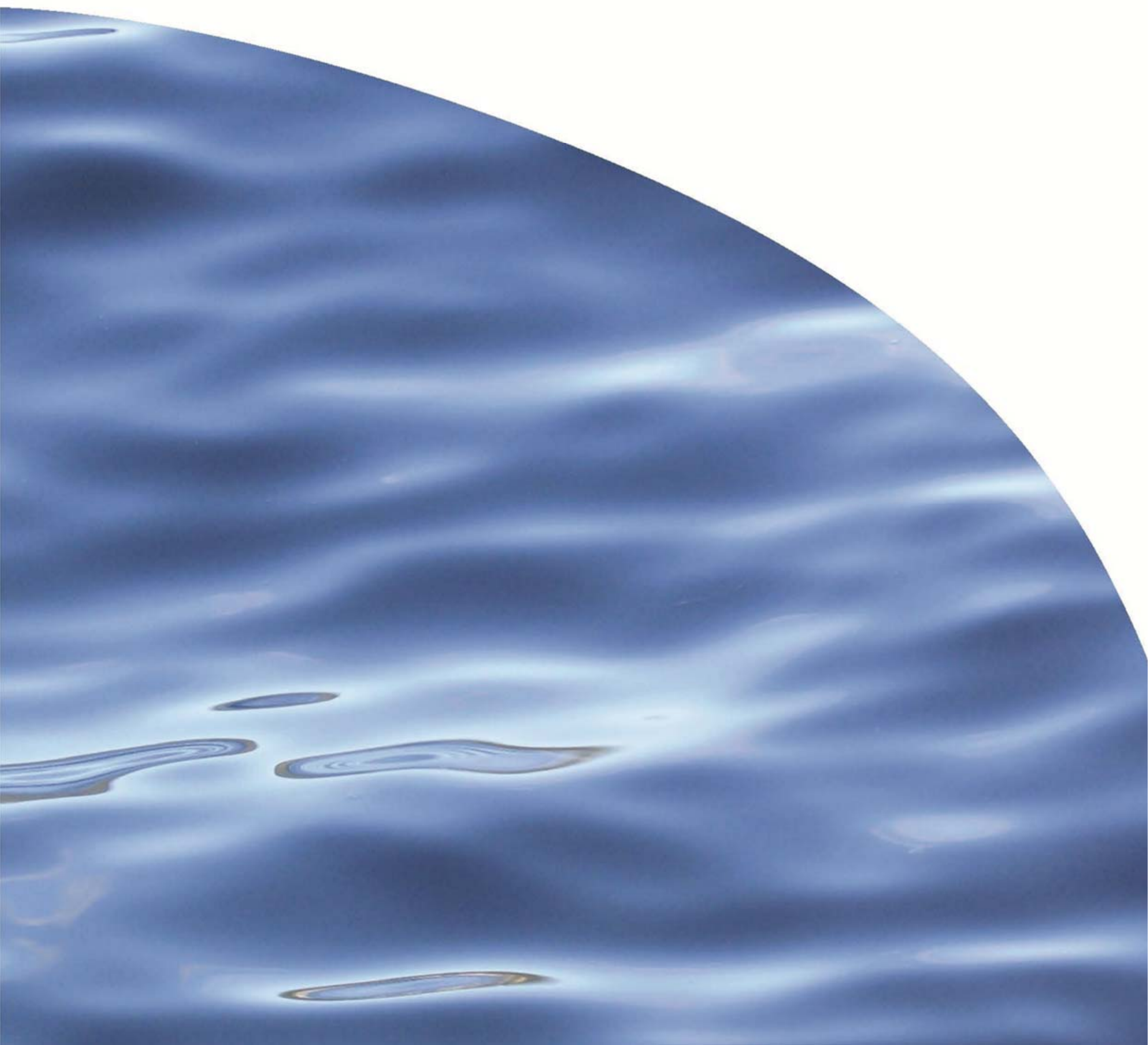
REPORT NO. 2959

CLAY POINT SALMON FARM: ANNUAL MONITORING REPORT (2016–2017)



CLAY POINT SALMON FARM: ANNUAL MONITORING REPORT (2016–2017)

DEANNA ELVINES, LAUREN FLETCHER

Prepared for The New Zealand King Salmon Co. Ltd

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

REVIEWED BY:
Grant Hopkins

APPROVED FOR RELEASE BY:
Chris Cornelisen

ISSUE DATE:28 April 2017

RECOMMENDED CITATION: 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.

EXECUTIVE SUMMARY

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

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

  All sample concentrations were below the threshold for possible biological effects.

- *The level of enrichment beneath the pens were within the EQS.*

  Some indicators have deteriorated since the previous monitoring assessment in November 2015. However, macrofaunal communities are pre-, or at, peak of opportunist levels with a high level of assimilative capacity.

- *The levels of enrichment were within the modified EQS for the 300 E and 300 W stations.*

  The 300 E station showed moderate enrichment levels, while the 300 W station clearly showed minor enrichment effects. The 300 W station has deteriorated from the November 2015 survey, while the 300 E station has shown a marginal improvement.

- Water column monitoring results will be reported in the next annual monitoring report for CLA, and will include data collected from November and December 2016 (in addition to the 2017 data).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

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

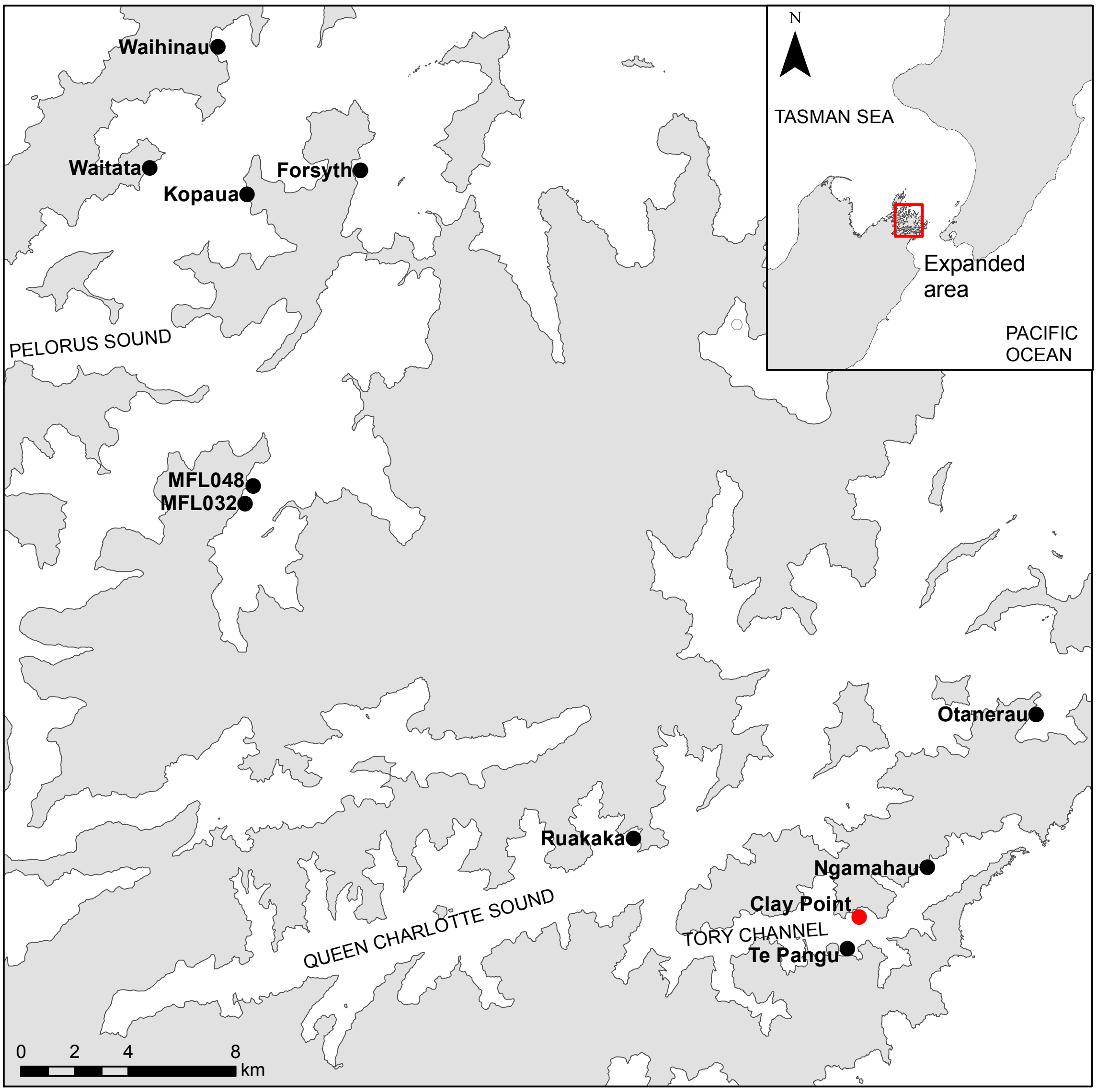


Figure 1. Map of the Marlborough Sounds area showing the location of the Clay Point (CLA) salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

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

1.1. Scope of report

This report presents the assessment of depositional effects on soft sediment habitats for the Clay Point (CLA) salmon farm 2016-2017. Although not included in this report, the consent also requires monitoring for:

- Effects on water quality
- Depositional effects on reef habitats.

In terms of effects on water quality, the CLA consent (requiring water column monitoring) was renewed in November 2016, and now requires monitoring to measure performance against water quality standards (thresholds) and water quality objectives. Given that water column monitoring data are presented for a calendar year (see Elvines & Fletcher 2016), the data for CLA will be first presented in the 2017–18 annual monitoring report. Note that water column monitoring data in Tory Channel have been presented in the TEP (Elvines & Fletcher 2017) and NGA (Elvines et al. 2017) monitoring reports.

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

1.2. Site details and history of feed usage

The CLA salmon farm has been in operation since 2007. 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. The site has mid-water average flows of *c.* 19.6 cm/sec, and maximum velocities up to *c.* 109 cm/sec; therefore it is a high-flow site.

A total of 4,531 tonnes of feed was used over the 12-month period leading up to the 2017 benthic monitoring (Figure 2), but only 4,477 tonnes in the 2016 calendar year. This volume is approximately 1 tonne higher than that discharged in 2015. The current consent for CLA (U160675) allows 4,500 tonnes of feed per annum, and has flexibility to allow for an increase. The highest monthly feed input was 578 tonnes, in December 2014 (Figure 3).

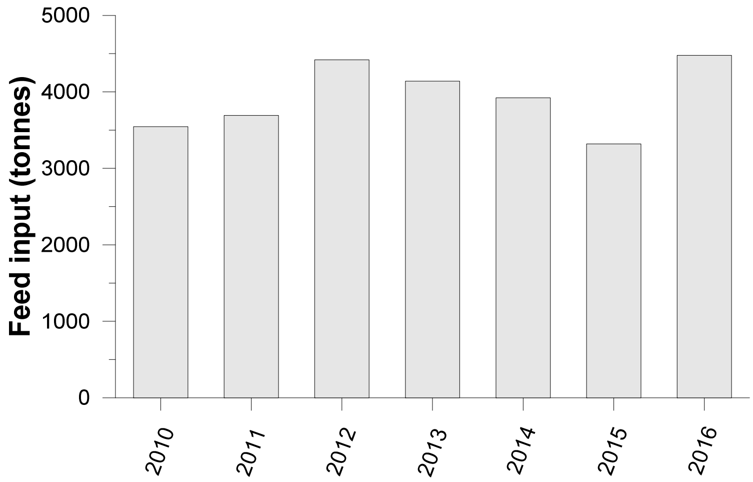


Figure 2. Annual feed inputs (calendar year) at the Clay Point salmon farm, 2010–2016. Feed input data provided by NZ King Salmon.

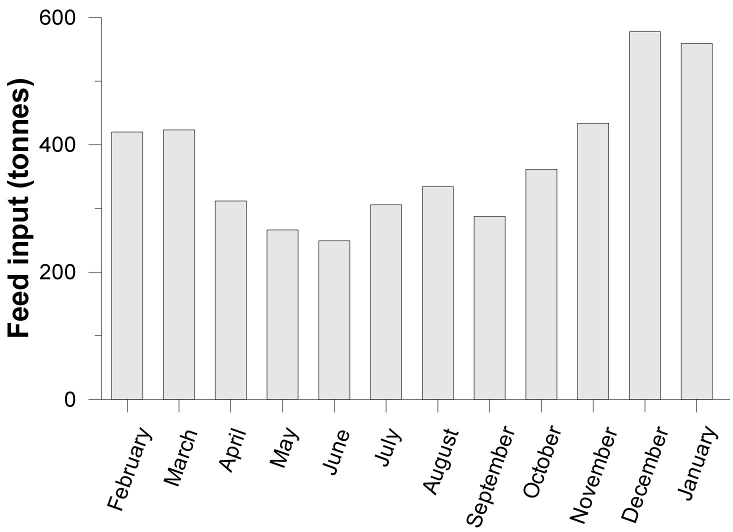


Figure 3. Monthly feed inputs at the Clay Point salmon farm for the 12 months preceding soft sediment sampling. Feed input data provided by NZ King Salmon.

2. METHODS

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

2.1. Soft-sediment habitats

2.1.1. Sampling locations

Annual soft sediment monitoring at CLA was undertaken on 24 and 26 January 2017. Sampling stations at the CLA farm are described and named as follows (also see Figure 4):

- Three net pen stations, within the zone of maximal effect (ZME), beneath the edge of the net pens; **Pen 1**, **Pen 2** and **Pen 3**.
- Two stations in opposing directions along the predominant depositional axes (east and west) to monitor enrichment within the outer limit of effects (which is set at 600 m); **300 E** and **300 W**.
- Three reference or 'control' stations, one near-field (**TC-Ctl-1**) and two far-field (**TC-Ctl-3** and **TC-Ctl-4)**.

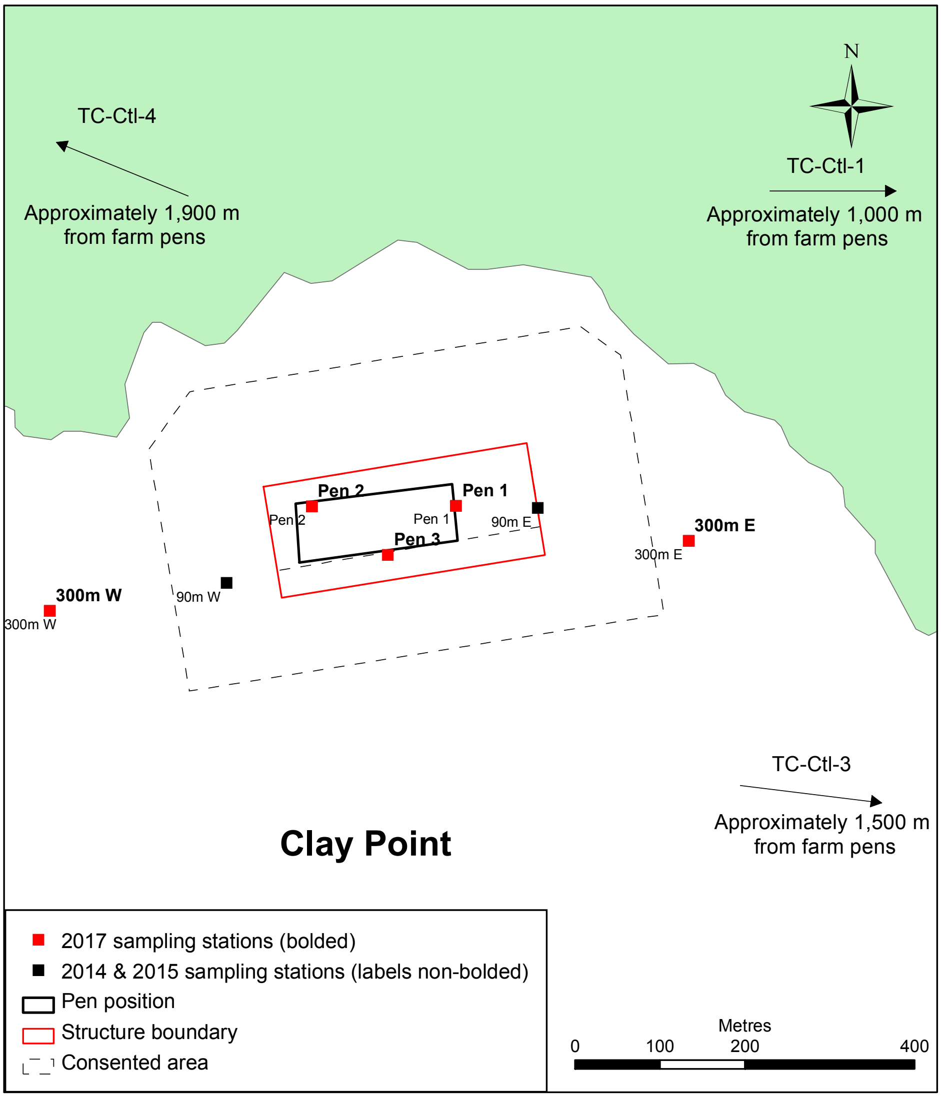


Figure 4. Soft sediment sampling locations at the Clay Point salmon farm site. 'TC-Ctl' = Tory Channel Control. Position accuracy is ± 5 m.

2.1.2. Environmental variables

Standard benthic monitoring

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

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

Two additional replicate samples ('d' and 'e' replicates) were collected from each farm station (i.e. Pen stations, 300 E, 300 W) to determine the redox potential (measured in the field), and to obtain organic content and macrofauna samples for archive purposes.

Video footage was collected at each station to qualitatively assess bacterial mat coverage, general seabed condition and presence of sediment out-gassing. The sea surface was also scanned for visible sediment out-gassing as this could provide further evidence of particularly enriched conditions. General observations of epifauna[2] were also made.

2.1.3. Assessment of Enrichment Stage

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to Enrichment Stage (ES). The ES assessment references a selection of informative chemical and biological indicator variables[3].

For each indicator variable (raw data), an equivalent ES score was calculated using previously described relationships (MPI 2015). Average ES scores were then calculated for the sediment chemistry variables (redox and sulphides), the macrofauna composition variables (abundance, richness, evenness, diversity and biotic indices), and organic content (% AFDW). The overall ES for a given sample was then calculated by determining the weighted average[4] of those three groups of variables. Finally, the overall ES for the sampling station was calculated from the average of the replicate samples with the degree of certainty reflected in the associated 95% confidence interval.

---

[1] The term 'macrofauna' describes the animals buried in the sediment.
[2] Epifauna are animals living on the surface of the seabed.
[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] 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).

3. COMPLIANCE FRAMEWORK

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

3.1. 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. 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 (Elvines & Fletcher 2016).

Table 1. Environmental quality standards (EQS) for the Clay Point salmon farm for each zone.

Compliance zone	Industry operational goal
EQS at ZME (as per MPI 2015)	Overall ES ≤ 5.0
EQS at the proxy OLE (at a distance of 300 m; as per Elvines & Fletcher 2016).	Overall ES < 3.7

3.2. Copper and zinc

The BMP guidelines state that the ANZECC (2000) ISQG-Low criteria for copper and zinc are the most appropriate trigger values for sediments beneath farms (Table 2). Therefore these guideline thresholds should be used to trigger further action if exceeded.

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

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

4. RESULTS

4.1. Qualitative description

Representative images of the seabed and conspicuous taxa at each station are provided in Appendix 2. Video footage of the seabed beneath the Pen stations showed coarse, dark grey sediments that were easily disturbed. Patches of *Beggiatoa*-like bacteria were evident at all three Pen stations. Bacterial growth was present primarily around empty mussel shells on the substrate at Pen 1, although light patches on the sediment surface were also noted. Bacterial growth was more pronounced on the sediment at Pen 2 and Pen 3, although this was still patchy. Light brown-red globules, resembling fish feed pellets, were also evident on the surface of the sediment at all three pen stations.

Anemones (*Actinothoe albocincta*) were common on the seabed at Pen 1 and Pen 2, as well as snake stars (*Ophiopsammus maculata*) and both blue and green-lipped mussels (*Mytilus galloprovincialis* and *Perna canaliculus*). Unattached colonial ascidian fragments (likely *Didemnum* sp.) were visible on the seabed at Pen 1. Drift macroalgae (*Ulva* sp.) was visible at both Pen 1 and Pen 2. In addition, a flounder (*Rhombosolea* sp.) was observed in the sediments under Pen 2. Epifaunal diversity appeared to be lower at Pen 3, with only anemones noted in the footage from this station.

Sediments at 300 E and 300 W were lighter in colour than at the Pen stations, and were sandy in texture with considerable shell hash present throughout. Snake stars, cushion stars (*Patiriella regularis*) and anemones were frequently observed in the footage. Fanworms and sponges were observed occasionally at both stations, along with saddle sea squirts (*Cnemidocarpa* sp.) at 300 W only. Drift macroalgae (*Ulva* sp. and *Caulerpa brownii*) were present at both stations.

Reference stations (TC-Ctl-1, TC-Ctl-3 and TC-Ctl-4) were characterised by fine, light grey sediments with shell hash and larger shell debris. Small cobbles were common at TC-Ctl-3, while diatom mats on the surface of the substrate were a conspicuous feature of TC-Ctl-4. Burrow holes, track marks and worm casts were occasionally visible at TC-Ctl-1 and TC-Ctl-4. Epifaunal diversity was lower at these two reference stations, although snake stars were common. In addition, a hermit crab (*Pagurus* sp.), an unidentified anemone and drift macroalgae (*Ulva* sp.) were noted at TC-Ctl-1. Blue mussels, scallops, cushion stars, and sea cucumbers were observed at TC-Ctl-4.

TC-Ctl-3 had more diverse epifauna due to occasional reef-like structures present on the sand and cobble substrate. Epifauna included fanworms, sponges, encrusting bryozoans, hydroids and saddle sea squirts. Macroalgae including *Ulva* sp., encrusting coralline algae and a variety of red foliose species were also noted. A range of mobile epifauna, including eleven-armed sea stars (*Coscinasterias* *calamaria*), an apricot sea star (*Sclerasterias mollis*) a sea cucumber (*Australostichopus mollis)* and a single kina (*Evechinus chloroticus*) were also observed. Blue cod (*Parapercis colias*) and spotted wrasse (*Notolabrus celidotus*) were common.

4.2. Assessment of seabed enrichment

This section discusses the sediment Enrichment Stage (ES) calculated for each station (Table 3). Discussion is provided on results of individual variables (Figure 5) where relevant.

4.2.1. Enrichment Stage assessments for 2017

Mean overall ES scores at the Pen stations were 4.3–4.9 (Table 3), indicating very high enrichment levels beneath the pens. Overall ES scores from all three Pen stations were within the EQS for this zone. Pen stations 2 and 3 (on the western side, and channel-ward side of the farm, respectively) showed similar overall enrichment states, although Pen 2 had relatively higher organic content (twice as high as reference) and more deteriorated sediment chemistry (Figure 5). Macrofaunal abundances at this station were reasonably consistent and averaged 4,693 individuals per core. Combined with the number of taxa persisting here (15–21 taxa per core), macrofaunal communities at Pen 2 are *pre-peak*[5], as indicated by the ES score (overall ES 4.3). Conditions at Pen 3 showed relatively high variability in most indicators. There were ‘pockets’ of low abundance and very low taxa richness (436 and 5, respectively), and pockets of higher total abundances and taxa richness (1,685 and 3,390 with 14 taxa per core). Organic matter and sediment chemistry at Pen 3 were generally less deteriorated than at other Pen stations, and the overall ES indicates the macrofauna is pre-peak. Pen 1 on the eastern side of the farm was in the most advanced enrichment state, with an overall ES of 4.9 (but still within the EQS for this zone) indicating very high enrichment levels. This station had very high organic matter for a high-flow site (3x reference), and extremely high sulphide levels (Figure 5). Macrofaunal abundances were also extremely high (7,983–13,979 individuals per core) with very low taxa richness (5–12 taxa per core). All measures indicate that this station is at peak of opportunist macrofaunal conditions, and with the high levels of organic matter, this station may progress to excessive enrichment levels.

Conditions along the eastern transect (i.e. at the 300 E station) have historically been poorer compared to the west, and results in 2017 were no exception. The ES measured within the OLE at 300 E and 300 W were 2.9 and 2.7 respectively. Sediments at both stations were moderately enriched but within the modified EQS (ES < 3.7) for this distance. Highly elevated sulphides were observed at the eastern

[5] Peak in this case refers to a state of ‘peak’ macrofaunal abundances.

station, despite organic matter only being elevated in one sample and redox being similar to reference conditions. Communities have responded with very high abundances (2–8x reference), and compositional changes are reflected in the AMBI and mAMBI values. These are evident as increased numbers of enrichment tolerant taxa and in order of dominance, these were: nematodes, the polychaete sub-family Exogoninae, oligochaetes, and the capitellid polychaete *Barantolla lepte*. Despite the normal sediment chemistry and organic matter at the western station, the macrofaunal community change at this station was similar (including dominance by opportunists), although somewhat less pronounced.

Table 3. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each station sampled in January 2017. Full breakdowns of indicator variable contributions are provided in Appendix 3 and Appendix 4. ZME = Zone of Maximum Effect. EQS = Environmental Quality Standard. OLE = Outer Limit of Effects.

Station	Summary of indicator variables		ES (95% CI)
Pen 1 (ZME)	%OM highly elevated (3× reference), average redox negative, and sulphides extremely elevated. Macrofauna abundance extremely high (average 10,894 per core, 2× that of Nov '15) and heavily reduced taxa richness in some samples (5–12 per core).	Organic loading:	6 (0)
		Sediment chemistry:	4.6 (0.2)
		Macrofauna:	4.8 (0)
		Overall:	**4.9 (0)**
Pen 2 (ZME)	%OM elevated (2× reference), redox consistently negative, and sulphides highly elevated. Macrofauna abundance very high (average 4,693 per core), taxa richness reduced (average of 19 taxa per core).	Organic loading:	3.3 (1.7)
		Sediment chemistry:	4.5 (0.2)
		Macrofauna:	4.4 (0)
		Overall:	**4.3 (0.2)**
Pen 3 (ZME)	%OM elevated, redox both positive and negative, sulphides highly variable (normal–high). Macrofauna abundance elevated but quite variable (436–3,390 individuals per core) and taxa richness reduced (5-14 taxa per core).	Organic loading:	3 (2)
		Sediment chemistry:	3.7 (0.8)
		Macrofauna:	4.6 (0.2)
		Overall:	**4.3 (0.3)**
		ZME; EQS	**≤ 5.0**
300m E (OLE)	%OM marginally elevated in one sample. Redox normal but sulphides highly elevated. Total abundance elevated (801–2,384 individuals per core), taxa richness slightly elevated. Compositional changes observed in macrofaunal community.	Organic loading:	2 (0)
		Sediment chemistry:	3.6 (0.3)
		Macrofauna:	2.9 (0.8)
		Overall:	**2.9 (0.5)**
300m W (OLE)	%OM, redox and sulphides similar to reference. Total abundance elevated (~2× controls), number of taxa normal. AMBI indicative of moderate disturbance.	Organic loading:	2 (0)
		Sediment chemistry:	3.1 (0)
		Macrofauna:	2.6 (0.5)
		Overall:	**2.7 (0.3)**
		OLE proxy; modified EQS	**< 3.7**
TC-Ctl-1	%OM low, redox and sulphides normal. Abundances elevated in some samples compared to previous years, but taxa richness and community composition indicative of background seabed conditions.	Organic loading:	1.7 (0.7)
		Sediment chemistry:	2.5 (1.1)
		Macrofauna:	2 (0.2)
		Overall:	**2 (0.4)**
TC-Ctl-3	%OM low, redox and sulphides normal. Abundances elevated in some samples compared to previous years, but taxa richness and community composition indicative of background seabed conditions.	Organic loading:	1.3 (0.7)
		Sediment chemistry:	3.1 (0.2)
		Macrofauna:	2 (0.3)
		Overall:	**2.2 (0.2)**
TC-Ctl-4	%OM low, redox and sulphides normal. Community composition indicative of background seabed conditions. No indication that far-field enrichment is occurring in neighbouring bays.	Organic loading:	2 (0)
		Sediment chemistry:	3 (0.6)
		Macrofauna:	2 (0.1)
		Overall:	**2.2 (0.2)**

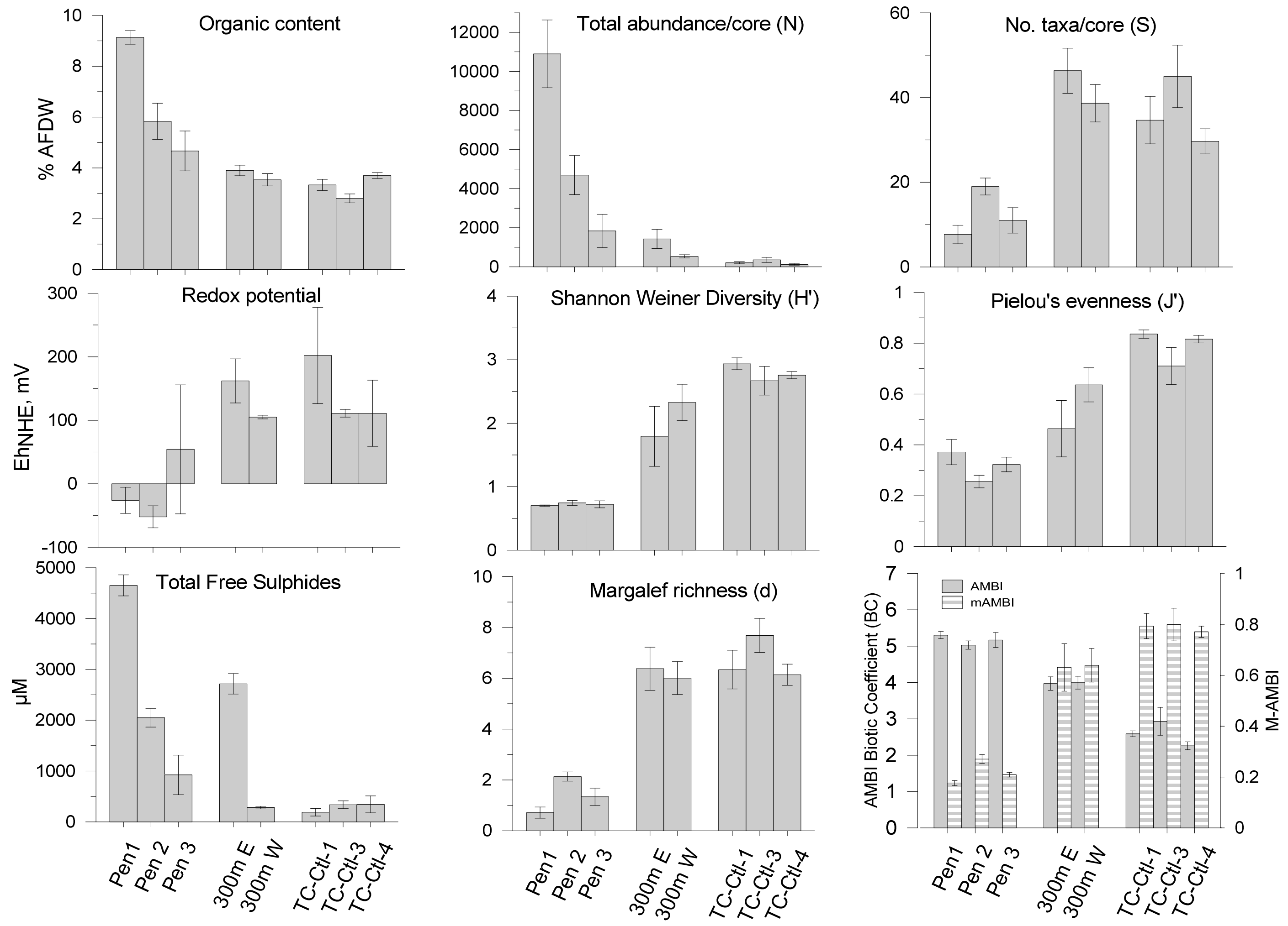


Figure 5. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and macrofauna statistics determined at the Clay Point salmon farm and reference monitoring stations, January 2017. TC-Ctl = Tory Channel control. Error bars = ± 1 SE, n = 3.

4.2.2. Historical comparison

A comparison of previous monitoring assessments (Table 4 and Figure 6) shows overall enrichment levels at the Pen stations have increased from November 2015 to January 2017 (note the change in survey timing), but are still within the range observed over the past four years, and still remain compliant with the EQS of ES ≤ 5.0. Pen 1 shows higher organic content and total abundances from November 2015 to January 2017, while taxa richness remained unchanged. Pen 2 shows a more marked deterioration over this period, evident as increased organic matter, lower redox, higher total abundances (Appendix 5: Figure 5.1) as well as lower taxa richness values; almost half of that recorded in November 2015. Because the Pen 3 station has not been monitored in the past, no historical data exist for comparison.

At 300 E the mean ES was lower than the previous two years. This is probably due to increased taxa richness, despite the increase in abundances and sulphide concentrations from the previous monitoring assessment. However, ES scores at 300 W have increased, and this station shows lower redox and higher abundances from November 2015, as well as slightly lower taxa richness. Although the overall ES for the 300 W station is within the modified EQS (of 3.7), it is worth noting the reasonably large (0.4) increase in ES at this station between these last two monitoring assessments.

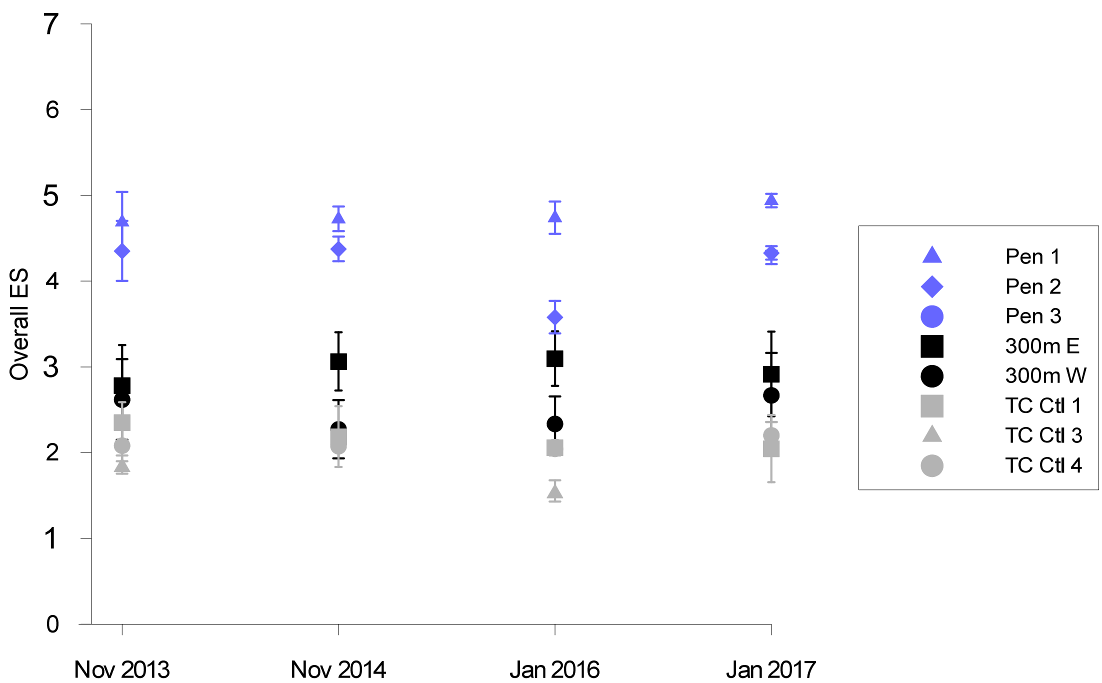


Figure 6. Four year time series of average overall ES (±SE or 95% CI in 2015/16) at the Clay Point farm monitoring stations.

Table 4. Comparison of average overall Enrichment Stage scores for assessments from annual (and interim) monitoring 2013–2017

	Enrichment Stage				
	2013	**2014**	**Mar 2015**	**Nov 2015**	**Jan 17**
Pen 1	4.7 (0.2)	4.7 (0.1)	-	4.7 (0.2)	**4.9 (0)**
Pen 2	4.4 (0.1)	4.4 (0)	-	3.6 (0.1)	**4.3 (0.2)**
Pen 3	-	-	-	-	**4.3 (0.3)**
300 m E	2.8 (0.3)	3.1 (0.2)	3.2 (0.1)	3.1 (0.3)	**2.9 (0.5)**
300 m W	2.6 (0.2)	2.3 (0.1)	-	2.3 (0.1)	**2.7 (0.3)**
TC-Ctl-1	2.4 (0.1)	2.2 (0.2)	-	2.1 (0.1)	**2.0 (0.4)**
TC-Ctl-3	1.8 (0.1)	2.0 (0.1)	-	1.8 (0.2)	**2.2 (0.2)**
TC-Ctl-4	2.1 (0.1)	2.1 (0)	-	2.0 (0.1)	**2.2 (0.2)**

4.3. Copper and zinc concentrations

Total recoverable copper and zinc concentrations were below the ANZECC (2000) ISQG-Low trigger level for possible biological effects (65 mg/kg and 200 mg/kg respectively) (Table 5). Concentrations of zinc were elevated (*c.* twofold) compared to concentrations at the Tory Channel reference site (37 mg/kg) in 2013 (Appendix 5: Figure 5.2). Total recoverable copper concentrations were also slightly elevated compared to reference concentrations (Appendix 5: Figure 5.2).

Table 5. Total recoverable copper and zinc concentrations (mg/kg dry weight) in bulk sediment from Clay Point pen samples, January 2017.

Sample	Copper	Zinc
Pen 1	12	150
Pen 2	9.2	88
Pen 3	6	58
ANZECC ISQG-Low	**65**	**200**
ANZECC ISQG-High	**270**	**410**

5. SUMMARY OF FINDINGS

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

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

  All sample concentrations were below the threshold for possible biological effects.

- The level of enrichment beneath the pens were within the EQS.

  Some indicators have deteriorated since the previous monitoring assessment in November 2015. However, macrofaunal communities are pre-, or at, peak of opportunist levels with a high level of assimilative capacity.

- *The levels of enrichment were within the modified EQS for the 300 E and 300 W stations.*

  The 300 E station showed moderate enrichment levels, while the 300 W station clearly showed minor enrichment effects. The 300 W station has deteriorated from the November 2015 survey, while the 300 E station has shown a marginal improvement.

- Water column monitoring results will be reported in the next annual monitoring report for CLA, and will include data collected from November and December 2016 (in addition to the 2017 data).

6. 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.

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

Elvines D, 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. Te Pangu Bay Salmon Farm: Annual Monitoring Summary 2016 - 2017. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 3008. 30 p. plus appendices.

Elvines D, Knight B, Berthelsen A, Fletcher L 2017. Ngamahau Bay Salmon Farm: Annual Monitoring Summary (2016 - 2017). Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 3001. 37 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.

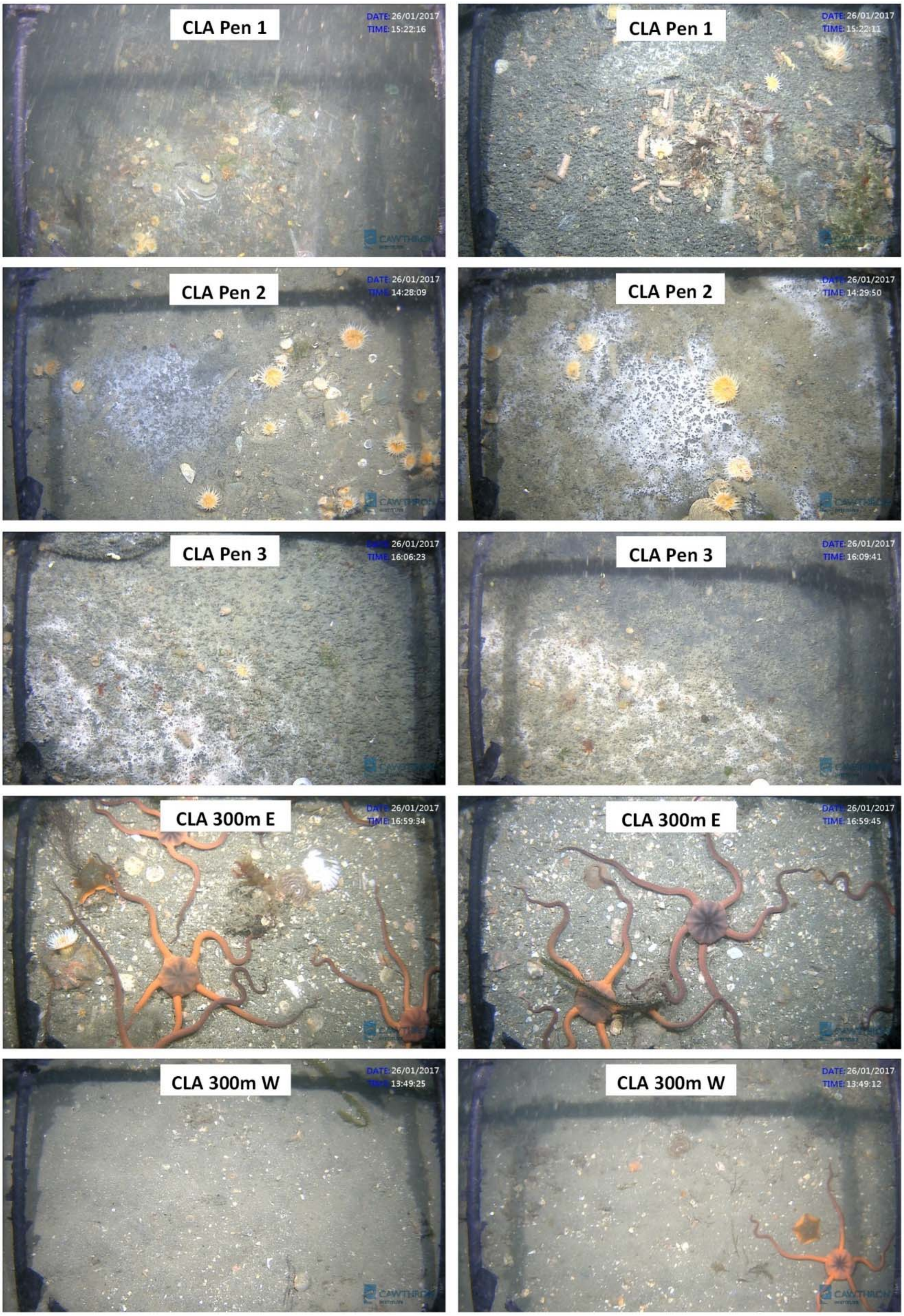
Ministry of Primary Industries (MPI) 2015. Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Part 1: Benthic environmental quality standards and monitoring protocol (Version 1.0 January 2015). Prepared for the Ministry for Primary Industries by the Benthic Standards Working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

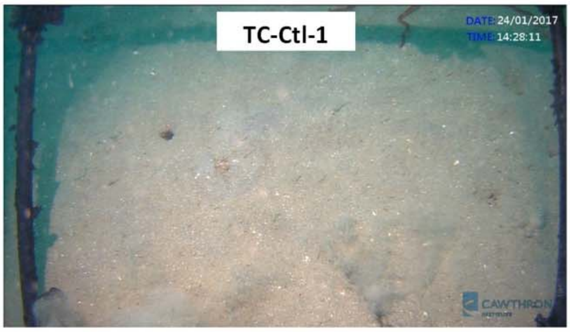
7. APPENDICES

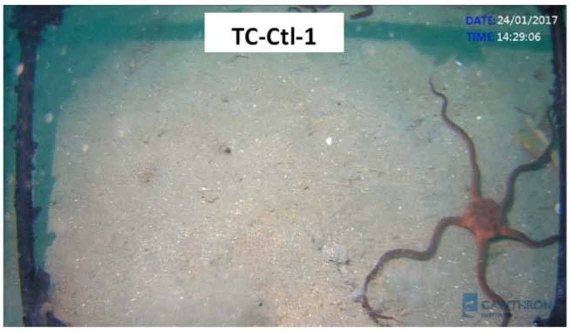
Appendix 1. Laboratory analytical methods for sediment samples (January 2016) processed by either Hill Laboratories (a), and Cawthron Institute (b).

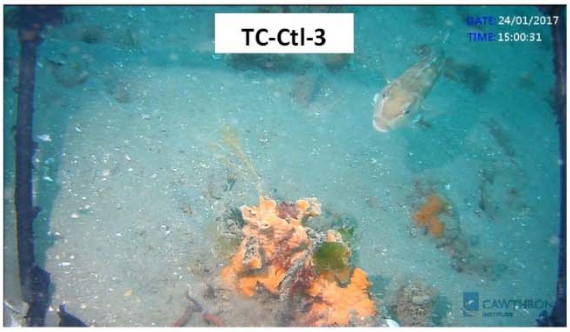
Analyte	Method	Default detection limit
Organic matter (as ash-free dry weight) [a]	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 22nd ed. 2012. Calculation: 100 – Ash (dry wt).	0.04 g/100 g
Total recoverable copper & zinc [a]	Dried sample. Nitric/ hydrochloric acid digestion, ICP-MS, trace level. US EPA 200.2.	0.2 - 2 mg/kg (Cu) 0.4 - 4 mg/kg (Zn)
Total free sulphides [b]	Cawthron Protocol 60.102. Sample solubilised in high pH solution with chelating agent and anti-oxidant. Measured in millivolt (mV) using a sulphide specific electrode and calibrated using a sulphide standard.	

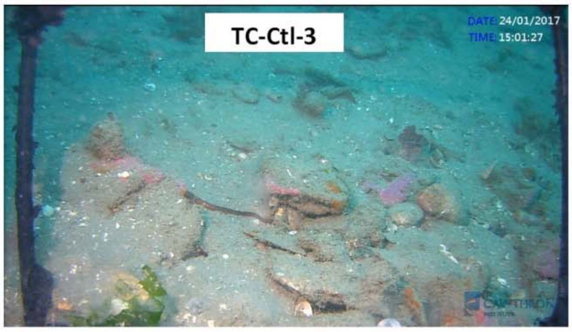
Appendix 2. Representative images of the seafloor at each CLA soft sediment sampling station (January 2017).

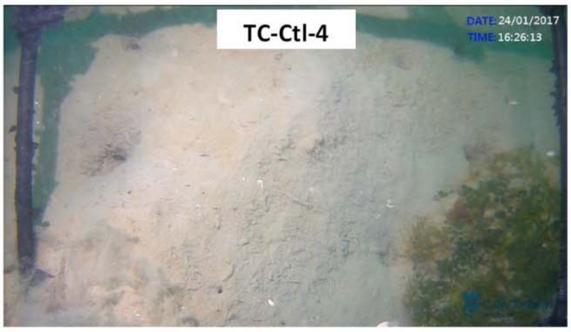


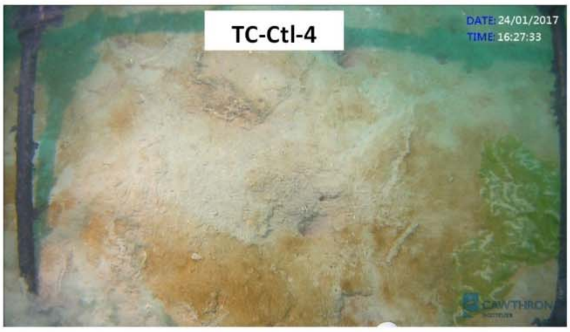

TC-Ctl-1
DATE 24/01/2017
TIME 14:28:11


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


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


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


TC-Ctl-4
DATE 24/01/2017
TIME 16:26:13


TC-Ctl-4
DATE 24/01/2017
TIME 16:27:33

Appendix 3. Detailed Enrichment Stage (ES) calculations for each station at the Clay Point salmon farm, January 2017. For details about how these values were calculated, see MPI (2015). Underlined text are cases where best professional judgement (BPJ; Keeley et al. 2012) was used.

SITE INFORMATION

Date: Jan-17

Farm/site: CLA

Flow environment: HF

RAW DATA (to be entered)

Station:	Repl.	TOM	Redox	TFS	N	S	J'	d	SWDI	AMBI	M-AMBI	BQI
Pen1	a	9.4	-55	4297	7983	5	0.45	0.4	0.724	5.359	0.15822	1.6
Pen1	b	9.4	-37	5017	10721	6	0.39	0.5	0.691	5.111	0.18077	1.83
Pen1	c	8.6	14	4643	13979	12	0.28	1.2	0.694	5.438	0.19062	2.25
Pen 2	a	7.2	-52	2312	5398	21	0.24	2.3	0.716	4.924	0.28862	3.03
Pen 2	b	4.8	-22	1696	5958	21	0.23	2.3	0.692	4.911	0.28714	3.04
Pen 2	c	5.5	-82	2139	2722	15	0.3	1.8	0.826	5.256	0.23722	2.52
Pen 3	a	3.6	-145	619	436	5	0.38	0.7	0.612	4.779	0.19343	1.79
Pen 3	b	4.2	120	454	1685	14	0.3	1.8	0.794	5.48	0.20966	2.35
Pen 3	c	6.2	188	1696	3390	14	0.29	1.6	0.761	5.248	0.22508	2.47
300m E	a	3.8	95	2312	1091	57	0.64	8	2.605	3.675	0.80464	7.21
300m E	b	4.3	180	2917	2384	41	0.26	5.1	0.972	4.311	0.4852	4.29
300m E	c	3.6	211	2917	801	41	0.49	6	1.803	3.933	0.60328	4.97
300m W	a	3.4	105	264	380	37	0.73	6.1	2.65	3.978	0.66471	6.29
300m W	b	4	110	333	589	32	0.51	4.9	1.757	4.309	0.51399	4.75
300m W	c	3.2	100	244	650	47	0.67	7.1	2.572	3.7	0.73914	6.29
TC-Ctl-1	a	3.6	89	281	102	24	0.87	5	2.749	2.753	0.69655	8.96
TC-Ctl-1	b	2.9	346	40	250	43	0.81	7.6	3.041	2.505	0.86139	8.6
TC-Ctl-1	c	3.5	171	242	268	37	0.84	6.4	3.016	2.512	0.82214	8.56
TC-Ctl-3	a	3.1	112	475	485	56	0.73	8.9	2.956	2.582	0.92416	9.39
TC-Ctl-3	b	2.5	121	208	493	48	0.57	7.6	2.224	3.698	0.70862	6.68
TC-Ctl-3	c	2.8	100	326	95	31	0.82	6.6	2.826	2.517	0.76574	10.6
TC-Ctl-4	a	3.7	215	326	114	34	0.81	7	2.867	2.432	0.79493	9.14
TC-Ctl-4	b	3.9	65	63	57	24	0.84	5.7	2.68	2.291	0.72674	6.63
TC-Ctl-4	c	3.5	53	641	182	31	0.79	5.8	2.721	2.057	0.79201	9.25

ES equivalents / Variable group weightings: Organic loading 0.1, Sediment chemistry 0.2, Macro-fauna 0.7

Station:	Repl.	TOM	Redox	TFS	N	S	d	SWDI	AMBI	M-AMBI	BQI	Organic loading	Sediment chemistry	Macro-fauna	Overall ES
Pen1	a	6	4.62	4.83	4.72	5.5	5.53	4.36	4.75	5.47	5.67	6	4.73	4.9	4.98
Pen1	b	6	4.46	4.93	4.94	5.5	5.5	4.43	4.5	5.41	5.45	6	4.7	4.91	4.98
Pen1	c	6	4	4.88	5.15	4.38	5.25	4.42	4.83	5.39	5.08	6	4.44	4.82	4.86
Pen 2	a	5	4.6	4.43	4.42	3.76	4.63	4.38	4.31	5.01	4.42	5	4.52	4.4	4.48
Pen 2	b	2	4.33	4.23	4.49	3.76	4.65	4.43	4.29	5.02	4.42	2	4.28	4.42	4.15
Pen 2	c	3	4.87	4.38	3.89	4.17	4.94	4.16	4.64	5.23	4.84	3	4.63	4.47	4.36
Pen 3	a	2	5.43	3.58	4.5	5.5	5.46	4.6	4.16	5.38	5.49	2	4.51	4.83	4.48
Pen 3	b	2	3.05	3.38	3.52	4.24	4.95	4.22	4.87	5.33	4.98	2	3.22	4.51	4
Pen 3	c	5	2.44	4.23	4.06	4.24	5.03	4.29	4.64	5.28	4.88	5	3.34	4.55	4.35
300m E	a	2	3.27	4.43	3.19	1.27	1.66	1.92	3.03	1.98	2.08	2	3.85	2.18	2.5
300m E	b	2	2.51	4.58	3.79	2.38	2.89	3.87	3.68	3.82	3.52	2	3.55	3.51	3.37
300m E	c	2	2.23	4.58	2.96	2.38	2.42	2.61	3.29	3.04	3.1	2	3.41	2.86	2.88
300m W	a	2	3.18	3.03	2.38	2.65	2.38	1.9	3.34	2.66	2.43	2	3.11	2.45	2.54
300m W	b	2	3.14	3.18	2.72	3	3.06	2.66	3.68	3.63	3.23	2	3.16	3.12	3.02
300m W	c	2	3.23	2.98	2.8	1.96	1.92	1.94	3.05	2.26	2.43	2	3.11	2.32	2.45
TC-Ctl-1	a	2	3.33	3.07	1.38	3.55	2.99	1.86	2.09	2.48	1.67	2	3.2	2.16	2.35
TC-Ctl-1	b	1	1.02	1.81	2.06	2.24	1.75	1.77	1.83	1.82	1.73	1	1.42	1.84	1.67
TC-Ctl-1	c	2	2.59	2.97	2.12	2.65	2.19	1.78	1.84	1.92	1.74	2	2.78	1.95	2.12
TC-Ctl-3	a	2	3.12	3.41	2.57	1.34	1.57	1.79	1.91	1.74	1.63	2	3.27	1.8	2.11
TC-Ctl-3	b	1	3.04	2.88	2.58	1.89	1.76	2.18	3.05	2.41	2.27	1	2.96	2.35	2.34
TC-Ctl-3	c	1	3.23	3.17	1.32	3.07	2.13	1.83	1.85	2.13	1.6	1	3.2	1.92	2.08
TC-Ctl-4	a	2	2.19	3.17	1.46	2.86	1.97	1.81	1.76	2.02	1.65	2	2.68	1.88	2.05
TC-Ctl-4	b	2	3.54	2.1	0.93	3.55	2.58	1.89	1.61	2.32	2.3	2	2.82	2.07	2.21
TC-Ctl-4	c	2	3.65	3.6	1.82	3.07	2.54	1.87	1.38	2.03	1.64	2	3.63	1.99	2.32

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

		Units	Pen1	Pen 2	Pen 3	300 E	300 W	TC-Ctl-1	TC-Ctl-3	TC-Ctl-4
	Depth	m	36	38	30	30	32	18	30	20
Sediments	AFDW	%	9.1 (0.3)	5.8 (0.7)	4.7 (0.8)	3.9 (0.2)	3.5 (0.2)	3.3 (0.2)	2.8 (0.2)	3.7 (0.1)
	Redox	Eh_{NHE}, mV	-26 (21)	-52 (17)	54 (102)	162 (35)	105 (3)	202 (76)	111 (6)	111 (52)
	Sulphides	µM	4,653 (208)	2,049 (184)	923 (389)	2,715 (202)	281 (27)	187 (75)	336 (77)	343 (167)
	Bacterial mat	-	Patchy	Patchy	Patchy	No	No	No	No	No
	Out-gassing	-	No	No	No	No	No	No	No	No
	Odour	-	Moderate	Moderate	Mild-strong	No	No	No	No	No
macrofauna statistics	Abundance	No./core	10,894 (1,733)	4,693 (999)	1,837 (856)	1,425 (487)	540 (82)	207 (53)	358 (131)	118 (36)
	No. taxa	No./core	7.7 (2.2)	19 (2)	11 (3)	46.3 (5.3)	38.7 (4.4)	34.7 (5.6)	45 (7.4)	29.7 (3)
	Evenness	Stat.	0.4 (0)	0.3 (0)	0.3 (0)	0.5 (0.1)	0.6 (0.1)	0.8 (0)	0.7 (0.1)	0.8 (0)
	Richness	Stat.	0.7 (0.2)	2.1 (0.2)	1.3 (0.3)	6.4 (0.8)	6 (0.6)	6.3 (0.8)	7.7 (0.7)	6.1 (0.4)
	SWDI	Index	0.7 (0)	0.7 (0)	0.7 (0.1)	1.8 (0.5)	2.3 (0.3)	2.9 (0.1)	2.7 (0.2)	2.8 (0.1)
	AMBI	Index	5.3 (0.1)	5 (0.1)	5.2 (0.2)	4 (0.2)	4 (0.2)	2.6 (0.1)	2.9 (0.4)	2.3 (0.1)
	M-AMBI	Index	0.2 (0)	0.3 (0)	0.2 (0)	0.6 (0.1)	0.6 (0.1)	0.8 (0)	0.8 (0.1)	0.8 (0)
	BQI	Index	1.9 (0.2)	2.9 (0.2)	2.2 (0.2)	5.5 (0.9)	5.8 (0.5)	8.7 (0.1)	8.9 (1.2)	8.3 (0.9)

Appendix 5. Historical comparisons.

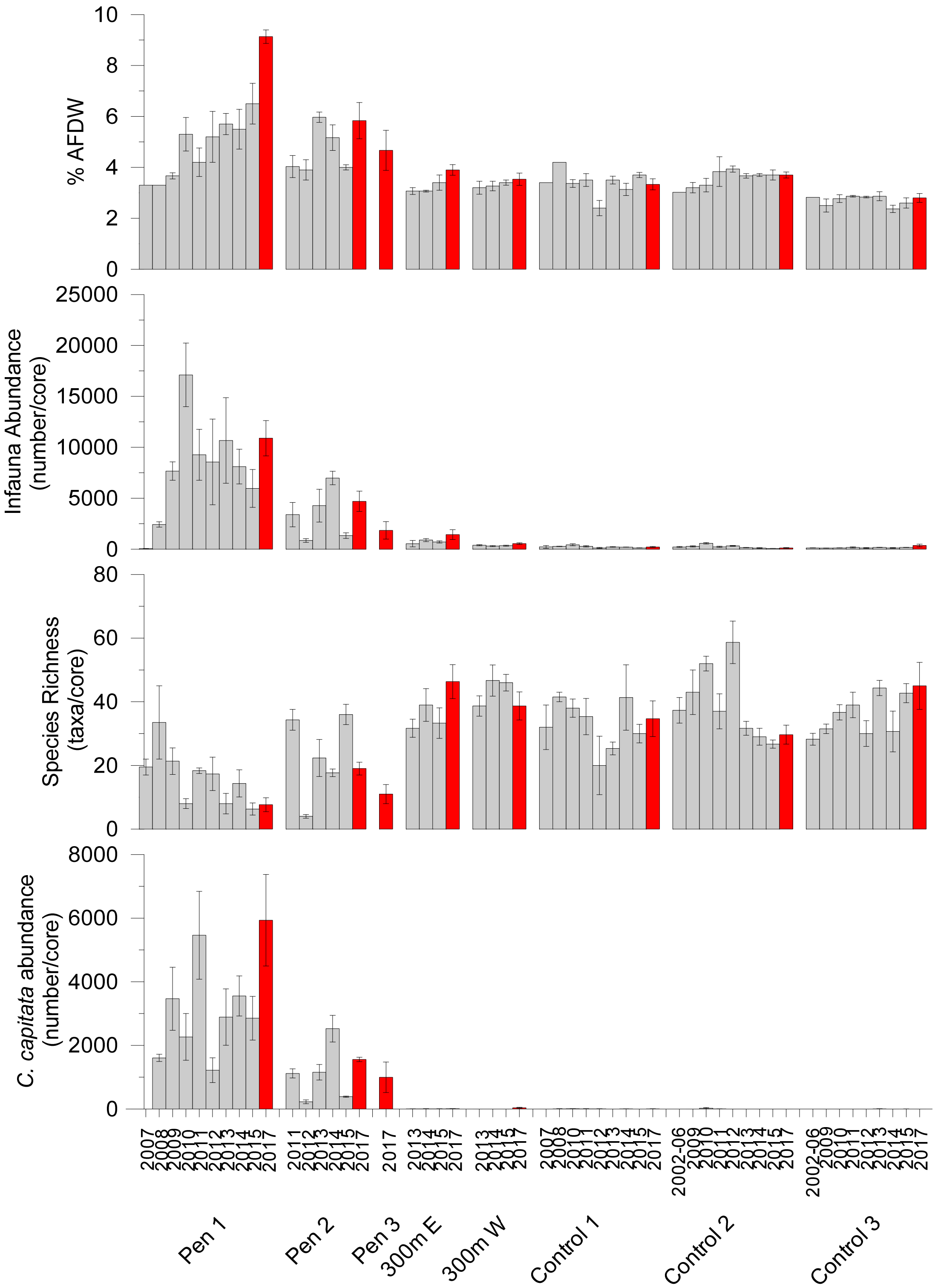


Figure A5.1. Mean (± SE) ash-free dry weight (AFDW), macrofauna abundance (number/core), taxa richness (taxa/core), and *Capitella capitata* densities (number/core) recorded for the Clay Point salmon farm annual monitoring since 2007. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000).

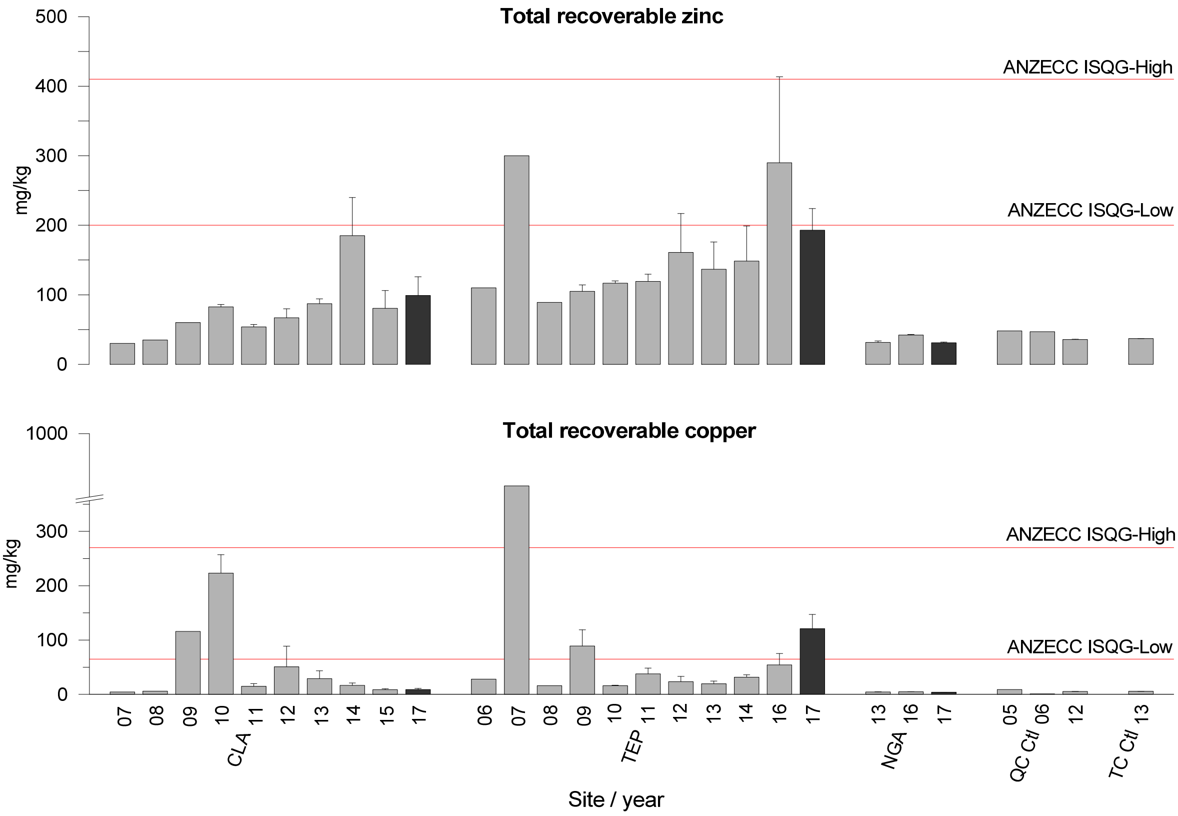


Figure A5.2. Average sediment total recoverable copper and zinc concentrations beneath the Tory Channel NZ King Salmon farms and two reference stations (TC = Tory Channel, QC = Queen Charlotte, Ctl = control). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low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