REPORT NO. 3325

2018-2019 ANNUAL ENVIRONMENTAL MONITORING SUMMARY FOR THE CLAY POINT SALMON FARM

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Prepared for The New Zealand King Salmon Co. Ltd.

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1. BACKGROUND

This report presents the environmental monitoring results for the Clay Point salmon farm (CLA) located in Tory Channel (consent number U160675) and established in 2007. 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, CLA is assessed as a high flow site. The average water current speeds are 19.6 cm/sec and maximum velocities reach up to *c.* 109 cm/sec. Water depth at the farm site varies between 30–40 m, and the net pens extend from the surface to a depth of c. 20 m.

A total of 3,493 tonnes of feed was discharged at the CLA site in 2018, which is within the maximum allowable annual discharge (4,500 tonnes), and 367 tonnes lower than the total feed discharged in 2017. In the 12 months prior to sampling monthly feed levels steadily increased from June through to January (Figure 1), with the highest monthly feed discharge during January (481 tonnes).

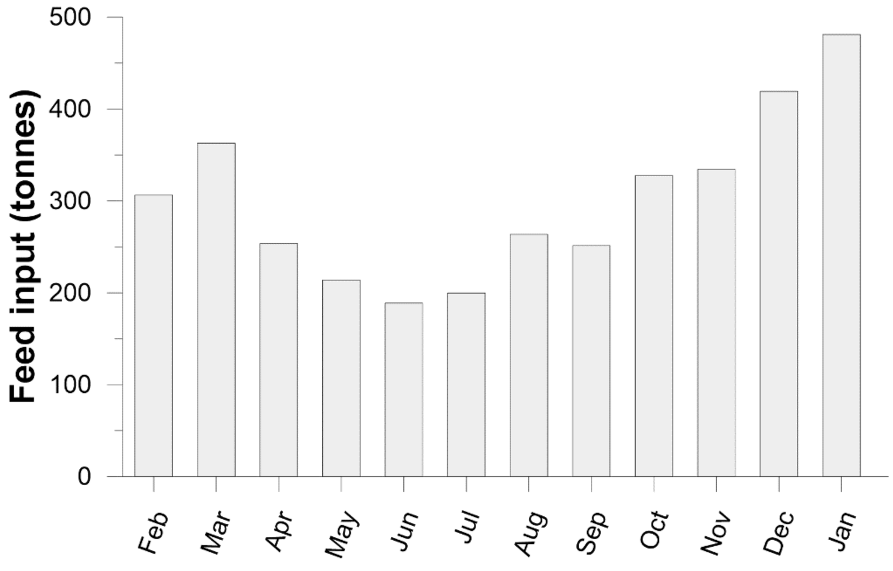

Figure 1. Monthly feed inputs at the Clay Point salmon farm (CLA) for the 12 months preceding soft-sediment sampling. Feed input data provided by NZ King Salmon.

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 CLA was undertaken on 14 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[1]: **300 E** and **300 W** (Figure 2).

Three reference or 'control' stations; one near-field (**TC-Ctl-1**) 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).

[1] The consented EQS for the OLE at CLA 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).

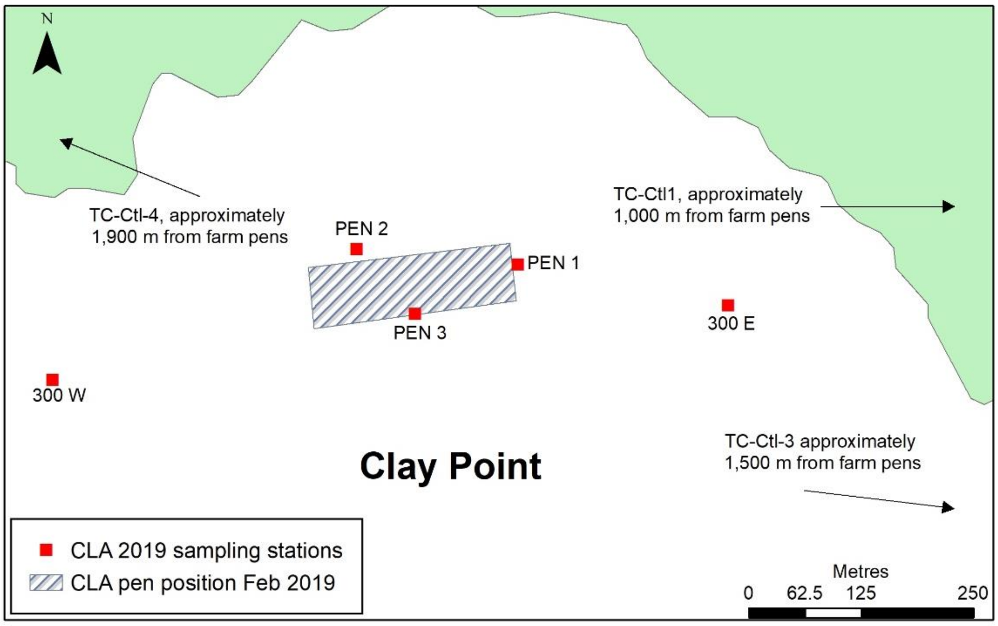

Figure 2. Soft-sediment sampling locations at the Clay Point salmon farm (CLA) site. 'TC-Ctl' = Tory Channel Control. Position accuracy is ± 5 m.

2.1.1. Enrichment of soft-sediment habitats near Clay Point salmon farm

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

Measured levels of enrichment beneath the pens were within the allowable Enrichment Stage (ES) scores (i.e. ES ≤ 5.0) at all three sampling stations (Table 1). While ES scores have decreased at all pen stations since the previous monitoring survey (Pen 1 by ES 0.4, Pen 2 by ES 0.6 and Pen 3 by ES 0.3, Figure 3), these scores indicate high to very-high enrichment. In some areas beneath the pens, coverage of *Beggiatoa*-like bacteria was patchy-major to mat-forming (> 90%, Figure 3). Despite this high level of bacterial coverage, macrofaunal abundance was high, consistent with productive and assimilative macrofaunal conditions (Table 2 summarises all observations for the CLA sites).

Levels of enrichment at the 300 E (ES 2.7) and 300 W (ES 2.6) stations were within the EQS (i.e. ES < 3.7). Both stations demonstrated minor to moderate enrichment, yet the ES score at 300 E has decreased by 0.6 since 2018 (Figure 3). While this decrease is largely due to reductions in total free sulphide levels and macrofaunal abundance (both have decreased by about half), these parameters remain elevated in comparison to reference stations (Table 2). ES values at the 300 W station have increased from ES 2.3, likely due to a c. three-fold increase in total free sulphide values since 2018 (Bennett & Elvines 2018a). Macrofaunal abundance at this station has decreased since 2018 but remains marginally elevated compared to reference stations (Table 2). The biotic indices (AMBI, mAMBI) at both OLE stations are similar to reference stations.

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 2018a). In response to the earlier increase in ES at this station, a recommendation was made in the Te Pangu Bay salmon farm monitoring report (Bennett & Elvines 2018b) 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 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 CLA consent in 2013 to determine whether far-field enrichment effects were occurring as a result of salmon farming in Tory Channel (Newcombe et al. 2014). 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 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.

Table 1. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each of the Clay Point salmon farm (CLA) stations sampled in February 2019. All stations were compliant.

Station	Organic loading ES	Sediment chemistry ES	Macrofauna ES	Overall ES	Compliant with EQS?
Pen 1	4.0 (0.0)	5.1 (0.1)	4.6 (0.1)	**4.6 (0.0)**	✓
Pen 2	3.3 (0.7)	4.4 (0.3)	4.0 (0.4)	**4.0 (0.3)**	✓
Pen 3	3.3 (0.7)	4.2 (0.4)	4.1 (0.4)	**4.1 (0.3)**	✓
Zone of maximal effect (ZME); EQS ≤ 5.0					
300 E	2.3 (0.7)	3.4 (0.5)	2.5 (0.1)	**2.7 (0.2)**	✓
300 W	3.0 (0.0)	3.6 (0.1)	2.3 (0.2)	**2.6 (0.1)**	✓
OLE proxy; modified EQS < 3.7					

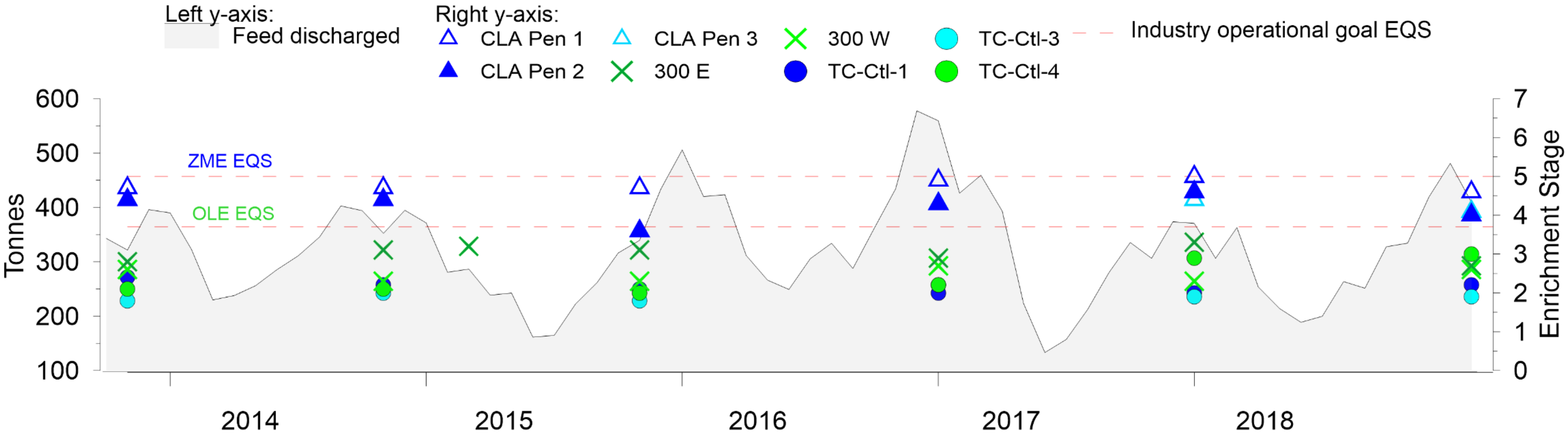

Figure 3. Time series of monthly feed discharge (tonnes, shown by shaded area under curve) and average Enrichment Stage (ES) score for the last six years of annual monitoring at the Clay Point salmon farm (CLA). Overall ES scores reported are averages for each station, and relevant Tory Channel reference 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 2c) from MPI (2015).

Table 2. Summary of visual assessment and indicator variables measured for each of the Clay Point salmon farm (CLA) stations during the February 2019 monitoring survey. All farm comparisons are made to the TC-Ctl-1 and TC-Ctl-3 reference station 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
Pen 1	Patchy-major to mat forming	No	Blue and green-lipped mussels, blue cod	Sediment with dark (possibly anoxic) patches, feed pellets, worms, drift algae	%OM elevated	Redox strongly negative, sulphides very elevated	Total abundance very high (average 3,904 individuals per core). Reduced taxa richness in some samples (average 11 per core). Biotic indices indicate impacted community.
Pen 2	Patchy-major to mat forming	Yes*	Blue and green-lipped mussels, anemones	Sediment with dark (possibly anoxic) patches, worm tubes, drift algae	%OM elevated	Redox negative, sulphides highly elevated	Total abundance variable but average very high (4,475 individuals per core). Taxa richness marginally reduced (average 30 taxa per core). Biotic indices indicate impacted community composition.
Pen 3	Patchy-major to mat forming	No	Blue and green-lipped mussels, anemones	Sediment with dark (possibly anoxic) patches, worm tubes, drift algae	%OM marginally elevated	Redox negative, sulphides highly elevated	Total abundance very high (average 6,141 individuals per core in one sample). Taxa richness marginally reduced (average 28 taxa per core). Biotic indices indicate impacted community composition.
300 E	None	No	Anemones, snake stars, sea cucumbers, hermit crab, anemones	Sand, shell hash, burrow holes	%OM marginally elevated	Redox marginally reduced, sulphides elevated	Total abundance high (average 838 individuals per core). Taxa richness marginally elevated (average 46 per core). No major community compositional changes.
300 W	None	No	Anemones, snake stars, sea cucumbers, anemones	Sand, shell hash, burrow holes	%OM normal	Redox marginally reduced, sulphides elevated	Total abundance high (average 405 individuals per core). Taxa richness marginally reduced (31 taxa per core). No major community compositional changes.

*Evidence of outgassing was observed in sediment cores but was not visible in seabed video footage.

Table 2. continued Summary of visual assessment and indicator variables measured for each of the Clay Point salmon farm (CLA) 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-1	None	No	Snake stars	Fine sand, diatom mat coverage, burrow holes, trail marks	%OM marginally elevated	Redox normal, sulphides normal	Total abundance slightly elevated (average 269 individuals per core). Comparable taxa richness (average 37 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	Yes	Sea cucumber, 11-armed sea star	Fine sand, mil 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.

2.1.2. Copper and zinc beneath the Clay Point pens

No biological effects are expected from copper or zinc in the sediments. Total recoverable copper and zinc concentrations (7 to 12 mg/kg and 93 to 122 mg/kg for copper and zinc respectively, Table 3) were below the ANZECC (2000) ISQG-Low trigger levels at all pen stations. Copper and zinc concentrations are elevated compared to baseline levels (5.2 to 6.7 mg/kg and 34 to 48 mg/kg for copper and zinc; Morrisey et al. 2015). However, concentrations are in line with levels reported at these stations during the previous monitoring round (6 to 13 mg/kg and 57 to 176 mg/kg for copper and zinc; Bennett & Elvines 2018a).

Table 3. Total recoverable copper and zinc concentrations (mg/kg dry weight) in bulk sediment from Clay Point salmon farm (CLA) pen station samples, February 2019.

Sample	Copper	Zinc
Pen 1	10	122
Pen 2	12	94
Pen 3	7	93
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 CLA net pen on the downstream side (**CLA Net Pen**), where only DO is measured.

Additional sampling details are provided in Appendix 3.

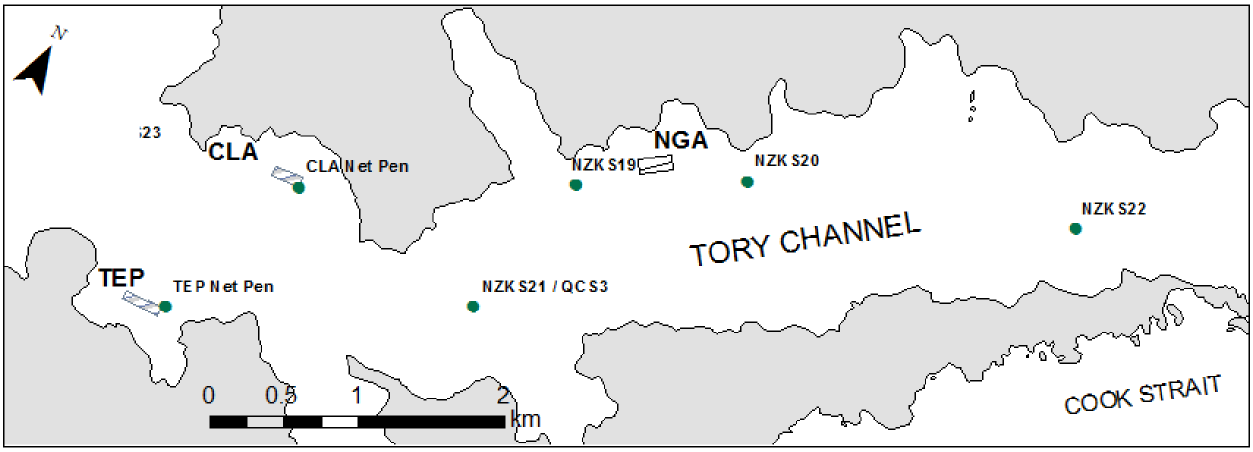

Figure 4. NZ King Salmon and Marlborough District Council (MDC) routine and full-suite water quality monitoring stations in Tory Channel, including the Clay Point salmon farm (CLA) net pen sampling station. NZKS21 is also a Marlborough District Council State of Environment monitoring station (QCS3).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

2.2.1. Summary of water column monitoring results

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

Dissolved oxygen (DO) saturations at the net pen were within the DO WQS (> 70%, Table 4) in all months. Further from the net pen, there were DO WQS breaches in January, March, April, June and August (> 90%, Table 4). The second step DO WQS threshold was breached at stations NZKS19–21 in March, at NZKS20–21 in April and at NZKS21 in June (see Appendix 4, Table A4.1 for DO concentrations). This indicates low DO saturations across most Tory Channel sampling stations[2]. 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 CLA farm is causing elevated TN concentrations 'outside the confines of

[2] 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 reduced DO saturations causing exceedances of the WQS [2] at some of the stations in March.

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 Clay Point salmon farm (CLA) 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	✓	Jan, Mar, Aug	Jan, Mar, Apr, Aug	Jan, Mar, Apr, Jun, Aug	Jan, Mar, Aug
WQS	***70 % (pen)***	***> 90 % (reference)***			
TN	n/a	✓	✓	May	✓
WQS	***≤ 300 mg-N/m³***				
Chl-*a*	n/a	✓	✓	✓	✓
WQS	***≤ 3.5 mg/m³***				

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

3. KEY FINDINGS

All soft-sediment sampling stations at the CLA farm were within the allowable Enrichment Stage (ES) scores (i.e. ES ≤ 5.0). ES scores at all pen stations have decreased since the previous monitoring round (Table 3). However, coverage of *Beggiatoa*-like bacteria met one of the descriptive EQS at the 'minor' action level in some areas beneath all pen stations.

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.

4. REFERENCES

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

Bennett H, Dunmore R 2018. Marine environmental monitoring - adaptive management plan (2019) for the Te Pangu Bay and Clay Point salmon farms. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 3254. 19 p. plus appendices.

Bennett H, Elvines D 2018a. 2017-2018 Annual environmental monitoring summary for the Clay Point salmon farm. Prepared for the New Zealand King Salmon Co. Ltd. Cawthron Report No..10 p. plus appendices.

Bennett H, Elvines D 2018b. 2017-2018 Annual environmental monitoring report for the Te Pangu Bay salmon farm. Prepared for The New Zealand King Salmon Co. Ltd Cawthron Report No. 3148. 29 p. plus appendices.

Bennett H, McGrath E, Campos C, Newcombe E, Scheel M, Elvines D 2019. 2018-2019 Annual environmental monitoring summary for the Ngamahau Bay salmon farm. Prepared for the New Zealand King Salmon Co. Ltd. *In prep*.

Dunmore R 2019. Reef environmental monitoring results for the New Zealand King Salmon Company Ltd salmon farms: 2018. *In prep.*

Elvines D, Fletcher L 2016. Marine Environmental Monitoring – Adaptive Management Plan (2017) for the Te Pangu and Clay Point salmon farms. Prepared for the New Zealand King Salmon Co. Ltd. Cawthron Report No. 2955. 24 p. plus appendices.

Elvines D, Fletcher L 2017. Clay Point salmon farm: annual monitoring report (2016–2017). Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2959. 16 p. plus appendices.

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

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

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

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

Newcombe E, Keeley N, Forrest R 2014. Environmental impacts of the Clay Point salmon farm: annual monitoring 2013. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2468. 20 p. plus appendices.

5. APPENDICES

Appendix 1. Methodology for soft-sediment sampling.

A1.1 Background

The following sub-sections provide detail on the soft-sediment sampling methodology, described in the most recent MEMAMP (Bennett & Dunmore 2018). 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 percent 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. 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 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[3].

For each indicator variable (raw data), an equivalent ES score was calculated using previously described relationships (MPI 2015)[4]. 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[5] 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.

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.	

[3] 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.

[4] 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 2c from MPI 2015.

[5] 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.

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 CLA 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 Clay Point salmon farm (CLA) as per the MEMAMP; Bennett & Dunmore (2018) and the best management practice guidelines—benthic (BMP; MPI 2015).

Compliance zone and EQS type	Description of EQS
ZME (zone of maximal effect)	
Consented EQS at ZME	Mean overall ES ≤ 5.0 (see BMP for a description of other EQS)
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 names 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

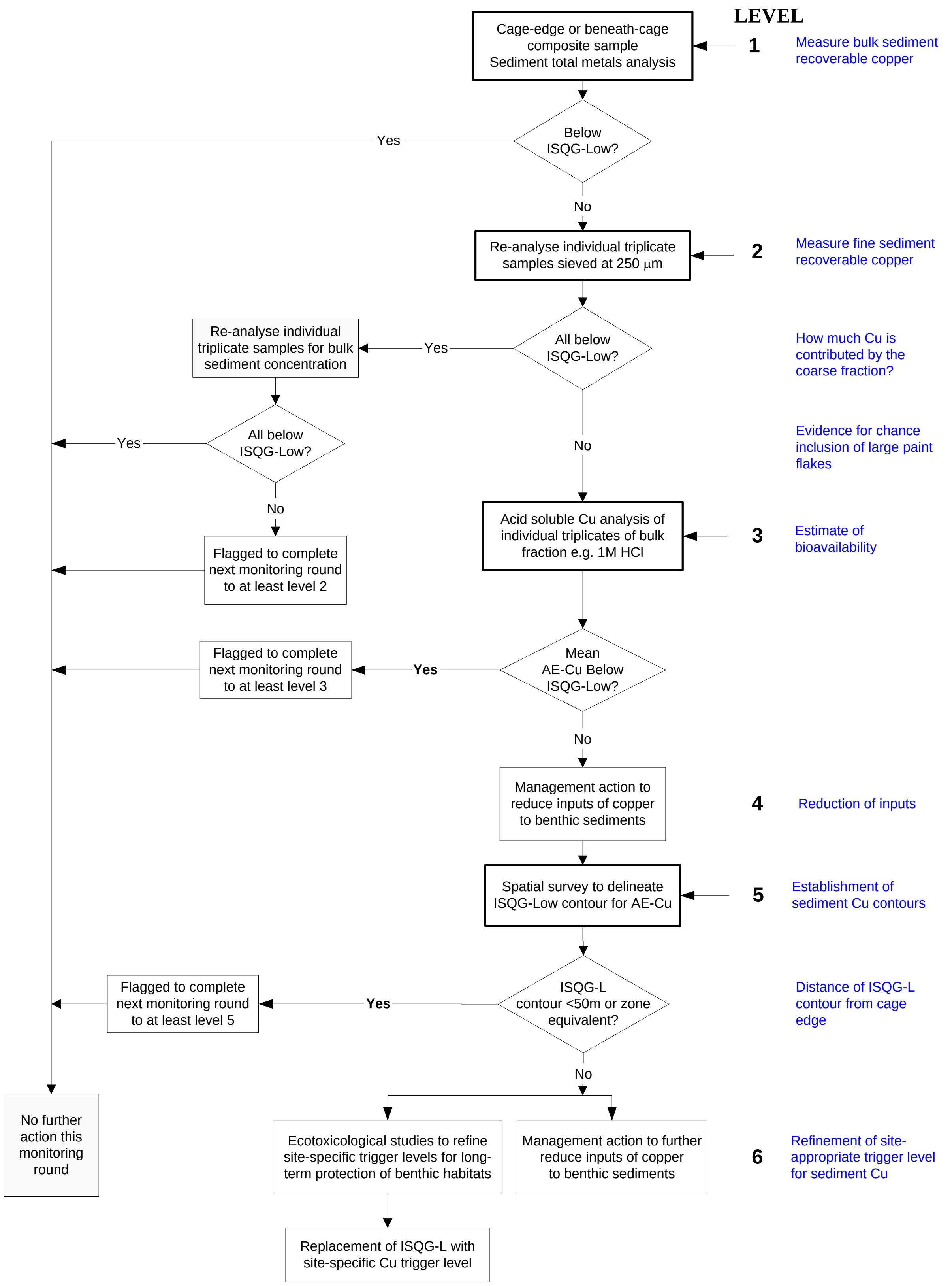

Figure A1.1. Decision response hierarchy for metals tiered monitoring approach (from MPI 2015). Copper is the example shown here.

Appendix 2. Comprehensive discussion of results of the February 2019 soft-sediment monitoring survey at the Clay Point salmon farm (CLA).

A2.1 Qualitative description of soft sediment habitats

Video footage of the seabed beneath the pen stations showed soft, dark grey sediments. Evidence of outgassing was visible at Pen 2 only[6]. *Beggiatoa*-like bacterial coverage was patchy-major to mat forming[7] at all pen stations (see Figure A2.1 for representative images of the seafloor at each of the Clay Point sites), meeting one of the descriptive EQS at the 'minor' action level (see MPI 2015). 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 "Assessment of seabed enrichment" section below)[8].

Feed pellets (sometimes a significant amount), fish faeces and a number of small red worms were evident on the surface of the sediment at Pen 1 (Figure A2.1). Epifauna at Pen 1 included anemones and clusters of blue and green-lipped mussels (*Mytilus galloprovincialis* and *Perna canaliculus*). Drift and attached macroalgae (*Ulva* sp.) was also present, as well as a blue cod (*Parapercis colias*). Worm tubes were observed at Pen 2 and Pen 3 (Figure A2.1). Other epifauna observed at these sites included clusters of blue and green-lipped mussels, anemones (*Anthothoe albocincta*) and drift macroalgae.

Substrate at the stations 300 m from the farm (300 W and 300 E) was lighter in colour and contained more sand and shell hash than at the pen stations. There were no *Beggiatoa*-like bacteria observed in the video footage. Epifaunal diversity and abundance was also comparatively greater at these stations with a number of anemones, sea cucumber (*Australostichopus mollis*), snake stars (*Ophiosammus maculata*), cushion stars (*Patiriella regularis*), a hermit crab (likely *Pagurus* sp.) and burrow holes noted at 300 E. Snake stars and cushion stars were observed at 300 W. Bioturbation in the form of burrow holes was also noted at this site.

The substrate at the TC-Ctl-1 reference station was predominantly fine sand, covered in a rusty-coloured diatom mat (Figure A2.1). There were a number of burrow holes and trail marks at this station, while the only epifauna observed were snake stars. 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

[6] Evidence of outgassing was observed in sediment cores but was not visible in seabed video footage.
[7] Categories defined in MPI 2015
[8] 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.

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 obscures 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.

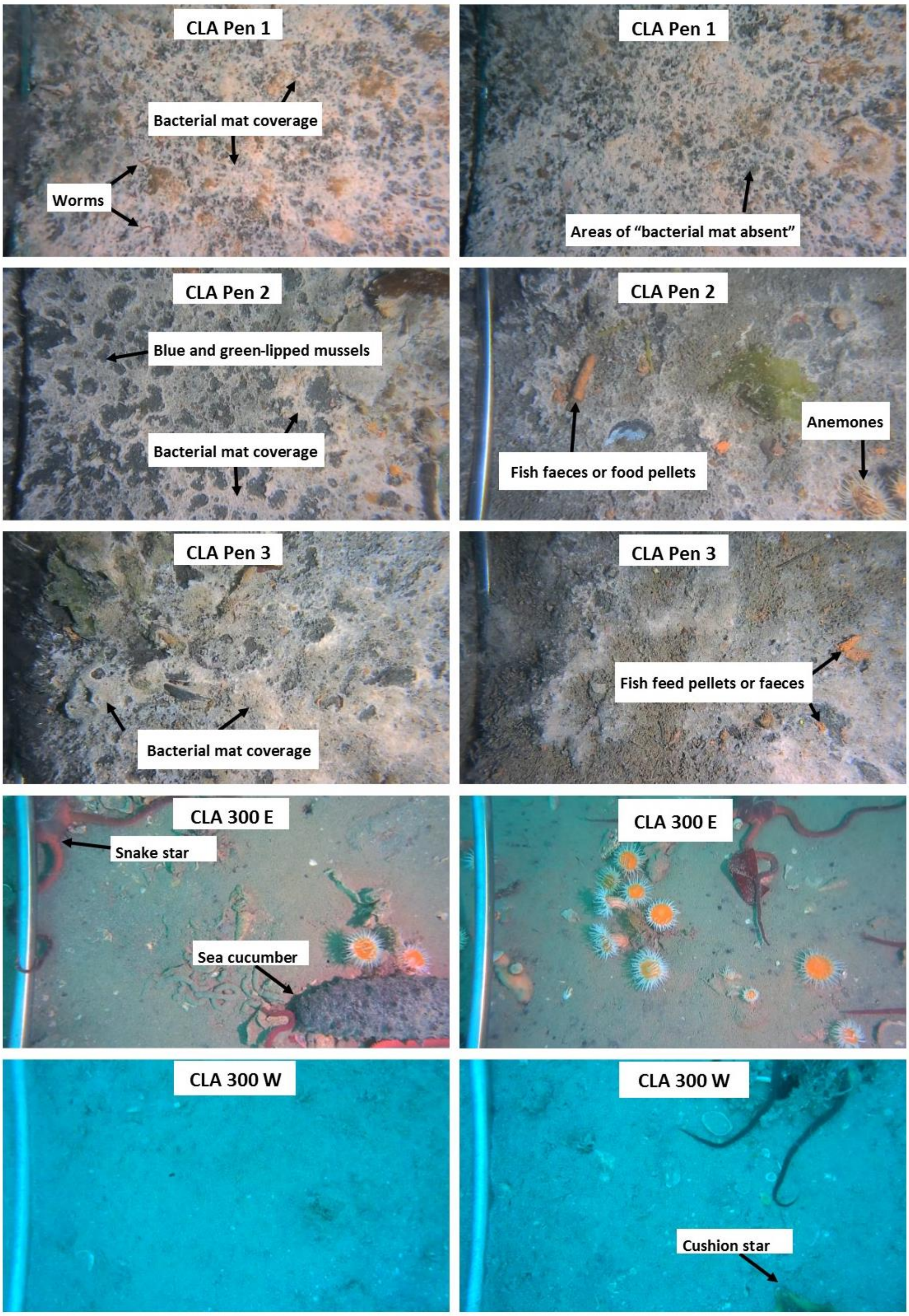

Figure A2.1. Representative images of the seafloor at each of the Clay Point salmon farm (CLA) monitoring stations, February 2019.

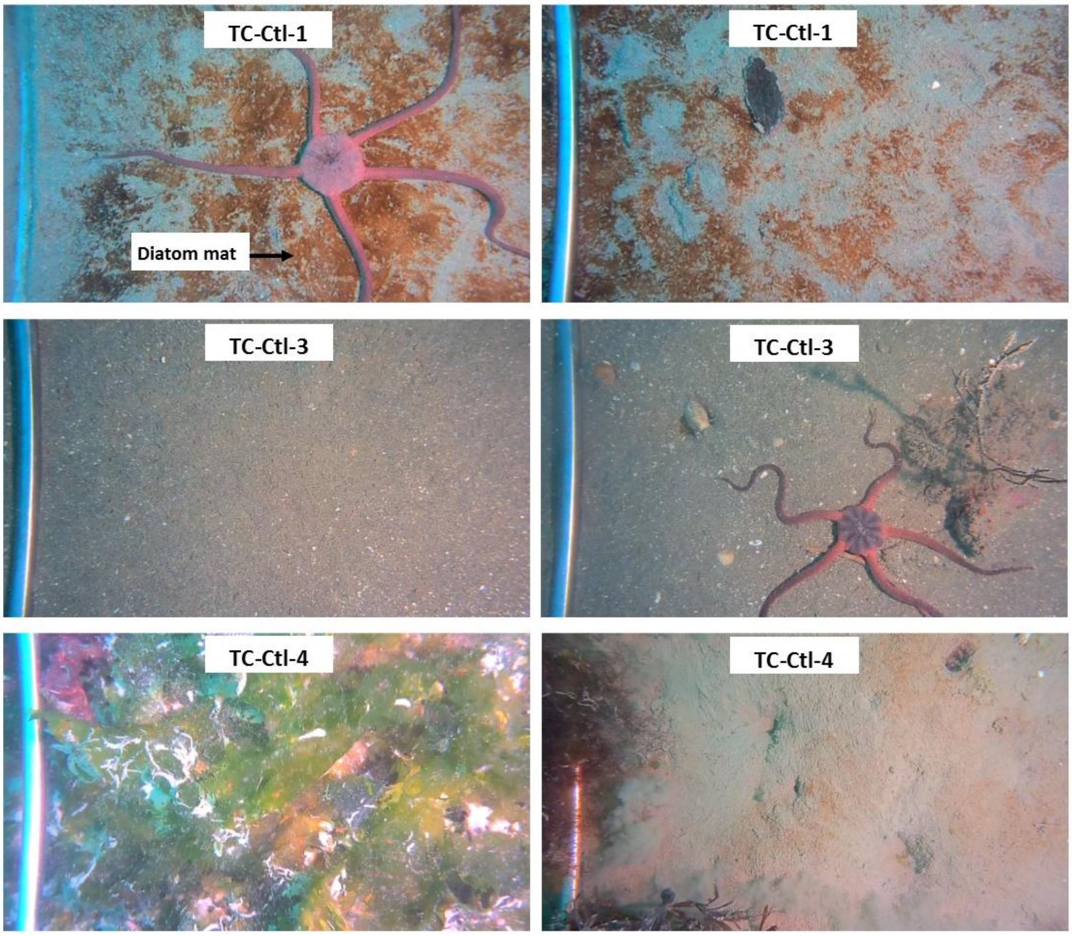

Figure A2.1. continued. Representative images of the seafloor at each of the Clay Point salmon farm (CLA) monitoring stations, February 2019. Lower left photo shows macroalgal cover.

A2.2 Assessment of enrichment to soft-sediment habitats

The average overall ES scores at the pen stations were 4.6, 4.0 and 4.1 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 (ES ≤ 5.0) for this zone and have decreased from the previous monitoring surveys (ES 5.0, 4.6 and 4.4, Bennett & Elvines 2018a). The Pen 2 and Pen 3 stations (on the western side (Pen 2) and channel-ward side (Pen 3) of the farm) showed similar overall enrichment states to each other, while Pen 1 on the eastern side of the farm was in the most advanced enrichment state.

The Pen 1 station had elevated organic matter in comparison to reference stations, (see Figure A2.2, where sediment chemistry and macrofauna statistics are presented across all CLA monitoring stations), although these values have decreased considerably since 2018 (Bennett & Elvines 2018a). Similarly, total free sulphide values remained elevated, yet have decreased by over half since last year. Redox potential has declined since 2018 (Bennett & Elvines 2018a).

Enrichment effects at Pen 1 were also reflected in community composition. Macrofaunal abundance remained high in comparison to the reference stations (average 3,904 individuals per sample as compared to 269 [TC-Ctl-2] and 278 [TC-Ctl-3]; Table A2.2), yet have almost halved since the previous monitoring survey. Similarly, taxa richness was low compared to reference stations (average 11 taxa per core as compared to 37 in TC-Ctl-1 and TC-Ctl-3, Figure A2.2), although we note that this has doubled since last year (Bennett & Elvines 2018), suggesting a degree of recovery at this site. Enrichment-driven compositional changes were supported by very low diversity and evenness as well as high AMBI (and corresponding low mAMBI) values when compared to the reference stations. As with last year, communities beneath the pens were dominated by two enrichment-tolerant opportunistic taxa (nematodes and *Capitella capitata*).

Pens 2 and 3 had similar overall levels of organic matter which, in both cases, are elevated and have increased since 2018 (Bennett & Elvines 2018a, Figure A2.2). Redox potential was reduced at both stations. Total free sulphide concentrations were nearly half those measured in the previous monitoring round (Bennett & Elvines 2018a), although they still remain elevated compared to reference values. Total macrofaunal abundance at Pen 2 has nearly doubled since last year and remains elevated (average 4,475 individuals per core), while average values at Pen 3 have remained stable and elevated (6,141 individuals per core, Figure A2.2). Taxa richness, however, has more than doubled since last year and is now in line with reference values (average 30 and 29 taxa per core as compared to 37 at both TC-Ctl-1 and TC-Ctl-3, respectively). Communities beneath both pens were dominated by two enrichment-tolerant opportunistic taxa (nematodes and *Capitella capitata*), as well as polydorid polychaetes (Spionidae).

The overall ES scores measured within the OLE proxy stations at 300 E and 300 W were 2.7 and 2.6, respectively, and were within the allowable ES for this sampling distance (ES < 3.7). While conditions at the 300 E station have historically been poorer compared to the west (Elvines & Fletcher 2017; Bennett & Elvines 2018a), the ES level has decreased from 2018 (from ES 3.3, Figure 3). This decrease in ES score is largely due to a decrease in total free sulphides by about half, an increase in redox potential and a decrease in macrofaunal abundances (from average 1,913 in 2018 to 836 individuals per core, Figure A2.2). Nevertheless, total free sulphides and abundances remain highly elevated compared to reference stations (Figure A2.2).

At the 300 W station, the overall ES score has increased from ES 2.3 (Figure 3). This increase is reflected in a roughly three-fold increase in sulphide concentrations since 2018 (Bennett & Elvines 2018) and is now around four times greater than reference station values (TC-Ctl-1 and TC-Ctl-3). Macrofaunal abundance has decreased since

2018 and is slightly elevated compared to reference stations. Taxa richness, evenness and AMBI (and corresponding mAMBI) scores are comparable to reference stations at both sites.

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 2018a). In response to the earlier increase in ES at this station, a recommendation was made in the Te Pangu Bay salmon farm monitoring report (Bennett & Elvines 2018b) 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 showing similar conditions was reported in the last monitoring survey (Bennett & Elvines 2018a). 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 a part of the CLA consent in 2013 to determine whether far-field enrichment effects were occurring as a result of salmon farming in Tory Channel (Newcombe et al. 2014). 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 may 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.

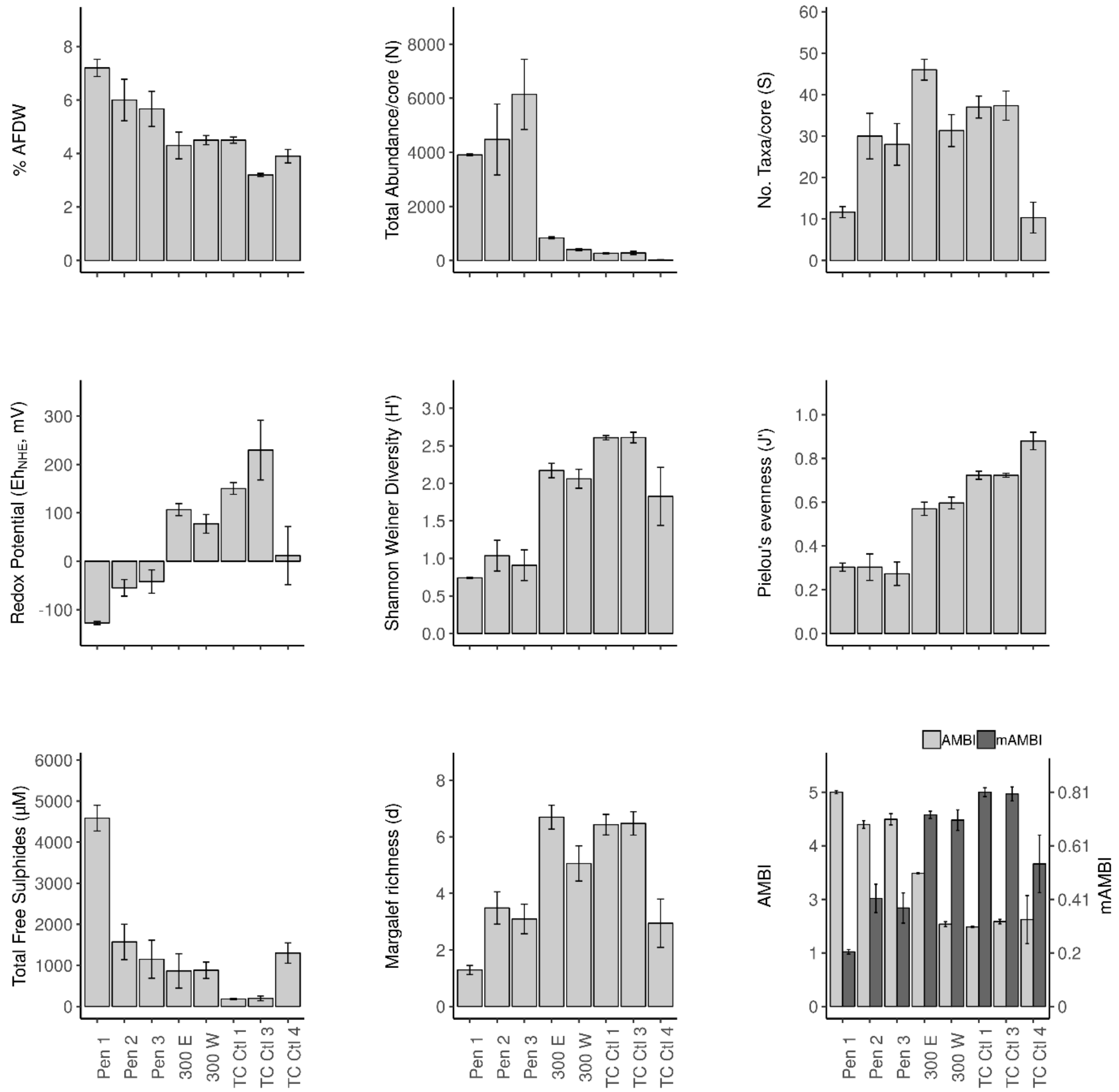

Figure A2.2. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and macrofauna statistics determined at the Clay Point salmon farm (CLA) and reference monitoring stations, February 2019. TC-Ctl = Tory Channel control. Error bars = ± 1 SE,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

Table A2.1. Detailed Enrichment Stage (ES) calculations for each station at the Clay Point salmon farm (CLA) 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 2band 2c from MPI 2015.

SITE INFORMATION																												
Date:	Feb-19																								Variable group weightings:			
Farm/site:	Clay Point																								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	6.7	-134	5182	3973	13	0.28	1.45	0.73	5.38	0.21	3.18	4	5.34	4.96	4.18	4.31	4.04	5.11	4.36	4.78	5.33	4.31	4	5.15	4.55	4.61
Pen 1	B	7.1	-126	4123	3879	9	0.34	0.97	0.75	5.32	0.19	2.76	4	5.26	4.81	4.16	**4.59**	3.75	5.33	4.32	4.71	5.38	4.64	4	5.04	4.61	4.63
Pen 1	C	7.8	-123	4449	3861	13	0.29	1.45	0.75	5.25	0.22	3.13	4	5.24	4.86	4.16	4.31	3.99	5.11	4.3	4.64	5.29	4.34	4	5.05	4.52	4.57
Pen 2	A	5.6	-84	1924	5420	24	0.2	2.68	0.64	4.7	0.31	3.56	3	4.88	4.31	4.42	n/c	4.42	4.43	4.53	4.08	4.88	4.02	3	4.6	4.4	4.3
Pen 2	B	7.5	-56	714	6122	41	0.3	4.59	1.13	4.38	0.5	4.21	4	4.63	3.67	4.51	n/c	3.94	3.23	3.59	3.75	3.72	3.57	4	4.15	3.76	3.86
Pen 2	C	4.9	-25	2076	1885	25	0.41	3.18	1.33	4.47	0.42	3.84	3	4.35	4.36	3.61	n/c	3.42	4.12	3.25	3.84	4.26	3.82	3	4.36	3.76	3.8
Pen 3	A	6	-7	662	8526	34	0.21	3.65	0.74	4.69	0.39	3.96	3	4.19	3.63	4.77	n/c	4.37	3.82	4.33	4.06	4.45	3.74	3	3.91	4.22	4.04
Pen 3	B	4.4	-88	2076	4066	18	0.23	2.05	0.67	4.87	0.27	3.32	3	4.92	4.36	4.2	3.97	4.28	4.79	4.48	4.25	5.1	4.2	3	4.64	4.41	4.31
Pen 3	C	6.6	-31	714	5833	32	0.38	3.58	1.32	4.39	0.47	3.99	4	4.41	3.67	4.48	n/c	3.56	3.87	3.28	3.76	3.95	3.72	4	4.04	3.8	3.87
300 E	A	3.8	82	1652	856	44	0.55	6.37	2.08	3.34	0.7	5.45	2	3.39	4.22	3.01	n/c	2.75	2.23	2.31	2.68	2.44	2.84	2	3.8	2.61	2.79
300 E	B	3.8	121	228	894	43	0.63	6.18	2.36	3.3	0.73	6.05	2	3.04	2.94	3.04	n/c	2.36	2.32	2.07	2.64	2.28	2.54	2	2.99	2.47	2.52
300 E	C	5.3	117	714	764	51	0.53	7.53	2.07	3.29	0.75	5.27	3	3.08	3.67	2.92	n/c	2.84	1.78	2.32	2.63	2.21	2.93	3	3.37	2.52	2.74
300 W	A	4.5	44	527	340	33	0.65	5.49	2.29	2.02	0.75	8.57	3	3.73	3.48	2.3	n/c	2.27	2.69	2.13	1.34	2.21	1.74	3	3.61	2.1	2.49
300 W	B	4.2	77	1218	473	37	0.56	5.85	2.04	1.95	0.75	9.76	3	3.44	4.02	2.55	n/c	2.7	2.49	2.35	1.26	2.22	1.6	3	3.73	2.17	2.56
300 W	C	4.8	111	898	404	24	0.58	3.83	1.86	2.16	0.63	8.1	3	3.13	3.82	2.43	n/c	2.6	3.71	2.55	1.48	2.86	1.83	3	3.48	2.49	2.74

Table A2.1. continued. Detailed Enrichment Stage (ES) calculations for each station at the Clay Point salmon farm (CLA) 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 2band 2c from MPI 2015.

SITE INFORMATION	
Date:	Feb-19
Farm/site:	Clay Point
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 1	A	4.7	171	156	271	38	0.7	6.6	2.55	1.98	0.81	9.76	3	2.59	2.69	2.12	n/c	2.03	2.12	1.95	1.3	1.95	1.6	3	2.64	1.87	2.14
TC Ctl 1	B	4.3	129	211	223	32	0.76	5.73	2.65	2	0.79	10.47	3	2.97	2.89	1.98	n/c	1.74	2.55	1.9	1.32	2.05	1.59	3	2.93	1.88	2.2
TC Ctl 1	C	4.5	151	181	313	41	0.71	6.96	2.62	1.94	0.84	10.01	3	2.77	2.79	2.24	n/c	1.98	1.97	1.91	1.25	1.86	1.59	3	2.78	1.83	2.14
TC Ctl 3	A	3.3	352	124	224	36	0.74	6.47	2.64	2.06	0.81	10.43	1	0.96	2.54	1.98	n/c	1.84	2.18	1.91	1.38	1.97	1.59	1	1.75	1.84	1.73
TC Ctl 3	B	3.2	182	156	217	32	0.71	5.76	2.48	2.04	0.76	10.84	1	2.49	2.69	1.95	n/c	1.98	2.54	2	1.36	2.14	1.61	1	2.59	1.94	1.98
TC Ctl 3	C	3.1	155	309	397	44	0.72	7.19	2.71	2.22	0.86	10.57	1	2.73	3.13	2.42	n/c	1.93	1.88	1.87	1.54	1.83	1.6	1	2.93	1.87	1.99
TC Ctl 4	A	4.2	104	1487	26	13	0.84	3.68	2.16	1.88	0.62	5.02	3	3.19	4.15	0.33	4.31	1.36	3.8	2.24	1.19	2.94	3.07	3	3.67	2.41	2.72
TC Ctl 4	B	4.1	32	1605	36	15	0.84	3.91	2.27	1.29	0.68	6.9	3	3.84	4.2	0.58	4.17	1.36	3.66	2.15	0.59	2.56	2.19	3	4.02	2.16	2.61
TC Ctl 4	C	3.4	-101	810	5	3	0.96	1.24	1.05	3.3	0.33	2.3	1	5.04	3.76	**<u>3.5</u>**	**<u>5.7</u>**	0.78	5.21	3.72	2.65	4.81	5.03	1	4.4	3.93	3.73

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

		Units	Pen 1	Pen 2	Pen 3	300 E	300 W	TC-Ctl-1	TC-Ctl-3	TC-Ctl-4
	Depth	m	38	18	30	24	37	25	28	20
Sediments	AFDW	%	7.2 (0.3)	6.0 (0.8)	5.7 (0.7)	4.3 (0.5)	4.5 (0.2)	4.5 (0.1)	3.2 (0.1)	3.9 (0.3)
	Redox	Eh_{NHE}, mV	-127.7 (3.3)	-55 (17)	-42 (24)	106.7 (12.4)	77.3 (19.3)	150.3 (12.1)	229.7 (61.7)	11.7 (60)
	Sulphides*	µM	4584.7 (313.1)	1571.3 (430.9)	1150.7 (462.9)	864.7 (417.9)	881 (199.7)	182.7 (15.9)	196.3 (57.1)	1300.7 (247.7)
	Bacterial mat	-	Yes	Yes	Yes	No	No	No	No	No
	Outgassing	-	No	Yes	No	No	No	No	No	No
	Odour	-	Yes	Mild-moderate	Yes	No	No	No	No	Yes
Macrofauna statistics	Abundance	No./core	3904.3 (34.7)	4475.7 (1311.1)	6141.7 (1296.7)	838 (38.6)	405.7 (38.4)	269 (26)	279.3 (58.9)	22.3 (9.1)
	No. taxa	No./core	11.7 (1.3)	30 (5.5)	28 (5)	46 (2.5)	31.3 (3.8)	37 (2.6)	37.3 (3.5)	10.3 (3.7)
	Evenness	Stat.	0.3 (0.0)	0.3 (0.1)	0.3 (0.1)	0.6 (0.0)	0.6 (0.0)	0.7 (0.0)	0.7 (0.0)	0.9 (0.0)
	Richness	Stat.	1.3 (0.2)	3.5 (0.6)	3.1 (0.5)	6.7 (0.4)	5.1 (0.6)	6.4 (0.4)	6.5 (0.4)	2.9 (0.9)
	SWDI	Index	0.7 (0.0)	1 (0.2)	0.9 (0.2)	2.2 (0.1)	2.1 (0.1)	2.6 (0.0)	2.6 (0.1)	1.8 (0.4)
	AMBI	Index	5.3 (0.0)	4.5 (0.1)	4.6 (0.1)	3.3 (0.0)	2.0 (0.1)	2.0 (0.0)	2.1 (0.1)	2.2 (0.6)
	mAMBI	Index	0.2 (0.0)	0.4 (0.1)	0.4 (0.1)	0.7 (0.0)	0.7 (0.0)	0.8 (0.0)	0.8 (0.0)	0.5 (0.1)
	BQI	Index	3.0 (0.1)	3.9 (0.2)	3.8 (0.2)	5.6 (0.2)	8.8 (0.5)	10.1 (0.2)	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 CLA is currently linked to routine water column monitoring in the wider Tory Channel area[9], with the addition of a CTD (conductivity-temperature-depth instrument) cast station at the CLA pen edge to monitor dissolved oxygen (DO) levels. The objective of the monitoring is to detect wider potential water column effects in Tory Channel from salmon farming, and to assess compliance with 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 stations 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 27a, see Section A3.3).

Samples were collected by MDC staff at the same time as the wide-scale 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.

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

Table A3.1 Laboratory analytical methods for water samples (February 2019) 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.

A3.2.1 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			

A3.2.2 Water quality objectives

In addition to the water quality standards (thresholds), Condition 27 of the CLA consent (consent number U160675) 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 Clay Point salmon farm (CLA) water column monitoring.

A4.1 Dissolved oxygen

Minimum DO saturations at the CLA net pen were within the first step WQS in all months (i.e. > 70%; Table A4.1). DO saturations at this station ranged from 82.1% (March) to 98.5% (October).

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 reduced DO saturations causing exceedances of the WQS [2] at some of the stations in March. Although the reduced levels did not cause a breach of the WQS threshold at the net pen, 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 across the Tory Channel, and the extent of the footprint out to the CE Ref station remain important observations.

The average temperature and salinity data for 2018 (Figure A4.1) do not suggest any differences in the water quality characteristics between the net pen and other stations in the Tory Channel therefore suggesting a channel-wide DO reduction in March. 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 Table A3.3) WQS are shown where applicable. Bold values indicate those below the WQS (1), shaded values indicate those also below the WQS (2) (see Table A3.3). 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 Table A3.3).

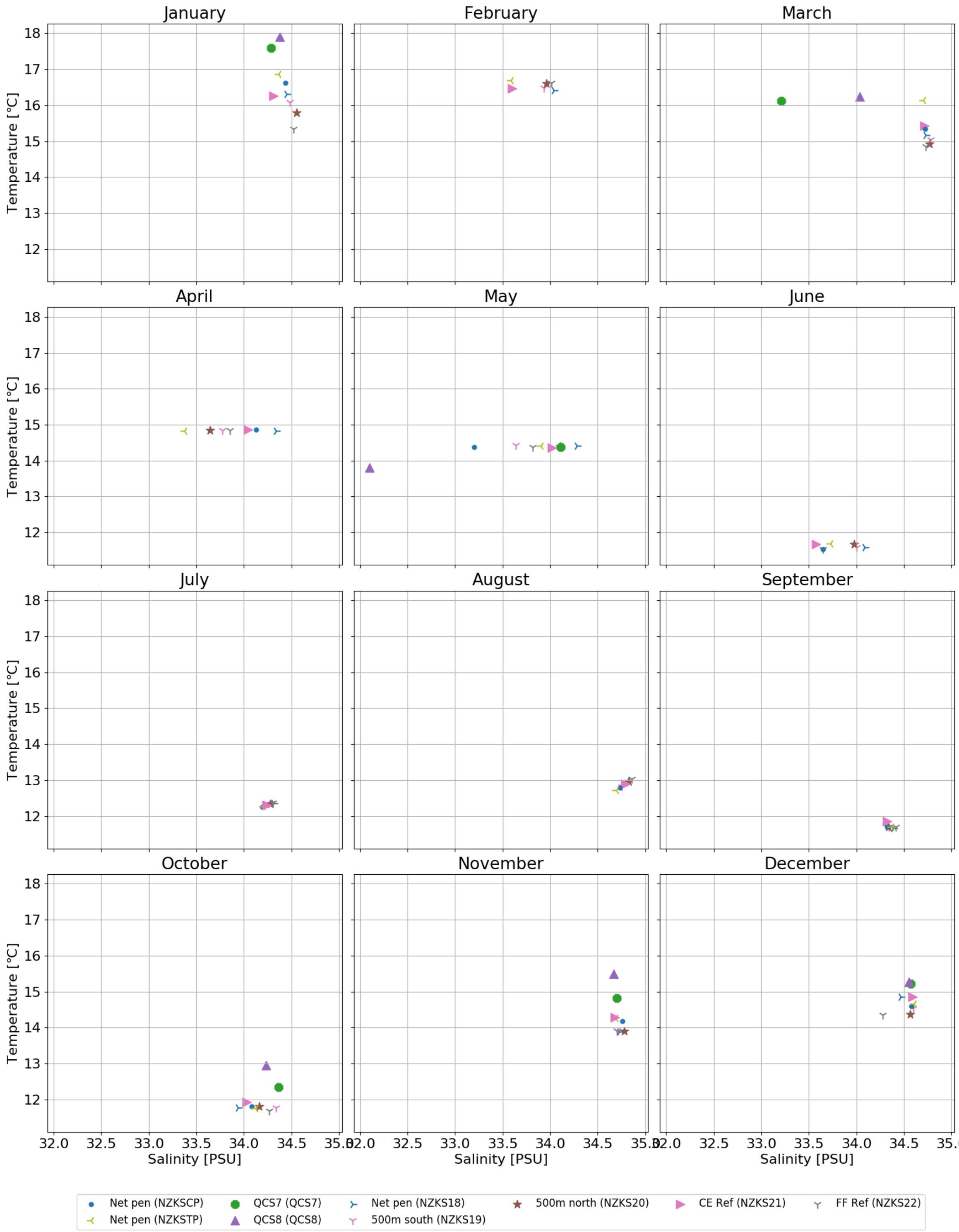

Figure A4.1. Average temperature and salinity characteristics from 1.5–15 m depth for each NZ King Salmon or Marlborough District Council (MDC) sampling station in Tory Channel. QCS7 and QCS8 are further inside Tory Channel and are also plotted for context. Data from some stations are excluded where 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.

Month	NZKS19	NZKS20	NZKS21 (QCS-3)	NZKS22
	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.

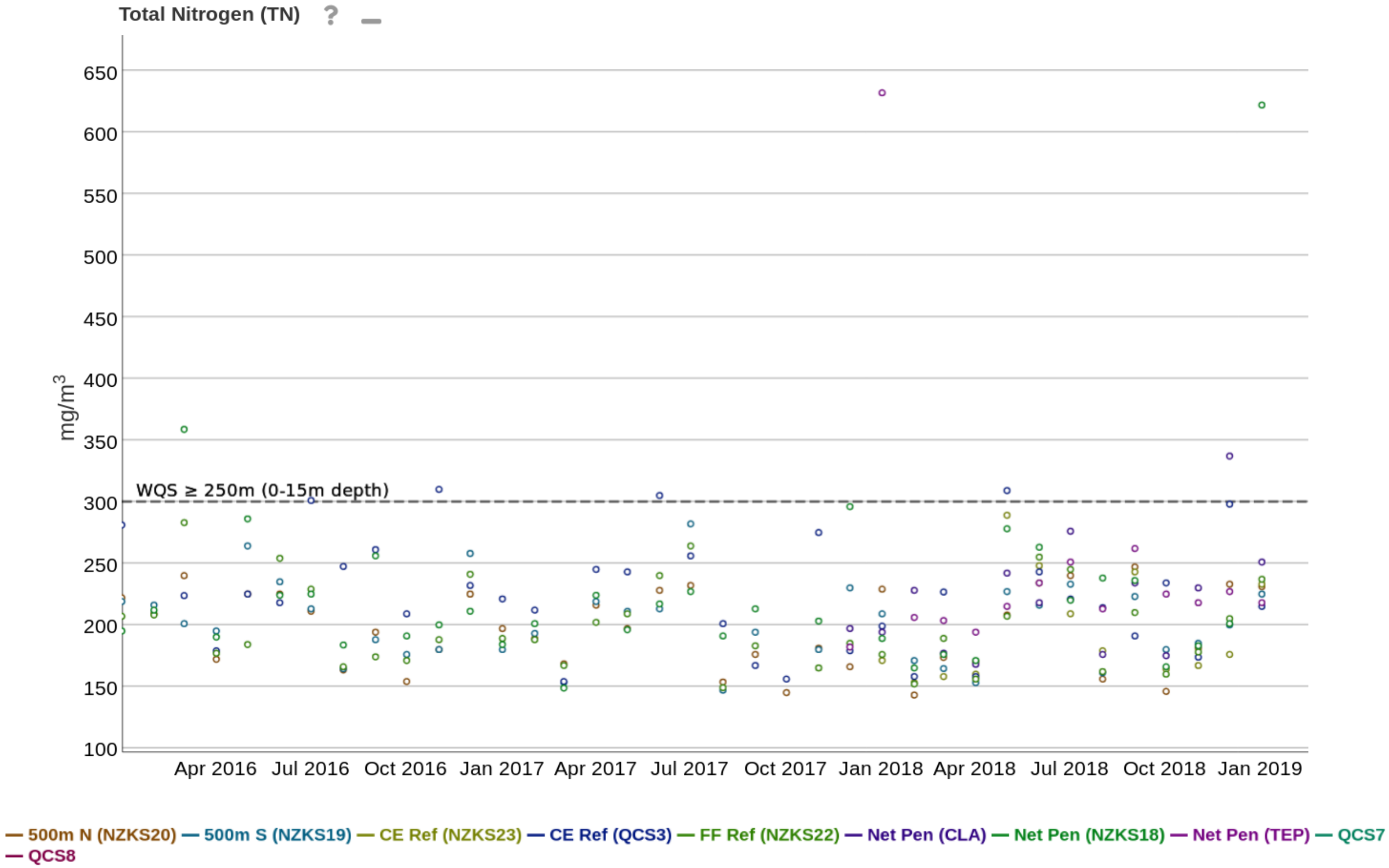

Figure A4.2. Concentrations (mg/m³) of total nitrogen in 15 m surface integrated samples at all Tory Channel sampling stations. QCS3 = NZKS21. CE = cumulative effect, FF = far-field, Ref = reference. QCS7 and QCS8 are further inside Tory Channel and are plotted for context.

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**			