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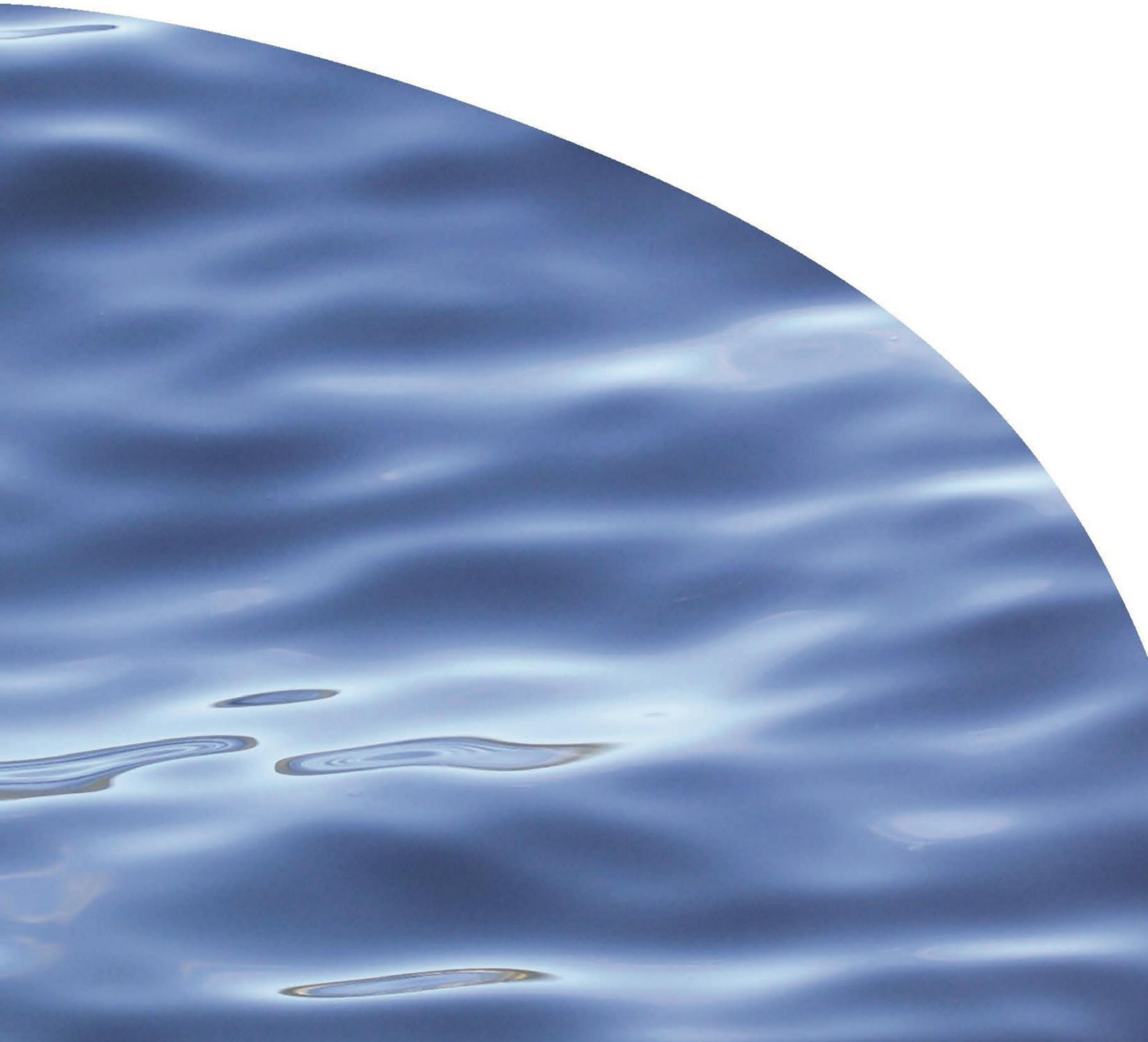
2018-2019 ANNUAL ENVIRONMENTAL MONITORING SUMMARY FOR THE TE PANGU BAY SALMON FARM



2018-2019 ANNUAL ENVIRONMENTAL MONITORING SUMMARY FOR THE TE PANGU BAY SALMON FARM

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Prepared for The New Zealand King Salmon Co. Ltd.

Reissued to provide updated information regarding the results of copper and zinc analyses in accordance with level 3 monitoring (Section 2.1.2). No material changes to findings.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. BACKGROUND

This report presents the environmental monitoring results for the Te Pangu Bay (TEP) salmon farm located in Tory Channel (consent number U150081) and established in 1992. Data presented include an assessment of depositional effects on soft-sediment habitats and effects on the water column. Results from reef habitat monitoring are reported separately in Dunmore (2019).

In terms of its hydrodynamics, TEP is assessed as a high flow site. The average water current speeds are c. 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.

A total of 4,858 tonnes of feed was discharged at the TEP site in 2018, which is within the maximum allowable annual discharge (5,500 tonnes[1]), and 359 tonnes lower than the total feed discharged in 2017. The highest monthly feed discharge during the 12 months prior to sampling was in April (464 tonnes). Feed levels steadily decreased until July, and then increased slowly through to December (Figure 1).

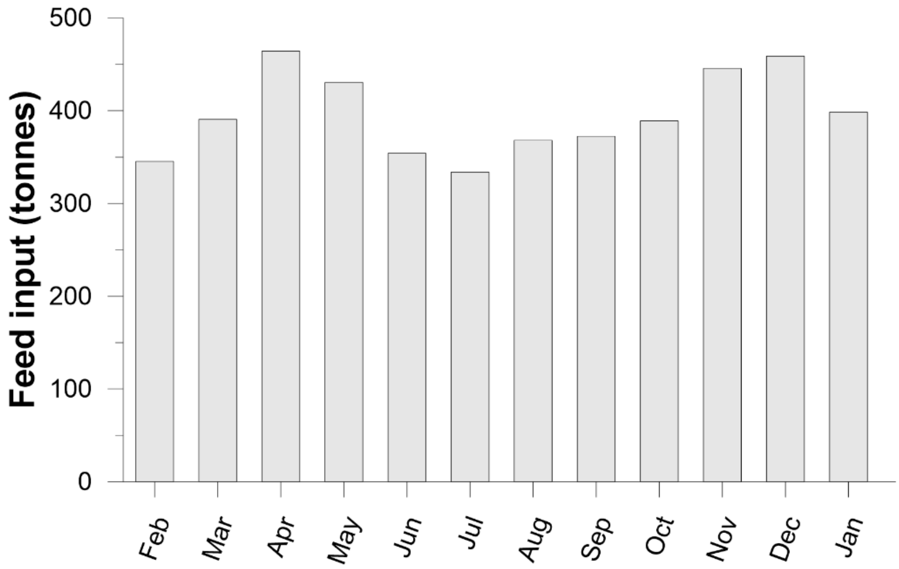

Figure 1. Monthly feed inputs at the Te Pangu Bay (TEP) salmon farm for the 12 months preceding soft-sediment sampling. Feed input data provided by NZ King Salmon.

[1] Or 6,000 tonnes if the farm is located in the 'seaward net pen area'.

2. KEY SAMPLING DETAILS AND RESULTS

An overview of the key sampling details and results is provided in this section. More comprehensive discussion of methodology and monitoring results are provided in the relevant appendices.

2.1. Soft sediments

Annual soft-sediment monitoring at TEP was undertaken on 12 February 2019. Sampling stations comprised three stations immediately adjacent to the net pens, **Pen 1**, **Pen 2** and **Pen 3** to monitor benthic impacts at the salmon farm, as well as two stations to monitor enrichment within the outer limit of effects[2], **300 NE** and **300 NW** (Figure 2).

An additional station inshore of the farm (**Embayment**) was sampled to monitor potential cumulative enrichment effects within Te Pangu Bay.

Three reference or 'control' stations; one near-field (**TC-Ctl-2**) and two far-field (**TC-Ctl-3** and **TC-Ctl-4**) were also sampled.

Sediments at all stations were assessed for organic content, redox potential, total free sulphides and infaunal community composition (see Appendix 1 for all sampling details). In addition, copper and zinc concentrations were also measured beneath the net pens.

The results are measured against environmental quality standards (EQS) set by the resource consent and the best management practice (BMP) guidelines developed for salmon farming in the Marlborough Sounds region (see MPI 2015; Appendix 1 for benthic EQS).

[2] The consented EQS for the OLE at TEP has been modified to accommodate the closer sampling distance (300 m compared to the maximum OLE of 600 m). For further detail on the modified EQS for this zone, readers are referred to the MEMAMP (Bennett & Dunmore 2018).

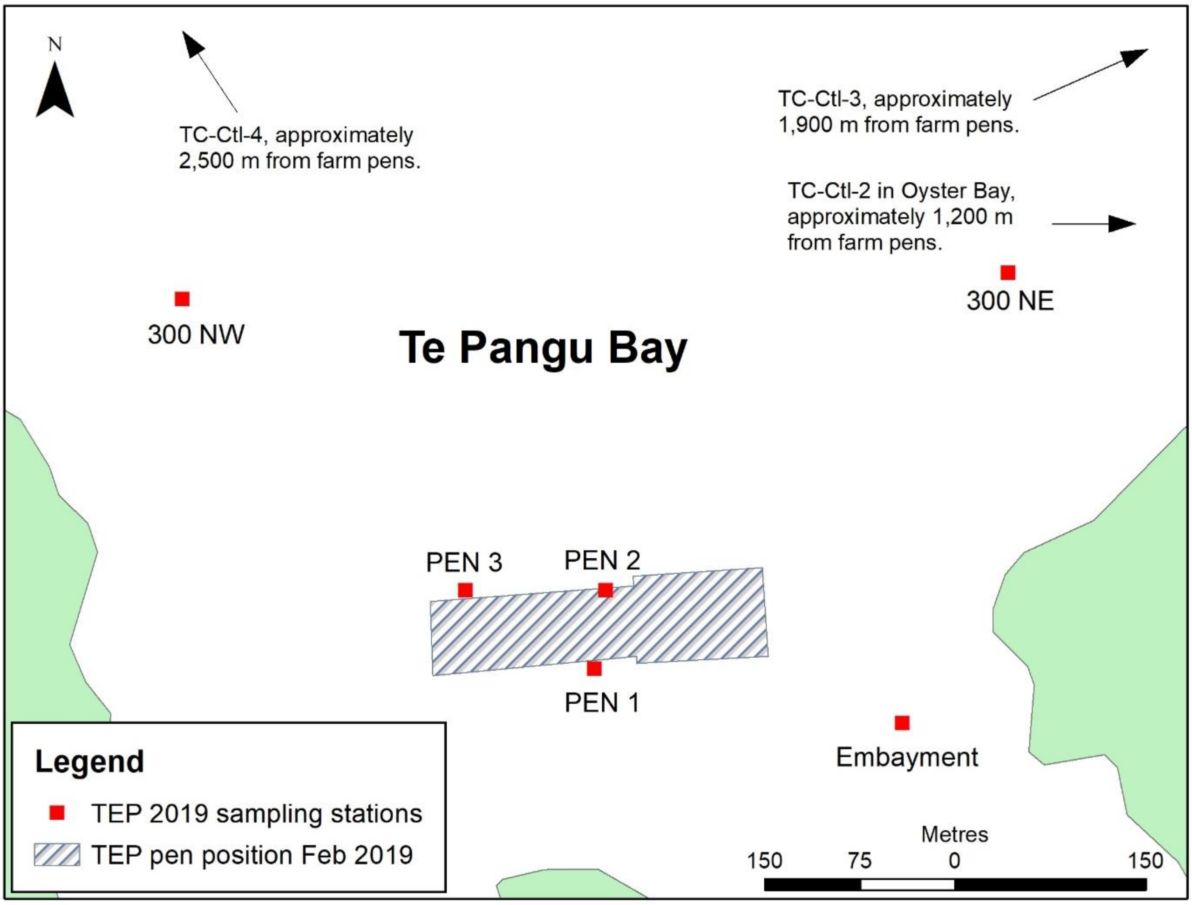

Figure 2. Soft sediment sampling locations at the Te Pangu Bay salmon farm (TEP) site. 'TC-Ctl' = Tory Channel Control. Position accuracy is ± 5 m.

2.1.1. Enrichment of soft-sediment habitats near Te Pangu Bay salmon farm

A summary of key findings is provided below, while detailed monitoring results are provided in Appendix 2.

The average overall Enrichment Stage (ES) scores were 4.9, 4.4 and 4.5 for Pen 1, Pen 2 and Pen 3, respectively (Table 1), indicating high to very high enrichment levels. The overall ES scores for all pen stations were within the EQS for this zone (ES ≤ 5.0) and have decreased marginally since the 2018 monitoring survey (from ES 5.0, 4.6 and 4.7, respectively; see Figure 3 where ES scores are shown with feed levels over time). Macrofaunal abundance at Pen 1 has reduced from last year and is more than 10-fold lower than at Pens 2 and 3 (Table 2 summarises all observations for the TEP sites). The decline in macrofaunal abundance at Pen 1 could reflect patchiness in beneath-pen communities typical of highly enriched sediments, or a transition from 'peak-of-opportunist'[3] (i.e. very low taxa richness and highly elevated

[3] Refers to peak abundance of opportunistic taxa (e.g. capitellids and nematodes), where waste assimilation is theoretically maximal (see Keeley et al. 2012, 2013).

abundances) to ‘pre-peak’ based on higher taxa richness compared to last year. In any case, the assimilative capacity[4] at this station is reduced from ‘peak’ conditions.

Under the BMP, bacterial coverage at Pen 1 met one of the descriptive EQS at the ‘minor’ action level (see MPI 2015)[5]. A high level of bacterial cover is typically an indicator of excessively enriched, anaerobic sediments with impoverished macrofauna (MPI 2015). However, we note that while assimilative capacity at this station is reduced from ‘peak’ conditions, communities beneath the pen stations still had a high capacity for assimilating organic waste. Additional footage collected by NZ King Salmon farm staff on a regular basis from beneath the TEP pens from October 2017 to February 2019 demonstrates that some level of bacterial coverage is present throughout the year at all pens surveyed.

Enrichment effects at Pen 2 and Pen 3 were also evident for all indicators, although to a lesser degree. Macrofaunal abundance at these stations was highly elevated and taxa richness reduced (Table 2), reflecting ‘peak-of-opportunist’ conditions.

The overall ES scores measured within the OLE proxy stations at 300 NE and 300 NW were 3.2 and 2.3, respectively, and were within the allowable ES (ES < 3.7, Table 1). While macrofaunal abundance was high at both OLE stations in comparison to the reference stations, the remaining parameters at the 300 NW station were largely comparable with reference values. Conditions at the 300 NE station remain poor compared to 300 NW (as reported in 2018; Bennett & Elvines 2018), with low diversity and evenness as well as slightly elevated AMBI (and a corresponding low mAMBI), indicating an impacted community (Table 2).

The overall ES score at the Embayment station was 2.2, (lower than the ES score of 2.9 determined in 2018). This ES score reduction was reflected by increased redox potential, as well as a marginal increase in macrofaunal richness and diversity since 2018 (Bennett & Elvines 2018), resulting in biotic indices (AMBI, mAMBI) comparable to reference stations (TC-Ctl-2 and TC-Ctl-3 only, Table 2).

We also note that the average overall ES score at the TC-Ctl-4 station (ES 3.0) has increased by 0.1 since the previous monitoring round (ES 2.9, Figure 3). Although only a small increase, this trend continues from 2018, where the ES had increased by 0.7 from the 2017 monitoring survey (Bennett & Elvines 2018). In response to the earlier increase in ES at this station, a recommendation was made for a regional time series analysis to be carried out if a) the ES score continued to increase, and b) far-field farm related enrichment could not be ruled out. Parameters driving the increase

[4] The compliance threshold of ES5 for the ZME represents a peak-of-opportunist macrofaunal community. Communities in this state have a greater capacity for assimilating organic waste. Maintaining benthic macrofaunal assimilative capacity is thus inferred by the compliance threshold set by the BMP.

[5] Bacterial coverage under Pen 1 exceeds the benthic quality standard set out in condition 33c, which requires ‘that the coverage of the *Beggiatoa*-like bacteria may be not greater than localised and patchy in distribution in the ZME’. However, we note that as per condition 37 the BMP should be followed for compliance purposes.

in ES score at this station include elevated total free sulphides and decreased redox potential, as well as decreased macrofaunal abundance and taxa richness when compared to the other reference stations (see Appendix 2, Figure A2.2). The TC-Ctl-4 reference site (situated in Ngaruru Bay) was established under the Clay Point consent in 2013 to determine whether far-field enrichment effects were occurring as a result of salmon farming in Tory Channel (Newcombe et al. 2013). The deterioration in macrofaunal community composition at this station coincides with the establishment of the Ngamahau Bay salmon farm (and a subsequent c. 1,300-tonne increase of feed use in Tory Channel). This suggests farm related enrichment effects may be driving such changes. However, as we are unable to confirm the effects are farm-related, a detailed analysis of all available Tory Chanel data is recommended to better understand the processes driving the changes at the TC-Ctl-4 reference site, and / or rule out far-field cumulative enrichment effects from the salmon farms in Tory Channel. This analysis will help to determine whether additional sampling and / or monitoring is required. It is recommended that this is performed as an immediate follow-up to annual monitoring.

Table 1. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each of the Te Pangu Bay salmon farm (TEP) sampling stations, February 2019. All stations were compliant.

Station	Organic loading ES	Sediment chemistry ES	Macrofauna ES	Overall ES	Compliant with EQS?
Pen 1	5.3 (1.7)	5.2 (0.1)	4.7 (0.5)	**4.9 (0.2)**	✓
Pen 2	4.0 (0.0)	4.5 (0.7)	4.5 (0.1)	**4.4 (0.1)**	✓
Pen 3	5.0 (0.0)	4.0 (0.9)	4.5 (0.1)	**4.5 (0.1)**	✓
Zone of maximal effect (ZME); EQS ≤ 5.0					
300 NE	2.3 (1.3)	3.9 (1.1)	3.1 (0.6)	**3.2 (0.7)**	✓
300 NW	2.3 (0.7)	3.5 (0.4)	1.9 (0.1)	**2.3 (0.2)**	✓
OLE proxy; modified EQS < 3.7					

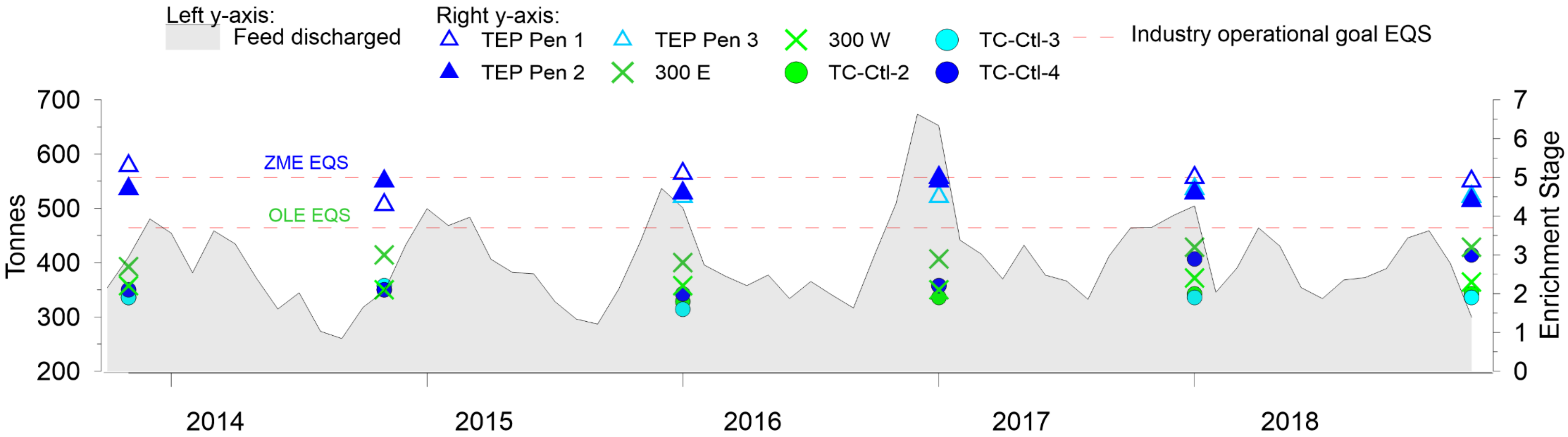

Figure 3. Time series of monthly feed discharge (tonnes, shown by shaded area under curve) and average Enrichment Stage (ES) score for the last six years of annual monitoring at the Te Pangu Bay salmon farm (TEP). Overall ES scores reported are averages for each station and relevant Tory Channel reference stations. The best practice environmental quality thresholds for the zone of maximal effect (ZME, ES 5.0) and outer limit of effects (OLE, ES 3.7) are shown as red dashed lines. Feed data were provided by NZ King Salmon. Note that ES scores prior to 2018 do not implement the calculation rules from appendix 10.2 (bullet points 2b and c) from MPI (2015).

Table 2. Summary of visual assessment and indicator variables measured for each of the Te Pangu Bay salmon farm (TEP) stations during the February 2019 monitoring survey. All farm comparisons are made to the TC-Ctl-2 and TC-Ctl-3 reference station values, unless otherwise stated. %OM = percent organic matter. Representative images of the soft-sediment habitat at each site are provided in Appendix 2.

Station	Bacteria	Out-gassing	Observed epifauna	Other observations	Organic loading	Sediment chemistry	Macrofauna
Pen 1	Moderate mat coverage	Yes	Emergent polychaete worms, blue and green-lipped mussels, anemones	Soft, dark grey sediment, feed pellets or fish faeces	%OM highly elevated	Redox very negative, sulphides highly elevated	Total abundance very high (average 1,744 individuals per core). Heavily reduced taxa richness in some samples (8-15 per core). Impacted community composition.
Pen 2	Trace mat coverage	No	Hermit crabs, blue and green-lipped mussels, anemones, snake stars	Soft, dark grey sediment, feed pellets or fish faeces, worm tubes	%OM elevated	Redox negative, sulphides highly elevated	Total abundance variable but very high (4,234-15,228 individuals per core). Taxa richness reduced (average 24 per core). Impacted community composition.
Pen 3	Patchy mat coverage	No	Hermit crabs, blue and green-lipped mussels, anemones, snake stars	Soft, dark grey sediment, feed pellets or fish faeces, worm tubes	%OM highly elevated	Redox positive, sulphides elevated	Total abundance extremely high (11,353-19,803 individuals per core). Taxa richness reduced (22-31 taxa per core). Impacted community composition.
300 NE	Sparse mat coverage	No	Snake stars, cushion stars, anemones	Sand mixed with shell hash, sparse *Beggiatoa*-like coverage	%OM normal	Redox reduced and sulphides elevated	Total abundance very high (805-1,661 individuals per core). Taxa richness normal (average 45 individuals per core). Community compositional changes indicated by biotic indices and dominance of enrichment-tolerant opportunistic taxa (comparable to 2018).
300 NW	Sparse mat coverage	No	Snake stars, cushion stars, ascidians	Sand mixed with shell hash, sparse *Beggiatoa*-like coverage	%OM normal	Redox marginally reduced and sulphides elevated	Total abundance very high (average 1,132 individuals per core). Taxa richness elevated (average 76 taxa per core). No major community compositional changes.
Embayment	None	No	Snake stars, cushion stars	Fine sediments with shell hash, burrow holes, trail marks, drift algae	%OM normal	Redox and sulphides positive	Comparable total abundance (average 239 individuals per core) and taxa richness (average 29 taxa per core). No change in community composition.

Table 2. continued Summary of visual assessment and indicator variables measured for each of the Te Pangu Bay salmon farm (TEP) stations during the February 2019 monitoring survey. Reference station comparisons are made to the 2017-2018 values. %OM = percent organic matter. Representative images of the soft-sediment habitat at each site are provided in Appendix 2.

Station	Bacteria	Out-gassing	Observed epifauna	Other observations	Organic loading	Sediment chemistry	Macrofauna
TC-Ctl-2*	None	No	see note*	see note*	%OM marginally elevated	Redox positive, sulphides normal	Total abundance slightly elevated (average 472 individuals per core). Comparable taxa richness (average 47 per core). No major change in community composition.
TC-Ctl-3	None	No	Snake stars, hermit crabs, colonial ascidians	Fine grey sandy sediment with shell hash, burrow holes and mounds	%OM normal	Redox positive, sulphides normal	Total abundance slightly elevated (average 279 individuals per core). Comparable taxa richness (average 37 per core). No major change in community composition.
TC-Ctl-4	None	No	Sea cucumber, 11-armed sea star	Fine sand, mild to medium diatom mat, coverage, burrow holes	%OM normal	Redox positive and sulphides elevated	Total abundance variable and low (5-36). Taxa richness low (3–15 taxa per core). Community composition shows no dominance by enrichment tolerant taxa.

* Due to a video file error the video footage for this site was unable to be viewed. Field notes suggest this site remained visually similar to the previous year.

2.1.2. Copper and zinc beneath the Te Pangu Bay pens

Copper

The average total recoverable copper concentration from the nine replicates beneath the pens was 36 mg/kg and is below the ISQG-Low criterion of 65 mg/kg (although we note that one replicate at both Pen 1 and 2 exceeded this threshold, Table 3). With the exception of two samples, concentrations are well below levels reported at these stations during the last annual monitoring event (78 to 225 mg/kg; Bennett & Elvines 2018).

The dilute-acid extractable fraction (an indicator of bio-availability; ANZECC 2000) was below the ISQG-Low threshold in all replicates (average 7.9 mg/kg; Table 3). 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. Dilute-acid extractable copper concentrations have decreased slightly from the 2018 results (average 12 mg/kg; Bennett & Elvines 2018).

Zinc

The overall average total recoverable zinc concentration across pen stations was below the ISQG-Low criterion of 200 mg/kg (185 mg/kg; Table 3). However, the total recoverable zinc concentrations for at least one replicate from each pen station approached and / or exceeded ISQG-Low, possibly indicating localised biological effects from zinc. The overall pen average is in line with the average total recoverable zinc concentration reported at these stations during the last annual monitoring event (177 mg/kg; Bennett & Elvines 2018).

The dilute-acid extractable fraction (a surrogate for bioavailability) of zinc was also below the ISQG-Low threshold across all replicates, with an overall pen average of 127 mg/kg (Table 3), decreasing from the 2018 results (average 183 mg/kg; Bennett & Elvines 2018).

Table 3. Copper and zinc concentrations (mg/kg dry weight) in bulk sediment from Te Pangu Bay salmon farm (TEP), February 2019. Pen and overall averages (±SE) are also shown. Bold values exceed ANZECC (2000) ISQG-Low, and underlined values exceed ISQG-High.

		Copper		Zinc	
Sample		Total recoverable	Dilute-acid-extractable	Total recoverable	Dilute-acid-extractable
Pen 1	a	16.8	8.6	196	145
	b	43	11.4	**210**	199
	c	**80**	8.6	**260**	160
Pen 1 average		47 (±18)	9.5 (±1)	**222 (±19)**	168 (±16)
Pen 2	a	13.9	6.7	133	85
	b	**78**	10.2	**200**	111
	c	18.4	8.5	151	93
Pen 2 average		37 (±21)	8.5 (±1)	161 (±20)	96 (±8)
Pen 3	a	13.8	5.9	147	108
	b	14.3	5.7	162	123
	c	44	5.7	**210**	118
Pen 3 average		24 (±10)	5.8 (±0.1)	173 (±19)	116 (±4)
Overall pen average		36 (±7)	7.9 (±1)	185 (±19)	127 (±9)
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

2.2. Water column

Water column monitoring was undertaken monthly, typically in the third week of each month. Dissolved oxygen (DO), total nitrogen (TN) and chlorophyll-*a* (chl-*a*) were measured at the following stations (Figure 4):

- two stations across the channel in Ngamahau Bay; **NZKS19** and **NZKS20**
- two mid-channel stations; **NZKS21** and **NZKS22**.

In addition, there is one sampling station beside the TEP net pen on the downstream side (**TEP Net Pen**), where only DO is measured.

Additional sampling details are provided in Appendix 3.

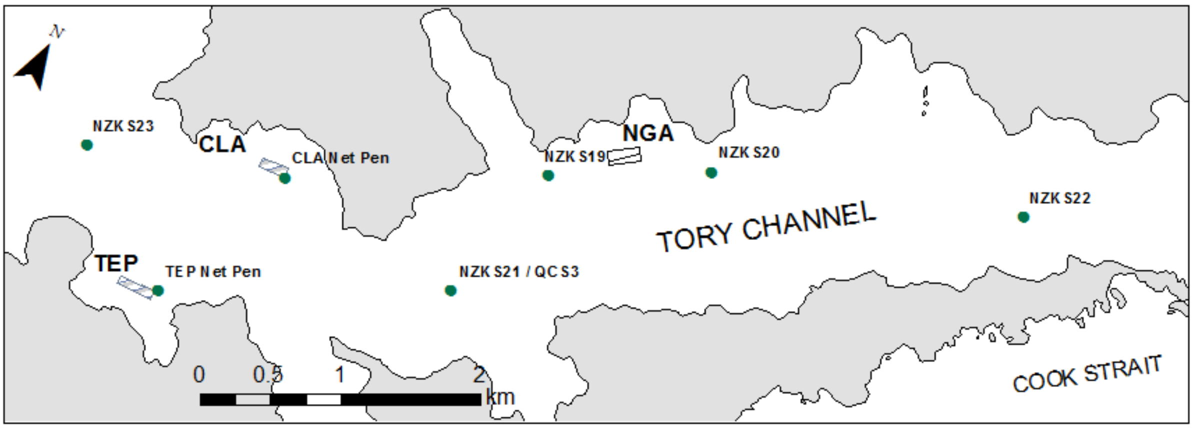

Figure 4. NZ King Salmon and Marlborough District Council (MDC) routine and full-suite water quality monitoring stations in Tory Channel, including the Te Pangu Bay salmon farm (TEP) net pen sampling station. NZKS21 is also an MDC State of the Environment monitoring station (QCS3). NZKS23 is not included in the TEP water column monitoring programme. Note that the net pen sampling station is only indicative because the exact location is tidally dependent. NGA = Ngamahau Bay farm. CLA = Clay Point farm.

2.2.1. Summary of water column monitoring results

A more detailed account of the 2018 TEP water column results is provided in Appendix 4. A summary of key findings is provided below.

Dissolved oxygen saturations at the net pen breached the first and second step DO WQS threshold in March (Table 4) but complied with the thresholds across all other months. Further from the net pen, there were DO WQS breaches in January, March, April, June and August. The second step DO WQS threshold was also breached at stations NZKS19–21 in March, at stations NZKS20–21 in April and at station NZKS21 in June. This indicates low DO saturations across most Tory Channel sampling stations[6]. Nevertheless, as the DO WQS were not were breached in three successive months an amber state was not triggered.

With one exception (NZKS21 station in May), all TN results were within the TN WQS (i.e. ≤ 300 mg-N/m^3). The exceedance occurred at the mid-channel sampling station, and the frequency at which these 'exceedances' have occurred is in line with that observed in the past. Given the results to date, there is no evidence to suggest that 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.

No chl-*a* results exceeded the WQS (Table 4).

Table 4. Summary of water column compliance for parameters measured at each of the Te Pangu Bay salmon farm (TEP) monitoring stations. Ticks indicate measured concentrations were within the water quality standards (WQS) thresholds on all occasions. Sampling months during which WQS thresholds were exceeded are indicated.

	Net Pen	NZKS19	NZKS20	NZKS21	NZKS22
DO	Mar	Jan, Mar, Aug	Jan, Mar, Apr, Aug	Jan, Mar, Apr, Jun, Aug	Jan, Mar, Aug
*WQS**	***> 70 % (pens)***	***> 90 % (reference stations)***			
TN	n/a	✓	✓	May	✓
WQS	-	***< 300 mg-N/m^3***			
Chl-*a*	n/a	✓	✓	✓	✓
WQS	-	***≤ 3.5 mg/m^3***			

*refers to the first step threshold. Second step thresholds were also exceeded on occasion (see Appendix 4, Table A4.1).

[6] Note that in March the water column profiles at the far-field control stations were taken with the YSI EXO Sonde CTD instrument (used by MDC) while at the near-farm stations parameters were measured with the Seabird 19+ instrument (used by Cawthron). The YSI instrument consistently measures higher dissolved oxygen than the Seabird, and this is very likely to have contributed to the apparent exceedances of the WQS [2] in March.

3. KEY FINDINGS

All soft-sediment sampling stations at the TEP farm were compliant, however coverage of *Beggiatoa*-like bacteria met one of the descriptive EQS at the 'minor' action level in some areas beneath Pen 1. The assimilative capacity at this station was reduced from 'peak' conditions, however communities still had a high capacity for assimilating organic waste.

Conditions at the TC-Ctl-4 reference station (a potential far-field effects station) continue to show signs of deterioration. As we are unable to confirm the effects are farm-related, a detailed analysis of all available Tory Channel data is recommended to better understand the processes driving the observed changes at this site. This analysis will help to determine whether additional sampling and / or monitoring is required.

None of the WQS for total nitrogen (TN), dissolved oxygen (DO) and chlorophyll-*a* (chl-*a*) were breached in three successive months, i.e. an amber state was not triggered. No recommendations are made for the water column sampling design for the next sampling round, pending finalisation of a working group review of the water column approaches as they relate to the Marlborough Sounds salmon farming industry.

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5. APPENDICES

Appendix 1. Methodology and compliance framework for soft-sediment sampling.

A1.1 Background

Detailed methodology and rationale for the sampling approach can be found in the most recent MEMAMP (see Bennett & Dunmore 2018); 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) developed for salmon farming in the Marlborough Sounds (MPI 2015).

A1.2 Sampling protocol

Three replicate sediment 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 and dilute-acid-extractable copper and zinc concentrations[7]. Laboratory analytical methods for sediment samples can be found in Table A1.1.

A separate core (130 mm diameter, approx. 100 mm deep) was collected from each grab for macrofauna identification and enumeration. Core contents were sieved to 0.5 mm and preserved in a solution of 95% ethanol and 5% glyoxal. Animals were identified and counted by specialists at the Cawthron taxonomy laboratory.

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 of the seabed was taken at each station to qualitatively assess the level of visible bacterial coverage, general seabed condition and presence of sediment outgassing. The sea surface was also scanned for visible sediment

[7] We note that due to previous exceedances of the copper and zinc thresholds at this site, level 3 monitoring of copper and zinc is required (see Appendix 1, Figure A1.1). Due to an administrative error, sample analysis was undertaken in accordance with level 1. The results of the level 3 analysis will be submitted as an addendum once this data is available.

outgassing as this could provide further evidence of particularly enriched conditions. General observations of epibiota (surface-dwelling animals) were also made.

A1.3 Data analysis: 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[8].

For each indicator variable (raw data), an equivalent ES score was calculated using previously described relationships (MPI 2015)[9]. Average ES scores were then calculated for:

- sediment chemistry variables (redox and sulphides)
- macrofauna composition variables: abundance (N), total number of taxa (S), Shannon-Weiner diversity index (H'), Pielou's evenness index (J'), Margalef richness index (d) and biotic indices (AMBI, mAMBI and BQI)
- organic content (% AFDW).

The overall ES score for a given sample was then calculated by determining the weighted average[10] 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.

[8] 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.

[9] We note that ES calculations in the previous monitoring reports for this site did not implement the rules from appendix 10.2: bullet points 2b and c from MPI 2015.

[10] 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.

Table A1.1 Laboratory analytical methods for sediment samples (February 2019) processed by either Hill Laboratories (a) or Cawthron Institute (b).

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]	< 2 mm 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 antioxidant. Measured in millivolt (mV) using a sulphide specific electrode and calibrated using a sulphide standard.	

A1.4 Compliance framework for soft-sediment monitoring results

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

A1.4.1 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 TEP consent states that 'Benthic Standards' [= EQS] for this site are to be in accordance with those set out in the 'best management practice guidelines—benthic' (BMP; MPI 2015) that exist for salmon farming in the Marlborough Sounds (see Table A1.2). However, 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 MEMAMP (Bennett & Dunmore 2018).

Table A1.2. Environmental quality standards (EQS) for each zone at the Te Pangu Bay salmon farm (TEP) as per the MEMAMP; Bennett & Dunmore (2018).

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

A1.4.2 Copper and zinc

The BMP guidelines specifies the ANZECC (2000) ISQG-Low criteria for copper and zinc as the most appropriate trigger values for sediments beneath farms, and therefore they should be used as the first-tier trigger level for further actions (Table A1.3 and Figure A1.1). Readers are referred to the BMP guidelines for more information regarding the copper and zinc EQS.

Table A1.3. ANZECC (2000) Interim Sediment Quality Guideline concentrations for copper and zinc (mg/kg).

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

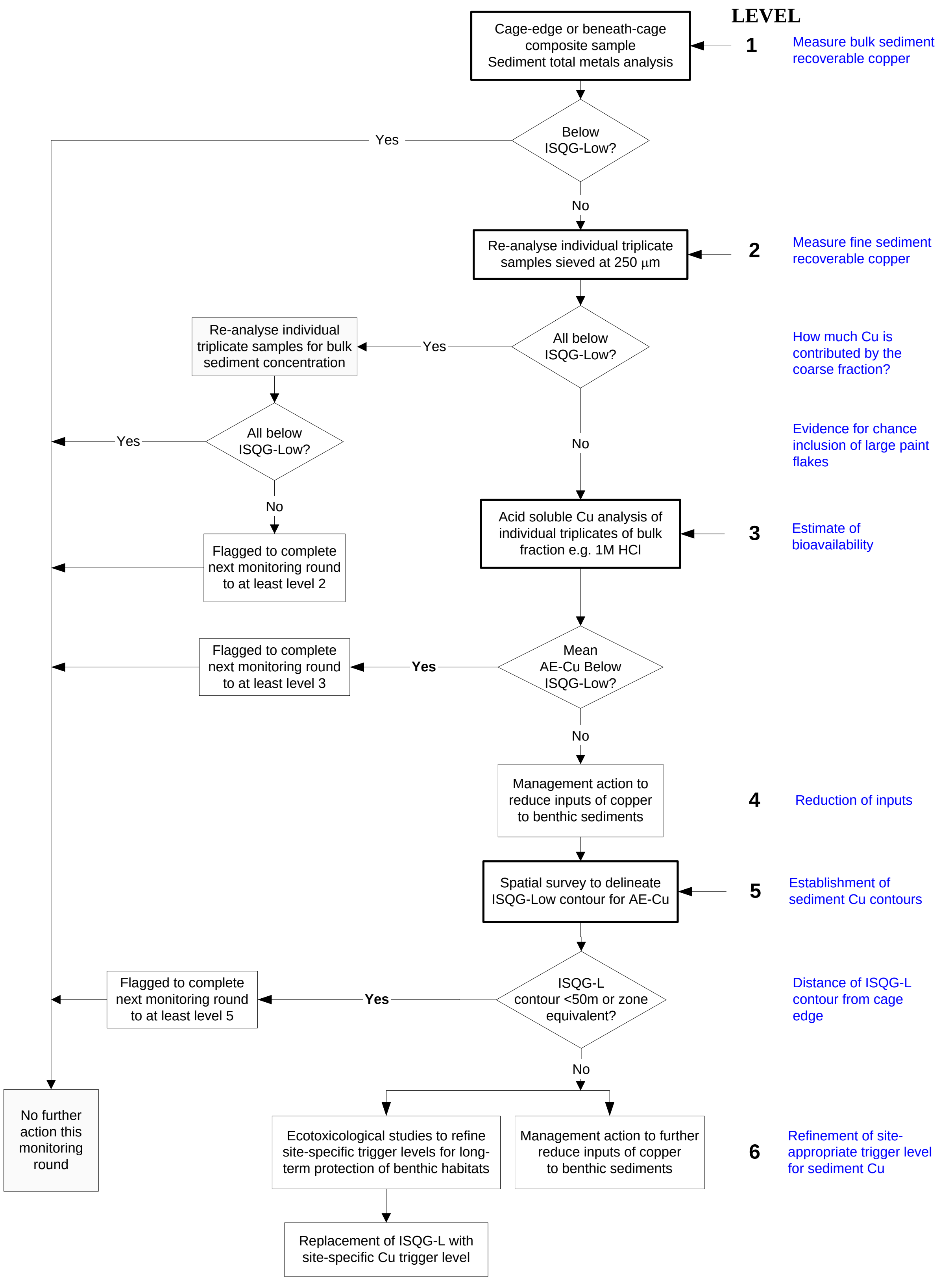

Figure A1.1. Decision response hierarchy for metals tiered monitoring approach (from MPI 2015). Copper is the example shown here.

Appendix 2. Comprehensive discussion of results of the February 2019 soft-sediment monitoring survey at the Te Pangu salmon farm (TEP).

A2.1 Qualitative description of soft sediment habitats

Video footage of the seabed beneath the pen stations showed soft, dark grey sediments. Feed pellets or fish faeces were evident on the surface of the sediment at all pen stations (see Figure A2.1 for representative images of the seafloor at each of the TEP sites). Evidence of outgassing was visible at Pen 1 only. *Beggiatoa*-like bacterial coverage under the pens ranged from trace (Pen 2)[11] and patchy coverage (Pen 3) to moderate mat-forming coverage (Pen 1, Figure A2.1). Under the BMP, bacterial coverage at Pen 1 met one of the descriptive EQS at the 'minor' action level (see MPI 2015)[12]. High levels of bacterial cover typically indicate excessively enriched, anaerobic sediments with impoverished macrofauna (MPI 2015). However, we note that communities beneath the pen stations still had a high capacity for assimilating organic waste (see the next section 'Assessment of seabed enrichment').

Additional footage was collected by NZ King Salmon farm staff on a regular basis from beneath the TEP pens from October 2017 to February 2019 to determine changes in *Beggiatoa*-like bacterial coverage at other times of year. Bacterial coverage ranged from patchy-minor (obvious patches of bacterial mat covering < 50% of the substrate), to patchy-major (mat coverage of > 50% of the seabed), to full mat coverage (obvious, smothering mat patches that cover > 90% of the substrate, MPI 2015). These data demonstrate that while bacterial coverage may be variable in some locations over time, some level of coverage (at least patchy-minor) is present throughout the year at all pens surveyed. A high level of bacterial cover is typically an indicator of excessively enriched, anaerobic sediments with impoverished macrofauna (MPI 2015). However, we note that macrofaunal communities beneath the pen stations still had a high assimilative capacity (see the next section 'Assessment of seabed enrichment')[13]. Accordingly, visible bacterial cover may not be a reliable indicator of macrofaunal community composition

A significant number of worms were observed on, and protruding from, the seabed and bacterial mat at Pen 1 (Figure A2.1). Abundant worm tubes were also evident at Pens 2 and 3. Epifauna (surface-dwelling animals) noted at Pen 1 included clusters of blue and green-lipped mussels (*Mytilus galloprovincialis* and *Perna canaliculus*), anemones (*Anthothoe albocincta*) and drift macroalgae (*Ulva* sp., Figure A2.1).

[11] Bacterial coverage at Pen 2 was observed in sediment grab samples but not in seabed video footage.

[12] Bacterial coverage under Pen 1 exceeded the benthic quality standard set out in condition 33c, which requires 'that the coverage of the *Beggiatoa*-like bacteria may be not greater than localised and patchy in distribution in the ZME'. However, we note that as per condition 37 the BMP should be followed for compliance purposes.

[13] The compliance threshold of ES5 for the ZME represents a peak-of-opportunist macrofaunal community. Communities in this state have a greater capacity for assimilating organic waste. Maintaining benthic macrofaunal assimilative capacity is thus inferred by the compliance threshold set by the BMP.

Similar epifauna were observed at Pens 2 and 3 and included hermit crabs, blue and green-lipped mussels, anemones and snake stars (*Ophiosammus maculata*).

The substrate at 300 NW and 300 NE contained more sand and shell hash than at the pen stations. Sparse, *Beggiatoa*-like bacterial coverage was observed. Epifaunal diversity and abundance was also comparatively greater at these stations, with snake stars and cushion stars (*Patiriella regularis*) prevalent at both sites. Anemones were abundant at 300 NE, while ascidians were common at 300 NW. Drift algae was found at both sites.

The substrate at the Embayment station was a mixture of sand and finer sediments, with only a small proportion of shell hash. Burrow holes and trail marks were evident on the surface of the sediment. Snake stars and cushion stars were abundant. Drift macroalgae were also present. We note that due to a video file failure the video footage for the TC-Ctl-2 site was unable to be viewed. Field notes suggest this site remained visually similar to the previous year where substrate was sandy, with shell hash, larger shell debris and small cobbles present. Snake stars, bryozoans and ascidians were noted at this station. The TC-Ctl-3 reference station substrate was predominantly fine, light grey sandy sediment with some shell hash present. Burrow holes and mounds were evident (Figure A2.1). Noticeable epifauna included snake stars, hermit crabs and colonial ascidians.

The substrate at the TC-Ctl-4 reference station was predominantly fine sand with mild to medium diatom mat coverage. Large portions of the site feature a dense layer of macroalgae that obscured the seafloor (Figure A2.1). Burrows were evident at this site in areas not dominated by macroalgae. A sea cucumber and an 11-armed sea star (*Coscinasterias muricata*) were also noted.

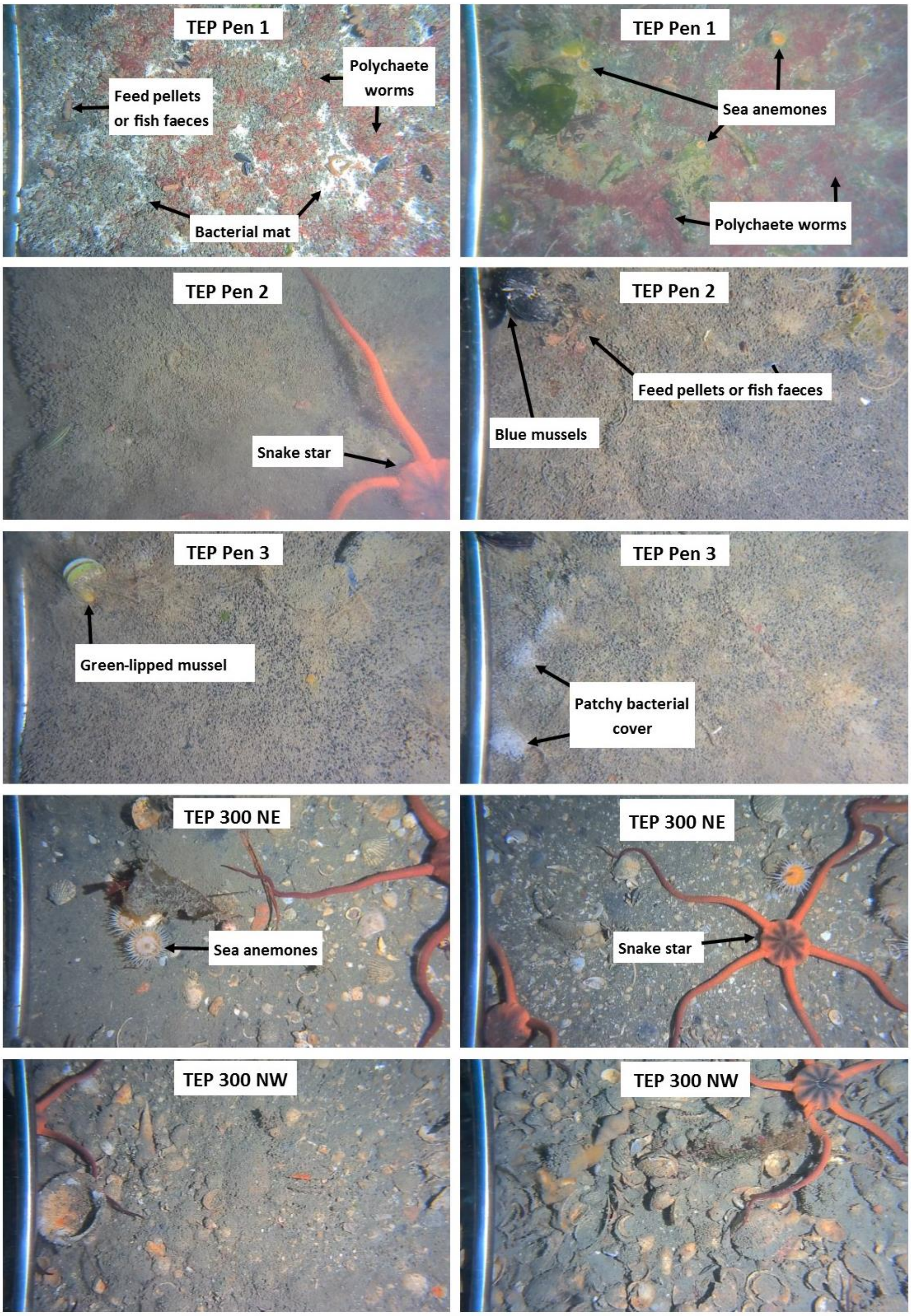

Figure A2.1. Representative images of the seafloor at each of the Te Pangu Bay salmon farm (TEP) monitoring stations, February 2019.

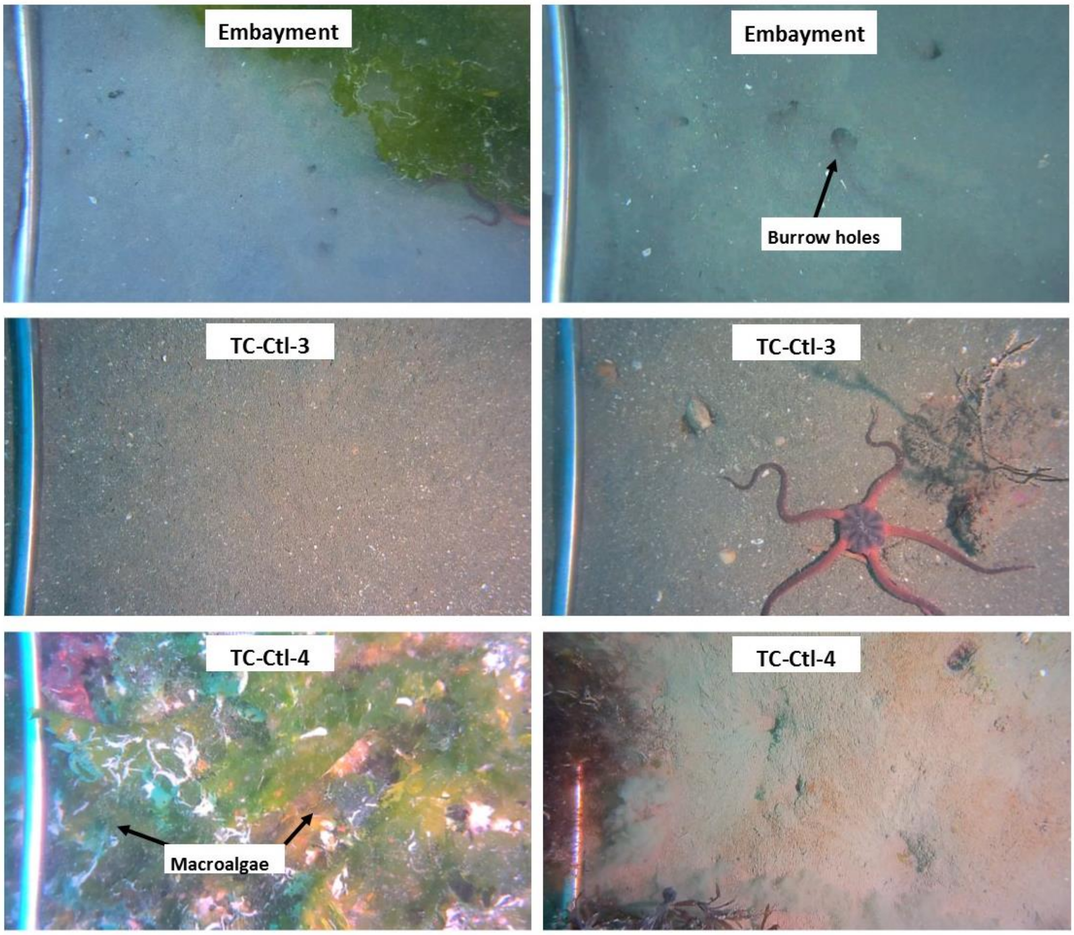

Figure A2.1. continued. Representative images of the seafloor at each of the Te Pangu Bay salmon farm (TEP) monitoring stations, February 2019.

A2.2 Assessment of enrichment to soft-sediment habitats

The average overall ES scores at the pen stations were 4.9, 4.4 and 4.5 for Pen 1, Pen 2 and Pen 3, respectively (Table 1), indicating high to very high enrichment levels. The overall ES scores for all pen stations were within the EQS for this zone (ES ≤ 5.0) and have decreased marginally since the 2018 monitoring survey (from ES 5.0, 4.6 and 4.7, respectively).

Consistent with typical conditions approaching ES 5, enrichment effects at Pen 1 were evident in all indicators. Organic matter and total free sulphide concentrations were extremely elevated, and redox potential was strongly negative (see Figure A2.2, where sediment chemistry and macrofauna statistics are presented across all TEP monitoring stations). Enrichment effects were also reflected in community composition; while macrofaunal abundance was reduced by over half from the previous monitoring survey (average 1,744 individuals per sample as compared to 4,201 in 2018), it remained high in comparison to the reference stations (22 to 471 individuals per sample, Figure A2.2). Taxa richness was low compared to reference stations (average 10 taxa per core as compared to 47 and 37 in TC-Ctl-2 and TC-Ctl-3, Figure A2.2), but has increased slightly from the previous survey (Bennett & Elvines 2018). Enrichment effects were evidenced by low diversity and evenness as well as high AMBI (and a corresponding low mAMBI) values when compared to the reference stations. The decline in macrofaunal abundance at Pen 1 could reflect patchiness in beneath-pen communities typical of highly enriched sediments, or a transition from ‘peak-of-opportunist’[14] (i.e. very low taxa richness and highly elevated abundances) to ‘pre-peak’ based on higher taxa richness compared to last year. In any case, the assimilative capacity at this station is reduced from ‘peak’ conditions. As with last year, the Pen 1 macrofaunal community was dominated by two enrichment-tolerant opportunistic taxa (nematodes and *Capitella capitata*).

The organic content and total free sulphides at Pen 2 remain elevated since last year compared to reference stations, while the redox potential values remain comparatively negative (Figure A2.2). Pen 3 demonstrated an increase in organic content and a c. three-fold decrease in total free sulphides since 2018, remaining elevated in comparison to reference stations. The redox potential at Pen 3 has become positive since last year but is still reduced compared to reference stations (Bennett & Elvines 2018, Figure A2.2).

Pens 2 and 3 were characterised by very high macrofaunal abundance. Pen 2 values were c. 30 times greater than reference stations (average 10,880 individuals per core), while macrofaunal abundance at Pen 3 was extremely high with an average of 15,142 individuals per core (Figure A2.2, Table A2.2). In both instances these abundances had increased considerably from the previous year (from 4,094 and 5,171 individuals per sample at Pens 2 and 3, respectively, Bennett & Elvines 2018). Taxa richness at Pens 2 and 3 (average 24 taxa (Pen 2) and 25 taxa (Pen 3) per core) remained low in comparison to reference stations (Figure A2.1, Table A2.2) but have increased marginally from the 2018 monitoring surveys (average 13 and 9 taxa per core, respectively, Bennett & Elvines 2018). As at Pen 1, compositional changes across pen stations were reflected by low diversity and evenness as well as high AMBI (and low mAMBI) values compared to the reference stations. Macrofaunal communities beneath Pen 2 and Pen 3 were also dominated enrichment-tolerant opportunistic nematodes and *Capitella capitata*.

The overall ES scores measured within the OLE proxy stations at 300 NE and 300 NW were 3.2 and 2.3, respectively, and were within the allowable ES for this sampling distance (ES < 3.7). The 300 NE ES score has decreased by 0.1 from 2018, while the 300 NW score remains the same (Bennett & Elvines 2018). Conditions along the eastern transect (i.e. at the 300 NE station) have historically

[14] Refers to peak abundance of opportunistic taxa (e.g. capitellids and nematodes), where waste assimilation is theoretically maximal (see Keeley et al. 2012 and Keeley et al. 2013).

been poorer compared to the west, a trend supported by the 2018 results (Bennett & Elvines 2018). The organic content both OLE stations were comparable to the reference stations, while total free sulphide concentrations were elevated and redox potential was comparably low, particularly at 300 NE (as compared to TC-Ctl-2 and TC-Ctl-3 only, Figure A2.2, Table A2.2).

Macrofaunal abundance was high at both OLE stations (Figure A2.2.). Taxa richness at 300 NE (average 42 taxa per sample) was within the range of reference values, while those at 300 NW were slightly elevated (average 75 taxa per sample as compared to 37 [TC-Ctl-2] and 47 [TC-Ctl-3], Figure A2.2). Low diversity and evenness as well as slightly elevated AMBI (and a corresponding low mAMBI) scores indicate an impacted community composition at 300 NE when compared to reference stations (as reported in the last monitoring round, Bennett & Elvines 2018). Macrofaunal communities at 300 NE were dominated by nematodes, and communities at 300 NW were dominated by the capitellid polychaete *Barantolla lepte*, nematodes, as well as polychaetes from the subfamily Exogoninae and subclass Oligochaeta (similar to last year; Bennett & Elvines 2018).

The overall ES score at the Embayment station was 2.2 (reduced from an ES of 2.9 in 2018). This ES score reduction was reflected in increased redox potential values (c. two-fold since 2018), as well as community composition (a marginal increase in macrofaunal richness and diversity since 2018, Bennett & Elvines 2018), resulting in biotic indices (AMBI, mAMBI) comparable to reference stations (TC-Ctl-2 and TC-Ctl-3 only; Figure A2.2). As with last year, the three dominant taxa at the Embayment station were polychaetes from the subclass Oligochaeta and the family Paraonidae, and the capitellid polychaete *Barantolla lepte*.

We also note that the average overall ES score at the TC-Ctl-4 station (ES 3.0) has increased by 0.1 since the previous monitoring round (ES 2.9, Figure 3). Although only a small increase, this trend continues from 2018, where the ES had increased by 0.7 from the 2017/2018 monitoring survey (Bennett & Elvines 2018). In response to the earlier increase in ES at this station, a recommendation was made for a regional time series analysis to be carried out if a) the ES score continued to increase, and b) far-field farm related enrichment could not be ruled out.

Changes driving the increase in ES score at the TC-Ctl-4 station include elevated total free sulphides and decreased redox potential, as well as decreased macrofaunal abundance and taxa richness when compared to the other reference stations (Figure A2.2). One sample (replicate C) had particularly deteriorated conditions, including total free sulphides c. six-fold higher than the other reference stations and considerably reduced macrofaunal abundance (5 individuals per core). Interestingly, a sample with similar conditions was reported in the last monitoring survey (Bennett & Elvines 2018). Despite changes in taxa richness and abundance, the TC-Ctl-4 community was not characterised by a dominance of enrichment-tolerant taxa, as would be expected with the moderately enrichment conditions observed here.

The TC-Ctl-4 station (situated in Ngaruru Bay) was established as part of the Clay Point salmon farm consent in 2013 to determine whether far-field enrichment effects were occurring as a result of salmon farming in Tory Channel (Newcombe et al. 2013). The deterioration in macrofaunal community composition at this site coincides with the establishment of the Ngamahau Bay salmon farm (and a subsequent c. 1,300-tonne increase of feed use in Tory Channel). This might suggest cumulative, farm-related enrichment effects may be driving such changes. However, as we are unable to confirm the effects are farm-related, a detailed analysis of all available Tory Channel data is recommended to better understand the processes driving the changes at the TC-Ctl-4 reference site, and / or rule out far-field cumulative enrichment effects from the salmon farms in Tory Channel. This analysis will help to determine whether additional sampling and / or monitoring is required. It is recommended that this is performed as an immediate follow up to annual monitoring.

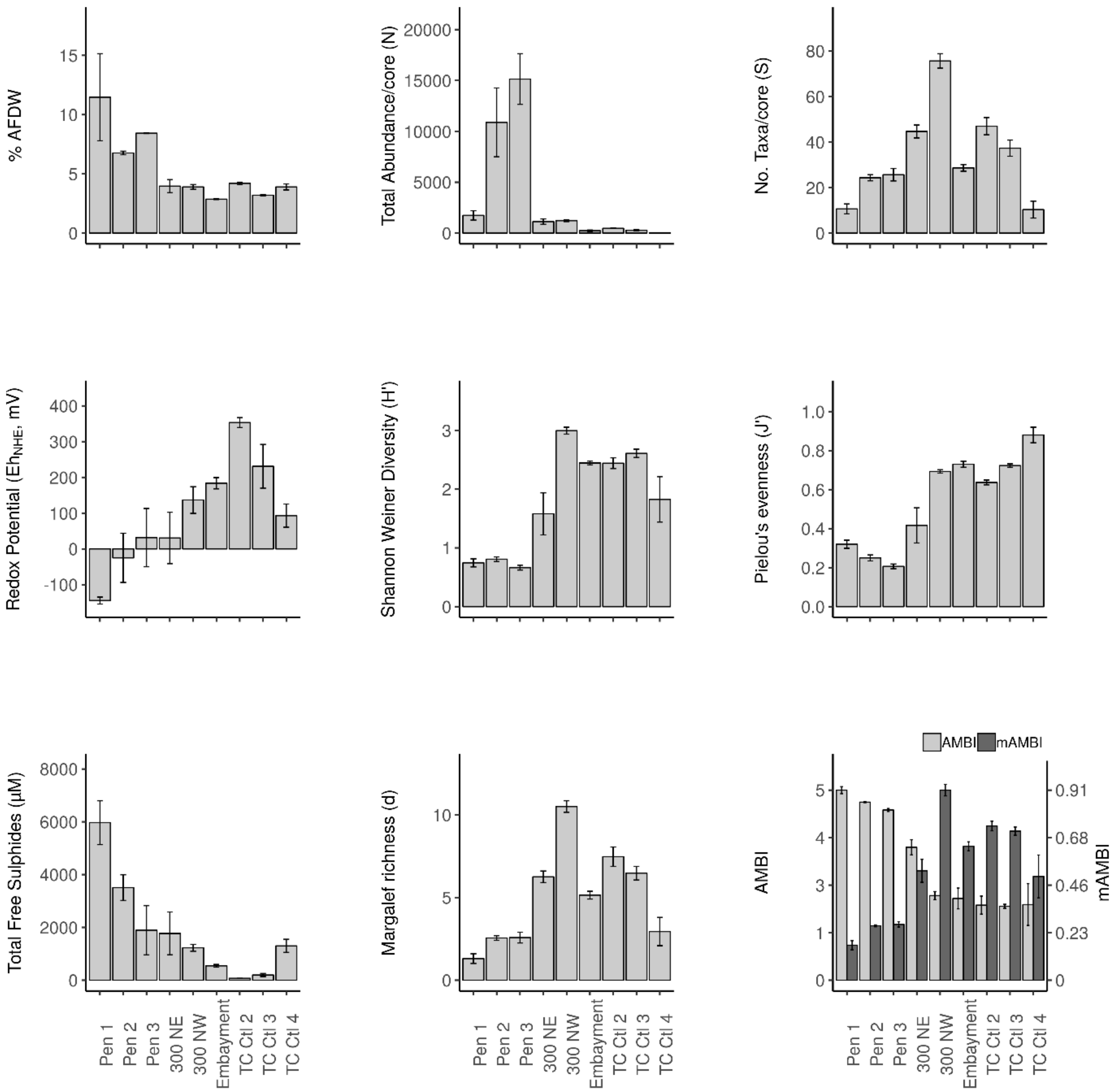

Figure A2.2. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and macrofauna statistics determined at the Te Pangu Bay salmon farm (TEP) monitoring stations, February 2019. TC-Ctl = Tory Channel control. Error bars = ± 1 SE, n = 3.

Table A2.1. Detailed Enrichment Stage (ES) calculations for each station at the Te Pangu Bay salmon farm (TEP) stations, February 2019. For details about how these values were calculated, see MPI (2015). Underlined values are cases where best professional judgement (BPJ; Keeley et al. 2012) was used. Note that ES calculations in previous annual monitoring reports did not implement the rules from Appendix 10.2: bullet points 2b&c from MPI 2015.

SITE INFORMATION																											
Date:	**Feb-19**																							**Variable group weightings:**			
Farm/site:	**Te Pangu Bay**																							**0.1**	**0.2**	**0.7**	
Flow environment:	**HF**																										
		RAW DATA (to be entered)											**ES equivalents**														
Station:	**Rep**	**TOM**	**Redox**	**Sulphides**	**N**	**S**	**j**	**d**	**H'**	**AMBI**	**M-AMBI**	**BQI**	**TOM**	**Redox**	**Sulphides**	**N**	**S**	**j**	**d**	**H'**	**AMBI**	**M-AMBI**	**BQI**	**Organic Loading**	**Sediment chemistry**	**Macro fauna**	**Overall ES**
Pen 1	A	18.8	-125	6798	1655	15	0.31	1.89	0.84	5.33	0.2	3.46	7	5.25	5.13	3.51	4.17	3.89	4.88	4.12	4.72	5.35	4.09	7	5.19	4.34	4.78
Pen 1	B	8.2	-152	6798	2581	9	0.36	1.02	0.78	5.3	0.17	2.82	5	5.5	5.13	3.85	**<u>4.75</u>**	3.66	5.31	4.24	4.69	5.44	4.59	**5**	5.31	4.55	4.75
Pen 1	C	7.4	-156	4309	996	8	0.29	1.01	0.61	5.62	0.13	2.73	4	5.53	4.84	n/c		3.99	5.31	4.6	5.01	5.51	4.67	**4**	5.18	**<u>5.25</u>**	5.11
Pen 2	A	6.5	108	2531	13178	27	0.23	2.74	0.77	5.1	0.27	3.88	4	3.16	4.49	5.1		4.28	4.39	4.27	4.49	5.11	3.79	4	3.82	4.49	4.31
Pen 2	B	7	-122	3994	4234	23	0.28	2.63	0.88	5.07	0.26	3.79	4	5.23	4.79	4.23		4.04	4.46	4.04	4.46	5.13	3.85	4	5.01	4.31	4.42
Pen 2	C	6.8	-61	3994	15228	23	0.24	2.28	0.77	5.06	0.25	3.67	4	4.68	4.79	5.21		4.23	4.66	4.28	4.44	5.18	3.94	4	4.73	4.56	4.54
Pen 3	A	8.5	181	597	19835	22	0.19	2.12	0.59	4.77	0.25	3.48	5	2.5	3.56	5.41		4.47	4.75	4.66	4.15	5.19	4.08	5	3.03	4.67	4.38
Pen 3	B	8.4	13	3701	11353	31	0.2	3.21	0.68	4.91	0.29	3.94	5	4.01	4.74	4.99		4.42	4.1	4.45	4.29	5	3.75	5	4.37	4.43	4.47
Pen 3	C	8.4	-99	1378	14238	24	0.23	2.4	0.72	4.88	0.26	3.67	5	5.02	4.1	5.16		4.28	4.59	4.36	4.26	5.12	3.94	5	4.56	4.53	4.58
300 NE	A	3	139	222	930	48	0.56	6.88	2.18	3.39	0.63	6.05	1	2.88	2.92	3.07		2.7	2	2.22	2.74	2.87	2.54	1	2.9	2.59	2.49
300 NE	B	4.9	-105	2947	1661	47	0.25	6.2	0.94	4.13	0.44	4.31	3	5.07	4.59	3.51		4.18	2.31	3.92	3.5	4.1	3.5	3	4.83	3.57	3.77
300 NE	C	4	58	2147	805	39	0.44	5.68	1.61	3.84	0.5	4.61	3	3.61	4.39	2.96		3.27	2.58	2.85	3.2	3.74	3.31	3	4	3.13	3.29
300 NW	A	4.3	82	1487	1299	76	0.68	10.46	2.96	2.29	0.92	9.27	3	3.39	4.15	3.33		2.12	**<u>1.4</u>**	1.79	1.61	1.74	1.64	3	3.77	1.95	2.42
300 NW	B	3.7	208	1097	1325	81	0.71	11.13	3.11	2.3	0.95	9.3	2	2.26	3.95	3.34		1.98	**<u>1</u>**	1.76	1.63	1.74	1.63	2	3.1	1.87	2.13
300 NW	C	3.7	120	1097	1050	70	0.69	9.92	2.92	2.64	0.86	8.49	2	3.05	3.95	3.16		2.08	**<u>1.2</u>**	1.8	1.97	1.82	1.75	2	3.5	1.97	2.28

Table A2.1. continued. Detailed Enrichment Stage (ES) calculations for each station at the Te Pangu Bay (TEP) salmon farm stations, February 2019. For details about how these values were calculated, see MPI (2015). Underlined values are cases where best professional judgement (BPJ; Keeley et al. 2012) was used. Note that ES calculations in previous annual monitoring reports did not implement the rules from Appendix 10.2: bullet points 2b&c from MPI 2015.

SITE INFORMATION	
Date:	Feb-19
Farm/site:	Te Pangu Bay
Flow environment:	HF

		RAW DATA (to be entered)											ES equivalents											Variable group weightings: 0.1	0.2	0.7	
Station:	Rep	TOM	Redox	Sulphides	N	S	j	d	H'	AMBI	M-AMBI	BQI	TOM	Redox	Sulphides	N	S	j	d	H'	AMBI	M-AMBI	BQI	Organic Loading	Sediment chemistry	Macro fauna	Overall ES
TC Ctl 2	A	4.3	342	71	451	41	0.63	6.55	2.34	1.64	0.73	8.28	3	1.05	2.18	2.52	n/c	2.36	2.14	2.09	0.95	2.28	1.79	3	1.62	2.02	2.04
TC Ctl 2	B	4.3	381	71	477	46	0.62	7.3	2.37	2.5	0.7	7.95	3	0.7	2.18	2.56	n/c	2.41	1.85	2.07	1.82	2.45	1.87	3	1.44	2.15	2.09
TC Ctl 2	C	4	337	71	487	54	0.66	8.56	2.62	2.28	0.78	8.14	3	1.1	2.18	2.57	n/c	2.22	1.58	1.91	1.6	2.07	1.82	3	1.64	1.97	2.01
TC Ctl 3	A	3.3	352	124	224	36	0.74	6.47	2.64	2.06	0.71	10.43	1	0.96	2.54	1.98	n/c	1.84	2.18	1.91	1.38	2.38	1.59	1	1.75	1.89	1.78
TC Ctl 3	B	3.2	186	156	217	32	0.71	5.76	2.48	2.04	0.68	10.84	1	2.46	2.69	1.95	n/c	1.98	2.54	2	1.36	2.57	1.61	1	2.57	2	2.02
TC Ctl 3	C	3.1	155	309	397	44	0.72	7.19	2.71	2.22	0.75	10.59	1	2.73	3.13	2.42	n/c	1.93	1.88	1.87	1.54	2.21	1.6	1	2.93	1.92	2.03
TC Ctl 4	A	4.2	104	1487	26	13	0.84	3.68	2.16	1.88	0.57	4.97	3	3.19	4.15	0.33	4.31	1.36	3.8	2.24	1.19	3.27	3.1	3	3.67	2.45	2.75
TC Ctl 4	B	4.1	32	1605	36	15	0.84	3.91	2.27	1.29	0.63	6.9	3	3.84	4.2	0.58	4.17	1.36	3.66	2.15	0.59	2.88	2.19	3	4.02	2.2	2.64
TC Ctl 4	C	3.4	143	810	5	3	0.96	1.24	1.05	3.3	0.29	2.3	1	2.84	3.76	3.5	5.7	0.78	5.21	3.72	2.65	4.98	5.03	1	3.3	3.95	3.52
Embayment	A	2.9	193	476	183	26	0.74	4.8	2.42	2.27	0.63	9.58	1	2.39	3.41	1.82	n/c	1.84	3.1	2.03	1.6	2.86	1.61	1	2.9	2.12	2.17
Embayment	B	2.8	205	645	383	31	0.7	5.04	2.4	2.87	0.61	9.68	1	2.28	3.61	2.39	n/c	2.03	2.95	2.04	2.21	2.99	1.6	1	2.95	2.32	2.31
Embayment	C	2.9	153	513	150	29	0.75	5.59	2.51	1.85	0.68	9.39	1	2.75	3.46	1.67	n/c	1.79	2.63	1.98	1.16	2.55	1.63	1	3.11	1.92	2.06

Table A2.2. Summary of the average (SE) sediment physical and chemical properties, macrofauna variables and calculated indices for the Te Pangu Bay salmon farm (TEP) stations during the February 2019 monitoring survey.

		Units	Pen 1	Pen 2	Pen 3	300 NE	300 NW
	Depth	m	28	33	35	41	36
Sediments	AFDW	%	11.5 (3.7)	6.8 (0.1)	8.4 (0.0)	4 (0.5)	3.9 (0.2)
	Redox	Eh_{NHE}, mV	-144.3 (9.7)	-25 (68.8)	31.7 (81.4)	30.7 (71.8)	136.7 (37.3)
	Sulphides*	µM	5968.3 (829.7)	3506.3 (487.7)	1892 (932.2)	1772 (808.7)	1227 (130)
	Bacterial mat	-	No	No	No	No	No
	Outgassing	-	Yes	No	No	No	No
	Odour	-	No	No	No	No	No
Macrofauna statistics	Abundance	No./core	1744 (459.7)	10880 (3375.3)	15142 (2489.9)	1132 (267)	1224.7 (87.7)
	No. taxa	No./core	10.7 (2.2)	24.3 (1.3)	25.7 (2.7)	44.7 (2.8)	75.7 (3.2)
	Evenness	Stat.	0.3 (0.0)	0.2 (0.0)	0.2 (0.0)	0.4 (0.1)	0.7 (0.0)
	Richness	Stat.	1.3 (0.3)	2.5 (0.1)	2.6 (0.3)	6.3 (0.3)	10.5 (0.3)
	SWDI	Index	0.7 (0.1)	0.8 (0.0)	0.7 (0.0)	1.6 (0.4)	3 (0.1)
	AMBI	Index	5.4 (0.1)	5.1 (0.0)	4.9 (0.0)	3.8 (0.2)	2.4 (0.1)
	mAMBI	Index	0.2 (0.0)	0.3 (0.0)	0.3 (0.0)	0.5 (0.1)	0.9 (0.0)
	BQI	Index	3 (0.2)	3.8 (0.1)	3.7 (0.1)	5 (0.5)	9 (0.3)

Table A2.2. continued Summary of the average (SE) sediment physical and chemical properties, macrofauna variables and calculated indices for the Te Pangu Bay salmon farm (TEP) stations during the February 2019 monitoring survey.

		Units	Embayment	TC Ctl 2	TC Ctl 3	TC Ctl 4
	Depth	m	5	32	28	20
Sediments	AFDW	%	2.9 (0.0)	4.2 (0.1)	3.2 (0.1)	3.9 (0.3)
	Redox	Eh_{NHE}, mV	183.7 (15.7)	353.3 (13.9)	231 (61.2)	93 (32.5)
	Sulphides*	µM	544.7 (51.3)	71 (0.0)	196.3 (57.1)	1300.7 (247.7)
	Bacterial mat	-	No	No	No	No
	Outgassing	-	No	No	No	No
	Odour	-	No	No	No	No
Macrofauna statistics	Abundance	No./core	238.7 (72.8)	471.7 (10.7)	279.3 (58.9)	22.3 (9.1)
	No. taxa	No./core	28.7 (1.5)	47 (3.8)	37.3 (3.5)	10.3 (3.7)
	Evenness	Stat.	0.7 (0.0)	0.6 (0.0)	0.7 (0.0)	0.9 (0.0)
	Richness	Stat.	5.1 (0.2)	7.5 (0.6)	6.5 (0.4)	2.9 (0.9)
	SWDI	Index	2.4 (0.0)	2.4 (0.1)	2.6 (0.1)	1.8 (0.4)
	AMBI	Index	2.3 (0.3)	2.1 (0.3)	2.1 (0.1)	2.2 (0.6)
	mAMBI	Index	0.6 (0.0)	0.7 (0.0)	0.7 (0.0)	0.5 (0.1)
	BQI	Index	9.5 (0.1)	8.1 (0.1)	10.6 (0.1)	4.7 (1.3)

Appendix 3. Water column sampling methodology and compliance framework

A3.1 Background

The following sub-sections provide detail on the water column sampling methodology. Additional detail and rationale for the sampling approach can be found in Elvines and Fletcher (2016). Water column monitoring at TEP is currently linked to routine water column monitoring in the wider Tory Channel area[15], with the addition of a CTD (conductivity-temperature-depth instrument) cast station at the TEP pen edge to monitor dissolved oxygen (DO) levels. The objective of the monitoring is to detect potential water column effects in Tory Channel from salmon farming, and to assess compliance with the TEP water quality standards (WQS) and water quality objectives (WQO; Table A3.2).

A3.2 Sampling protocol

Parameters measured monthly at stations NZKS19–22 were total nitrogen (TN), chlorophyll-*a* (chl-*a*) and dissolved oxygen (DO). The only parameter measured monthly at the net pen station was DO.

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 YSI EXO Sonde CTD instrument.

Phytoplankton samples were also collected (from NZKS19 and NZKS22 in February/ March and NZKS21 and NZKS22 in July/August), but these results are not presented in this report (although a summary is provided in the Ngamahau annual monitoring report; Bennett et al. 2019). The results will be analysed as part of larger time series analysis when more data are available (to fulfil condition 30a—see Section A3.4).

Samples were collected by MDC staff, at the same time as the widescale State of the Environment (SOE) monitoring in Queen Charlotte Sound (led by MDC). Cawthron staff carried out sampling alongside MDC in March and August 2018.

Laboratory analytical methods for water samples can be found in Table A3.1.

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

Table A3.1 Laboratory analytical methods for water samples (January 2018) processed by the NIWA laboratory in Hamilton.

Analyte	Method	Default detection limit
Chlorophyll-*a* (chl-*a*)	Acetone pigment extraction, spectrofluorometric measurement. A*10200H.	0.1 mg/m^3
Total nitrogen (TN)	Persulphate digest, auto cadmium reduction, FIA. Lachat.	10 mg/m^3

A3.3 Compliance framework for water quality monitoring results

The environmental monitoring results from water quality monitoring are used to determine whether the farms are compliant with the respective environmental quality standards (EQS: water) specified in the consent conditions.

A3.3.1 Water quality standards

Initial water quality standards (WQS) developed by Morrisey et al. (2015) set specific thresholds for three parameters: chl-*a*, DO and TN. If these thresholds are exceeded in three consecutive months, then an 'amber alert' status is reached, and further action must be taken. The current WQS are summarised in Table A3.2, and along with the decision tree for further action are discussed and specified in the MEMAMP (Bennett & Dunmore 2018).

Table A3.2. Water quality standards (WQS) for chlorophyll-*a* (chl-*a*), total nitrogen (TN) and dissolved oxygen (DO). Further discussion of the WQS and how they are applied can be found in the MEMAMP (Bennett & Dunmore 2018).

	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			

A3.3.2 Water quality objectives

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

27. 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 an oligotrophic/mesotrophic state towards a eutrophic state;

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

Appendix 4. Additional detail on the results of the 2018 Te Pangu Bay salmon farm (TEP) water column monitoring.

A4.1 Dissolved oxygen

When considering monthly minimum DO data relative to WQS at the TEP net pen, the DO saturations ranged from 68.7% (March) to 93.9% (July). The minimum DO saturation recorded in March is a breach of the first and second step WQS thresholds (Table A4.1).

Stations NZKS19–NZKS20 and CE-Ref (NZKS21) breached the WQS of DO > 90% during January, March and August (Table A4.1). DO saturations at NZKS20 and NZKS21 were at the WQS threshold in April. NZKS21 also breached the WQS threshold in June. The second step DO WQS threshold was breached at NZKS19–21 in March, at NZKS20–21 in April and at NZKS21 in June.

Note that in March the water column profiles at the far-field control stations were taken with the YSI EXO Sonde CTD instrument (used by MDC) while at the near-farm stations parameters were measured with the Seabird 19+ instrument (used by Cawthron). The YSI instrument consistently measures higher dissolved oxygen than the Seabird, and this is very likely to have contributed to the apparent exceedances of the WQS [2] in March. It may be appropriate to further consider the implications of the differing instrumentation as part of the finalisation or implementation of the BMP guidelines. However, the pattern of low DO, and the extent of the footprint out to the CE Ref station remain important observations.

The temperature and salinity data (Figure A4.1) indicated similar average levels at the net pen and at other stations in the Tory Channel in March. Therefore, the channel-wide DO reductions in March could be associated with land runoff, rather than a result of the TEP farm. It is worth noting that reductions of DO may happen in the absence of photosynthetic oxygen production during dark hours. Such diel changes in DO are not captured using the current method that employs only single-point-in-time sampling.

Table A4.1. 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 (Appendix 3, Section A3.4) WQS are shown where applicable. Bold values indicate those below WQS (1), shaded values indicate those also below WQS (2) (see Appendix 3, Section A3.4). n/s = not sampled.

Month	TEP Net pen	CLA Net pen	NZKS19 500 m north	NZKS20 500 m south	NZKS21 CE-Ref	NZKS22 FF-Ref	WQS (2)*
Jan	90.3	87.1	**88**	**87.4**	**88.3**	**88**	**≥ 86.9**
Feb	87	n/s	92.4	93	91.3	98.3	
Mar	**68.7**†	82.1†	**71.4**†	**74.6**†	**70.8**†	**84.2**†	**≥ 83.2**
Apr	86.5	89.4	91.3	**90**	**90**	91.4	**≥ 90.3**
May	87.7	86	93	94.1	93.1	94.6	
Jun	89.6	92.9	90.2	90.8	**89.8**	92.9	**≥ 91.8**
Jul	93.9	93.3	94	94.8	93.6	95.2	
Aug	93.3†	86.3†	**87.5**†	**87**†	**87.2**†	**86.7**†	**≥ 85.6**
Sep	91.6	93.5	97.3	97.7	98.9	97.1	
Oct	91.9	98.5	98.6	98.7	99.2	98	
Nov	89	85.5	96.8	96.4	96.8	97.4	
Dec	86.9	82.7	94.5	94.9	93.6	95.2	
WQS (1)	**> 70%**		**> 90%**			**n/a**	

† Seabird 19+ CTD values. All other values are from the YSI EXO Sonde CTD.

*The second step WQS threshold is month-specific and is calculated by subtracting 1.2% from the average of applicable reference station DO saturations (also see Appendix 3, Section A3.4).

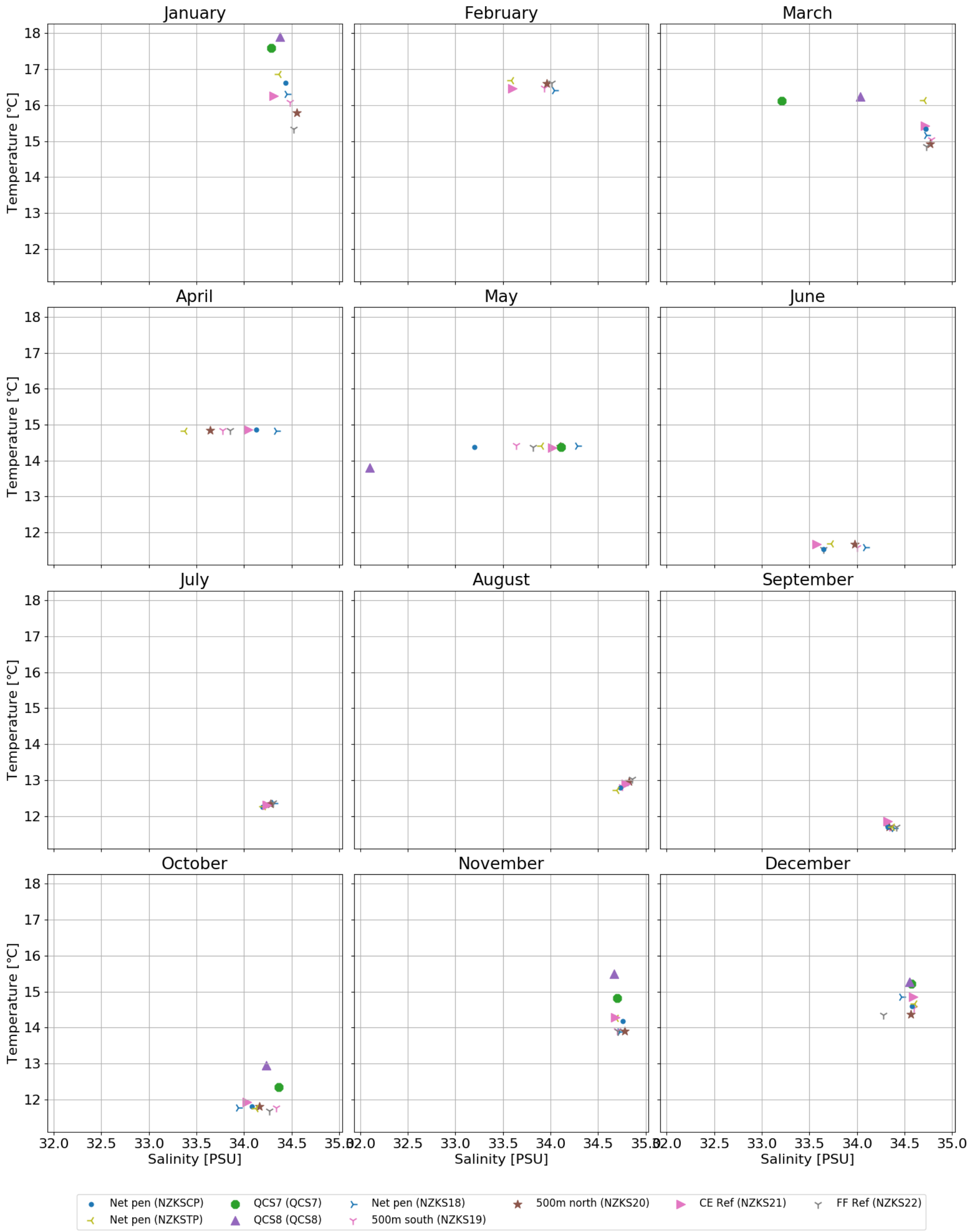

Figure A4.1. Average temperature and salinity characteristics from 1.5–15 m depth for each NZ King Salmon or Marlborough District Council (MDC) sampling station in Tory Channel. QCS7 and QCS8 are further inside Tory Channel and are also plotted for context. Data from some stations are excluded where two different CTD instruments were used (i.e. QCS7, QCS8 and NZKS21 in March and August). CE = cumulative effect, FF = far-field, ref = reference.

A4.2 Total nitrogen

With one exception, all TN results were within the TN WQS (i.e. ≤ 300 mg-N/m^3) (Table A4.2). The exception was the NZKS21 station in the middle of Tory Channel (309 mg-N/m^3 in May). Similar one-off exceedances of the TN WQS were observed at this station in previous years (see Elvines & Fletcher 2017; Bennett & Elvines 2018). Morrisey et al. (2015) showed that background concentrations of TN > 300 mg/m^3 can occur on an annual basis, albeit on 'rare' occasions. However, the time-series of data available for TN (Figure A.4.2) does not suggest that the 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.'

Table A4.2. Surface integrated results for total nitrogen (mg/m^3) for all months in 2018. Shaded values indicate those above the WQS. CE = cumulative effect, FF = far-field, Ref = reference.

	NZKS19	NZKS20	NZKS21 (QCS-3)	NZKS22
Month	**500 m north**	**500 m south**	**CE-ref**	**FF-ref**
Jan	209.0	229.0	199.0	176.0
Feb	171.0	143.0	158.0	152.0
Mar*	164.5	173.5	226.7	189.0
Apr	153.0	170.0	158.0	156.0
May	227.0	208.0	309.0	207.0
Jun	216.0	234.0	243.0	255.0
Jul	233.0	240.0	221.0	245.0
Aug	161.0	156.0	214.0	162.0
Sep	223.0	247.0	191.0	210.0
Oct	180.0	146.0	234.0	160.0
Nov	185.0	181.0	173.8	178.0
Dec	200.0	233.0	298.0	205.0
WQS	**300 mg-N/m^3**			**n/a**

* Mean value across triplicate samples.

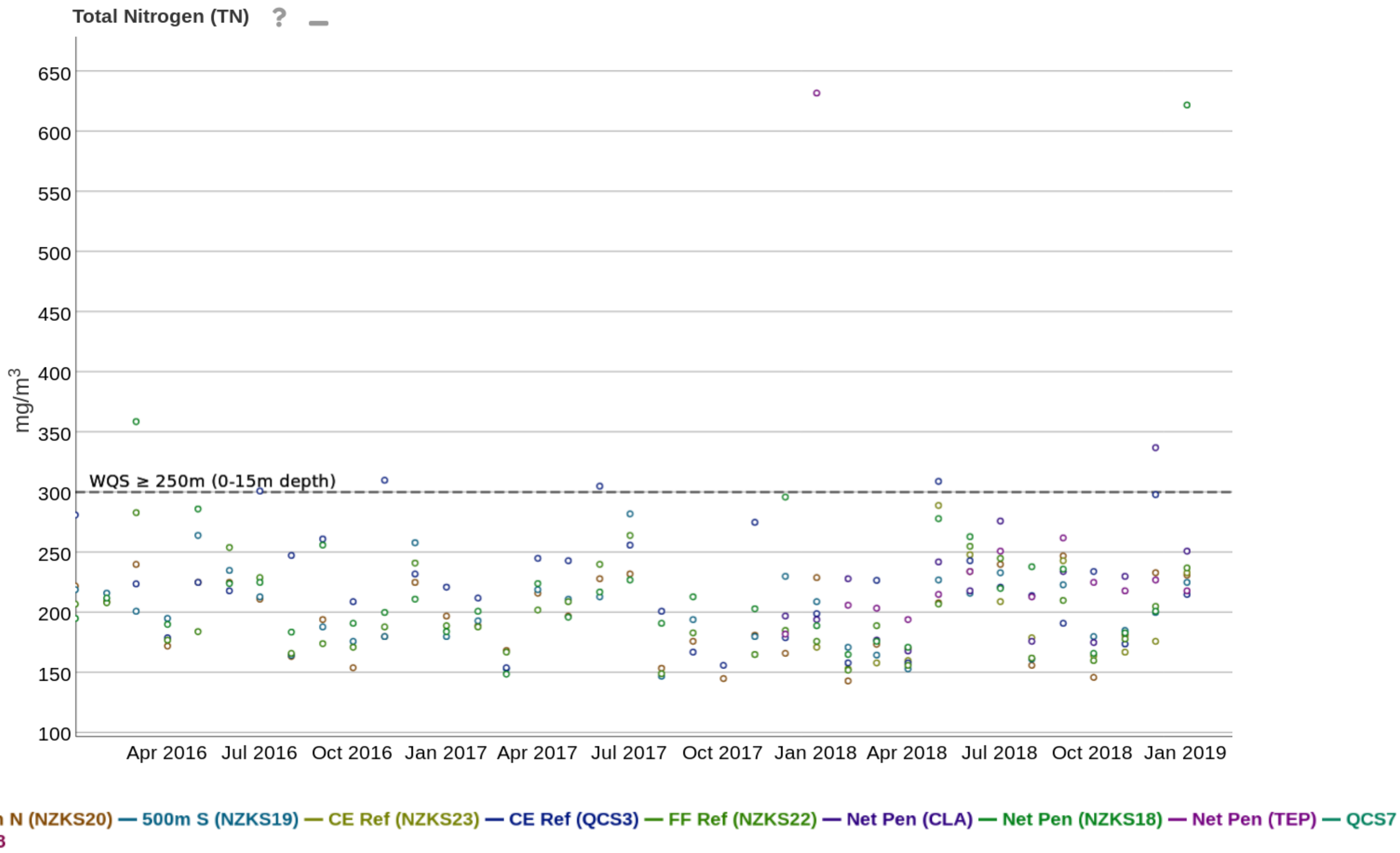

Figure A4.2. Concentrations (mg/m^3) of total nitrogen in 15 m surface integrated samples at all Tory Channel sampling stations. QCS3 = NZKS21. CE = cumulative effect, FF = far-field, Ref = reference. QCS7 and QCS8 are further inside Tory Channel and are plotted for context.

A4.3 Chlorophyll-*a*

Chl-*a* concentrations across all stations and months of 2018 ranged from 0.2 mg/m^3 to 2.1 mg/m^3 and, consequently, were well below the WQS (i.e. ≤ 3.5 mg/m^3; Table A4.3). The highest concentrations were observed in September (2.1 mg/m^3).

Table A4.3. Surface integrated results for chlorophyll-*a* (mg/m^3) from all sampled months in 2018. CE = cumulative effect, FF = far-field, Ref = reference. No values were above the chl-*a* WQS threshold (i.e. > 3.5 mg/m^3).

	NZKS19	**NZKS20**	**NZKS21 (QCS-3)**	**NZKS22**
Month	**500 m north**	**500 m south**	**CE-Ref**	**FF-Ref**
Jan	0.4	0.3	0.3	0.2
Feb	1.0	1.0	1.1	0.9
Mar	0.5	0.5	0.8	0.4
Apr	0.7	0.5	0.4	0.6
May	0.6	0.7	0.7	0.7
Jun	0.3	0.3	0.3	0.3
Jul	0.3	0.3	0.2	0.3
Aug	0.5	0.5	0.5	0.3
Sep	1.7	2.1	2.1	1.4
Oct	1.1	1.0	1.1	0.8
Nov	0.9	1.1	1.0	1.1
Dec	1.0	1.1	1.2	1.1
WQS	**≤ 3.5 mg/m^3**			