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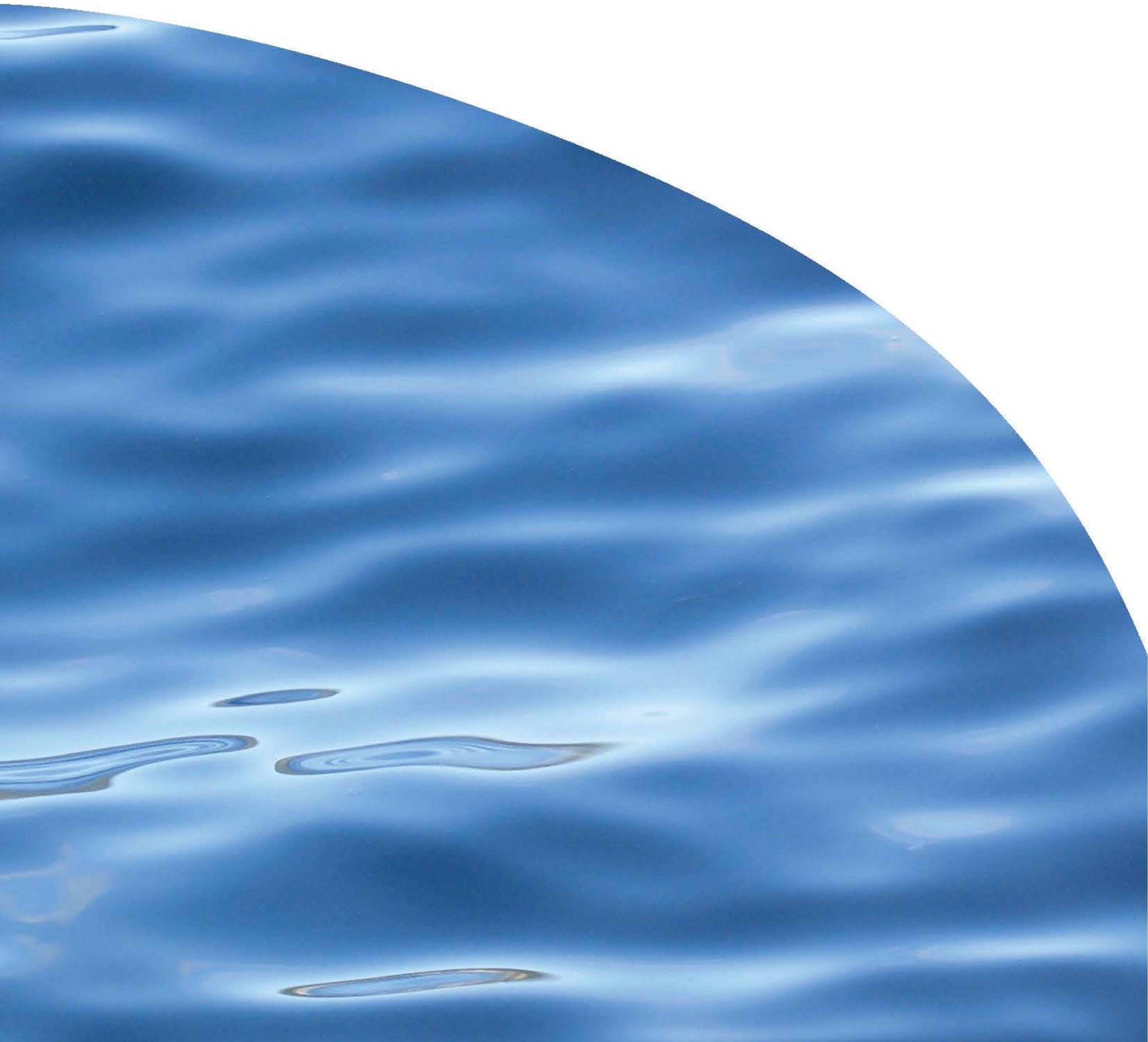
ENVIRONMENTAL IMPACTS OF THE OTANERAU BAY SALMON FARM: ANNUAL MONITORING 2015



ENVIRONMENTAL IMPACTS OF THE OTANERAU BAY SALMON FARM: ANNUAL MONITORING 2015

DEANNA ELVINES, DAVID TAYLOR, EMMA NEWCOMBE, ANNA BERTHELSEN

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:
Nigel Keeley

APPROVED FOR RELEASE BY:
Natasha Berkett

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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, Ngamahau Bay and Richmond Bay (RIC).

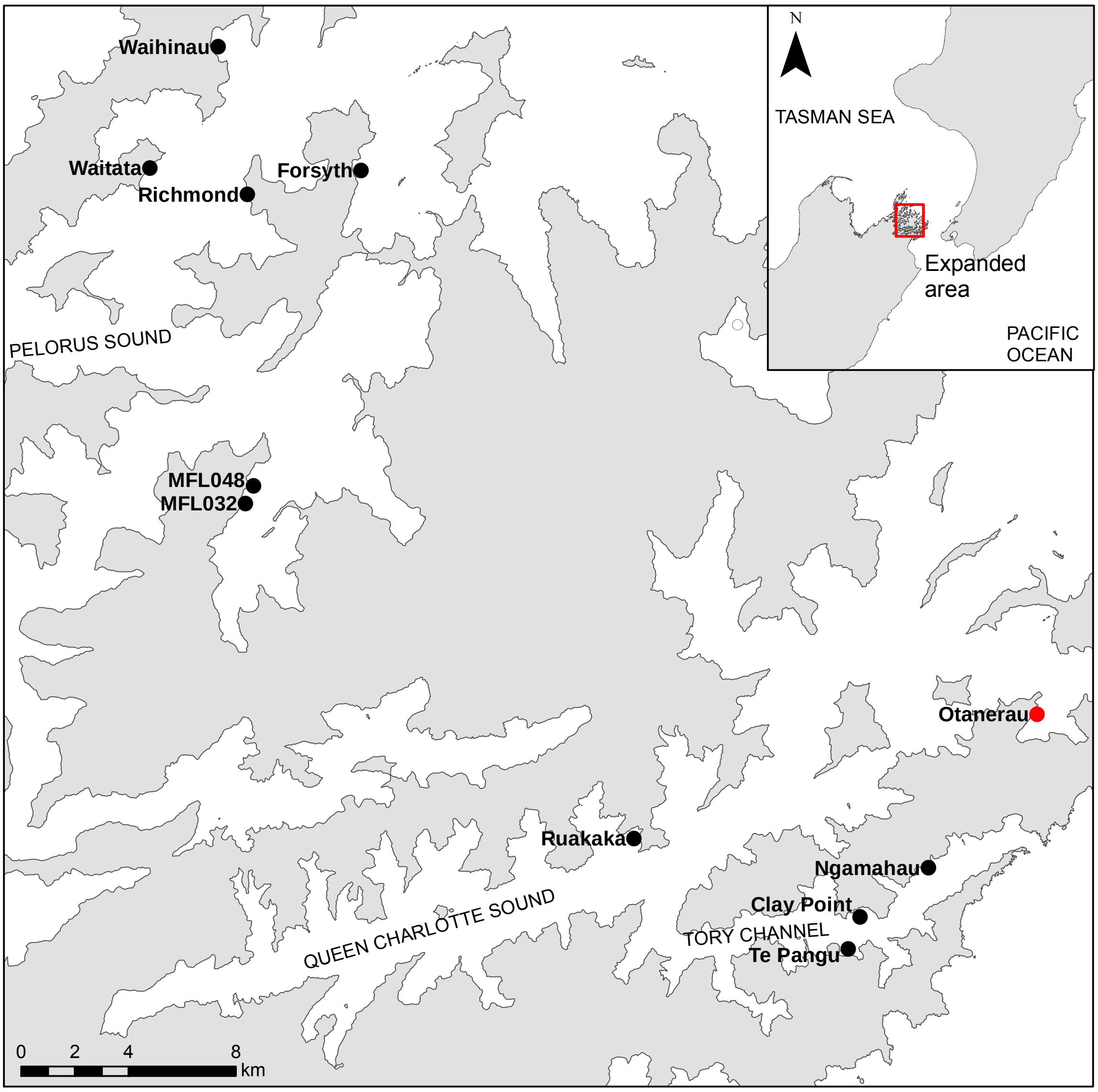

Figure 1. Map of the Marlborough Sounds area showing the location of the Otanerau Bay (OTA) salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

NZ King Salmon is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The monitoring programme is conducted under a marine environmental monitoring adaptive management plan (MEMAMP) (Elvines & Taylor 2015) that was prepared by Cawthron Institute (Cawthron) on behalf of NZ King Salmon, and approved by Marlborough District Council (MDC) prior to implementation.

Consent conditions for all of the farms (with the exception of Waihinau) broadly require monitoring of the effects of deposition on the seabed, with particular regard to the seabed community composition and abundance, dissolved oxygen (DO) levels and water quality. The environmental monitoring results are used to determine whether the farms are compliant with the environmental quality standards (EQS) specified in the consent conditions for each farm. These 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).

In addition, water column monitoring (measuring nutrients and chlorophyll-*a*) has historically been undertaken each year at one low-flow and one high-flow farm. In 2014 and 2015, water column monitoring was undertaken at all NZ King Salmon farm sites, using *in situ* water column profiling at pen edge and down-current stations generally. The TEP, CLA, NGA, WTA and RIC farms also have monitoring requirements for adjacent rocky reef and/or other notable habitat types.

This report presents the 2015 annual monitoring results for the Otanerau Bay (OTA) salmon farm.

1.1. Site details and history of feed usage

The Otanerau Bay farm site was established in 1990. Water depth at the farm site is ~36 m, and the net pens extend from the surface to a depth of ~20 m. It has an average water current speed of ~6 cm/s, so is considered a low- to moderate-flow site.

In the past decade, feed inputs at this farm have ranged from 1,000[1] to 2,289 tonnes per annum (Figure 2). There has been a general reduction in feed use since 2008, however the 2015 feed levels are slightly higher (63 tonnes) than in the previous 12 month period. Over the 12 month period prior to monitoring (November 2014 to October 2015), a total of 1,011 tonnes of feed was used (Figure 3). The majority was fed out from May to October 2015, with October having the highest monthly input. The site had zero feed input for the months of January, February and March 2015.

[1] Feed input data provided by NZ King Salmon. Note that previous amounts reported in the text of the 2014 annual monitoring report, differ to that reported here, due to typographical error.

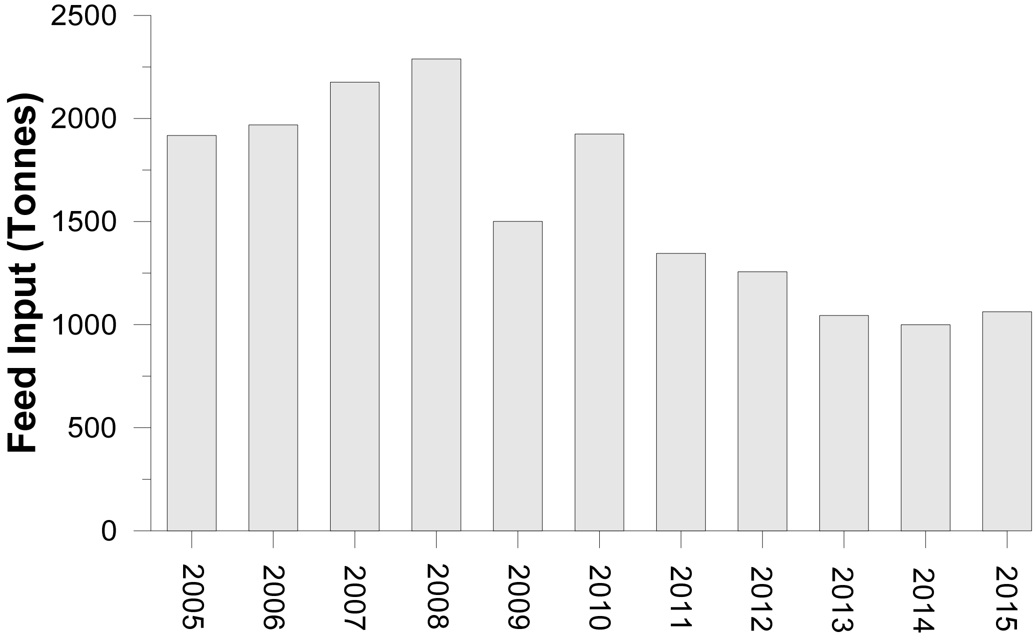

Figure 2. Annual feed inputs (December through November) at the Otanerau Bay (OTA) salmon farm, 2005–2015.

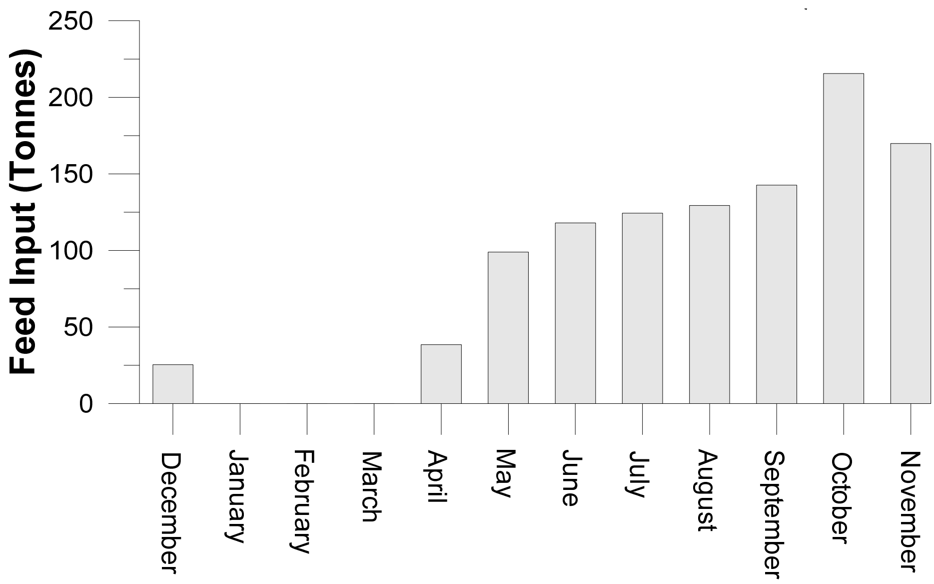

Figure 3. Monthly feed inputs at the Otanerau Bay (OTA) salmon farm from December 2014 to November 2015.

2. METHODS

Sampling for the OTA annual monitoring was undertaken on 11 and 17 November 2015. A condensed summary of the techniques that were used in the present survey is provided below. Detailed methods and rationale describing the sampling protocol for all of NZ King Salmon's farms can be found in the most recent MEMAMP (Elvines & Taylor 2015). Copies are held by MDC and NZ King Salmon. This plan 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 BMP document (MPI 2015).

2.1. Soft-sediment habitats

2.1.1. Sampling locations

Sampling stations at the OTA farm are described as follows (also see Figure 4):

- Three net pen stations at the edge of the net pens: Pen 1, Pen 2 and Pen 3.

  Note, Pen 2 and Pen 3 locations differ from those sampled in 2014, due to pen movement (Figure 4). As such, it is not possible to make direct comparisons between the 2014 and 2015 results at these stations.
- Two stations along a transect extending east from the pens: at 50 m (Zone 1–2 boundary) and 150 m (Zone 2–3 boundary).
- Two reference or 'control' stations; QC Ctl-1-new and QC Ctl-2. *Note, the QC-Ctl-1-new site was also used in the 2014 survey due to the original location being inaccessible.*

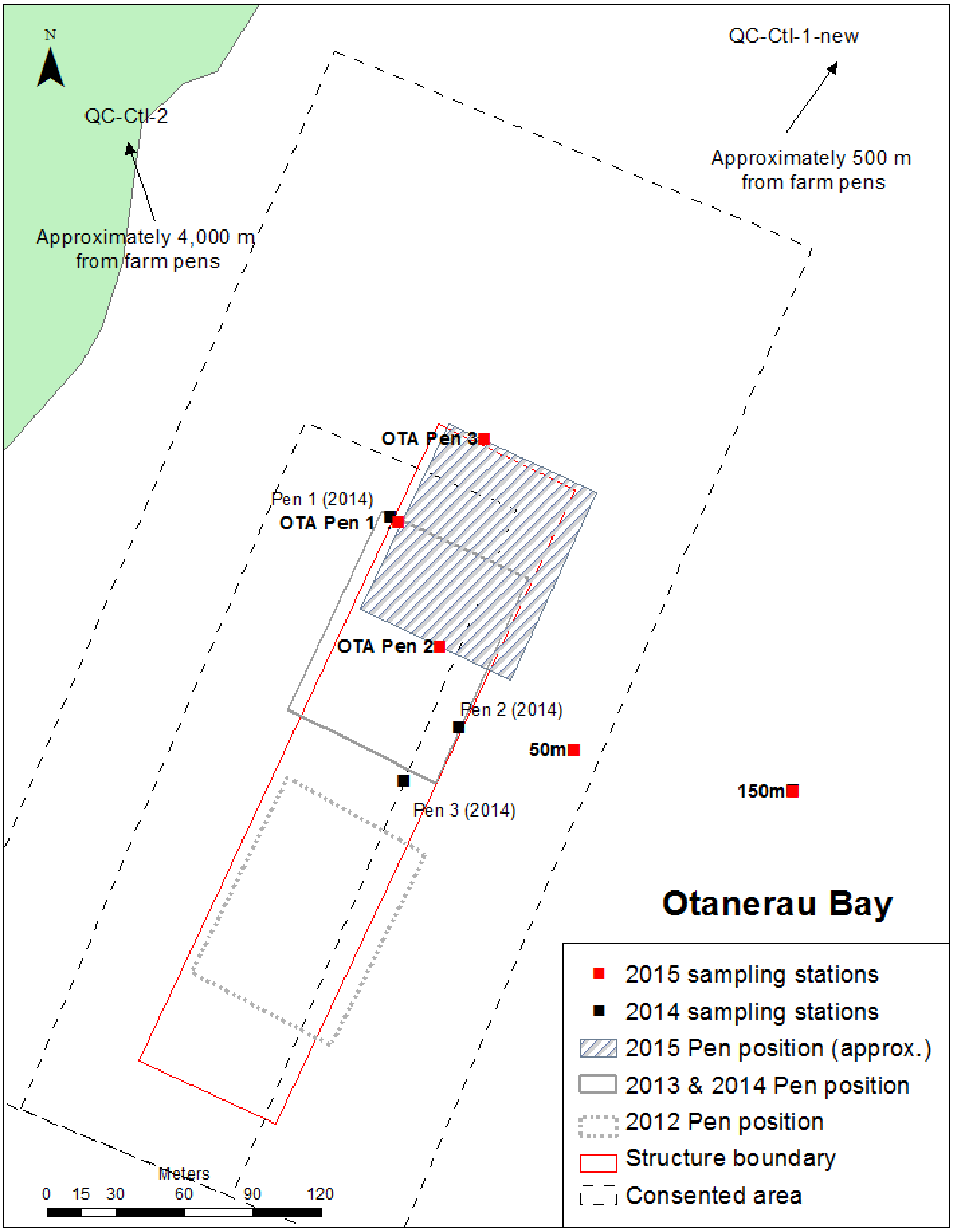

Figure 4. Soft-sediment sampling locations for the 2015 monitoring of the Otanerau Bay (OTA) salmon farm site. 'QC Ctl' = Queen Charlotte Control. Position accuracy is ± 5 m.

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 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 three pen stations were analysed for copper and zinc concentrations (total recoverable and dilute-acid-extractable[2] in the < 250 µm grain size fraction[3]). In addition, a composited triplicate sample from the 50 m station was analysed for total recoverable copper and zinc concentrations. Laboratory analytical methods for sediment samples can be found in Appendix 2.

A separate core (130 mm diameter, about 100 mm deep) was collected from each grab for infauna identification and enumeration. The term 'infauna' describes the animals buried in the sediment. However, these samples do not reliably measure the larger animals living on the sediment surface (epifauna). Raw infauna 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.

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

2.1.3. Assessment of enrichment stage

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to enrichment stage (ES). 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 infauna composition variables (abundance, richness, evenness, diversity and biotic indices) and organic content (as % 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

[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] Because of historical exceedance of ISQG-High for zinc, the total recoverable and dilute acid extractable concentrations were analysed on the fine grain size fraction (<250µm) in the first instance to avoid chance inclusion of paint flakes that are often a cause for high concentrations at contaminated sites.

[4] Weighting used in 2015 was the same as that used in 2014: organic loading = 0.1, sediment chemistry = 0.2, infauna composition = 0.7)

the sampling station was calculated from the average of the replicate samples with the degree of certainty reflected in the associated 95% confidence interval.

2.2. Water column

In-situ water column profiles of dissolved oxygen, turbidity, temperature, salinity, and chlorophyll-*a* were recorded at the net pen, and at the 50 m and 150 m sampling stations, as well as a control site (QC-CTL-2) for comparison. The information was collected by slowly raising a data-logging sensor array from the seabed to the surface.

2.3. Inshore habitats

The Otanerau Bay salmon farm is a low to moderate-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. The last visual assessment was undertaken in 2014 and the site is not due for this type of sampling again until the 2016 annual monitoring survey.

3. COMPLIANCE FRAMEWORK

The environmental quality standards (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 not possible to report definitively on compliance with any particular consent condition. We should note that a targeted working group has developed best management practice guidelines (MPI 2015) to address this issue.

Cawthron has endeavoured to interpret the existing conditions in a quantitative manner in previous reporting and has proposed some 'allowable' equivalent enrichment stages (ES; refer Section 2.1.3) for each of the zones prescribed by the consents. Although somewhat subjective, this approach was guided by the language and the intent of the consent conditions as much as practicable.

Table 1. Environmental quality standards (EQS) for Otanerau Bay (OTA) salmon farm described for each zone (taken from consent U040217) and the proposed equivalent enrichment stage (ES).

Spatial zone	Spatial extent	Description and bottom line	Equivalent 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.

4. RESULTS

4.1. Soft-sediment habitats

4.1.1. Habitat descriptions

Drop-camera images and video footage of the seabed (Appendix 3) from the pen stations revealed soft easily disturbed, dark muddy sediments with mussel shell and other shell debris covering the seafloor. There was obvious evidence of *Beggiatoa*-like bacteria on the shells. Pen 2 had a greater coverage of shell debris and bacterial growth was also more evident.

Poor water clarity at the 50 m and 150 m stations prevented good imaging of the seafloor at these sites. However, from the limited observations, the substrate appeared to be a lighter brown to grey colour compared to the pen stations. Bioturbation was evident in the form of burrow-holes but there were few other notable features at these stations. The QC-CTL-1 substrate was muddy and appeared similar to the 50 m and 150 m stations, but again seabed observations were limited by water clarity. The QC-CTL-2 control site had light grey muddy substrate and also comprised shell hash and larger shell debris.

4.1.2. Physico-chemical characteristics

Average sediment organic matter concentrations (measured as % AFDW) were elevated beneath the pens (7.8–17.2%), in comparison to controls (4.9–7.5%; Figure 5). Pen 2 had the highest average organic matter. The results for the Zone 1–2 (50 m) and Zone 2–3 (150 m) boundary stations were similar to those from the control sites.

Average redox potentials in all pen stations were negative (- 192 to -124 Eh_{NHE}, mV) and lower than all other stations. The average redox potential at the Zone 1–2 boundary (94 to 131 Eh_{NHE}, mV at 50 m), and the Zone 2–3 boundary (82 to 192 Eh_{NHE}, mV at 150 m) appeared to be slightly lower than the controls (98 to 295 and 200 to 379 at QC-CTL-1 and QC-CTL-2 respectively).

Sulphide levels were extremely elevated at all three pen stations, and are the highest ever observed at all NZ King Salmon farm sites. At Pen 2 and Pen 3, average sulphide levels were 12,862 ±3,535 µM and 15,429 ±1,726 µM, respectively. Average sulphide levels at Pen 1 were even higher than the other pen stations at 19,978 ±747 µM. In comparison, average sulphide levels at the controls were 18 ±6 and 143 ±91 for QC-CTL-1 and QC-CTL-2 respectively. Average sulphide levels at the Zone 1–2 boundary (50 m) (658 ±35 µM) and the Zone 2–3 boundary (150 m) (568 ±85 µM) were also elevated.

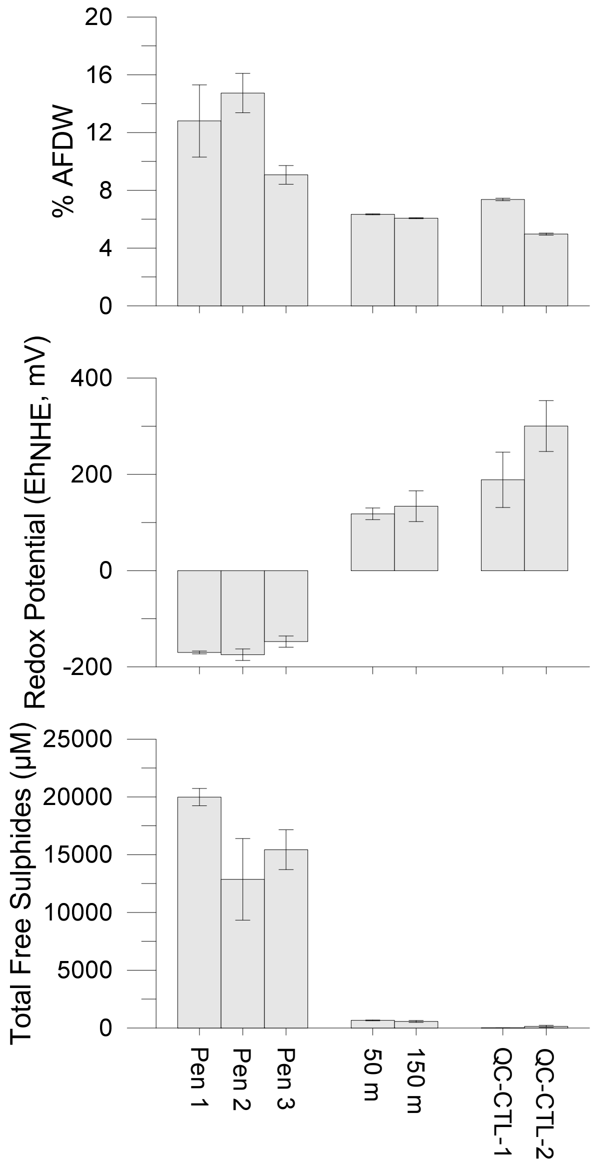

Figure 5. Sediment organic matter (% AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) at Otanerau Bay (OTA) monitoring stations, 2015. Error bars = ± 1 SE, n = 3.

4.1.3. Biological communities

All three pen stations had very low taxa richness (Figure 6), with at least one replicate from each station having ≤ 5 taxa per core. Average richness values at Pen 1, 2 and 3 were 6 ±3, 6 ±1 and 8 ±2, respectively. Average richness values at the control sites were 20 ±1 and 36 ±3 for QC-CTL 1 and QC-CTL-2 respectively. Diversity, Margalef richness and EQR scores were also lower at all pen stations compared to the controls.

Total abundances at Pen 2 were generally high compared to control site abundances, but were also variable (309–2,135 individuals per core). Pen 1 abundances were also variable (3–197 individuals per core), with two replicates having < 10 individuals per core. Pen 3 total abundances showed less variability (24–79 individuals per core) but were lower than at controls. All pen communities showed dominance of enrichment-tolerant, opportunistic taxa including *Capitella capitata* (Appendix 4; Figure A4.1), nematodes and dorveillid polychaetes, which was reflected in high AMBI scores (3.5–5.9).

The Zone 1–2 boundary (50 m) also showed lower species richness (8–13 taxa per core), diversity, Margalef's richness and EQR scores compared to the controls. However, the total abundances at this zone boundary were comparable to controls. Although communities here were not dominated by *C. capitata* or nematodes, they did have higher abundances of *Prionospio* polychaetes and phoxocephalid amphipods. The Zone 2–3 boundary (150 m) showed conditions comparable with one or both controls for all community measures. Average abundances at the control sites was 91 ±17 and 137 ±26 for QC-CTL-1 and QC-CTL-2 respectively.

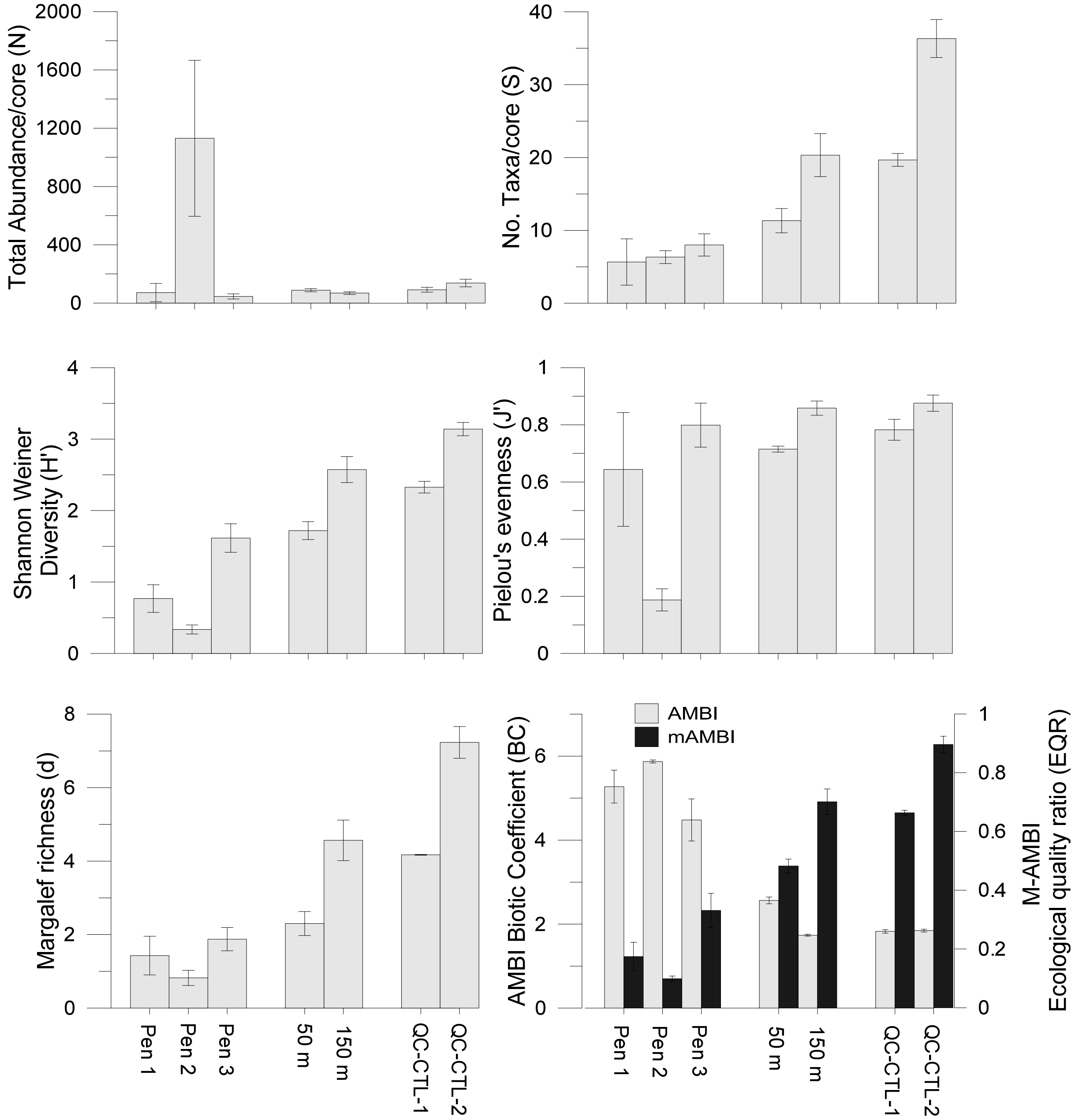

Figure 6. Infauna statistics for Otanerau Bay (OTA) monitoring stations, 2015. Error bars = ± 1 SE, n = 3.

4.1.4. Copper and zinc concentrations

The combined average total recoverable copper concentration across Pen 1 and Pen 2 was 79 mg/kg (SE 3, n=6), whereas the Pen 3 average was much higher (241 mg/kg; SE 25, n=3) (Table 2). Pen 3 also had higher concentrations of copper (84 mg/kg; SE 16, n=3) in the dilute-acid-extractable (DAE) fraction (a surrogate for the bio-available fraction: ANZECC 2000), and was above ISQG-Low. At the other pen stations DAE copper concentrations were below the ISQG-low guideline level (30 mg/kg; SE 2, n=6). The average DAE concentrations across all pen stations (43 mg/kg, SE 28, n=9) was also below the ISQG-Low guideline. The variability in copper concentrations across the three pen stations indicates an element of patchiness within the wider (historically) farmed area. At the 50m station, total recoverable copper concentration was well below ISQG-Low.

The combined average total recoverable zinc concentration across the three pen stations (510 mg/kg; SE 36; n= 9) exceeded the ISQG-High trigger level (410 mg/kg) for probable biological effects. The concentration of the DAE fraction was 401 mg/kg (SE 23 mg/kg). This was just below the ANZECC ISQG-High level for probable biological effects. No single sample had DAE zinc concentrations below ISQG-Low levels, and four exceeded the ISQG-High levels. Total recoverable zinc at the 50 m station was 130 mg/kg, below the ISQG-Low trigger level of 200 mg/kg (Table 2).

Historical comparisons[5] (Appendix 4; Figure A4.2) showed the average total recoverable zinc concentration beneath the pens in the < 250µm size fraction, was similar to that recorded in the previous year for the bulk sediment fraction. Average total recoverable copper concentrations in the < 250µm size fraction at the pen stations were lower compared to 2014, which may suggest either presence of some larger copper-rich particulate material, or a continued decrease from a high in 2011. Sediment copper and zinc concentrations were not measured at the control stations in 2015, but average concentrations have historically been less than 10 mg/kg and 50 mg/kg respectively.

[5] Direct comparisons cannot be made between 2014 and 2015 due to methodological differences (bulk sediment analysed in 2014 vs. < 250µm fraction analysed in 2015), and due to relocation of pen stations as a result of the new pen position.

Table 2. Copper and zinc concentrations (mg/kg dry weight) in sediment size fraction <250µm (or bulk sediment for the 50 m sample), November 2015. Bold values exceed ANZECC (2000) ISQG-Low, and underlined values exceed ISQG-High.

Sample		Total recoverable copper	Dilute-acid-extractable copper	Total recoverable zinc	Dilute-acid-extractable zinc
Pen 1	a	**72**	27	**380**	**320**
	b	**81**	23	**350**	**290**
	c	**74**	28	**<u>410</u>**	**350**
Pen 2	a	**89**	30	**<u>590</u>**	**<u>470</u>**
	b	**69**	31	**<u>520</u>**	**<u>410</u>**
	c	**88**	38	**<u>580</u>**	**<u>470</u>**
Pen 3	a	**250**	**104**	**<u>550</u>**	**410**
	b	**195**	64	**<u>530</u>**	**400**
	c	**<u>280</u>**	**96**	**<u>680</u>**	**<u>490</u>**
50 m		29		130	
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

4.2. Water column

In water column profiling casts at the Otanerau Bay farm site (Figure 7), temperature showed some evidence of stratification (at all sites except the control) as temperature increased gradually above 15 m. Salinity was constant throughout the water column at all sites.

Mid-water reductions in dissolved oxygen were apparent at the pen station and 50 m, and to a lesser extent at 150 m from the pen. This indicated an increase in oxygen demand, likely due to respiration by the salmon stock. DO levels remained at concentrations of greater than 6.7 mg/L, which constitutes a less than 20% reduction in DO concentration. Short-term fluctuations in DO concentration can be 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. Aside from the mid-water reductions in DO, a general trend of decreasing DO with depth was apparent. This was least apparent at the pen station, and no notable reduction was observed associated with the seabed.

A substantial increase in turbidity was apparent near the seabed under the pens, this was also detected at 50 m and 150 m from the pens (the latter more strongly than the former). A lesser increase in turbidity near the seabed was apparent at the control station.

Chlorophyll-*a* concentrations (a proxy for phytoplankton biomass) peaked between depths of ~10 and ~25 m across all sites. At 25–30 m in depth chlorophyll-*a* concentrations were particularly high at 150 m from the pens (> 7 µg/L). However a similar peak occurred at the control site (~5 µg/L), indicating that this is not farm-related. Chlorophyll-*a* peaks such as these are not unusual in the Marlborough Sounds generally (L. Mackenzie, Cawthron Institute, pers. comm.), and have a range of causes, including a diatom bloom sinking, or flagellates forming density layers in the water column. A more intensive water column survey would be required to assess the cause and extent of this observation.

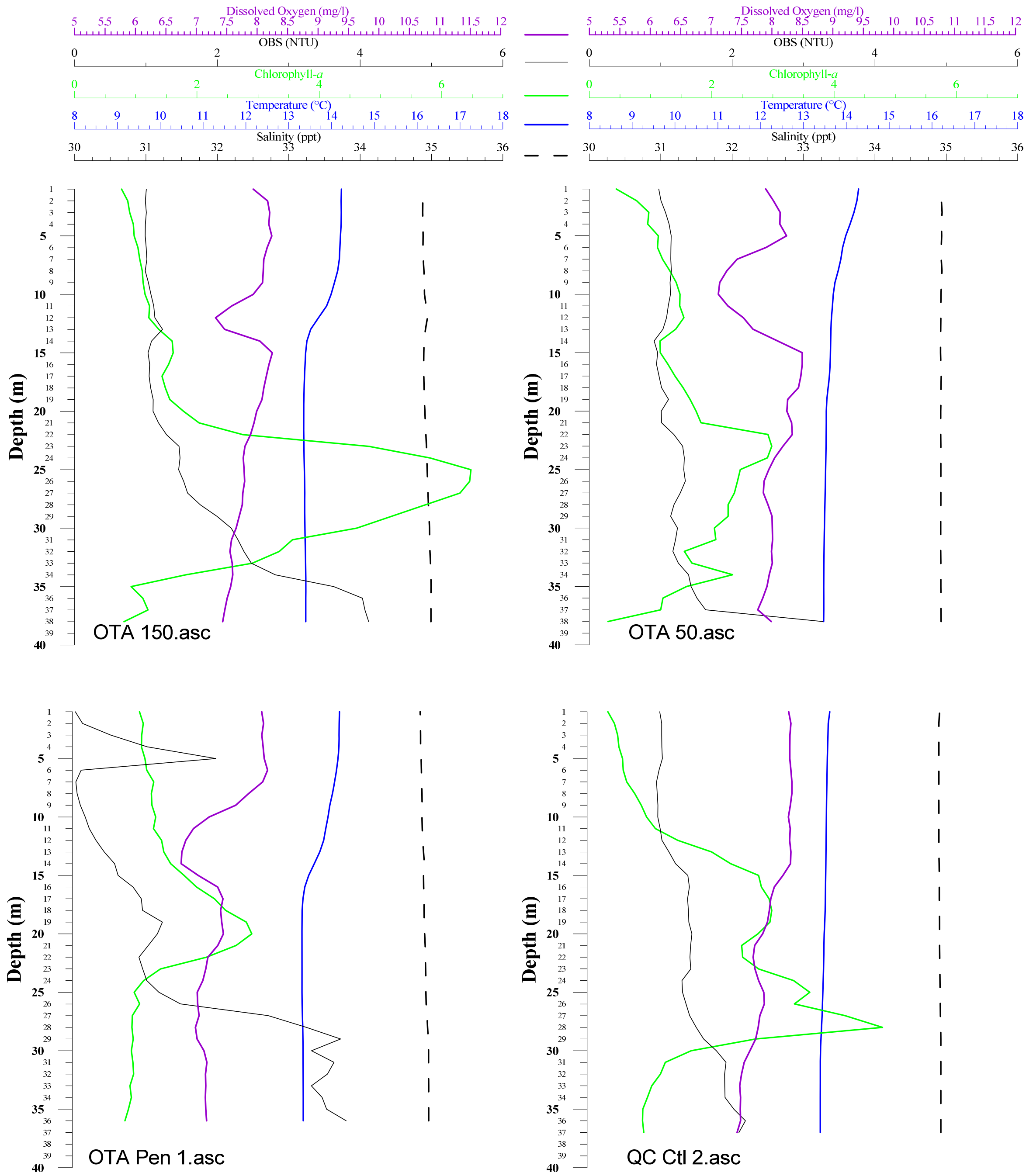

Figure 7. Dissolved oxygen, turbidity (optical back-scatter; OBS), chlorophyll-a, temperature, and salinity, as measured by an *in situ* sensor array raised through the water column (2015).

4.3. Results summary

Overall, sediment organic content, redox potential and sulphide levels indicated strongly reduced (hypoxic) conditions in the sediments at the pen stations. The Zone 1–2 boundary showed signs of moderate enrichment with lower redox and higher sulphide results compared to controls.

Biological communities at the pen stations, particularly Pen 2, were indicative of highly enriched conditions, with low species richness, diversity scores and biotic indices indicating low ecological quality status. Pen 2 also had high abundances of opportunistic taxa and low evenness. Community measures at the outer zone boundary stations (150 m) were similar to control stations.

Although recoverable copper concentrations beneath the net pens were still above ISQG-Low, the DAE fraction showed that levels of bio-available copper are likely to be below this threshold. Total recoverable zinc concentrations were above ISQG-High. The DAE fraction was just below this threshold, therefore still well above the threshold for possible biological effects.

Water column measurements did not indicate impacts of farming activities due to benthic enrichment-related processes (*e.g.*, unusually high chl-*a* concentrations associated with farm sites, or significant reduction of near-bottom DO). Mid-water reductions in DO were evident near to the net pens and up to 150 m away, which could be related fish respiration.

5. ASSESSMENT OF SEABED ENRICHMENT

5.1. Enrichment stage assessments for 2015

The 2015 assessment of soft-sediment conditions references a selection of informative chemical and biological indicator variables[6]. For each indicator variable an equivalent ES score is calculated, and these scores are then incorporated into the overall ES (Table 3) for the station.

Strongly hypoxic conditions at the pen stations produced a sediment chemistry ES equivalent of 6.2–6.3. Biological indicators generally suggested post-peak abundance conditions at Pen 1 and Pen 2, leading to an overall ES of 5.9 and 5.6, respectively. However, several higher richness values (*e.g.* 8–12 taxa per core) were inconsistent with some of the other indicators and with typical post-peak conditions. The recent shifting of this farm and the seasonally variable feed inputs (*i.e*. short fallowing follower by rapid increase of inputs) means that conditions within the seabed are unlikely to be stable; rather, highly temporally dynamic.

The Pen 3 station was situated in an area of seabed that had only recently been exposed to 'beneath pen' conditions (Figure 1), and results indicated slightly less enriched conditions, with an overall ES of 4.8. Despite only having moderate levels of organic matter (equivalent ES 3.9), sediment chemistry at Pen 3 was extremely poor, comparable to that at Pen 1 and Pen 2 (equivalent ES 6.2 for sediment chemistry). The equivalent ES for macrofauna (4.5) indicated pre-peak communities, although some individual community measures (S, N) were not consistent with a pre-peak state. Reduced abundances in most samples, coupled with moderate to low taxa richness probably reflects recently initiated transition toward peak-of-opportunists by a gradual disappearance of taxa sensitive to enrichment. Interestingly, abundances of opportunistic taxa have not undergone the concurrent increase that normally occurs with increasing enrichment. This could be related to a rapid deterioration in sediment oxic status temporarily suppressing their response (*e.g*. Keeley *et al*. 2015), or similarly, suppression due to the potentially toxic concentrations of copper or zinc. Nonetheless, conditions at all pen stations are consistent with the assumed EQS (*i.e.* ES < 6.0) for Zone 1.

Overall ES at the Zone 2–3 boundary (50 m) was 3.2, resulting from elevated sulphides, lower taxa richness and slightly altered community structure compared to natural conditions. The Zone 2–3 boundary (150 m) was comparable to reference conditions, with overall ES scores of 2.3, 2.2 and 1.8 for the sites respectively. Both the 50 m and 150 m boundaries are consistent with the assumed EQS for their respective zones (Section 3).

[6] 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.

Table 3. Average enrichment stage (ES) values (95%CI) calculated for indicator variables, and overall, for each Otanerau Bay (OTA) farm sampling station; 2015. For full breakdown of indicator variable contributions see Appendix 1.

	Summary of indicator variables		ES (95%CI)
Pen 1	%OM elevated but variable among samples (0 to 2.5× controls) redox strongly negative, sulphides very extremely elevated. Total abundance very low but variable (3-197 per core; post-peak). Taxa richness very low to normal (3–12 per core), and dominance by opportunistic species.	Organic loading:	4.8 (0.7)
		Sediment chemistry:	6.3 (0)
		Infauna composition:	5.9 (0.6)
		Overall:	**5.9 (0.4)**
Pen 2	%OM highly elevated (~2.5× controls), redox strongly negative, sulphides extremely elevated (160× controls). Total abundances variable (but post-peak). Dominance by opportunistic taxa. Taxa richness low (5-8 per core).	Organic loading:	5.3 (0.3)
		Sediment chemistry:	6.3 (0.1)
		Infauna composition:	5.5 (0)
		Overall:	**5.6 (0.1)**
Pen 3	%OM elevated (~1.5× controls), redox strongly negative, sulphides highly elevated. Total abundance normal to low (24-79 per core) and taxa richness low (5–10 per core).	Organic loading:	3.9 (0.2)
		Sediment chemistry:	6.2 (0.1)
		Infauna composition:	4.5 (0.2)
		Overall:	**4.8 (0.1)**
50 m (Zone 1–2 boundary)	%OM normal, redox very slightly lower than controls, sulphides elevated (8× controls). Total abundance normal but taxa richness reduced compared to controls (8–13 per core).	Organic loading:	3.0 (0)
		Sediment chemistry:	3.1 (0)
		Infauna composition:	3.2 (0.2)
		Overall:	**3.2 (0.1)**
150 m (Zone 2–3 boundary)	%OM normal, redox very slightly lower than controls, and sulphides elevated (~7× controls). Abundance and richness at natural levels.	Organic loading:	2.9 (0)
		Sediment chemistry:	2.9 (0.2)
		Infauna composition:	2.1 (0.1)
		Overall:	**2.3 (0.1)**
QC-Ctl-1	Normal reference conditions. Infauna community composition indicative of background seabed conditions.	Organic loading:	3.3 (0)
		Sediment chemistry:	1.6 (0.2)
		Infauna composition:	2.2 (0)
		Overall:	**2.2 (0)**
QC-Ctl-2	Normal reference conditions. Infauna community composition indicative of background seabed conditions.	Organic loading:	2.4 (0)
		Sediment chemistry:	1.5 (0.3)
		Infauna composition:	1.8 (0.1)
		Overall:	**1.8 (0)**

5.2. Historical comparison

Direct comparison cannot be made between 2014 and 2015 for Pen 1 and Pen 3, as their locations vary due to the movement of the pens in the past 12 months. However, more general comparisons can still be made, and it should be noted that Pen 2 results are directly comparable between years.

After a gradual improvement in conditions from the more severe level of deterioration observed in 2012, overall ES scores are higher (or the same) at the pen stations compared to 2014. The most noticeable difference across all variables from 2014 to 2015 was the extremely elevated sulphides (by approximately an order of magnitude) across all pen stations in 2015. Organic matter concentrations and redox potentials were similar to or marginally lower beneath the pens (Appendix 4; Figure A4.1) compared to 2014 and infauna communities had lower abundances (on average), predominantly from the decline of *C. capitata* and other opportunists.

Feed levels at the Otanerau Bay farm site were more or less similar to the amount used over the previous 12 month period (~1,000 tpa). Nonetheless, enrichment conditions at the site have deteriorated from those recorded in 2014, with strongly hypoxic (nearly anoxic) sediment conditions and variable states of post-peak macrofaunal communities.

Despite the varying conditions at the pen stations, the Zones 1–2 and 2–3 boundary ES values are reasonably similar to previous years.

Table 4. Comparison of enrichment stage (ES) scores for assessments from monitoring in 2012–2015.

	Enrichment stage (95%CI)			
	2012	**2013**	**2014**	**2015**
Pen 1	5.58 (0.19)	5.1 (0.1)	5.0 (0)	**5.9 (0.4)**
Pen 2	6.15 (0.05)	4.8 (0.2)	5.7 (0)	**5.6 (0.1)**
Pen 3	n.a.	5.6 (0.3)	4.8 (0.4)	**4.8 (0.1)**
50 m	3.25 (0.17)	3.5 (0.1)	3.5 (0.4)	**3.2 (0.1)**
150 m	2.02 (0.06)	2.2 (0.1)	2.2 (0.1)	**2.3 (0.1)**
QC Ctl 1	2.24 (0.00)	2.6 (0.1)	2.0 (0)*	**2.2 (0)**
QC Ctl 2	1.65 (0.01)	1.8 (0.1)	2.0 (0.1)	**1.8 (0)**

* in a slightly different location (~180 m away) compared to previous years.

6. CONCLUSIONS AND RECOMMENDATION

Overall, the results at Otanerau show:

- Water column measurements did not indicate impacts of farming activities due to benthic enrichment-related processes.
- Seabed enrichment levels were consistent with the stated EQS requirements. However as predicted in the previous annual monitoring report, continued deterioration of sediment chemistry beneath the pens has resulted in further deterioration of the macrofauna, although not yet to the level recorded in 2012 prior to scaling back of the farm. As noted in preceding monitoring reports, by not reducing the feeding intensity within the pens, the same highly enriched conditions continue to occur directly beneath them.
- Total recoverable copper concentrations beneath the net pens in the < 250µm fraction remain above the guideline threshold for possible biological effects. However, levels of bio-available copper (indicated by the DAE fraction) were mostly below this threshold (except in some Pen 3 samples).
- Biological effects are expected as a result of high levels of zinc beneath the pens. This is because a significant proportion is predominantly in a readily bio-available form (DAE fraction). Biological effects may be evident in the seemingly suppressed peak in opportunistic fauna at Pen 3. Due to the high DAE proportion, there is no evidence to suggest that high concentrations are due to the presence of larger paint flake particulates at this site. Elevated levels of zinc do not appear to extend beyond 50 m from the pen site.

6.1. Recommendation

It is recommended that 2 additional replicate samples for archive are collected from the net pen stations in the next monitoring round, as per the BMP (MPI 2015). This recommendation is made due to the instability of benthic conditions beneath the pens (refer Section 5.1).

7. REFERENCES

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Keeley N, Forrest B. MacLeod C. 2015. Benthic recovery and re-impact responses from salmon farm enrichment: implications for farm management. Aquaculture 435: 412-423.

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8. APPENDICES

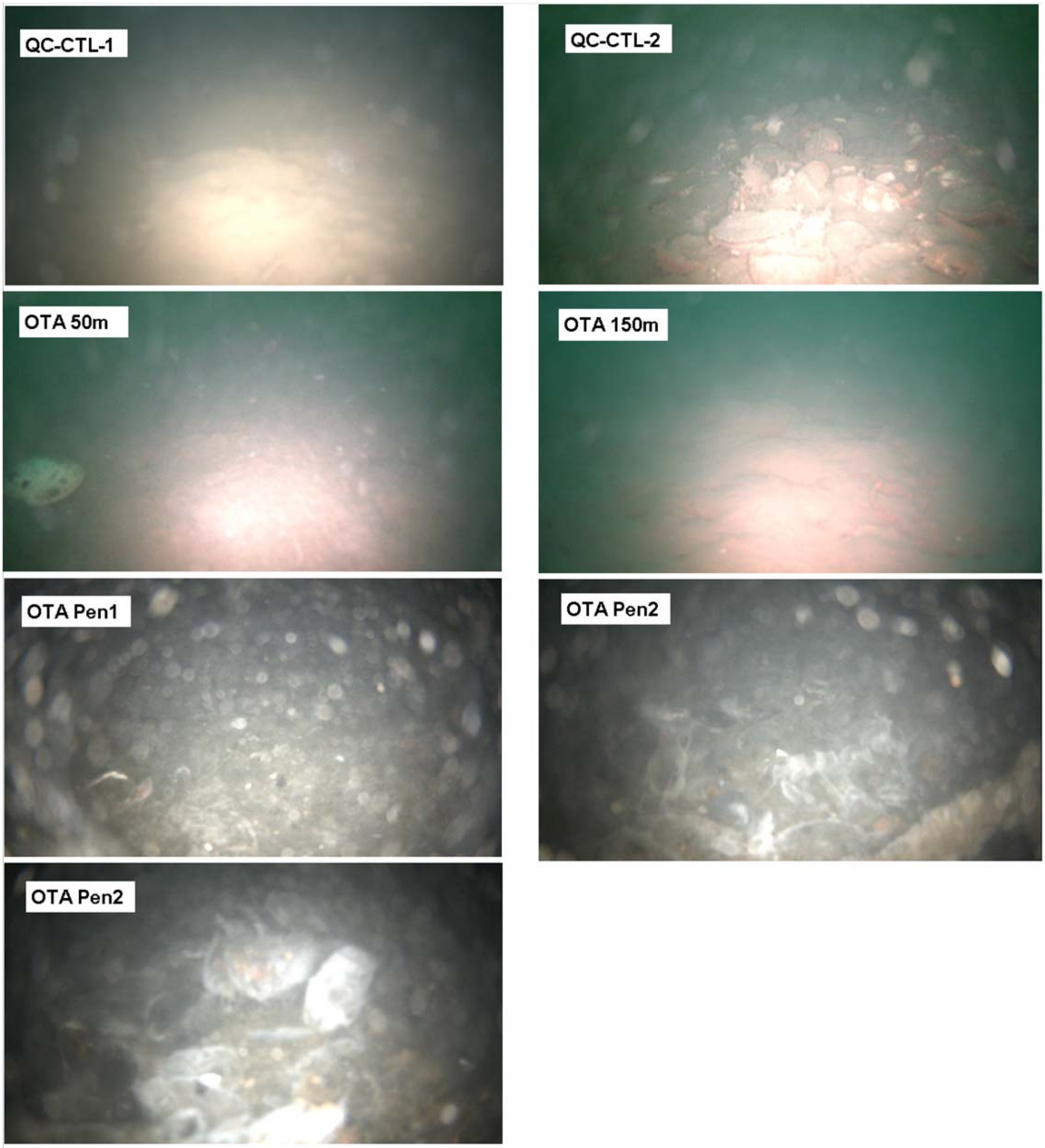
Appendix 1. Summary of the average (± SE) sediment physical and chemical properties, infauna variables and calculated indices for the Otanerau Bay (OTA) salmon farm stations during the 2015 monitoring survey.

	Station	Units	Pen-1	Pen 2	Pen 3	50 m	150 m	QC-Ctl-1	QC-Ctl-2
	Depth	m	35	35	36	37	37	42	37
Sediments	AFDW	%	12.8 (2.5)	14.7 (1.4)	9.1 (0.6)	6.3 (0)	6.1 (0)	7.4 (0.1)	5 (0.1)
	Redox	Eh_{NHE}, mV	-170 (3)	-175 (12)	-147 (12)	118 (12)	134 (32)	189 (57)	300 (53)
	Sulphides	μM	19978 (747)	12862 (3535)	15429 (1725)	658 (35)	568 (85)	18 (6)	143 (91)
	Bacterial mat	-	Yes	Yes	Yes	No	No	No	No
	Out-gassing	-	No	No	Yes	No	No	No	No
	Odour	-	Moderate	Moderate	Strong	Mild	None	None	None
Infauna statistics	Abundance	No./core	71 (63)	1130 (535)	45 (17)	88 (11)	68 (9)	91 (17)	137 (26)
	No. taxa	No./core	5.7 (3.2)	6.3 (0.9)	8 (1.5)	11.3 (1.7)	20.3 (3)	19.7 (0.9)	36.3 (2.6)
	Evenness	Stat.	0.6 (0.2)	0.2 (0)	0.8 (0.1)	0.7 (0)	0.9 (0)	0.8 (0)	0.9 (0)
	Richness	Stat.	1.4 (0.5)	0.8 (0.2)	1.9 (0.3)	2.3 (0.3)	4.6 (0.6)	4.2 (0)	7.2 (0.4)
	SWDI	Index	0.8 (0.2)	0.3 (0.1)	1.6 (0.2)	1.7 (0.1)	2.6 (0.2)	2.3 (0.1)	3.1 (0.1)
	AMBI	Index	5.3 (0.4)	5.9 (0)	4.5 (0.5)	2.6 (0.1)	1.7 (0)	1.8 (0)	1.8 (0)
	M-AMBI	Index	0.2 (0)	0.1 (0)	0.3 (0.1)	0.5 (0)	0.7 (0)	0.7 (0)	0.9 (0)
	BQI	Index	1.2 (0.5)	1.5 (0.1)	2.3 (0)	4.4 (0.2)	8 (0.4)	8.2 (0.2)	9.8 (0.2)

Appendix 2. Laboratory analytical methods for sediment samples (November 2015) processed by either Hill Laboratories (a) or Cawthron Institute (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 &/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 3. Representative images of the seafloor at each station (2015).



Appendix 4. Historical comparisons.

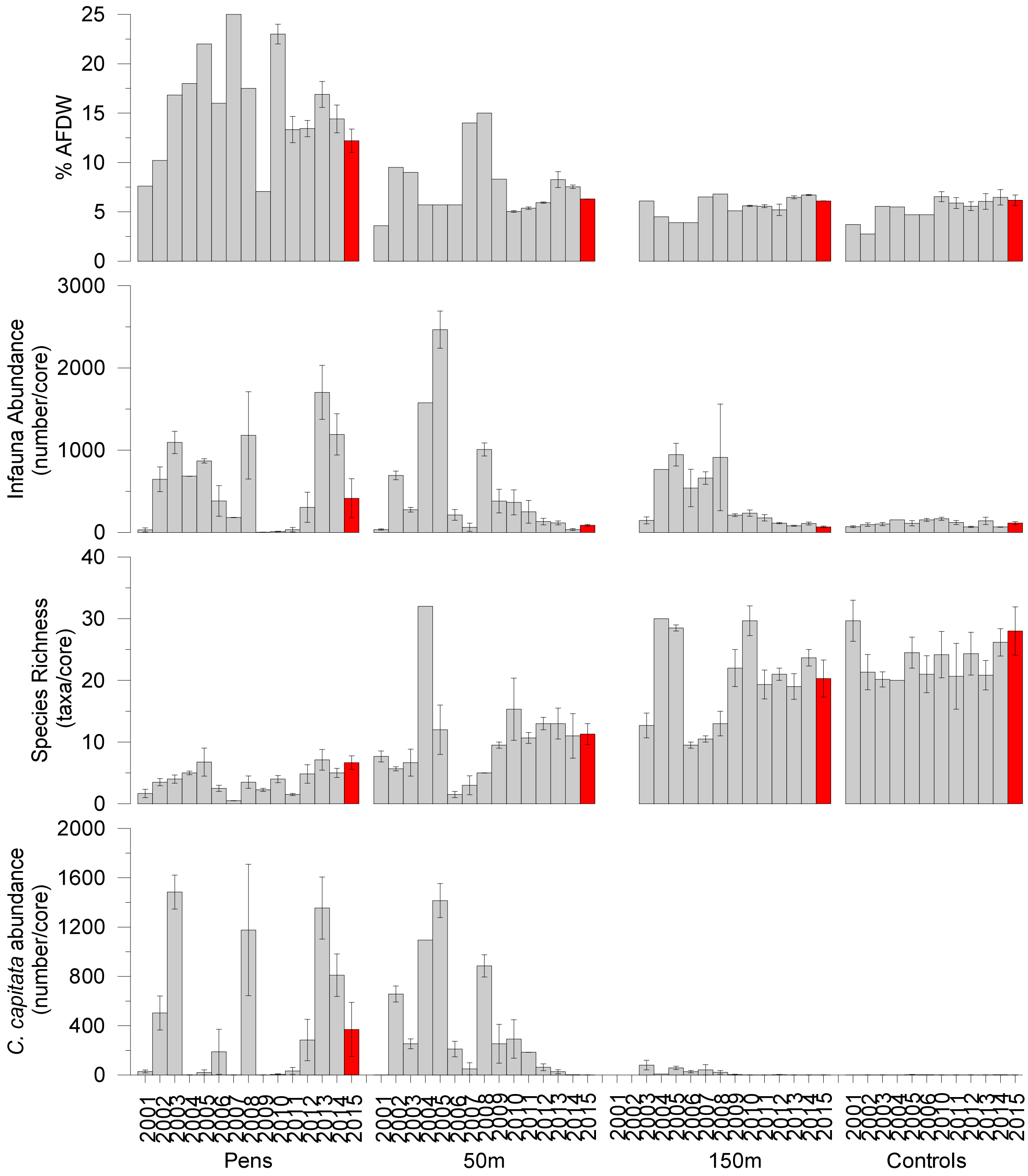


Figure A4.1. Comparison of annual monitoring of mean (± SE) ash-free dry weight (AFDW), infauna abundance and richness (no. taxa), and *Capitella capitata* densities recorded for Otanerau Bay (OTA) salmon farm annual monitoring since 2001. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000 guidelines).

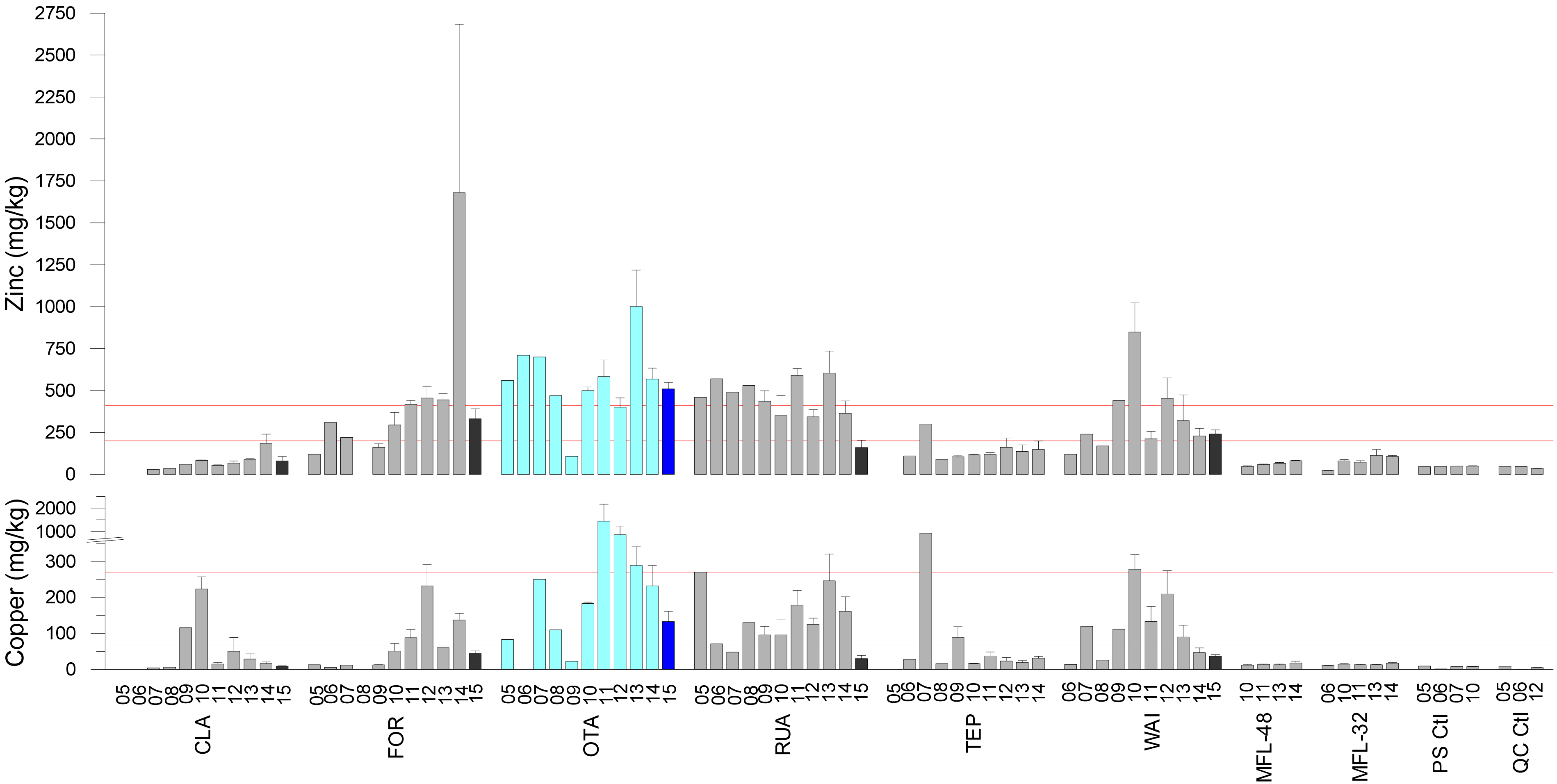


Figure A4.2. Comparison of the last 11 years of annual monitoring of sediment total recoverable copper and zinc concentrations beneath eight NZ King Salmon farms and two control stations (PS = Pelorus Sound, QC = Queen Charlotte). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low trigger levels. Otanerau Bay (OTA) salmon farm data are in blue. Note; the latest metals results from OTA, WAI, FOR and RUA are not directly comparable to previous years due to the methodological differences in 2015 (only <250µm grain size fraction analysed in 2015).

Appendix 5. Detailed enrichment stage (ES) calculations for each station at the Otanerau Bay (OTA) salmon farm, 2015. 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: Nov-15
Farm/site: Otanerau Bay
Flow environ LF

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

RAW DATA

Station:	Rep	TOM	Redox	TFS	N	S	j	d	Hloge	AMBI	M-AMBI	BQI
Pen 1	A	15.5	-165	21466	197	12	0.3	2.1	0.8	5.6	0.2	2.3
Pen 1	B	7.8	-175	19117	13	2	0.6	0.4	0.4	5.8	0.1	0.6
Pen 1	C	15.1	-170	19351	3	3	1.0	1.8	1.1	4.5	0.2	0.7
Pen 2	A	14.5	-152	7381	2135	5	0.2	0.5	0.3	5.9	0.1	1.4
Pen 2	B	12.5	-192	19470	309	8	0.1	1.2	0.3	5.9	0.1	1.7
Pen 2	C	17.2	-180	11735	947	6	0.3	0.7	0.5	5.8	0.1	1.5
Pen 3	A	8.1	-160	12098	79	10	0.7	2.1	1.5	4.9	0.3	2.2
Pen 3	B	10.3	-124	16313	32	9	0.9	2.3	2.0	3.5	0.4	2.3
Pen 3	C	8.8	-158	17876	24	5	0.8	1.3	1.3	5.1	0.2	2.3
50 m	A	6.3	94	624	106	13	0.7	2.6	1.9	2.7	0.5	4.6
50 m	B	6.3	131	624	88	13	0.7	2.7	1.8	2.6	0.5	4.6
50 m	C	6.4	129	727	69	8	0.7	1.7	1.5	2.4	0.4	3.9
150 m	A	6.1	82	651	63	19	0.9	4.3	2.6	1.7	0.7	7.8
150 m	B	6	192	655	86	26	0.9	5.6	2.9	1.8	0.8	8.8
150 m	C	6.1	127	397	55	16	0.8	3.7	2.2	1.7	0.6	7.4
QC-CTL-1	A	7.5	98	20	60	18	0.8	4.2	2.4	1.9	0.7	8.0
QC-CTL-1	B	7.4	173	7	95	20	0.8	4.2	2.4	1.8	0.7	8.0
QC-CTL-1	C	7.2	295	27	118	21	0.7	4.2	2.2	1.8	0.7	8.5
QC-CTL-2	A	4.9	379	2	185	41	0.8	7.7	3.1	1.8	0.9	10.2
QC-CTL-2	B	4.9	322	312	96	36	0.9	7.7	3.3	1.8	0.9	9.5
QC-CTL-2	C	5.1	200	115	130	32	0.9	6.4	3.0	1.9	0.8	9.6

ES equivalents

Station:	Rep	TOM	Redox	TFS	N	S	d	Hloge	AMBI	M-AMBI	BQI	Organic loading	Sediment chemistry	Macro fauna	Overall ES
Pen 1	A	5.52	5.61	7	6	4	3.81	4.88	4.7	5.5	4.63	5.52	6.31	4.79	5.17
Pen 1	B	3.49	5.7	7	6	7	6.01	5.48	4.86	6.25	6.39	3.49	6.35	6.5	6.17
Pen 1	C	5.44	5.66	7	6.5	7	4.11	4.33	3.91	5.42	6.36	5.44	6.33	6.5	6.36
Pen 2	A	5.32	5.5	6.55	5	5	5.81	5.71	4.94	6.22	5.53	5.32	6.03	5.45	5.55
Pen 2	B	4.87	5.86	7	6	6	4.84	5.77	4.98	6.11	5.23	4.87	6.43	5.49	5.62
Pen 2	C	5.81	5.75	7	6	6	5.51	5.42	4.89	6.05	5.37	5.81	6.38	5.58	5.76
Pen 3	A	3.59	5.57	7	4	6	3.84	3.64	4.19	4.97	4.7	3.59	6.29	4.41	4.7
Pen 3	B	4.27	5.25	7	5	6	3.57	2.77	3.15	4.29	4.62	4.27	6.13	4.2	4.59
Pen 3	C	3.82	5.55	7	5	6	4.79	3.91	4.35	5.36	4.58	3.82	6.28	4.86	5.04
50 m	A	2.96	3.28	3.02	2.4	3	3.31	2.97	2.56	3.92	2.79	2.96	3.15	3.04	3.05
50 m	B	2.96	2.95	3.02	2.2	3	3.21	3.12	2.49	3.94	2.77	2.96	2.99	3.01	3
50 m	C	2.99	2.97	3.19	3.5	4	4.3	3.69	2.35	4.31	3.27	2.99	3.08	3.63	3.46
150 m	A	2.88	3.39	3.07	1.9	2	1.99	1.74	1.85	2.93	1.53	2.88	3.23	2.05	2.37
150 m	B	2.85	2.4	3.08	2.2	2	1.53	1.28	1.87	2.45	1.43	2.85	2.74	1.81	2.1
150 m	C	2.88	2.99	2.56	1.8	3	2.35	2.36	1.82	3.26	1.6	2.88	2.78	2.29	2.45
QC-CTL-1	A	3.39	3.25	0.83	1.9	3	2.1	2.09	1.97	3.14	1.5	3.39	2.04	2.17	2.27
QC-CTL-1	B	3.35	2.57	0.8	2.3	2	2.08	2.06	1.86	2.99	1.5	3.35	1.69	2.15	2.18
QC-CTL-1	C	3.28	1.47	0.89	2.5	2	2.07	2.5	1.92	3.11	1.44	3.28	1.18	2.24	2.13
QC-CTL-2	A	2.42	0.72	1.12	2.9	3	1.63	0.93	1.91	1.63	1.53	2.42	0.92	1.93	1.78
QC-CTL-2	B	2.42	1.23	2.33	2.3	2	1.64	0.51	1.9	1.73	1.45	2.42	1.78	1.69	1.78
QC-CTL-2	C	2.5	2.33	1.55	2.6	2	1.45	1.03	1.98	2.12	1.45	2.5	1.94	1.8	1.9