
Chlorophyll-*a* (c) (chl-a)	Acetone pigment extraction, spectrofluorometric measurement. A*10200H.	0.1 mg/m^3
Dissolved reactive silicon (c) (DRSi)	Molybdosilicate / ascorbic acid reduction. APHA4500Si.	1 mg/m^3
Total phosphorus (c) (TP)	Persulphate digest, molybdenum blue FIA. Lachat.	1 mg/m^3
Urea nitrogen(c) (Urea-N)	Automated diacetyl-monoxime colorimetry. MSeawater.	1 mg/m^3
Nitrite nitrogen(c) (NO$_2$-N)	Diazotization with sulphanilamide and NEDD. Lachat.	1 mg/m^3
Nitrate and nitrite nitrogen (c) (NO$_3$-N)	DRP,NH4-N,NO3-N, Simultaneous Auto-analysis. Astoria.	1 mg/m^3
Ammonium nitrogen (c) (NH$_4$-N)	DRP,NH4-N,NO3-N, Simultaneous Auto-analysis. Astoria.	1 mg/m^3
Dissolved reactive phosphorus (c) (DRP)	DRP,NH4-N,NO3-N, Simultaneous Auto-analysis. Astoria.	1 mg/m^3
Total nitrogen (c) (TN)	Persulphate digest, auto cadmium reduction, FIA. Lachat.	10 mg/m^3
Particulate nitrogen (c) (PN)	Calculation of TN – TDN (TDN determined by persulphate digest, auto cadmium reduction, FIA). Lachat.	10 mg/m^3
Dissolved inorganic nitrogen (DIN)	Derived using NO$_3$-N + NO$_2$-N + NH$_4$-N.	
Phytoplankton biovolume (b)	From Morrisey et al. (2015): Estimated for each taxon using formulae representing the geometrical solids that approximated cell shape (Rott 1981, Hillebrand et al. 1999).	
Phytoplankton carbon biomass (b)	From Morrisey et al. (2015): Cell numbers and biovolumes were used to calculate cell carbon using regression equations of Meden-deuer and Lessard (2000) for dinoflagellates and cyanobacteria, and that of Cornet-Barthaux et al. (2007) for diatoms.	

Appendix 2. Conditions 65c and 65e for water column monitoring.

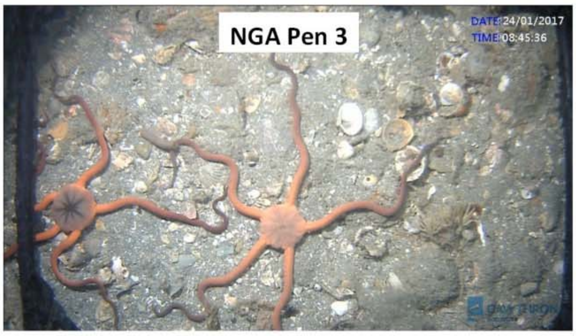
Condition 65(c)

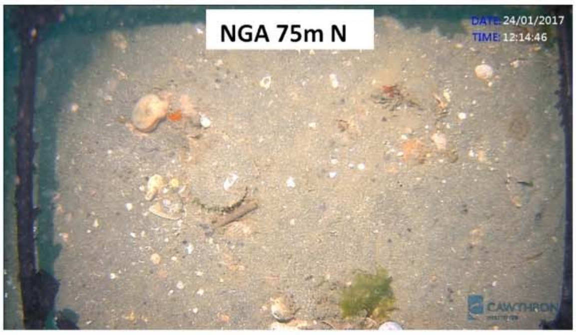
> *"Monitoring in order to determine compliance with the WQS in Condition 44. Throughout the term of the consent this shall include long-term water column monitoring for nutrient (NH4-N, NO3-N, NO2-N, DRP, Si, TN and TP) and chlorophyll a concentrations, phytoplankton composition and biomass, salinity, clarity, temperature, turbidity and dissolved oxygen (DO) at locations stipulated in Condition 63c. The precise location of the long- term monitoring stations and the range of specific nutrient parameters monitored may, however, be adjusted over time in response to monitoring results and/or in response to modelling considered necessary by the Peer Review Panel in accordance with Condition 70c. This monitoring is to be undertaken at least four times per year with at least two surveys occurring during mid-summer periods of highest salmon feed discharge rates and at least two surveys occurring periods associated with winter/spring and/or autumn diatom maxima."*

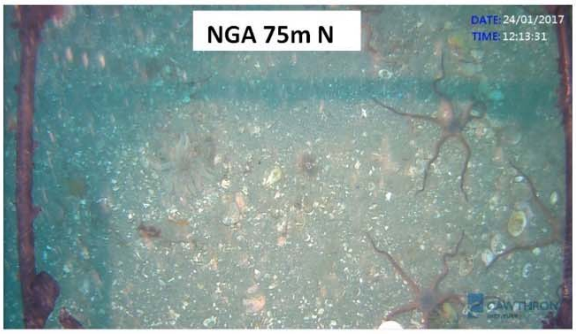
Condition 65e)

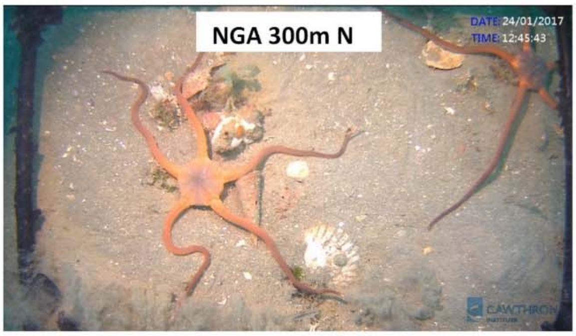
> *"Targeted water column surveys to quantify the localised effect of the marine farm on surrounding water quality, for the purpose of obtaining information regarding marine farm-specific, near-farm mixing properties in order to provide a context for evaluating compliance with the WQS in Condition 44. This shall involve a series of fine-scale surveys in the vicinity of the marine farm (within 1km from the net pens) measuring: salinity, clarity, temperature, chlorophyll a, turbidity, dissolved oxygen (DO), nutrient concentrations (NH4-N, NO3-N, NO2-N, DRP, Si, TN and TP) phytoplankton composition and biomass along transects that move away from the marine farm and span potential nutrient gradients. The surveys shall be undertaken at least twice per year and continued for at least two years after the marine farm has reached stable maximum feed discharge levels and no future increases are proposed."*

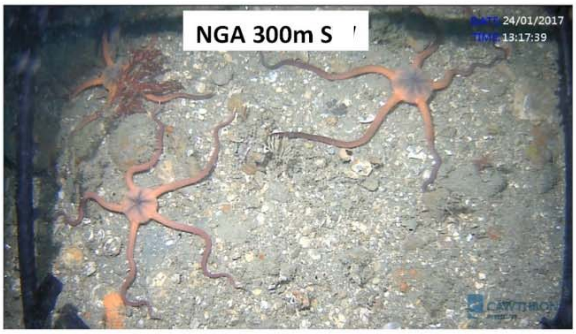
Appendix 3. Representative images of the seafloor at each soft sediment sampling station (January 2017).

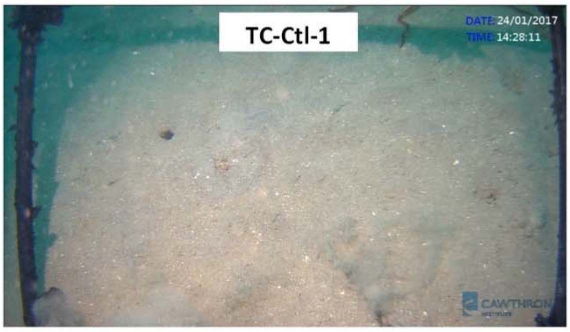


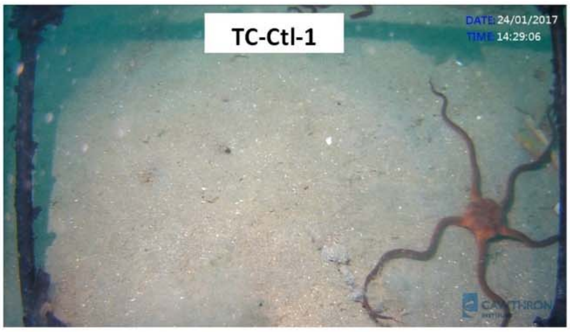


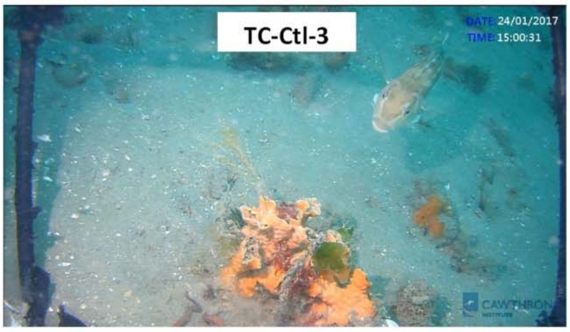


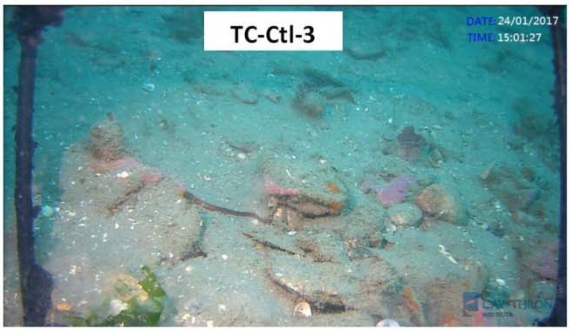


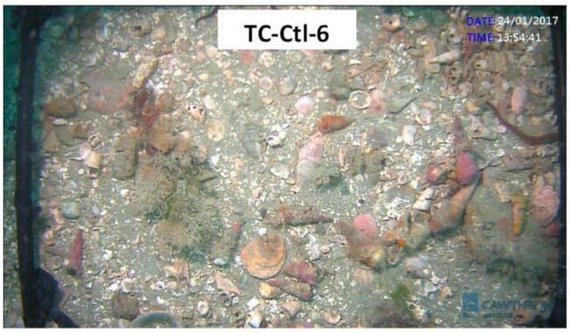


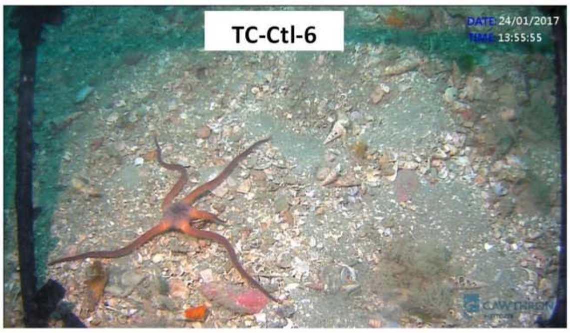

TC-Ctl-1
DATE: 24/01/2017
TIME: 14:28:11


TC-Ctl-1
DATE: 24/01/2017
TIME: 14:29:06

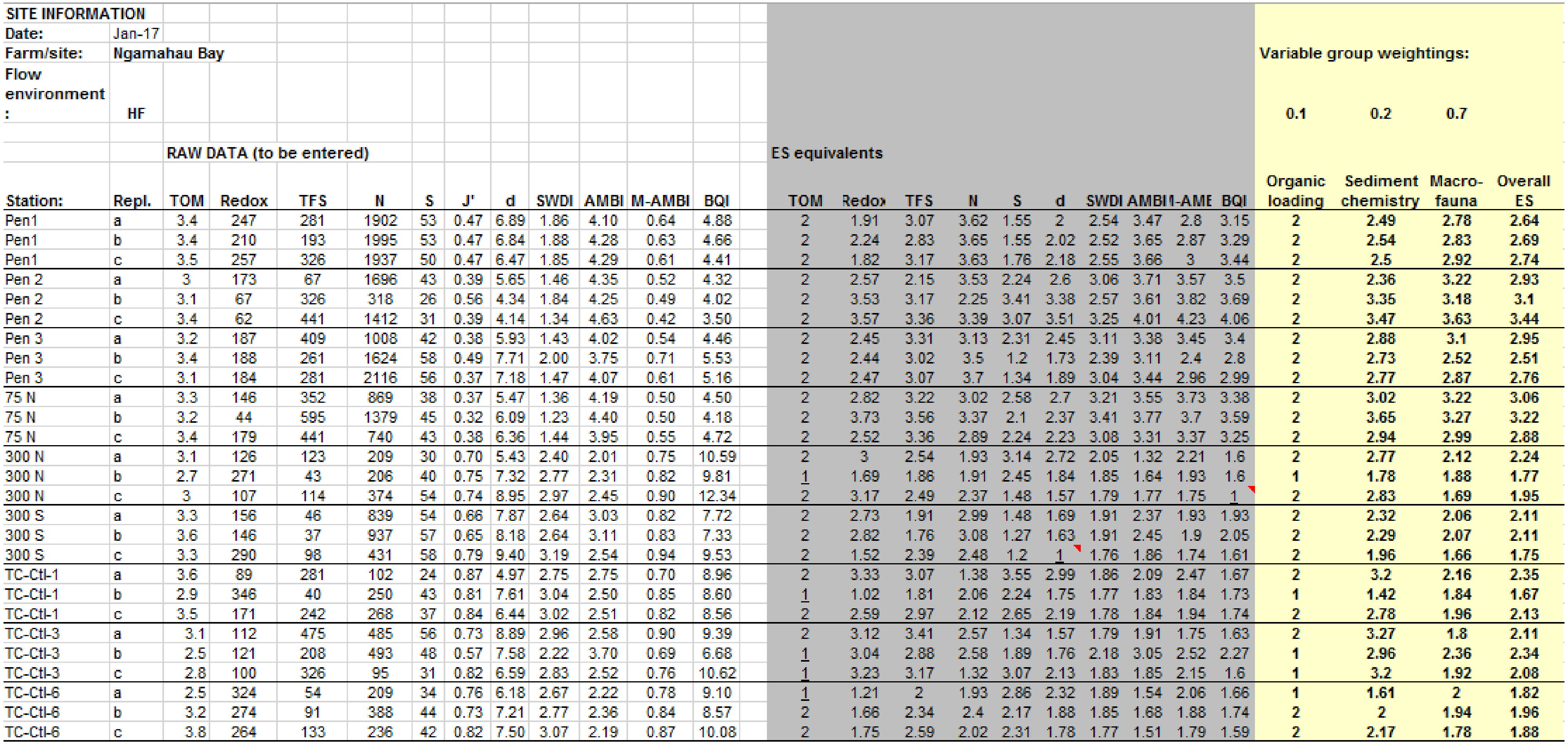

TC-Ctl-3
DATE: 24/01/2017
TIME: 15:00:31


TC-Ctl-3
DATE: 24/01/2017
TIME: 15:01:27


TC-Ctl-6
DATE: 24/01/2017
TIME: 13:54:41


TC-Ctl-6
DATE: 24/01/2017
TIME: 13:55:55

Appendix 4. Detailed enrichment stage (ES) calculations for each station at the Ngamahau Bay salmon farm, January 2017. For details about how these values were calculated, see MPI (2015). Underlined text are cases where best professional judgement (BPJ; Keeley et al. 2012) was used.



SITE INFORMATION
Date: Jan-17
Farm/site: Ngamahau Bay
Flow environment: HF

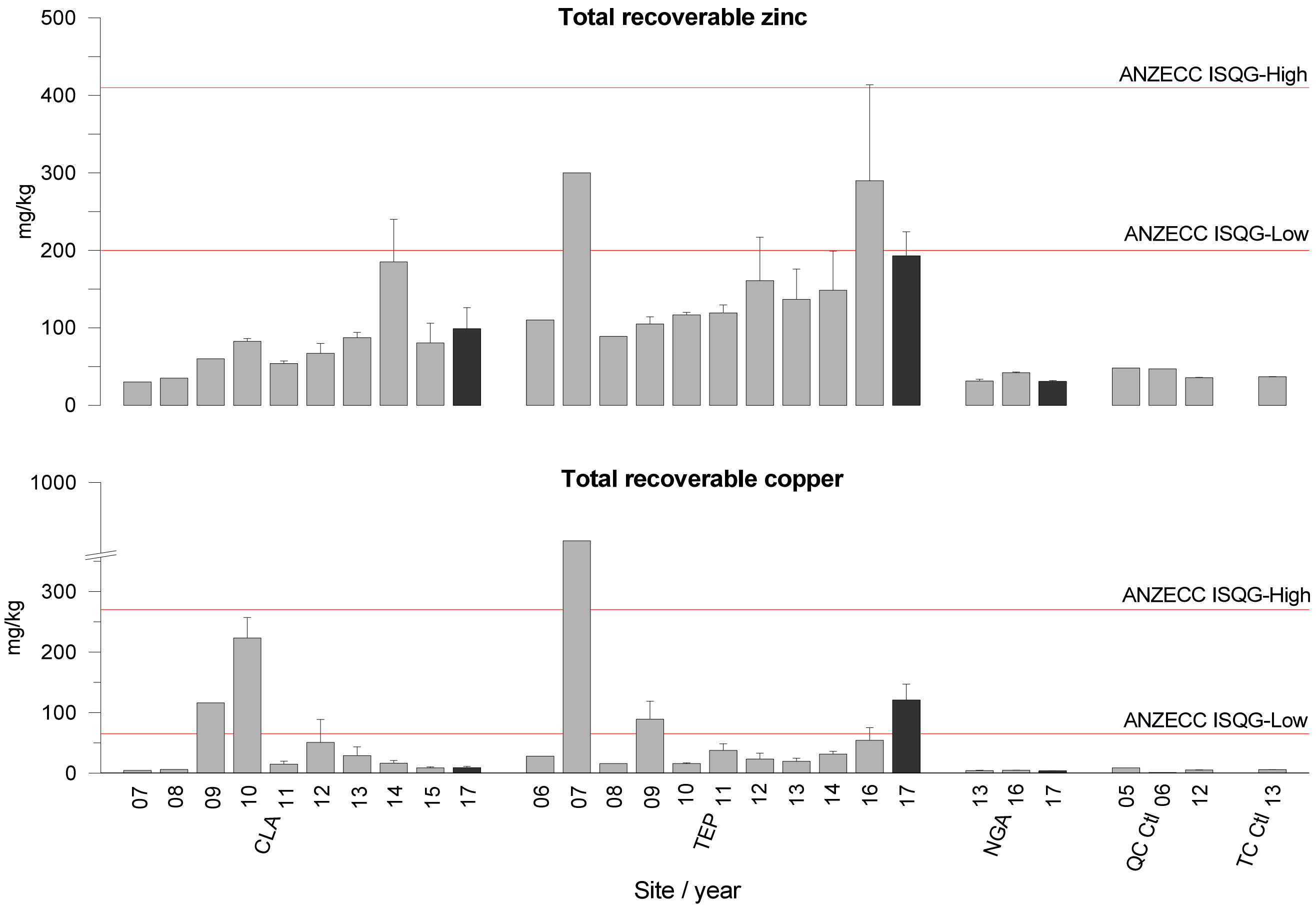
Variable group weightings:

		RAW DATA (to be entered)											ES equivalents										0.1	0.2	0.7	
Station:	**Repl.**	**TOM**	**Redox**	**TFS**	**N**	**S**	**J'**	**d**	**SWDI**	**AMBI**	**M-AMBI**	**BQI**	**TOM**	**Redox**	**TFS**	**N**	**S**	**d**	**SWDI**	**AMBI**	**I-AMB**	**BQI**	**Organic loading**	**Sediment chemistry**	**Macro-fauna**	**Overall ES**
Pen1	a	3.4	247	281	1902	53	0.47	6.89	1.86	4.10	0.64	4.88	2	1.91	3.07	3.62	1.55	2	2.54	3.47	2.8	3.15	2	2.49	2.78	2.64
Pen1	b	3.4	210	193	1995	53	0.47	6.84	1.88	4.28	0.63	4.66	2	2.24	2.83	3.65	1.55	2.02	2.52	3.65	2.87	3.29	2	2.54	2.83	2.69
Pen1	c	3.5	257	326	1937	50	0.47	6.47	1.85	4.29	0.61	4.41	2	1.82	3.17	3.63	1.76	2.18	2.55	3.66	3	3.44	2	2.5	2.92	2.74
Pen 2	a	3	173	67	1696	43	0.39	5.65	1.46	4.35	0.52	4.32	2	2.57	2.15	3.53	2.24	2.6	3.06	3.71	3.57	3.5	2	2.36	3.22	2.93
Pen 2	b	3.1	67	326	318	26	0.56	4.34	1.84	4.25	0.49	4.02	2	3.53	3.17	2.25	3.41	3.38	2.57	3.61	3.82	3.69	2	3.35	3.18	3.1
Pen 2	c	3.4	62	441	1412	31	0.39	4.14	1.34	4.63	0.42	3.50	2	3.57	3.36	3.39	3.07	3.51	3.25	4.01	4.23	4.06	2	3.47	3.63	3.44
Pen 3	a	3.2	187	409	1008	42	0.38	5.93	1.43	4.02	0.54	4.46	2	2.45	3.31	3.13	2.31	2.45	3.11	3.38	3.45	3.4	2	2.88	3.1	2.95
Pen 3	b	3.4	188	261	1624	58	0.49	7.71	2.00	3.75	0.71	5.53	2	2.44	3.02	3.5	1.2	1.73	2.39	3.11	2.4	2.8	2	2.73	2.52	2.51
Pen 3	c	3.1	184	281	2116	56	0.37	7.18	1.47	4.07	0.61	5.16	2	2.47	3.07	3.7	1.34	1.89	3.04	3.44	2.96	2.99	2	2.77	2.87	2.76
75 N	a	3.3	146	352	869	38	0.37	5.47	1.36	4.19	0.50	4.50	2	2.82	3.22	3.02	2.58	2.7	3.21	3.55	3.73	3.38	2	3.02	3.22	3.06
75 N	b	3.2	44	595	1379	45	0.32	6.09	1.23	4.40	0.50	4.18	2	3.73	3.56	3.37	2.1	2.37	3.41	3.77	3.7	3.59	2	3.65	3.27	3.22
75 N	c	3.4	179	441	740	43	0.38	6.36	1.44	3.95	0.55	4.72	2	2.52	3.36	2.89	2.24	2.23	3.08	3.31	3.37	3.25	2	2.94	2.99	2.88
300 N	a	3.1	126	123	209	30	0.70	5.43	2.40	2.01	0.75	10.59	2	3	2.54	1.93	3.14	2.72	2.05	1.32	2.21	1.6	2	2.77	2.12	2.24
300 N	b	2.7	271	43	206	40	0.75	7.32	2.77	2.31	0.82	9.81	1	1.69	1.86	1.91	2.45	1.84	1.85	1.64	1.93	1.6	1	1.78	1.88	1.77
300 N	c	3	107	114	374	54	0.74	8.95	2.97	2.45	0.90	12.34	2	3.17	2.49	2.37	1.48	1.57	1.79	1.77	1.75	1	2	2.83	1.69	1.95
300 S	a	3.3	156	46	839	54	0.66	7.87	2.64	3.03	0.82	7.72	2	2.73	1.91	2.99	1.48	1.69	1.91	2.37	1.93	1.93	2	2.32	2.06	2.11
300 S	b	3.6	146	37	937	57	0.65	8.18	2.64	3.11	0.83	7.33	2	2.82	1.76	3.08	1.27	1.63	1.91	2.45	1.9	2.05	2	2.29	2.07	2.11
300 S	c	3.3	290	98	431	58	0.79	9.40	3.19	2.54	0.94	9.53	2	1.52	2.39	2.48	1.2	1	1.76	1.86	1.74	1.61	2	1.96	1.66	1.75
TC-Ctl-1	a	3.6	89	281	102	24	0.87	4.97	2.75	2.75	0.70	8.96	2	3.33	3.07	1.38	3.55	2.99	1.86	2.09	2.47	1.67	2	3.2	2.16	2.35
TC-Ctl-1	b	2.9	346	40	250	43	0.81	7.61	3.04	2.50	0.85	8.60	1	1.02	1.81	2.06	2.24	1.75	1.77	1.83	1.84	1.73	1	1.42	1.84	1.67
TC-Ctl-1	c	3.5	171	242	268	37	0.84	6.44	3.02	2.51	0.82	8.56	2	2.59	2.97	2.12	2.65	2.19	1.78	1.84	1.94	1.74	2	2.78	1.96	2.13
TC-Ctl-3	a	3.1	112	475	485	56	0.73	8.89	2.96	2.58	0.90	9.39	2	3.12	3.41	2.57	1.34	1.57	1.79	1.91	1.75	1.63	2	3.27	1.8	2.11
TC-Ctl-3	b	2.5	121	208	493	48	0.57	7.58	2.22	3.70	0.69	6.68	1	3.04	2.88	2.58	1.89	1.76	2.18	3.05	2.52	2.27	1	2.96	2.36	2.34
TC-Ctl-3	c	2.8	100	326	95	31	0.82	6.59	2.83	2.52	0.76	10.62	1	3.23	3.17	1.32	3.07	2.13	1.83	1.85	2.15	1.6	1	3.2	1.92	2.08
TC-Ctl-6	a	2.5	324	54	209	34	0.76	6.18	2.67	2.22	0.78	9.10	1	1.21	2	1.93	2.86	2.32	1.89	1.54	2.06	1.66	1	1.61	2	1.82
TC-Ctl-6	b	3.2	274	91	388	44	0.73	7.21	2.77	2.36	0.84	8.57	2	1.66	2.34	2.4	2.17	1.88	1.85	1.68	1.88	1.74	2	2	1.94	1.96
TC-Ctl-6	c	3.8	264	133	236	42	0.82	7.50	3.07	2.19	0.87	10.08	2	1.75	2.59	2.02	2.31	1.78	1.77	1.51	1.79	1.59	2	2.17	1.78	1.88

Appendix 5. Summary of the average (SE) sediment physical and chemical properties, macrofauna variables and calculated indices for the Ngamahau Bay salmon farm stations during the January 2017 monitoring survey.

		Units	Pen1	Pen 2	Pen 3	75m N	300m N	300m S	TC Ctl 1	TC Ctl 2	TC Ctl 3
	Depth	m	32	30	32	20	25	39	18	31	30
Sediments	AFDW	%	3.4 (0)	3.2 (0.1)	3.2 (0.1)	3.3 (0.1)	2.9 (0.1)	3.4 (0.1)	3.3 (0.2)	2.8 (0.2)	3.2 (0.4)
	Redox	Eh_{NHE}, mV	238 (14)	101 (36)	186.3 (1)	123 (40)	168 (52)	197 (46)	202 (76)	111 (6)	287 (19)
	Sulphides*	µM	267 (40)	278 (110)	317 (46)	463 (71)	93 (25)	61 (19)	188 (74)	336 (77)	93 (23)
	Bacterial mat	-	No	No	No	No	No	No	No	No	No
	Out-gassing	-	No	No	No	No	No	No	No	No	No
	Odour	-	Mild	Mild	Mild	No	No	No	No	No	No
macrofauna statistics	Abundance	No./core	1945 (27)	1142 (420)	1583 (321)	996 (195)	263 (56)	736 (155)	207 (53)	358 (131)	278 (56)
	No. taxa	No./core	52 (1)	33.3 (5)	52 (5)	42 (2.1)	41.3 (7)	56.3 (1.2)	34.7 (5.6)	45 (7.4)	40 (3.1)
	Evenness	Stat.	0.5 (0)	0.4 (0.1)	0.4 (0)	0.4 (0)	0.7 (0)	0.7 (0)	0.8 (0)	0.7 (0.1)	0.8 (0)
	Richness	Stat.	6.7 (0.1)	4.7 (0.5)	6.9 (0.5)	6 (0.3)	7.2 (1)	8.5 (0.5)	6.3 (0.8)	7.7 (0.7)	7 (0.4)
	SWDI	Index	1.9 (0)	1.5 (0.2)	1.6 (0.2)	1.3 (0.1)	2.7 (0.2)	2.8 (0.2)	2.9 (0.1)	2.7 (0.2)	2.8 (0.1)
	AMBI	Index	4.2 (0.1)	4.4 (0.1)	3.9 (0.1)	4.2 (0.1)	2.3 (0.1)	2.9 (0.2)	2.6 (0.1)	2.9 (0.4)	2.3 (0.1)
	M-AMBI	Index	0.6 (0)	0.5 (0)	0.6 (0)	0.5 (0)	0.8 (0)	0.9 (0)	0.8 (0)	0.8 (0.1)	0.8 (0)
	BQI	Index	4.7 (0.1)	3.9 (0.2)	5 (0.3)	4.5 (0.2)	10.9 (0.7)	8.2 (0.7)	8.7 (0.1)	8.9 (1.2)	9.3 (0.4)

Appendix 6. Average sediment total recoverable copper and zinc concentrations beneath the Tory Channel NZ King Salmon farms and two reference stations (TC = Tory Channel, QC = Queen Charlotte, Ctl = control). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low trigger levels.



Appendix 7. Comparison of CTD data collected concurrently at two different sampling stations by Cawthron Institute and MDC instruments in March and August 2016.

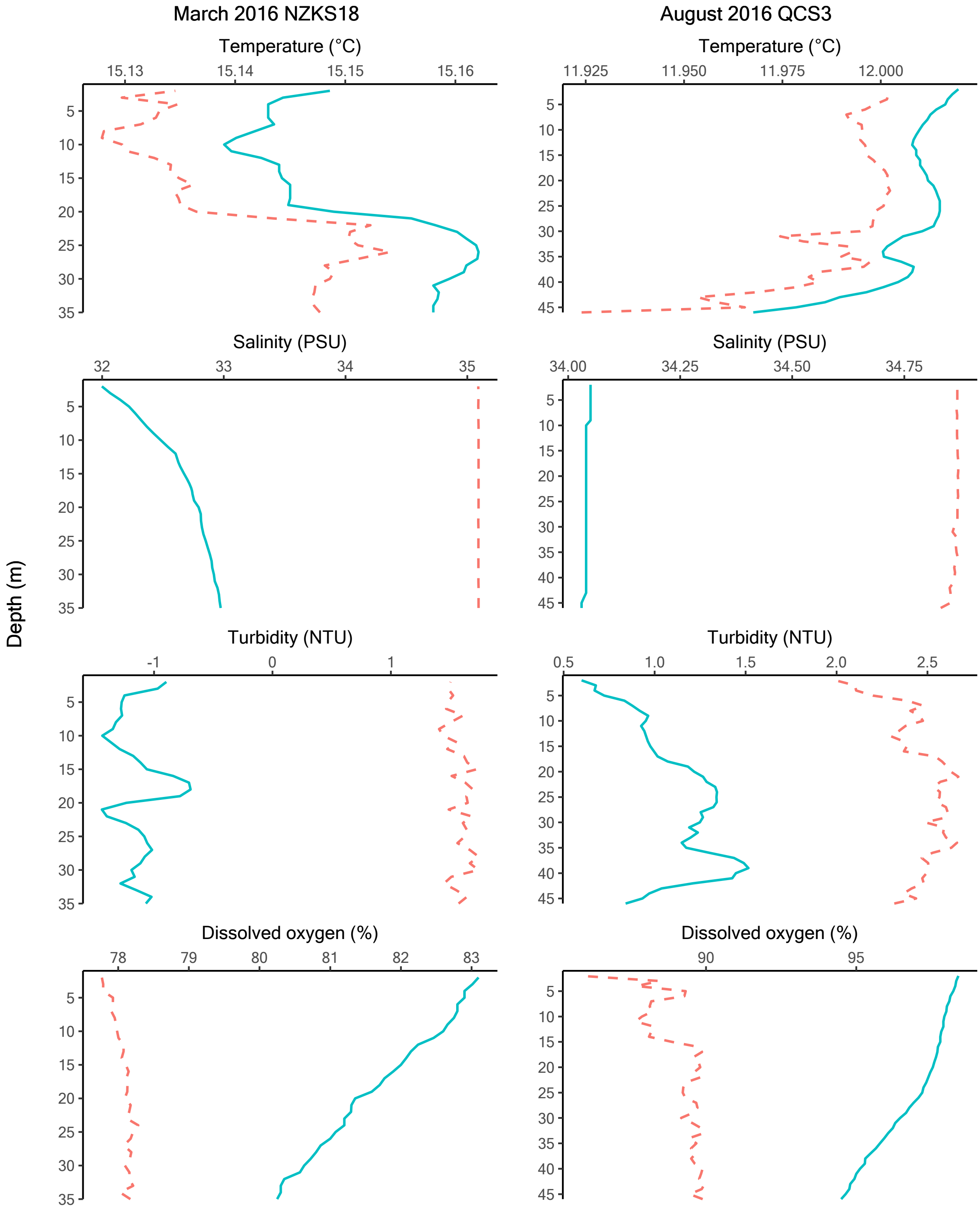


Figure A7.1. Downcast temperature, salinity, turbidity and dissolved oxygen: Cawthron CTD (Seabird 19: red dashed line) and MDC CTD (YSI EXO Sonde; blue solid line).

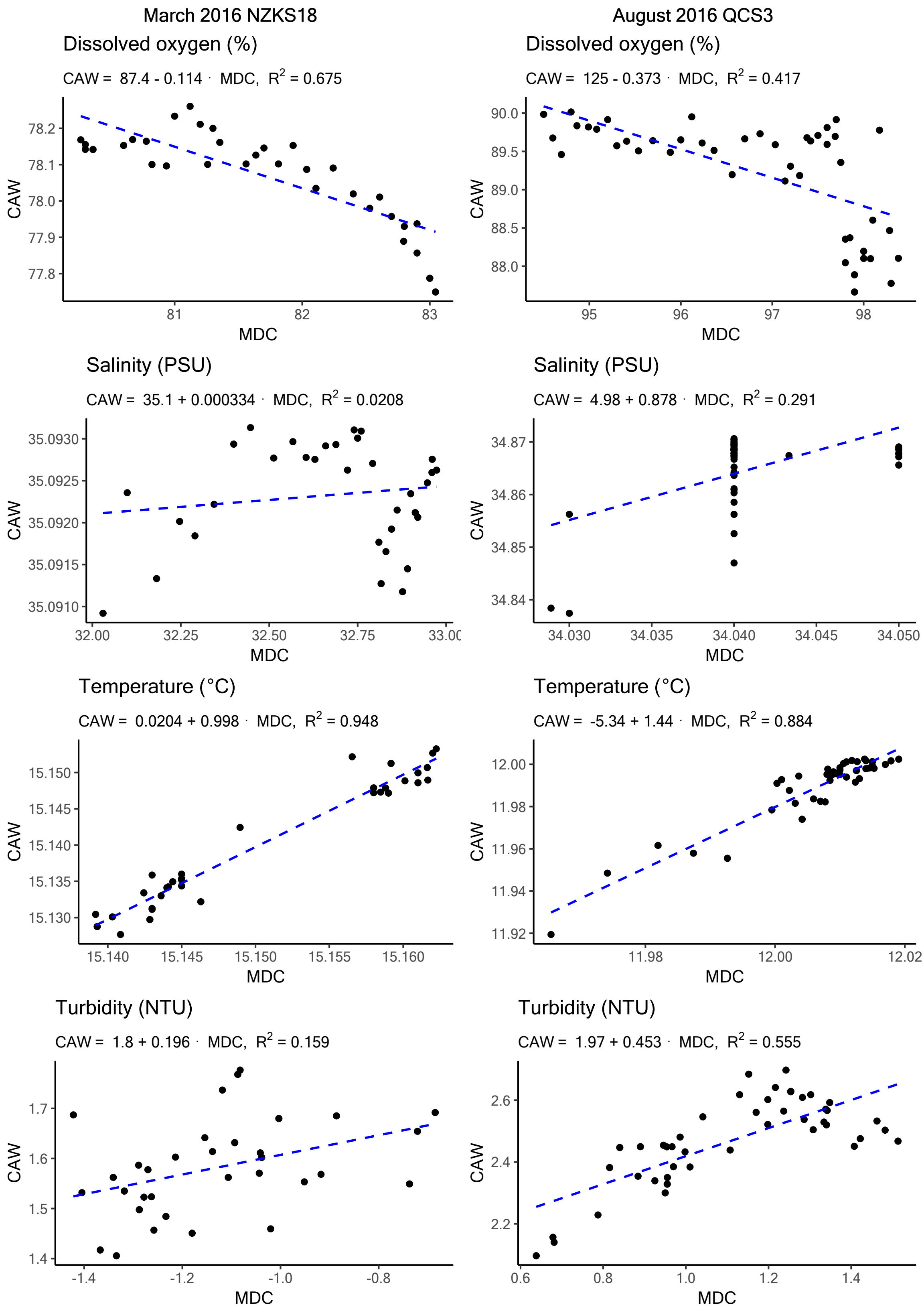


Figure A7.2. Statistical comparison. Dotted blue lines are the linear least-squares fitted lines, with the associated slope, intercept and goodness of fit (R^2) information displayed with their graphs.

Appendix 8. Full results from nutrient analyses for February, March, July and August at routine monitoring stations. Note, samples collected from MDC reference sites were not analysed for TP and NO2-N in February and July, as these are not part of their monitored nutrient suite.

Nutrient	Sample	NZKS 18	NZKS 19	NZKS 20	NZKS 21	NZKS 22
		Net pen	500 m south	500 m north	(QCS-3) NF-ref	FF ref
February '16						
NH_4-N	Surface	22.4	22.6	21.7	23.0	20.2
NO_3-N	Surface	76.8	77.2	78.1	75.0	80.5
NO_2-N	Surface	5.0	5.0	5.0	-	5.0
TN	Surface	212.0	216.0	209.0	231.0	208.0
DIN	Surface	104.2	104.8	104.8	30.5	105.7
TP	Surface	21.0	21.0	18.0	-	18.0
DRP	Surface	20.3	20.4	18.1	18.0	18.0
DRSi	Surface	112.0	107.0	105.0	115.0	100.0
March '16						
NH_4-N	Surface	23.0	18.0	22.9	16.2	17.4
	Near-bed	19.9	22.3	16.7	18.2	20.2
NO_3-N	Surface	93.7	94.0	99.5	97.1	102.3
	Near-bed	92.9	94.0	101.0	106.0	104.0
NO_2-N	Surface	3.0	3.0	3.0	6.5	2.0
	Near-bed	3.0	3.0	3.0	6.6	2.0
PN	Surface	207.6	86.0	92.3	67.8	147.3
	Near-bed	147.2	100.7	69.3	88.4	190.8
TN	Surface	358.7	201.0	240.0	219.0	283.0
	Near-bed	263.0	220.0	190.0	211.0	317.0
TDN	Surface	151.1	115	147.7	151.2	135.7
	Near-bed	115.8	119.3	120.7	122.6	126.2
DIN	Surface	119.7	115	125.4	119.8	121.7
	Near-bed	115.8	119.3	120.7	130.8	126.2
TP	Surface	30.0	24.0	25.7	24.0	25.0
	Near-bed	25.0	23.0	25.0	25.0	24.0
DRP	Surface	21.6	21.4	22.9	21.1	22.3
	Near-bed	21.1	21.6	21.7	22.0	22.8
DRSi	Surface	127.3	123.0	121.3	122.0	121.7
	Near-bed	124.0	121.0	121.0	122.0	120.0
July '16						
NH_4-N	Surface	11.9	8.8	9.7	9.0	8.1
NO_3-N	Surface	115.0	103.0	109.0	109.0	110.5
NO_2-N	Surface	3.3	3.8	3.5	-	3.4
TN	Surface	225.0	213.0	211.0	301.0	239.5
DIN	Surface	130.2	115.6	122.2	19.9	122
TP	Surface	26.0	24.0	25.0	-	27.0
DRP	Surface	19.6	19.0	19.7	21.0	20.0
DRSi	Surface	206.0	102.0	91.3	92.0	89.6

Appendix 8 continued

Nutrient	Sample	NZKS 18 Net pen	NZKS 19 500 m south	NZKS 20 500 m north	NZKS 21 (QCS-3) NF-ref	NZKS 22 FF ref
August ‘16						
NH_4-N	Surface	6.7	6.1	8.3	7.3	7.3
	Near-bed	6.3	7.9	7.2	12.6	8.3
NO_3-N	Surface	86.5	84.0	84.6	83.8	84.1
	Near-bed	85.1	83.9	82.3	82.7	80.6
NO_2-N	Surface	1.9	1.5	1.7	3.3	2.0
	Near-bed	1.6	1.8	1.8	5.9	2.0
PN	Surface	14.3	10.7	10.3	50.4	12.0
	Near-bed	6.0	8.0	24.0	38.8	28.0
TN	Surface	183.7	164.3	163.3	247.8	166.0
	Near-bed	158.0	168.0	172.0	272.0	176.0
TDN	Surface	169.4	153.6	153	197.4	154
	Near-bed	152	160	148	233.2	148
DIN	Surface	95.1	91.6	94.6	94.4	93.4
	Near-bed	93	93.6	91.3	101.2	90.9
TP	Surface	21.3	20.3	19.7	19.0	20.0
	Near-bed	18.0	20.0	21.0	21.0	21.0
DRP	Surface	17.8	16.9	17.4	16.8	17.2
	Near-bed	17.0	17.8	16.9	17.5	17.8
DRSi	Surface	157.3	149.3	149.3	157.5	117.0
	Near-bed	114.0	132.0	125.0	183.5	163.0

Appendix 9. Calculation of a theoretical near-farm nitrogen concentration increase.

Table A9.1 provides information used to derive an average potential increase in total dissolved nitrogen (TDN) concentrations immediately downstream of a salmon farm net pen, assuming perfectly linear flow through a farm aligned parallel to the flow. Because the relationship is linear, the increase in TDN can be scaled to other scenarios; doubling the feed loading (or halving the current speed) would double the potential nitrogen concentration increase. Note that a value of 45% protein content was assumed, whereas average protein content appears to be about 40% (based on information provided by NZ King Salmon), hence the TDN release may be overestimated.

Table A9.1. Information used to derive an average potential increase in dissolved inorganic nitrogen (TDN) concentrations immediately downstream of a salmon farm net pen assuming perfectly linear flow through a farm aligned parallel to the flow and an even distribution of fish.

Description	Value	Reference
Feed load per year (ton/day)	10	
TDN release per ton of feed (kg)	45.6	Knight (2016)
Average mass load per sec (mg/s)	5277.8	
Farm width (m)	50.0	
Farm depth (m)	20.0	
Cross sectional area (m^2)	1000	
Current speed (m/s)	0.2	
Average TDN concentration change (mg/m^3)	26.4	

Appendix 10. Results and discussion of the usefulness of including urea-N and PN in the NZKS water column sampling program.

Background

Urea-N and particulate nitrogen (PN) were included in the sampling program with the intention of evaluating their usefulness for tracing farm-related wastes, and assessing farm related influences in the water column.

For context, results from urea-N and PN are plotted with the two nutrients that showed the strongest graded trends in the fine-scale surveys; total nitrogen (TN) and ammonium (NH_4-N) (Figure A10.1). TN and NH_4-N are required to be measured for consent compliance.

Urea-N

Salmon excrete nitrogenous waste in the form of ammonium and urea (approximately 80-90%, and 10-20%, respectively), which results in localised elevated dissolved nitrogen concentrations in the water column around finfish farms. The rate of excretion of both dissolved nitrogen forms in teleost fishes is highly variable in time (Karakassis et al. 2001), and can be related to (but not necessarily coinciding with) feed consumption among other things (Merino et al. 2007 and references therein). Ammonium and urea are taken up by phytoplankton or converted through biological processes (nitrification) to nitrate-N/nitrite-N; which in turn may be assimilated by phytoplankton or denitrified and lost from the system. Combined with the lower rate of biological uptake of urea than ammonium by phytoplankton (e.g. Twomey et al. 2005), dissolved nitrogen in the form of urea may be expected to be longer-lived in the water column than its ammonium counterpart.

In addition, although ammonium is usually the predominant form of excreted nitrogen, there are a multitude of other sources of ammonium in the marine environment (e.g. mussel farms). In comparison, urea has relatively fewer sources; e.g. marine mammal excretions, other (non-farmed) fish excretions, which are inherently also sources of ammonium). Because urea is longer-lived and has fewer sources, it is comparatively more useful than ammonium as a tracer for dissolved nitrogen wastes.

There are stark differences in graded trends between these two dissolved nitrogen forms during two of just five sampling occasions. For example, at the Ngamahau Bay salmon farm site (NGA) in March 2016, urea-N concentrations were higher than NH_4-N, sharply decreasing 100 m downstream, and continuing to decrease (though more gradually) toward 250 m downstream. For ammonium, in addition to lower concentrations at the pen edge, concentrations showed a more graduated decrease with increasing distance downstream. In contrast, the opposite trend was observed at Kopaua Bay (KOP) salmon farm site in August 2016, with higher NH_4-N concentrations at the pen edge and a sharper decrease compared to urea-N. Differences in these gradients highlights how urea-N is a complementary analyte to ammonium for understanding near-field nutrient enrichment from finfish farming. As such, we recommend continuation of urea-N in the short-term with the long-term outlook being that it is considered as a parameter (over other less useful nutrients) for ongoing water column monitoring in the event that monitoring conditions are reviewed. In addition, we recommend analysis of urea-N is extended to more of the farther-afield water column monitoring stations (during fine-scale sampling) (e.g. all 500 m stations, and some reference stations) to provide a better context for reference urea-N concentrations and the potential for far-field tracing properties.

Particulate nitrogen

Particulate nitrogen (PN), an indicator of seston[12] abundance, was preliminarily included in the sampling program, as a "… *useful indicator of general system activity, since seston forms the food of organisms higher in the food web.*" (Morrisey et al. 2015), and was therefore considered to be of greater value than some of the other measured variables for assessing the influence of fish-farming on the properties of the pelagic zone (Morrisey et al. 2015). PN is also an indicator of marine-farm related wastes in the water column (e.g. uneaten fish food, faeces; Figure A10.2). In addition, a major source of PN includes the water column phytoplankton and zooplankton themselves, and as such may be a useful indicator of phytoplankton biomass in conjunction with Chl-*a* measurements (Zeldis et al. 2008).

PN has proven to be a more useful analyte than some of the other measured variables that are required to be monitored under the consent conditions. Despite the current lack of a specific and defined objectives for measuring PN concentrations in the status quo, as well as its strong inter-correlation with TN (Figure A10.1), we recommend continuation of PN in the short-term.

---

[12] Living and non-living matter in suspension in a water body.

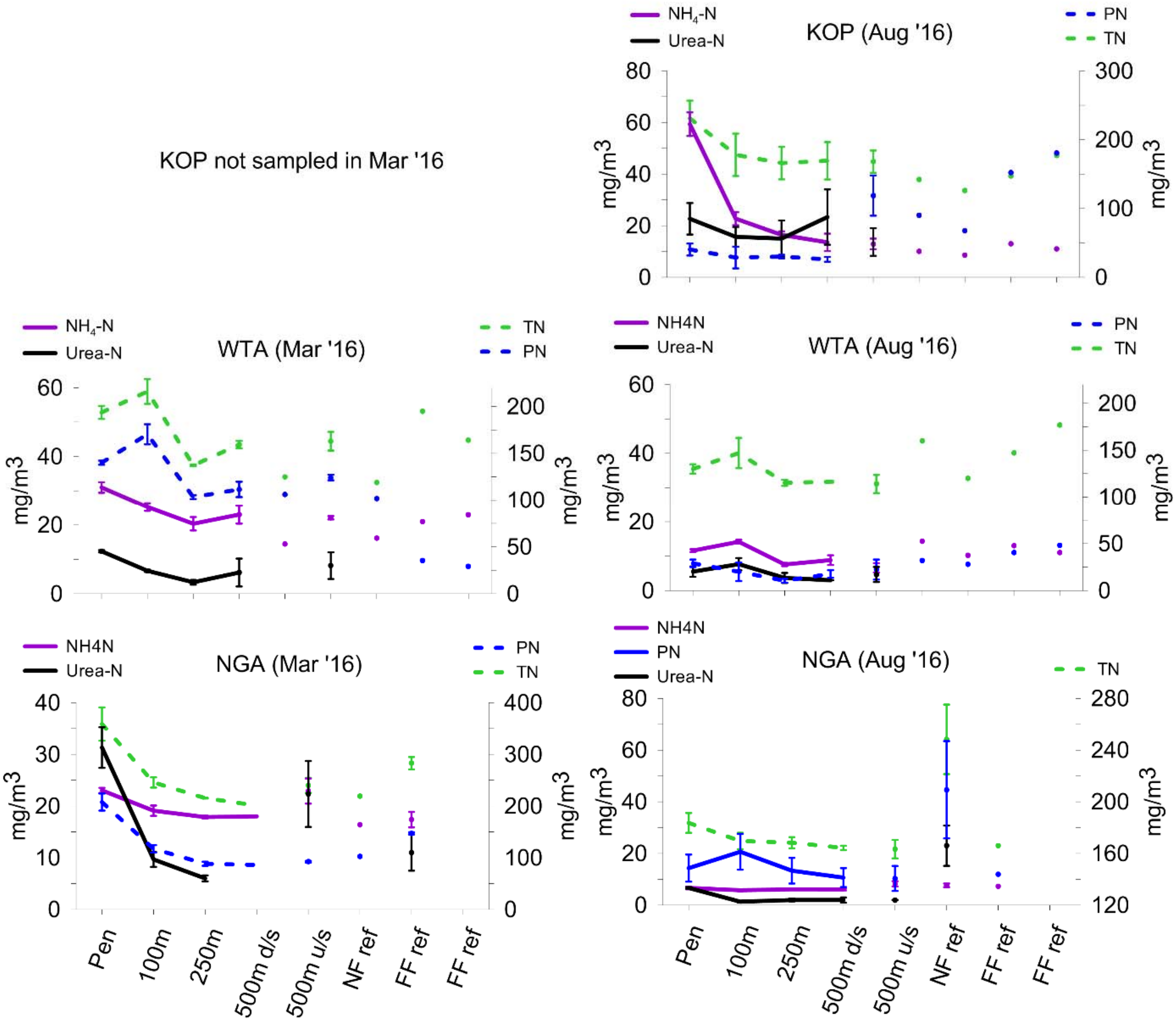


Figure A10.1. Concentrations (mg/m^3) of particulate nitrogen (PN), Urea-N, ammonium (NH$_4$-N) and total nitrogen (TN) in integrated surface (mean ±SE) samples. Note: triplicate samples were only taken for some surface integrated samples. d/s = downstream, u/s = upstream, s/w = seaward, NF ref = near-field reference. Note, there is no 500 m seaward station near the NGA farm.

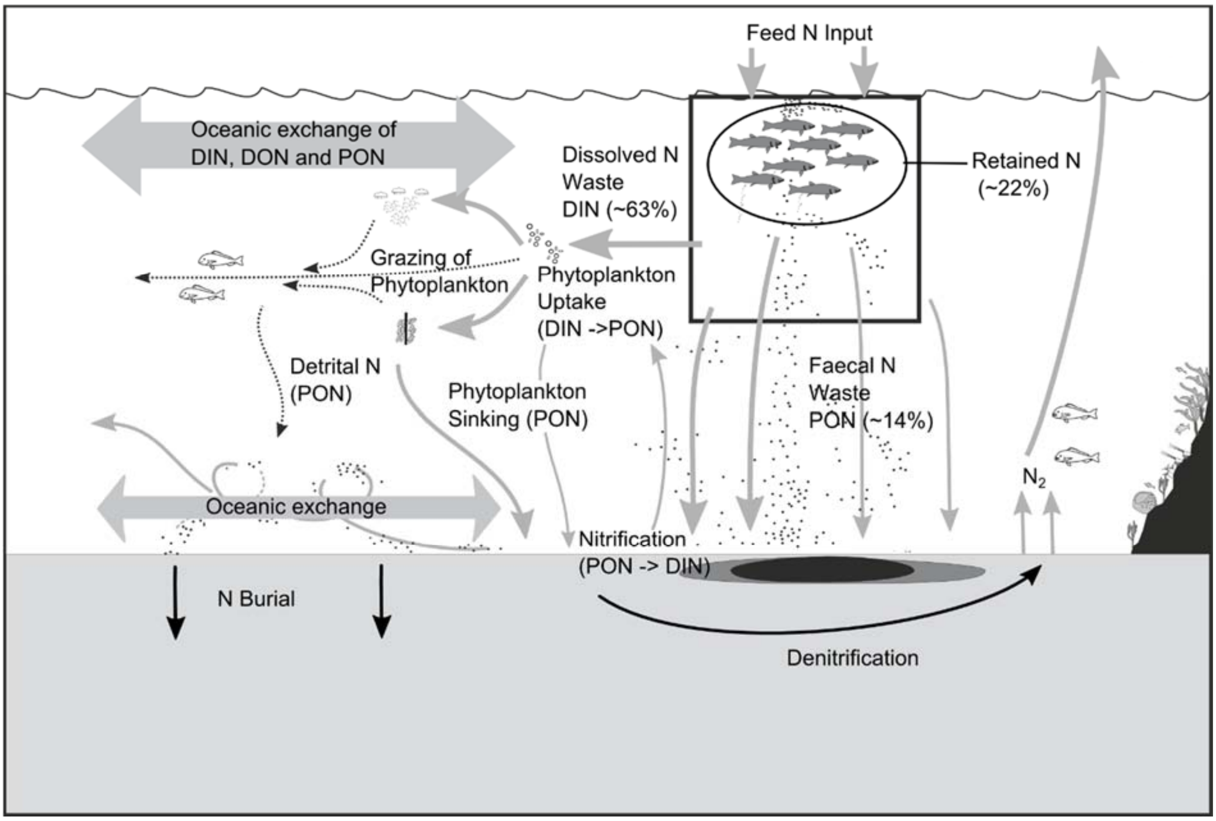


Figure A10.2. Schematic of flux and fate of feed nitrogen from a salmon farm (Knight 2012).

Appendix 11. Surface estimated phytoplankton biomass (mgC/m^3) for two major taxon groupings of diatoms and dinoflagellates in 2016. d/s = downstream.

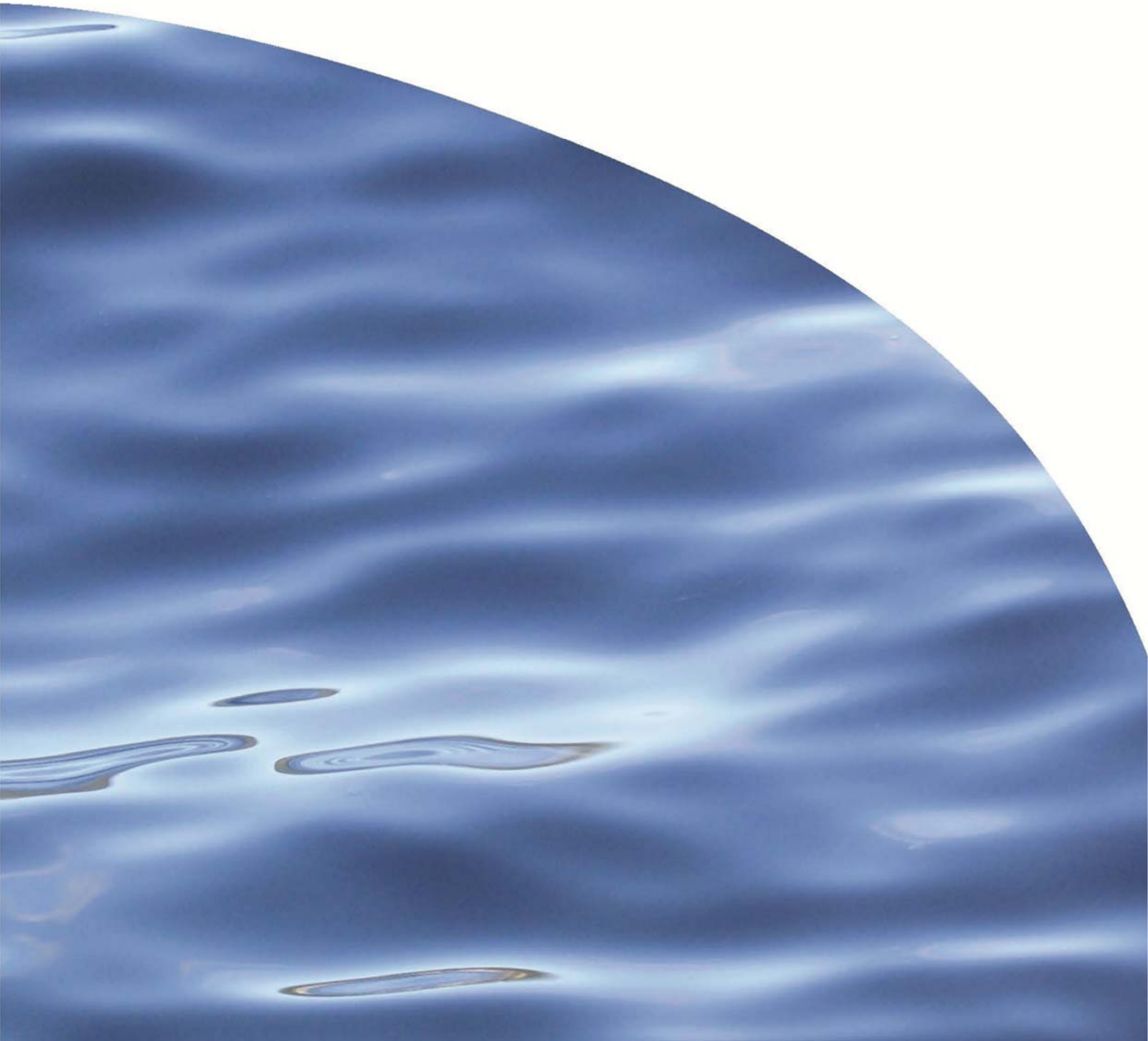
	NZKS18	NGA100	NGA250	NZKS19	NZKS20	NZKS21	NZKS22
	Net pen	100 m d/s	250 m d/s	500 m south	500 m north	(QCS-3) NF-ref	FF ref
Feb 2016							
Diatom	1.69	-	-	1.95	1.69	2.37	1.82
Dinoflagellate	0.00	-	-	0.00	1.10	0.60	0.32
Other	0.58	-	-		0.10	4.94	0.58
Mar 2016							
Diatom	5.85	9.81	4.94	10.58	7.99	3.50	2.22
Dinoflagellate	0.54	0.06	0.12	0.11	0.68	0.00	0.00
Other	0.02	0.00	0.00	0.07	1.47	1.44	0.29
July 2016							
Diatom	1.23	-	-	1.67	1.00	0.79	0.92
Dinoflagellate	0.77	-	-	0.00	0.70	0.27	0.32
Other	0.58	-	-	0.00	0.02	2.79	0.00
August 2016							
Diatom	3.09	2.72	1.42	1.88	1.53	1.83	3.01
Dinoflagellate	0.00	0.00	0.06	0.00	0.00	0.00	0.25
Other	0.00	5.76	0.00	0.00	0.00	0.00	0.00

PART TWO: REEF ENVIRONMENTAL MONITORING 2016

The report containing the results of the 2016 reef monitoring will be forwarded for PRP and TWP review prior to the submission of all reports to MDC.

REPORT NO. 3009

REEF ENVIRONMENTAL MONITORING RESULTS FOR THE NEW ZEALAND KING SALMON COMPANY LTD SALMON FARMS: 2016



REEF ENVIRONMENTAL MONITORING RESULTS FOR THE NEW ZEALAND KING SALMON COMPANY LTD SALMON FARMS: 2016

ROBYN DUNMORE

Prepared for New Zealand King Salmon Co. Ltd

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Nigel Keeley

APPROVED FOR RELEASE BY:
Grant Hopkins

ISSUE DATE: 09 May 2017

RECOMMENDED CITATION: Dunmore R 2017. Reef environmental monitoring results for the New Zealand King Salmon Company Ltd salmon farms: 2016. Prepared for New Zealand King Salmon Co Ltd. Cawthron Report No. 3009. 68 p. plus appendices.

EXECUTIVE SUMMARY

The New Zealand King Salmon Company Ltd (NZ King Salmon) is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The rocky reef communities that are in close proximity to some of the NZ King Salmon farms are included in this monitoring. This applies to farms in Tory Channel (Clay Point (CP), Te Pangu (TP) and Ngamahau Bay (NB)), and in Pelorus Sound (Waitata Reach (WR) and Kopaua (Richmond Bay, RB)). Permanent markers for photoquadrat analysis are installed at deep (10–22 m) sites at all farms, and permanent transects are installed at shallow subtidal (~ 5-7 m) and intertidal (0 m MLW) sites at new farms (NB, WR and RB). The sites near the Clay Point farm have been monitored since it was first established in 2007 and those near the Te Pangu farm have been monitored since 2009 in response to feed increases. Sites near Ngamahau Bay, Waitata Reach and Kopaua (Richmond Bay) have been monitored since 2015, prior to their establishment in 2015 and 2016. Reference sites in both Tory Channel and Pelorus Sound are also monitored.

Data from the 2016 survey were qualitatively and quantitatively analysed to assess farm-related effects on the rocky reef communities. This report constitutes a summary of the key findings, which were as follows:

- Qualitative analysis of the images from the permanent quadrat rocky reef monitoring sites indicated that the reef communities near to the farms remained diverse.
- Statistical analyses of the community, individual taxa and group taxa data did not show changes consistent with farm-related impacts.
- The communities at the permanent quadrat sites, and at shallow subtidal and intertidal transect sites did not show any obvious directional changes over time attributable to impacts from the farms; changes in organism abundances were observed at both farm and reference sites.
- Potentially enrichment-sensitive organisms (e.g. vase sponges, tree hydroids) were present in comparable densities among farm and control sites through time.
- Some minor changes in the abundances of particular organisms were observed at some sites (e.g. a decrease in tree hydroids at CP2, increases in encrusting bryozoans at CP1, CP3 and TP1, and an increase in brittle stars at TP1). These taxa should receive particular attention in future surveys.

Overall, it is concluded that the reef communities in the vicinity of the Clay Point, Te Pangu, Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) farms have not been impacted since the monitoring programme was implemented. It is recommended that the photo-quadrats be subjected to a qualitative analysis in 2017 and a quantitative analysis on alternate years thereafter (unless feed use and/or farming arrangements change appreciably). The shallow subtidal and intertidal transect data collected at NB, WR and RB should be quantitatively analysed in 2017.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

1.1. Background

New Zealand King Salmon Company Limited (NZ King Salmon) is the largest finfish farming company in New Zealand and has a long history in the Marlborough Sounds. NZ King Salmon has 11 consented farms in the region: Te Pangu Bay (TP, formerly TEP in previous reef monitoring reports), Ruakaka Bay (RUA), Otanerau Bay (OTA), Waihinau Bay (WAI), Forsyth Bay (FOR), Clay Point (CP, formerly CLA in previous reef monitoring reports), Marine Farm Licence 48 (MFL-48), Marine Farm Licence 32 (MFL-32), Waitata Reach (WR), Ngamahau Bay (NB) and Kopaua (Richmond Bay, RB).[1]

NZ King Salmon is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The monitoring programme is conducted under a marine environmental monitoring adaptive management plan (MEMAMP) (Elvines & Taylor 2016; Elvines et al. 2016) that was prepared by Cawthron Institute (Cawthron) on behalf of NZ King Salmon, and approved by Marlborough District Council (MDC) prior to implementation. Consent conditions for all of the farms (with the exception of WAI) broadly require monitoring of the effects of deposition on the seabed, with particular regard to the benthic (seabed) community composition and abundance, dissolved oxygen (DO) levels and water quality. The environmental monitoring results are used to determine whether the farms are compliant with the environmental quality standards (EQS) specified in the consent conditions for each farm.

In addition, TP, CP, NB, WR and RB have rocky reef communities that are in close proximity to the farm and are monitored as a precautionary measure and/or because of scheduled feed increases that may alter impact potential. The reef monitoring is designed to detect ecologically significant changes in community composition and abundances of a selection of potentially sensitive sessile epibiota (e.g. sponges and hydroids). The reef monitoring program has been conducted since 2007 (at CP) and has been progressively expanded over the years in response to changes in activities and the addition of new farms. This report provides a quantitative and qualitative assessment of the results to date.

---

[1] For the purposes of this report the Kopaua farm will be referred to as RB to correspond to the permanent markers, and to minimise confusion with one of the reference stations at Ketu Bay (KB).

1.2. Monitoring history and farm feed levels

The CP sites were first monitored immediately prior to when the farm became operational in December 2007. Feed inputs have historically ranged from 3,152 to 4,420 tonnes per annum (since 2009, Figure 1). Feed use in 2016 was 4,477 tonnes.

The TP farm was established in 1992, but reef sites have only been monitored quantitatively since 2009, when resource consent was granted for a staged increase in feed levels over the following years. Prior to that, the reefs were inspected qualitatively using video transects. Feed inputs at this farm have historically ranged from 4,192 to 5,013 tonnes per annum (since 2009, Figure 1). Feed input was 4,961 tonnes in 2016.

NB reefs were first monitored in November 2015, and the farm was operational in the same month. In 2016 1,315 tonnes of feed was used at this site (Figure 1).

WR was first monitored in November 2015, prior to its establishment in January 2016. Feed input was 2,644 tonnes in 2016 (Figure 1).

RB was first monitored in November 2015 (permanent quadrats) and April 2016 (permanent transects), prior to the farm becoming operational in May 2016. Over the following seven months, 1,107 tonnes of feed was used at this site (Figure 1).

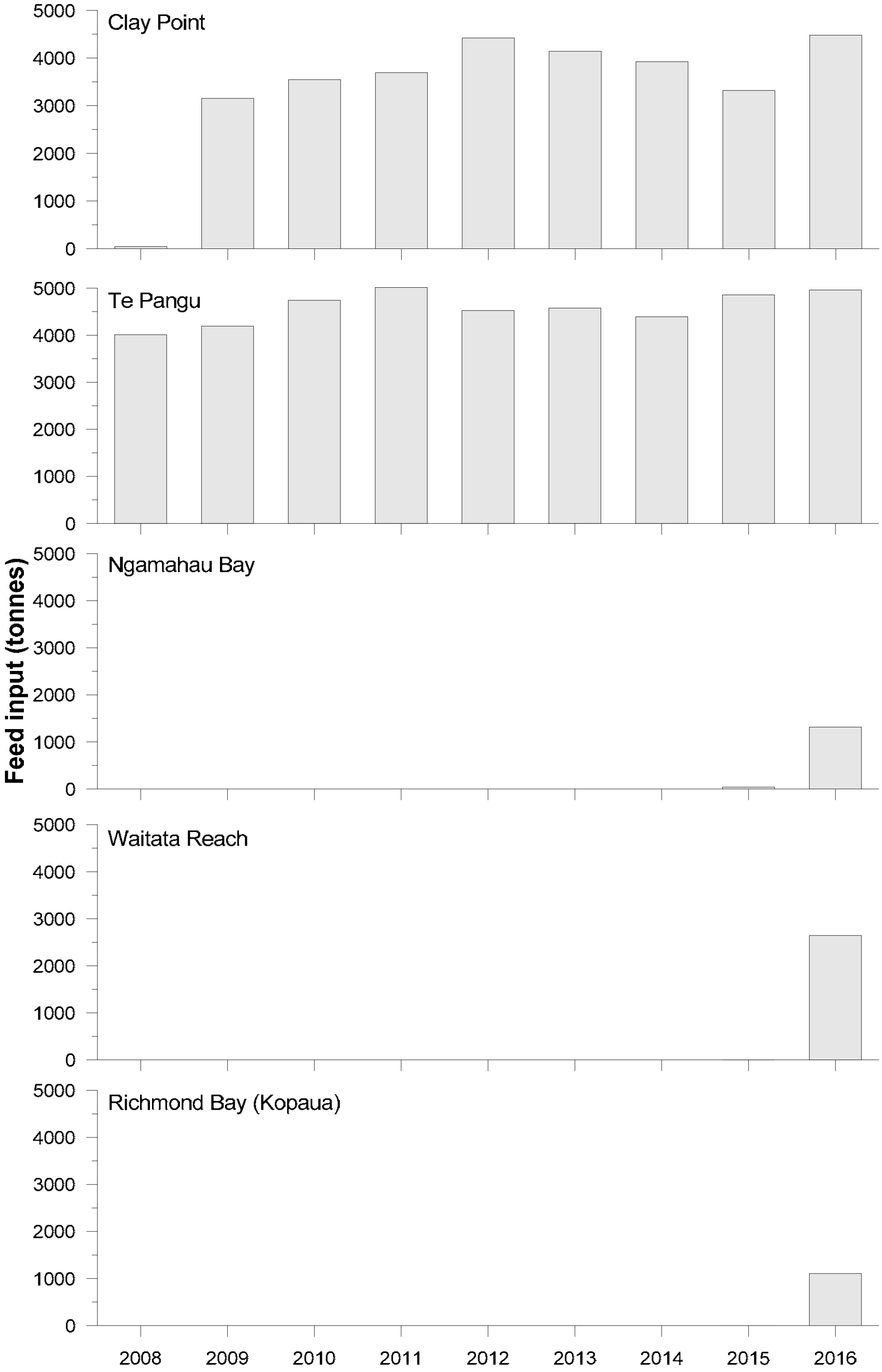


Figure 1. Annual feed inputs at all reef monitoring farms, 2008–2016.

2. METHODS

2.1. Background

All of the NZ King Salmon farms in this monitoring programme (CP, TP, NB, WR and RB) have reef areas inshore of the net pens that are inhabited by organisms considered potentially sensitive to organic deposition (e.g. hydroids, bryozoans and sponges) (Keeley et al. 2006; Atalah et al. 2011; Clark et al. 2011; Ellis et al. 2011; Morrisey et al. 2015). Accordingly, these reef habitats are being monitored for any potential effects from deposition attributable to salmon farming operations. Monitoring encompasses a range of methodologies designed to detect changes in the intertidal and subtidal habitats as follows (Table 1, Figure 2):

- permanent markers for photoquadrat analysis are installed at deep (10-22 m) sites at all farms (CP, TP, NB, WR and RB)
- permanent transects are installed at shallow subtidal (~ 5-7 m) and intertidal (0 m MLW) sites at farms established in 2015/2016 (NB, WR and RB)
- subtidal video transects are surveyed at selected sites at new farms (NB, WR and RB) where permanent markers could not be installed.

Potential impact sites were established on nearby reefs (~80–730 m away from the pens) that could potentially be impacted or that had been requested to be surveyed by stakeholders. ‘Reference’ sites were located 540–4050 m from the pens and are outside the primary depositional footprint. The reference sites were established on areas of reef that were as comparable as possible to impact sites in terms of depth, substrate, aspect and habitats.

Monitoring occurred during 8–11 November 2016 and on 24 November 2016 at the Tory Channel sites, and during 25–28 October 2016 at the Pelorus Sound sites.

2.2. Site locations

Permanent quadrat sites (Table 1, Figure 2) were positioned in suitable habitats, within depths that could be effectively surveyed by divers (< 25 m). In Tory Channel, there are three farms (TP, CP and NB; Table 1, Figure 2A). There are three potential ‘impact’ sites at CP (CP1, CP2 and CP3), two potential ‘impact’ sites at TP (TP1 and TP2), and three reference sites (CP4, TP3 and TP4). The CP sites were established in 2007, and the TP sites were established in 2009. There are three potential ‘impact’ sites at Ngamahau Bay (NB1, NB2 and NB3) and one reference site at Thoms Bay (NB4), which were established in 2015. Reference sites CP4, TP 3 and TP4 are also used for comparisons with NB data.

In Pelorus Sound, there are two farms (WR and RB; Figure 2B). There are two potential 'impact' sites at Waitata Reach (WR1 and WR2), and two potential 'impact' sites at Kopaua/Richmond Bay (RB1 and RB2), along with three reference sites at Treble Tree and Ketu Bay (TT1, TT2 and KB1).

Permanent transect sites were established inshore of the permanent quadrat sites (Table 1, Figure 2). This was to characterise communities in shallow subtidal (~ 5–7 m depths) and intertidal (0 m MLW) habitats adjacent to 'potential impact' and reference sites. Extra sites were also installed at sites which did not have suitable habitat for permanent quadrats (e.g. NB3b) or at additional reference sites (e.g. NB5, Figure 2).

Subtidal video transects were used to survey areas at NB3b, WR3 and RB3 (Table 1, Figure 2). Some of the notable biological habitats identified in the baseline survey (e.g. RB3; Morrisey et al. 2015), or sites identified by stakeholders (e.g. NB3b) were not suitable for the establishment of permanent quadrat sites because they were too deep and/or did not contain suitable rocky substrate (e.g. hydroid beds in sandy areas). Video footage characterised the habitats in these areas. Additional footage was also taken inshore of the NB farm, as this area was dominated by the green alga *Ulva* sp. (sea lettuce). This alga can be indicative of nutrient enrichment, so it was important to document its abundance at this site prior to the farm being operational.

Table 1. Details of rocky reef monitoring sites and monitoring methods in Tory Channel (TC) and Pelorus Sound (PS). ** Site requested to be surveyed by stakeholders.

Area	Site	Description	Year established	Permanent quadrats	Permanent transects	Video transects	Approx. distance to nearest farm (m)	Depth of perm. quadrats (m)	Lat.	Long.
Tory Channel (TC)	CP1	CP Farm	2007	✓			130	19	-41 14.15802	174 14.39089
	CP2	CP Farm	2007	✓			130	17	-41 14.14943	174 14.38643
	CP3	CP Farm	2007	✓			90	22	-41 14.17334	174 14.42411
	CP4	TC Reference	2007	✓			540	18	-41 14.23008	174 15.07588
	TP1	TP Farm	2009	✓			270	21	-41 14.74980	174 14.02902
	TP2	TP Farm	2009	✓			80	13	-41 14.89779	174 14.28811
	TP3	TC Reference	2009	✓			1100	15	-41 14.59809	174 15.27330
	TP4	TC Reference	2009	✓			880	15	-41 13.72925	174 15.56597
	NB1	NB farm	2015	✓	✓		140	15	-41 13.56926	174 16.08389
	NB2	NB farm	2015	✓	✓		240	15	-41 13.33096	174 16.3742
	NB3	NB farm	2015	✓	✓		510	15	-41 13.23041	174 16.22981
	NB4	TC Reference	2015	✓	✓		1750	15	-41 13.46871	174 15.93879
	NB3b	NB farm **	2015		✓	✓	520		-41 13.591	174 15.735
	NB5	NB Reference	2015		✓		2600		-41 13.057	174 17.975
Pelorus Sound (PS)	WR1	WR farm	2015	✓	✓		270	17	-40 58.04916	173 57.37847
	WR2	WR farm	2015	✓	✓		420	17	-40 58.24654	173 57.03904
	WR3	WR farm	2015		✓	✓	560		-40 58.358	173 56.830
	RB1	RB farm	2015	✓	✓		300	10	-40 59.89079	173 57.74394
	RB2	RB farm	2015	✓	✓		150	11	-40 59.86054	173 57.93612
	RB3	RB farm	2015		✓	✓	730		-40 59.54294	173 57.84731
	TT1	PS Reference	2015	✓	✓		4050	14	-40.59.776	173 55.170
	TT2	PS Reference	2015	✓	✓		2270	13	-40 58.981	173 55.911
	KB1	PS Reference	2015	✓	✓		3600	16	-40 58.110	173 59.711

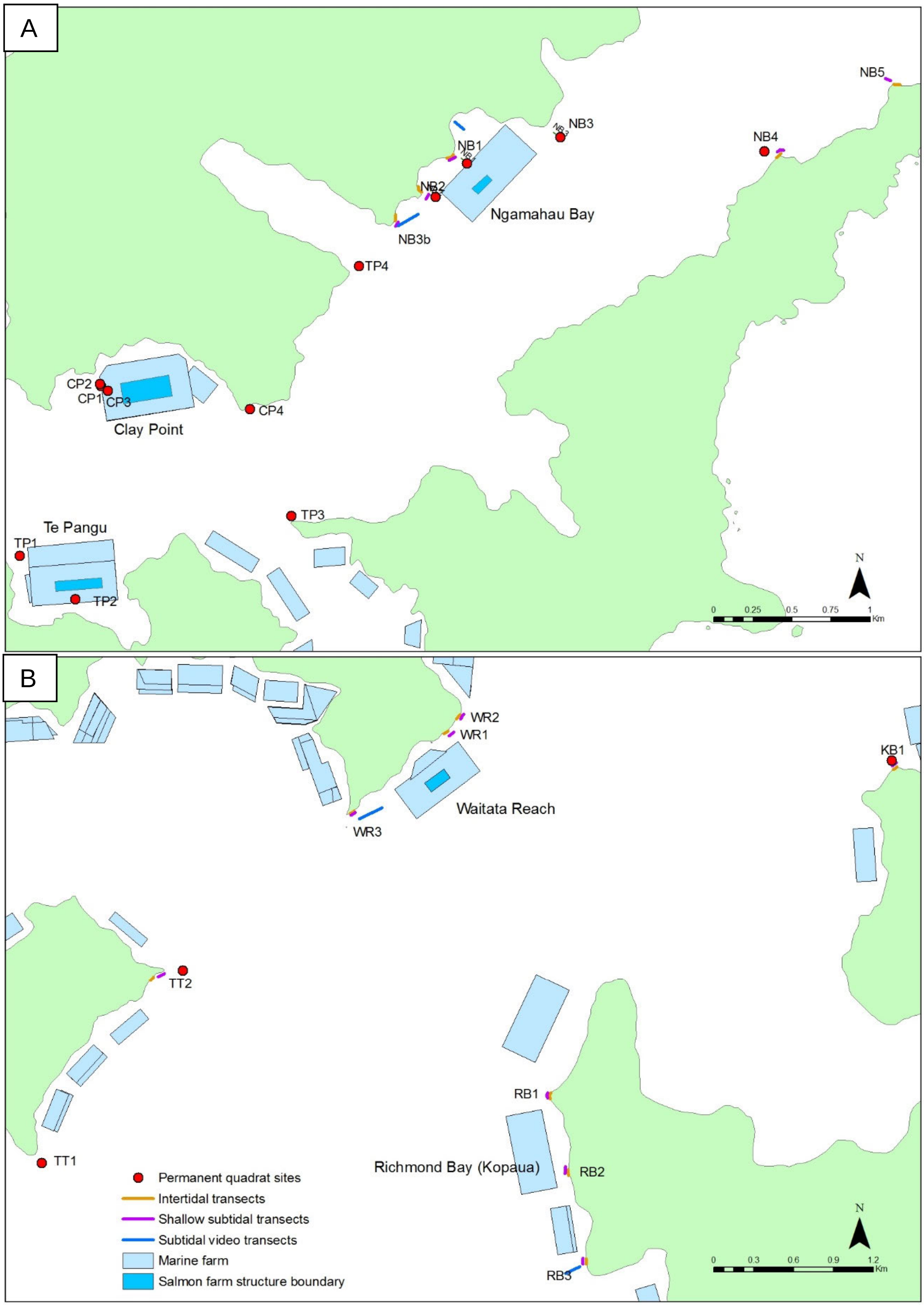


Figure 2. Location of rocky reef monitoring sites in Tory Channel (A) and Pelorus Sound (B). Permanent quadrat sites (red circles), and intertidal, shallow subtidal and subtidal video transects (orange, purple and blue lines, respectively) are shown. Other farms shown are mussel farms.

2.3. Permanent quadrat sites

2.3.1. Sampling methods

At each reef site, four replicate stations[2] were permanently marked with a pair of pins cemented into the rock at a distance apart that corresponds to the short side of a rectangular 0.25 m^2 photo-quadrat (41 x 61 cm). The pins are identified with yellow cattle tags (marked with the site and station name, and upper or lower pin relating to position) and some of the pins are marked with a float on a short nylon cord (Figure 3). This set-up aids relocation of the stations and allows the precise repositioning of six 0.25 m^2 photo-quadrats such that the same exact patch of reef, and individual, sessile (attached) macrobiota, can be monitored through time.

Six quadrat photos were taken at each station, producing four replicate clusters of six per site (e.g. Figure 3). Photos were taken with a 10 megapixel digital SLR camera attached at a set distance from the 0.25 m^2 quadrat. Each photo was qualitatively compared to the photos from the same position in previous years, and quantitatively analysed as described in Section 2.3.2. Randomly allocated photo-quadrats were also taken in the general vicinity of each sampling station, to encompass larger areas and capture taxa that may be sensitive to disturbance caused while finding tags and collecting photos. These photographs were archived at Cawthron and can be used at a future date if necessary.

Video footage around the sites was collected in 2016 to characterise the general areas, encompassing larger extents than those captured by photo-quadrats. Footage was reviewed and archived for the assessment of any obvious changes of visual characteristics over time.

---

[2] Five stations were installed at NB4, because during installation of the first set of pins, a more suitable patch of reef was discovered nearby so a further four stations were installed.

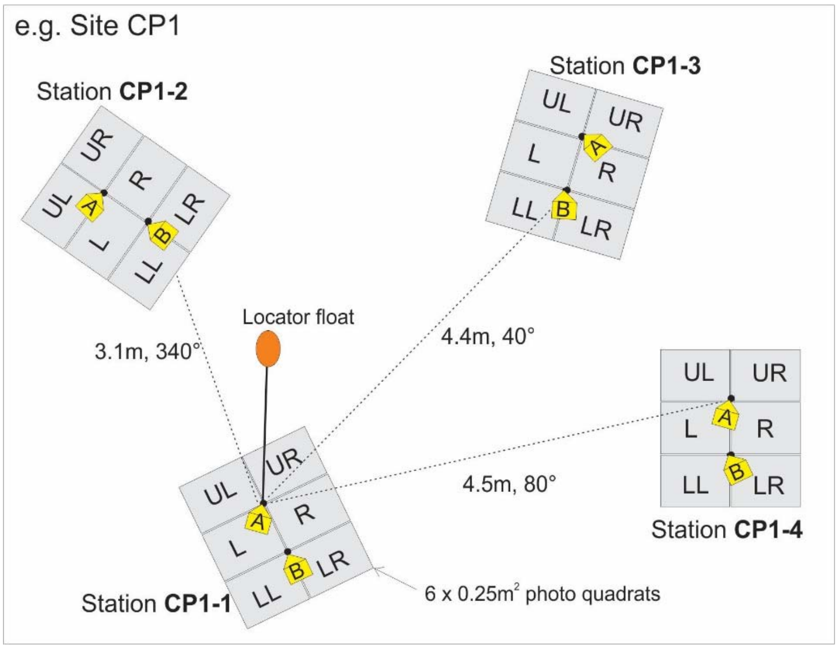


Figure 3. Example of the arrangement of the four photo-quadrat stations that are set up at each sampling site. Each rectangular sampling station comprises a 2 × 3 cluster of 0.25 m^2 photo-quadrats, aligned according to the two permanent marker pins. UL, UR, L, R, LL and LR denote upper-left, upper-right, left, right, lower-left and lower-right, respectively.

2.3.2. Analyses

The primary purpose of the reef monitoring is to track the fate of a few representative sessile organisms (e.g. hydroids and sponges) that are considered potentially sensitive to deposition of organic material over time. This was achieved by obtaining sequential images for each site and assessing them qualitatively for presence / absence and any changes in community composition or sedimentation. Additionally, abundance and area occupied (in the case of encrusting species) by conspicuous resident biota was determined using purpose-designed spatial referencing software (i.e., analysis software designed for use in ArcGIS, e.g. Figure 4). Resident biota were defined as those that were either sessile (e.g. sponges and algae), or have a limited range (e.g. sea stars and sea cucumbers). Highly mobile and/or temporary inhabitant taxa such as crayfish (which were very uncommon) and large fish were excluded. Conspicuous biota were recorded either by a point or, if sufficiently large and immobile (e.g. sponges, ascidians, encrusting bryozoans, algae), the organism's shape was traced and a polygon created to determine size (e.g. Figure 4). This also allowed percentage-cover of organisms (within the quadrat area) to be determined. Organisms which fan out from a small base and can have variable percentage-cover because of their movement due to water currents (e.g. hydroid trees) were recorded with a point positioned at the base.

Two quadrats per station were analysed (L and R quadrats, (Figure 3). The other photographs were archived, and can be analysed in future if required. Count data from the two quadrats were summed for analyses and percent cover data were averaged, so there was effectively one quadrat at each station representing a total area of 0.5 m^2.

A variety of graphical and statistical comparisons were used to compare between sites and years. The dataset was analysed using PERMANOVA+ (in PRIMER v7, Anderson et al. 2008), which allows the testing for interactions among factors, and therefore allows BACI type designs where the interaction between time (before/after) and site (i.e. control/impact) is of most interest. Data were square-root transformed to de-emphasise the influence of abundant organisms, and analyses were based on Bray-Curtis similarities. The experimental designs used to analyse the data depended upon the farm, as these varied in number of years and sites (Table 2). The first analysis used all of the CP data (2007 to 2016), and the second analysis used both CP and TP data, from 2009 (the first time TP was monitored) to 2016. The CP data were incorporated in the second analysis because they provided a more balanced design, whereby the CP impact sites (from 2009 onwards) could be compared against three reference sites (as opposed to one in the 2007 analysis). Having replicate ‘impact’ sites (i.e. TP and CP) also strengthened the overall design. The new farms (NB, WR and RB) were analysed independently of each other. In order to deal with non-independence of replicates (stations) through time in a repeated measures analysis, station was included as a factor and was nested within site (Anderson et al. 2008).

Adverse impact may be determined by a significant deterioration in community structure and/or notable die-off of conspicuous macrobiota at impact sites relative to control sites (i.e. a significant Year×Treatment interaction term). Given that no reef sites are closer than ~80 m to the cages, any obvious changes that are observed at the impact sites but not at the reference sites (i.e. possibly attributable to the farm), should be treated as requiring a management response. When the Year×Treatment was significant, a pairwise assessment in PERMANOVA was used to compare variation within each site, between years. Additionally, principal coordinates analysis (PCO) was run on the resemblance matrix created from distances among centroids for the unique Year/Site combinations.

Abundance or percentage cover data of individual taxa (e.g. thecate tree hydroids) or groups of taxa (e.g. sea stars and brown, red and green algae) were plotted through time and also analysed using the same PERMANOVA design described in Table 2. For the Bray-Curtis similarity matrices, a dummy variable of 0.1 was used so that double zero data were treated as 100% similar.

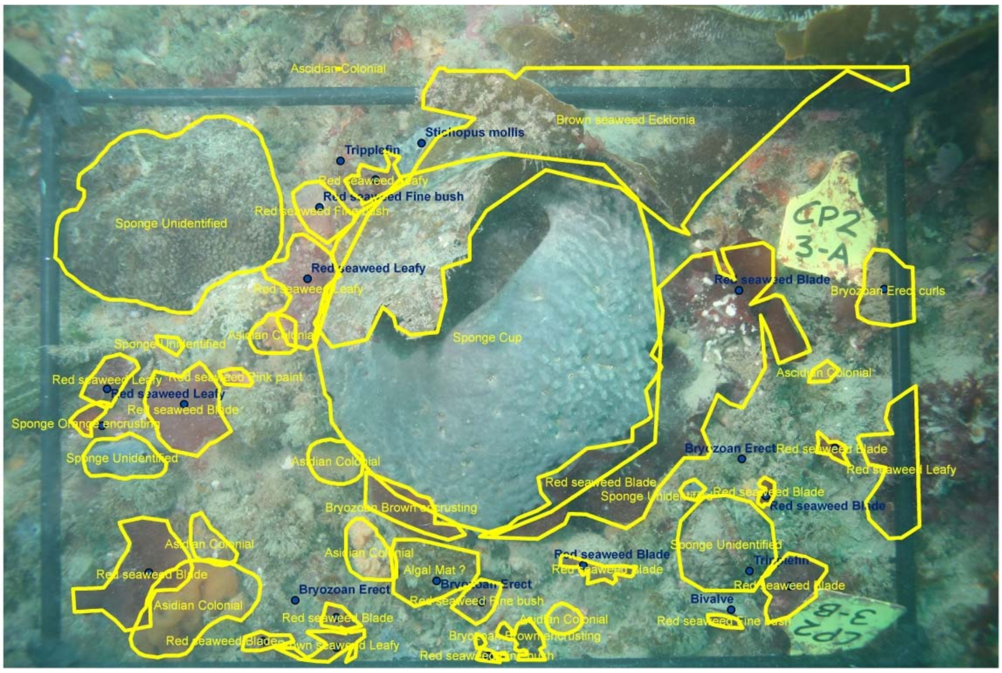


Figure 4. Example of photo-quadrat from a Clay Point reef monitoring site showing spatial analysis in ArcGIS.

Table 2. Designs of PERMANOVA analyses.

Analysis	Factor	Levels	Nested within	Type
CP	Year	8: 2007–2016		Fixed
	Treatment	2: Farm (CP1–CP3) and Reference (CP4)		Fixed
	Site	4: CP1–CP4	Treatment	Random
	Station	4: 1–4	Site	Random
CP and TP	Year	6: 2009–2016		Fixed
	Treatment	3: CP Farm (CP1–CP3), TP Farm (TP1, TP2) and Reference (CP4, TP3, TP4)		Fixed
	Site	8: CP1–CP4, TP1–TP4	Treatment	Random
	Station	4: 1–4	Site	Random
NB	Year	2: 2015–2016		Fixed
	Treatment	2: NB Farm (NB1, NB2, NB3) and reference (CP4, TP3, TP4, NB4).		Fixed
	Site	7: NB1, NB2, NB3, CP4, TP3, TP4, NB4	Treatment	Random
	Station	4: 1–4	Site	Random
WR	Year	2: 2015–2016		Fixed
	Treatment	2: WR Farm (WR1, WR2) and Reference (KB1, TT1, TT2).		Fixed
	Site	5: WR1, WR2, KB1, TT1, TT2	Treatment	Random
	Station	4: 1–4	Site	Random
RB	Year	2: 2015–2016		Fixed
	Treatment	2: RB Farm (RB1, RB2) and Reference (KB1, TT1, TT2).		Fixed
	Site	5: RB1, RB2, KB1, TT1, TT2	Treatment	Random
	Station	4: 1–4	Site	Random

2.4. Shallow subtidal and intertidal permanent transects

2.4.1. Sampling methods

For each shallow subtidal and intertidal site, the ends of two replicate 20 m transects were permanently marked with a pin cemented into the rock (Figure 5). The pins were identified with yellow cattle tags (marked with the site, transect number and transect end; e.g. NB1-1A or NB1-1B) and a float on a short nylon cord. For the subtidal transects, a lead-line (marked with a cattle tag every 5 m) was attached to the pins and laid along the transects to aid future relocation. Replicate transects are at the same approximate depth (approximately 5-7 m for subtidal transects) or tidal height (approximately 0 m MLW for intertidal transects), and are within 5 m alongshore of each other.

Five 1 m^2 quadrats were surveyed by divers at haphazard distances along the tape. For each quadrat the percent cover of seaweed and sessile invertebrates, and numbers of mobile invertebrates and triplefins was recorded. In addition, dominant habitat boundaries (e.g. seaweed, tubeworm mounds, sand or cobble areas) and the abundance of fish and large mobile invertebrates within 1 m of either side of the subtidal transects was recorded.

Video footage was taken along the subtidal transects, and photographs were taken along the intertidal transects. These provided a visual assessment with which potential future changes can be assessed.

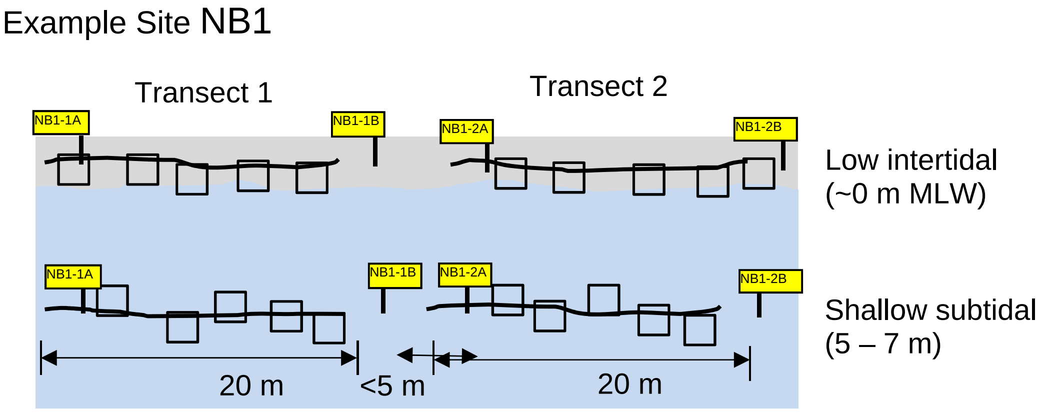


Figure 5. Schematic representation of the arrangement of the four transects that are set up at permanent transect sites in the low intertidal and shallow subtidal. There are two replicate 20 m transects per depth, and five random 1 m^2 quadrats are surveyed along each transect.

2.4.2. Analyses

For the quadrat data, abundance or percentage cover data of groups of taxa (e.g. sponges, echinoderms and brown, red and green algae) were plotted through time. Community assemblage data were analysed using PERMANOVA+ (in PRIMER v7, Anderson et al. 2008), under the same designs in Table 2. Data were also examined using non-metric multidimensional scaling (nMDS) on Bray-Curtis resemblance matrices based on average abundances per site. For the Bray-Curtis similarity matrices, a dummy variable of 0.1 was used so that double zero data were treated as 100% similar.

The numbers of large invertebrates (total numbers of gastropods and echinoderms, and *Evechinus chloroticus* - kina) and fish (total fish, *Notolabrus celidotus*—spotties, *Parapercis colias*—blue cod) observed along each transect were plotted through time.

2.5. Subtidal video transects

Video transects were obtained using a surface data-fed video, with a Seaviewer 6000 Sea-drop 1080p HD-SDI underwater video camera suspended just above the seabed. Transects ranged from 50 to 200 m in length. Footage was reviewed and archived for the assessment of any obvious changes in visual characteristics over time.

3. RESULTS & DISCUSSION

3.1. Permanent quadrats

Representative photographs from each of the reef sites are presented in Figure 8 through Figure 13. All other images are archived.

3.1.1. Visual assessment of images

Overall, photographs and video footage indicated that the reef communities at all farm sites were not obviously altered relative to reference locations. As observed in previous years, on average, various hydroids, sponges, ascidians and macroalgae were consistently present at both reference and potential impact sites. This study has highlighted the fact that some taxa can be very long-lived, with some sponges and hydroids present throughout all of the 9- or 7-year periods at CP and TP respectively. Whereas, other taxa, such as some ephemeral algae, were short-lived and abundances fluctuated between years.

Deposition-sensitive organisms situated at potential impact sites, such as sponges and hydroids, were present in similar numbers (Figure 8 to Figure 11). For example, the grey vase sponges depicted in CP2-3-L and TP1-3-L (Figure 8 and Figure 10), have been present since the monitoring first began. However, the sponge depicted in CP2-3-L (Figure 8) appeared to be contracted in 2011–2016, compared to 2007–2010 when it appeared to be more ‘inflated’. The sponge depicted in TP1-3-L also appears to have changed its shape and size (Figure 10). Sponges at reference sites also exhibited changes. For example, an orange sponge at TP3-3 and a blue sponge at TP4-1 both disappeared (Figure 11). The orange sponge was absent in 2015, and the blue sponge absent from 2013 onwards. It is not known whether these changes are related to changes in the environment (e.g. increased sedimentation), other anthropogenic or natural disturbances (e.g. fishing, recreational diving) or whether this is a natural process (e.g. age-related).

In 2016, dying and unhealthy *Ecionemia alata* (previously *Ancorina alata*) sponges were observed at Pelorus Sound reference site TT1. It is unknown what is affecting these sponges, but it could be a disease or bacterial infection (N. Keeley, pers. comm.). Some sponges had white areas on their surface, and others were completely decayed (Figure 6). This is not due to salmon farm effects (as it was observed at a reference site), but as recommended in last year’s report (Dunmore 2016), observations of sponge condition/health, and presence/absence should be made in future surveys.

Figure 6. Sponges (*Ecionemia alata*) at TT1 showing signs of decay (circled in red in top images) and (bottom) a healthy sponge in one of the permanent quadrats (TT1-4) in 2015, with the remnants in 2016.

The most obvious overall visual change across all sites through years was the change in abundances of macroalgae. Red and brown macroalgal cover appeared to have declined in 2012 and 2013 at both reference and potential impact sites, but cover increased again in 2014 and/or 2015-2016. This was most apparent at the TP sites, which generally contained more algae. There were also noticeable changes in the abundances of large brown algae such as *Undaria pinnatifida* and *Ecklonia radiata*, and smaller taxa such as *Desmarestia ligulata*. These changes in macroalgal cover appear to be natural fluctuations in abundances, rather than due to farm-related effects.

Mobile invertebrates such as brittle stars (*Ophiopsammus maculata*), cushion stars (*Patiriella regularis*), kina (*Evechinus chloroticus*) and sea cucumbers (*Australostichopus mollis*) did not show changes in abundances consistent with a farm-related effect. Similar temporal changes were observed at both reference and farm sites. Kina occurrence appeared to be related to the presence/absence of drift algae upon which they feed (e.g. see CP3-2, Figure 9). Interestingly, duck's bill limpets *Scutus breviculus* (a mobile invertebrate) were present in the stations at

TP2-1 and TP2-2 (usually in the same quadrat[3], Figure 10) from 2009–2016. This is another example of the longevity of a species and also sheds light on the habitual / residential nature of this mobile invertebrate.

As noted in previous years, the seabed inshore of TP2 (a farm site) appeared to be enriched, evidenced by an algal film on surface sediments, with dark, partially anaerobic sediments underneath. *Ulva* sp. (sea lettuce) was abundant inshore and at TP2. Despite this apparent enrichment, the TP2 reef community appeared healthy and diverse, containing a normal array of sponges, hydroids, ascidians, mobile invertebrates (e.g. sea stars, kina), and abundant macroalgae such as the brown algae *Ecklonia radiata*, *Macrocystis pyrifera* and *Carpophyllum* spp., and numerous red algal species.

While abundances of tree hydroid colonies were maintained in some quadrats, declines in abundances and / or recruitment were observed in others, and this was evident across both reference and potential impact sites. Some hydroids were lost through time from the potential impact sites CP1, CP2, TP1 and TP2, but also from reference sites CP4 and TP4. Importantly, recruitment and/or growth of existing hydroids were observed at potential impact sites. In some cases, the differences amongst years may be partly an artefact of the sampling method due to slight variations in the precise location of the quadrat and the flow of the currents while sampling (i.e. the tree hydroids may appear larger if the colony was tall and positioned close to the camera lens and smaller if it was near the edge and extended outside the frame). Given that losses were also apparent at the reference sites, and recruitment was observed at potential impact sites, it can be assumed that the variations in tree hydroid abundance are natural fluctuations and not attributable to farm impacts.

At one site, CP1, fishing line was observed covering a large area of seabed. The line was wrapped around many of the tree hydroids present at the site (Figure 7), and some of the hydroids appeared damaged and detached from the substrate. This certainly caused the removal of several hydroids.

---

[3] Although the duck's bill limpet was not in the same quadrat in TP2-2 in 2016, it was present in the adjacent (left) quadrat.

Figure 7. Fishing line entangled around tree hydroids at CP1.

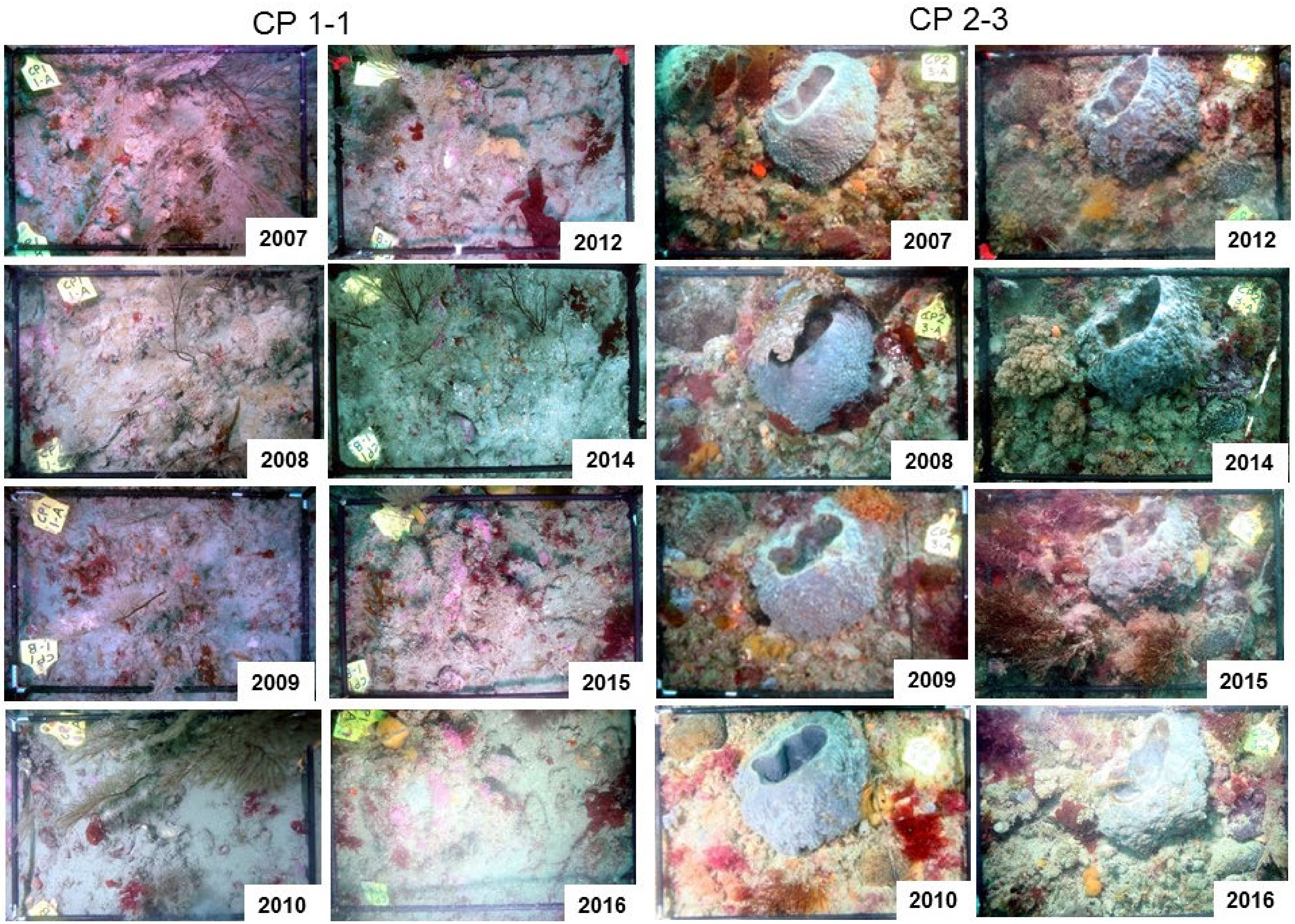


Figure 8. Representative photos from the near-farm CP-1 and CP-2 reef monitoring sites, taken during the baseline survey (2007 pre-farm), and after approximately one–to-nine years of operation (2008–2016).

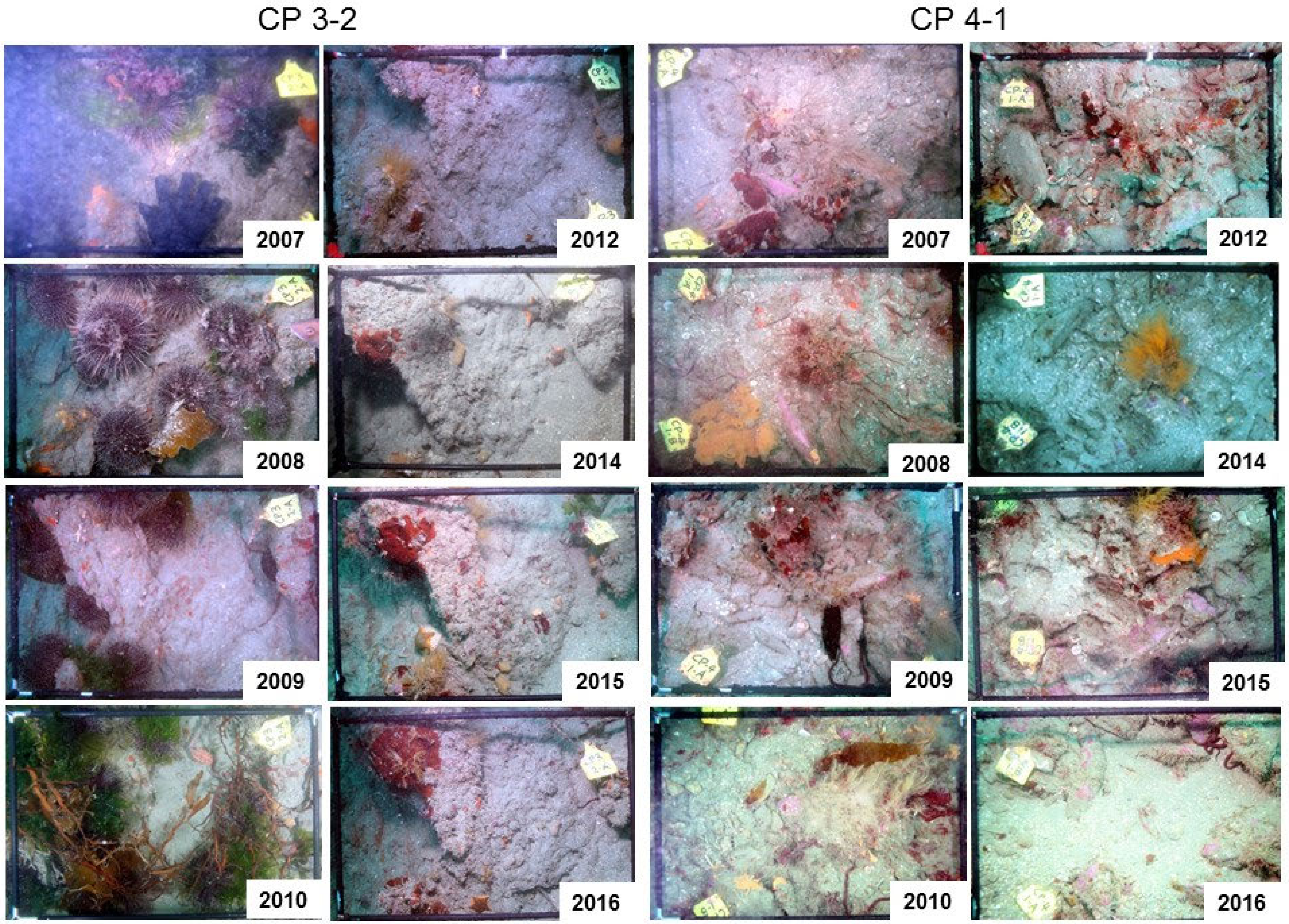


Figure 9. Representative photos from the near-farm CP-3 and reference CP-4 reef monitoring sites, taken during the baseline survey (2007 pre-farm), and after approximately one-to-nine years of operation (2008–2016).

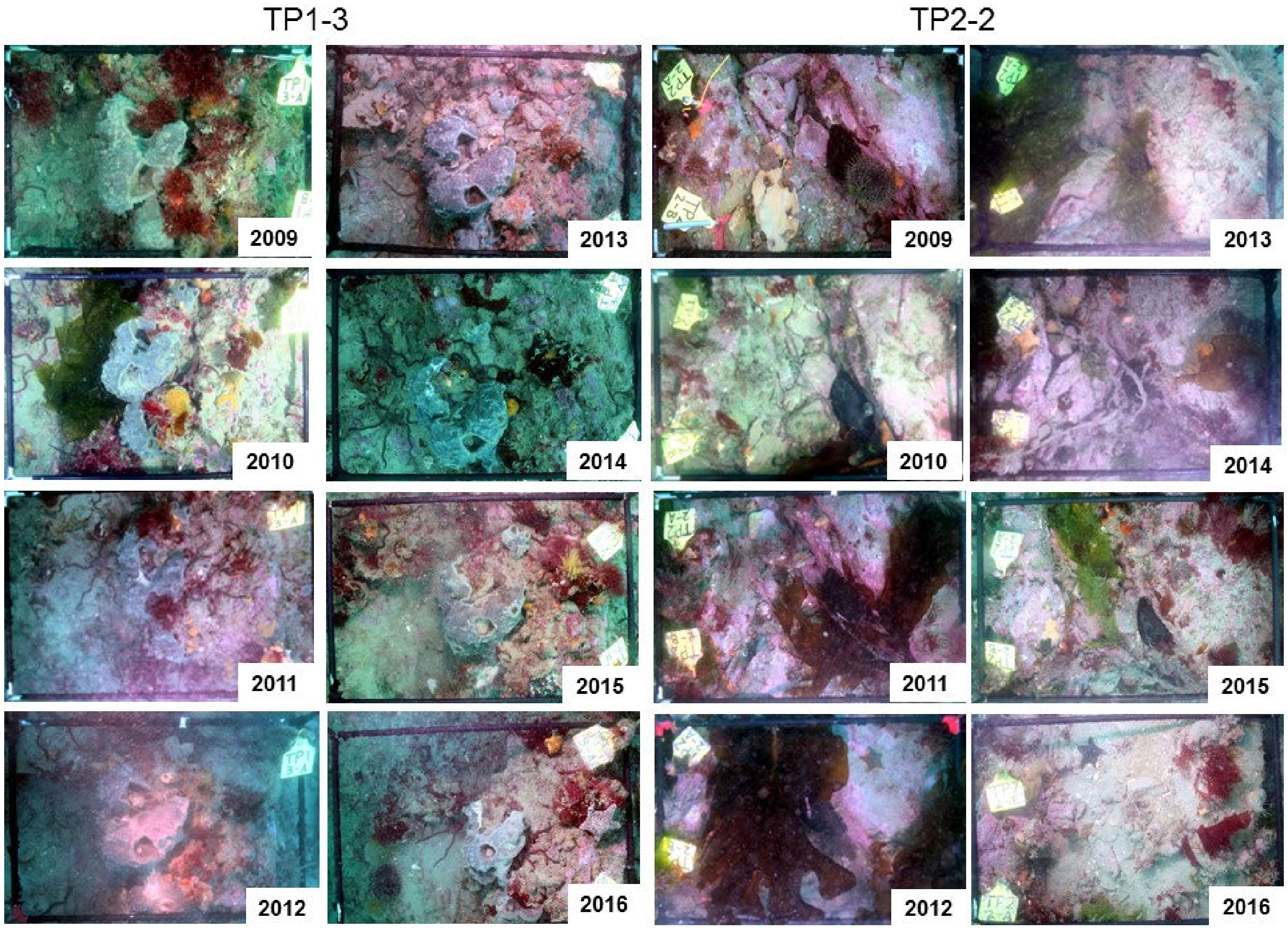


Figure 10. Representative photos from the near-farm TP-1 and TP-2 reef monitoring sites, taken during the baseline survey (2009, prior to feed increase), and after approximately one-to-seven years of operation (2010-2016).

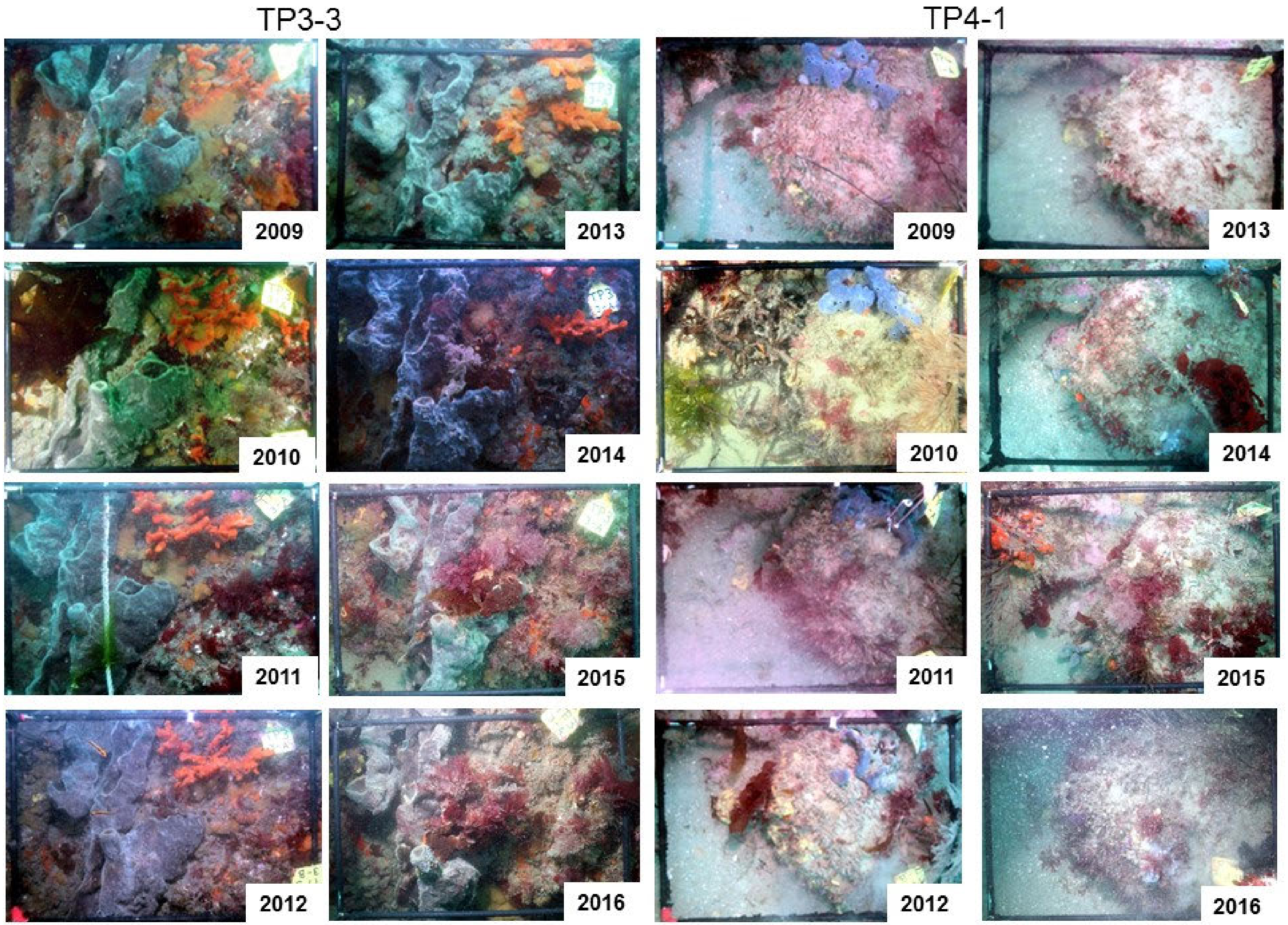


Figure 11. Representative photos from the reference TP-3 and TP-4 reef monitoring sites, taken during the baseline survey (2009, prior to feed increase), and after approximately one-to-seven years of operation (2010-2016).

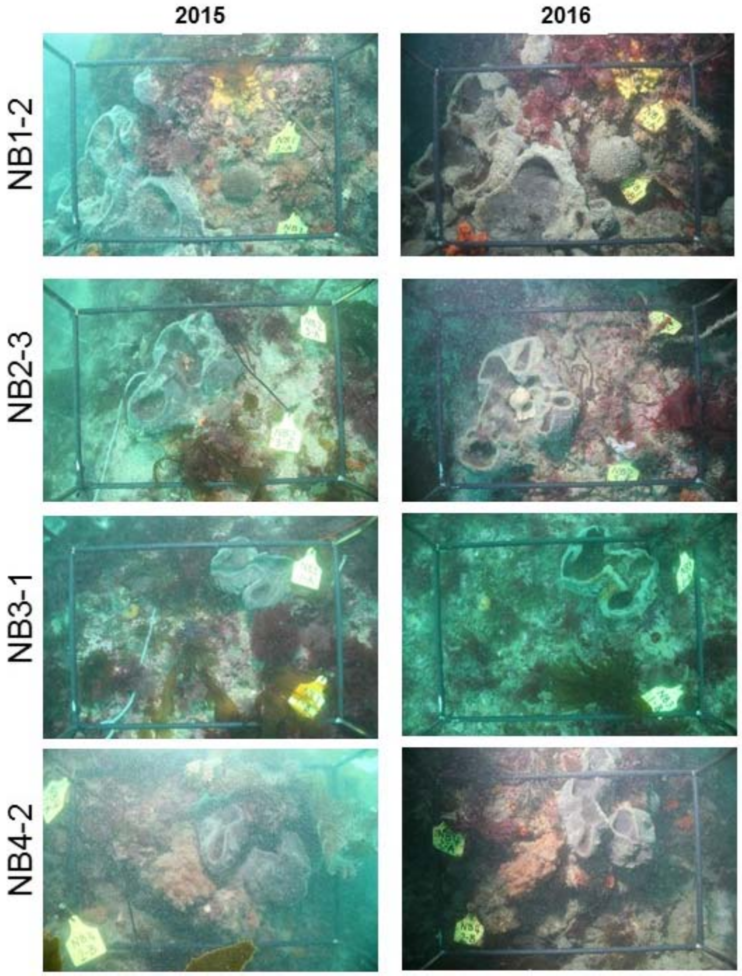


Figure 12. Representative photos from the near-farm NB-1, NB-2 and NB-3, and reference NB4 reef monitoring sites, taken during the baseline survey (2015, prior to feed increase), and after approximately one year of operation (2016).

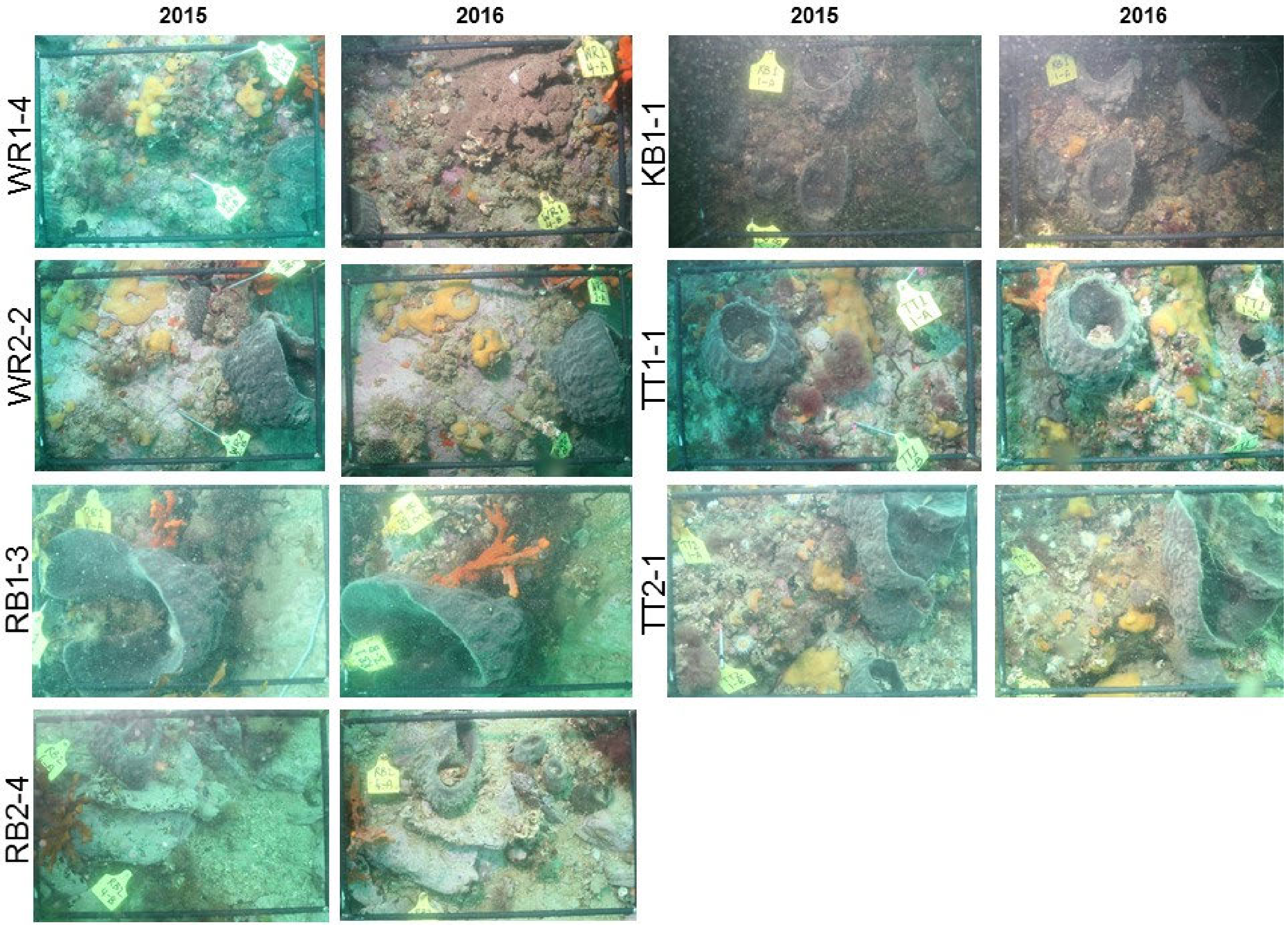


Figure 13. Representative photos from the near-farm WR-1, WR-2, RB-1 and RB-2, and reference KB-1, TT-1 and TT-2 reef monitoring sites, taken during the baseline survey (2015, prior to feed increase), and after approximately one year of operation (2016).

3.1.2. Analysis of overall community assemblages

Results of the quantitative analyses of the reef communities at Clay Point and Te Pangu were similar to the previous analyses in 2012 and 2014, in that the data did not show changes consistent with a farm-related impact. Analyses of data from the new farms Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) also did not show farm-related effects.

Clay Point

PERMANOVA results for CP 2007–2016 community assemblage data, comparing sites through time showed that Year, Site(Treatment), Station(Site(Treatment)) and Year×Site(Treatment) were highly significant ($p = 0.0001$) (Table 3, Appendix 4). This indicates that Stations were very different from each other, and that one or more Sites changed differently through time (i.e. Year). However, importantly, the Year×Treatment interaction (indicative of farm-related changes) was not significant. Pairwise comparisons revealed that all of the sites had some years that were significantly different ($p < 0.05$) to other years (Table 4). These differences in the way the sites change through time explain the significant Year×Site(Treatment) interaction.

Principal coordinates analysis (PCO) of distances among centroids illustrates the differences between sites and years based on the whole community data (Figure 14). The vector overlay shows the taxa that defined the different sites in different years. For example, CP1 was characterised by hydroid trees (*Solandaria* sp.), colonial ascidians and red algae (encrusting corallines, blades and leafy). CP2 communities were characterised by red algae, colonial ascidians and sponges. CP3 and CP4 had more sea stars. While there was variability between years within sites, communities at the reference site were more variable than those at the farm sites, and there was not an overall directional change.

Table 3. Summary of PERMANOVA results for Clay Point farm (CP; 2007–2016), CP and Te Pangu farm (TP; 2009–2016), and Ngamahau Bay (NB), Waitata Reach (WR) and Richmond Bay (RB, Kopaua) (2015-2016) epibiota community data. P values: * < 0.05, ** < 0.01, *** < 0.001. Refer to Appendix 1 for full results. Dark grey shaded rows indicate analyses were not done due to insufficient abundance of those taxa.

Source	Whole community data	Sea stars	Tree Hydroids	Sponges	Ascidians	Encrusting bryozoans	All foliose algae	Brown foliose algae	Red foliose algae	Green foliose algae	Triplefins
Clay Point											
Year	***		***				***	*	***		
Treatment					***						*
Site(Treatment)	***	*	***	*			***	***	***		
Year×Treatment			**								
Station(Site(Treatment))	***	**	**	***	***	**	***	*	***		
Year×Site(Treatment)	***						***	***	***		
Clay Point and Te Pangu											
Year	***	***	*		*	*	***	***	***		
Treatment											**
Site(Treatment)	***	***	***	*	***	*	***	***	***	***	
Year×Treatment											
Station(Site(Treatment))	***	***	***	***	***	***	***	*	***		
Year×Site(Treatment)	***	***	**		**		***	***	***		
Ngamahau Bay											
Year	*		▨							▨	
Treatment			▨	*		*				▨	
Site(Treatment)	***	*	▨		*		***	***	***	▨	
Year×Treatment			▨							▨	
Station(Site(Treatment))	***		▨	***		**		*		▨	
Year×Site(Treatment)	***	*	▨				***	***	***	▨	
Waitata Reach											
Year	*		▨			*				▨	
Treatment			▨							▨	
Site(Treatment)	***	***	▨		***		**		*	▨	
Year×Treatment			▨							▨	
Station(Site(Treatment))	***		▨	***						▨	
Year×Site(Treatment)	**		▨		***					▨	
Richmond Bay (Kopaua)											
Year			▨							▨	
Treatment			▨							▨	
Site(Treatment)	***	**	▨		**		***			▨	
Year×Treatment			▨							▨	
Station(Site(Treatment))	***		▨	***			*	**		▨	
Year×Site(Treatment)			▨		*		**			▨	

Table 4. Significant ($p < 0.05$) pairwise tests for the term Year×Site(Treatment), for pairs of levels of the factor Year for overall community assemblages at CP.

Site	**Year**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
CP1	2008									
	2009									
	2010									
	2011									
	2012									
	2013				*					
	2014						*			
	2015	*			*		*	*	*	
	2016									*
CP2	2008									
	2009									
	2010	*								
	2011	*								
	2012									
	2013				*	*				
	2014				*					
	2015					*		*	*	
	2016	*								
CP3	2008									
	2009									
	2010									
	2011									
	2012									
	2013									
	2014									
	2015									
	2016			*				*		
CP4	2008									
	2009									
	2010									
	2011									
	2012									
	2013	*	*			*				
	2014		*			*				
	2015		*					*		
	2016									

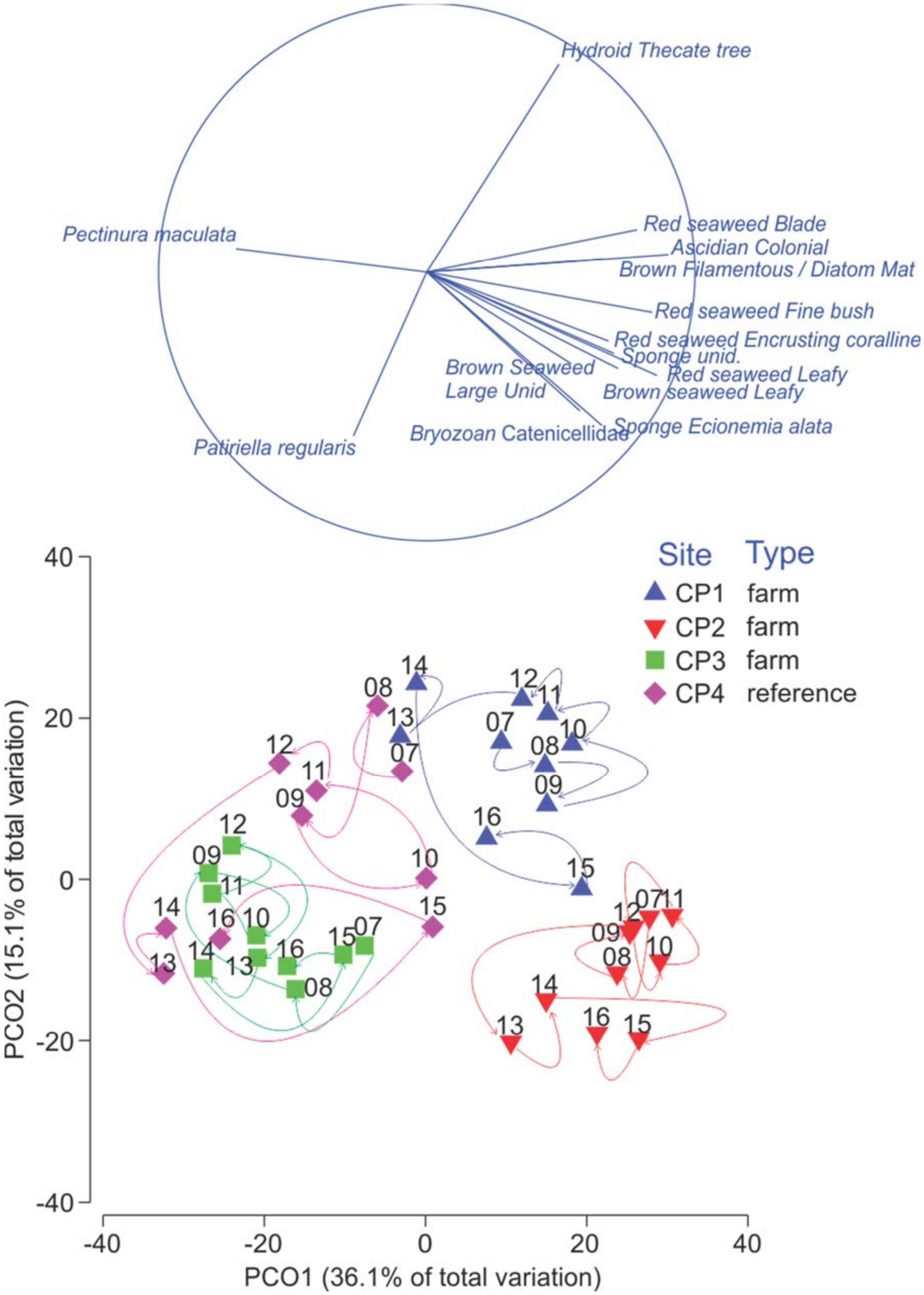


Figure 14. Principal coordinates analysis (PCO) of distance among centroids for Clay Point (CP) farm and reference sites from 2007–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.6 correlation.

Clay Point and Te Pangu

PERMANOVA analysis of CP and TP epibiota community data from 2009–2016, comparing sites through time, showed that Year, Site(Treatment), Station(Site(Treatment)) and Year×Site(Treatment) were highly significant (p=0.0001; Table 3, Appendix 4), and this is consistent with the CP analysis above. This indicates that Stations were different from each other, and that one or more Sites changed through time (i.e*.* Year) differently to the others. The Year×Treatment interaction (indicative of farm-related changes) was not significant for any of the variable groupings. Pairwise comparisons revealed that all sites, with the exception of TP3, had some years that were significantly different ($p < 0.05$) to other years (Table 5), but no trends consistent with a permanent ecological change / shift in community composition.

Principal coordinates analysis (PCO) of distances among centroids (Figure 15) shows that CP3 and CP4 were different to the other sites. This was expected, as CP3 and CP4 were sandier than the other sites, and had lower abundances of the taxa that defined the other sites. The other sites generally had greater cover of algae, with TP2 and 3 characterised by more *Undaria pinnatifida* and red algae. CP1 was characterised by higher numbers of hydroid trees (*Solandaria* sp.). As found for the CP analysis, there were no clear directional changes with time that would indicate a farm-related effect; communities at both farm and reference sites had the same directional change. This indicates the changes occur over a larger spatial scale and likely reflect natural variability.

Table 5. Significant ($p < 0.05$) pairwise tests for the term Year×Site(Treatment) for pairs of levels of the factor Year for overall community assemblages at CP and TP. Note: there were no significant interactions for TP3.

Site	**Year**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
CP1	2010							
	2011							
	2012							
	2013		*					
	2014				*			
	2015		*		*	*	*	
	2016				*		*	*
CP2	2010							
	2011							
	2012							
	2013		*	*				
	2014		*	*				
	2015			*		*	*	
	2016							
CP3	2010							
	2011							
	2012							
	2013							
	2014							
	2015	*						
	2016	*				*		
CP4	2010							
	2011							
	2012							
	2013			*				
	2014			*				
	2015					*		
	2016							
TP1	2010							
	2011							
	2012							
	2013	*	*					
	2014	*						
	2015					*		
	2016	*	*		*			
TP2	2010							
	2011							
	2012							
	2013				*			
	2014							
	2015							
	2016							
TP4	2010							
	2011							
	2012							
	2013	*	*	*				
	2014							
	2015					*		
	2016					*		

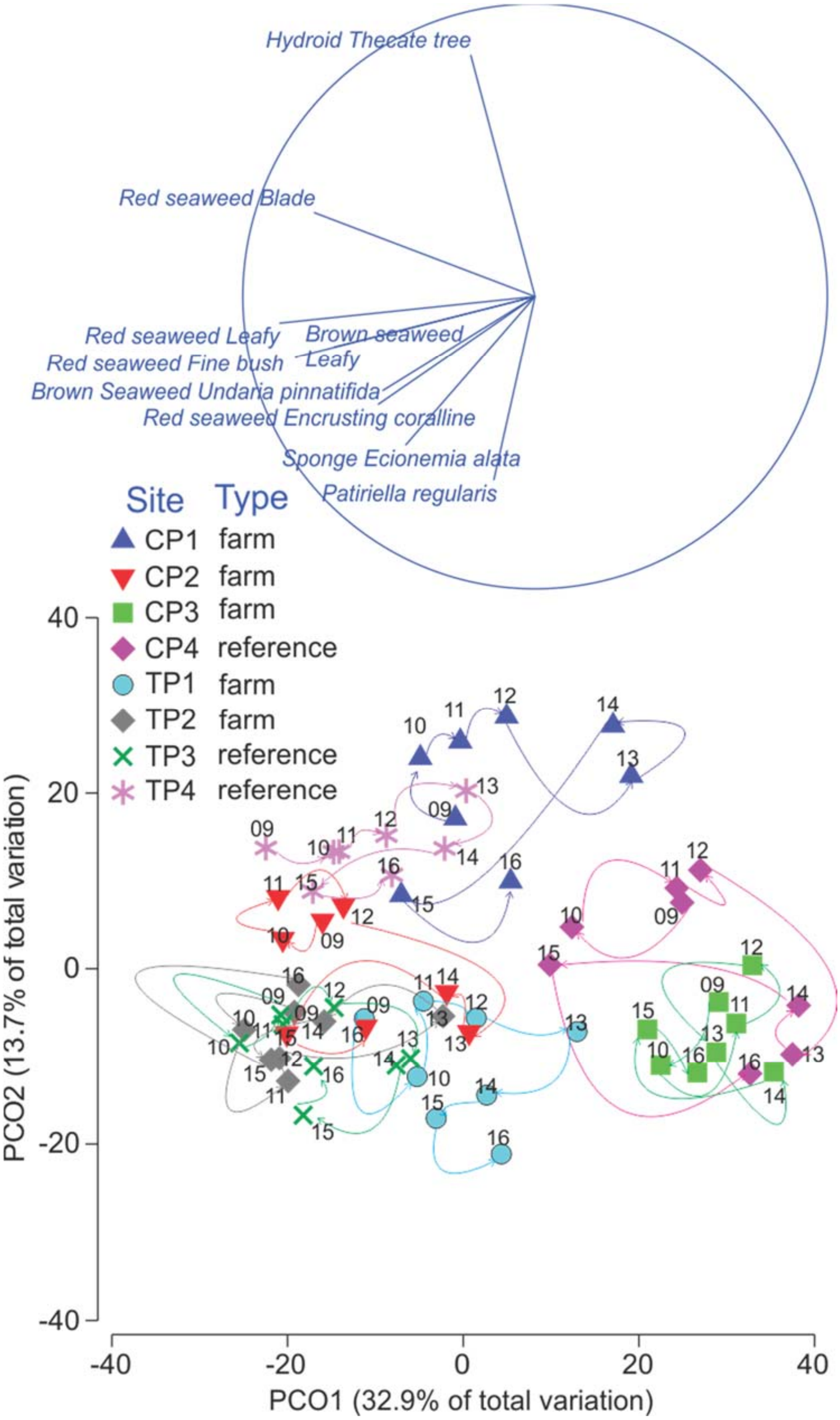


Figure 15. Principal coordinates analysis (PCO) of distance among centroids for Clay Point (CP) and Te Pangu (TP) farm and reference sites from 2009–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.6 correlation.

Ngamahau Bay, Waitata Reach and Richmond Bay

PERMANOVA analysis of NB and WR community data from 2015–2016, comparing sites through time, showed that Year, Site(Treatment), Station(Site(Treatment)) and Year×Site(Treatment) were significant (Table 3, Appendix 4). This is consistent with the analyses of only CP data and CP and TP data combined. This indicates that Stations were different from each other, and that one or more Sites changed through time (i.e. Year) differently to the others. PERMANOVA analysis of the RB data revealed Site(Treatment) and Station(Site(Treatment)) as significant factors (Table 3, Appendix 4), meaning that the Sites and Stations were different from each other. Importantly, the Year×Treatment interaction (indicative of farm-related changes) was not significant for NB, WR and RB.

Pairwise comparisons revealed that some of the NB and WR farm and reference sites were significantly different ($p < 0.05$) in 2015 and 2016 (Table 6). These differences in the way the sites change through time explain the significant Year×Site(Treatment) interaction for NB and WR (Table 3). RB farm sites were not significantly different between years.

Principal coordinates analysis (PCO) of distances among centroids for NB, WR and RB (Figure 16 to Figure 18) showed in general, similar variability in communities between years at both reference and farm sites. The largest variability between years occurred at the Pelorus Sound reference site KB1. There were no directional changes in communities that would be associated with effects from the farms.

Table 6. Significant ($p < 0.05$) pairwise tests for the term Year×Site(Treatment) for pairs of levels of the factor Year for overall community assemblages at NB, WR and RB.

Area	Type	Site	Year	2015
Tory Channel	farm	NB1	2016	
		NB2	2016	*
		NB3	2016	*
	reference	NB4	2016	*
		TP3	2016	
		TP4	2016	
		CP4	2016	
Pelorus Sound	farm	WR1	2016	*
		WR2	2016	
		RB1	2016	
		RB2	2016	
	reference	TT1	2016	
		TT2	2016	*
		KB1	2016	*

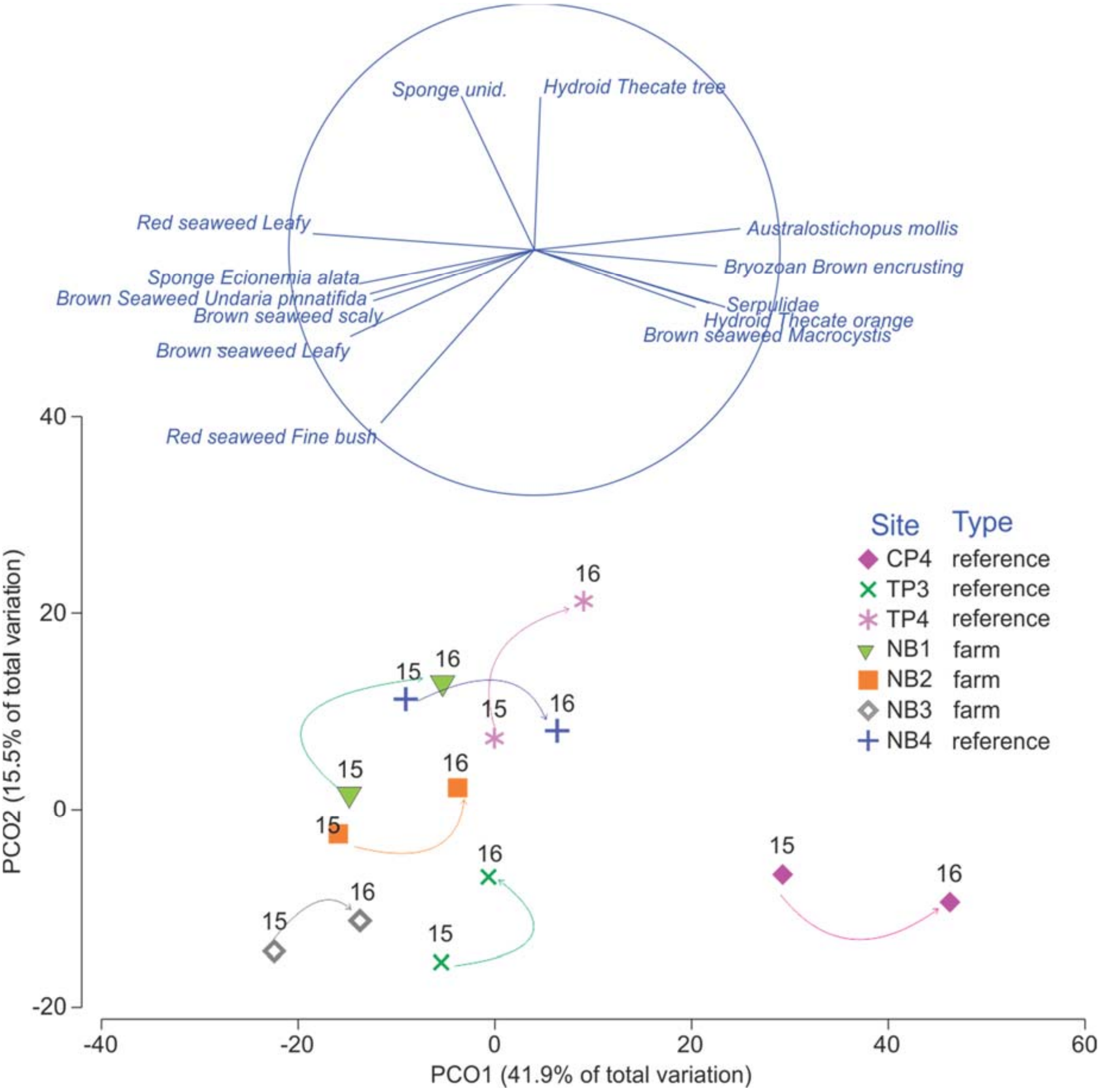


Figure 16. Principal coordinates analysis (PCO) of distance among centroids for Ngamahau Bay (NB) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.6 correlation.

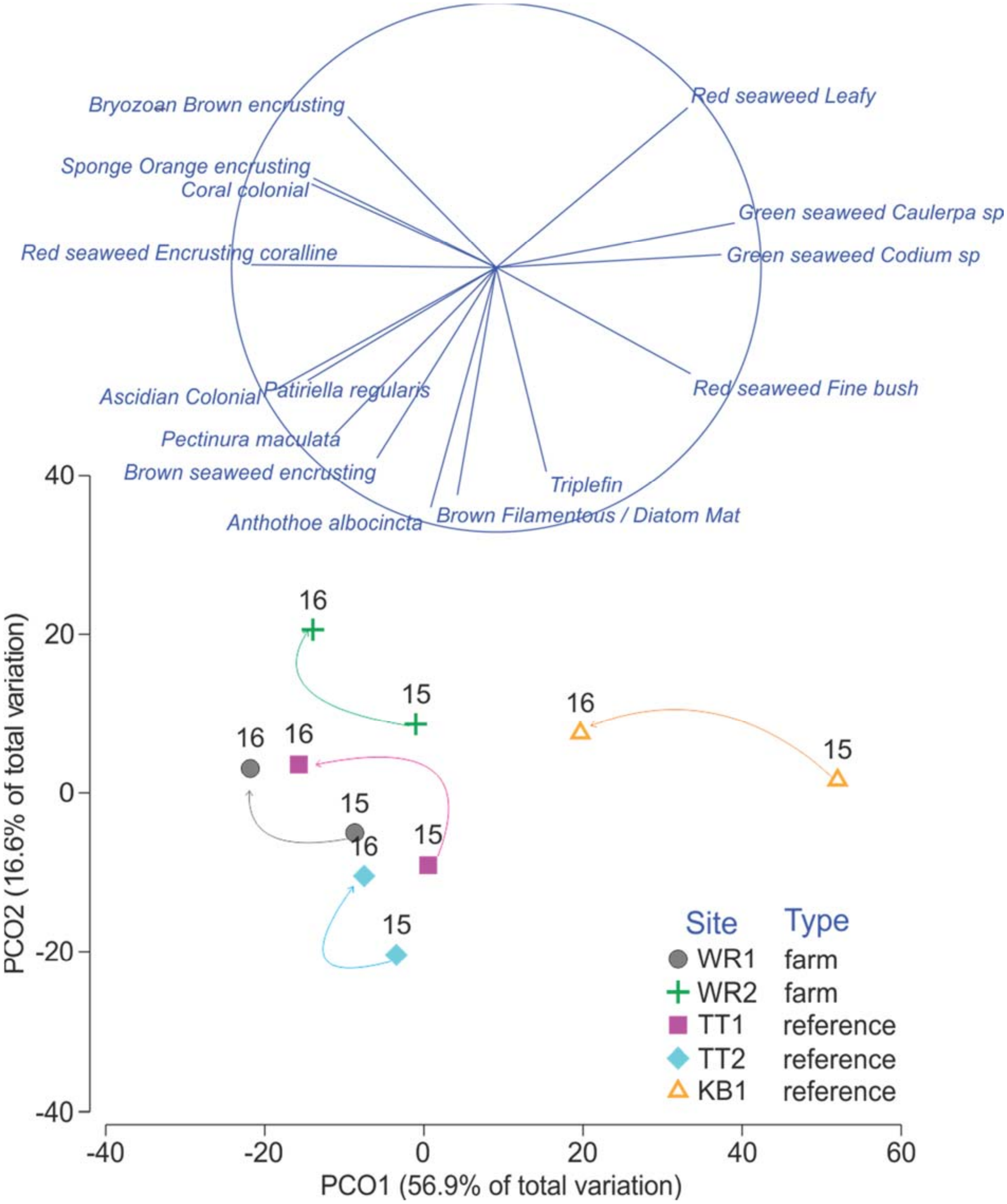


Figure 17. Principal coordinates analysis (PCO) of distance among centroids for Waitata Reach (WR) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.7 correlation.

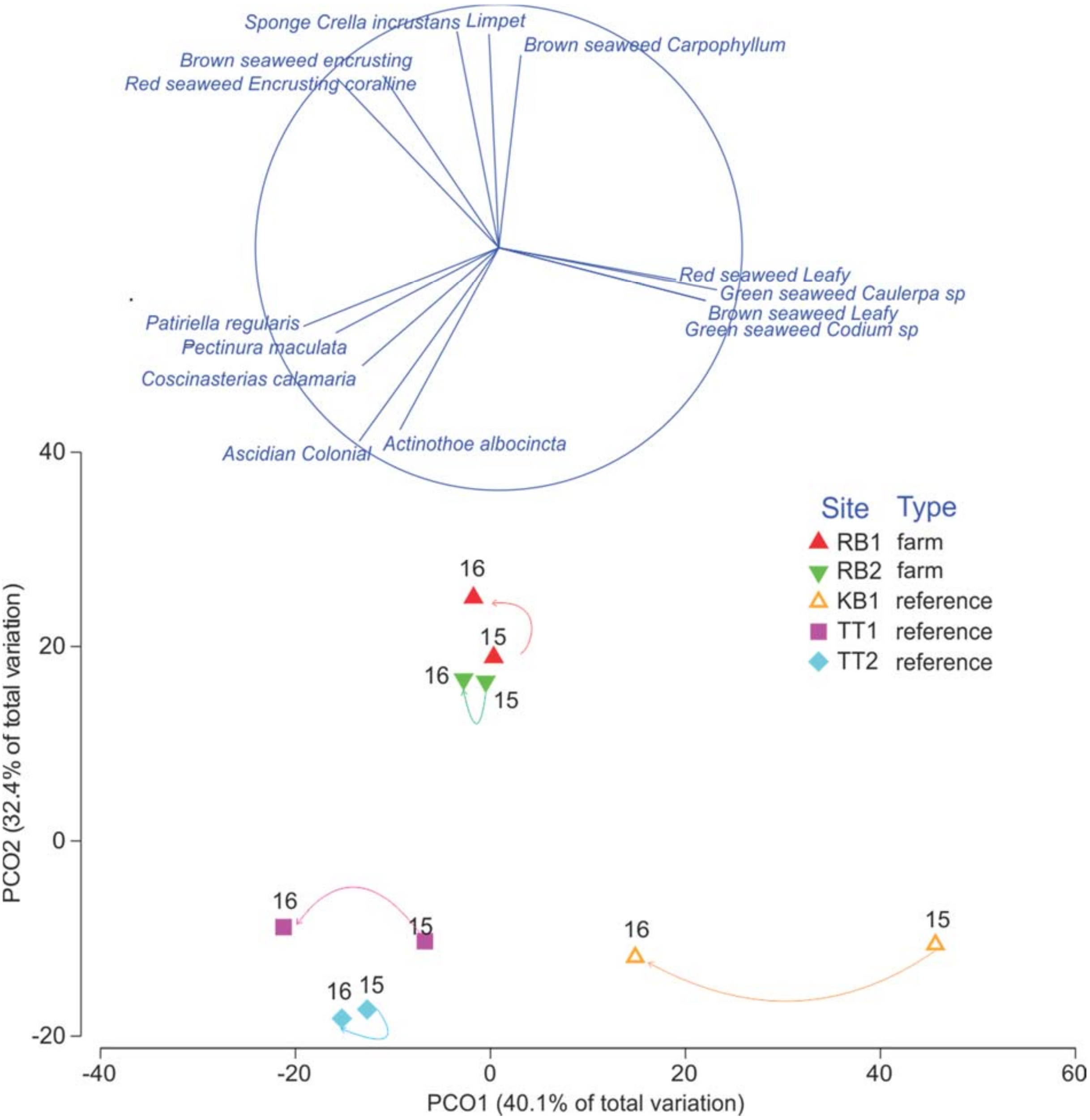


Figure 18. Principal coordinates analysis (PCO) of distance among centroids for Richmond Bay (RB) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.7 correlation.

3.1.3. Analysis of individual taxa and taxa groups

There were no obvious trends in abundances or percentage cover of individual or groups of taxa consistent with a farm-related effect (Figure 19 to Figure 26). Taxa abundances and cover were temporally variable and large fluctuations in time were apparent, but this was generally observed at both farm and reference sites. The most noticeable changes were in foliose algal cover, with declines across all CP and TP sites in 2011 or 2012 and a subsequent increase from 2014 to 2016 (Figure 19). This was particularly evident in red algal cover.

PERMANOVA results for CP (2007–2016), CP and TP data (2009–2016) and NB, WR and RB data (2015-2016) for individual and groups of taxa often had significant Site(Treatment) and Station(Site(Treatment)) terms (Table 3, Appendix 4). This indicates a large spatial variability at this scale, with Sites and Stations being very different from each other. Taxa that had significant Year terms in the CP and TP analyses had years that were significantly different from each other, and this is not unusual given that the surveys encompassed a long timeframe.

Total, red and brown foliose algae had significant Year×Site(Treatment) interaction terms in both the CP, CP and TP, and NB analyses (Table 3, Appendix 4). For the CP, and CP and TP analyses, there had been a decline in total foliose algae in 2012-2013, but percentage cover increased in 2014-2016 (Figure 19). This was reflected in the red foliose algal abundances, and was also generally evident in brown foliose algal abundances. Green foliose algae were present in much lower abundances and did not show the same trend. For the NB analysis, there was lower brown foliose algae in 2016 at a farm (NB2) and a reference site (NB4), and red algae increased at the reference sites TP3 and TP4 (Figure 19, Figure 20). Algal cover was generally similar across years for other sites at NB, WR and RB.

Sea stars did not show any obvious trends at farm and reference sites, but there had been an increase in numbers at TP1 (Figure 21). This was driven by an increase in the number of brittle stars, and numbers have approximately doubled since 2009. The cushion star *Patiriella regularis* was present at all sites, but did not show any trend through time. There were no overall trends observed in sea star abundances at NB, WR or RB (Figure 22).

There were no trends in sponge and ascidian cover at any of the sites surveyed (Figure 23, Figure 24). Ascidians were less abundant at the reference site CP4, which explained the significant Treatment term for the CP analysis. Encrusting bryozoans increased in percentage cover at three farm sites (CP1, CP3 and TP1) (Figure 23). With the exception of TP1, these changes were small in terms of overall cover (~1-2%). There were also increases in percent cover of encrusting bryozoans at NB and WR farm and reference sites in 2016 (Figure 24).

Tree hydroids were present at the CP and TP sites (except for at CP3 and TP3), but were only present at NB1 for the new sites (hence they were not plotted for the new sites). There was no obvious trend in abundances of tree hydroid colonies at CP and TP sites, but average numbers varied by 1–2 individuals each year (Figure 25). This variability was observed at both reference and farm sites. Differences amongst years may be partly an artefact of the sampling method; slight variations in the precise location of the quadrat and the flow of the currents while sampling could exclude some marginally positioned tree hydroids. At CP1, the presence of a large amount of fishing line caused some hydroids to be damaged and detached from the substrate. Some hydroid trees have also been inadvertently broken off when searching for the locator pins or during placement of the camera quadrat by divers.

Tree hydroids in the CP analysis were the only taxa that had significant Year×Treatment interaction terms (Table 3, Appendix 4). Pairwise comparisons showed that most of the variability was in the reference site (CP4), and that the years that were significantly different were generally when there were no hydroid trees present.

For the CP (2007–2016), and CP and TP data (2009–2016) triplefins had significant Treatment terms. This means that the farm (CP or TP) or reference sites had consistently different abundances of these taxa. Pairwise comparisons showed that the CP farm sites were significantly different from the reference sites. However, the Year×Treatment interaction was not significant, so the farm and reference sites were not changing differently through time. There was no trend in triplefin abundances at farm or reference sites at the new farm sites (Figure 26).

.

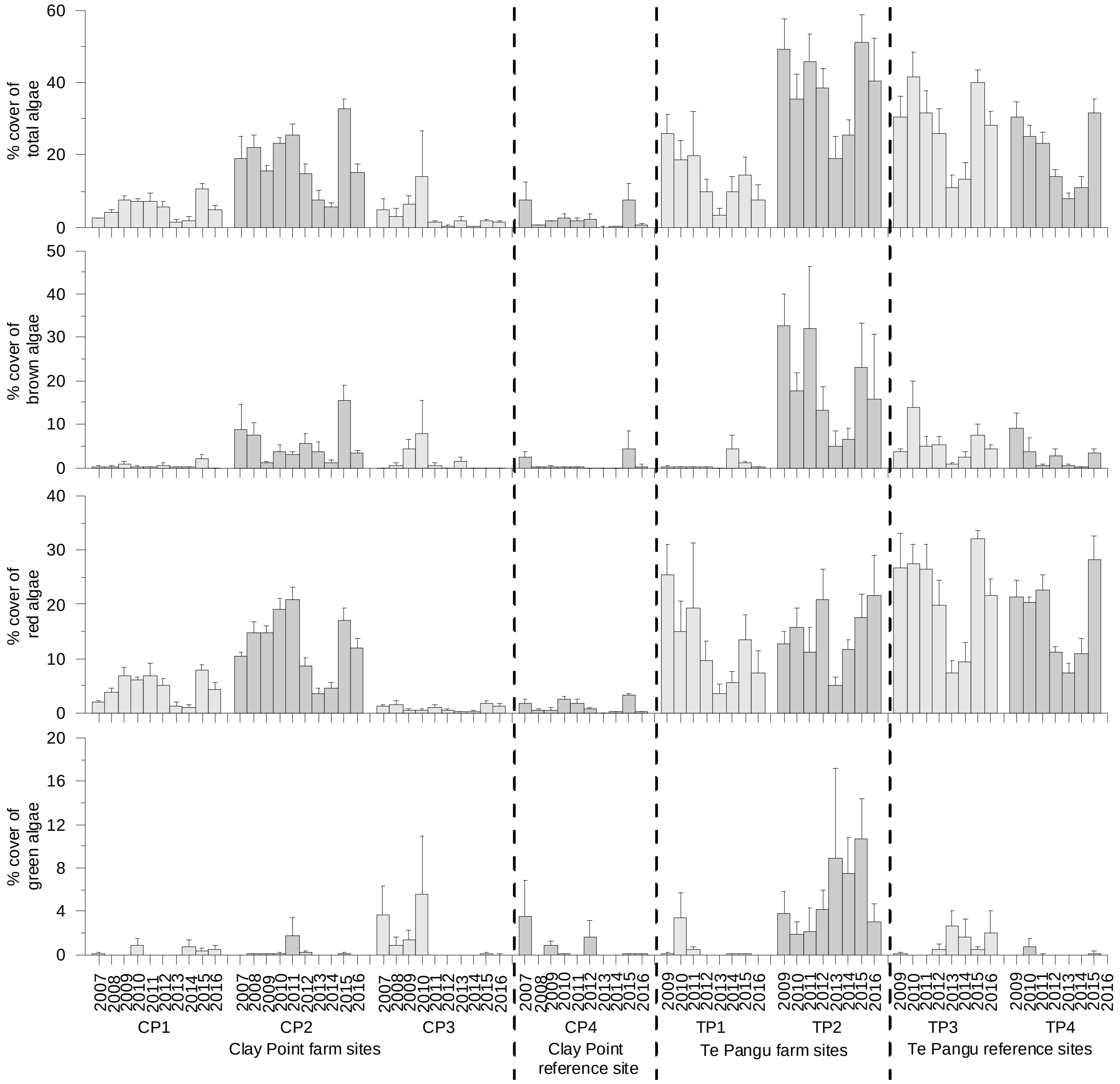


Figure 19. Percentage cover of foliose algae through time at the Clay Point (CP) and Te Pangu (TP) farm and reference sites. Note: n = 4 with the exception of n = 3 for CP1 2001 and CP3 2008 and 2010; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

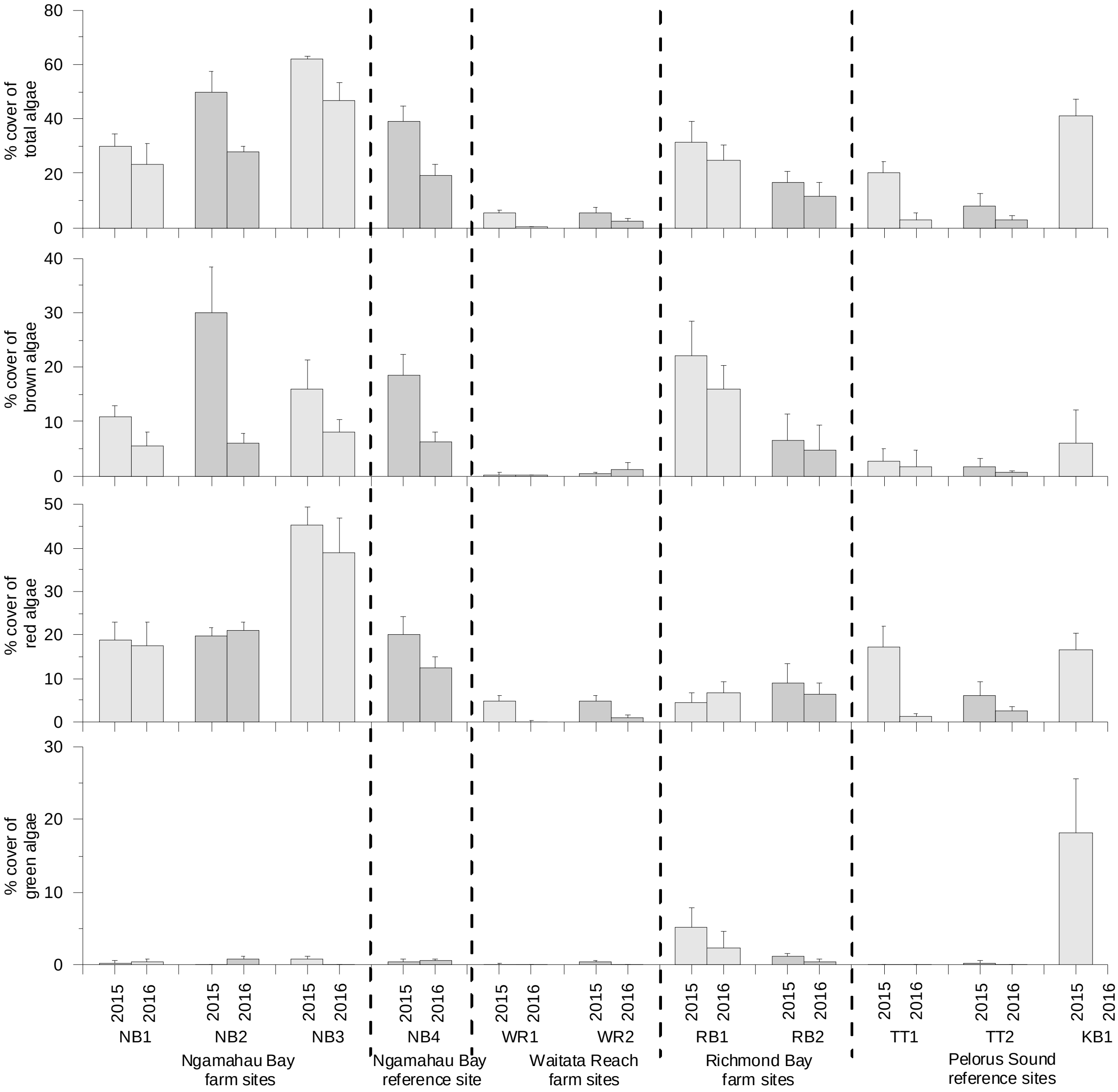


Figure 20. Percentage cover of foliose algae through time at the Ngamahau Bay (NB), Waitata Reach (WR) and Richmond Bay (RB) farm and reference sites. Note: n = 4 with the exception of n = 5 for NB4; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

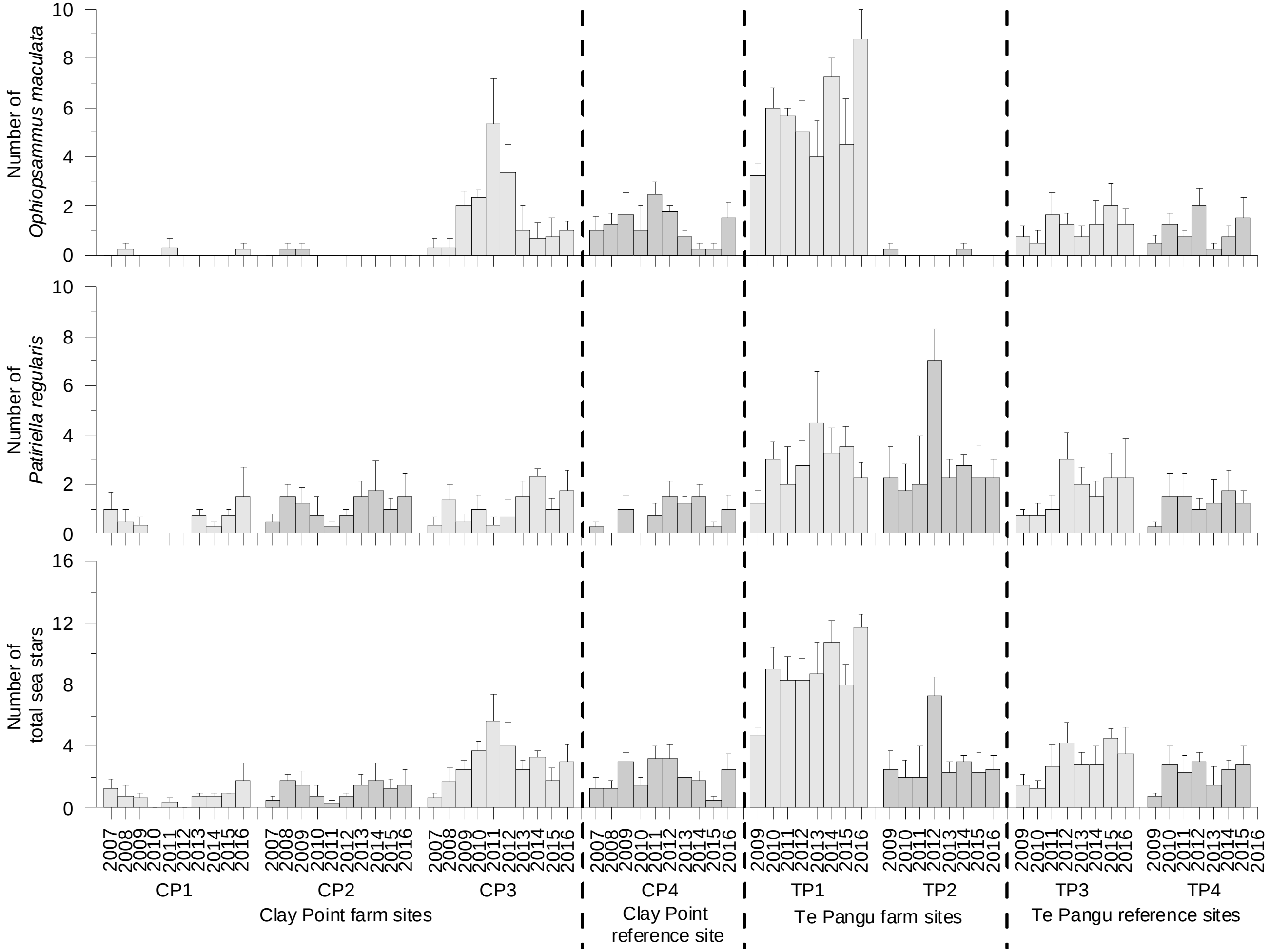


Figure 21. Abundances of sea stars through time at the Clay Point (CP) and Te Pangu (TP) farm and reference sites. Note: n = 4 with the exception of n = 3 for CP1 2001 and CP3 2008 and 2010; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

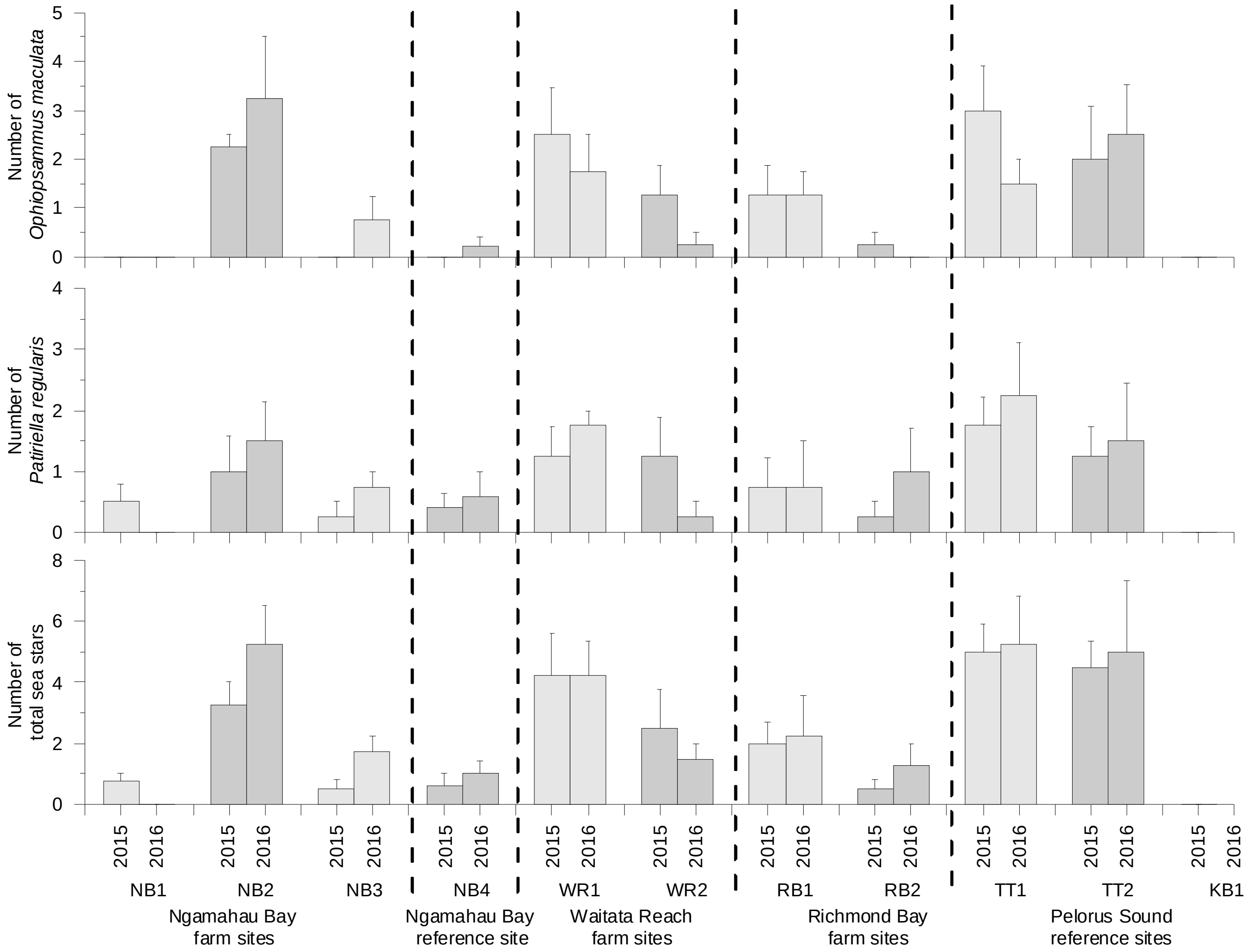


Figure 22. Abundances of sea stars through time at the Ngamahau Bay (NB), Waitata Reach (WR) and Richmond Bay (RB) farm and reference sites. Note: n=4 with the exception of n=5 for NB4; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

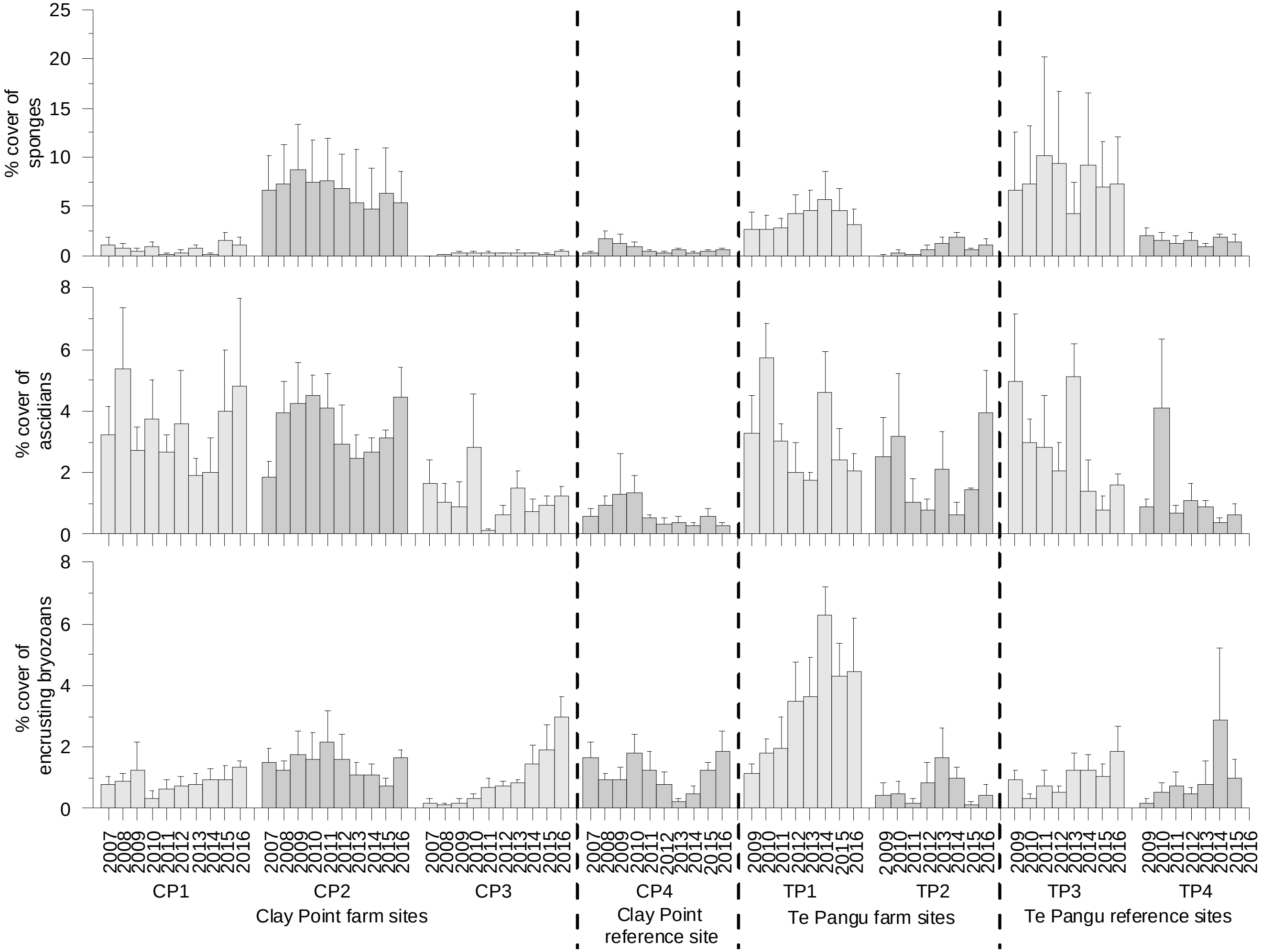


Figure 23. Percentage cover of sponges, ascidians and encrusting bryozoans through time at the Clay Point (CP) and Te Pangu (TP) farm and reference sites. Note: n=4 with the exception of n=3 for CP1 2001 and CP3 2008 and 2010; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

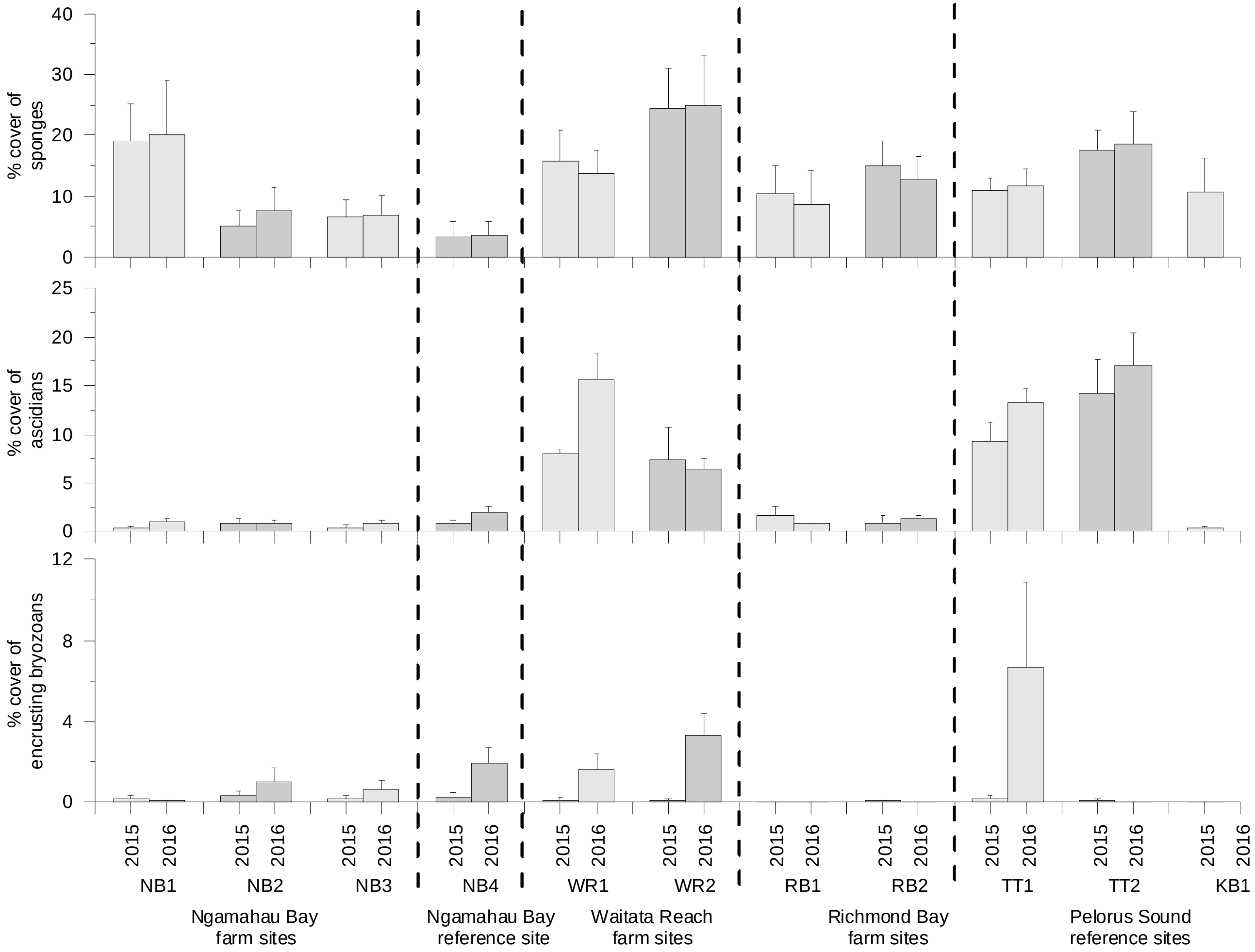


Figure 24. Percentage cover of sponges, ascidians and encrusting bryozoans through time at the Ngamahau Bay (NB), Waitata Reach (WR) and Richmond Bay (RB) farm and reference sites. Note: n=4 with the exception of n=3 for CP1 2001 and CP3 2008 and 2010; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

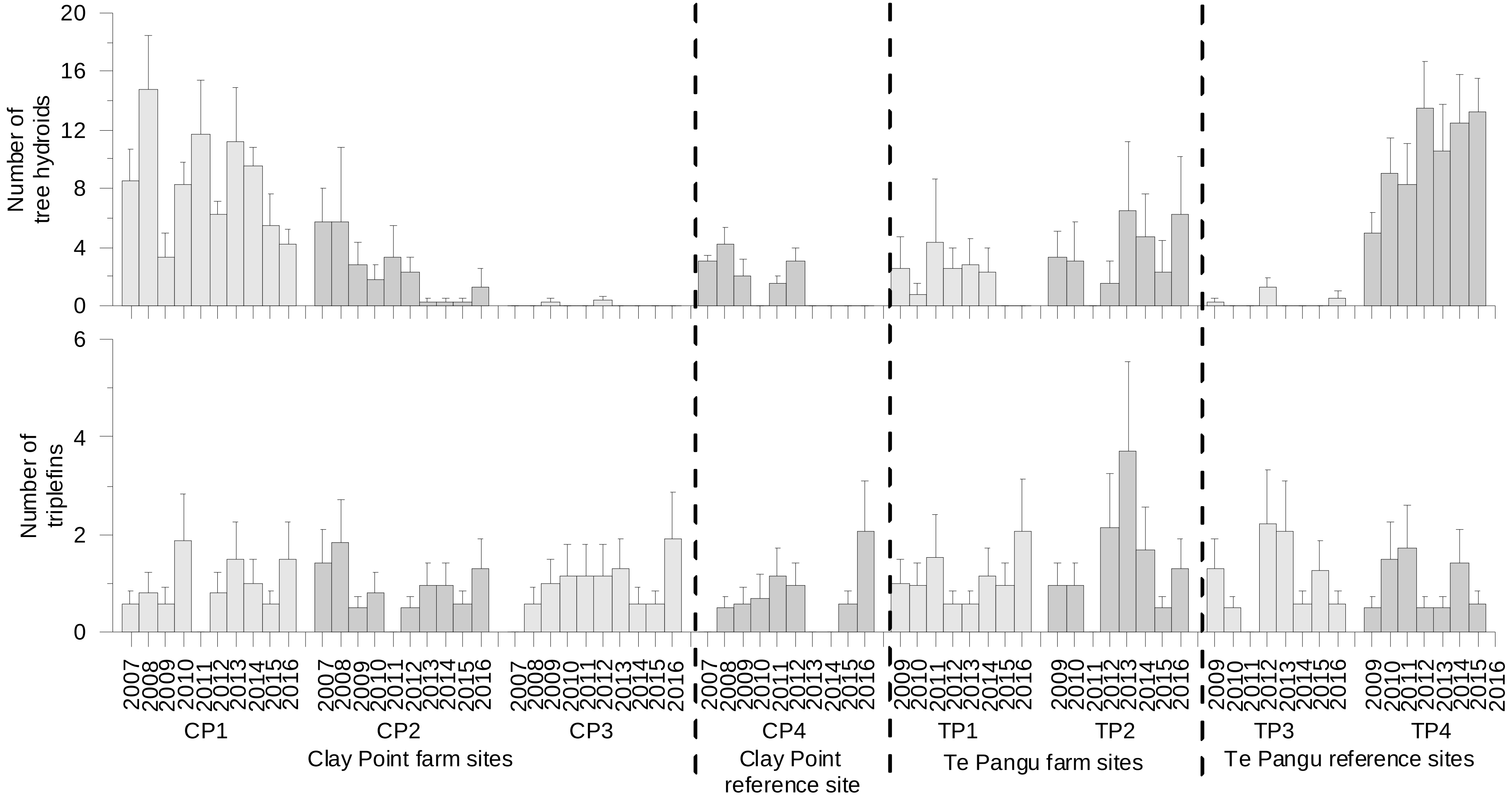


Figure 25. Abundances of tree hydroids and triplefins through time at the Clay Point (CP) and Te Pangu (TP) farm and reference sites. Note: n=4 with the exception of n=3 for CP1 2001 and CP3 2008 and 2010; error bars represent 1 s.e. Quadrat areas were 0.5 m^2.

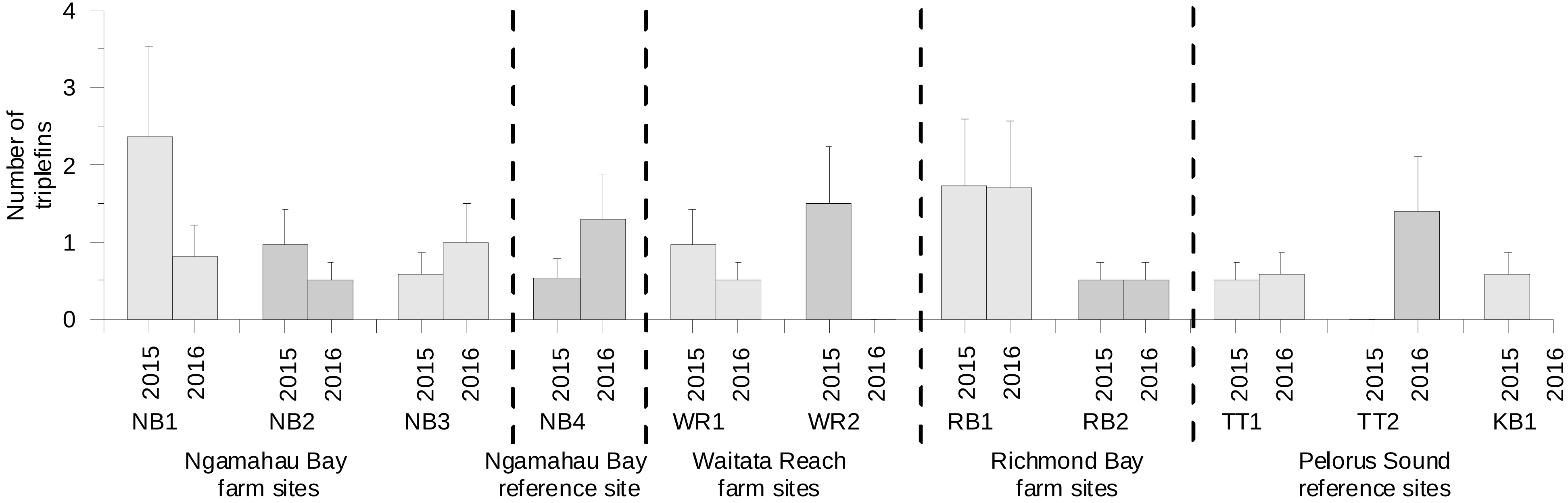


Figure 26. Abundances of triplefins through time at the Ngamahau Bay (NB), Waitata Reach (WR) and Richmond Bay (RB) farm and reference sites. Note: n=4 with the exception of n=5 for NB4; error bars represent s.e. Quadrat areas were 1 0.5 m^2.

3.2. Shallow subtidal transects

3.2.1. Habitats, large invertebrates and fish surveys

There was no evidence of farm-related effects on the shallow subtidal habitats at any of the farm sites. There were no observations of increased abundances of taxa that can be associated with increased enrichment (e.g. *Ulva* sp., benthic diatoms and filamentous brown algae), or notable decreases in taxa surveyed.

Numbers of total gastropods (a group that includes snails, duck's bill limpets and pāua) increased in 2016, particularly at RB2 and RB3 (Figure 27). This was driven by increases in abundances of *Lunella smaragda* (cat's eye snails). Numbers of echinoderms (sea stars, sea cucumbers, kina) were also higher in 2016, largely driven by increases in the number of kina. Numbers of these mobile invertebrates fluctuate naturally, and temporal changes can be expected.

Fish are highly mobile and therefore counts can be temporally variable. The data do give an indication of dominant taxa at each site, which can be compared over time. Fish were abundant at all sites, and the ubiquitous spottie was the dominant species (Figure 28). Blue cod were not common at the Tory Channel sites (NB), which had habitats dominated by algae. They were more abundant at Pelorus Sound sites, which had sandy, more open sites more suitable for blue cod.

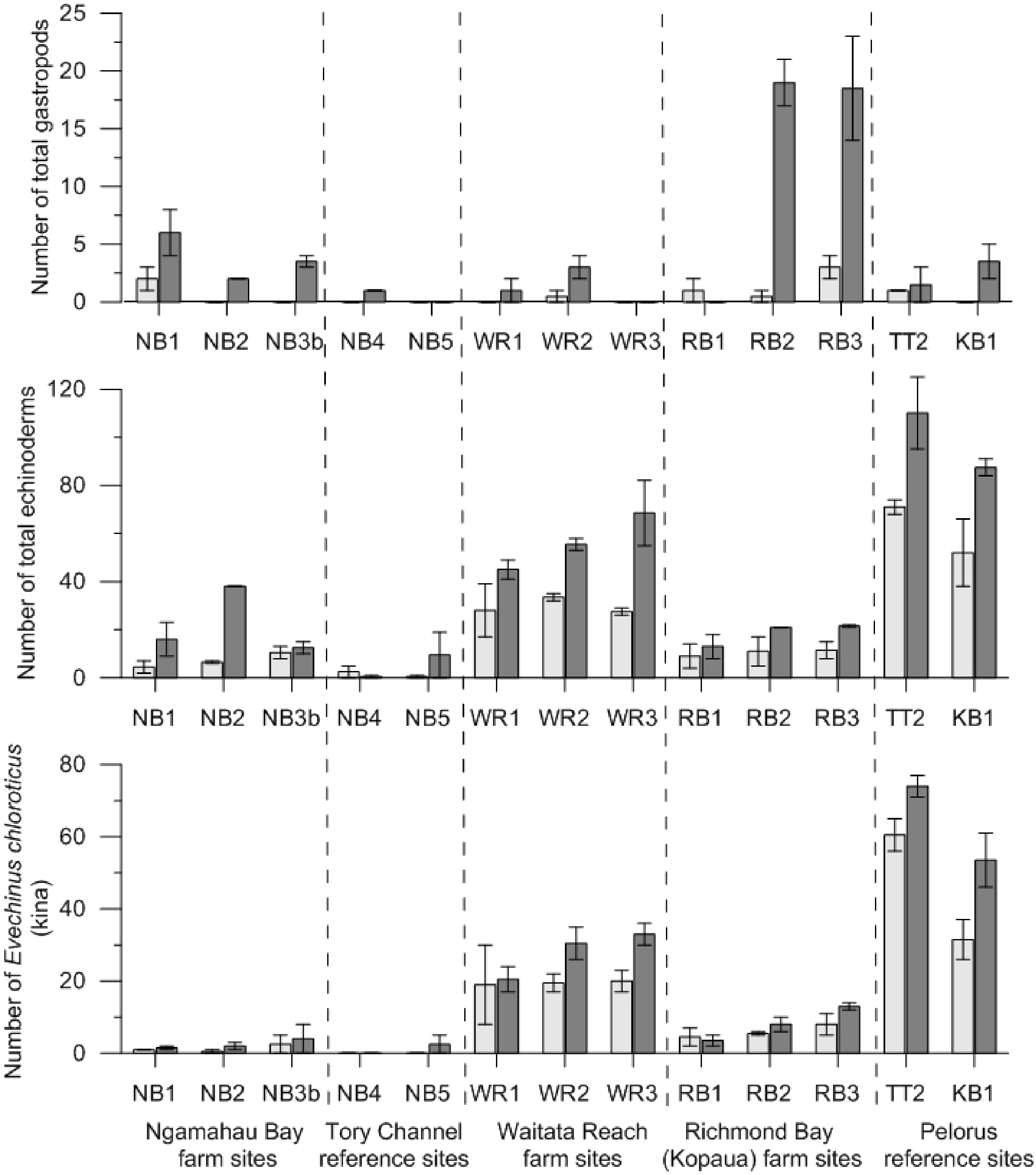


Figure 27. Abundances of total gastropods and echinoderms, and kina along transects at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. N = 2, error bars represent 1 s.e., transects were 20 x 2 m.

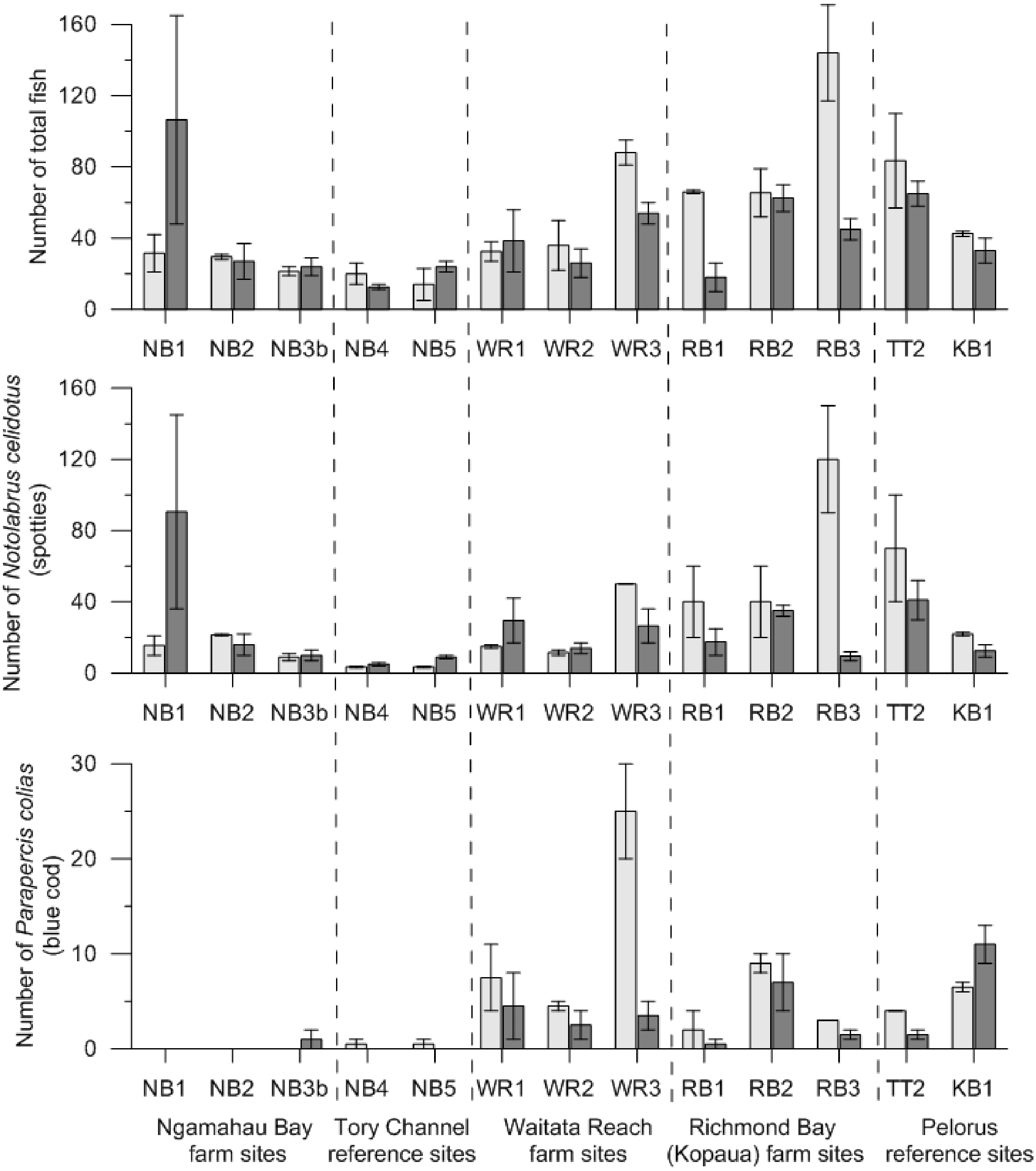


Figure 28. Abundances of total fish, spotties and blue cod along transects at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 2, error bars represent 1 s.e., transects were 20 x 2 m.

3.2.2. Community assemblages

PERMANOVA results for the NB, WR and RB 2015–2016 community assemblage data (surveyed by quadrats), showed that at all farms, Site(Treatment), and Year×Site(Treatment) were highly significant (p=0.001) (Table 7, Appendix 2), and that Station(Site(Treatment)) were significant at NB and WR. This indicates that Sites (at all sites) and Stations (at NB and WR sites) were different from each other, and that one or more Sites changed differently through time (i.e. Year). Pairwise comparisons revealed that with the exception of the reference site NB5, all sites were significantly different in 2015 and 2016 (Table 8).

The reef communities at both reference and farm sites were variable across sites and years (Figure 29, Figure 30). For example, in Tory Channel the farm site NB1 and the reference site NB4 were the most different between 2015 and 2016 amongst all sites, whilst the farm site NB2 and reference site NB5 were the most similar (Figure 29). Differences between years were largely driven by small differences in the presence/absence and abundances of taxa such as algae, ascidians and tube worms. Despite the variability between years, all sites shared over 56% similarity between each other at both Tory Channel and Pelorus Sound sites.

Table 7. Summary of PERMANOVA results for Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) (2015-2016) epibiota community data in shallow subtidal permanent transects. P values: * < 0.05, ** < 0.01, *** < 0.001. Refer to Appendix 2 for full results.

Source	P value significance
Ngamahau Bay	
Year	
Treatment	
Site(Treatment)	***
Year×Treatment	
Station(Site(Treatment))	**
Year×Site(Treatment)	***
Waitata Reach	
Year	
Treatment	
Site(Treatment)	***
Year×Treatment	
Station(Site(Treatment))	**
Year×Site(Treatment)	***
Richmond Bay (Kopaua)	
Year	
Treatment	
Site(Treatment)	***
Year×Treatment	
Station(Site(Treatment))	
Year×Site(Treatment)	***

Table 8. Significant (p < 0.05) pairwise tests for the term Year×Site(Treatment) for pairs of levels of the factor Year for overall community assemblages at NB, WR and RB.

Area	Type	Site	Year	2015
Tory Channel	farm	NB1	2016	**
		NB2	2016	**
		NB3b	2016	*
	reference	NB4	2016	**
		NB5	2016	
Pelorus Sound	farm	WR1	2016	**
		WR2	2016	*
		WR3	2016	**
		RB1	2016	**
		RB2	2016	***
		RB3	2016	***
	reference	TT2	2016	*
		KB1	2016	***

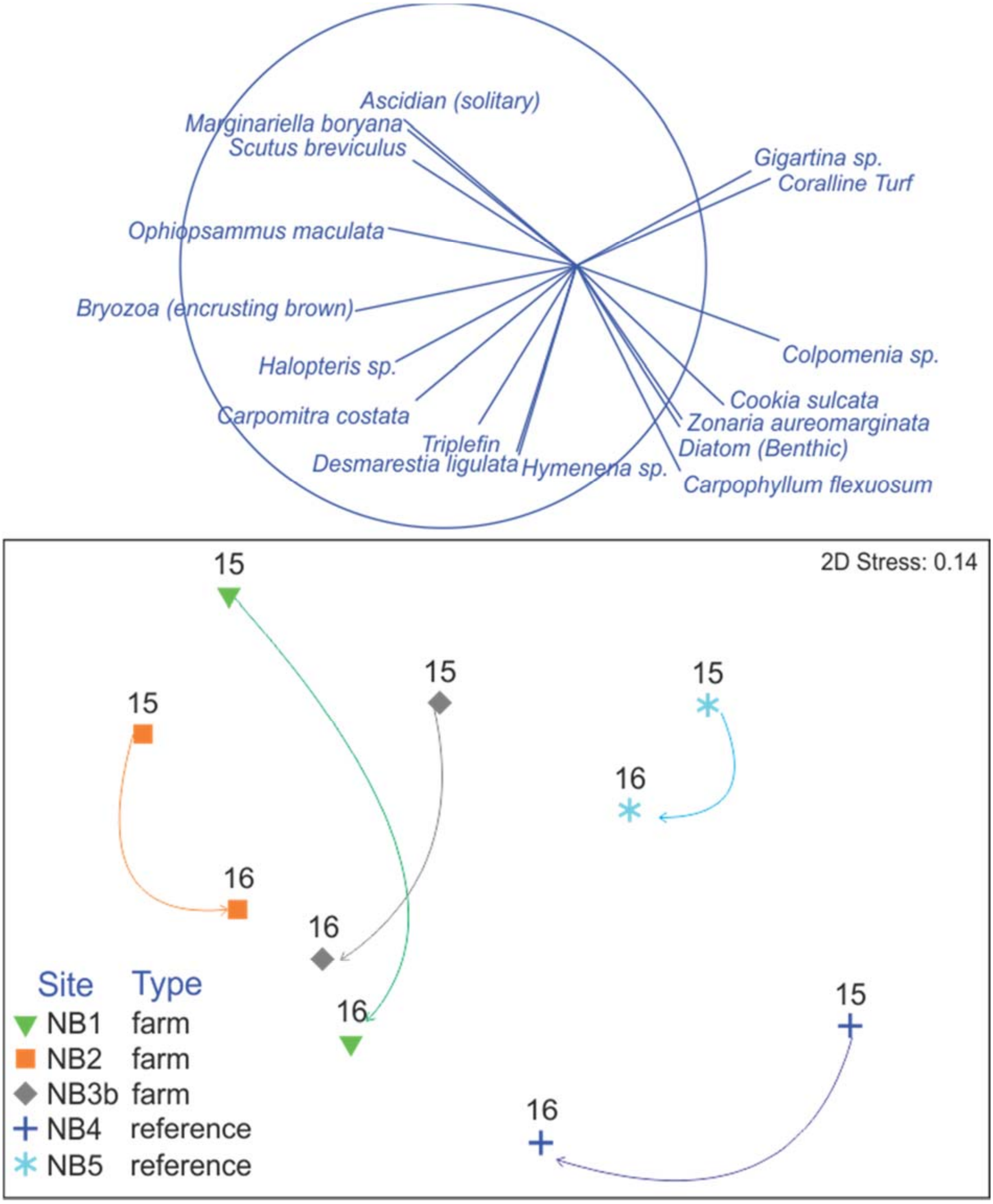


Figure 29. Non-metric MDS plots of shallow subtidal communities at Ngamahau Bay (NB) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.7 correlation. Data were square root transformed, n=10, and quadrat size was 1 m^2.

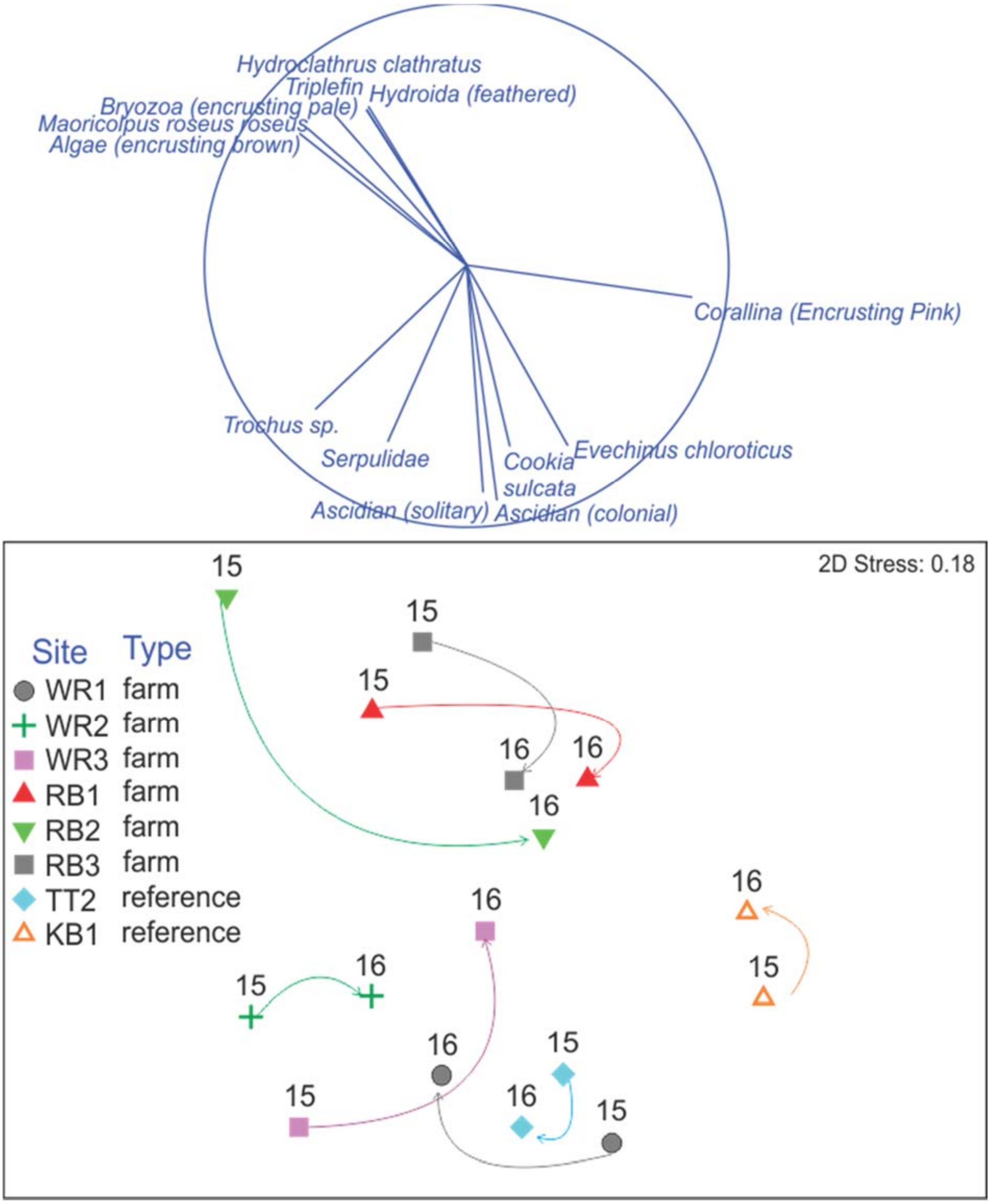


Figure 30. Non-metric MDS plots of shallow subtidal communities at Waitata Reach (WR) and Richmond Bay (RB, Kopaua) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.7 correlation. Data were square root transformed, n = 10, and quadrat size was 1 m^2.

There were no changes in the abundances of selected taxa that would be associated with effects from the salmon farms, as changes in percentage cover or numbers were observed at both farm and reference sites (Figure 31, Figure 32). For example, the percentage cover of red algae was lower in 2016 at both a farm (NB3b) and reference site (NB4) (Figure 31).

NB sites in Tory Channel were algal-dominated (Figure 31), particularly by large brown algae such as *Carpophyllum flexuosum*, *Ecklonia radiata* and *Undaria pinnatifida*. Red and green algae were also common. Pelorus Sound sites had less algae, but brown algae were common (primarily *Carpophyllum flexuosum* and *Colpomenia* sp.).

Pelorus Sound sites had more sessile and mobile invertebrates than Tory Channel sites (Figure 32). Solitary and encrusting ascidians, sponges (primarily *Ecionemia alata*), gastropods (e.g. *Calliostoma* sp., *Trochus* sp. and the cat's eye snail *L. smaragda*) and echinoderms (mostly *Evechinus chloroticus* (kina), sea stars (*Patiriella regularis*, *Ophiopsammus maculata*) and sea cucumbers (*Australostichopus mollis*)) were all common. The algal-dominated Tory Channel sites had fewer invertebrates, with generally only sea stars common.

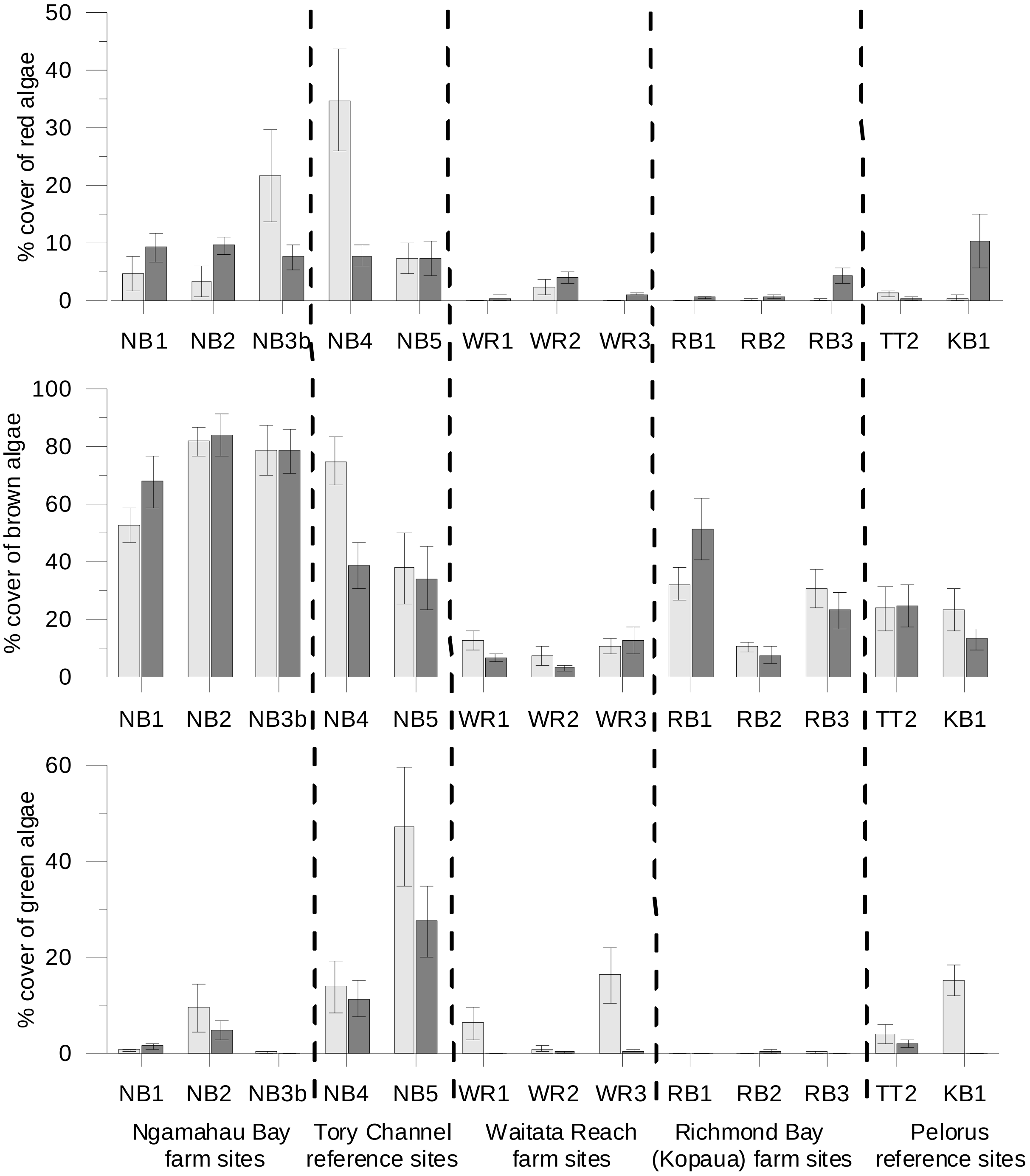


Figure 31. Percentage cover of red, brown and green algae in the shallow subtidal at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 10, error bars represent 1 s.e., quadrats were 1 m^2.

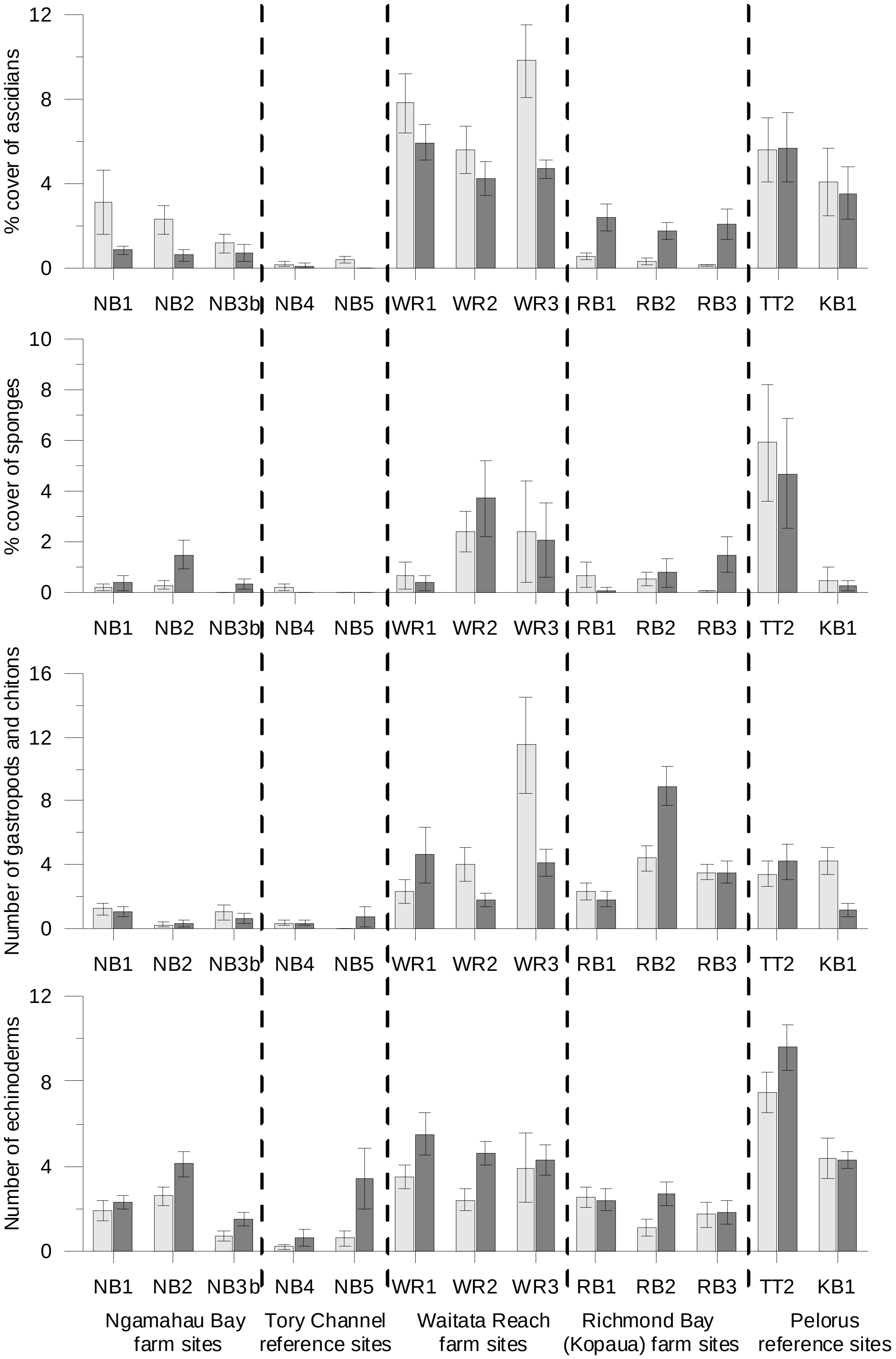


Figure 32. Percentage cover of ascidians and sponges, and abundances of gastropods and chitons, and echinoderms in the shallow subtidal at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 10, error bars represent 1 s.e., quadrats were 1m^2.

3.3. Intertidal transects

3.3.1. Community assemblages

As in the shallow subtidal transects, there was no evidence of farm-related effects on the intertidal habitats at any of the farm sites; there were no directional changes in communities at farm sites or changes in abundances of taxa (e.g. declines in specific taxa or increases in taxa that respond to enriched conditions).

PERMANOVA results for the NB, WR and RB 2015–2016 community assemblage data (surveyed by quadrats) showed that at all farms, Year was significant ($p < 0.05$), Site(Treatment) was highly significant (p=0.001), and Year×Site(Treatment) was significant (p=0.01) (Table 9, Appendix 3). Replicate(Site(Treatment)) was also highly significant (p=0.001) at NB and WR. Pairwise comparisons revealed that, with the exception of the farm sites NB3b and RB3, all sites were significantly different in 2015 and 2016 (Table 10).

Communities were, in general, no more variable between years at farm sites than reference sites (Figure 33, Figure 34). For example, the communities at the reference site NB5 were the most different between years amongst the Tory Channel sites. The farm site RB3b in Pelorus Sound was the most different between years, and this was primarily driven by an increase in the percentage cover of *Chamaesipho* sp. (barnacles), and the presence of a benthic diatom film in one quadrat.

Sites in 2015 and 2016 shared 57% and 56% similarity at Tory Channel and Pelorus Sound, respectively. Small differences in the abundance of algae, barnacles or grazers (e.g. limpets or cat’s eye snails) were generally reasons for variances between years.

Table 9. Summary of PERMANOVA results for Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) (2015-2016) epibiota community data in intertidal permanent transects. P values: * < 0.05, ** < 0.01, *** < 0.001. Refer to Appendix 3 for the full results.

Source	P value significance
Ngamahau Bay	
Year	*
Treatment	
Site(Treatment)	***
Year×Treatment	
Replicate(Site(Treatment))	***
Year×Site(Treatment)	**
Waitata Reach	
Year	*
Treatment	
Site(Treatment)	***
Year×Treatment	
Replicate(Site(Treatment))	***
Year×Site(Treatment)	**
Richmond Bay (Kopaua)	
Year	*
Treatment	
Site(Treatment)	***
Year×Treatment	
Replicate(Site(Treatment))	
Year×Site(Treatment)	**

Table 10. Significant (p < 0.05) pairwise tests for the term Year×Site(Treatment) for pairs of levels of the factor Year for overall community assemblages at NB, WR and RB.

Area	Type	Site	Year	2015
Tory Channel	farm	NB1	2016	**
		NB2	2016	*
		NB3b	2016	
	reference	NB4	2016	***
		NB5	2016	**
Pelorus Sound	farm	WR1	2016	*
		WR2	2016	**
		WR3	2016	***
		RB1	2016	*
		RB2	2016	**
		RB3	2016	
	reference	TT2	2016	**
		KB1	2016	**

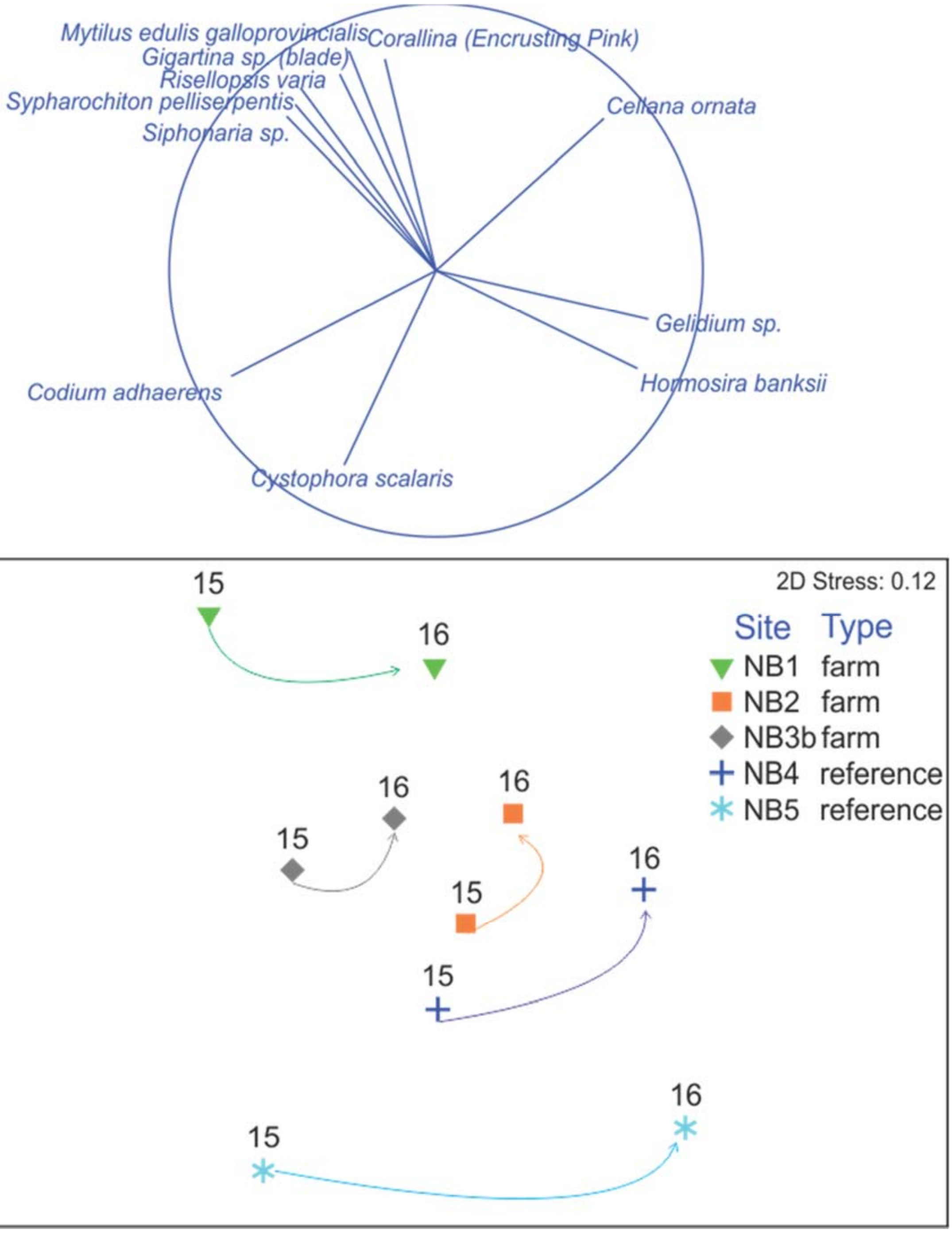


Figure 33. Non-metric MDS plots of intertidal communities at Ngamahau Bay (NB) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.8 correlation. Data were square root transformed, n = 10, and quadrat size was 1 m^2.

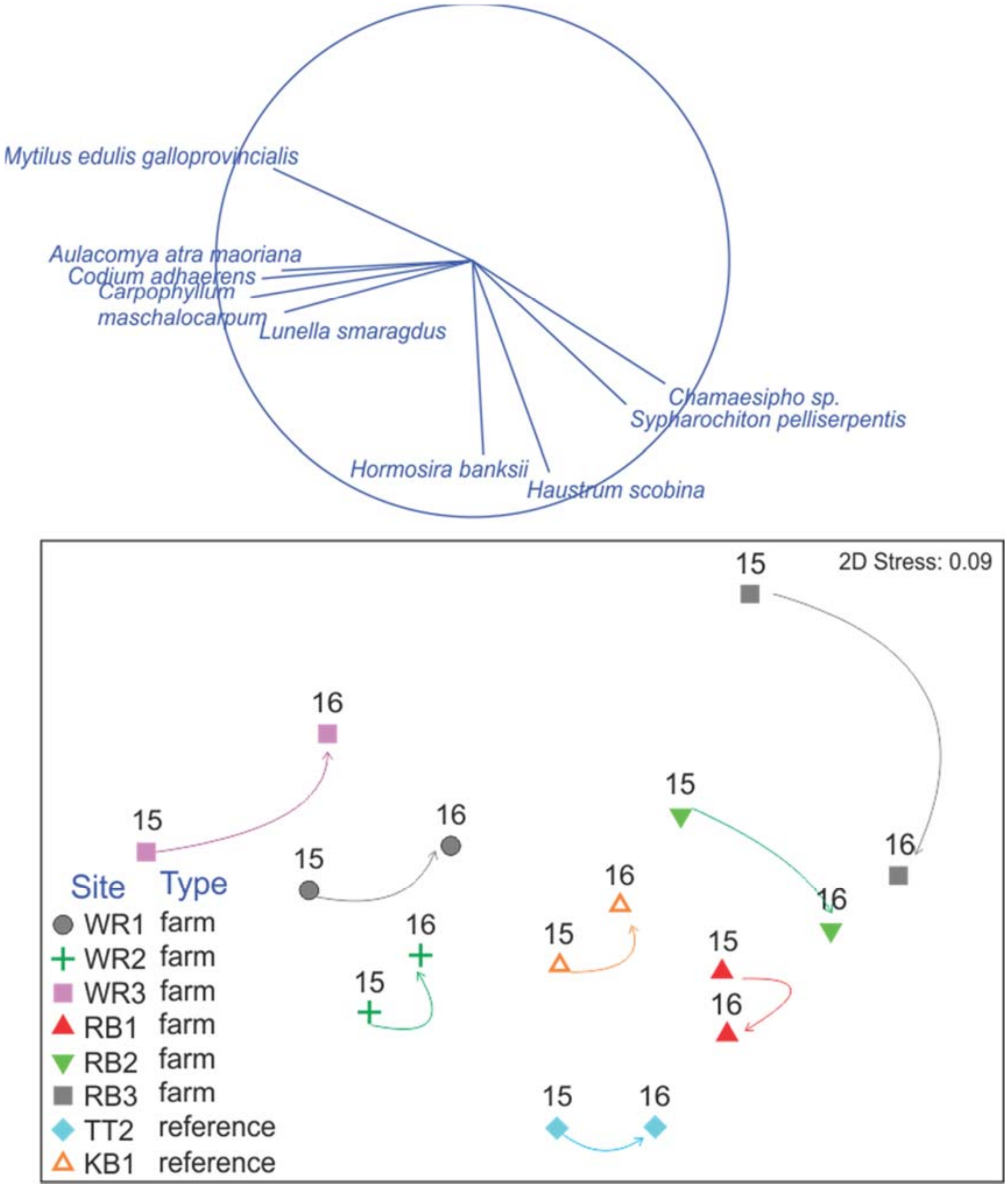


Figure 34. Non-metric MDS plots of intertidal communities at Waitata Reach (WR) and Richmond Bay (RB, Kopaua) farm and reference sites from 2015–2016, based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.7 correlation. Data were square root transformed, n = 10, and quadrat size was 1 m^2.

There were no changes in abundances in selected taxa that would be associated with salmon farm effects. Changes in percentage cover or numbers were observed at both farm and reference sites (Figure 35, Figure 36). For example, the percentage cover of green algae was lower in 2016 at both a farm (NB1) and reference site (NB4) (Figure 35). As observed in the shallow subtidal habitats, sites in Tory Channel had more algae than Pelorus Sound sites. *Hormosira banksii* (Neptune's necklace) and *Xiphophora gladiata* were common brown algae, *Gigartina* spp. were the most abundant foliose red algae, and *Ulva* sp. was the most dominant green alga. At Pelorus Sound sites, *Carpophyllum maschalocarpum* and *H. banksii* were the most common brown algae, and the green alga *Codium adherens* was abundant at WR sites.

Pelorus Sound sites had high percentage covers of barnacles (Figure 36), and WR sites had the blue mussel (*Mytilus galloprovincialis*) present. All sites had an abundance of grazers (limpets, snails chitons) and predatory snails (whelks) (Figure 36), with the most abundant being limpets, and the snails *L. smaragda* (cat's eye snails) and *Diloma aethiops* (spotted topshell) (Figure 37).

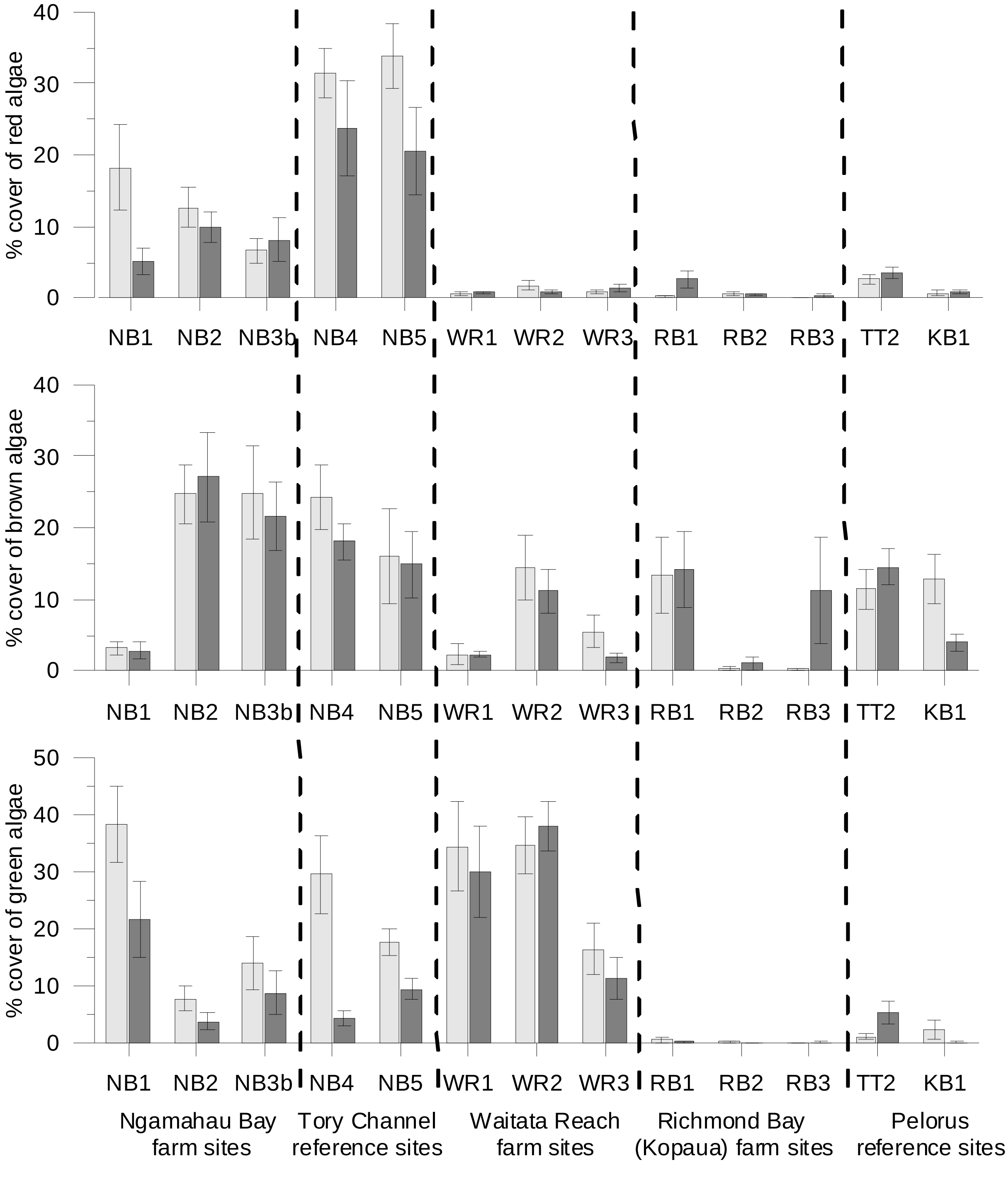


Figure 35. Percentage cover of red, brown and green algae in the intertidal zone at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 10, error bars represent 1 s.e., quadrat areas were $1m^2$.

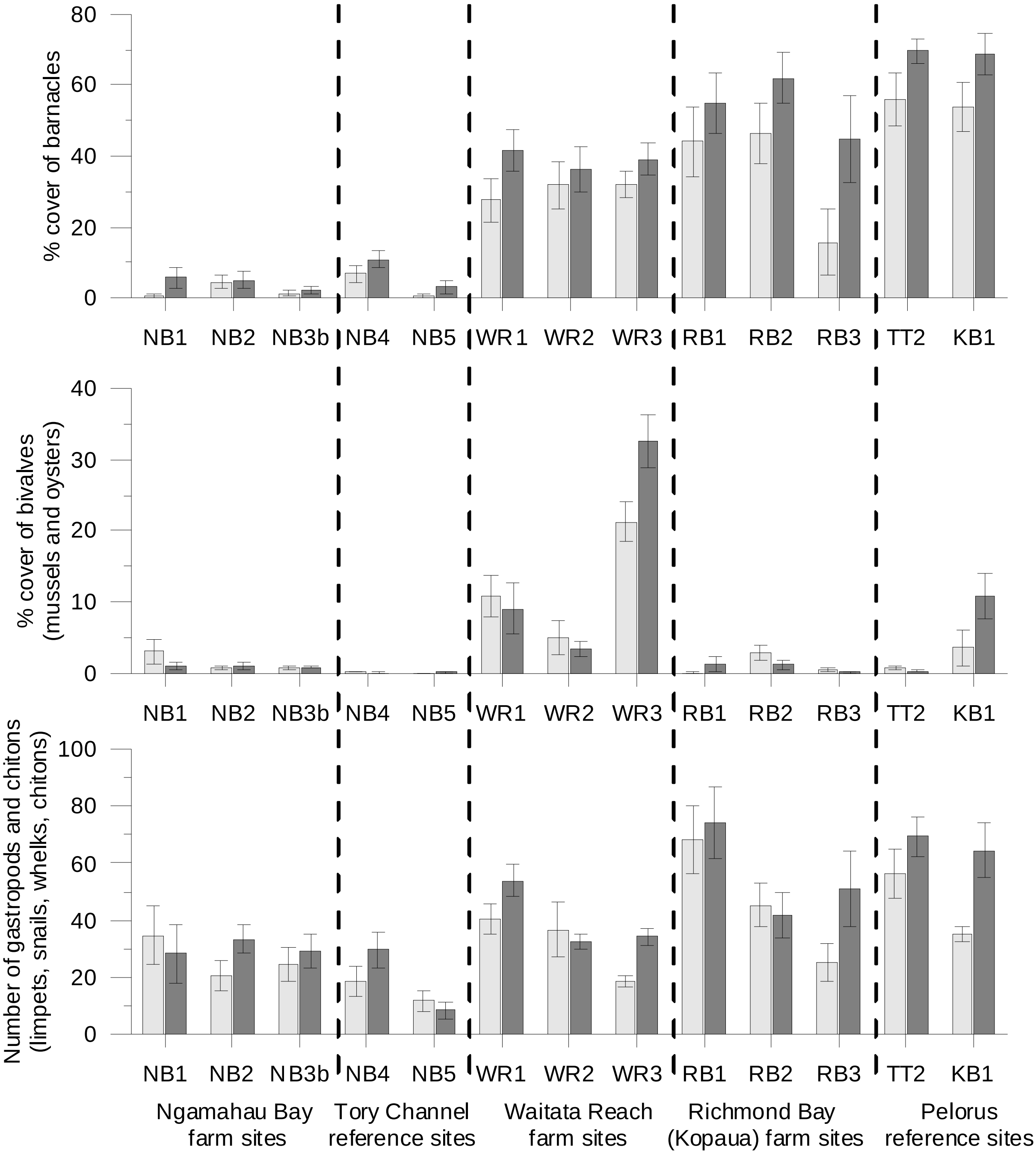


Figure 36. Percentage cover of barnacles and bivalves, and abundances of gastropods and chitons in the intertidal zone at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 10, error bars represent 1 s.e., quadrat areas were 1m^2.

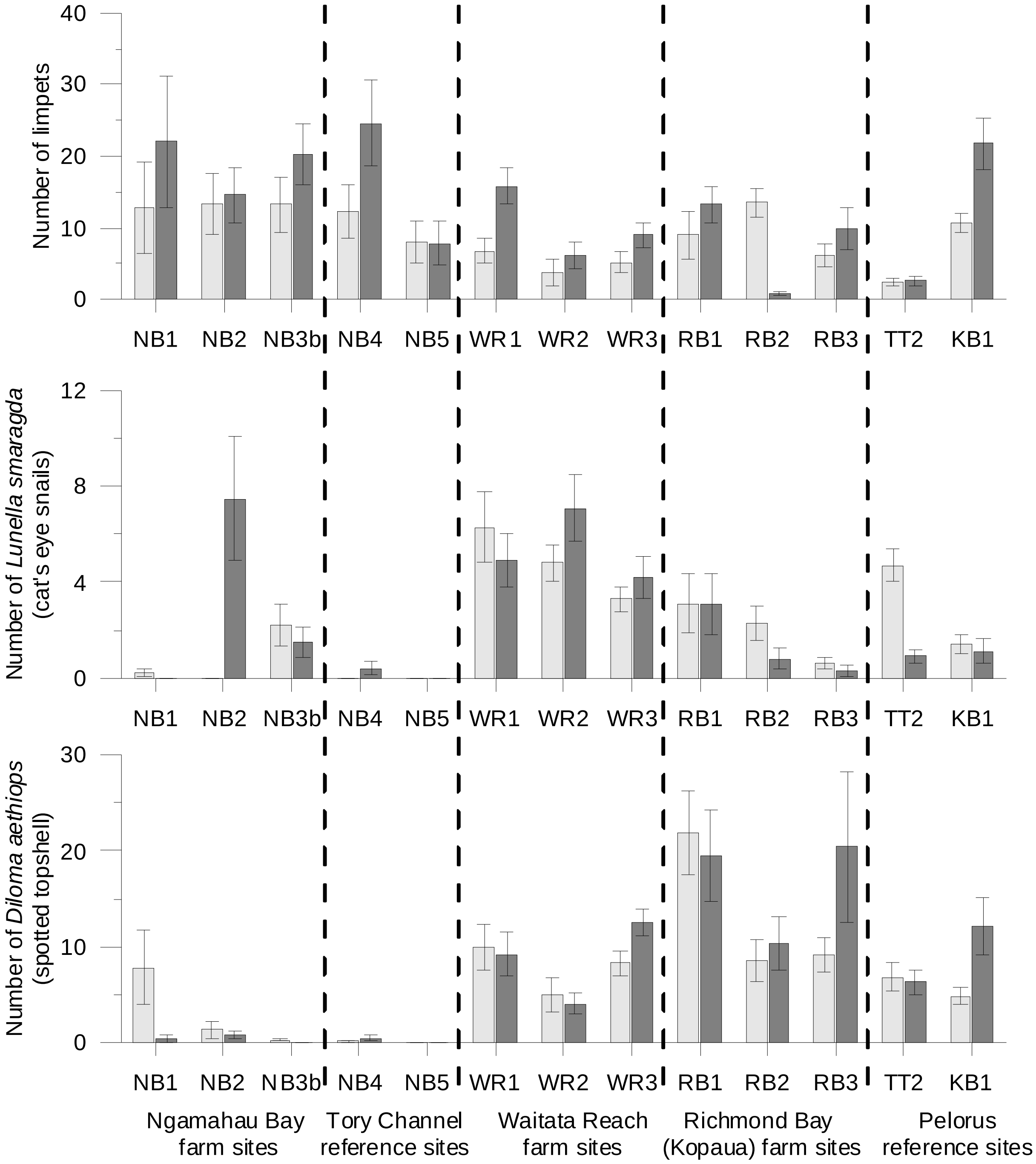


Figure 37. Abundances of limpets, cat's eye snails and spotted topshells in the intertidal zone at near-farm and reference sites in Tory Channel and Pelorus Sound. Light shaded bars are 2015 data, and dark shaded bars are 2016 data. n = 10, error bars represent 1 s.e., quadrat areas were 1 m^2.

3.4. Subtidal video transects

Habitats surveyed at NB3b, RB3 and WR3 did not appear to be affected by salmon farm operations. Notable biological features, such as tree hydroids, sponges, ascidians and macroalgae appeared healthy and abundant (Figure 38).

The inshore area of Ngamahau Bay contained a large expanse of the green alga *Ulva* sp. (Figure 39). This was first observed in 2015, prior to the farm becoming operational.

Figure 38. Screenshot of video footage collected at NB3b in 2016, showing tree hydroids.

Figure 39. Screenshot of video footage taken in 2015, inshore at Ngamahau Bay, showing the dense stand of the green alga *Ulva* sp.

4. SUMMARY AND CONCLUSIONS

4.1. General findings

Rocky reef communities are naturally associated with a high level of organism-specific spatial and temporal variability, which presents challenges for any quantitative monitoring programs. The results of this study continue to illustrate these natural processes. Nevertheless, this relatively novel monitoring program provides valuable insight in to the relative state of the reef communities and their inhabitants that are in close proximity to the farms. The value and power of these results increase with every new time point and with the addition of more sites. In the process, the study also provides a check of the overall ecological state of the subtidal communities in Tory Channel and parts of Pelorus Sound, and contributes to our understanding of the fundamental ecology of some organisms; for example, longevity and habitat preferences.

Qualitative analysis of the images from the rocky reef permanent quadrat sites at Clay Point, Te Pangu, Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) indicated that the diversity within the reef communities near to the farms was consistent with previous surveys. There were no clear directional changes in communities that would be consistent with impacts from the farms; comparable changes in abundances and percentage cover were observed at both potential impact and reference sites. An important aspect of the monitoring is that potentially enrichment-sensitive organisms (e.g. cup sponges, thecate tree hydroids) such as those observed in quadrats CP1-1, CP2-3 and TP1-3 have been tracked through time and these organisms were still present in similar densities.

Statistical analyses of the community data did not show significant Year×Treatment interaction terms, which would have indicated that the reference and farm sites were changing differently from each other through time (i.e. a farm-related effect). In general, statistical analyses of individual and group taxa also did not show significant Year×Treatment interaction terms, with the exception of thecate tree hydroids in the CP analysis. Tree hydroids were variable at the reference site CP4, where numbers fluctuated in some years, from low numbers to being absent.

YearxSite(Treatment) interactions were often significant for the community and taxa group data. This could be an indication of some sites changing through time (i.e. one or more farm sites but not all of them), and it is important to examine this interaction as the farm sites are not all exposed to the same degree of effects due to differences in their distances from the farms. The pairwise comparisons did not indicate any sudden or gradual temporal shifts in community or taxa group data. Numbers of tree hydroids and brittle stars, and percentage cover of encrusting bryozoans have changed at some sites, and although minor, these taxa should receive particular attention in future surveys.

Surveys of the intertidal and shallow subtidal at NB, WR and RB did not show any changes that would be consistent with farm effects. As observed at the permanent quadrat sites, communities and taxa groups were variable across years but this was observed at both farm and reference sites. The farms have only been operational a short time period, and the level of natural temporal variability at the sites is yet to be assessed. This assessment will be strengthened in time, with comparison to the reference sites.

Natural high spatial variability exists between quadrats, stations and sites. Temporal variation can also be high as a result of natural fluctuations in taxa and sedimentation, and this can directly and indirectly affect results. For example, increases in macroalgae are directly reflected in percentage cover of algae present, but the recorded abundances of other taxa can also be indirectly affected due to the macroalgae obscuring the understorey taxa. Natural fluctuations in siltation can also temporarily obscure small organisms. This high variability emphasises the necessity of focusing on overall trends, rather than fluctuations in individual quadrats.

4.2. Recommendations for future surveys

It is recommended that future surveys continue to collect randomly positioned photos in the general vicinity of each site and video footage to capture area and taxa that may be sensitive to disturbance caused while finding tags and collecting photos.

Unhealthy and dead individuals of the grey sponge *Ecionemia alata* were observed at a reference site in 2016, and it is not known whether this problem could become more widespread. Abundances and conditions of sponges have also varied at other sites, so particular attention should be given to observations of sponge health.

It is also recommended that the permanent photo-quadrats be qualitatively analysed in 2017 and quantitatively analysed on alternate years (unless feed use and/or farming arrangements change appreciably). An appreciable change in feed use is considered to be an increase in feed loading that is close to the maximum allowable increase at a particular farm, which ranges from 500 to 1000 tonnes per annum. The shallow subtidal and intertidal transect data collected at NB, WR and RB should be quantitatively analysed in 2017.

5. REFERENCES

Anderson MJ, Gorley RN, Clarke KR 2008. PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E: Plymouth, UK. 214p.

Atalah J, Taylor D, Keeley N, Forrest R, Goodwin E, Dunmore R 2011. Assessment of effects of farming salmon at Richmond, Pelorus Sound: deposition and benthic effects. Prepared for The New Zealand King Salmon Company Ltd. Cawthron Report No. 1989. 48 p.

Clark DE, Taylor D, Keeley N, Dunmore RA, Forrest R, Goodwin E 2011. Assessment of effects of farming salmon at Ngamahau, Queen Charlotte Sound: deposition and benthic effects. Prepared for the New Zealand King Salmon Company Ltd. Cawthron Report No. 1993. 52 p.

Dunmore R 2016. Reef environmental monitoring results for NZKS salmon farms: 2015. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2831. 18 p. plus appendices.

Dunmore R, Keeley N. 2013. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2014. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2687. 26 p. plus appendices.

Dunmore R, Keeley N, Forrest R. 2011. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2010. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 1922. 22 p. plus appendices

Dunmore R, Keeley N, Peacock L 2015. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2014. Prepared for New Zealand King Salmon Limited. Cawthron Report No. 2687. 25 p. plus appendices.

Ellis J, Clark DE, Keeley N, Taylor D, Atalah J, Forrest R, Goodwin E 2011. Assessment of effects of farming salmon at Waitata Bay, Pelorus Sound: deposition and benthic effects. Prepared for the New Zealand King Salmon Company Ltd. Cawthron Report No. 1986. 59 p.

Elvines D, Newcombe E, Keeley N Taylor D. 2015a. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2014. Prepared for The New Zealand King Salmon Co. Limited. Cawthron Report No. 2687. 22 p. plus appendices.

Elvines D, Newcombe E, Keeley N Taylor D. 2015b. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2014. Prepared for The New Zealand King Salmon Co. Limited. Cawthron Report No. 2687. 20 p. plus appendices.

Elvines D, Taylor D 2016. Marine Environmental Monitoring - Adaptive Management Plan 2016–2017 for Salmon farms: Clay Point, Ruakaka, Otanerau, Forsyth, and Waihinau Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2863. 16 p. plus appendices.

Elvines D, Taylor D, Knight B, Dunmore R 2016. Marine Environmental Monitoring - Adaptive Management Plan 2016-2017, for salmon farms Ngamahau, Kopaua and Waitata. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2862. 31 p. plus appendices.

Elvines D, Morrisey D, Taylor D, 2015. New Zealand King Salmon Company Ltd annual monitoring programme and methods: new farm sites: June 2015 to July 2016. Prepared for The New Zealand King Salmon Co. Limited. Cawthron Report No. 2679. 38 p. plus appendices.

Keeley NB, Hopkins GH, Gillespie PG 2006. Assessment of the potential environmental impacts of the proposed Clay Point salmon farm, Marlborough Sounds, NZ. Prepared for New Zealand King Salmon Company Ltd. Cawthron Report No. 1105. 68 p.

Morrisey D, Anderson T, Broekhuizen N, Stenton-Dozey J, Brown S, Plew D 2015. Baseline monitoring report for new salmon farms, Marlborough Sounds. NIWA Client Report No: NEL1014-020. Prepared for New Zealand King Salmon. 252pp.

1. APPENDICES

Appendix 1. PERMANOVA results for entire epibiota community data, and individual or groups of taxa (sea stars, hydroids, sponges, ascidians, all foliose algae, brown algae, red foliose algae, green algae, and triplefins). Data are from permanent quadrat data from Clay Point (2007–2016), Clay Point and Te Pangu (2009–2016), and Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) (2015-2016). See Table 2 for details of design of analyses. Data were square root transformed and PERMANOVA was based on a Bray-Curtis similarity matrix (individual and group taxa matrices used a dummy variable of 0.1). Sums of squares Type III (partial). Permutation of residuals under a reduced model with 9999 permutations.

Clay Point 2007–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	39239	4359.9	2.8003	**0.0001**
Treatment	1	15321	15321	0.5692	0.7468
Site(Treatment)	2	55476	27738	8.2712	**0.0001**
YearxTreatment	9	14975	1663.9	1.0687	0.3566
Station(Site(Treatment))	12	40062	3338.5	3.802	**0.0001**
YearxSite(Treatment)	18	28167	1564.8	1.7821	**0.0001**
Residual	97	85175	878.1		

Clay Point and Te Pangu 2009–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	40264	5752	4.2823	**0.0001**
Treatment	2	32698	16349	0.72401	0.7201
Site(Treatment)	5	1.1333E+05	22666	7.5152	**0.0001**
YearxTreatment	14	15187	1084.8	0.80648	0.9504
Station(Site(Treatment))	24	72953	3039.7	4.3468	**0.0001**
YearxSite(Treatment)	35	47226	1349.3	1.9296	**0.0001**
Residual	155	1.0839E+05	699.29	155	

Ngamahau Bay 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	3523.6	3523.6	3.4001	**0.0252**
Treatment	1	8031.1	8031.1	1.4491	0.1767
Site(Treatment)	5	28250	5649.9	3.9367	**0.0001**
YearxTreatment	1	856.15	856.15	0.82614	0.5551
Station(Site(Treatment))	23	33009	1435.2	2.757	**0.0001**
YearxSite(Treatment)	5	5249.4	1049.9	2.0168	**0.0006**
Residual	23	11973	520.56		

Waitata Reach 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	4796.8	4796.8	6.2757	**0.034**
Treatment	1	5435.3	5435.3	1.051	0.4009
Site(Treatment)	3	15515	5171.5	4.6417	**0.0001**
YearxTreatment	1	947.85	947.85	1.2401	0.3546
Station(Site(Treatment))	15	16712	1114.1	3.2277	**0.0001**
YearxSite(Treatment)	3	2293	764.34	2.2144	**0.0093**
Residual	15	5177.7	345.18		

Richmond Bay (Kopaua) 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	1812.1	1812.1	2.6339	0.1423
Treatment	1	9982.6	9982.6	1.9207	0.1972
Site(Treatment)	3	15592	5197.2	4.4112	**0.0001**
YearxTreatment	1	1956.4	1956.4	2.8437	0.1261
Station(Site(Treatment))	15	17673	1178.2	2.903	**0.0001**
YearxSite(Treatment)	3	2063.9	687.98	1.6951	0.0771
Residual	15	6087.9	405.86		

Clay Point 2007–2016: Sea stars

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	11522	1280.2	0.6149	0.8151
Treatment	1	6367.7	6367.7	0.46019	0.4976
Site(Treatment)	2	28466	14233	4.9879	**0.0201**
YearxTreatment	9	16066	1785.1	0.8574	0.5965
Station(Site(Treatment))	12	34097	2841.5	2.2104	**0.0093**
YearxSite(Treatment)	18	37642	2091.2	1.6267	0.0521
Residual	97	1.25E+05	1285.5		

Clay Point and Te Pangu 2009–2016: Sea stars

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	21898	3128.4	4.6613	**0.0001**
Treatment	2	20249	10124	0.64706	0.6529
Site(Treatment)	5	78532	15706	10.533	**0.0001**
YearxTreatment	14	6643.5	474.54	0.706	0.9349
Station(Site(Treatment))	24	36075	1503.1	4.6651	**0.0001**
YearxSite(Treatment)	35	23606	674.45	2.0932	**0.0001**
Residual	155	49943	322.21		

Ngamahau Bay 2015–2016: Sea stars

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	826.08	826.08	0.2751	0.6968
Treatment	1	452.35	452.35	0.090233	0.8854
Site(Treatment)	5	25267	5053.5	2.6035	**0.0388**
YearxTreatment	1	621.14	621.14	0.20686	0.7336
Station(Site(Treatment))	22	42703	1941	1.53	0.1252
YearxSite(Treatment)	5	15128	3025.5	2.3849	**0.0433**
Residual	22	27910	1268.6		

Waitata Reach 2015–2016: Sea stars

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	896.59	896.59	0.45583	0.6232
Treatment	1	4082.2	4082.2	0.46854	0.7956
Site(Treatment)	3	26138	8712.5	8.0278	**0.001**
YearxTreatment	1	200.6	200.6	0.10199	0.8816
Station(Site(Treatment))	15	16279	1085.3	1.1594	0.3345
YearxSite(Treatment)	3	5900.8	1966.9	2.1012	0.0948
Residual	15	14042	936.12		

Richmond Bay 2015–2016: Sea stars

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	141.11	141.11	0.07745	0.8804
Treatment	1	3635.6	3635.6	0.4124	0.5944
Site(Treatment)	3	26448	8815.9	5.9347	**0.0043**
YearxTreatment	1	188.07	188.07	0.10322	0.8513
Station(Site(Treatment))	15	22282	1485.5	0.89436	0.5971
YearxSite(Treatment)	3	5466	1822	1.097	0.3825
Residual	15	24914	1661		

Clay Point 2007–2016: Hydroid trees (*Solandaria* sp.)

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	65223	7247	6.6118	**0.0002**
Treatment	1	2152.2	2152.2	0.035323	0.5789
Site(Treatment)	2	1.26E+05	62826	33.687	**0.0001**
YearxTreatment	9	30717	3413	3.1139	**0.0082**
Station(Site(Treatment))	12	22277	1856.4	2.4723	**0.0023**
YearxSite(Treatment)	18	19801	1100.1	1.465	0.0894
Residual	97	72836	750.89		

Clay Point and Te Pangu 2009–2016: Hydroid trees (*Solandaria* sp.)

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	25567	3652.4	2.7763	**0.017**
Treatment	2	5533.4	2766.7	0.065212	0.9846
Site(Treatment)	5	2.13E+05	42589	11.312	**0.0001**
YearxTreatment	14	18778	1341.3	1.0183	0.4581
Station(Site(Treatment))	24	91103	3795.9	5.1229	**0.0001**
YearxSite(Treatment)	35	46236	1321	1.7828	**0.0047**
Residual	155	1.15E+05	740.97		

Clay Point 2007–2016: Sponges

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	12357	1373	1.3788	0.2372
Treatment	1	3233.7	3233.7	0.19807	0.5446
Site(Treatment)	2	33625	16813	3.1818	**0.0315**
YearxTreatment	9	5217.8	579.75	0.58221	0.8517
Station(Site(Treatment))	12	63129	5260.8	5.7981	**0.0001**
YearxSite(Treatment)	18	17943	996.81	1.0986	0.3287
Residual	97	88010	907.32		

Clay Point and Te Pangu 2009–2016: Sponges

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	9723.6	1389.1	1.6891	0.0864
Treatment	2	11179	5589.3	0.54068	0.6323
Site(Treatment)	5	51870	10374	2.3775	**0.0253**
YearxTreatment	14	17691	1263.7	1.5371	0.0943
Station(Site(Treatment))	24	1.06E+05	4398.5	4.7482	**0.0001**
YearxSite(Treatment)	35	28749	821.4	0.88671	0.7159
Residual	155	1.44E+05	926.35		

Ngamahau Bay 2015–2016: Sponges

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	546.75	546.75	1.1269	0.3574
Treatment	1	10960	10960	3.7538	**0.0433**
Site(Treatment)	5	14636	2927.2	1.2433	0.2613
YearxTreatment	1	891.72	891.72	1.8379	0.1994
Station(Site(Treatment))	22	51796	2354.4	4.5237	**0.0001**
YearxSite(Treatment)	5	2423.6	484.71	0.93132	0.5424
Residual	22	11450	520.46		

Waitata Reach 2015–2016: Sponges

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	242.53	242.53	1.6695	0.2782
Treatment	1	1686.8	1686.8	1.236	0.397
Site(Treatment)	3	4093.9	1364.6	0.89645	0.5562
YearxTreatment	1	157.48	157.48	1.0841	0.3769
Station(Site(Treatment))	15	22834	1522.3	9.2243	**0.0001**
YearxSite(Treatment)	3	435.8	145.27	0.88027	0.5385
Residual	15	2475.4	165.03		

Richmond Bay 2015–2016: Sponges

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	292.15	292.15	1.3517	0.3233
Treatment	1	1071.2	1071.2	0.44912	0.5041
Site(Treatment)	3	7155.6	2385.2	1.1909	0.3139
YearxTreatment	1	345.82	345.82	1.6	0.2935
Station(Site(Treatment))	15	30043	2002.8	9.4426	**0.0001**
YearxSite(Treatment)	3	648.43	216.14	1.019	0.4535
Residual	15	3181.6	212.11		

Clay Point 2007–2016: Ascidians

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	11426	1269.5	1.7849	0.1053
Treatment	1	22854	22854	2.5266	**0.0001**
Site(Treatment)	2	18628	9314	5.0464	0.0112
YearxTreatment	9	10569	1174.4	1.6511	0.1534
Station(Site(Treatment))	12	22051	1837.6	3.4871	**0.0001**
YearxSite(Treatment)	18	12841	713.41	1.3538	0.0897
Residual	97	51116	526.97		

Clay Point and Te Pangu 2009–2016: Ascidians

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	15912	2273.1	2.1998	**0.0123**
Treatment	2	16192	8096.1	1.1101	0.3829
Site(Treatment)	5	36595	7319.1	5.0299	**0.0004**
YearxTreatment	14	13487	963.35	0.93133	0.5728
Station(Site(Treatment))	24	35114	1463.1	2.166	**0.0001**
YearxSite(Treatment)	35	36286	1036.7	1.5348	**0.0067**
Residual	155	1.05E+05	675.47		

Ngamahau Bay 2015–2016: Ascidians

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	4763.6	4763.6	4.0268	0.0761
Treatment	1	513.46	513.46	0.23948	0.8043
Site(Treatment)	5	10796	2159.3	2.1984	**0.0395**
YearxTreatment	1	1116.3	1116.3	0.94367	0.3968
Station(Site(Treatment))	22	21608	982.2	0.79279	0.7719
YearxSite(Treatment)	5	5911.2	1182.2	0.95425	0.4979
Residual	22	27256	1238.9		

Waitata Reach 2015–2016: Ascidians

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	2893.2	2893.2	1.5113	0.2989
Treatment	1	940.58	940.58	0.253	1
Site(Treatment)	3	11153	3717.8	12.01	**0.0001**
YearxTreatment	1	928.81	928.81	0.48517	0.5683
Station(Site(Treatment))	15	4643.3	309.56	0.84999	0.7374
YearxSite(Treatment)	3	5743.2	1914.4	5.2566	**0.0002**
Residual	15	5462.8	364.19		

Richmond Bay 2015–2016: Ascidians

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	2944.4	2944.4	1.3563	0.3162
Treatment	1	15028	15028	4.4626	0.2002
Site(Treatment)	3	10103	3367.6	4.3896	**0.0011**
YearxTreatment	1	2375	2375	1.0941	0.3837
Station(Site(Treatment))	15	11508	767.18	0.92596	0.5853
YearxSite(Treatment)	3	6512.4	2170.8	2.6201	**0.0336**
Residual	15	12428	828.52		

Clay Point 2007–2016: Encrusting bryozoans

Source	df	SS	MS	Pseudo-F	P(perm)
Year	9	11513	1279.2	1.1023	0.4031
Treatment	1	660.51	660.51	0.22912	0.505
Site(Treatment)	2	5893.3	2946.6	1.3861	0.2747
YearxTreatment	9	11867	1318.5	1.1362	0.3729
Station(Site(Treatment))	12	25426	2118.9	2.4713	**0.0019**
YearxSite(Treatment)	18	20951	1164	1.3576	0.1195
Residual	97	83167	857.39		

Clay Point and Te Pangu 2009–2016: Encrusting bryozoans

Source	df	SS	MS	Pseudo-F	P(perm)
Year	7	10667	1523.9	1.9165	**0.0465**
Treatment	2	7008	3504	0.37744	0.8125
Site(Treatment)	5	46579	9315.7	2.6152	**0.0336**
YearxTreatment	14	17546	1253.3	1.5773	0.0803
Station(Site(Treatment))	24	86119	3588.3	3.5832	**0.0001**
YearxSite(Treatment)	35	27762	793.21	0.79209	0.8528
Residual	155	1.55E+05	1001.4		

Ngamahau Bay 2015–2016: Encrusting bryozoans

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	2441.3	2441.3	3.3019	0.1116
Treatment	1	19843	19843	10.555	**0.0119**
Site(Treatment)	5	9354.3	1870.9	0.72615	0.6365
YearxTreatment	1	371.38	371.38	0.5023	0.6115
Station(Site(Treatment))	22	56681	2576.4	3.2203	**0.0013**
YearxSite(Treatment)	5	3692.8	738.56	0.92313	0.4907
Residual	22	17601	800.06		

Waitata Reach 2015–2016: Encrusting bryozoans

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	13979	13979	9.0252	**0.0379**
Treatment	1	12023	12023	10.641	0.0988
Site(Treatment)	3	3389.6	1129.9	0.76581	0.5787
YearxTreatment	1	9943.3	9943.3	6.4195	0.0687
Station(Site(Treatment))	15	22131	1475.4	1.4837	0.1878
YearxSite(Treatment)	3	4646.8	1548.9	1.5576	0.2036
Residual	15	14917	994.44		

Richmond Bay 2015–2016: Encrusting bryozoans

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	534.82	534.82	0.33736	0.7214
Treatment	1	1981.4	1981.4	1.7003	0.203
Site(Treatment)	3	3496	1165.3	0.94276	0.4628
YearxTreatment	1	551.87	551.87	0.34812	0.6878
Station(Site(Treatment))	15	18541	1236.1	1.6622	0.1195
YearxSite(Treatment)	3	4755.9	1585.3	2.1318	0.0977
Residual	15	11154	743.63		

Clay Point 2007–2016: All foliose algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	51916	5768.5	4.8787	**0.0003**
Treatment	1	13062	13062	0.4994	0.578
Site(Treatment)	2	53927	26963	23.573	**0.0001**
YearxTreatment	9	19778	2197.6	1.8586	0.0653
Station(Site(Treatment))	12	13663	1138.6	2.2049	**0.0002**
YearxSite(Treatment)	18	21422	1190.1	2.3047	**0.0001**
Residual	97	50089	516.38		

Clay Point and Te Pangu 2009–2016: All foliose algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	51916	5768.5	4.8787	**0.0003**
Treatment	1	13062	13062	0.4994	0.578
Site(Treatment)	2	53927	26963	23.573	**0.0001**
YearxTreatment	9	19778	2197.6	1.8586	0.0653
Station(Site(Treatment))	12	13663	1138.6	2.2049	**0.0002**
YearxSite(Treatment)	18	21422	1190.1	2.3047	**0.0001**
Residual	97	50089	516.38		

Ngamahau Bay 2015–2016: All foliose algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	1882.2	1882.2	1.6959	0.2508
Treatment	1	5164.6	5164.6	1.5669	0.2337
Site(Treatment)	5	16670	3334	8.5557	**0.0001**
YearxTreatment	1	899.42	899.42	0.81039	0.4487
Station(Site(Treatment))	22	8573.1	389.69	1.7914	0.0054
YearxSite(Treatment)	5	5607.8	1121.6	5.1559	**0.0001**
Residual	22	4785.6	217.53		

Waitata Reach 2015–2016: All foliose algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	9206.5	9206.5	7.0571	0.0624
Treatment	1	6747.7	6747.7	1.8214	0.2068
Site(Treatment)	3	11114	3704.7	3.9036	**0.0025**
YearxTreatment	1	5203.5	5203.5	3.9887	0.0786
Station(Site(Treatment))	15	14235	949.03	1.1509	0.3113
YearxSite(Treatment)	3	3913.7	1304.6	1.582	0.1752
Residual	15	12369	824.63		

Richmond Bay 2015–2016: All foliose algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	2518.5	2518.5	2.5912	0.183
Treatment	1	2717.9	2717.9	0.66347	0.501
Site(Treatment)	3	12289	4096.5	7.3695	**0.0005**
YearxTreatment	1	713.81	713.81	0.73441	0.4637
Station(Site(Treatment))	15	8338	555.87	1.9937	**0.0167**
YearxSite(Treatment)	3	2915.8	971.94	3.4861	**0.0094**
Residual	15	4182.1	278.81		

Clay Point 2007–2016: Brown algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	9	55700	6188.9	2.2533	**0.0172**
Treatment	1	7517	7517	0.17911	0.5797
Site(Treatment)	2	86518	43259	24.886	**0.0001**
YearxTreatment	9	24520	2724.4	0.99194	0.4848
Station(Site(Treatment))	12	20765	1730.4	1.7085	**0.0216**
YearxSite(Treatment)	18	49800	2766.7	2.7317	**0.0001**
Residual	9	55700	6188.9		

Clay Point and Te Pangu 2009–2016: Brown algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	7	56903	8129	3.2531	**0.0008**
Treatment	2	10061	5030.4	0.16913	0.9122
Site(Treatment)	5	1.49E+05	29854	18.962	**0.0001**
YearxTreatment	14	34616	2472.5	0.98784	0.497
Station(Site(Treatment))	24	37910	1579.6	1.4762	**0.0178**
YearxSite(Treatment)	35	87935	2512.4	2.3479	**0.0001**
Residual	155	1.66E+05	1070.1		

Ngamahau Bay 2015–2016: Brown algae

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	2796.1	2796.1	1.5276	0.2541
Treatment	1	9020.7	9020.7	2.4007	0.1442
Site(Treatment)	5	18977	3795.4	4.3671	**0.0003**
YearxTreatment	1	1556.6	1556.6	0.85043	0.4688
Station(Site(Treatment))	22	19120	869.09	1.7679	**0.0191**
YearxSite(Treatment)	5	9239.5	1847.9	3.759	**0.0004**
Residual	22	10815	491.59		

Waitata Reach 2015–2016: Brown algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	646.47	646.47	0.23539	0.703
Treatment	1	3518	3518	1.7238	0.1992
Site(Treatment)	3	6122.6	2040.9	0.76165	0.5805
YearxTreatment	1	435.86	435.86	0.15871	0.7831
Station(Site(Treatment))	15	40193	2679.5	1.4947	0.1634
YearxSite(Treatment)	3	8239	2746.3	1.532	0.2289
Residual	15	26890	1792.6		

Richmond Bay 2015–2016: Brown algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	580.31	580.31	0.21861	0.7621
Treatment	1	10853	10853	2.4528	0.1008
Site(Treatment)	3	13275	4424.9	1.5652	0.1944
YearxTreatment	1	296.77	296.77	0.1118	0.8315
Station(Site(Treatment))	15	42404	2826.9	2.5653	**0.007**
YearxSite(Treatment)	3	7963.6	2654.5	2.4089	0.0538
Residual	15	16530	1102		

Clay Point 2007–2016: Foliose red algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	9	42540	4726.6	5.2704	**0.0003**
Treatment	1	17000	17000	0.60715	0.5465
Site(Treatment)	2	57737	28869	29.154	**0.0001**
YearxTreatment	9	18427	2047.4	2.2829	0.0169
Station(Site(Treatment))	12	11828	985.7	2.2232	**0.0009**
YearxSite(Treatment)	18	16237	902.08	2.0346	**0.0005**
Residual	97	43007	443.37		

Clay Point and Te Pangu 2009–2016: Foliose red algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	7	33079	4725.6	3.7485	**0.0001**
Treatment	2	23882	11941	0.5389	0.6205
Site(Treatment)	5	1.11E+05	22243	22.133	**0.0001**
YearxTreatment	14	8505.8	607.56	0.4809	0.984
Station(Site(Treatment))	24	24285	1011.9	3.0428	**0.0001**
YearxSite(Treatment)	35	44433	1269.5	3.8176	**0.0001**
Residual	7	33079	4725.6		

Ngamahau Bay 2015–2016: Foliose red algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	1227.3	1227.3	0.95144	0.4239
Treatment	1	4185.4	4185.4	1.0413	0.3644
Site(Treatment)	5	20343	4068.6	14.835	**0.0001**
YearxTreatment	1	910.66	910.66	0.70596	0.4789
Station(Site(Treatment))	22	6033.6	274.25	1.6159	0.0174
YearxSite(Treatment)	5	6523.3	1304.7	7.6869	**0.0001**
Residual	22	3733.9	169.72		

Waitata Reach 2015–2016: Foliose red algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	12169	12169	7.688	0.0527
Treatment	1	4257.1	4257.1	1.9506	0.1972
Site(Treatment)	3	6547.3	2182.4	2.5522	**0.0286**
YearxTreatment	1	5779.2	5779.2	3.6511	0.0954
Station(Site(Treatment))	15	12827	855.12	1.1771	0.3046
YearxSite(Treatment)	3	4748.6	1582.9	2.1789	0.0657
Residual	15	10897	726.44		

Richmond Bay 2015–2016: Foliose red algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	3078.3	3078.3	3.2919	0.1128
Treatment	1	785.18	785.18	0.4871	0.6019
Site(Treatment)	3	4835.8	1611.9	1.466	0.2182
YearxTreatment	1	3592.7	3592.7	3.842	0.1262
Station(Site(Treatment))	15	16493	1099.6	1.6003	0.0791
YearxSite(Treatment)	3	2805.3	935.12	1.361	0.2499
Residual	15	10306	687.08		

Clay Point 2007–2016: Green algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	9	22278	2475.3	2.0337	0.0647
Treatment	1	416.23	416.23	0.45907	0.6189
Site(Treatment)	2	1796.2	898.08	0.49012	0.693
YearxTreatment	9	10558	1173.1	0.9638	0.5063
Station(Site(Treatment))	12	22020	1835	1.5566	0.0894
YearxSite(Treatment)	18	21916	1217.6	1.0328	0.4135
Residual	97	1.14E+05	1178.9		

Clay Point and Te Pangu 2009–2016: Green algae

Source	df	SS	MS	Pseudo-F	P(perm)
Year	7	13087	1869.6	1.0913	0.3781
Treatment	2	41477	20739	2.0304	0.0816
Site(Treatment)	5	51242	10248	8.1224	**0.0001**
YearxTreatment	14	15959	1140	0.66493	0.8212
Station(Site(Treatment))	24	30275	1261.4	0.97577	0.5117
YearxSite(Treatment)	35	60101	1717.2	1.3283	0.0933
Residual	155	2.00E+05	1292.8		

Clay Point 2007–2016: Triplefins

Source	df	SS	MS	Pseudo-F	P(perm)
Year	9	29615	3290.6	2.0231	0.075
Treatment	1	10984	10984	6.9667	**0.0001**
Site(Treatment)	2	3142.5	1571.3	0.97719	0.3974
YearxTreatment	9	9167.1	1018.6	0.62624	0.778
Station(Site(Treatment))	12	19305	1608.8	0.92144	0.5338
YearxSite(Treatment)	18	29252	1625.1	0.93079	0.5599
Residual	97	1.69E+05	1745.9		

Clay Point and Te Pangu 2009–2016: Triplefins

Source	df	SS	MS	Pseudo-F	P(perm)
Year	7	13876	1982.2	1.2529	0.2907
Treatment	2	26174	13087	5.3015	**0.0039**
Site(Treatment)	5	12357	2471.4	1.3723	0.2635
YearxTreatment	14	28586	2041.9	1.291	0.2509
Station(Site(Treatment))	24	43237	1801.5	1.0359	0.4171
YearxSite(Treatment)	35	55321	1580.6	0.90884	0.6175
Residual	155	2.70E+05	1739.1		

Ngamahau Bay 2015–2016: Triplefins

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	157.88	157.88	0.1715	0.8058
Treatment	1	12.029	12.029	0.017472	0.954
Site(Treatment)	5	3346.5	669.3	0.31146	0.893
YearxTreatment	1	405.25	405.25	0.44021	0.6039
Station(Site(Treatment))	22	47277	2148.9	0.91912	0.5778
YearxSite(Treatment)	5	4510	902.01	0.3858	0.8713
Residual	22	51437	2338		

Waitata Reach 2015–2016: Triplefins

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	6692.1	6692.1	8.8055	0.0644
Treatment	1	6393.5	6393.5	8.6453	0.101
Site(Treatment)	3	2218.6	739.53	0.54368	0.6588
YearxTreatment	1	600.31	600.31	0.78989	0.4476
Station(Site(Treatment))	15	20404	1360.2	0.59708	0.8359
YearxSite(Treatment)	3	2280	759.99	0.3336	0.803
Residual	15	34173	2278.2		

Richmond Bay 2015–2016: Triplefins

Source	df	SS	MS	Pseudo-F	P(perm)
Year	1	172.77	172.77	0.14814	0.7753
Treatment	1	216.36	216.36	0.14825	0.7934
Site(Treatment)	3	4378.1	1459.4	2.1572	0.1195
YearxTreatment	1	4221	4221	3.6192	0.1486
Station(Site(Treatment))	15	10148	676.52	0.21821	0.9974
YearxSite(Treatment)	3	3498.8	1166.3	0.37617	0.776
Residual	15	46506	3100.4		

Appendix 2. PERMANOVA results for entire epibiota community data. Data are from quadrats surveyed in permanent shallow subtidal transects at Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) (2015-2016). See Table 2 for details of design of analyses. Data were square root transformed and PERMANOVA was based on a Bray-Curtis similarity matrix (individual and group taxa matrices used a dummy variable of 0.1). Sums of squares Type III (partial). Permutation of residuals under a reduced model with 9999 permutations.

Ngamahau Bay 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	11724	11724	3.8245	0.0469
Treatment	1	24243	24243	2.4736	0.0989
Site(Treatment)	3	29402	9800.8	6.1807	**0.0001**
YearxTreatment	1	5258	5258	1.7152	0.2355
Station(Site(Treatment))	45	71357	1585.7	1.3189	**0.0078**
YearxSite(Treatment)	3	9196.6	3065.5	2.5497	**0.0006**
Residual	45	54105	1202.3		

Waitata Reach 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	7633.3	7633.3	2.7748	0.0951
Treatment	1	8431.8	8431.8	1.0797	0.3998
Site(Treatment)	3	23429	7809.8	6.4399	**0.0001**
YearxTreatment	1	2296.4	2296.4	0.83477	0.5545
Station(Site(Treatment))	45	54572	1212.7	1.2323	**0.0093**
YearxSite(Treatment)	3	8252.8	2750.9	2.7954	**0.0001**
Residual	45	44285	984.1		

Richmond Bay (Kopaua) 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	8244.3	8244.3	3.4319	0.0685
Treatment	1	16372	16372	2.2326	0.0961
Site(Treatment)	3	21999	7332.9	9.3875	**0.0001**
YearxTreatment	1	5903.3	5903.3	2.4574	0.1178
Station(Site(Treatment))	45	35151	781.13	1.1224	0.1011
YearxSite(Treatment)	3	7206.8	2402.3	3.4517	**0.0001**
Residual	45	31319	695.98		

Appendix 3. PERMANOVA results for entire epibiota community data. Data are from quadrats surveyed in permanent intertidal transects at Ngamahau Bay, Waitata Reach and Richmond Bay (Kopaua) (2015-2016). See Table 2 for details of design of analyses. Data were square root transformed and PERMANOVA was based on a Bray-Curtis similarity matrix (individual and group taxa matrices used a dummy variable of 0.1). Sums of squares Type III (partial). Permutation of residuals under a reduced model with 9999 permutations.

Ngamahau Bay 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	11135	11135	4.9248	**0.032**
Treatment	1	13478	13478	1.4389	0.3057
Site(Treatment)	3	28099	9366.5	6.1154	**0.0001**
YearxTreatment	1	6283.4	6283.4	2.779	0.0875
Replicate(Site(Treatment))	45	68923	1531.6	1.4509	**0.0003**
YearxSite(Treatment)	3	6783.1	2261	2.1418	**0.0014**
Residual	45	47505	1055.7		

Waitata Reach 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	7465	7465	6.3419	**0.0455**
Treatment	1	23671	23671	3.3293	0.0984
Site(Treatment)	3	21330	7109.9	8.5756	**0.0001**
YearxTreatment	1	1965.6	1965.6	1.6699	0.2357
Replicate(Site(Treatment))	45	37309	829.09	1.4076	**0.0003**
YearxSite(Treatment)	3	3531.3	1177.1	1.9985	**0.0026**
Residual	45	26505	589.01		

Richmond Bay (Kopaua) 2015–2016: All percentage cover and count data

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Year	1	5243.7	5243.7	2.5564	**0.0958**
Treatment	1	10030	10030	1.5924	0.1978
Site(Treatment)	3	18895	6298.4	5.6099	**0.0001**
YearxTreatment	1	2608.1	2608.1	1.2715	0.3591
Replicate(Site(Treatment))	45	50523	1122.7	1.1058	0.1262
YearxSite(Treatment)	3	6153.5	2051.2	2.0203	**0.0014**
Residual	45	45688	1015.3		

CAWTHRON
The power of science®

08 May 2017 ID:1716

Mark Gillard
Environmental Compliance Manager
The New Zealand King Salmon Co. Ltd.
93 Beatty Street
Tahunanui
Nelson 7011

Cc: Peer Review Panel
Marlborough District Council

Dear Mark

RESPONSE TO PEER REVIEW PANEL ON THE 2016-2017 ANNUAL MONITORING REPORTS FOR THE WAITATA REACH, NGAMAHAU BAY AND KOPAUA SALMON FARMS

We would like to provide some context in response to the comments detailed in the 28 April 2017 document from the Peer Review Panel on the draft annual monitoring report for the Waitata Reach, Ngamahau Bay and Kopaua salmon farms, 2016-2017 (Cawthron Report No. 2999, 3000 and 3001), and the annual reef environmental monitoring results for these farms (Cawthron Report No. 3009).

We thank the PRP for their feedback. We also note the purpose of the review is to provide recommendations to the council and the consent holder in respect of the adequacy and appropriateness of any aspect of an Annual Report which relate to;

- Change in water quality standards (WQS) [as per condition 67bi or 68bi]
- Any adjustment to the areas and dimensions of the seabed EQS compliance zones [as per condition 67bii or 68bii]
- Any increase in feed discharge to the marine farm [as per condition 67biii or 68biii]
- The adequacy and appropriateness of the annual reports (in respect of components other than those specified above) [as per condition 67c or 68c]
- Whether the annual report adequately [as per condition 69d or 70d]:
  - responds to the results of the monitoring undertaken in terms of the previous MEMAMP, and
  - achieves the requirements of condition 67
- Its recommendations regarding the conclusions, recommendations and other matters specified in the annual report. This includes any changes to the WQS and the hierarchy of response to breaches of the WQS [as per condition 69d or 70d]
- Its recommendations as to whether it considers any particular condition(s) should be subject to review in accordance with Sections 127 and 128 of the Act (RMA) [as per condition 69h or 70h].

The following paragraphs provide the applicable[1] comments from the PRP (black, italicised) followed by Cawthron's response (blue text) to each comment:

In 'general comments' applying to all reports:

1. *We are concerned at the ongoing issue with measurements of turbidity and DO in particular but also salinity with two instruments used. Surely these can be properly calibrated so that we get accurate and reliable data?*

   We agree these differences in data (predominantly DO) are undesirable. While we don't consider it necessary to incorporate any more discussion on this in the annual monitoring reports, some further discussion is provided below.

   For the most part, it appears that differences between the MDC and the Cawthron data are associated with the different types of the DO sensors used on each instrument.

   In order to ensure comparability between sites (to account for any sensor-related differences) in future we will use the same Cawthron instrument across all of the sites during the fine-scale sampling (even though MDC will sample their sites with their own CTD). In addition, instrument comparisons (using concurrent downcast data as was done in the 2016 data collection) will continue to be undertaken as a cross-check, to identify potential calibration issues as they arise, and enable comparisons to be made between the Cawthron and MDC data should this become necessary. Considering the issues have been recognised and solutions identified, future performance issues should be negligible.

2. *The various recommendations, which refer in some instances to fine-scale monitoring, and in others to full-suite monitoring, make it somewhat difficult to understand the implication of the monitoring across:*
   - *The "long-term water column monitoring" and "targeted water column monitoring" surveys as required by conditions 66c/66e, and using the terminology from those conditions (noting also that the conditions extend flexibility to adjust those two programs differently over time).*
   - *The Annual Monitoring Summary Reports, however, refers to monitoring being either:*
     - *'routine monitoring' (as mentioned in the Annual Report);*
     - *'full-suite monitoring' (as mentioned in the Annual Report);*
     - *'fine-scale monitoring' (as mentioned in the Annual Report);*

   Refer to methods Section 2.2.1 in the annual reports, and to the current MEMAMP. Routine and full-suite monitoring combined fulfil condition 65/66c, while fine-scale monitoring fulfils condition 65/66e. Condition numbering has been added to the recommendations section also, where applicable.

3. *Considering the differences in terminology (see above bullet point), as changes to monitoring are proposed, it would be very useful for a tabulated summary of all those proposed changes to water column monitoring to see how those relate to the*

---

[1] Note, this document omits review comments from the PRP that did not require a response.

conditions 66c/66e. (e.g. an updated 'proposed' version of the Table 4 from the relevant AMP – report no. 2679, but also highlighting differences between stations as some recommendations relate to that). Without that, the PRP cannot adequately assess the full extent of the proposed changes to the monitoring program.

The purpose of the annual reports in this regard is only to identify and recommend where improvements can be made to annual monitoring techniques. We consider it more appropriate to provide a description of the monitoring that includes the recommended changes in the upcoming MEMAMP.

4. *The PRP also note with regard to the water column sampling parameters, that at present the monitoring is unable to confirm that the water quality objectives of the consent have been fully met due to the timescales of data availability. This is confirmed at page 12 of the Waitata annual report (and similarly for the Kopaua report), and means it is premature to suggest substantial reduction of sampling efforts without very sound technical justification.*

The final draft report (and final report) clarified which WQO this statement was referring to. We note that determining compliance with some of the monitoring objectives (i.e. 66e: near-farm mixing properties, quantifying localised effects of the marine farm), and overarching water quality objectives can be better achieved using the techniques recommended in the current annual reports (i.e. diel study, dispersal study). Also see limitations of the current sampling method in Section 4.2.3 of the annual report.

Because some aspects of the monitoring programme contribute very little (if at all) to determining compliance with some of the water quality objectives, we do not consider our recommendations to reduce these aspects of the monitoring programme to be premature, particularly if replaced by more suitable methods.

We are more than happy to discuss implications of monitoring 'reductions' or any other proposed changes. However, we consider the most beneficial time to do this would be following PRP receipt of the upcoming MEMAMP, wherein the proposed monitoring regime will be described.

5. *We consider it would be worthwhile for the consent holder, PRP and Cawthron to sit around the table and revisit the water quality monitoring programme. It may be this requires at least another monitoring cycle.*

See note above. We agree a discussion would be the most efficient way to go about this, with the view that MDC should also be part of this consultation.

In comments on the Waitata Reach salmon farm annual monitoring report:

6. *"moderate" and "minor" levels of enrichment are noted in this report but we are not sure how these terms are defined. It would help to have a definition made explicit as*

"moderate" and changes to these classifications would be something that would have to be watched as we get more information on trends.

Refer to Table 3 of the BMP (MPI 2015) for explicit definitions. Changes are assessed using the ES index as per the BMP.

7. [this also applies to other reports] *We would question dropping chlorophyll a from the fine scale water column monitoring at this early point because of wider concerns from marine farming in the Marlborough Sounds and the farms could be contributing. Subject to the provision and review of the requested tabulated summary of proposed water column monitoring changes, the PRP agree with the technical basis for dropping phytoplankton biomass and community composition and silicate from near-farm fine-scale sites as these are unlikely to be impacted and limiting phosphorus to the seabed sampling around the pen. This assumes that P is not a co-limiting nutrient at any time in these systems?*

   The reports do not propose chlorophyll-*a* is dropped from the overall monitoring programme, rather it recommends dropping measurements from the multiple sites located in close proximity to each other around the farm (i.e. fine-scale monitoring stations at 100m and 250m downstream).

   We consider that any effect on chlorophyll-*a* (similar to phytoplankton biomass and community composition) is likely to be distant from the farm. As such, we do not think there is any benefit or increased understanding from measuring chlorophyll-*a* on a fine spatial-scale around the farm, when increases in Chl-*a* can be detected by sampling the routine monitoring stations on a monthly basis.

   We are happy to discuss this further (including reduction of phytoplankton, silicate and phosphorus sampling) as part of the MEMAMP review process.

8. *Please check reference to condition 63c (Waitata), perhaps this should be to condition 66c, which addresses modification to the parameters and nutrients being monitored as part of the 'long-term water column monitoring' (as condition 63c deals with the baseline monitoring).*

   We have correctly referenced condition 63c, under which the station locations evolved. The final paragraph of this condition also makes reference to condition 66c, as the PRP has identified. Reference to both conditions have now been made in this bullet point.

9. *We would question the need for far-field DRSi as changes are unlikely to be related to farms and the role of this monitoring is not to provide information on parameters that farming will not affect.*

   Cawthron agrees that the role of monitoring is indeed not to provide information on parameters that farming will not affect.

   The key here was to confirm that this nutrient continues to be non-limiting in the Sounds. The stations we recommended using for this purpose are (by name) far-field stations. The 'far-field' stations (and other state of environment monitoring stations) are monitored monthly for DRSi by MDC.

10. *Please consider including within the 'Executive Summary' and 'Recommendations' section the recommendation from Appendix 10 to extend the Urea-N monitoring during 'fine-scale monitoring'. The recommendation in the Exec summary and recommendations is for continuation, but Appendix 10 calls for extension to new sites. That recommendation for extension is rather lost in Appendix 10 as it is not clearly carried through to the report itself.*

    The recommendation stated analysis of these nutrients would be extended to additional stations (500 m and reference), consistent with the recommendation made in the discussion provided in Appendix 10. Note, explicit reference to fine-scale monitoring was made in the recommendations of the final draft version.

11. *We agree with the ongoing monitoring of urea and PN at this early stage. The idea that some parts of monitoring are reduced therefore in-lieu of something else is not appropriate especially with the effort and cost of monitoring. Whereas the consent conditions allow some flexibility for the 'long-term water column monitoring' parameters, we are not convinced about the flexibility of the consent conditions to permit substitutions or changes for the 'targeted water column' surveys. As a result, the PRP consider that diel studies and physical mixing investigations are more appropriate prior to installation and when deciding sites. There should also be information around on diel changes and there is no evidence of farm effects yet. Refer also to the general comments from the PRP regarding changes to the water column monitoring program.*

    As the PRP have identified, there is considerable effort and cost associated with monitoring. This is why we intended the additional monitoring recommendations to be 'in-lieu' of monitoring that does not contribute to monitoring objectives. We consider the recommended monitoring studies more informative for achieving the monitoring objectives (as previously mentioned).

    We recognise there may be aspects of monitoring that there is no flexibility to change, and as well as the PRP, we also seek feedback from MDC (most effectively during the MEMAMP process) on how these are approached. In particular we note the reference to Section 128, esp. S128 (1)(a)(iii), of the resource management as per condition 69h or 70h, where revision of the monitoring plan is justified, but where there is no flexibility provided by the consent condition.

    The suggestion that the diel studies and physical mixing investigations are more appropriate prior to installation is counterintuitive (there is no point measuring diel changes in farm tracers or physical mixing through and around the farm, if the farm is not installed). Some alteration to the wording of these recommendations is provided in the final reports, in context of how they relate to the water quality objectives. Any discussion relating to these may be better tabled for the MEMAMP review.

12. *Although not specified in the MEM-AMP it would be useful to have a measure of stocking rates included if possible as this would impact on release of nutrients and other water column effects.*

Feed discharge and nitrogen information is provided for this purpose. See earlier comment on the scope of reports.

13. *P2 – Not clear why there was any feed added during when the farm lay fallow?*

    The feed graph correctly shows zero feed input for November, with tick-marks representing the month.

14. *P8 – are the water samples frozen when archived and if so suspect they will not last more than 6 months?*

    Yes, samples were frozen for archive, pending the lab reports for TN and Chl-*a* for each month. They were unlikely to be needed beyond this time frame.

15. *P12 - May have missed it in MEM_AMP but how is "statistically significant" shift defined? It would be useful to know when there will be enough data to meet the requirements of Condition 43.*

    This is outside the scope of the current monitoring report, being that it is the first one.

    By way of an indication, explicitly determining (or dispelling) such a shift will be more difficult with smaller time series of data due to the high variability in some nutrient enrichment indicators. For example, results from particulate nitrogen (a large component of TN) show year to year changes of 100% in this parameter.

    As such, the approach would likely involve analysis of temporal change (determined by statistical comparisons) over a scale of 3 or more years, using nutrient enrichment indicators (e.g. TN and chlorophyll-*a*). Meanwhile, data from these indicators are collected and analysed as per the other water quality objectives, as detailed in the current annual reports.

16. *TN – second threshold – would it not be useful to define this before we get to the situation of needing it?*

    We agree it would be useful to have this defined prior to it becoming an issue, however the second step threshold would need to be somewhat arbitrary initially. This is because it is difficult to define an effective second step threshold when there are few data exceeding that threshold in the first instance.

    An approach to determine this value could be considered in the upcoming MEMAMP, but may be better to do this when more data are available.

17. Use of terms such as "*comparatively*" need to be defined that is cf. to what?

    After checking the reports, it is unclear which usage of this word needs clarification.

18. *While most parameters are showing some changes at least at the Pen sites elevated sulphides and redox will need to be watched. While not specified in the conditions it would be useful to have a brief comment on levels that would be a concern included in the reports, particularly as we see changes over time and trends towards levels*

that could cause a breach of ES. The compliance levels are largely at the overall ES scale which may be too coarse to pick up trends in some of these parameters.

Seabed enrichment is measured as a state of ES, as this incorporates a suite of indicators/variables and is a more robust measure enrichment. In addition, for brevity (and consistent with the scope of the monitoring reports which is to determine compliance with the EQS), we do not discuss individual parameters unless the findings merit this. Also refer to footnote ‘2’ in Section 2.1.3.

19. *As noted earlier could elevated levels of ammonia-N etc. be due more to stocking levels than feed inputs?*

Although an interesting consideration, we note that interpretation of monitoring results is limited to measuring effects for compliance outcomes (similar to previous comment).

In this sense, unless the results are problematic, it is not relevant for these reports to determine if increases in ammonium are related to stocking levels vs. feed inputs, rather, only to salmon farming in a general sense.

20. *Table 7, Table 8, Table 9, Section 4.24 and others which refer to the water column monitoring site NZKS12 as a “**near field reference site**”. The site is described in the report and used for its conclusions as a ‘reference’ site which infers it is not impacted or affected by Salmon farm inputs. Please review the applicability of using the terminology “reference site” for this site (NZKS12). The consent conditions (63c - Waitata) require the monitoring of ‘side embayments likely to suffer impacts’. If NZKS12 is called a reference site, then which sites, based on the dispersion modelling, meet the requirements of 63c? Suggest a review and if necessary amend tables and discussions accordingly.*

The water column monitoring station locations were determined by NIWA in the baseline plan (condition 63) and baseline report. Please refer to these documents for rationale on station selection, and how the stations meet condition 63.

These same locations were adopted (as per the consent conditions) for annual monitoring. We do not infer that the near-field reference stations will be un-impacted from salmon farming effects (see that the WQS are applied to the NF-Refs in the relevant results tables), and we refer you to the detailed discussion in the MEMAMP as to how the stations are used in relation to the WQS.

In comments on the Ngamahau Bay salmon farm annual monitoring report:

21. *This is the second annual monitoring report so we would have expected to see commentary comparing results with the 2016 report, especially trends.*

See earlier comment regarding scope of monitoring reports. Agree historical comparisons will become more important as the farm reaches higher production levels.

22. *P3 – check bullet 2 as think should be 300 m in each direction.*
23. *P27 – para 1, bit confused where it says "absence of fine-scale sampling" then later "observed in fine-scale March sampling?*

    These were addressed in the final draft version (and final report).

In comments on the Kopaua salmon farm annual monitoring report:

24. *p18 – if there is a time-series for PS-Ctl-3 then would be useful to have a comment on any trends.*

    With only six months of farm occupation and no annual time series data for the farm site, we consider there is little benefit to including historic time series of PS-Ctl-3 data. Commenting on general trends at a reference station is also outside the scope of the monitoring report.

    The time series from this reference site is available in other monitoring reports for your information.

In comments on the annual reef environmental monitoring results for all three farms:

25. *This report includes the results for a number of farms including Waitata, Ngamahau and Kopaua. We have only reviewed the ones relevant to these farms and there are only a few minor comments. The report looks good and we note no effects can be attributed to the farms. With such high variability between sites, years etc it does seem that changes would have to be very significant to be picked up. How will they assess potential, change with such high variability.*

    We agree that there is high variability in the datasets, and we have employed a fixed quadrat method to reduce this. The variability highlights the necessity to focus on trends, rather than changes at particular stations or specific years. Overall directional trends in community data, coupled with statistics, will show any changes occurring at the farms. Examining the group or individual taxa abundances will then determine which taxa are being affected. It is important to examine the full suite of indicators to determine whether the farm sites are changing due to farming effects.

    General comments
26. *Generally this report looks fine and meets the consent requirements.*
    We agree with the recommendation on alternate years for quantitative surveys as there is now sufficient information available at other farms to justify this. Would be useful to define what "appreciable change" means eg 10%?

    An "appreciable change" in feed loading is considered to be a significant increase in feed level in comparison to the previous year, but should not be based on a strict percentage. Consents currently limit feed increases to 500 or 1000 tonnes per annum, depending on the farm. We would consider an increase in feed loading of approximately the maximum staged increase (i.e. approximately 500-1000 tonnes per annum, depending on the farm) to be an appreciable change, which would trigger a full quantitative analysis of photoquadrats. We have changed the final paragraph in Section 4.2 to read:

It is also recommended that the permanent photo-quadrats be qualitatively analysed in 2017 and quantitatively analysed on alternate years (unless feed use and/or farming arrangements change appreciably). An appreciable change in feed use is considered to be an increase in feed loading that is close to the maximum allowable increase at a particular farm, which ranges from 500 to 1000 tonnes per annum. The shallow subtidal and intertidal transect data collected at NB, WR and RB should be quantitatively analysed in 2017.

Specific comments

27. *P13 – random may be a better term rather than "haphazard"*

    We did not use a random number generator or similar to place the quadrats; they were placed 1-4 meters apart along the transect. Hence the term haphazard rather than random.

28. *P61 – do we have any leads as to why Ulva is an issue with Ngamahau?*

    We do not know why there is an abundance of Ulva at Ngamahau, but it also occurs inshore of Te Pangu. Presumably, the calm waters in the bay and appropriate nutrient and light conditions have produced suitable growth conditions.

Please find attached the revised final reports.

Yours sincerely

Scientist

Deanna Elvines
Marine Ecologist
Cawthron Institute

Reviewed by

Grant Hopkins
Senior Scientist
Cawthron Institute