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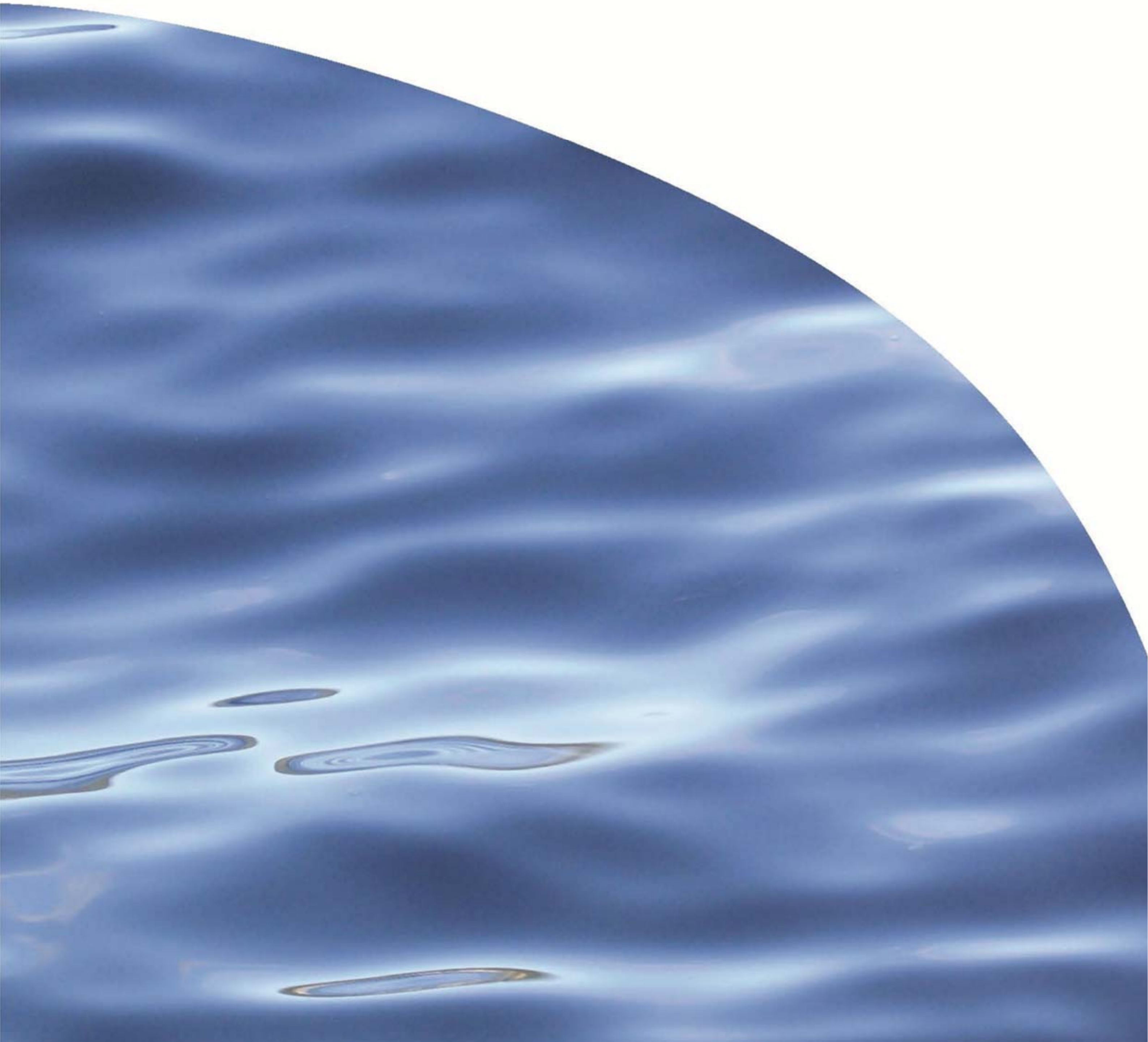
TE PANGU BAY SALMON FARM: ANNUAL MONITORING REPORT (2016–2017)



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

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EXECUTIVE SUMMARY

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

- *No biological effects are expected from copper in the sediments beneath the pens, but localised effects from high zinc levels are possible.*

  Copper was mostly present in particulate form, while zinc levels were variable, but often at high levels that were potentially bioavailable.
- *There were no obvious changes in enrichment levels observed from the previous annual monitoring*.
- *The levels of enrichment were within the EQS for the 300 NE and 300 NW stations.*

  The NE station showed moderate enrichment levels with modified macrofaunal conditions and patches of *Beggiatoa*-like bacteria. The embayment station also showed enrichment effects, while the 300 NW station showed only elevated abundances compared to reference conditions.
- *The levels of enrichment were within the allowable ES scores for the Pen stations. However, in some areas beneath the pens coverage of* Beggiatoa*-like bacteria was not consistent with the EQS description for this indicator.*

  Other indicators were variable beneath the pens, but generally indicated peak-abundances, consistent with very high enrichment levels. Productive and assimilative macrofaunal conditions have been maintained, despite the relatively high level of bacterial coverage.
- *No chlorophyll-a (Chl-a) results exceeded the water quality standards (WQS).*
- *With two exceptions, total nitrogen (TN) concentrations were within the TN WQS.*

  The exceedances occurred on two isolated occasions. The frequency at which these ‘exceedances’ occurred is in line with that observed in the past.
- *Dissolved oxygen (DO) saturations outside of 250 m from the net pens were below the ‘first step’ threshold of the DO WQS in five samples, and two of these samples were also lower than the 1.2% second-step threshold which considers reference DO saturations.*

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

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

- Revision of the DO WQS for Tory Channel, because the current WQS do not capture the full spectrum of natural DO fluctuations in this area, resulting in ‘false breaches’ of the WQS.
- More frequent visual surveys of the seabed (particularly in the warmer months) to determine changes in bacterial coverage on shorter time scales (and perhaps larger spatial scales), increasing our understanding of this qualitative compliance measure.

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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).

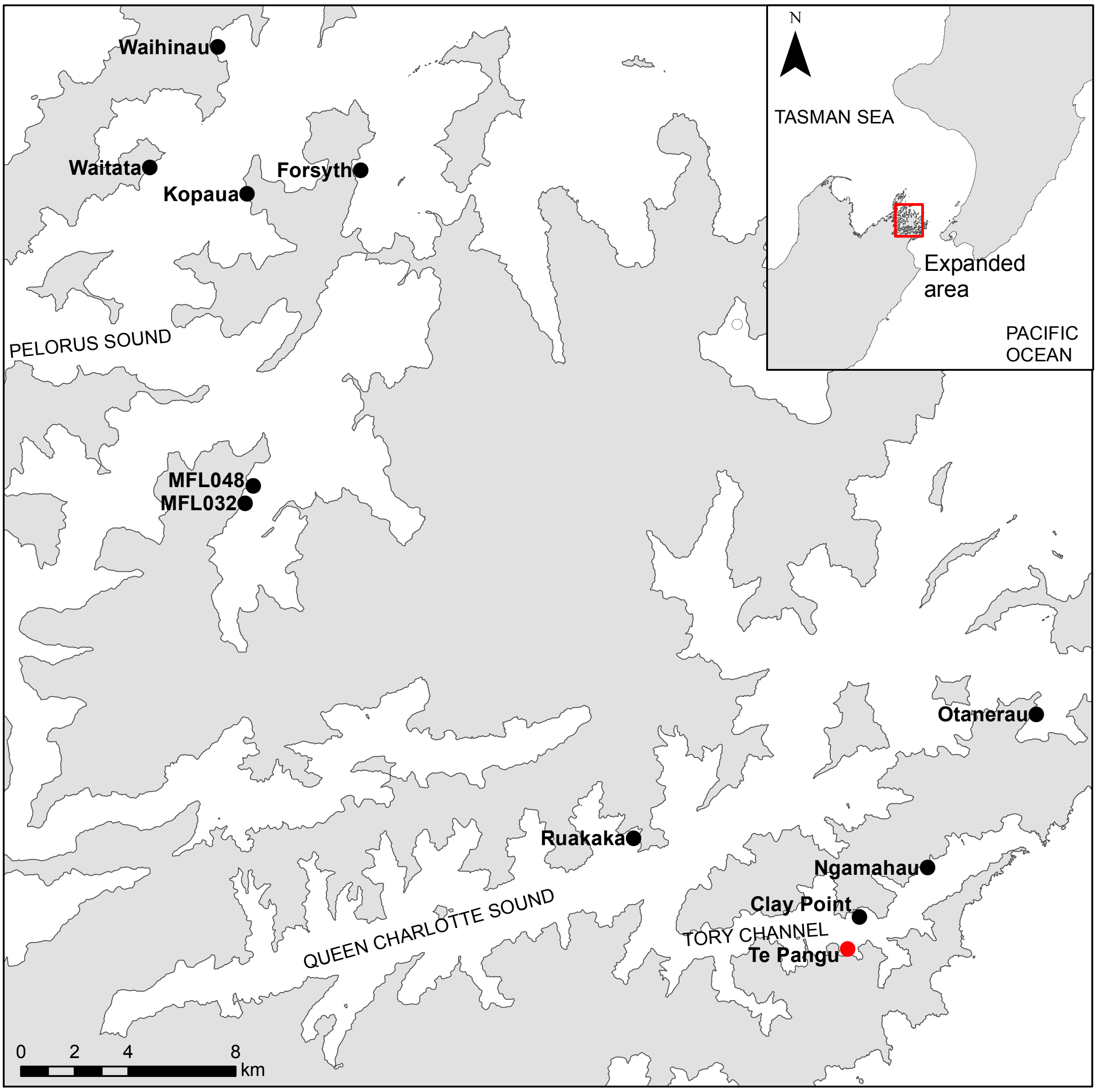


Figure 1. Map of the Marlborough Sounds area showing the location of the Te Pangu Bay (TEP) salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

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 & Fletcher 2016). 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 from the Te Pangu Bay (TEP) salmon farm, and includes an assessment of:

- Depositional effects soft sediment habitats.
- Effects on water quality.

Results from reef habitat monitoring are reported separately in Dunmore (2017).

1.1. Site details and history of feed usage

The TEP farm was established in 1992, and is currently operated under consent U150081. It is a high-flow site, with average water current speeds of about 15 cm/s. Water depth at the farm site is *c.* 30 m, and the net pens extend from the surface to a depth of *c.* 20 m.

In the 2016 calendar year 4,961 tonnes of feed was discharged, higher (by 100–570 tonnes) than the previous four 12-month periods (Figure 2). A total of 5,112 tonnes of feed was used in the 12 months preceding the benthic monitoring survey in January 2017 (Figure 3). Volumes discharged from February through September were reasonably constant between 315 and 395 tonnes, after which monthly feed discharge increased gradually, and peaked in December at 673 tonnes.

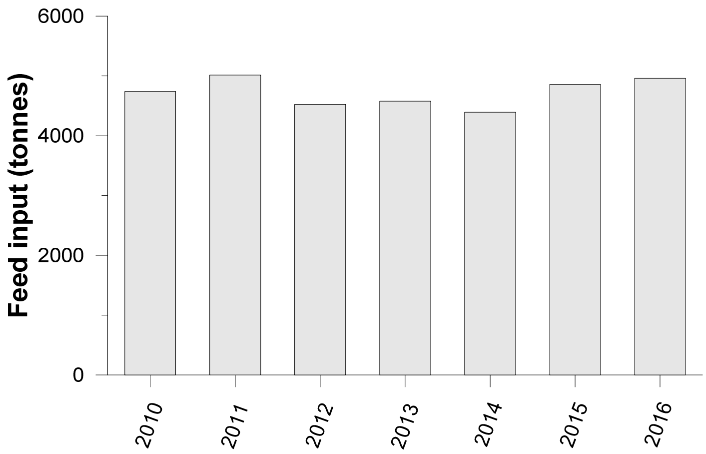


Figure 2. Annual feed inputs (calendar year) at the Te Pangu Bay salmon farm, 2010–2016. Feed input data provided by NZ King Salmon.

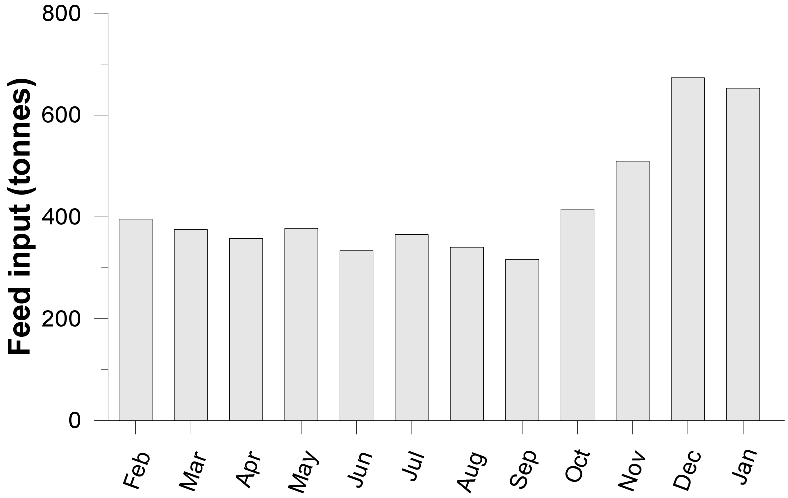


Figure 3. Monthly feed inputs at the Te Pangu Bay salmon farm for the 12 months preceding soft sediment sampling. Feed input data provided by NZ King Salmon.

2. METHODS

Detailed methodology and rationale for the sampling approach can be found in the most recent MEMAMP (Elvines & Fletcher 2016); 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 soft sediment monitoring at TEP was undertaken on 24 and 26 January 2017. Sampling stations at the TEP farm are described and named as follows (also see Figure 4):

- 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 in opposing directions along the predominant depositional axes (northeast and northwest) to monitor enrichment within the outer limit of effects (which is set at 600 m); **300 NE** and **300 NW**.
- Three reference or 'control' stations, one near-field (**TC-Ctl-2**) and two far-field (**TC-Ctl-3** and **TC-Ctl-4)**.
- One station to monitor potential cumulative enrichment effects, within the TEP embayment, sampled inshore of the farm (**Embayment)**.

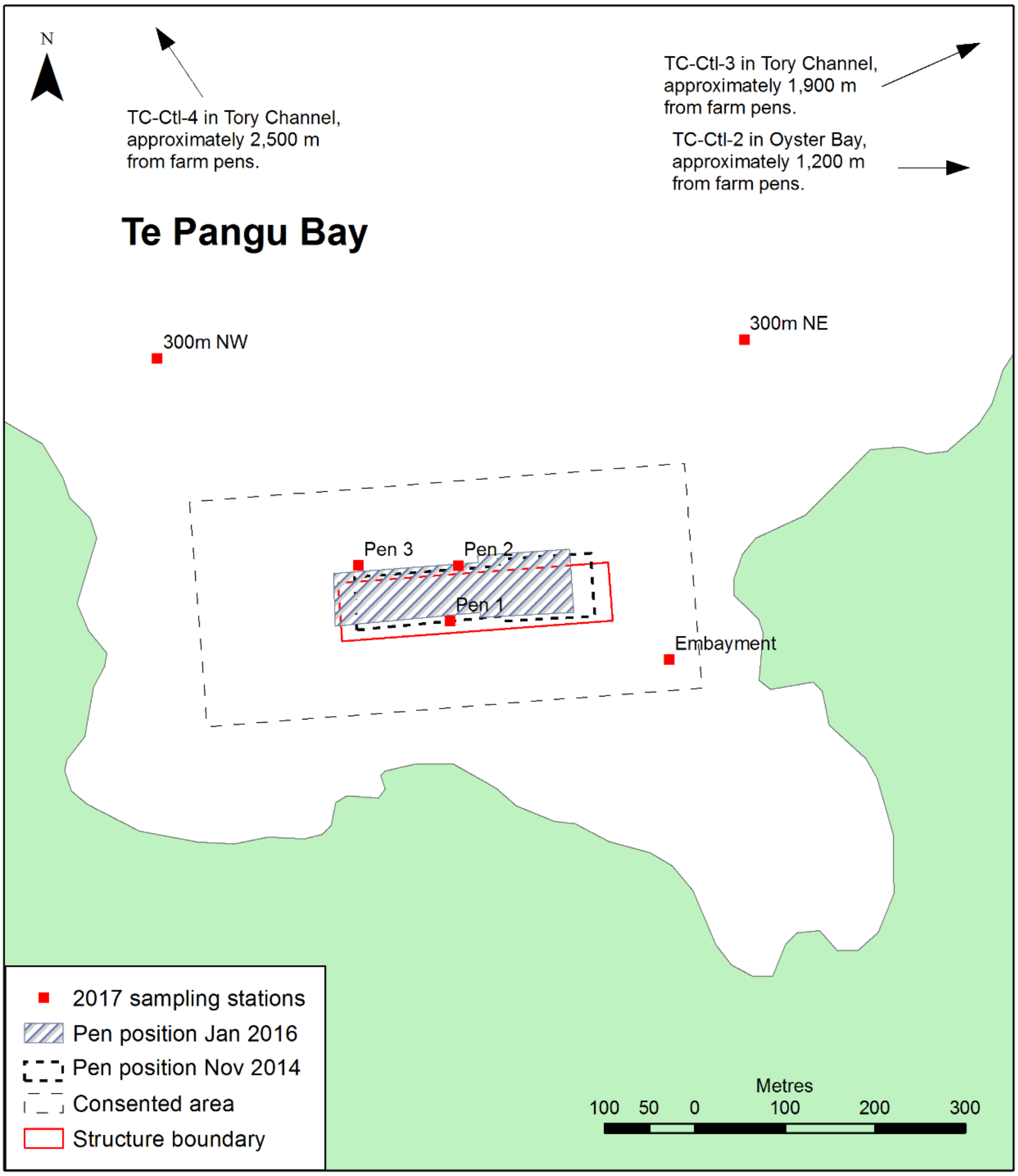


Figure 4. Soft sediment sampling locations at the Te Pangu (TEP) salmon farm site. 'TC-Ctl' = Tory Channel Control. Position accuracy is ± 5 m.

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, triplicate samples from the pen stations were analysed for total recoverable and dilute-acid-extractable 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 farm station (i.e. Pen stations, 300 NE, 300 NW) to determine the redox potential (measured in the field), and to obtain organic content and macrofauna samples for archive purposes.

Video footage was collected 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 is 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.

[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 = 0.7).

2.2. Water column

Water column monitoring at TEP is currently linked to routine water column monitoring in the wider Tory Channel area[4], with the addition of a CTD cast station at the TEP pen edge to monitor dissolved oxygen (DO) levels. The objective of the monitoring is to detect wider salmon farming water column effects in Tory Channel, and to assess compliance with the TEP water quality standards (WQS). The current report presents results from April[5] to December 2016.

2.2.1. Sampling locations

Sampling was undertaken at one station in the vicinity of TEP (beside the net pen on the downstream side; 'TEP net pen'), at two stations across the channel (NZKS19 and NZKS20), as well as at two reference stations (NZKS21 and NZKS22, Figure 5). Parameters measured monthly at stations NZKS19-22 were total nitrogen (TN), Chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO). In addition, phytoplankton samples were also collected from these stations in July and August. At the net pen station, only DO was measured, in order to determine compliance with the WQS < 250 m from the farm (see Section 3, compliance framework). Sampling at this station commenced in November. As such, there are only two months of DO data presented for this station in 2016.

2.2.2. Sample collection

At all stations (except the TEP net pen station) TN and Chl-*a* were measured from a single, surface-integrated sample, taken over the upper 15 m of the water column (obtained using a weighted hose). DO was measured at all stations through the entire water column profile using a conductivity-temperature-depth (CTD) instrument.

In addition, samples collected in July and August were also analysed for phytoplankton. 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 biovolume was estimated for recorded species and used to estimate cell carbon content (biomass) (Appendix 1).

[4] Undertaken as part of the Ngamahau (NGA) consent.

[5] The 2016 January – March water column monitoring results were presented in the previous annual monitoring report (Elvines et al. 2016a).

Sampling was undertaken by MDC and Cawthron staff, coinciding with MDC wide-scale state of the environment monitoring in the Queen Charlotte Sound.

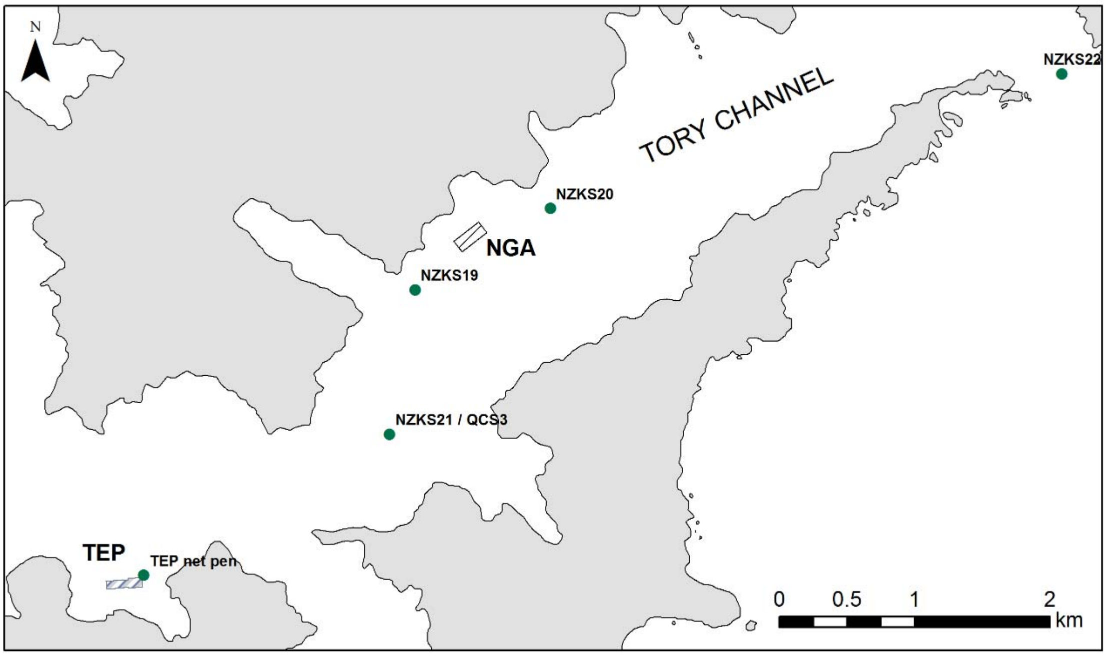


Figure 5. NZKS and MDC routine and full-suite water-quality monitoring stations in Tory Channel. The Te Pangu Bay (TEP) and Ngamahau Bay (NGA) salmon farms are also shown.

3. COMPLIANCE FRAMEWORK

The environmental monitoring results from soft sediment habitats and water quality 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 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 1) set precise parameters for the allowable environmental states within the zones. In the case of the EQS for the outer limit of effects (OLE), the consented EQS has been modified, to accommodate a closer sampling distance (i.e. 300 m) than the maximum OLE of 600 m. For further detail on the modified EQS for this zone, readers are referred to the discussion in the MEMAMP (Elvines & Fletcher 2016).

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 the current report where applicable.

Table 1. Environmental quality standards (EQS) for each zone at the Te Pangu Bay salmon farm (consent U150081).

Compliance zone and EQS type	Description of EQS
ZME (zone of maximal effect)	
Consented EQS at ZME	ES ≤ 5.0 No more than one replicate core with macrofauna virtually absent No obvious spontaneous outgassing (of hydrogen sulphide or methane) Coverage of *Beggiatoa* bacteria not greater than localised / patchy in distribution
OLE (outer limit of effects)	
Consented EQS at OLE of ≤ 600 m	ES < 3.0
Modified EQS measured at a distance of 300 m, as a proxy for the OLE EQS.	**ALERT** Mean overall ES < 3.7 **MINOR** Mean overall ES < 3.7, AND Mean ES less than 0.4 higher compared to previous year

3.1.2. Copper and zinc

Compliance for copper and zinc levels follows the decision hierarchy in the BMP (MPI 2015), shown in Figure 6. 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 2). Therefore these guideline thresholds should be used to trigger further action if exceeded.

Table 2. ANZECC (2000) Interim Sediment Quality Guideline concentrations for copper and zinc (mg/kg).

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

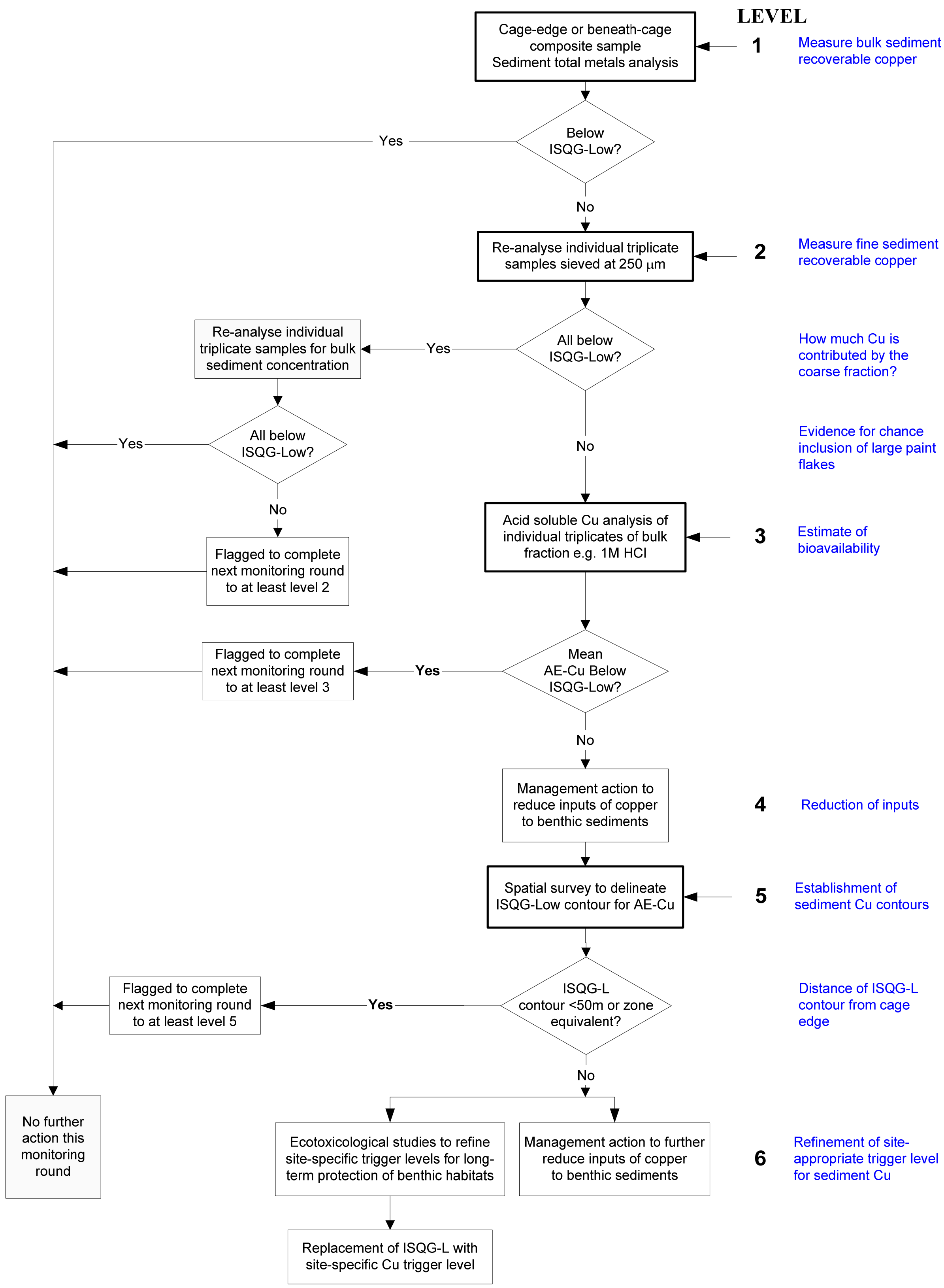


Figure 6. Decision response hierarchy for metals tiered monitoring approach (from MPI 2015). Copper is the example shown here.

3.2. Water column

3.2.1. Assessing performance against the water quality objectives

Condition 30 of the TEP consent (Consent number U150081) states water quality objectives (WQO) as follows:

30. 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 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 (HAB's);*

b. *To not cause reduction in dissolved oxygen concentrations to levels that are potentially harmful to marine biota;*

c. *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;*

d. *To not cause a statistically significant shift, beyond that which is likely to occur naturally, from a oligotrophic/mesotrophic state towards a eutrophic state;*

e. *To not cause an obvious or noxious build-up of macroalgae (e.g. sea lettuce) biomass.*

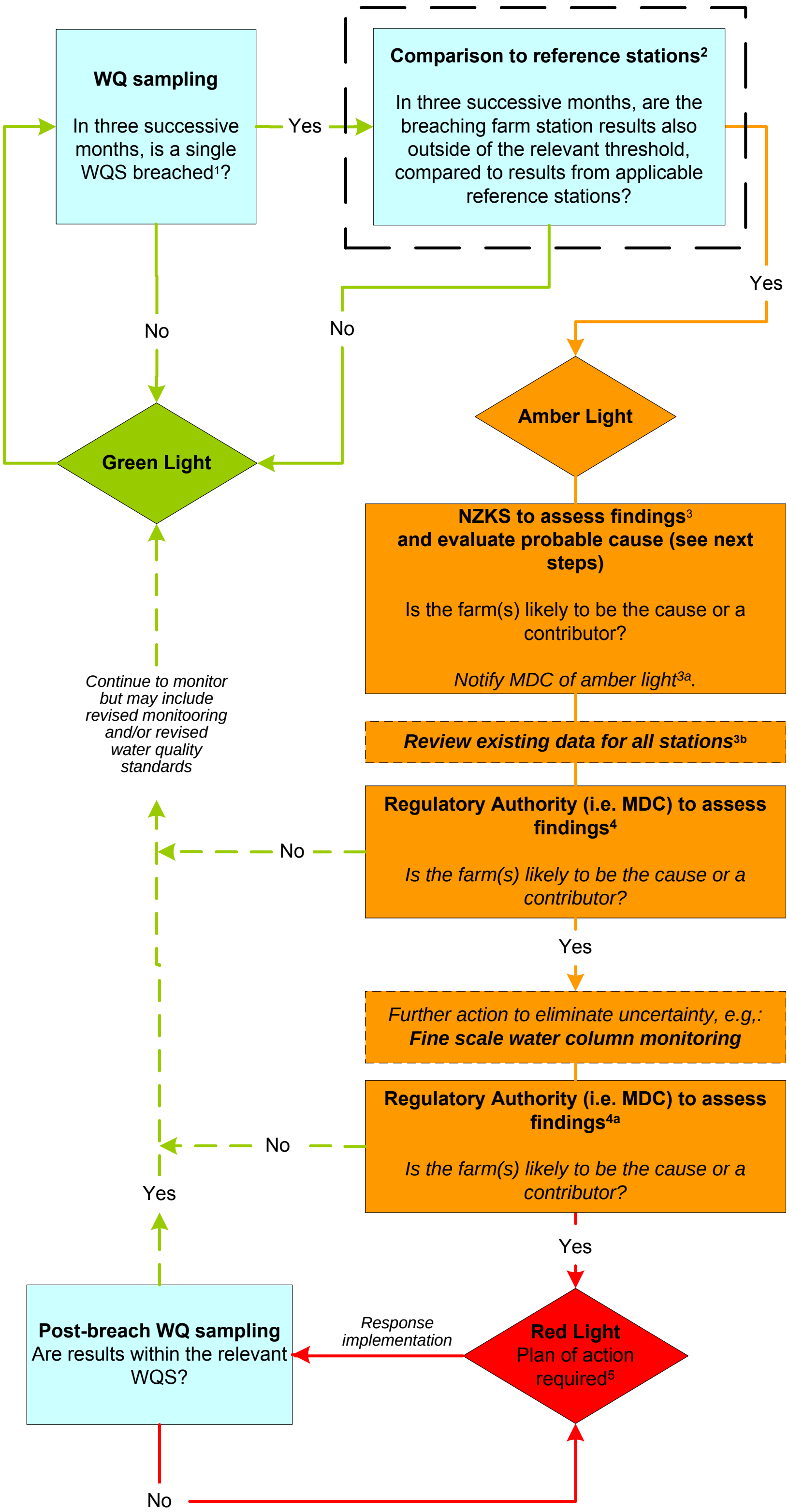
Some water quality objectives (i.e. 30a as it relates to HABs, and 30d) cannot be fully met by the current annual monitoring/reporting, due to implicit timescales for these objectives exceeding the time-series of farm-related water column data that are available to date. However, these objectives can be fully assessed in future reporting, when appropriate time scales of data are available. Objective 30e is investigated as part of the reef monitoring (see Dunmore 2017)

3.2.2. Compliance with water quality standards

In addition to water quality objectives, condition 31(d) sets water quality standards (WQS); thresholds for concentrations of total nitrogen, chlorophyll-*a* and dissolved oxygen (Table 3). Results from the sampling stations in Tory Channel (as in Section 2.2) are compared against these WQS. In the event that the WQS are breached or effects potentially attributable to salmon farming are detected, targeted investigations are triggered (see hierarchy of responses in Figure 7).

Table 3. Water quality standards for chlorophyll-*a* (Chl-*a*), total nitrogen (TN) and dissolved oxygen (DO) for the Te Pangu Bay farm. The second step threshold takes into account reference values (see note 2 in Figure 7). Further discussion of the WQS and how they are applied can be found in the MEMAMP for the Te Pangu, Clay Point (Elvines and Fletcher 2016) and Ngamahau farms (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 (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			



[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 7. Flow diagram illustrating the response regime for water quality monitoring against the water quality standards (WQS; Table 3) as specified in the current MEMAMP (Elvines et al. 2016b).

4. RESULTS

4.1. Soft-sediment habitats

4.1.1. Qualitative description

Representative images of the seabed at each station are provided in Appendix 2. At the Pen stations, the seabed comprised predominantly soft, dark grey sediments. Field observations confirmed the presence of an easily disturbed, jelly-like layer as the surface ~3 cm, with more consolidated sediments deeper in the profile. Light brown-red globules resembling feed pellets or fish faeces were evident on the surface of the sediment at all three Pen stations. No outgassing was seen in the footage, even on disturbance with the drop camera frame.

Beggiatoa-like bacteria was evident at all three Pen stations. Bacterial coverage was patchy at the Pen 2 station, but still reasonably high (~40%) in some areas. At Pen 1 and Pen 3, bacterial coverage was particularly high (~75%). This qualitative indicator is not consistent with the EQS, which requires coverage of *Beggiatoa*-like bacteria to be no greater than localised / patchy in distribution. High levels of bacterial cover typically indicates excessively enriched, anaerobic sediments with impoverished macrofauna (MPI 2015). However, we note that there was no concurrent deterioration in benthic indicator variables (see Section 4.1.2), with macrofauna at all Pen stations still maintaining productivity and assimilative capacity, and ES scores beneath the pens to be within the EQS, and consistent with the industry operational goal (MPI 2015). We therefore consider the conditions at the Pen stations are compliant with the intent of the EQS.

Given bacterial growth is also influenced by environmental factors (e.g. increased water temperature), it would be beneficial to perform more frequent visual surveys[6] (particularly in the warmer months). Determining changes in bacterial coverage on shorter time scales (and perhaps larger spatial scales) would increase our understanding of this qualitative compliance measure.

No epifauna were observed at Pen 1, but epifauna at the other two pen stations included green-lipped and blue mussels (*Mytilus galloprovincialis* and *Perna canaliculus*) and anemones (*Actinothoe albocincta*), snake stars (*Ophiopsammus maculata*), and a single cushion star (*Patiriella regularis*). Drift macroalgae (*Ulva* sp.) and diatom film were also present in some areas.

Sediments at the outer 300 m stations (NW and NE) were lighter than those at the Pen stations, and were also more sandy. Both stations had considerable amounts of shell hash present. A large band of *Beggiatoa*-like bacteria was present at 300 NE,

[6] Video footage could be collected by NZ King Salmon (using ROV or similar), repeated in the same locations over time (as advised by their science provider).

with approximately 50% substrate coverage in this area. *Beggiatoa*-like bacteria was not observed at 300 NW. Epifaunal diversity was higher at 300 NE than at 300 NW, with snake stars, cushion stars, anemones, cockles (unidentified), scallops (*Pecten novaezelandiae*) and sea cucumbers (*Australostichopus mollis)* observed. Snakes stars and cushion stars were also present at the 300 NW station, along with fanworms (unidentified) and saddle sea squirts (*Cnemidocarpa* sp.). Drift macroalgae (*Ulva* sp. and *Caulerpa brownii*) was also observed at 300 NE.

The substrate at the Embayment station was a mixture of sand and finer sediments, with only a small proportion of shell hash. Burrow holes, tube holes, and trail marks were evident on the surface of the sediment. Cushion stars were abundant, and drift macroalgae (*Ulva* sp. and *C. brownii*) were also present.

Sediments at TC-Ctl-2 and TC-Ctl-3 were sandy, with shell hash, larger shell debris and small cobble present. Sediments at TC-Ctl-4 were predominantly sand, with occasional fine shell hash. Diatom mats on the substrate surface were a conspicuous feature of this station. Burrow holes, tracks and worm casts were also observed. There was high epifaunal diversity across all reference stations, in particular TC-Ctl-3 which occasionally had reef-like structures present. Sessile invertebrate species included fanworms, colonial ascidians, sponges, encrusting bryozoans, hydroids, blue mussels and saddle sea squirts. Macroalgae included *Ulva* sp., encrusting coralline algae and a variety of red foliose species.

Mobile epifauna included eleven-armed sea stars, cushion stars, snake stars, sea cucumbers and scallops. Several sea cucumbers with distinctive branching tentacles (most likely from the Cucumaridae family) were noted at TC-Ctl-2. In addition, a single kina (*Evechinus chloroticus*) and apricot sea star (*Sclerasterias mollis*) were observed at TC-Ctl-3. Blue cod (*Parapercis colias*) and spotted wrasse (*Notolabrus celidotus*) were common at both TC-Ctl-2 and TC-Ctl-3.

4.1.2. Assessment of seabed enrichment

This section discusses the sediment Enrichment Stage (ES) calculated for each station (Table 4). Discussion is provided on results of individual variables (Figure 8) where relevant.

Enrichment Stage assessments for 2017

Overall ES scores across the three Pen stations were 4.5–5.0, all within the EQS for the ZME (Table 4). Pen 1 had the highest overall ES score of 5.0 (95% CI 0.1; n = 3) (Table 3). Organic content at this station was high, averaging just under 10%, with degraded sediment chemistry and macrofauna communities (Figure 8). Communities were still indicative of peak conditions, with abundances dominated by just a few taxa (nematodes, *Capitella capitata* and mostly single occurrences of several other taxa). The low total abundance (957 individuals per core) in one of the samples (and relative to other Pen stations), combined with the high organic content may suggest enrichment at this station may be progressing beyond peak conditions, and should be carefully monitored / managed. The Pen 2 station ES (4.9) was similar to Pen 1 and also had high organic content. At both Pen 2 and Pen 3, total abundances were very-high to extremely-high. Taxa richness was variable at both stations, including some very low values (< 10). All indicators generally suggest peak of opportunist conditions at Pen 2, and pre-peak at Pen 3, both with a high amount of assimilative capacity. Surprisingly, sulphides at the Pen 3 station (142 – 491 µM) were as low as reference values (average 235 µM). It is worth noting that reference values were anomalously high in several reference samples (e.g. 475 and 641 µM in TC Ctl 3a and TC Ctl 4c respectively).

The ES scores at 300 NW and 300 NE were within their modified EQS (for the OLE proxy), and the consented EQS (for the OLE at 600m). The 300 NE station showed moderate enrichment levels, and had an average overall ES score of 2.9. Sediment chemistry indicated deteriorated sediment conditions due to high sulphide levels, although these were variable. Taxa richness was similar to reference stations, but total abundances were high (~5 times reference) and compositional community differences were detected. The four dominant taxa at this station were nematodes, the polychaete sub-family Exogoninae, Oligochaeta, and the capitellid polychaete *Barantolla lepte*. The 300 NW station showed minor enrichment levels (overall ES 2.1). Organic matter and sediment chemistry were similar to reference conditions, as was taxa richness. No compositional differences were evident, although there were slightly elevated abundances.

The Embayment station showed moderate enrichment, with an overall ES score of 2.6. Organic matter and sediment chemistry were similar to reference conditions. Macrofauna at this station showed no obvious changes in total abundance, but there was reduced taxa richness, and compositional deteriorations as shown by the biotic indices (AMBI, mAMBI). The three most dominant taxa at the Embayment station were Oligochaeta, the polychaete family Paraonidae, and the capitellid polychaete *Barantolla lepte*.

Table 4. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each sampling station in January 2017. Full breakdowns of indicator variable contributions are provided in Appendix 3 and Appendix 4.

	Summary of indicator variables		ES (95% CI)
Pen 1	Organic matter (%OM) 2x ref, redox potential negative, total free sulphides highly elevated. Taxa richness extremely low (3–7 taxa per core), abundances variable, but very high in some samples (927–6,652 individuals per core).	Organic loading:	6.0 (0)
		Sediment chemistry:	4.6 (0.1)
		Macrofauna:	4.9 (0.1)
		Overall:	**5.0 (0.1)**
Pen 2	%OM almost 2x ref, redox negative, sulphides highly elevated. Taxa richness variable and very low in one sample (9 – 19 taxa per core), abundances extremely high (6,964–9,523 individuals per core). Peak macrofaunal conditions.	Organic loading:	6.0 (0)
		Sediment chemistry:	4.7 (0.1)
		Macrofauna:	4.7 (0.2)
		Overall:	**4.9 (0.2)**
Pen 3	%OM elevated, redox negative, sulphides normal. Taxa richness variable (7 – 14 taxa per core), and abundances high but variable (3,470–10,045 individuals per core).	Organic loading:	4.0 (2)
		Sediment chemistry:	3.9 (0.2)
		Macrofauna:	4.7 (0.1)
		Overall:	**4.5 (0.2)**
		ZME EQS	**≤ 5.0**
300 NE	%OM and redox similar to reference, sulphides elevated but variable. Abundances high (1,515 – 1,687 individuals per core), but taxa richness (43 – 59 taxa per core) similar to reference. Compositional differences detected in AMBI and mAMBI scores.	Organic loading:	2.3 (0.7)
		Sediment chemistry:	3.6 (0.5)
		Macrofauna:	2.8 (0.5)
		Overall:	**2.9 (0.5)**
300 NW	%OM, redox and sulphides similar to reference. Macrofaunal abundances slightly elevated (571–821 individuals per core), but taxa richness normal (4 –65 taxa per core). No compositional differences detected.	Organic loading:	2.0 (0)
		Sediment chemistry:	2.5 (0.3)
		Macrofauna:	1.9 (0.2)
		Overall:	**2.1 (0.1)**
		OLE proxy; modified EQS	**< 3.0**
Embayment	%OM, redox and sulphides similar to reference. Macrofaunal abundances similar to reference, but taxa richness reduced (26 – 27 taxa per core). Compositional differences observed as per AMBI and mAMBI scores.	Organic loading:	1.0 (0)
		Sediment chemistry:	3.0 (0.3)
		Macrofauna:	2.8 (0.2)
		Overall:	**2.6 (0.1)**

Table 4, continued.

	Summary of indicator variables		ES (95%CI)
TC-Ctl-2	Taxa richness 43 – 51 taxa per core, and abundances 312 – 574 individuals per core. Normal background conditions.	Organic loading:	2.0 (0)
		Sediment chemistry:	1.5 (0.2)
		Macrofauna:	2 (0.1)
		Overall:	**1.9 (0.1)**
TC-Ctl-3	Taxa richness 31 – 56 taxa per core, and abundances 95 – 493 individuals per core. Normal background conditions.	Organic loading:	1.3 (0.7)
		Sediment chemistry:	3.1 (0.2)
		Macrofauna:	2 (0.3)
		Overall:	**2.2 (0.2)**
TC-Ctl-4	Taxa richness 31 – 34 taxa per core, and abundances 57 – 182 individuals per core. Normal background conditions.	Organic loading:	2.0 (0)
		Sediment chemistry:	3.0 (0.6)
		Macrofauna:	2.0 (0.1)
		Overall:	**2.2 (0.2)**

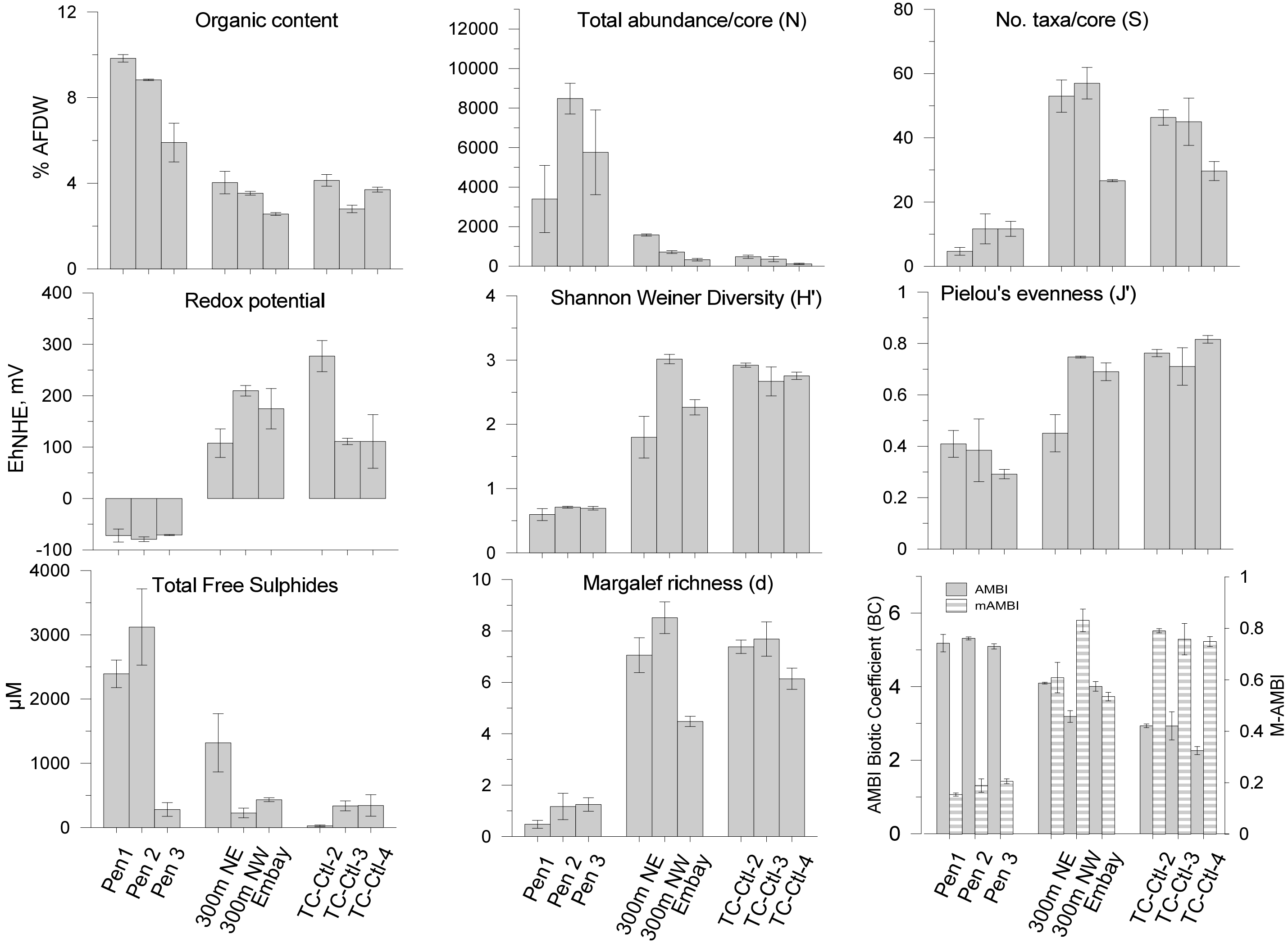


Figure 8. Average (±SE) sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and macrofauna statistics determined at the Te Pangu Bay salmon farm monitoring stations, January 2017. TC-Ctl = Tory channel control.

Historical comparison

A comparison of the last four monitoring assessments is shown in Figure 9 and Table 5. After a noticeable increase from ES 4.3 in November 2014 to ES 5.1 in January 2016, ES scores have marginally decreased to a compliant level in 2017. While Pen 2 shows an increase in overall ES this year[7] compared to 2016 (including increased organic content and *C. capitata* abundances; Appendix 5.1), Pen 1 and Pen 3 ES scores show no real change between these two years. The overall ES scores (and assimilative capacity) beneath the pens do not appear to correlate with the increased cover of *Beggiatoa*-like bacteria in 2016 and 2017.

Enrichment levels at the 300 NE, 300 NW and embayment stations has been reasonably stable across the past three monitoring assessments, with fluctuations on a similar scale to those seen at the reference stations between years. The mean change in ES was < 0.4 between the past two monitoring assessments, for all three stations.

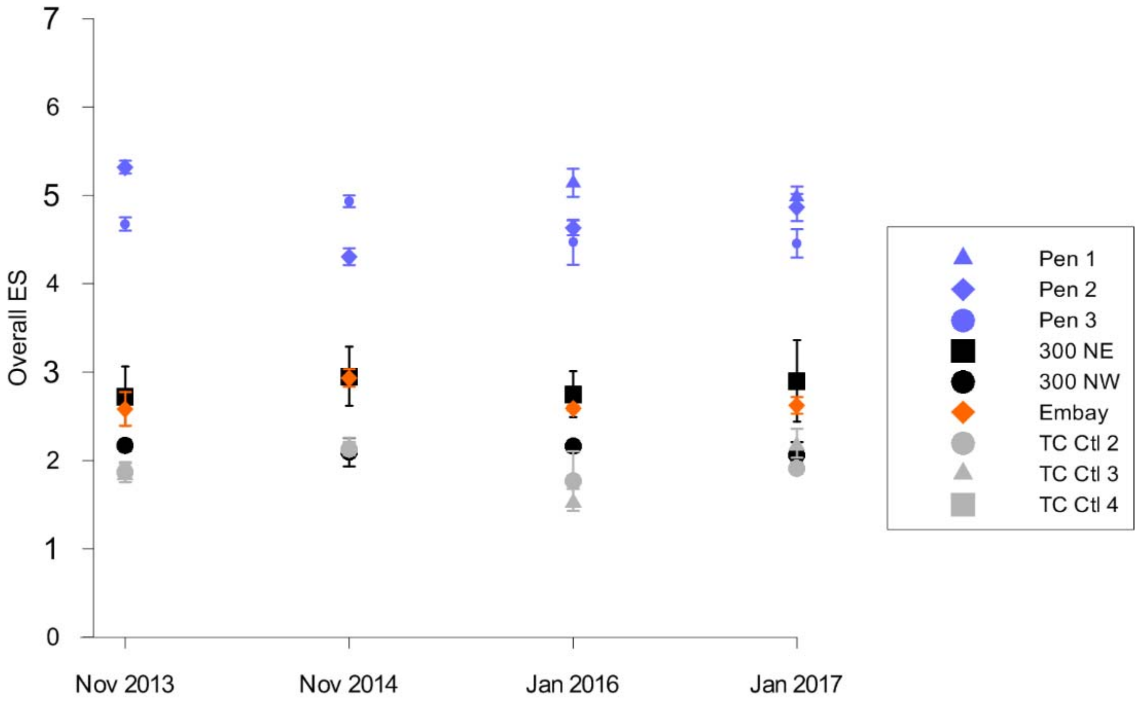


Figure 9. Four year time series of average overall ES (±SE or 95% CI in 2015/16) at the Te Pangu Bay farm monitoring stations.

[7] The Pen 2 ES from the past two years is not directly comparable with the 2013/2014 results, as the location differed between these periods.

Table 5. Comparison of average overall Enrichment Stage scores for assessments from annual monitoring for Te Pangu Bay 2013–2017. Values that exceed the EQS are underlined.

	Overall Enrichment Stage			
Station and type	**Nov 2013**	**Nov 2014**	**Jan 2016**	**Jan 2017**
Pen 1	<u>5.3 (0.1)</u>	4.3 (0)	<u>5.1 (0.2)</u>	**5 (0.1)**
Pen 2	4.7 (0)	4.9 (0)	4.6 (0.1)	**4.9 (0.2)**
Pen 3	-	-	4.5 (0.3)	**4.5 (0.2)**
300 NE	2.7 (0.2)	3 (0.2)	2.8 (0.3)	**2.9 (0.5)**
300 NW	2.2 (0.1)	2.1 (0)	2.2 (0)	**2.1 (0.1)**
Embayment (CE-Ref)	2.6 (0.1)	2.9 (0.1)	2.6 (0)	**2.6 (0.1)**
TC-Ctl-2 (Ref)	1.9 (0.1)	2.1 (0)	1.8 (0.3)	**1.9 (0.1)**
TC-Ctl-3 (Ref)	1.9 (0.1)	2.2 (0.1)	1.6 (0.1)	**2.2 (0.2)**
TC-Ctl-4 (Ref)	2.1 (0.1)	2.1 (0)	2.0 (0.1)*	**2.2 (0.2)**

*Sampled in November 2015.

4.1.3. Copper and zinc concentrations

Copper

Total recoverable copper concentrations from four of the nine replicates from beneath the pens exceeded the ISQG-Low (65 mg/kg) criterion (Table 6, Appendix 5.2). Despite copper concentrations being less than this threshold in the other five samples, the average beneath the pens (121 mg/kg, n = 9) also exceeded ISQG-Low. One sample exceeded ISQG-High with concentrations of 290 mg/kg.

The weak acid extractable fraction (an indicator of bio-availability; ANZECC 2000) was below this threshold in all replicates. As such, a reasonably large proportion of copper beneath the net pens is likely to be bound in particulate form, and no ecological effects are expected as a result.

Zinc

Total recoverable zinc concentrations from five of the nine replicates from beneath the pens exceeded the ISQG-Low criterion of 200 mg/kg (Table 6). No samples exceeded ISQG-High. The Pen 1 and Pen 2 averages were also above the ISQG-Low threshold, as was the overall pen average of 193 mg/kg.

Anomalously, dilute acid extractable concentrations in one sample (from Pen 3) was significantly higher than the total recoverable fraction. Hill Laboratories have advised in this case that total recoverable zinc in these samples was underestimated due to 'as yet undetermined' sample-matrix-specific chemical interactions with the strong acid digestion conditions. In any case, the dilute acid extractable results are the most ecologically relevant for drawing conclusions on potential effects of zinc[8], and accordingly, these are discussed as the most pertinent results.

The average dilute acid extractable zinc concentration across all pen samples was 178 mg/kg, below ISQG-Low. However, because the dilute acid extractable concentration of zinc exceeded ISQG-Low in three of the nine samples, localised biological effects from zinc are possible.

Table 6. Copper and zinc concentrations (mg/kg dry weight) in bulk sediment from Te Pangu Bay pen samples, January 2017. Pen and overall averages (±SE) are also shown. Bold values exceed ANZECC (2000) ISQG-Low, and underlined values exceed ISQG-High.

Sample		Copper		Zinc	
		Total recoverable	Dilute-acid-extractable	Total recoverable	Dilute-acid-extractable
Pen 1	a	**108**	8.9	**250**	159
	b	**230**	8.9	**270**	**240**
	c	**240**	9.6	**320**	**250**
Pen 1 average		**193 (±42)**	9 (±0)	**280 (±21)**	**216 (±29)**
Pen 2	a	30	13	114	103
	b	<u>**290**</u>	12.8	**290**	126
	c	38	8.9	**200**	148
Pen 2 average		**119 (±85)**	12 (±1)	**201 (±51)**	126 (±13)
Pen 3	a	10.3	3.9	99	91
	*b	24	8.5	94	97
	**c	**115**	5.9	104	**390**
Pen 3 average		50 (±33)	6 (±1)	99 (±3)	193 (±99)
Overall Pen average		**121 (±36)**	9 (±1)	**193 (±31)**	178 (±33)
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

*It was noted by Hills Laboratory that the result for the dilute acid extractable fraction was greater than that for the total recoverable fraction, but within analytical variation for the methods.

It was noted by Hills Laboratory that the result for the dilute acid extractable fraction was greater than that for the total recoverable fraction, and was **outside the analytical variation for the methods.

4.2. Water column

4.2.1. Dissolved oxygen

Minimum DO saturations within 250 m from the net pen (when measured) were 94.1% and 92.6%, well above the associated WQS (i.e. > 70%) (Table 7).

In April and August, minimum DO saturations at NZKS19 - 21 breached the 'first step' DO WQS (> 90%; WQS [1], Table 7), when concurrent reductions in DO were also

[8] As this indicates the bioavailability of the contaminant (ANZECC 2000).

observed at NZKS22. The reduced DO in April didn't breach the second step DO WQS threshold[9] (≥ 89.4), however the lower DO at NZKS20 and NZKS21 in August did. Importantly, the CTD instrument used at NZKS19, 20 and 21 in August was recording consistently lower (Appendix 6) than the CTD used at NZKS22 (results from which were used to derive the second step threshold). As such, the second step threshold has not been effective at preventing what is considered to be a false breach (i.e. not a farm-related effect) in these samples.

Despite the discrepancies in results from the two instruments, the current DO WQS do not appear to be appropriate for Tory Channel, as they do not capture the full 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.

Table 7. Water column monitoring results for minimum dissolved oxygen (% saturation) (1 m depth binned downcast data) at sampling stations in Tory Channel. Underlined values indicate those below the associated WQS (1), bolded values indicate those also below the WQS(2).

Month	TEP pen	NZKS19	NZKS20	NZKS21	NZKS22	WQS (2)
Apr	n/s	89.8	90.3	89.6	90.5	**≥ 89.4**
May	n/s	93.6	92.7	91.8	95.0	
June	n/s	94.2	94.2	93.2	95.2	
Jul	n/s	94.4	94.5	94.5	96.0	
Aug	n/s	89.3	**79.8**	**87.7**	89.6	**≥ 88.5**
Sep	n/s	95.6	94.3	94.4	95.5	
Oct	n/s	94.9	93.4	93.6	94.7	
Nov	94.1	91.9	91.8	90.9	92.6	
Dec	92.6	92.2	92.5	91.7	93.3	
WQS (1)	**> 70%**		**> 90%**		**n/a**	

4.2.2. Total 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), with one exception (Table 8). The exception was NZKS21, which had high TN concentrations on several sampling occasions (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.

While the farm undoubtedly has localised effects on nitrogen concentrations, such as those observed for other farms (e.g. Ngamahau; Elvines et al. 2017), natural variability appears to explain larger fluctuations of TN in the wider area. Monitoring at

[9] The second step WQS threshold is calculated by subtracting 1.2% from the average of applicable reference station DO saturations (also see Table 3).

the nearby Ngamahau Bay farm showed that this variability often exceeded increases in TN attributable to the farm. Given the results, there is no evidence to suggest the TEP farm is causing elevated TN 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*.

Because TN exceeded the WQS on only two isolated incidences, a second-step WQS threshold (as recommended in Knight et al. 2016) has not been determined for this nutrient.

Table 8. Water column monitoring results for total nitrogen (mg/m^3) in surface integrated samples from Tory Channel sampling stations, 2016. Underlined values indicate those that exceed the WQS.

Month	NZKS19	NZKS20	NZKS21	NZKS22
Apr	195.0	172.0	179.0	177.0
May	264.0	225.0	225.0	184.0
June	235.0	225.0	218.0	254.0
Jul	213.0	175.3	301.0	229.0
Aug	164.3*	163.3*	247.8*	166.0
Sep	188.0	194.0	261.0	174.0
Oct	176.0	154.0	209.0	171.0
Nov	180.0	180.0	310.0	188.0
Dec	258.0	225.0	232.0	241.0
WQS	**≤ 300 mg/m^3**			**n/a**

4.2.3. Chlorophyll-a and phytoplankton biomass and composition

In all cases, Chl-*a* concentrations (max. 1.5 mg /m^3) were within the Chl-*a* WQS (i.e. < 3.5 mg/m^3; Table 9). Estimated phytoplankton biomass values in July and August (Table 10) were in the range of 1 to 3 mg C/m^3. Biomass estimates were low compared to those estimates recorded for other regions of the Marlborough Sounds (e.g. Pelorus Sound, Elvines et al. 2017).

Diatoms were generally the dominant group of phytoplankton, typically accounting for > 70% of the biomass across most samples (Table 10). In July, phytoplankton community composition was more variable across the sampling stations. Dinoflagellates represented a higher proportion of the total biomass in samples from NZKS20 and NZKS22, while the sample from NZKS21 had a high representation of 'other' phytoplankton taxa (i.e. neither diatoms or dinoflagellates were the dominant taxa). The proportional measure of community composition appears more sensitive to small increases in cell abundances of non-diatom taxa, probably due to the low overall phytoplankton biomass.

The variation in phytoplankton collected across these sampling stations is consistent with that presented in the baseline report (Morrisey et al. 2015).

Table 9. Water column monitoring results for chlorophyll-*a* (mg/m^3) in surface integrated samples from Tory Channel sampling stations, 2016. No values exceeded the WQS.

Month	NZKS19	NZKS20	NZKS21	NZKS22
Apr	0.82	1.13	1.50	1.11
May	0.24	0.26	0.40	0.22
June	0.45	0.44	0.50	0.43
Jul	0.30	0.34	0.30	0.34
Aug	0.30*	0.32*	0.26*	0.16
Sep	0.76	0.78	0.80	0.83
Oct	0.64	0.54	0.80	0.44
Nov	0.76	0.54	0.60	0.48
Dec	0.81	0.46	0.60	0.39
WQS	**≤ 3.5 mg Chl-*a*/m^3**			

Table 10. Phytoplankton biomass (mgC/m^3) and composition (as percent of total phytoplankton biomass) in surface integrated samples from the Tory Channel sampling stations, 2016.

	NZKS19	NZKS20	NZKS21	NZKS22
July 2016				
Proportion (%)				
Diatom	100.0	58.2	20.5	74.2
Dinoflagellate	0.0	40.7	7.1	25.8
Other	0.0	1.1	72.4	0.0
Biovolume (mgC/m^3)				
Diatom	1.67	1.00	0.79	0.92
Dinoflagellate	0.00	0.70	0.27	0.32
Other	0.00	0.02	2.79	0.00
August 2016				
Proportion (%)				
Diatom	100.0	100.0	100.0	92.3
Dinoflagellate	0.0	0.0	0.0	7.7
Other	0.0	0.0	0.0	0.0
Biovolume (mgC/m^3)				
Diatom	1.88	1.53	1.83	3.01
Dinoflagellate	0.00	0.00	0.00	0.25
Other	0.00	0.00	0.00	0.00

5. SUMMARY OF FINDINGS

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

- *No biological effects are expected from copper in the sediments beneath the pens, but localised effects from high zinc levels are possible.*

  Copper was mostly present in particulate form, while zinc levels were variable, but often at high levels that were potentially bioavailable.

- *There were no obvious changes in enrichment levels observed from the previous annual monitoring*.
- *The levels of enrichment were within the EQS for the 300 NE and 300 NW stations.*

  The NE station showed moderate enrichment levels with modified macrofaunal conditions and patches of *Beggiatoa*-like bacteria. The embayment station also showed enrichment effects, while the 300 NW station showed only elevated abundances compared to reference conditions.

- *The levels of enrichment were within the allowable ES scores for the Pen stations. However, in some areas beneath the pens coverage of* Beggiatoa*-like bacteria was not consistent with the EQS description for this indicator.*

  Other indicators were variable beneath the pens, but generally indicated peak-abundances, consistent with very high enrichment levels. Productive and assimilative macrofaunal conditions have been maintained, despite the relatively high level of bacterial coverage.

- *No chlorophyll-a (Chl-a) results exceeded the water quality standards (WQS).*
- *With two exceptions, total nitrogen (TN) concentrations were within the TN WQS.*

  The exceedances occurred on two isolated occasions. The frequency at which these ‘exceedances’ occurred is in line with that observed in the past.

- *Dissolved oxygen (DO) saturations outside of 250 m from the net pens were below the ‘first step’ threshold of the DO WQS in five samples, and two of these samples were also lower than the 1.2% second-step threshold which considers reference DO saturations.*

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

6. RECOMMENDATIONS

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

- Revision of the DO WQS for Tory Channel, because the current WQS do not capture the full spectrum of natural DO fluctuations in this area, resulting in 'false breaches' of the WQS.
- More frequent visual surveys of the seabed (particularly in the warmer months) to determine changes in bacterial coverage on shorter time scales (and perhaps larger spatial scales), increasing our understanding of this qualitative compliance measure.

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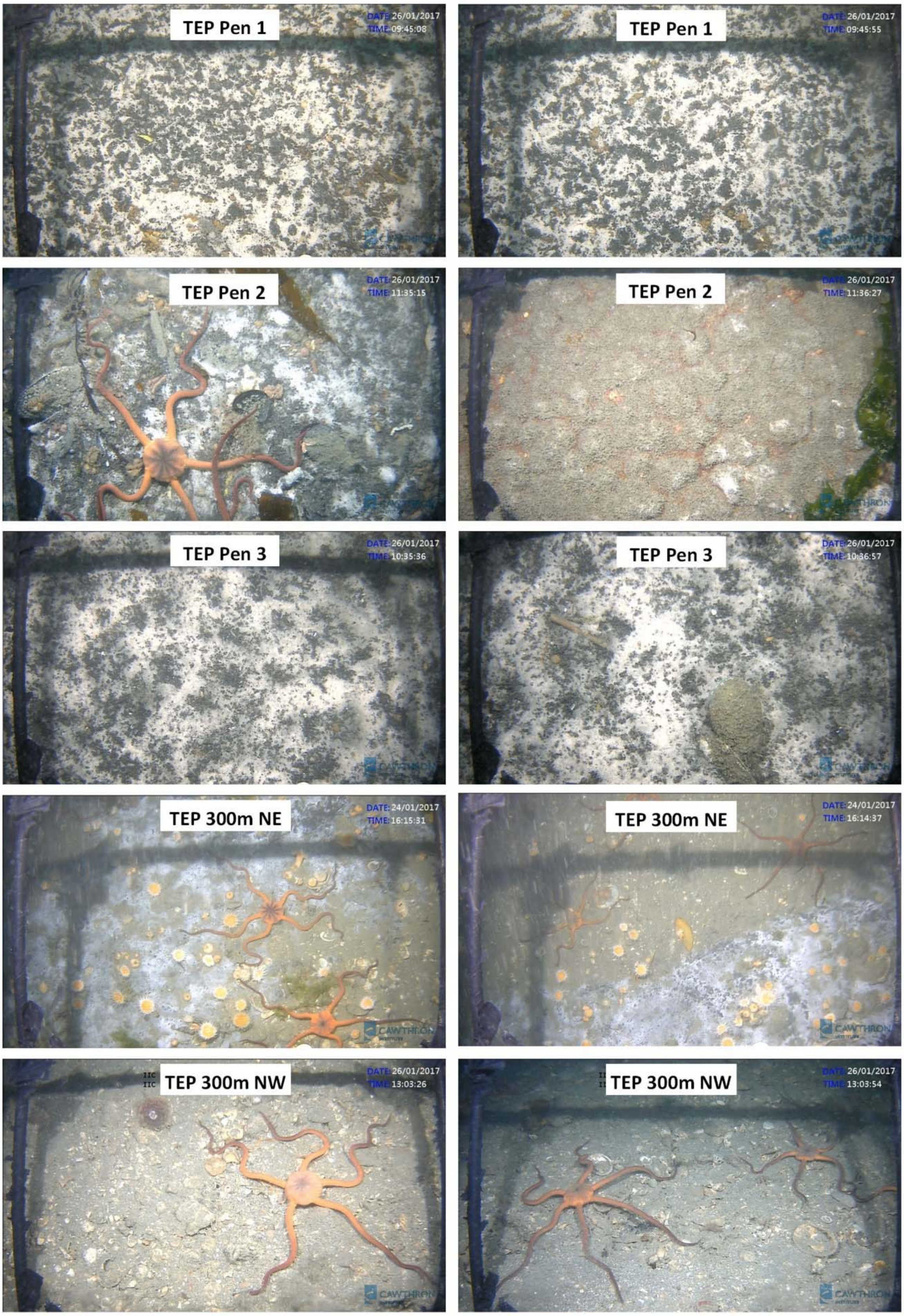
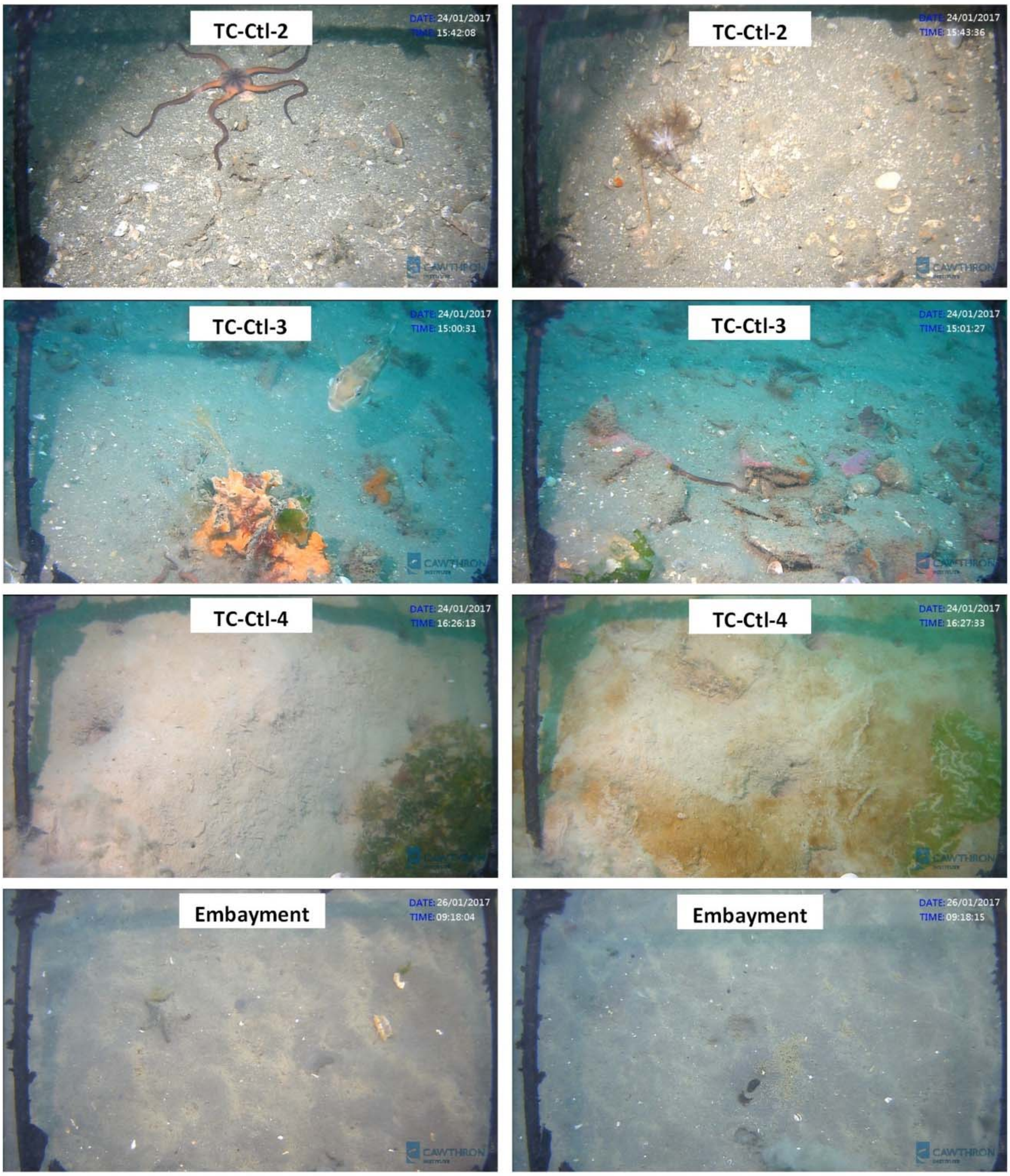
8. APPENDICES

Appendix 1. Laboratory analytical methods for sediment samples (January 2016) processed by either 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)
1M HCl extractable copper & zinc [a]	< 2mm sieved fraction, 1M HCl extraction, ICP-MS. CSIRO 2005.	1.2 mg/kg (Cu) 3 mg/kg (Zn)
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
Total nitrogen [(c)] (TN)	Persulphate digest, auto cadmium reduction, FIA. Lachat.	10 mg/m^3
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. Representative images of the seafloor at each soft sediment sampling station (January 2017).

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TIME: 09:18:04
Embayment
DATE: 26/01/2017
TIME: 09:18:15

Appendix 3. Detailed enrichment stage (ES) calculations for each soft sediment sampling station at the Te Pangu 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: TEP
Flow environment: HF

Variable group weightings: 0.1 | 0.2 | 0.7

		RAW DATA (to be entered)											ES equivalents													
Station:	Rep	TOM	Redox	TFS	N	S	J'	d	SWDI	AMBI	M-AMBI	BQI	TOM	Redox	TFS	N	S	d	SWDI	AMBI	M-AMBI	BQI	Organic loading	Sediment chemistry	Macro-fauna	Overall ES
Pen1	a	9.9	-48	2498	2610	7	0.34	0.76	0.67	5.48	0.15	1.80	6	4.56	4.48	3.86	5.00	5.42	4.48	4.87	5.48	5.47	6	4.52	4.79	4.86
Pen1	b	10.1	-77	2699	6652	3	0.37	0.23	0.41	4.71	0.17	1.41	6	4.82	4.53	4.58	6.00	5.60	5.05	4.09	5.45	5.84	6	4.68	5.03	5.06
Pen1	c	9.5	-91	1980	927	4	0.51	0.44	0.71	5.36	0.15	1.42	6	4.95	4.33	5.50	5.50	5.54	4.39	4.75	5.49	5.84	6	4.64	4.99	5.02
Pen 2	a	8.8	-87	3406	6964	3	0.63	0.23	0.69	5.32	0.14	1.24	6	4.91	4.68	4.61	6.00	5.61	4.43	4.71	5.49	6.01	6	4.8	4.9	4.99
Pen 2	b	8.9	-71	3977	9523	13	0.27	1.31	0.70	5.38	0.19	2.34	6	4.77	4.78	4.85	4.31	5.18	4.40	4.77	5.39	5.00	6	4.78	4.75	4.88
Pen 2	c	8.8	-80	1980	8949	19	0.25	1.98	0.74	5.24	0.23	2.74	6	4.85	4.33	4.80	3.90	4.83	4.33	4.63	5.24	4.65	6	4.59	4.57	4.72
Pen 3	a	4.2	-70	209	3772	7	0.33	0.73	0.64	4.96	0.19	2.01	2	4.76	2.88	4.14	5.50	5.43	4.54	4.35	5.39	5.28	2	3.82	4.81	4.33
Pen 3	b	7.3	-73	491	10045	14	0.27	1.41	0.71	5.21	0.21	2.49	5	4.79	3.43	4.89	4.24	5.13	4.38	4.60	5.33	4.86	5	4.11	4.69	4.61
Pen 3	c	6.2	-70	142	3470	14	0.28	1.60	0.73	5.11	0.22	2.55	5	4.76	2.63	4.08	4.24	5.03	4.35	4.50	5.30	4.82	5	3.7	4.55	4.43
300m NE	a	3.9	85	1244	1513	59	0.57	7.92	2.32	4.05	0.70	6.06	2	3.36	4.03	3.44	1.13	1.68	2.11	3.41	2.48	2.54	2	3.7	2.43	2.64
300m NE	b	5	75	2139	1540	43	0.32	5.72	1.20	4.11	0.50	4.66	3	3.45	4.38	3.46	2.24	2.56	3.47	3.48	3.75	3.29	3	3.92	3.26	3.37
300m NE	c	3.2	163	573	1687	57	0.46	7.54	1.88	4.12	0.63	5.54	2	2.66	3.53	3.53	1.27	1.77	2.52	3.49	2.84	2.79	2	3.1	2.67	2.69
300m NW	a	3.4	190	333	821	65	0.75	9.54	3.15	3.04	0.90	8.57	2	2.42	3.18	2.97	0.72	1.00	1.76	2.38	1.76	1.74	2	2.8	1.76	1.99
300m NW	b	3.7	215	83	752	58	0.74	8.61	3.01	3.01	0.85	8.61	2	2.19	2.28	2.91	1.20	1.58	1.78	2.35	1.84	1.73	2	2.24	1.9	1.98
300m NW	c	3.5	224	264	571	48	0.75	7.41	2.89	3.51	0.75	7.54	2	2.11	3.03	2.70	1.89	1.81	1.81	2.86	2.22	1.98	2	2.57	2.13	2.21
Embay	a	2.5	148	420	207	27	0.76	4.88	2.50	3.98	0.56	7.44	1	2.80	3.33	1.92	3.34	3.05	1.98	3.34	3.30	2.01	1	3.07	2.59	2.53
Embay	b	2.5	124	389	353	26	0.65	4.26	2.13	3.79	0.54	7.16	1	3.01	3.28	2.33	3.41	3.43	2.26	3.15	3.48	2.10	1	3.15	2.8	2.69
Embay	c	2.7	252	491	424	27	0.66	4.30	2.16	4.24	0.51	7.18	1	1.86	3.43	2.47	3.34	3.41	2.23	3.61	3.68	2.09	1	2.65	2.88	2.65
TC-Ctl-2	a	4.3	254	22	574	51	0.75	7.87	2.93	3.03	0.81	8.05	2	1.84	1.42	2.70	1.69	1.69	1.80	2.37	1.97	1.85	2	1.63	1.99	1.92
TC-Ctl-2	b	3.6	240	7	312	43	0.79	7.31	2.97	2.86	0.79	7.96	2	1.97	0.69	2.23	2.24	1.84	1.79	2.19	2.05	1.87	2	1.33	1.98	1.85
TC-Ctl-2	c	4.5	337	50	550	45	0.75	6.97	2.86	2.92	0.78	7.61	2	1.10	1.95	2.67	2.10	1.97	1.82	2.26	2.08	1.96	2	1.53	2.08	1.96
TC-Ctl-3	a	3.1	112	475	485	56	0.73	8.89	2.96	2.58	0.87	9.39	2	3.12	3.41	2.57	1.34	1.57	1.79	1.91	1.80	1.63	2	3.27	1.81	2.12
TC-Ctl-3	b	2.5	121	208	493	48	0.57	7.58	2.22	3.70	0.66	6.68	1	3.04	2.88	2.58	1.89	1.76	2.18	3.05	2.67	2.27	1	2.96	2.38	2.36
TC-Ctl-3	c	2.8	100	326	95	31	0.82	6.59	2.83	2.52	0.74	10.62	1	3.23	3.17	1.32	3.07	2.13	1.83	1.85	2.25	1.60	1	3.2	1.94	2.1
TC-Ctl-4	a	3.7	215	326	114	34	0.81	6.97	2.87	2.43	0.77	9.14	2	2.19	3.17	1.46	2.86	1.97	1.81	1.76	2.13	1.65	2	2.68	1.89	2.06
TC-Ctl-4	b	3.9	65	63	57	24	0.84	5.69	2.68	2.29	0.71	6.63	2	3.54	2.10	0.93	3.55	2.58	1.89	1.61	2.40	2.30	2	2.82	2.08	2.22
TC-Ctl-4	c	3.5	53	641	182	31	0.79	5.77	2.72	2.06	0.77	9.25	2	3.65	3.60	1.82	3.07	2.54	1.87	1.38	2.12	1.64	2	3.63	2	2.33

Appendix 4. Summary of the average (SE) sediment physical and chemical properties, macrofauna variables and calculated indices for the Te Pangu Bay salmon farm soft sediment sampling stations during the January 2017 monitoring survey.

		Units	Pen1	Pen 2	Pen 3	300m NE	300m NW	Embay	TC-Ctl-2	TC-Ctl-3	TC-Ctl-4
	Depth	m	28	31	35	48	31	3	31	30	20
Sediments	AFDW	%	9.8 (0.2)	8.8 (30)	5.9 (0.9)	4 (0.5)	3.5 (0.1)	2.6 (0.1)	4.1 (0.3)	2.8 (0.2)	3.7 (0.1)
	Redox	Eh_{NHE}, mV	-72 (13)	-79 (5)	-71 (1)	108 (28)	210 (10)	175 (39)	277 (30)	111 (6)	111 (52)
	Sulphides	µM	2392 (214)	3121 (594)	281 (107)	1319 (454)	227 (75)	433 (30)	26 (13)	336 (77)	343 (167)
	Bacterial mat	-	Consistent	Patchy	Consistent	Patchy	No	No	No	No	No
	Out-gassing	-	No	No	No	No	No	No	No	No	No
	Odour	-	Strong	moderate	moderate	Mild-mod	No	No	No	No	No
Macrofauna statistics	Abundance	No./core	3396 (1699)	8479 (775)	5762 (2143)	1580 (54)	715 (75)	328 (64)	479 (84)	358 (131)	118 (36)
	No. taxa	No./core	4.7 (1.2)	11.7 (4.7)	11.7 (2.3)	53 (5)	57 (4.9)	26.7 (0.3)	46.3 (2.4)	45 (7.4)	29.7 (3)
	Evenness	Stat.	0.4 (0.1)	0.4 (0.1)	0.3 (0)	0.5 (0.1)	0.7 (0)	0.7 (0)	0.8 (0)	0.7 (0.1)	0.8 (0)
	Richness	Stat.	0.5 (0.2)	1.2 (0.5)	1.2 (0.3)	7.1 (0.7)	8.5 (0.6)	4.5 (0.2)	7.4 (0.3)	7.7 (0.7)	6.1 (0.4)
	SWDI	Index	0.6 (0.1)	0.7 (0)	0.7 (0)	1.8 (0.3)	3 (0.1)	2.3 (0.1)	2.9 (0)	2.7 (0.2)	2.8 (0.1)
	AMBI	Index	5.2 (0.2)	5.3 (0)	5.1 (0.1)	4.1 (0)	3.2 (0.2)	4 (0.1)	2.9 (0.1)	2.9 (0.4)	2.3 (0.1)
	M-AMBI	Index	0.2 (0)	0.2 (0)	0.2 (0)	0.6 (0.1)	0.8 (0)	0.5 (0)	0.8 (0)	0.8 (0.1)	0.7 (0)
	BQI	Index	1.5 (0.1)	2.1 (0.4)	2.4 (0.2)	5.4 (0.4)	8.2 (0.3)	7.3 (0.1)	7.9 (0.1)	8.9 (1.2)	8.3 (0.9)

Appendix 5. Historical comparisons.

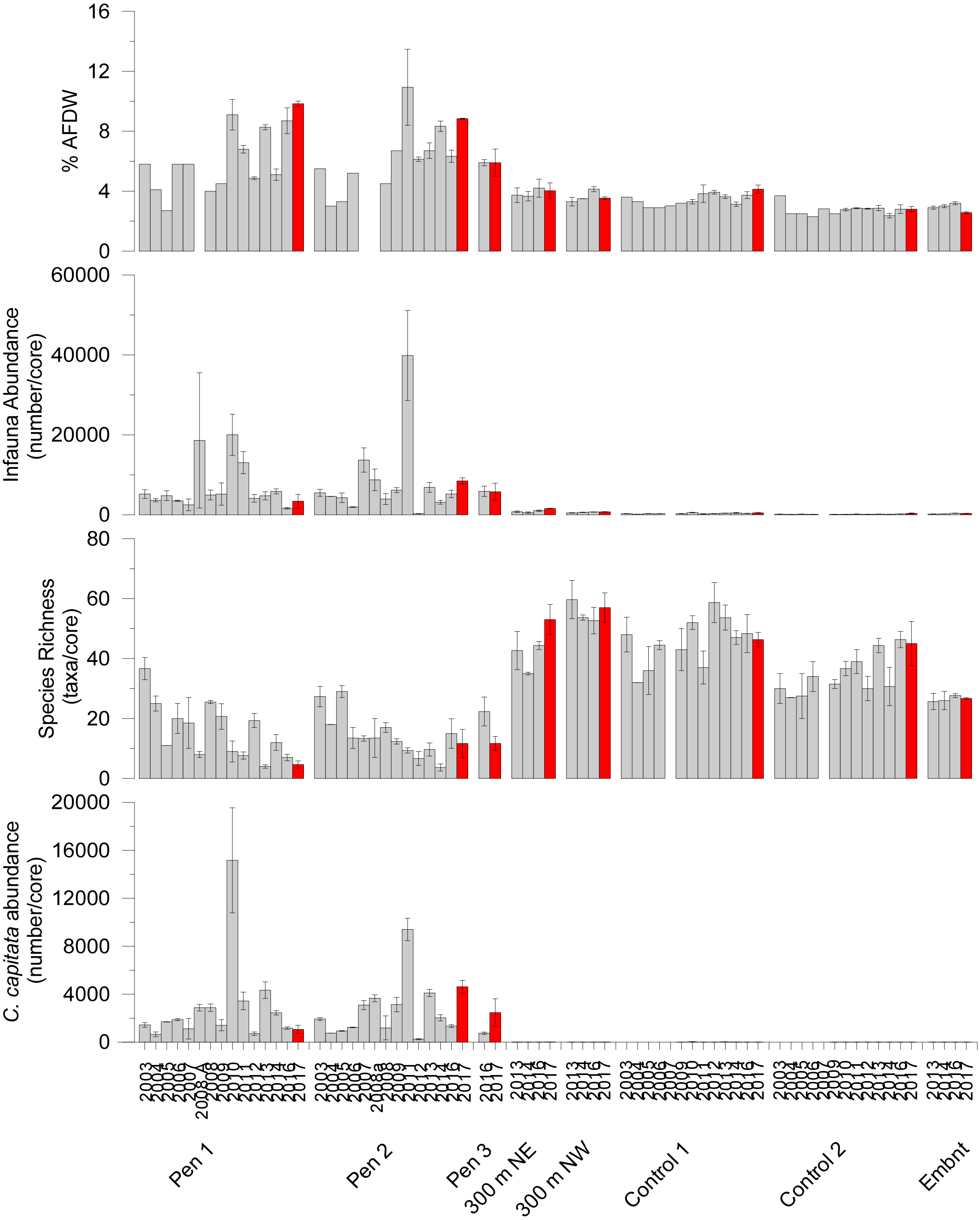

Figure A5.1. Mean (± SE) ash-free dry weight (AFDW), macrofauna abundance (number/core), taxa richness (taxa/core), and *Capitella capitata* densities (number/core) recorded for Te Pangu Bay salmon farm annual monitoring since 2003. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000).

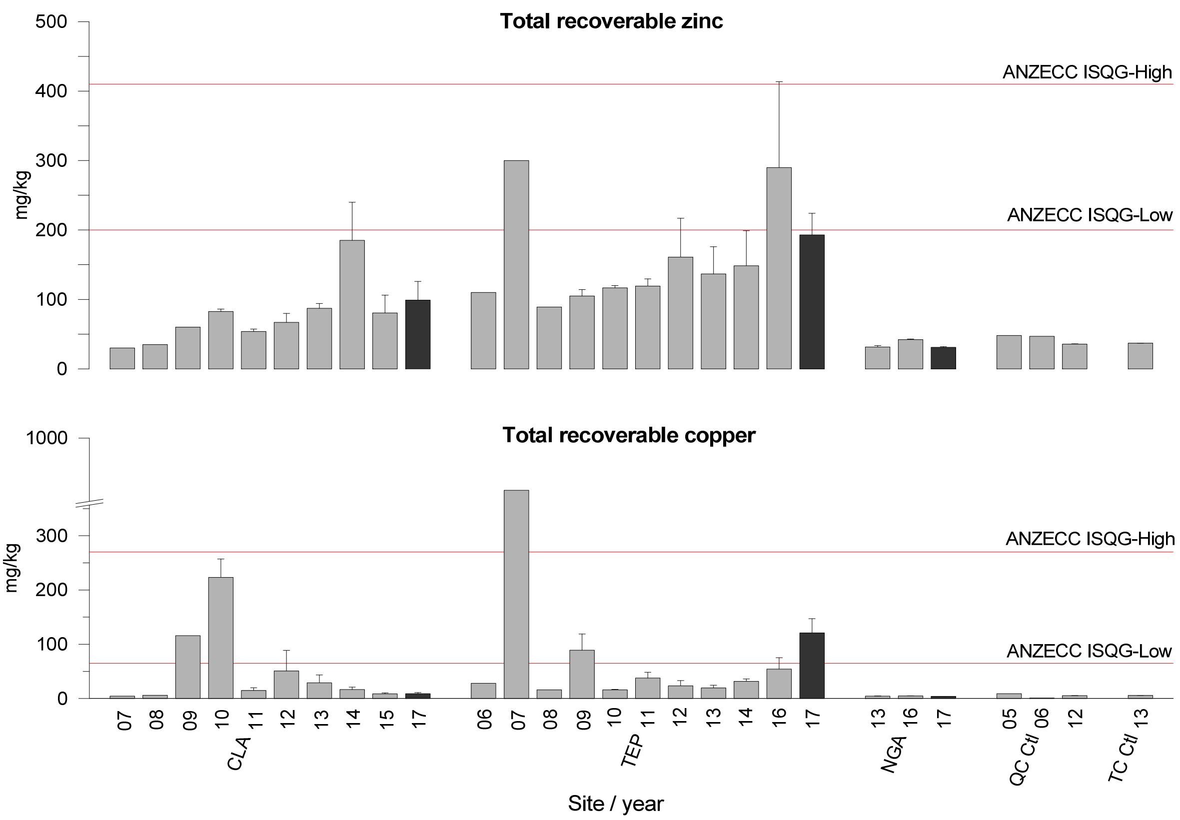

Figure A5.2. Average sediment total recoverable copper and zinc concentrations beneath the Tory Channel NZ King Salmon farms and two reference stations (TC = Tory Channel, QC = Queen Charlotte, Ctl = control). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low trigger levels.

Appendix 6. Comparison of dissolved oxygen (% saturation) data collected concurrently in August 2016 at two different sampling stations by Cawthron Institute (Seabird 19 CTD) and MDC (YSI EXO Sonde) CTD instruments.

A side-by-side comparison of data from the two CTD instruments (Seabird 19 CTD: Cawthron Institute, YSI EXO Sonde CTD: Marlborough District Council) used in August shows discrepancies between DO results from these two instruments. 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. However, in the absence of alternative data, the minimum DO saturations recorded using the MDC instrument in August (NZKS21 and NZKS22) are still presented in this report.

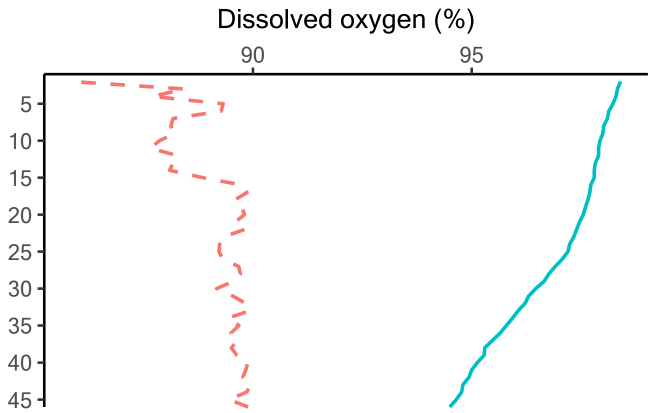

Figure A6.1. Coincident downcast data: Cawthron Institute (Seabird 19: red dashed line) and MDC (YSI EXO Sonde; blue solid line) CTD instruments.

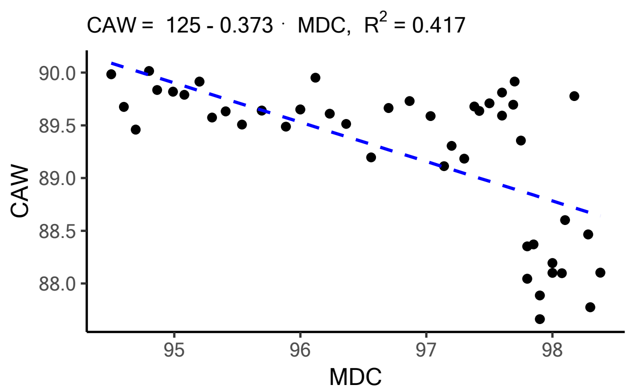

Figure A6.2. Statistical comparison: Cawthron (CAW), Marlborough District Council (MDC). Dotted blue lines are the linear least-squares fitted lines, with the associated slope, intercept and goodness of fit (R^2) information displayed with the graph.