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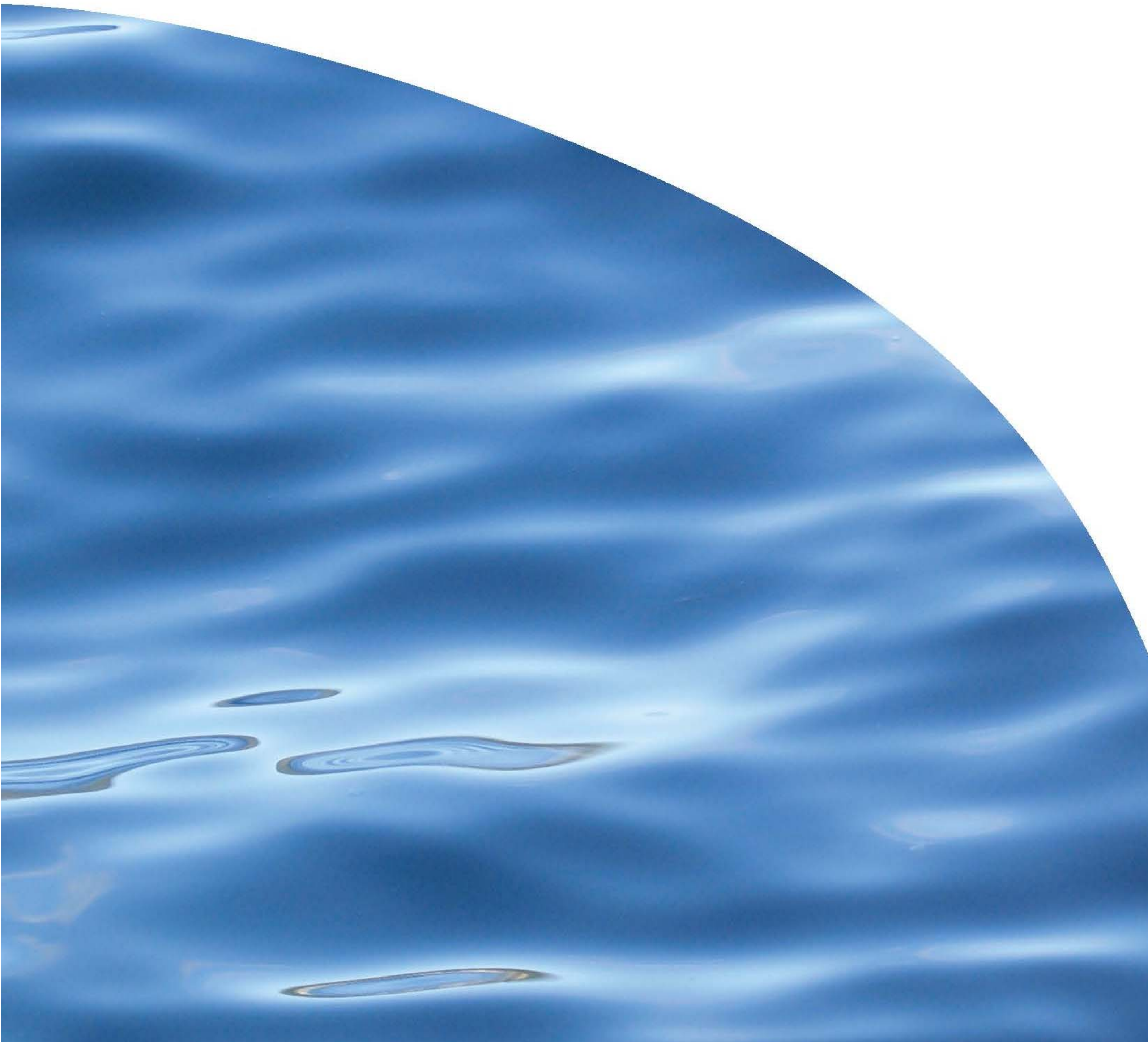
ENVIRONMENTAL IMPACTS OF THE OTANERAU BAY SALMON FARM: ANNUAL MONITORING 2013



ENVIRONMENTAL IMPACTS OF THE OTANERAU BAY SALMON FARM: ANNUAL MONITORING 2013

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Prepared for New Zealand King Salmon Company Limited.

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1. INTRODUCTION

New Zealand King Salmon Company 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 eight 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) and Marine Farm Licence 32 (MFL-32).

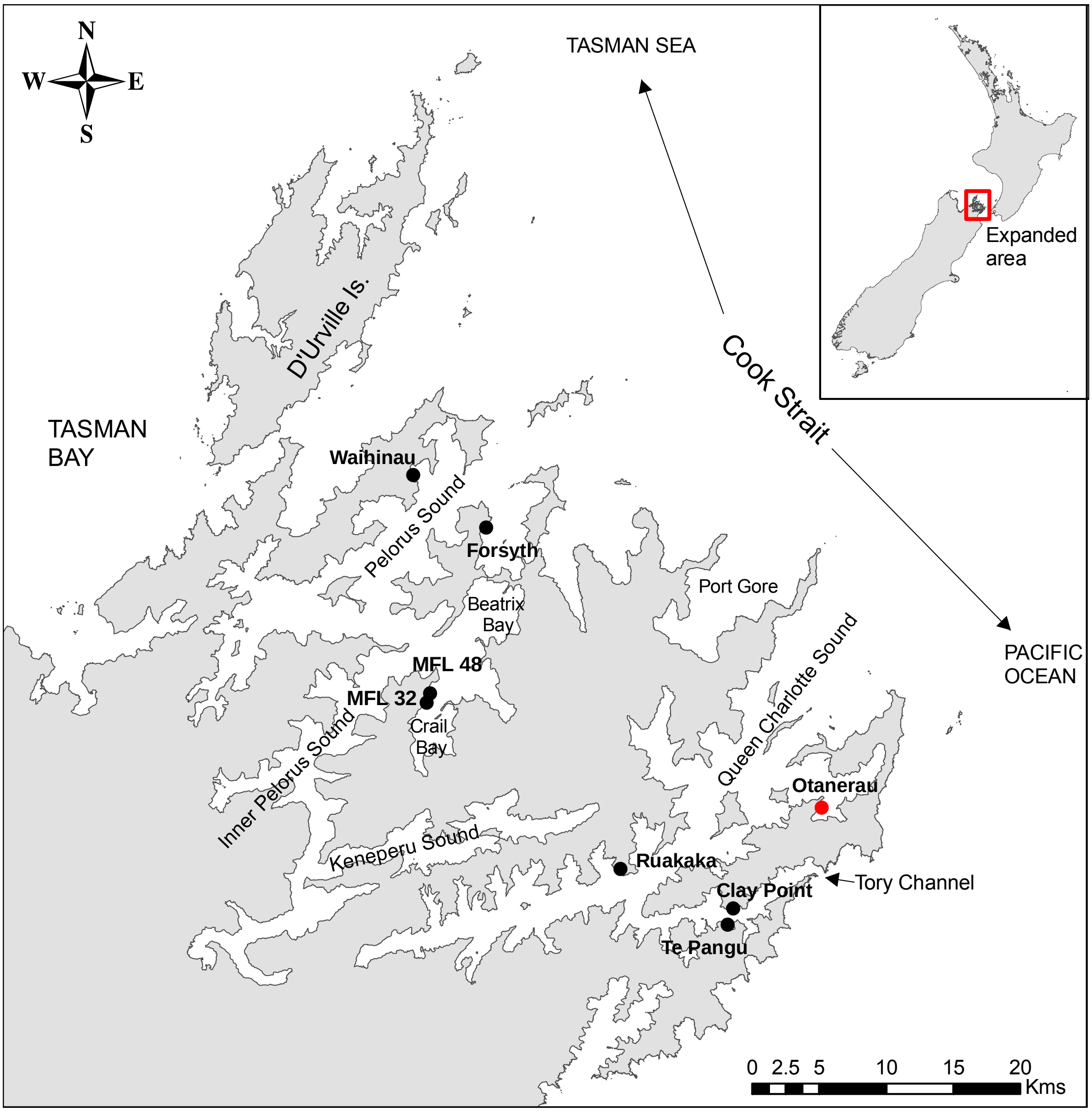

Figure 1. Map of the Marlborough Sounds area showing the location of the Otanerau Bay (OTA) salmon farm (red dot) along with NZ King Salmon's seven other farm sites (black dots).

NZ King Salmon is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The monitoring programme is conducted under an environmental monitoring plan (EMP) that is prepared by Cawthron Institute (Cawthron) on behalf of NZ King Salmon, and approved by Marlborough District Council (MDC) prior to implementation (Keeley 2013).

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 benthic community composition and abundance, dissolved oxygen (DO) 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'; a model, which 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 2013, water column monitoring was undertaken at all NZ King Salmon farm sites with a submersible sensor array used to measure *in situ* water column characteristics and discrete mid-water sampling at pen edge and down-current stations. Both TEP and CLA have adjacent rocky reef communities that are also quantitatively monitored annually. This report presents the 2013 annual monitoring results for the Otanerau Bay salmon farm.

1.1. Site details and history of feed usage

The Otanerau Bay farm site was established in 1990 and, with average water current speeds of ~ 6 cm/s, it is considered a low / moderate-flow site. Feed inputs at this farm have historically ranged from 1,501 to 2,568 tonnes per annum (since 2001, Figure 2). Over the 12-month period leading up to this year's monitoring (*i.e.* December 2012 to November 2013), a total of 1,045 tonnes of feed was used (Figure 3); the majority of which was used over the seven months preceding the survey, *i.e.* May to November 2013[1].

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

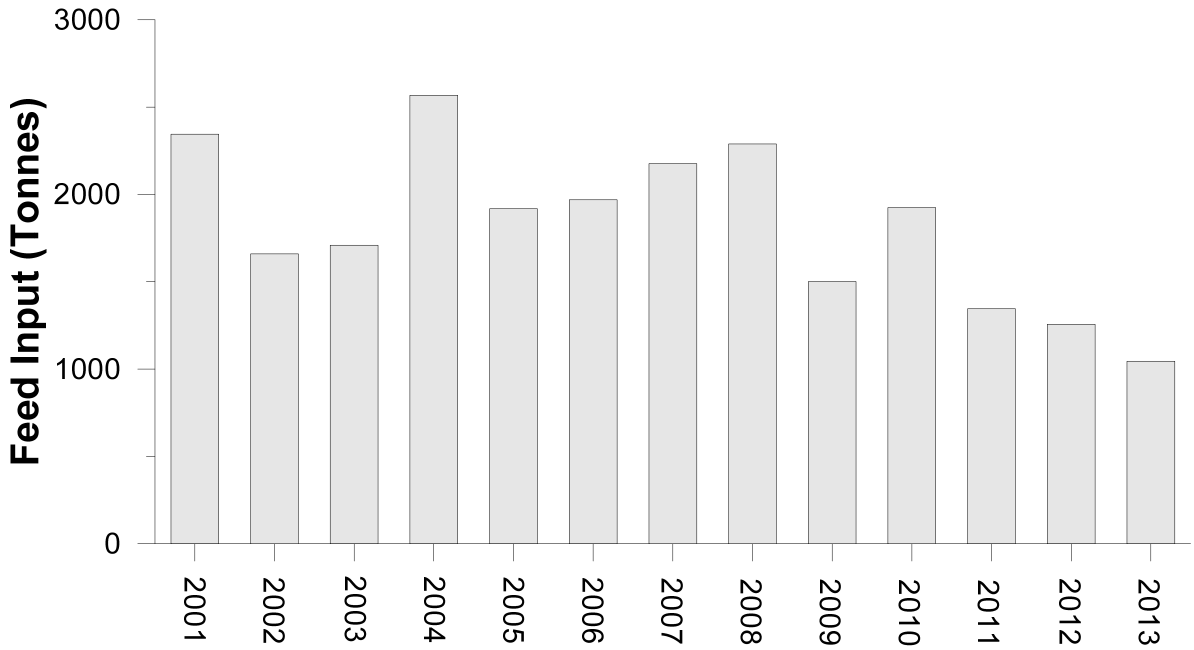

Figure 2. Annual feed inputs at the Otanerau Bay (OTA) salmon farm, 2001–2013.

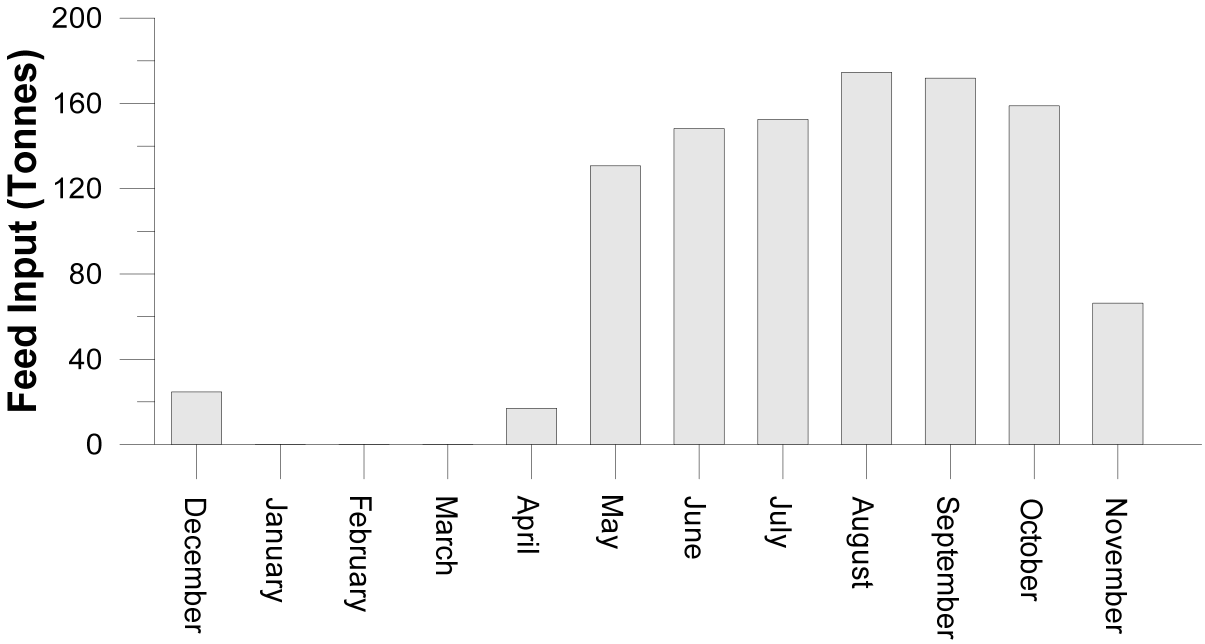

Figure 3. Monthly feed inputs at the Otanerau Bay (OTA) salmon farm from December 2012 to November 2013.

2. METHODS

Sampling at OTA was undertaken on 14 November 2013. Detailed methods and rationale describing the sampling protocol for all of NZ King Salmon's farms can be found in the most recent Annual Monitoring Programme and Methods (Keeley 2013). Copies are held by MDC and NZ King Salmon. This plan is updated and modified routinely to accommodate the most relevant and effective sampling methods. A condensed summary of the techniques that were used in the present survey is provided below.

2.1. Soft sediment habitats

2.1.1. Sampling locations

The OTA salmon farm was monitored at the following locations:

- three[2] net pen stations (at the edge of Zone 1)
- two stations along a transect aligned down-current from the pens at distances that correspond to the Zone 1–2 and 2–3 boundaries specified under the 'zones concept' (*i.e*. stations '50 m' and '150 m', respectively)
- two reference or 'control' (*i.e.* 'Ctl-1' and 'Ctl-2') stations were sampled (Figure 4).

For a full explanation of the zones concept, please refer to Keeley (2011).

In 2012 the orientation of the OTA transect was altered from previous years. The transect now runs perpendicular to the longest axis of the site and the predominant direction of flow. This departs from the recommended orientation specified in the EMP, which suggests the transect run down-current. This orientation was considered necessary to avoid the down-current stations being situated within the consented boundaries, in an area that was recently farmed (pens are presently at one end of a long, narrow site).

[2] In past years only two stations were monitored under the pens, but in 2013 a third station was added to account for high variability seen at this site during past monitoring surveys.

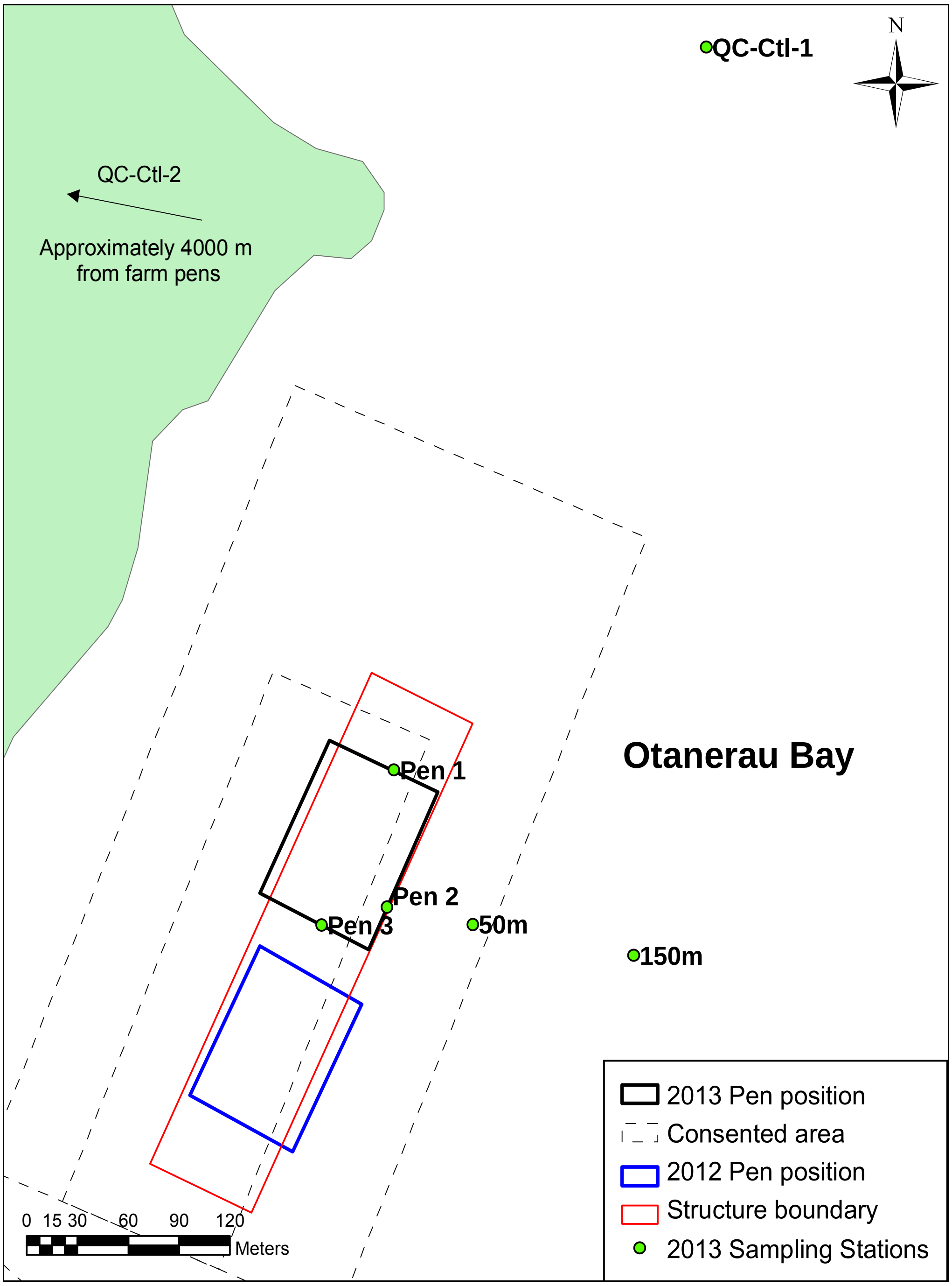

Figure 4. Soft sediment and inshore habitat sampling locations for the Otanerau Bay (OTA) salmon farm site. 'Ctl' = Control. Position accuracy is ± 5 m.

2.1.2. Environmental variables

Three replicate sediment grab samples were collected at each sampling station using a modified van Veen grab. Each grab sample was examined for sediment odour, texture and bacterial mat coverage, and the top 3 cm of one sediment core (63 mm diameter) was analysed for organic content (as % AFDW), redox potential (Eh_{NHE}, mV), and total free sulphides (μM). In addition, pen samples were analysed for copper and zinc concentrations. The sea surface was scanned for visible sediment out-gassing as this could provide further evidence of particularly enriched conditions.

A separate core (130 mm diameter, ~ 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), total number of taxa (S), 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).

Video footage was taken at each station to obtain a visual record of benthic conditions and epifauna.

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 (Keeley 2013). Average ES scores were then calculated for the sediment chemistry variables (redox and sulphides), the infauna composition variables (abundance, richness, diversity and biotic indices) and organic content (as % AFDW). The overall ES for a given sample was then calculated by determining the weighted average[3] 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 standard error.

2.2. Water column

Discrete samples were collected from mid-water using a van Dorn sampler. These were analysed in the laboratory for nitrate-N (NO_3-N), nitrite-N (NO_2-N), ammoniacal-N (NH_4-N), total N (TN), dissolved reactive phosphorous (DRP) and total phosphorus (TP).

In situ water column profiles of dissolved oxygen, turbidity, temperature, salinity, and chlorophyll-*a*[4] were recorded at each OTA sampling station by slowly raising a data-logging sensor array from the seabed to the surface.

[3] Weighting used in 2013 was the same as that used in 2012: organic loading = 0.1, sediment chemistry = 0.2, infauna composition = 0.7).

[4] In 2013 use of the data-logging sensor array allowed for *in situ* measurement of chlorophyll-*a* throughout the water column, laboratory analysis of chlorophyll-*a* from discrete water samples was therefore not necessary.

2.3. Inshore habitats

The Otanerau Bay salmon farm is a low / 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. Video footage is collected on each scheduled occasion and archived for assessment of any obvious changes of visual characteristics over time. This assessment was last undertaken in 2012 and is due to be conducted again in 2014, thus inshore habitats were not inspected during the 2013 annual monitoring survey.

3. RESULTS

3.1. Soft sediment habitats

3.1.1. Physico-chemical characteristics

The average sediment organic matter content was highest beneath the pens (mean = 16.9%) which was 2.8 times the average level for the control stations (Ctl-1 and Ctl-2, mean = 6%).Other sites showed little difference from the control stations (Figure 5).

Pen stations 1 and 2 had positive redox potentials (5 and 38 Eh_{NHE}, mV respectively), while Pen 3 redox levels were negative (-39 Eh_{NHE}, mV).

Pen stations 1 and 3 had variable but strongly elevated concentrations of total free sulphides (Pen 1 mean = 2,857 µM; Pen 3 mean = 5,954 µM), while levels under Pen 2 were much lower (Pen 2 mean = 588). Sulphides were still somewhat elevated at the 50 m station (mean = 773 µM), while the 150 m station and the two controls were similarly low (90 µM, 135 µM and 123 µM respectively).

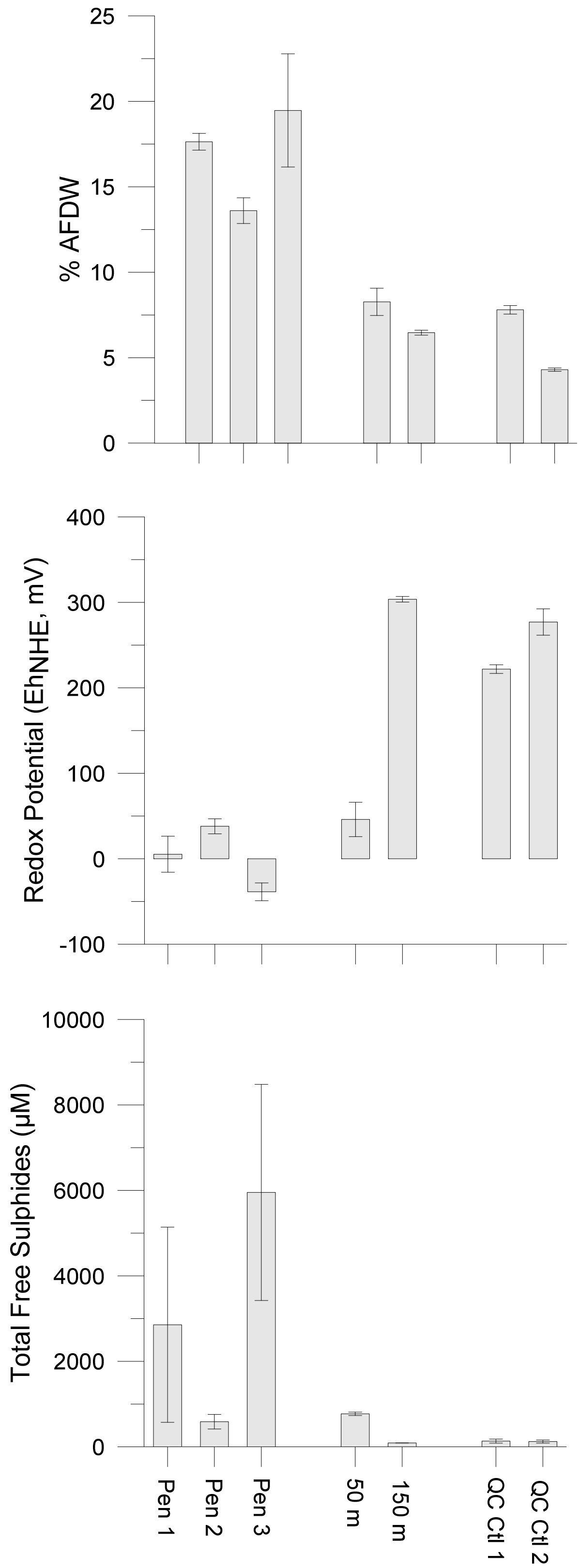

Figure 5. Multiplot of organic matter (as % AFDW), redox potential (Eh_{NHE}, mV), and total free sulphides (µM). Error bars = ±1 SE, n = 3. Samples with sulphide levels below the detection limit of 82 µM were assigned the detection level value.

3.1.2. Biological communities

The infauna community at the three pen stations contained high abundances, particularly of enrichment-tolerant taxa. These stations also exhibited reduced numbers of taxa (richness) and lower diversity (H'), evenness (J'), Margalef richness (d), and ecological quality ratio (EQR) than the 50 m, 150 m, and control sites (Figure 6). Samples from all pen stations were dominated by *Capitella capitata* (Appendix 2), and nematodes only reached densities of over 500 per core at a single replicate (at Pen 1). At the QC-Ctrl 1 and 2 stations total abundances were still slightly elevated (compared to 50 m and 150 m stations), and S was slightly reduced at Ctl-1 (~450 m down-current of farm). The increased abundance at Ctl-1 was due to moderately high numbers of *Prionospio yuriel* and paraonids, both of which are found in natural or mildly enriched situations.

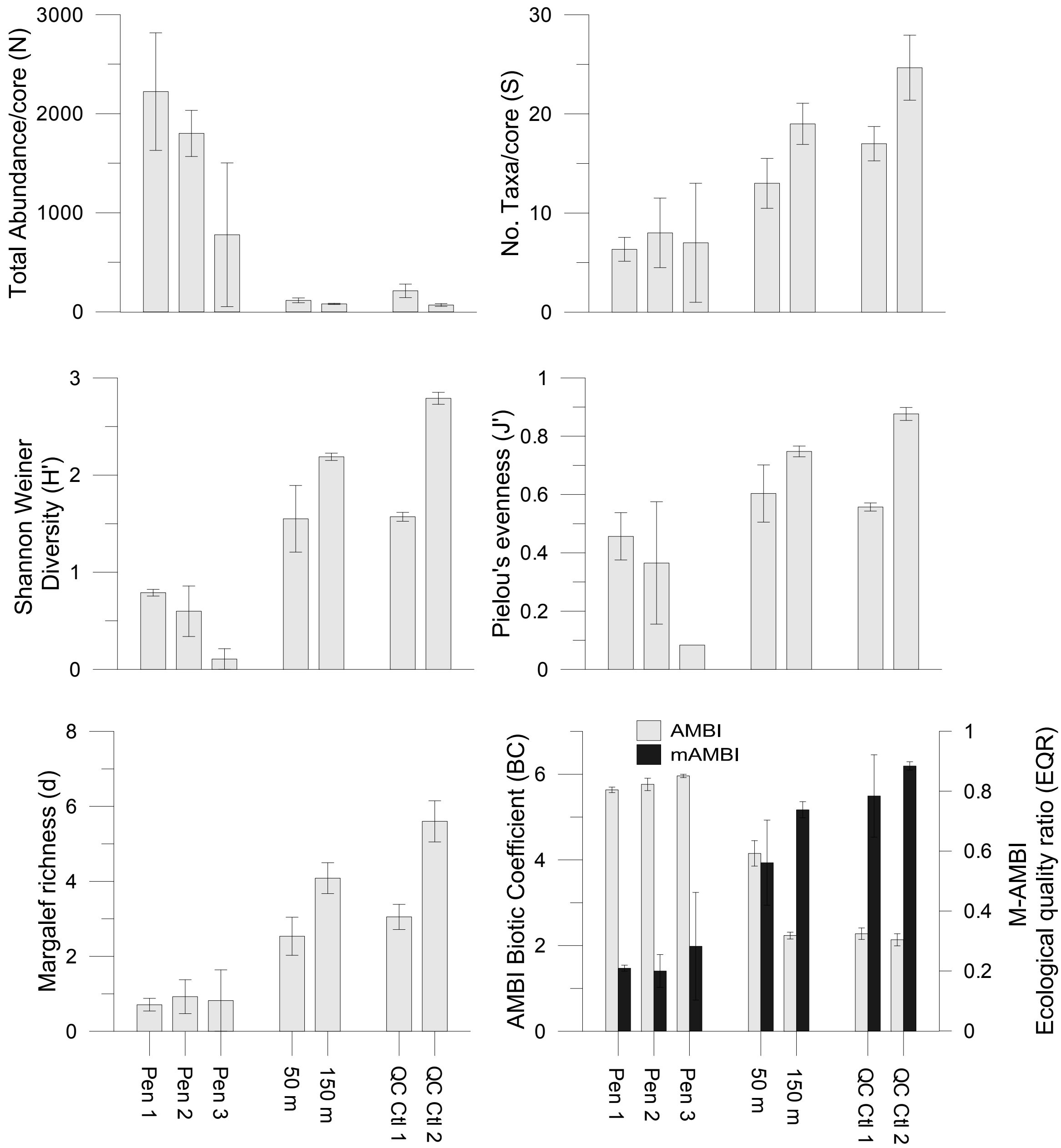

Figure 6. Infauna statistics. Error bars = ±1 SE, n = 3 except at Pen 3 where n = 2.

Video images revealed dark muddy sediments under the farms with some indications of *Beggiatoa*-like bacteria on the sediment surface. An easily disturbed layer of flocculent organic material was noted at Pen 1 and out-gassing was observed at Pen 2. At Pen 3, shell hash was abundant, and spotties (*Notolabrus celidotus*) and dogfish (*Squalus acanthias*) were observed. The seabed 50 m from the pens appeared to consist of soft, brown-grey mud with some broken shell material and worm/shrimp burrows. At the 150 m station the mud appeared to be soft and brown and worm/shrimp burrows were more abundant.

3.1.3. Copper and zinc concentrations

The highest mean zinc concentrations were recorded in sediment samples from below the pens. They exceeded the ISQG-High trigger level (410 mg/kg (Appendix 2, Figure A2.2) and were 2.5 times the 2012 levels. Average zinc concentrations at Pen stations 1, 2, and 3 were 1,507, 723, and 773 mg/kg respectively (n = 3). Although copper levels had continued decreasing from a high in 2011, the average copper concentration (288 mg/kg) was still highly elevated and above ISQG-High level of 270 mg/kg. Average copper concentrations at Pen stations 1, 2, and 3 were 251, 410, and 204 mg/kg respectively (n = 3).

Table 1. Copper and zinc concentrations in sediments (raw data).

Station	Replicate	Total recoverable copper (mg/kg dry wt)	Total recoverable zinc (mg/kg dry wt)
Pen 1	1	210	1,000
	2	370	820
	3	172	2,700
Pen 2	1	340	570
	2	320	650
	3	570	950
Pen 3	1	410	890
	2	133	710
	3	70	720

3.2. Water column

Water column nutrients generally showed little variation with respect to distance from the pens. There was, however, a slight increase in total nitrogen at the pen station.

Table 2. Water column sampling results at Otanerau Bay (OTA) salmon farm and the nearby Queen Charlotte (QC) Ctl-1 stations. Values are averages in g/m^2 , with 1 SE in brackets. n = 3 for all samples.

	Station			
	Pen 1	**50 m**	**150 m W**	**QC-Ctl 1**
Nitrate-N (NO_3-N)	0.028 (0.002)	0.022 (0.001)	0.019 (0.002)	0.027 (0)
Nitrite-N (NO_2-N)	0.005 (0)	0.003 (0)	0.002 (0)	0.006 (0)
Ammonia (NH_4-N)	0.007 (0.002)	0.005 (0)	0.005 (0)	0.007 (0.002)
Total nitrogen (TN)	0.201 (0.015)	0.149 (0.006)	0.139 (0.005)	0.143 (0.004)
Dissolved reactive phosphorous (DRP)	0.009 (0.001)	0.006 (0)	0.005 (0)	0.011 (0)
Total phosphorus (TP)	0.029 (0.008)	0.017 (0)	0.013 (0.001)	0.017 (0)

A moderate reduction in DO at pen stations occurred in the top ~15 m of the water column, however this is probably not ecologically significant. Other measures did not vary greatly between stations. Temperature and salinity were relatively constant throughout the water column indicating little density stratification, while turbidity increased and chlorophyll-*a* decreased with depth.

The increased turbidity in the near-bottom waters was also confirmed by the video camera footage which found lower visibility towards the seabed at both pen and down-current stations. However this increased turbidity was probably present throughout the bay as a result of sediment resuspension due to high winds on the day of sampling and the preceding days.

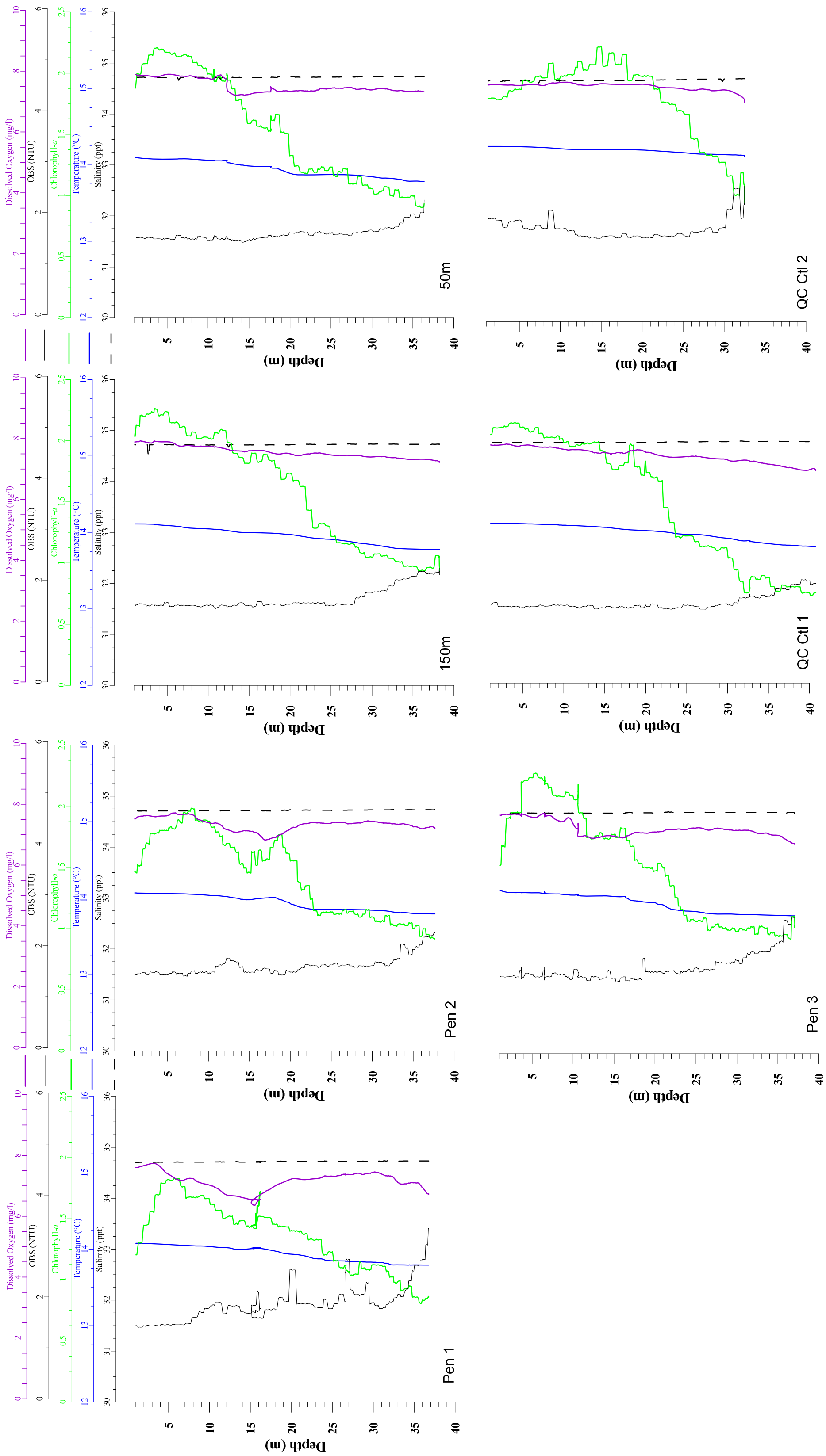

Figure 7. Dissolved oxygen, turbidity (optical backscatter), chlorophyll-*a*, temperature, and salinity as measured by an *in situ* sensor array raised through the water column.

4. ASSESSMENT OF SEABED ENRICHMENT

4.1. Compliance framework

The current consent conditions and previously interpreted equivalent ES scores for Otanerau Bay salmon farm are provided in Table 3. The Environmental Quality Standards (EQS) in the consent conditions are qualitative narratives and 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, we are presently unable to report definitively on compliance with any particular consent conditions. We should note that this is an issue that is presently being addressed as part of a new best management practice document that is being developed for NZ King Salmon by a targeted working group. This is likely to result in revised standards and consent conditions that may be introduced later in 2014.

However, Cawthron has previously endeavoured to interpret the conditions in quantitative manner and, in doing so, proposed some allowable environmental 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 practically possible.

Table 3. Environmental Quality Standards (EQS) for Otanerau Bay (OTA) salmon farm described for each zone (taken from consent UO40217) 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 Keeley (2012) for further details relating to ES scores.

4.2. Enrichment stage assessments for 2013

The 2013 assessment of soft-sediment conditions are summarised below with reference to a selection of informative chemical and biological indicators, all of which are incorporated into the overall ES. The oxic statuses used below are based on classifications provided by Hargrave *et al*. (2008)[5] from northern hemisphere environments and are intended to provide some context around the values. However, we stress that there are risks associated with placing emphasis on any individual indicators, and especially chemical indicators, which tend to be more spatially and temporally variable. As such, the derived ES value is considered a more robust measure of the overall seabed state.

[5] Hargrave *et al*. define benthic organic enrichment zones based on redox potential and total free sulphides. Along a scale of enrichment from 'Normal' to 'Anoxic' conditions, the five states describing increasing impact are termed Oxic-A, Oxic-B, Hypoxic-A, Hypoxic-B, and Anoxic.

Station	Summary		ES (SE)
Pen 1	Highly elevated %OM, redox near zero, sulphides high but variable. Total abundance high (~peak abundance) and taxa richness strongly reduced. AMBI indicated ‘Poor’ ecological quality status.	Organic loading:	5.9 (0.1)
		Sediment chemistry:	4.1 (0.5)
		Infauna composition:	5.2 (0.1)
		Overall:	**5.1 (0.1)**
Pen 2	Elevated %OM (~2 x Ctls), redox low, sulphides slightly elevated. Total abundance high (~peak abundance) and taxa richness strongly reduced.	Organic loading:	5.1 (0.2)
		Sediment chemistry:	3.3 (0.2)
		Infauna composition:	5.2 (0.3)
		Overall:	**4.8 (0.2)**
Pen 3	Highly elevated %OM, redox below zero, sulphides very high but variable. Total abundance high but beyond ‘peak’ and taxa richness strongly reduced; one replicate near-azoic (S = 1).	Organic loading:	5.9 (0.3)
		Sediment chemistry:	5.1 (0.6)
		Infauna composition:	5.5 (0.8)
		Overall:	**5.6 (0.3)**
50 m (Zone 1–2 boundary)	%OM slightly elevated, redox low and sulphides slightly elevated. Abundance normal, taxa richness slightly reduced.	Organic loading:	3.6 (0.3)
		Sediment chemistry:	3.5 (0.1)
		Infauna composition:	3.4 (0.2)
		Overall:	**3.5 (0.1)**
150 m (Zone 2–3 boundary)	%OM, redox and sulphides comparable to Ctl’s. Abundance and richness at natural levels.	Organic loading:	3 (0.1)
		Sediment chemistry:	1.4 (0)
		Infauna composition:	2.3 (0.1)
		Overall:	**2.2 (0.1)**
QC-Ctl-1	%OM, redox, sulphides at natural levels. Total abundance slightly elevated and S slightly reduced (indicative of mild enrichment).	Organic loading:	3.5 (0.1)
		Sediment chemistry:	1.9 (0.1)
		Infauna composition:	2.6 (0.1)
		Overall:	**2.6 (0.1)**
QC-Ctl-2	%OM, redox, sulphides and macrofauna statistics at natural levels.	Organic loading:	2.2 (0)
		Sediment chemistry:	1.6 (0.1)
		Infauna composition:	1.8 (0.1)
		Overall:	**1.8 (0.1)**

4.3. Historical comparison

A comparison of the past monitoring assessments shows that, since the previous survey, ES scores have decreased (*i.e.* conditions have improved) at Pen stations 1 and 2, while little change has been observed at other stations (Table 4).

Table 4. Comparison of enrichment stage (ES) scores for assessments from monitoring in 2010–2013. Note: n.a. = not assessed.

	Enrichment stage (s.e.)			
Station	**2010**	**2011**	**2012**	**2013**
Pen 1	6.2	5.77 (0.03)	5.58 (0.19)	**5.1 (0.1)**
Pen 2	n.a.	5.93 (0.14)	6.15 (0.05)	**4.8 (0.2)**
Pen 3	n.a.	n.a.	n.a.	**5.6 (0.3)**
50 m	3.4	3.10 (0.15)	3.25 (0.17)	**3.5 (0.1)**
150 m	2.0	2.10 (0.06)	2.02 (0.06)	**2.2 (0.1)**
QC Ctl 1	2.8	2.47 (0.09)	2.24 (0.00)	**2.6 (0.1)**
QC Ctl 2	1.8	1.83 (0.14)	1.65 (0.01)	**1.8 (0.1)**

5. SUMMARY AND CONCLUSIONS

5.1. Seabed enrichment

Seabed conditions alongside the pens were highly enriched and typically dominated by high abundances of opportunistic taxa (ES 4.8–5.1), but were generally consistent with the assumed EQS for the consent conditions (*i.e.* ES <6.0). Near-peak abundances were found at all three stations, however, Pen 3 was showing signs of post-peak conditions and one sample contained only a few individuals comprising one taxa (*i.e.* near-azoic). The sediment chemistry variables indicated only moderate enrichment at Pen 2 despite having a highly impacted macrofauna community.

It is notable that seabed conditions at Pen 3 was still in a highly enriched state despite a third consecutive reduction in annual feed inputs (from 1,924 tonnes in 2010 to 1,045 tonnes in 2013). The inability to rapidly recover at this location is probably attributable to the way the farm was scaled back *i.e.* a reduction in farm size (number of pens), as opposed to a reduction in intensity (feed use/m^2, or stocking density). By reducing the structure area and not necessarily the feeding intensity *per se*, the same highly enriched conditions may still occur directly beneath the remaining pens. Nevertheless, seabed conditions in 2013 had improved appreciably since 2012, with the continuing re-establishment of highly abundant opportunistic taxa under the pens. Thus conditions in 2013 were in line with the goal of maintaining peak abundance and a functional macrofauna beneath the pens.

The 50 m (Zone 2–3 station) was clearly enriched, with an overall ES of 3.5 due to both chemical and biological variables consistently indicating a slightly enriched state. This was a slightly higher level of enrichment than the previous two years, but was still consistent with assumed EQS for the Zone (*i.e.* ES ≤3.5)

Conditions at the Zone 3–4 boundary (150 m) were comparable to reference conditions. However, Ctl-1 (300 m from the pens) did appear very mildly enriched. This is consistent with previous assessments and has been attributable to the station being located in a small depression in the seabed where organic matter tends to accumulate. Hence it would naturally be slightly more enriched than other surrounding areas, but it should be noted that the source of organic matter is not necessarily farm-derived (e.g. extensive forestry has recently occurred in the bay).

It was also noted that a mussel farm is being established over top of the Ctl-1 station. Shell debris was not observed in video sled footage at time of survey, indicating mussel stock had yet been seeded on the farm. The presence of a mussel farm, however, is likely to make any future comparisons at this site very difficult, and may require the repositioning of Ctl-1 in future surveys.

5.2. Water column

Water column characteristics showed little variation associated with the farms. Where levels of total nitrogen (TN) are elevated, but dissolved inorganic nitrogen (DIN) is not, particulate organic nitrogen is identified as the cause of higher TN. Any impacts of elevated particulate nitrogen would be captured in benthic sampling.

5.3. Copper and zinc

Both copper and zinc concentrations in the sediment beneath the pens exceeded the ANZECC ISQG-High threshold for ‘probable biological effects’. As such, the bioavailable fraction of these constituents is presently being re-analysed. The results of this secondary analysis will be provided to NZ King Salmon in a subsequent letter report and any recommendations will be made following discussion with NZKS and MDC.

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7. APPENDICES

Appendix 1. Summary of 2013 results.

Table A1.1. Summary of the physical and chemical properties of sediments from the Otanerau Bay (OTA) salmon farm stations during the 2013 monitoring survey. Bracketed values [6]= 1 SE.

	Station	Units	Pen-1	Pen 2	Pen 3	50 m	150 m	QC-Ctl-1	QC-Ctl-2
	Depth	m	36	37	35.8	37	36.2	34	36
Sediments	AFDW	%	17.6 (0.5)	13.6 (0.8)	19.5 (3.3)	8.3 (0.8)	6.5 (0.1)	7.8 (0.3)	4.3 (0.1)
Sediments	Redox	Eh_{NHE}, mV	5.3 (21.2)	38 (8.7)	-38.7 (10.4)	46 (20.1)	303.7 (3.3)	222 (5)	277 (15.4)
Sediments	Sulphides	µM	2,856.7 (2283.5)	587.7 (169.9)	5,953.8 (2527.7)	773.1 (39.6)	90.1 (3.1)	134.5 (47.5)	123.3 (36.3)
Sediments	Bacterial mat	-	Trace amounts	Trace-5%	Trace	None	None	None	None
Sediments	Out-gassing	-	Not Observed	On disturbance	Not Observed	None	None	None	None
Sediments	Odour	-	Moderate to strong	Mild to moderate	Strong	None	None	None	None
Infauna statistics	Abundance	No./core	2,223 (592.6)	1,801 (232.8)	778 (725)	116.3 (24.1)	81.3 (5.8)	212.3 (68.9)	69.7 (13.6)
Infauna statistics	No. taxa	No./core	6.3 (1.2)	8 (3.5)	7 (6)	13 (2.5)	19 (2.1)	17 (1.7)	24.7 (3.3)
Infauna statistics	Richness	Stat.	0.7 (0.2)	0.9 (0.5)	0.8 (0.8)	2.5 (0.5)	4.1 (0.4)	3.1 (0.3)	5.6 (0.5)
Infauna statistics	Evenness	Stat.	0.5 (0.1)	0.4 (0.2)		0.6 (0.1)	0.7 (0)	0.6 (0)	0.9 (0)
Infauna statistics	Shannon-Weiner	Index	0.8 (0)	0.6 (0.3)	0.1 (0.1)	1.6 (0.3)	2.2 (0)	1.6 (0)	2.8 (0.1)
Infauna statistics	AMBI	Index	5.6 (0.1)	5.8 (0.1)	6 (0)	4.2 (0.3)	2.2 (0.1)	2.3 (0.1)	2.1 (0.1)
Infauna statistics	M-AMBI	Index	0.2 (0)	0.2 (0.1)	0.1 (0.1)	0.5 (0.1)	0.8 (0)	0.7 (0)	0.9 (0.1)
Infauna statistics	BQI	Index	1.7 (0.1)	1.7 (0.3)	1.3 (0.8)	3.5 (0.5)	7.9 (0.4)	7.5 (0.4)	8.6 (0.9)

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Appendix 2. Historical comparisons.

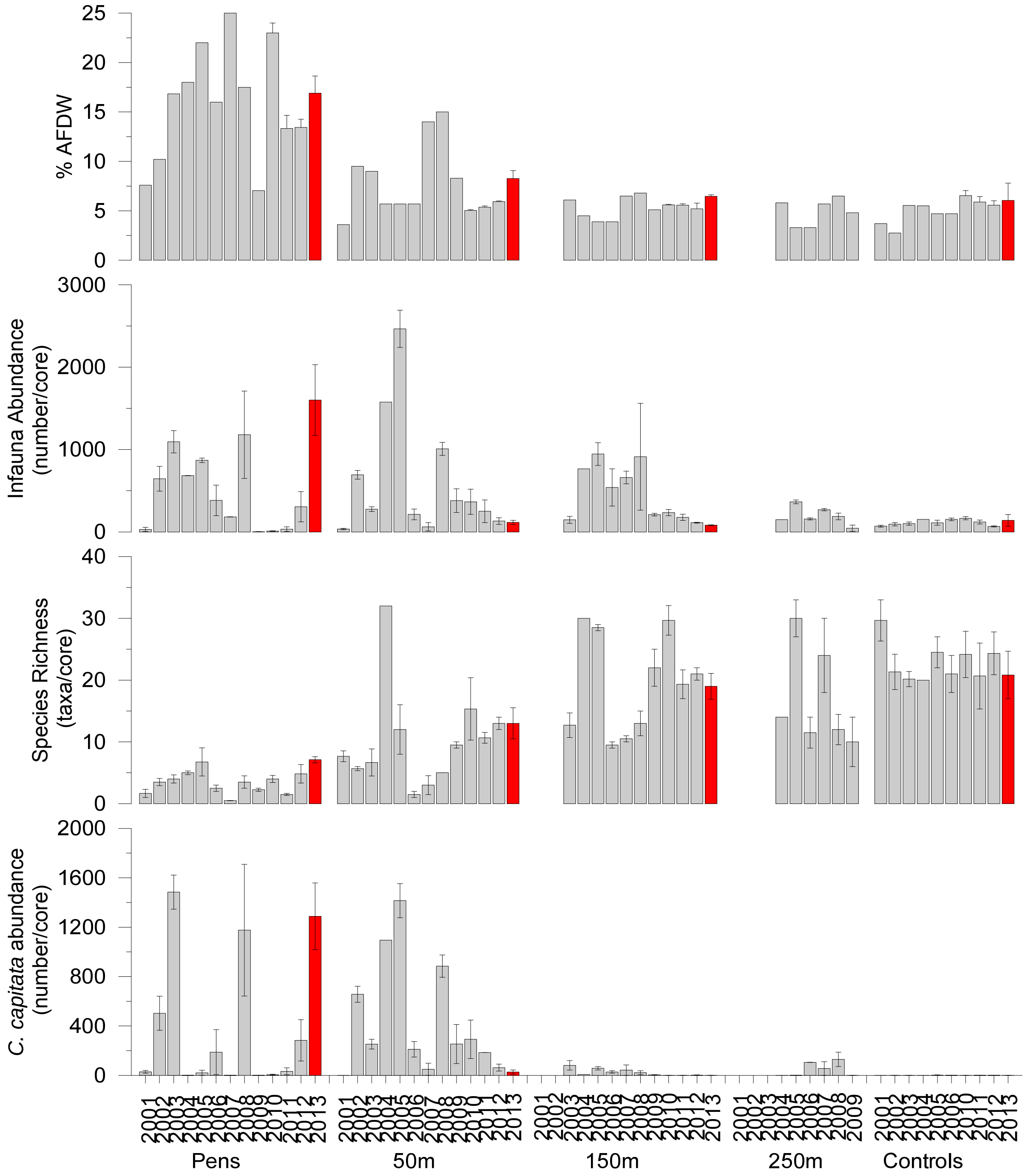

Figure A2.1. Comparison of mean ash-free dry weight (AFDW), infauna abundance and richness (No. taxa), and *C. capitata* densities recorded at Otanerau Bay (OTA) salmon farm since 2001. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000 guidelines). Note: 2009 pen and down-current stations were in different locations to previous years due changes in farm boundaries.

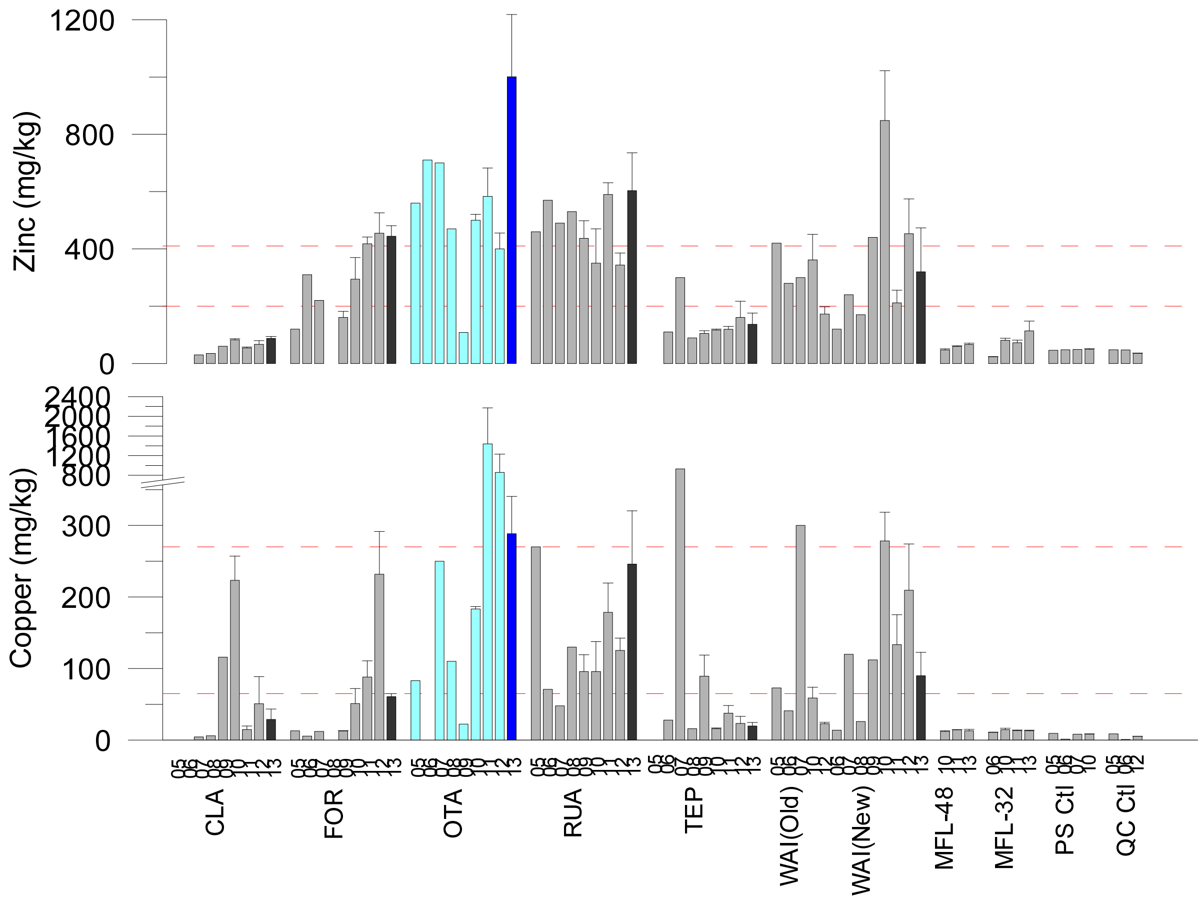

Figure A2.2. Comparison of the last nine years of annual monitoring data for sediment copper and zinc concentrations beneath all eight NZ King Salmon farms and two control stations (PS = Pelorus Sound, QC = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG-High and -Low trigger levels. Otanerau Bay (OTA) salmon farm data are in blue. Note break in y-axis and change in scale in copper graph (OTA) 2011 and 2012 average copper concentrations were 1440 mg/kg and 858 mg/kg respectively).

Appendix 3. Detailed enrichment stage (ES) calculations for each station at Otanerau Bay (OTA) salmon farm. For details pertaining to how the values in these tables were calculated, see Keeley 2012.

SITE INFORMATION
Date: Nov-13
Farm/site: **Otanerau**
Flow environment: **LF**

RAW DATA (to be entered)

Station:	Repl.	TOM	Redox	Sulphides	N Abundance	S No. Taxa	J' P. evenness	d Richness	H'(loge) SWDI	AMBI	M-AMBI	BQI
Pen 1	A	17.6	9	505.91	3233	4	0.62	0.37	0.86	5.52	0.19	1.37
Pen 1	B	18.5	-33.0	641.21	1181	7	0.38	0.85	0.75	5.74	0.21	1.74
Pen 1	C	16.8	40.0	7423.08	2255	8	0.37	0.91	0.76	5.65	0.23	1.83
Pen 2	A	13.6	26.0	879.50	2169	15	0.19	1.82	0.51	5.84	0.28	2.21
Pen 2	B	14.9	55.0	592.50	1864	5	0.12	0.53	0.20	5.96	0.10	1.39
Pen 2	C	12.3	33.0	291.01	1370	4	0.78	0.42	1.09	5.48	0.22	1.49
Pen 3	A	15.3	-21.0	1030.04	53	1	****	0.00	0.00	6.00	0.01	0.48
Pen 3	B	17.1	-57	9408.32	1503	13	0.08	1.64	0.21	5.92	0.21	2.05
Pen 3	C	26	-38.0	7423.08								
50 m	A	7.9	6.0	812.69	86	15	0.79	3.14	2.14	3.68	0.50	4.24
50 m	B	9.8	62.0	693.92	164	16	0.56	2.94	1.56	4.70	0.35	3.19
50 m	C	7.1	70.0	812.69	99	8	0.46	1.52	0.95	4.08	0.83	2.70
150 m	A	6.2	310.0	87.00	89	22	0.72	4.68	2.22	2.07	0.71	8.11
150 m	B	6.5	302.0	87.00	70	15	0.78	3.30	2.12	2.32	0.79	6.87
150 m	C	6.7	299.0	96.29	85	20	0.75	4.28	2.23	2.31	0.71	7.36
QC Ctl 1	A	7.6	232.0	229.60	165	20	0.55	3.72	1.66	2.40	0.68	7.48
QC Ctl 1	B	7.5	218.0	87.00	348	17	0.53	2.73	1.51	2.01	0.62	8.00
QC Ctl 1	C	8.3	216.0	87.00	124	14	0.58	2.70	1.54	2.42	1.06	6.57
QC Ctl 2	A	4.4	298.0	87.00	88	31	0.85	6.70	2.91	1.86	0.86	9.91
QC Ctl 2	B	4.1	286.0	196.05	43	20	0.92	5.05	2.76	2.32	0.90	6.84
QC Ctl 2	C	4.4	247.0	87.00	78	23	0.86	5.05	2.71	2.23	0.90	7.70

ES equivalents

Station:	Repl.	TOM	Redox	Sulphides	Abundance	No. Taxa	P. evenness	Richness	SWDI	AMBI	M-AMBI	BQI
Pen 1	A	5.87	4.05	2.8	5.3	5.5		6.04	4.74	4.67	5.62	5.56
Pen 1	B	5.99	4.43	3.05	5.5	5		5.34	4.93	4.83	5.55	5.16
Pen 1	C	5.75	3.77	6.56	4.99	5		5.26	4.9	4.77	5.43	5.07
Pen 2	A	5.12	3.9	3.42	4.96	2.97		4.1	5.33	4.91	5.15	4.7
Pen 2	B	5.4	3.63	2.97	5.5	5.5		5.8	5.87	5	6.14	5.54
Pen 2	C	4.82	3.83	2.26	5.5	5.5		5.97	4.35	4.65	5.45	5.44
Pen 3	A	5.48	4.32	3.61	6.5	6.5		6.62	6.21	5.03	6.59	6.58
Pen 3	B	5.79	4.64	6.99	4.65	3.34		4.32	5.85	4.97	5.53	4.86
Pen 3	C	6.41	4.47	6.56								
50 m	A	3.52	4.08	3.32	2.21	2.97		2.8	2.54	3.3	3.97	3.03
50 m	B	4.13	3.57	3.14	2.76	2.8		2.97	3.53	4.06	4.76	3.82
50 m	C	3.25	3.5	3.32	2.33	5		4.46	4.58	3.59	2.17	4.24
150 m	A	2.92	1.34	1.38	2.24	2.09		1.83	2.41	2.1	2.84	1.48
150 m	B	3.03	1.41	1.38	2.03	2.97		2.68	2.58	2.28	2.39	1.75
150 m	C	3.1	1.44	1.44	2.2	2.28		2.03	2.38	2.28	2.81	1.62
QC Ctl 1	A	3.42	2.04	2.06	2.76	2.28		2.36	3.36	2.34	2.99	1.59
QC Ctl 1	B	3.39	2.17	1.38	3.4	2.65		3.16	3.62	2.05	3.34	1.5
QC Ctl 1	C	3.65	2.19	1.38	2.52	3.15		3.19	3.57	2.36	1	1.85
QC Ctl 2	A	2.22	1.45	1.38	2.23	1.93		1.45	1.22	1.94	1	1.49
QC Ctl 2	B	2.1	1.56	1.93	1.62	2.28		1.68	1.48	2.28	1.82	1.76
QC Ctl 2	C	2.22	1.91	1.38	2.12	2.02		1.68	1.57	2.22	1.81	1.55

SUMMARY ES SCORES

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

Station:	Repl.	Station	Organic loading	Sediment chemistry	Macrofauna	Overall ES
Pen 1	A	**Pen 1**	**5.87**	**3.43**	**5.35**	**5.02**
Pen 1	B	**Pen 1**	**5.99**	**3.74**	**5.19**	**4.98**
Pen 1	C	**Pen 1**	**5.75**	**5.17**	**5.06**	**5.15**
Pen 2	A	**Pen 2**	**5.12**	**3.66**	**4.59**	**4.46**
Pen 2	B	**Pen 2**	**5.4**	**3.3**	**5.62**	**5.13**
Pen 2	C	**Pen 2**	**4.82**	**3.05**	**5.27**	**4.78**
Pen 3	A	**Pen 3**	**5.48**	**3.97**	**6.29**	**5.75**
Pen 3	B	**Pen 3**	**5.79**	**5.82**	**4.79**	**5.1**
Pen 3	C	**Pen 3**	**6.41**	**5.52**		**5.965**
50 m	A	**50 m**	**3.52**	**3.7**	**2.97**	**3.17**
50 m	B	**50 m**	**4.13**	**3.36**	**3.53**	**3.56**
50 m	C	**50 m**	**3.25**	**3.41**	**3.77**	**3.65**
150 m	A	**150 m**	**2.92**	**1.36**	**2.14**	**2.06**
150 m	B	**150 m**	**3.03**	**1.4**	**2.38**	**2.25**
150 m	C	**150 m**	**3.1**	**1.44**	**2.23**	**2.16**
QC Ctl 1	A	**QC Ctl 1**	**3.42**	**2.05**	**2.53**	**2.52**
QC Ctl 1	B	**QC Ctl 1**	**3.39**	**1.78**	**2.82**	**2.67**
QC Ctl 1	C	**QC Ctl 1**	**3.65**	**1.79**	**2.52**	**2.49**
QC Ctl 2	A	**QC Ctl 2**	**2.22**	**1.42**	**1.61**	**1.63**
QC Ctl 2	B	**QC Ctl 2**	**2.1**	**1.75**	**1.85**	**1.86**
QC Ctl 2	C	**QC Ctl 2**	**2.22**	**1.65**	**1.85**	**1.85**