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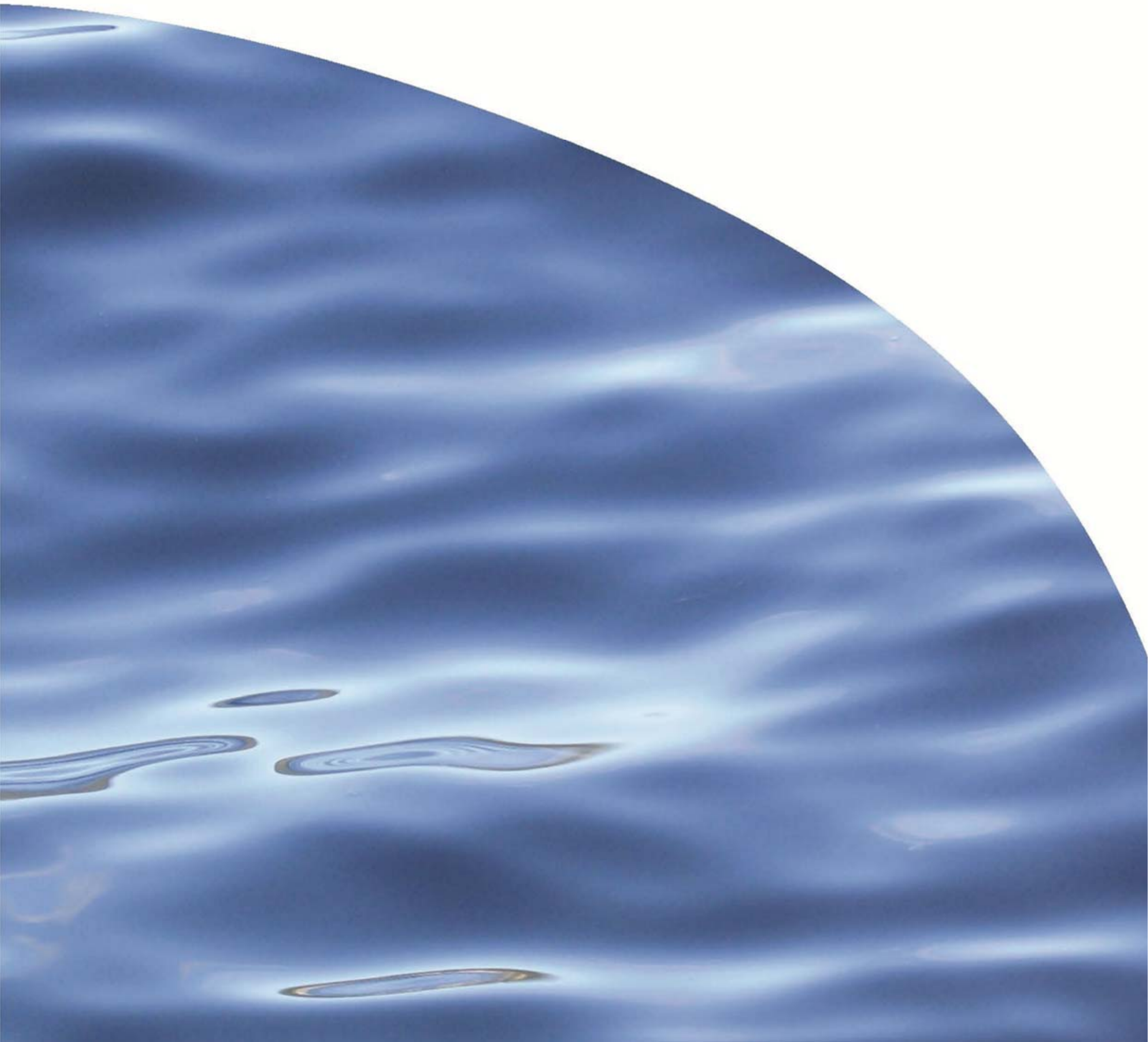
ENVIRONMENTAL IMPACTS OF THE RUAKAKA BAY SALMON FARM: ANNUAL MONITORING 2016



ENVIRONMENTAL IMPACTS OF THE RUAKAKA BAY SALMON FARM: ANNUAL MONITORING 2016

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Prepared for The New Zealand King Salmon Co. Ltd.

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1. INTRODUCTION

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

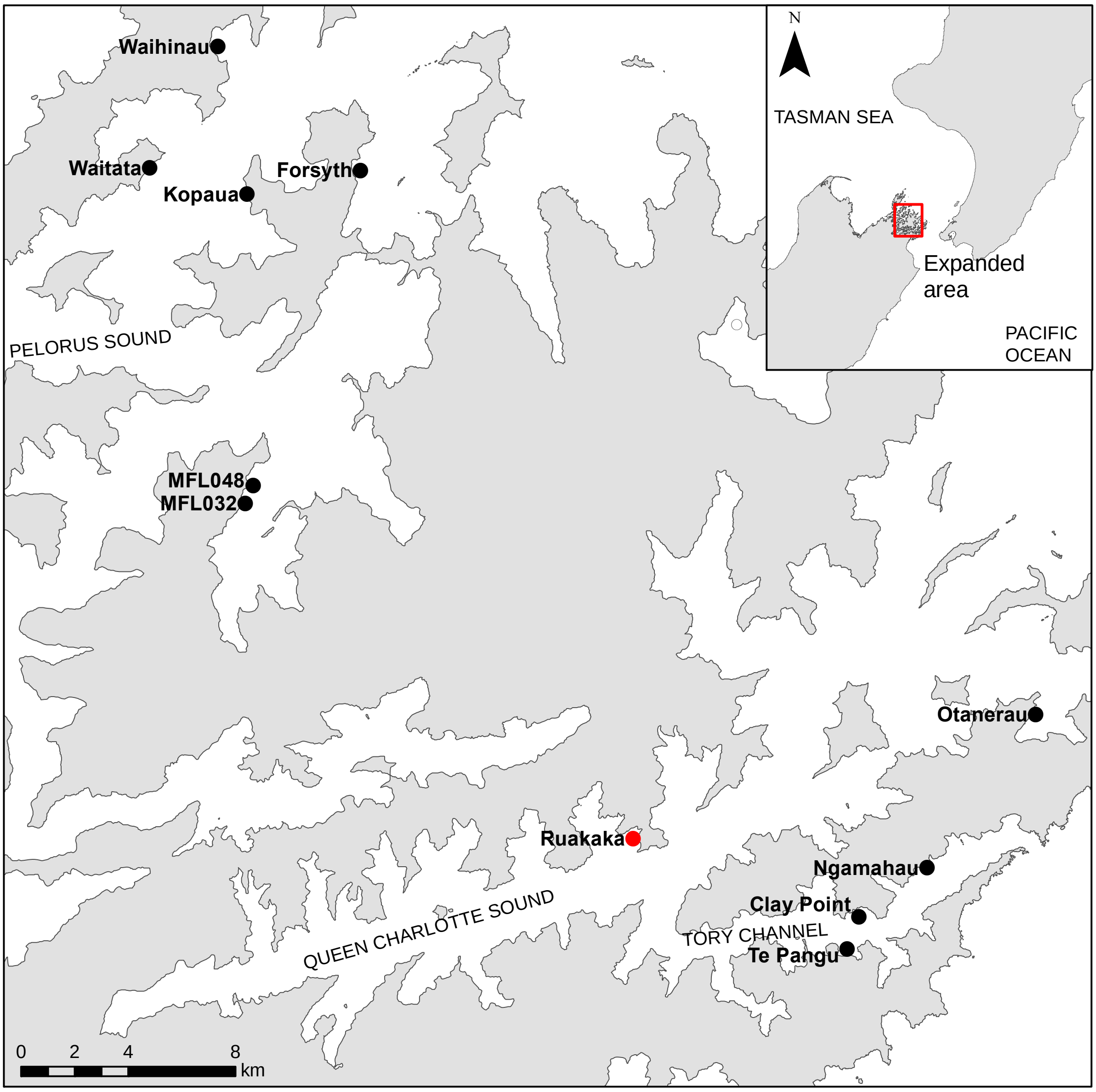

Figure 1. Map of the Marlborough Sounds area showing the location of the Ruakaka Bay (RUA) salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

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 & Taylor 2016a), prepared by Cawthron Institute (Cawthron) on behalf of NZ King Salmon, and approved by Marlborough District Council (MDC) prior to implementation.

This report presents the 2016 annual monitoring results for the above monitoring at the RUA salmon farm. The monitoring at RUA in 2016 covered:

- depositional effects on soft-sediment and inshore or reef habitats
- effects on water quality.

1.1. Site details and history of feed usage

The RUA farm was established in 1985. Water depth at the farm site is *c.* 35 m, with the net pens extending from the surface to a depth of *c.* 20 m. The site has average water current speeds of 3.7 cm/s, and is thus considered a low-flow site.

Over the past decade, feed inputs have ranged from 1,661[1] to 3,206 tonnes per annum (Figure 2). A total of 2,171 tonnes of feed was used over the 12-month period (November 2015 through October 2016), leading up to this year's monitoring, consistent with the amount discharged in the previous 12 month period (note this time period differs from that shown in Figure 2 and Figure 3 which show a period that allows historical comparisons). Over this period, feed discharge peaked in December 2015, and again July 2016. The month with the lowest discharge volume was March 2016.

[1] Feed input data provided by NZ King Salmon.

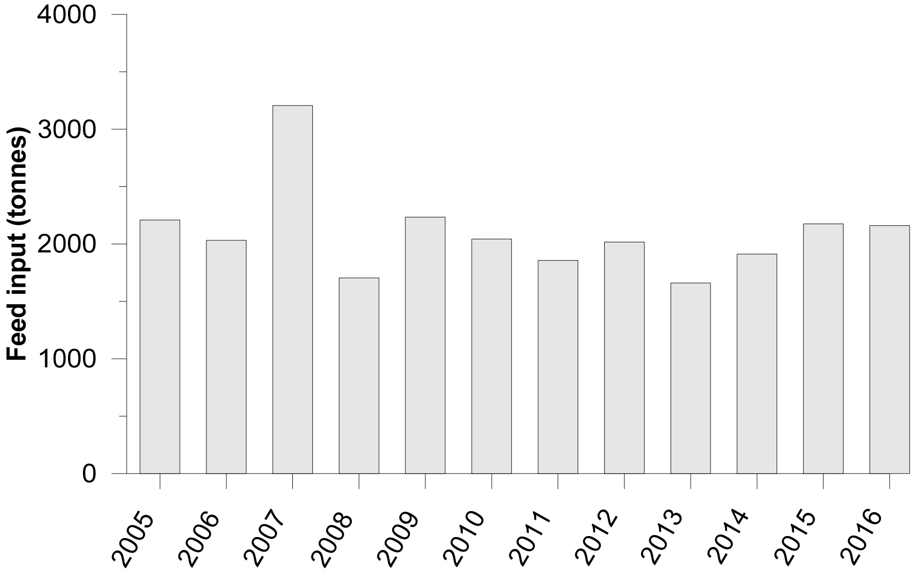

Figure 2. Annual feed inputs (December through November) at the Ruakaka Bay salmon farm, 2005–2016.

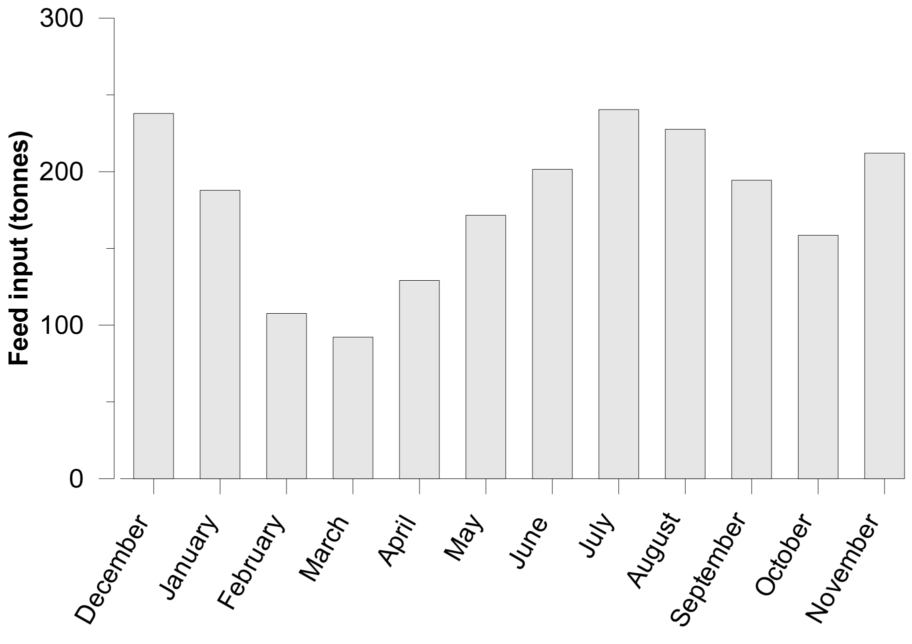

Figure 3. Monthly feed inputs at the Ruakaka Bay salmon farm from December 2015 to November 2016.

2. METHODS

Annual monitoring at RUA was undertaken on 17 and 18 November 2016, using the techniques summarised below. Detailed methodology and rationale for the sampling approach can be found in the most recent MEMAMP (Elvines & Taylor 2016a); copies are held by MDC and NZ King Salmon. The MEMAMP is updated and 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

Sampling stations at the RUA farm are described and named as follows (see Figure 4):

- two pen stations, beneath the edge of the net pens: ‘Pen 1’ and ‘Pen 2’
- two stations along a southerly transect (aligned in a down-current direction from the net pens) at the Zone 1/2 boundary and at the Zone 2/3 boundary: ‘50 m’ and ‘150 m’ respectively
- two reference or ‘control’ stations: ‘QC-Ctl-3’ and ‘QC-Ctl-4’.

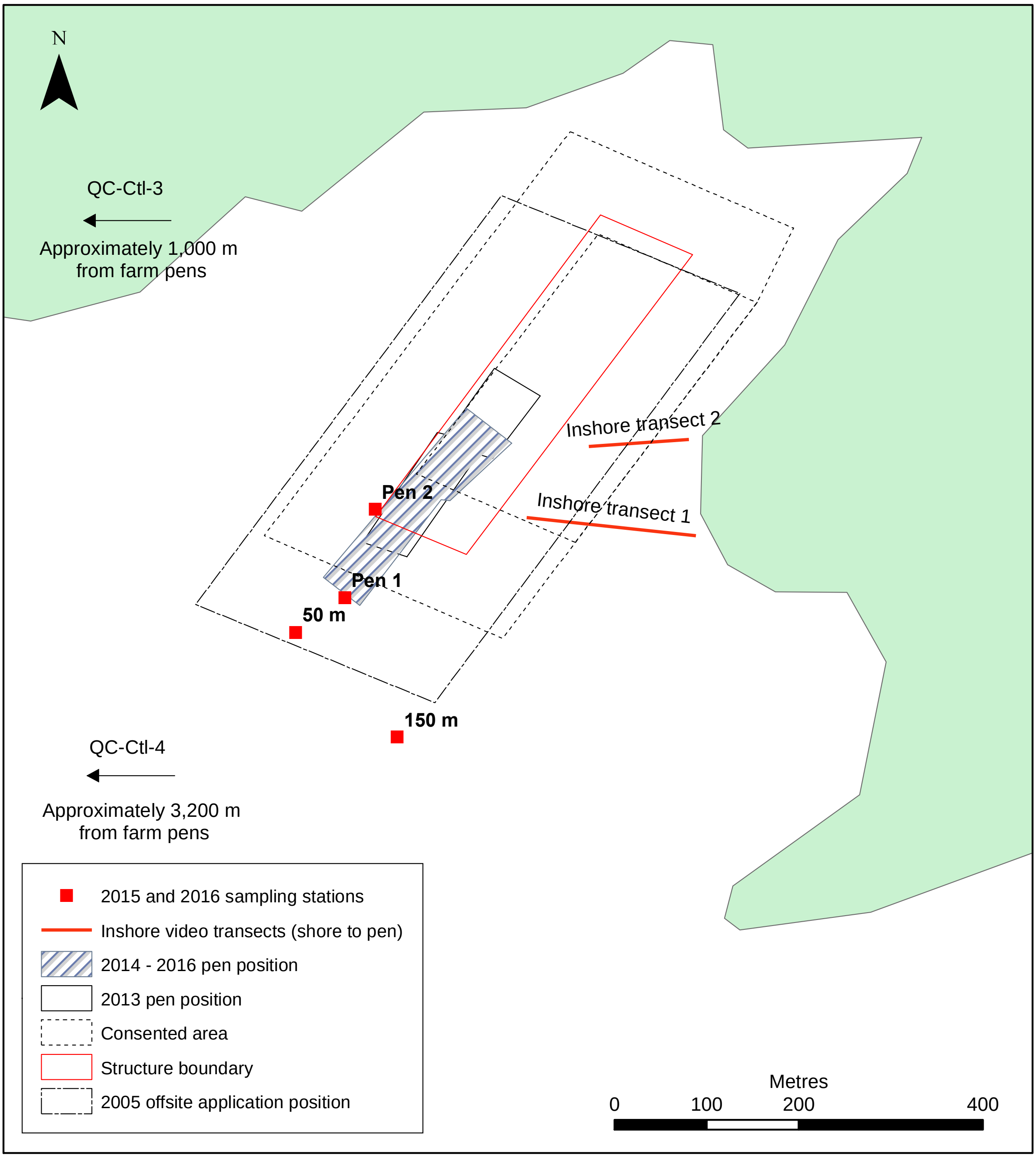

Figure 4. Soft sediment sampling locations at the Ruakaka Bay salmon farm site. 'QC Ctl' = Queen Charlotte Control. Position accuracy is ± 5 m. The '2005 offsite application position' reflects the area in the offsite farm application submitted by NZ King Salmon on 23 November 2005.

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 3 cm 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). Samples from the two pen stations were analysed for copper and zinc concentrations (total recoverable and dilute-acid-extractable[2]). 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[3] 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 M-AMBI ecological quality ratio (EQR). Refer to MPI (2015) for an explanation of each of the biotic indices.

Two additional replicate samples (with the exception of sulphides and metals) were taken from each RUA net pen station (i.e. Pen 1 and Pen 2) and were archived.

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

2.1.3. Assessment of Enrichment Stage (ES)

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to Enrichment Stage (ES). Each environmental result (raw data) was converted into an equivalent ES score 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.

[2] ANZECC threshold values are based on the bio-available fraction. For sediment particulates, the dilute-acid-extractable (1M HCl) fraction is used as a surrogate for bio-availability (ANZECC 2000).
[3] The term 'macrofauna' describes the animals buried in the sediment, known technically as infauna.
[4] Weighting used in the current workings was the same as that used in previous years: organic loading = 0.1, sediment chemistry = 0.2, macrofauna composition = 0.7).

2.2. Water column

Water column monitoring was carried out at the same time as the benthic monitoring component. Stations monitored at the RUA farm included[5]: Pen 2, 50 m and 150 m. Water column monitoring was also carried out at a reference station (QC-Ctl-3) for comparison.

At each station the following parameters were measured *in situ* using a conductivity-temperature-depth (CTD) instrument with an attached dissolved oxygen sensor; salinity, temperature, fluorescence (a proxy for chlorophyll-*a*), optical backscatter (a proxy for turbidity), and dissolved oxygen.

2.3. Inshore habitats

The RUA farm is a low-flow site that has no significant reef habitats within the primary depositional footprint. Inshore habitats are visually inspected qualitatively every second year for assessment of general health with respect to any signs of excessive organic deposition and any obvious changes in visual characteristics over time. As the last visual assessment was undertaken in 2014, this component was incorporated into the present annual monitoring survey. Video footage was collected along two transects using a remotely operable video sled (ROVS). For comparability, transects are the same as those surveyed in 2014 (Figure 4). Both transects ran west from the subtidal zone of the shoreline east of the farm location towards the net pens.

[5] NB: Although the CTD was deployed at the 50 m station, the instrument failed to log data and no results were available for graphical presentation.

3. COMPLIANCE FRAMEWORK

3.1. Soft sediment habitats

3.1.1. Enrichment

The environmental monitoring results from soft-sediment habitats are used to determine whether the farms are compliant with Environmental Quality Standards (EQS). The EQS are based on a seabed impact 'zones concept'; an approach that provides an upper limit to the spatial extent and magnitude of seabed impacts (see Keeley 2012).

The EQS in the consent conditions (Table 1) do not set precise parameters for the allowable environmental states within the zones. This is particularly true when dealing with intermediate stages on the enrichment continuum. Consequently, it is difficult to report definitively on compliance with particular consent conditions. We note that a targeted working group has developed best management practice guidelines (BMP; MPI 2015). Although these guidelines have not been formally adopted at this site, they do provide additional context against which to compare enrichment levels.

In addition, in previous reporting Cawthron has endeavoured to interpret the existing conditions in a quantitative manner and has proposed some 'allowable' equivalent Enrichment Stages (assumed ES; Table 1) for each of the zones prescribed by the consent. Although somewhat subjective, this approach was guided by the language and the intent of the consent conditions as much as practicable. In discussing the results, reference is also made to the EQS set out in the BMP, to provide further context.

Table 1. Environmental quality standards (EQS) for Ruakaka Bay (RUA) salmon farm described for each zone (consent U040217) and the assumed Enrichment Stage (ES) for each zone.

Spatial zone	Spatial extent	Description and bottom line	Assumed ES**
1	Beneath the pens and out to 50 m from their outside edge	Sediments become highly impacted and contain low species diversity dominated by opportunistic taxa (e.g. polychaetes, nematodes). It is expected that a gradient will exist within this zone, with higher impacts present directly beneath the pens.	Less than 6.0*
2	From 50 m to 150 m from the outside edge of the pens	A transitional zone between Zones 1 and 3. Within this zone, some enrichment and enhancement of opportunistic species may occur, however species diversity remains high with no displacement of functional groups. It is expected that a gradient will also exist within this zone.	3.5 or less*
3	Beyond 150 m from the outside edge of the pens	Normal conditions (i.e. background or control conditions).	2.5 or less and no more than 0.5 greater than the highest ES score for a relevant reference site*
All zones	These conditions are not permitted beneath any NZ King Salmon farm	Sediments that are anoxic and azoic (i.e. no life present).	7

*Refer to MPI (2015) for further details relating to ES scores.
**Not explicitly specified in consent U040217.

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3.1.2. Copper and zinc

Under the current consent there are no requirements to monitor copper and zinc levels in the sediment, nor are there EQS against which to compare compliance for these metals. However, results can be put in the context of the BMP guidelines (MPI 2015), which states that the ANZECC (2000) ISQG-Low criteria for copper and zinc as the most appropriate trigger values for sediments beneath farms (Table 2). Therefore these guideline thresholds should be used to trigger for further action if exceeded. For more information regarding the copper and zinc monitoring approach, readers are referred to the BMP.

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. Soft sediment habitats

4.1.1. Habitat descriptions

Assessment of video footage of the seabed at RUA pen stations was hampered by poor water clarity; however, in general sediments appeared dark and muddy and were easily disturbed. Mussel shell debris and unattached green foliose algae were common at both pen stations. The sediments at Pen 1 had a light coverage of *Beggiatoa*-like bacterial mat. Anemones and sponges were also occasionally observed at Pen 1, as was a single spiny dogfish (*Squalus acanthias*).

The sediment at the 50 m and 150 m stations was lighter in colour, not so easily disturbed and contained fewer shells than the pen stations. Burrow holes, trail marks and worm casts were observed at both stations. No conspicuous epifauna were noted aside from a single sea cucumber (*Australostichopus mollis*) at the 50 m station and several small unidentified fish at the 150 m station.

Substrates at the control sites were similar to the outer stations, with predominantly soft muddy sediments. Bioturbation was observed in the form of burrow holes and trail marks. Epifauna included brittle stars (*Ophiopsammus maculata*) as well as a single large anemone at QC-Ctl-3. Representative images of the seabed and conspicuous taxa at each station are provided in Appendix 2.

4.1.2. Assessment of seabed enrichment

This section discusses the sediment Enrichment Stage (ES) calculated for each station (Table 3). Discussion is provided on results from individual variables (Figure 6 and Figure 7) where relevant.

Enrichment Stage assessments for 2016

The seabed beneath the pens was very highly enriched, with overall ES scores of 5.1 and 5.7 for the Pen 1 and Pen 2 stations, respectively (Table 3). Macrofaunal conditions at Pen 1 indicate a ‘peak of opportunist’ level of enrichment with low taxa richness, but very high total abundances that were dominated by opportunists (e.g. *Capitella capitata*) (Figure 6). While sediment chemistry (redox and sulphides) was in a highly deteriorated state, organic content was still low (Figure 5). All indicators at Pen 2 showed comparatively higher level of deterioration (including extremely high total free sulphides in all samples; 9,082 ±2370 µM), approaching a state of excessive enrichment. Total macrofaunal abundances were variable, high in some samples and low in others (51–566 per core). Taxa richness was very low in all samples (2–6 per core). Together with the sediment chemistry and organic loading variables, these results indicate post peak macrofaunal conditions. Overall, the seabed within Zone 1 was within the assumed EQS for that zone (i.e. ES < 6.0). Both pen stations would exceed the EQS in the context of the BMP[6], and would elicit an 'alert' and/or 'minor' management response, for the Pen 1 and Pen 2 stations respectively.

At the 50 m station the seabed showed minor enrichment (overall ES 2.7) due to elevated sulphides, and variable macrofaunal richness and abundance. The 150 m station had on overall ES of 2.1, similar to the controls, despite the marginally elevated sediment chemistry at this station compared to the reference sites. Both boundary stations were within the assumed EQS for their respective zones. The 150 m station (Zone 3/4 boundary) was also within the EQS for this zone in the context of the BMP.

[6] Depending on the outcome of the ES after processing archive samples, which was not done in this case as the results were within the assumed EQS as it relates to the consent.

Table 3. Average Enrichment Stage (ES) scores and 95% confidence intervals (95% CI) calculated for indicator variables, and overall, for each Ruakaka Bay farm sampling station in November 2016. Full breakdowns of indicator variable contributions are provided in Appendix 3 and Appendix 4. Both the assumed EQS (Section 3.1.1) and the BMP ES from MPI (2015) are shown for context.

	Summary of indicator variables		**ES (95% CI)**
Pen 1	%OM normal, redox strongly negative, and sulphides high. Taxa richness low (< 10 per core), but total abundances highly elevated (4723–6906 per core) and dominated by *C. capitata* (i.e. peak).	Organic loading:	2.8 (0.6)
		Sediment chemistry:	4.7 (0.1)
		Macrofauna composition:	5.6 (0.1)
		Overall:	**5.1 (0)**
Pen 2	%OM high, redox very strongly negative, and sulphides extremely elevated in some samples. Taxa richness low (2–6 per core) total abundances variable, and high but post peak in some samples (51–566 per core).	Organic loading:	4.5 (1.6)
		Sediment chemistry:	6.2 (0.5)
		Macrofauna composition:	5.7 (0.3)
		Overall:	**5.7 (0.1)**
		Assumed EQS	**< 6.0**
		BMP ES	**≤ 5.0**
50 m (Zone 1-2 boundary)	%OM and redox normal. Sulphides elevated. Total abundance variable, elevated in some samples (53–285 per core). Taxa richness also variable, average comparable to reference sites.	Organic loading:	2.5 (0.1)
		Sediment chemistry:	3 (0.3)
		Macrofauna composition:	2.6 (0.9)
		Overall:	**2.7 (0.7)**
		Assumed EQS	**≤ 3.5**
150 m (Zone 2–3 boundary)	%OM normal, redox and sulphides marginally elevated compared to reference sites. Macrofauna statistics normal/comparable to controls.	Organic loading:	2.5 (0)
		Sediment chemistry:	2.7 (0.3)
		Macrofauna composition:	1.9 (0)
		Overall:	**2.1 (0)**
		Assumed EQS	**≤ 2.5**
		BMP ES	**< 3.0**
QC-Ctl-3	Normal background conditions.	Organic loading:	2.8 (0)
		Sediment chemistry:	2.2 (0.6)
		Macrofauna composition:	1.8 (0.1)
		Overall:	**2 (0.2)**
QC-Ctl-4	Normal background conditions.	Organic loading:	3.2 (0)
		Sediment chemistry:	1.4 (0.3)
		Macrofauna composition:	2.1 (0.2)
		Overall:	**2.1 (0.1)**

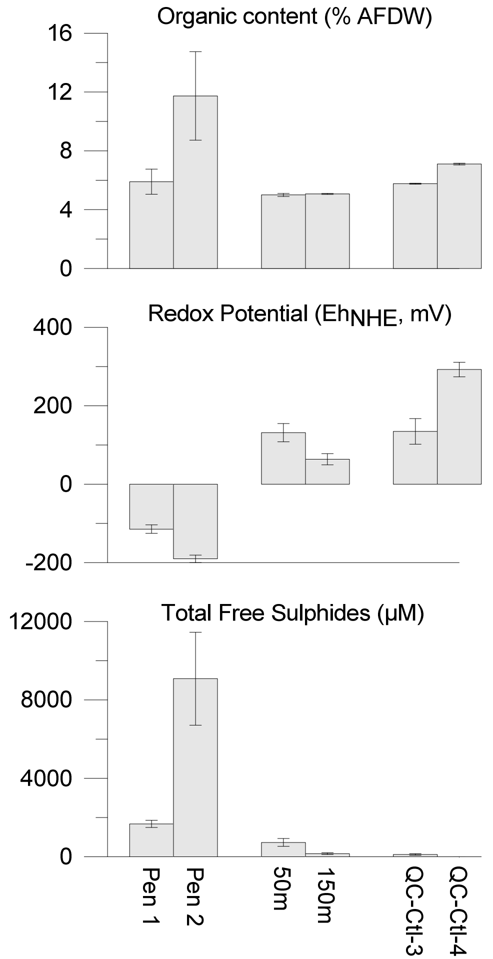


Figure 5. Average (±SE) sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) at Ruakaka Bay farm monitoring stations, November 2016.

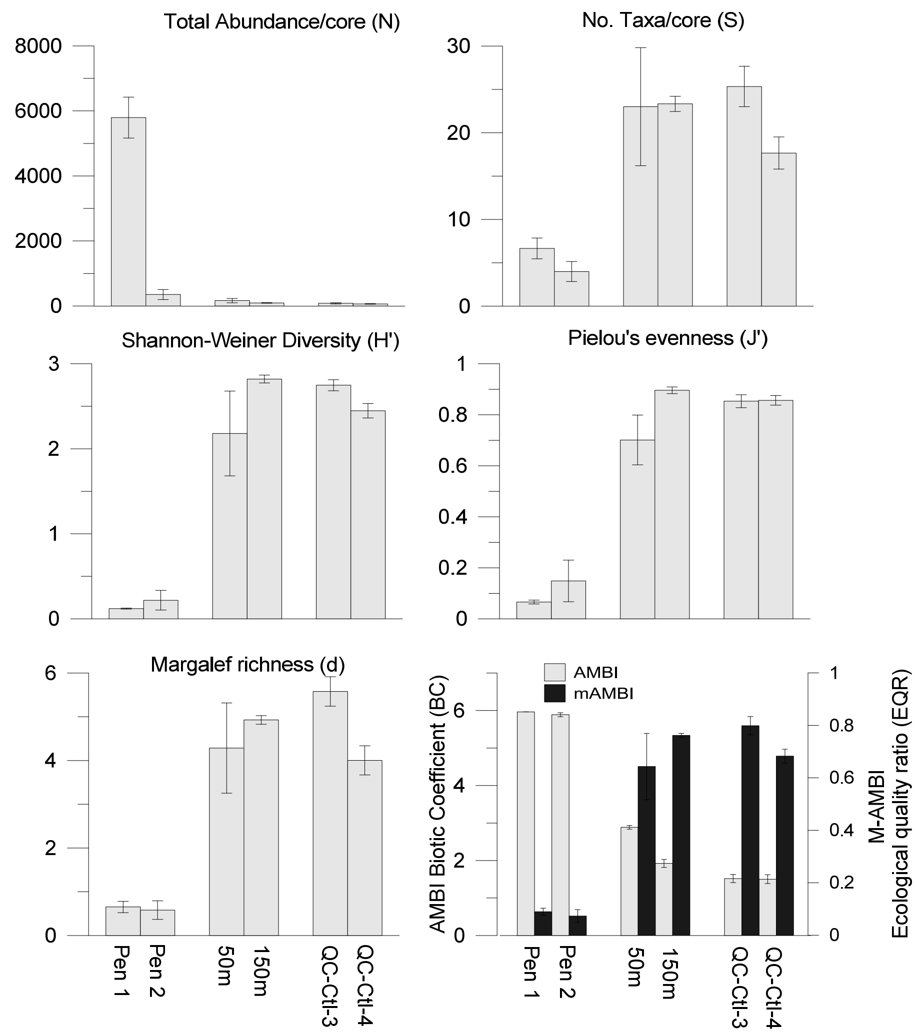


Figure 6. Average (±SE) macrofauna statistics at Ruakaka Bay farm monitoring stations, November 2016.

Historical comparison

A comparison of the last four monitoring assessments (conducted at roughly 12-monthly intervals) shows that conditions at the zone boundaries have remained within the assumed EQS set out in the consent conditions for the site (Table 4, Figure 7). However, note that the 2014, 2015 and 2016 results are not directly comparable with the 2013 results due to change in pen position between these periods.

Overall, the state of the communities beneath the pens are reasonably similar to that observed in 2015. A slight decrease in overall ES was observed at the Pen 1 station due to improved sediment chemistry. There was a concurrent increase in overall ES at the Pen 2 station, whereby macrofaunal communities shifted to post-peak conditions with lower and variable abundances and slightly lower taxa richness values compared to the previous year. While both the 50 m and 150 m stations had reasonably similar overall ES scores compared to 2014, there were subtle deteriorations in sediment chemistry at both stations, as well as macrofauna at the 50 m station.

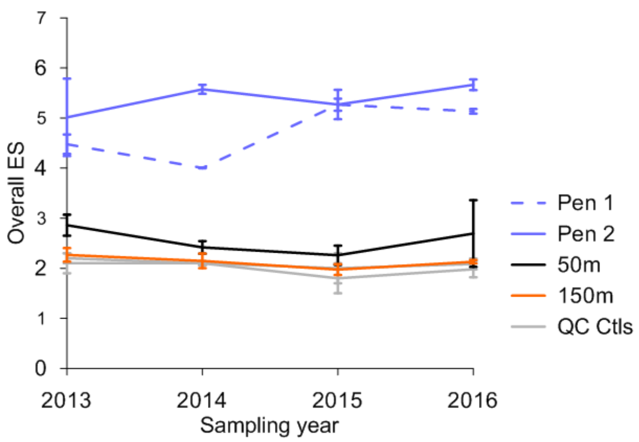


Figure 7. Four year time series of average overall ES (±SE or 95% CI in 2015/2016) at the Ruakaka Bay farm monitoring stations.

Table 4. Comparison of average (±SE or 95% CI for 2015 & 2016) Enrichment Stage scores at the Ruakaka Bay farm monitoring stations (2013 – 2016). Follow up monitoring results from March 2016 (Elvines & Taylor 2016b) are also shown.

	Overall Enrichment Stage				
Station	**2013**	**2014**	**2015**	**2016 (Mar)**	**2016 (Nov)**
Pen 1	4.5 (0.1)	4.0 (0)	5.3 (0.1)	5.2 (0.2)	**5.1 (0)**
Pen 2	5.0 (0.4)	5.6 (0.1)	5.3 (0.3)	5.3 (0.2)	**5.7 (0.1)**
50 m	2.9 (0.1)	2.4 (0.1)	2.3 (0.2)		**2.7 (0.7)**
150 m	2.3 (0.1)	2.1 (0.1)	2.0 (0.1)		**2.1 (0)**
QC Ctl 3	2.1 (0.2)	2.1 (0)	1.8 (0.3)		**2.0 (0.2)**
QC Ctl 4	2.2 (0.1)	2.1 (0)	2.0 (0.3)		**2.1 (0.1)**

4.1.3. Copper and zinc concentrations

The concentration of total recoverable copper in 4 of the 6 replicates exceeded the ANZECC (2000) ISQG-Low trigger level (65 mg/kg) for possible biological effects, as did the Pen 2 average (140 mg/kg), and the overall pen average (93 mg/kg). However, no replicates exceeded the threshold with concentrations of dilute-acid-extractable copper (a surrogate for the bio-available fraction: ANZECC 2000). The overall pen average for the dilute-acid-extractable of copper was only 17 mg/kg (i.e. well below the ISQG-Low trigger level).

The concentration of total recoverable zinc in Pen 1 replicates were all below the ISQG-Low trigger level of 200 mg/kg. However, at Pen 2, all replicates exceeded this threshold for both total recoverable, and dilute-acid-extractable zinc. The Pen 2 average and the overall pen average also exceeded this threshold. Given the similarity in concentrations between total recoverable and weak-acid-extractable zinc concentrations, it appears that zinc in the sediments is primarily present in a dilute acid extractable form, and thus is potentially bioavailable. Ecological effects are expected given the high levels of zinc combined with the high potential availability.

Results from 2016 are not directly comparable to those from 2015, due to methodological differences. However, based on historical data (Appendix 4: Figure A4.2) total recoverable zinc and copper are within the range recorded in the past eight years at the site, with no clear trends or changes over time.

Table 5. Copper and zinc concentrations (mg/kg dry weight) in bulk sediment from Ruakaka Bay pen samples, November 2016. Pen and overall averages (±SE) are also shown. Bold values exceed ANZECC (2000) ISQG-Low.

Sample		Total recoverable copper	Dilute-acid-extractable copper	Total recoverable zinc	Dilute-acid-extractable zinc
Pen 1	a	49.0	17.8	97.0	67.0
	b	**69.0**	12.4	128.0	120.0
	c	20.0	7.4	132.0	105.0
Pen 1 average		46 (±14)	13 (±3)	119 (±11)	97 (±16)
Pen 2	a	**180.0**	23.0	**340.0**	**310.0**
	b	**156.0**	20.0	**370.0**	**360.0**
	c	**85.0**	21.0	**300.0**	**300.0**
Pen 2 average		**140 (±29)**	21 (±1)	**337 (±20)**	**323 (±19)**
Overall pen average		93 (±25)	17 (±2)	**228 (±50)**	**210 (±52)**
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

4.2. Water column

A moderate thermocline and pycnocline was evident at a water depth of 14 m at the Pen and 150 m stations (Figure 8). Similar temperature and salinity profiles were observed at both control stations, although at the QC-Ctl-2 station surface waters remained slightly more saline.

At both the Pen and 150 m stations, DO was slightly lower at 13 m depth, just above the thermocline. This may have been due an increase in oxygen demand caused by respiration of the salmon stock. At the Pen station DO levels remained at concentrations of greater than 5.5 mg/L, which equates to a 21% reduction in DO concentration (from approximately 7 mg/L at control sites). The reduction was much less apparent at the 150 m station. Note that dispersion of the lower DO layer may have been reduced by the stratification of the water column. Short term fluctuations in DO concentration can occur, dictated by the feeding regime and related respiratory activity of the salmon. Thus, single point in time measurements may not capture the full extent of periodic DO reduction events.

Chlorophyll-*a* (chl-*a*) concentrations (a proxy for phytoplankton biomass) peaked from 5–10 m depth at both farm stations and at QC-Ctl-3. At these stations, chl-*a* tended to peak (3.5–3.9 µg/L) above the thermocline, and decreased abruptly below. At QC-Ctl-2, chl-*a* concentrations peaked at 2.2 µg/L (just below the thermocline) at 16 m depth. Overall, chl-*a* concentrations indicated productive conditions above the thermocline and less productive conditions below, but not to an extent that would suggest the onset of algal blooms.

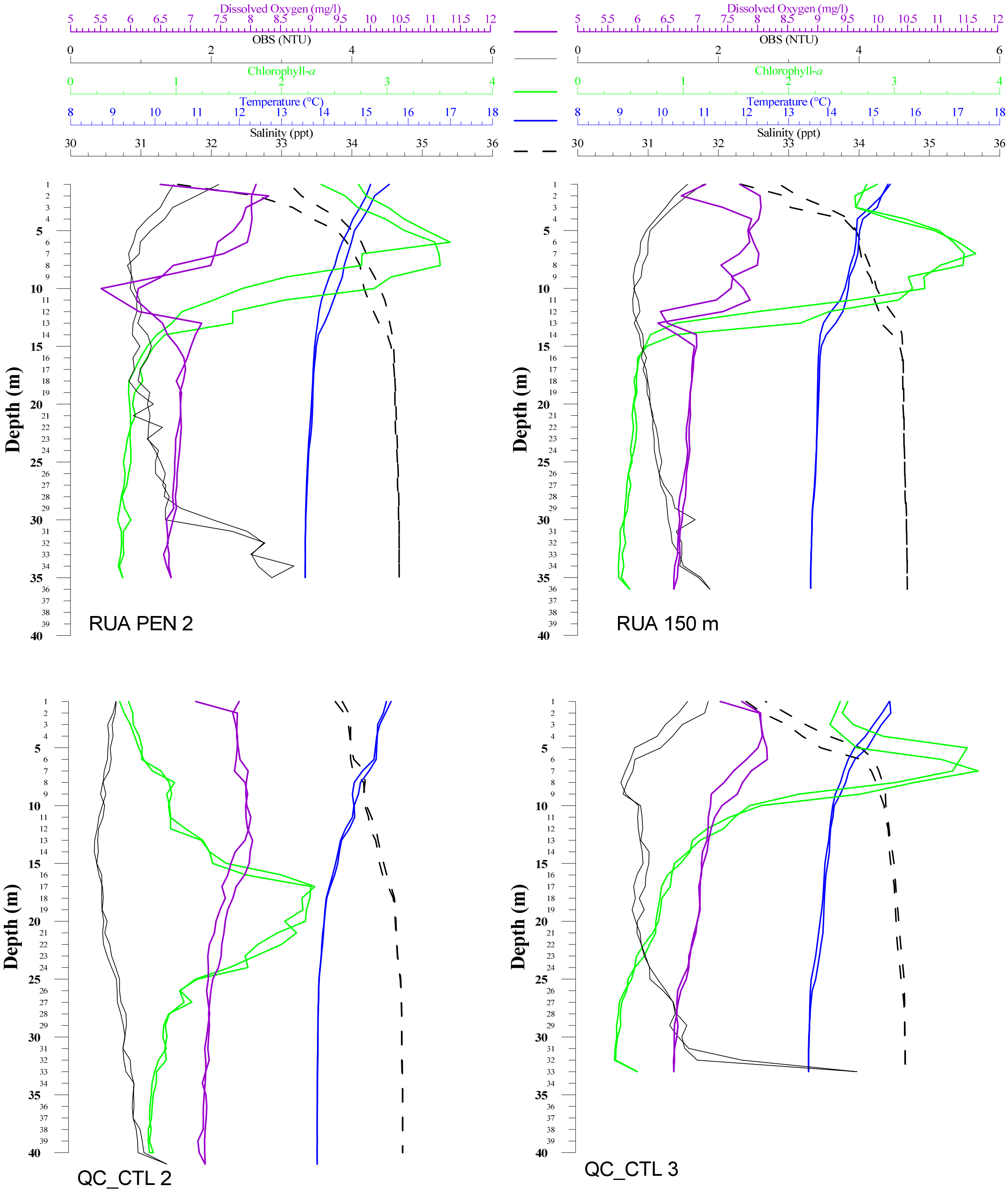


Figure 8. Dissolved oxygen, turbidity (optical back-scatter; OBS), chlorophyll-*a*, temperature, and salinity, as measured by an *in situ* sensor array raised through the water column, November 2016.

4.3. Inshore habitats

Visual assessment of the seabed along Transect 1 began within the shallow subtidal inshore of the farm structures (Figure 4). At this water depth, substrates comprised predominantly boulder habitat with considerable encrusting coralline and brown algae present. Scattered clumps of brown foliose algae were occasionally evident. Sand patches were observed but the substrate was largely rocky until ~15 m water depth, at which point the seabed became flatter with more cobble and coarse sand. Gravel and shell hash also became more common with increasing water depth. Closer to the farm structures a layer of finer sediment covered the coarser substrate and biogenic structures that were present on the seafloor, such as shell debris. Occasional microalgal (diatom) mats were also observed at this depth.

The substrate along Transect 2 was similar to Transect 1, with small clumps of brown foliose algae apparent, but scarce. A layer of sediments was again present in deeper water, nearby to the farm structures.

Both transects had similar epifauna present which was largely confined to inshore sections of both transects (i.e. in shallow water). Observed Invertebrates included kina (*Evechinus chloroticus*), blue or green-lipped mussels, brittle stars, cushion stars (*Patiriella regularis*), sea cucumbers, hydroids, eleven-armed sea stars (*Coscinasterias calamaria*), anemones and colonial ascidians or sponges. Large calcareous tubeworms were abundant on rocks and mussel shell surfaces. In addition, horse mussels (*Atrina zelandica*) were occasionally observed in deeper, sandy habitats along with solitary sea squirts (likely *Cnemidocarpa* sp.). Finger sponges and cockles were also observed in Transect 2 only. Triplefins (probably *Forsterygion lapillum*) and spotted wrasse (*Notolabrus celidotus)* were common along both transects.

5. SUMMARY OF FINDINGS

Overall, the November 2016 results from the Ruakaka Bay annual monitoring are as follows, with key findings italicised:

- *Water column measurements did not indicate impacts of farming activities due to enrichment-related processes (e.g., unusually high chl-a concentrations or significant reduction of near-bottom DO).*

  Minor reductions in DO were evident mid-water that coincided with the position of a weak thermal stratification and often a peak in chl-*a*.

- *Average total recoverable copper concentrations were below the threshold for possible biological effects. Zinc is primarily present in a potentially bioavailable form, in concentrations at which biological effects are expected.*

- *Both boundary stations were within the assumed EQS for their respective zones. The 150 m station was also within the EQS for this zone in the context of the BMP.*

  While both the 50 m and 150 m stations showed reasonably similar overall ES scores compared to 2014, there were subtle deteriorations in sediment chemistry at both stations, as well as impacted macrofauna at the 50 m station.

- *Results from the pen stations were within the assumed EQS for that zone (i.e. ES < 6.0).*

  Macrofaunal conditions at Pen 1 indicated a 'peak of opportunist' level of enrichment. Pen 2 showed comparatively higher levels of deterioration, approaching a state of excessive enrichment, with all indicators suggesting post peak macrofaunal conditions. A slight decrease in overall ES was observed at the Pen 1 station, with a concurrent increase in overall ES at the Pen 2 station compared to 2015.

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.

Elvines D, Taylor D 2016a. Marine environmental monitoring – adaptive management plan 2016-2017 for salmon farms: Clay Point, Ruakaka, Otanerau, Forsyth and Waihinau. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report N. 2863. 16 p. plus appendices.

Elvines D, Taylor D 2016b. Environmental Impacts of the Ruakaka Bay salmon farm: additional monitoring. March 2016. Prepared for The New Zealand King Salmon Co. Ltd. Cawthron Report No. 2786A. 5 p. plus appendices.

MPI 2015. Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Benthic environmental quality standards and monitoring protocol. Prepared by the Benthic Standards Working Group.

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

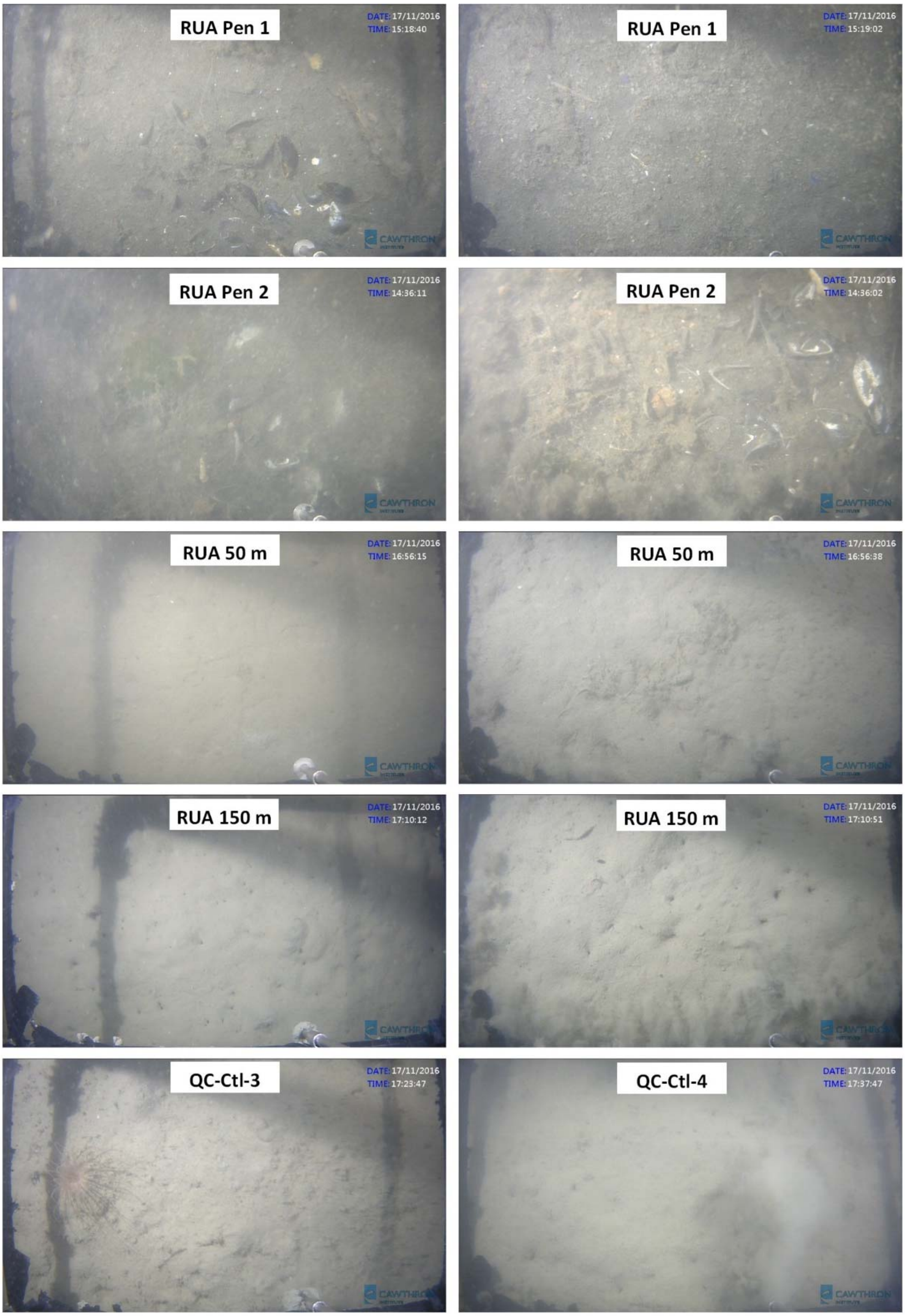
Keeley N, Macleod C, Forrest B 2012. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators (12) 154-166.

7. APPENDICES

Appendix 1. Laboratory analytical methods for sediment samples (November 2015) processed by either Hill Laboratories (a) or Cawthron Institute Analytical Services (b).

Analyte	Method	Default detection limit
Organic matter (as ash-free dry weight) [a]	APHA 2540 G 22nd ed. 2012.	0.04 g/100 g
1M HCl extractable copper & zinc [a]	< 250 µm sieved fraction. 1M HCl extraction, ICP-MS. CSIRO 2005.	1.2 mg/kg (copper) 3 mg/kg (zinc)
Total recoverable copper & zinc [a]	Bulk sediment and/or < 250 µm sieved fraction. Dried sample. Nitric / hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	0.2–2 mg/kg (copper) 0.4–4 mg/kg (zinc)
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 station for the Ruakaka Bay salmon farm, November 2016.



Appendix 3. Average (± SE) sediment physical and chemical properties, macrofauna variables and calculated indices for the Ruakaka Bay salmon farm stations, November 2016.

	Station	Units	Pen 1	Pen 2	50 m	150 m	QC-Ctl-3	QC-Ctl-4
	Depth	m	35	34	36	40	33	35
Sediments	AFDW	%	5.9 (0.9)	11.7 (3)	5 (0.1)	5.1 (0)	5.8 (0)	7.1 (0.1)
	Redox	Eh_{NHE}, mV	-115 (11)	-190 (10)	131 (23)	64 (14)	135 (33)	292 (18)
	Sulphides	µM	1677 (182)	9082 (2370)	730 (202)	159 (44)	113 (42)	2 (1)
	Bacterial mat	-	Patchy/slight	Patchy/slight	No	No	No	No
	Out-gassing	-	No	No	No	No	No	No
	Odour	-	Mild	Moderate	Mild	None	None	None
Macrofauna statistics	Abundance	No./core	5796 (630)	352 (155)	166 (67)	94 (10)	82 (19)	64 (8)
	No. taxa	No./core	6.7 (1.2)	4 (1.2)	23 (6.8)	23.3 (0.9)	25.3 (2.3)	17.7 (1.9)
	Evenness	Stat.	0.1 (0)	0.1 (0.1)	0.7 (0.1)	0.9 (0)	0.9 (0)	0.9 (0)
	Richness	Stat.	0.7 (0.1)	0.6 (0.2)	4.3 (1)	4.9 (0.1)	5.6 (0.3)	4 (0.3)
	SWDI	Index	0.1 (0)	0.2 (0.1)	2.2 (0.5)	2.8 (0)	2.7 (0.1)	2.4 (0.1)
	AMBI	Index	6 (0)	5.9 (0.1)	2.9 (0)	1.9 (0.1)	1.5 (0.1)	1.5 (0.1)
	M-AMBI	Index	0.1 (0)	0.1 (0)	0.6 (0.1)	0.8 (0)	0.8 (0)	0.7 (0)
	BQI	Index	1.5 (0.1)	1.2 (0.2)	5.5 (1.1)	7.5 (0.3)	9.7 (0.3)	8.3 (0.3)

Appendix 4. Detailed Enrichment Stage (ES) calculations for each station at the Ruakaka Bay (RUA) salmon farm, 2016. For details about how these values were calculated, see MPI (2015). Underlined text indicates cases where best professional judgement (BPJ; Keeley et al. 2012) was used.

SITE INFORMATION

Date:	Nov-16
Farm/site:	**Ruakaka Bay**
Flow environment:	**LF**

Variable group weightings: 0.1 (Organic loading), 0.2 (Sediment chemistry), 0.7 (Macro-fauna)

		RAW DATA (to be entered)											ES equivalents													
Station:	**Repl.**	**TOM**	**Redox**	**TFS**	**N**	**S**	**J'**	**d**	**SWDI**	**AMBI**	**M-AMBI**	**BQI**	**TOM**	**Redox**	**TFS**	**N**	**S**	**d**	**SWDI**	**AMBI**	**M-AMBI**	**BQI**	**Organic loading**	**Sediment chemistry**	**Macro-fauna**	**Overall ES**
Pen 1	a	5.2	-111	1494	5759	6	0.1	0.6	0.132	5.96	0.08	1.50	2.54	5.13	4.08	5.79	5	5.73	5.99	5	6.21	5.42	**2.54**	**4.61**	**5.59**	**5.09**
Pen 1	b	4.9	-135	1494	4723	5	0.1	0.5	0.118	5.96	0.07	1.37	2.42	5.34	4.08	5.62	5.5	5.89	6.01	5	6.28	5.55	**2.42**	**4.71**	**5.69**	**5.17**
Pen 1	c	7.6	-98	2041	6906	9	0.1	0.9	0.112	5.97	0.11	1.76	3.42	5.01	4.51	5.95	5	5.27	6.02	5.01	6.04	5.14	**3.42**	**4.76**	**5.49**	**5.14**
Pen 2	a	12	-204	12283	440	6	0.1	0.8	0.231	5.86	0.10	1.49	4.74	5.97	7	5.5	5	5.38	5.82	4.92	6.13	5.43	**4.74**	**6.49**	**5.45**	**5.59**
Pen 2	b	16.8	-172	4454	51	4	0.3	0.8	0.414	5.82	0.10	1.22	5.75	5.68	5.7	6	5.5	5.46	5.5	4.9	6.14	5.72	**5.75**	**5.69**	**5.6**	**5.63**
Pen 2	c	6.4	-195	10509	566	2	0	0.2	0.013	5.99	0.02	0.83	2.99	5.88	7	5.5	6	6.37	6.19	5.03	6.53	6.16	**2.99**	**6.44**	**5.97**	**5.77**
50m	a	4.9	88	569	285	33	0.7	5.7	2.603	2.80	0.80	6.16	2.42	3.34	2.92	3.23	2.04	1.52	1.74	2.64	2.33	2	**2.42**	**3.13**	**2.21**	**2.42**
50m	b	4.9	139	1132	53	10	0.5	2.3	1.186	2.97	0.39	3.28	2.42	2.88	3.72	1.79	4	3.61	4.18	2.77	4.54	3.75	**2.42**	**3.3**	**3.52**	**3.37**
50m	c	5.2	167	488	160	26	0.8	4.9	2.749	2.88	0.73	6.96	2.54	2.63	2.76	2.74	1.89	1.73	1.49	2.7	2.7	1.72	**2.54**	**2.7**	**2.14**	**2.29**
150m	a	5	64	98	84	22	0.9	4.7	2.733	1.76	0.75	6.95	2.46	3.55	1.45	2.19	2.09	1.8	1.52	1.86	2.63	1.72	**2.46**	**2.5**	**1.97**	**2.13**
150m	b	5.1	39	245	83	23	0.9	5	2.891	1.89	0.77	7.46	2.5	3.78	2.12	2.18	2.02	1.71	1.25	1.96	2.53	1.59	**2.5**	**2.95**	**1.89**	**2.16**
150m	c	5.1	88	133	114	25	0.9	5.1	2.837	2.12	0.77	8.13	2.5	3.34	1.65	2.45	1.92	1.68	1.34	2.14	2.5	1.48	**2.5**	**2.5**	**1.93**	**2.1**
QC-Ctl-3	a	5.7	102	155	114	30	0.8	6.1	2.791	1.31	0.87	10.37	2.73	3.21	1.75	2.45	1.9	1.46	1.42	1.53	1.98	1.56	**2.73**	**2.48**	**1.76**	**2**
QC-Ctl-3	b	5.8	200	29	49	23	0.9	5.7	2.83	1.66	0.77	9.33	2.77	2.33	0.91	1.73	2.02	1.52	1.35	1.79	2.49	1.43	**2.77**	**1.62**	**1.76**	**1.83**
QC-Ctl-3	c	5.8	102	155	84	23	0.8	5	2.621	1.59	0.76	9.55	2.77	3.21	1.75	2.19	2.02	1.71	1.71	1.74	2.58	1.45	**2.77**	**2.48**	**1.91**	**2.11**
QC-Ctl-4	a	7	261	1	78	20	0.8	4.4	2.455	1.36	0.72	8.92	3.21	1.78	1.55	2.12	2.28	1.98	2	1.57	2.79	1.43	**3.21**	**1.67**	**2.02**	**2.07**
QC-Ctl-4	b	7.1	325	1	49	14	0.9	3.3	2.297	1.41	0.63	7.83	3.25	1.2	1.29	1.73	3.15	2.64	2.27	1.6	3.26	1.52	**3.25**	**1.25**	**2.31**	**2.19**
QC-Ctl-4	c	7.2	291	5	65	19	0.9	4.3	2.589	1.73	0.70	8.05	3.28	1.51	0.86	1.97	2.39	2.01	1.77	1.85	2.89	1.49	**3.28**	**1.19**	**2.05**	**2**

Appendix 5. Historical comparisons.

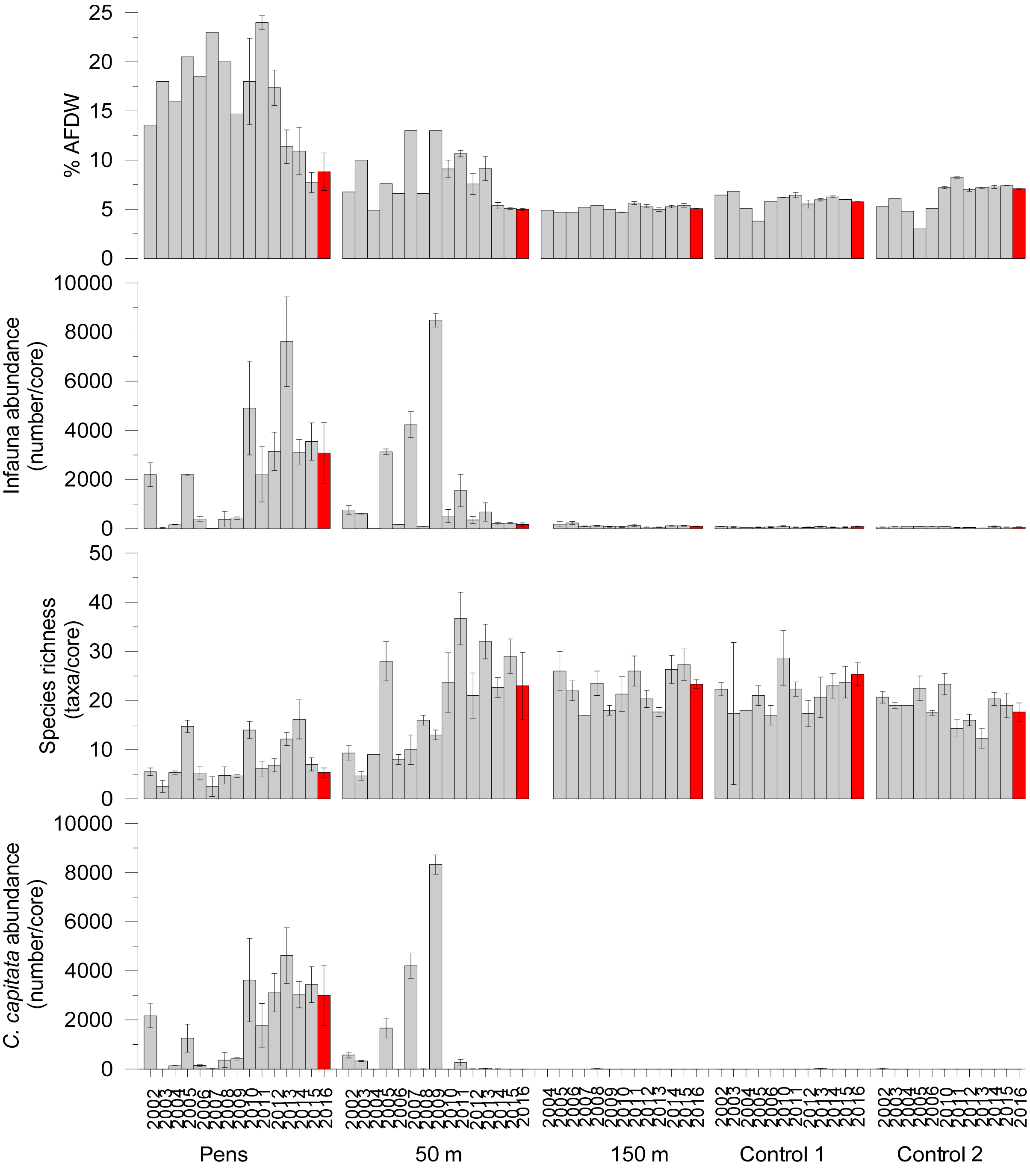


Figure A5.1. Mean (± SE) ash-free dry weight (AFDW), macrofauna abundance, richness (no. taxa), and *Capitella capitata* densities recorded for Ruakaka Bay (RUA) salmon farm annual monitoring since 2001. Densities of capitellid polychaetes of 1,000 individuals per m² (i.e. 13 per 0.013 m² core) are typically considered high (ANZECC 2000 guidelines). The 2016 results are shown in red.

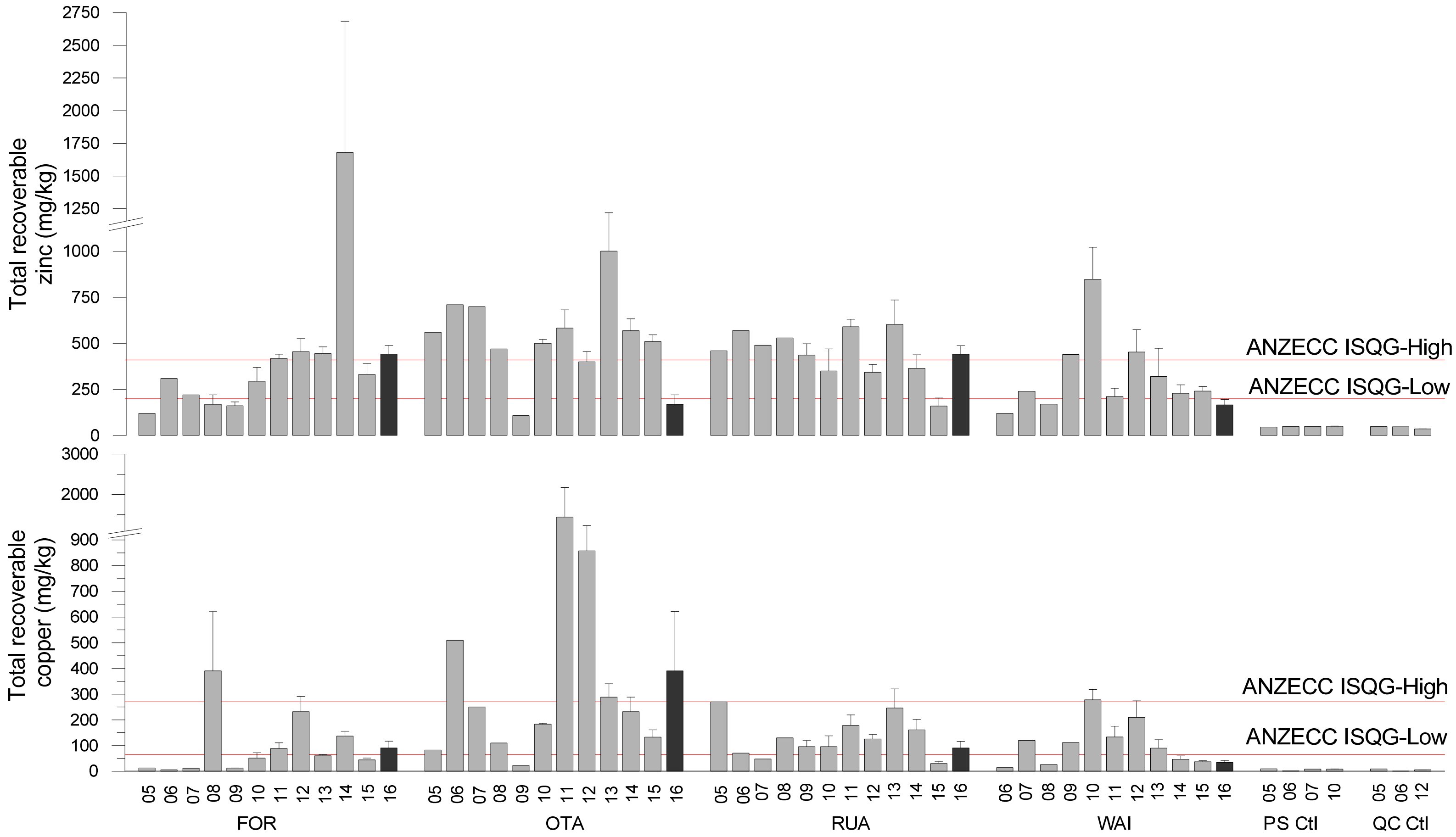


Figure A5.2. Comparison of the last 12 years of annual monitoring of sediment total recoverable copper and zinc concentrations beneath the four low-flow NZ King Salmon farms and two control stations (FOR = Forsyth Bay, OTA = Otanerau Bay, RUA = Ruakaka Bay, WAI = Waihinau Bay, PS = Pelorus Sound, QC = Queen Charlotte, Ctl = control). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low trigger levels. Note; the 2015 metals results are not directly comparable to other years due to the methodological differences (only < 250 µm grain size fraction analysed in 2015).