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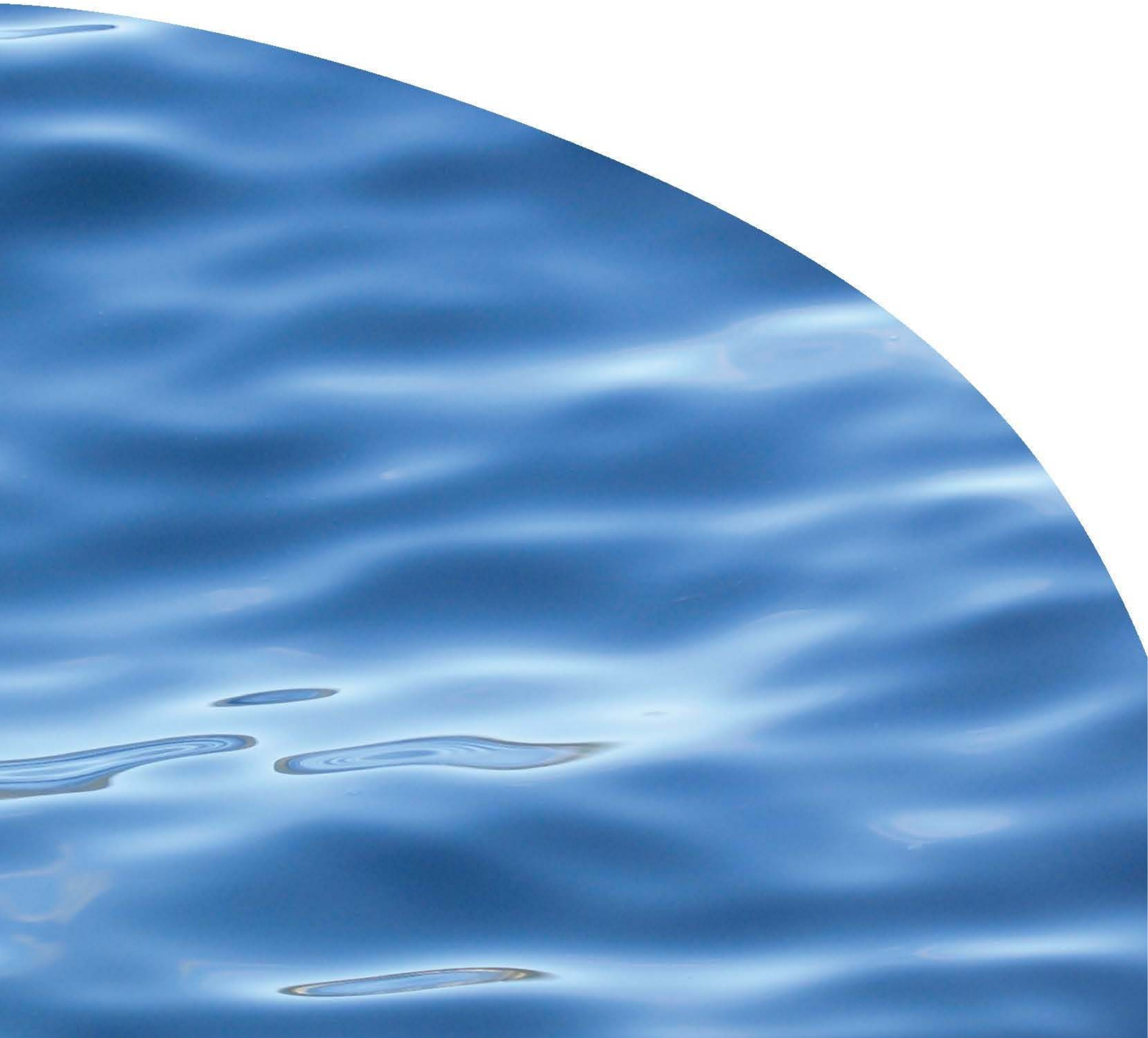
ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2013



ENVIRONMENTAL IMPACTS OF THE FORSYTH 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).

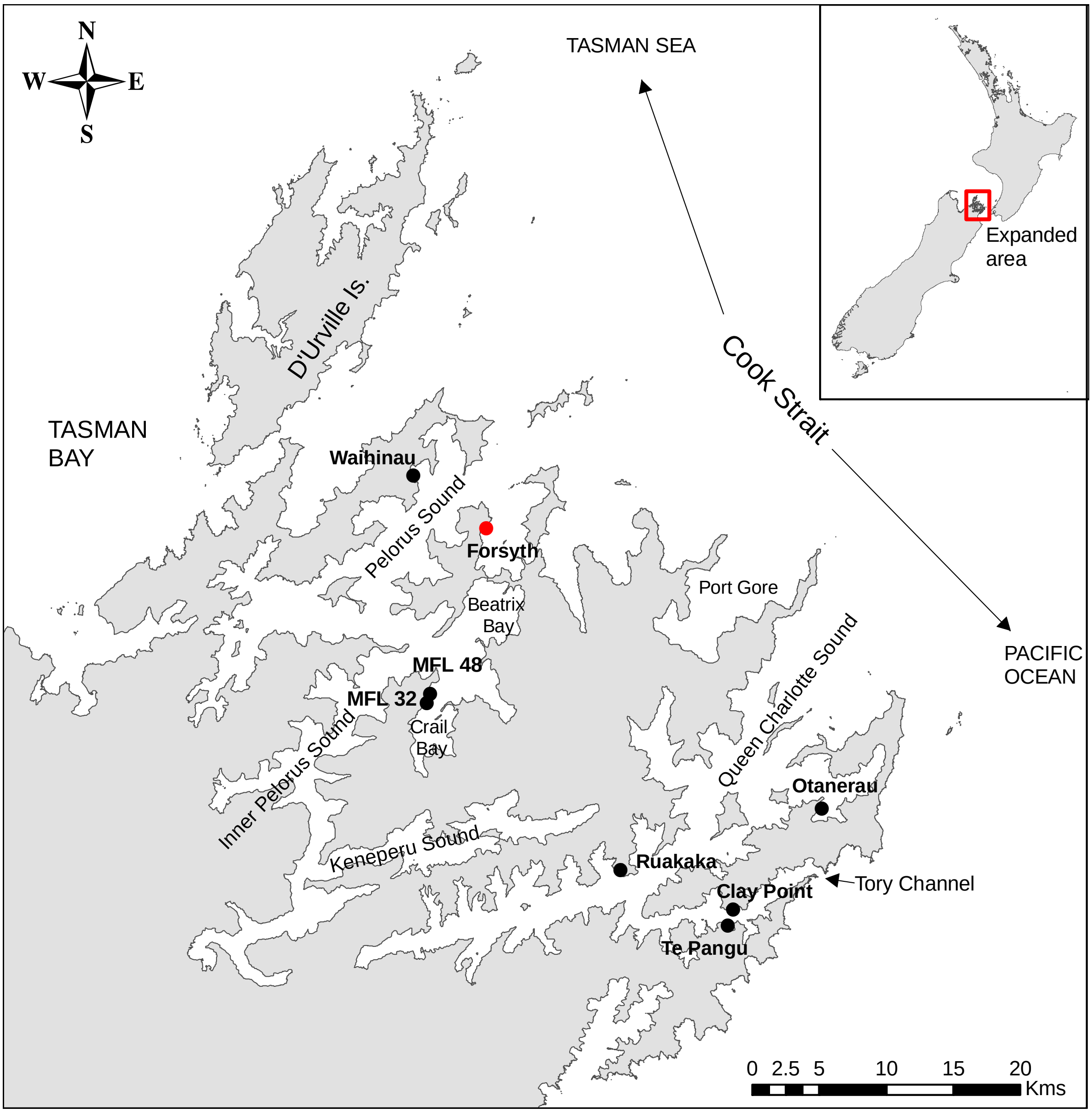

Figure 1. Map of the Marlborough Sounds area showing the location of the Forsyth Bay (FOR) salmon farm (red dot) along with NZ King Salmon's seven other farm sites (black dots).

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 using a combination of *in situ* depth profiling and discrete mid-water sampling at pen edge and down-current stations. Both TEP and CLA have adjacent rocky reef communities that are also monitored. This report presents the 2013 annual monitoring results for the Forsyth Bay (FOR) salmon farm.

1.1. Site details and history of feed usage

The FOR farm site was established in 1994 and, with average water current speeds of ~ 3 cm/s, it is considered a low-flow site.

Feed inputs at this farm have historically ranged from 1,987 to 3,261 tonnes (since 2001, Figure 2). The FOR site has been managed on a rotational/fallowing basis with the Waihinau Bay site, and was fallowed (*i.e.* farm removed and no feed input) for eight years prior to December 2009. During this period the seabed was able to recover considerably from what was a highly impacted state in 2001. By November 2009 the site was described as being almost fully recovered. The farm was re-established at Forsyth Bay for two years (December 2009–November 2011), before being fallowed again for 11 months (until October 2012). Between October 2012 and October 2013 (*i.e.* 13 months of occupation) the farm used 1,914 tonnes of feed, and in the 12-month period prior to the 2013 survey used a total of 1,783 tonnes (Figure 3)[1]. The site was fallowed again in October 2013 and was vacant at the time of monitoring.

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

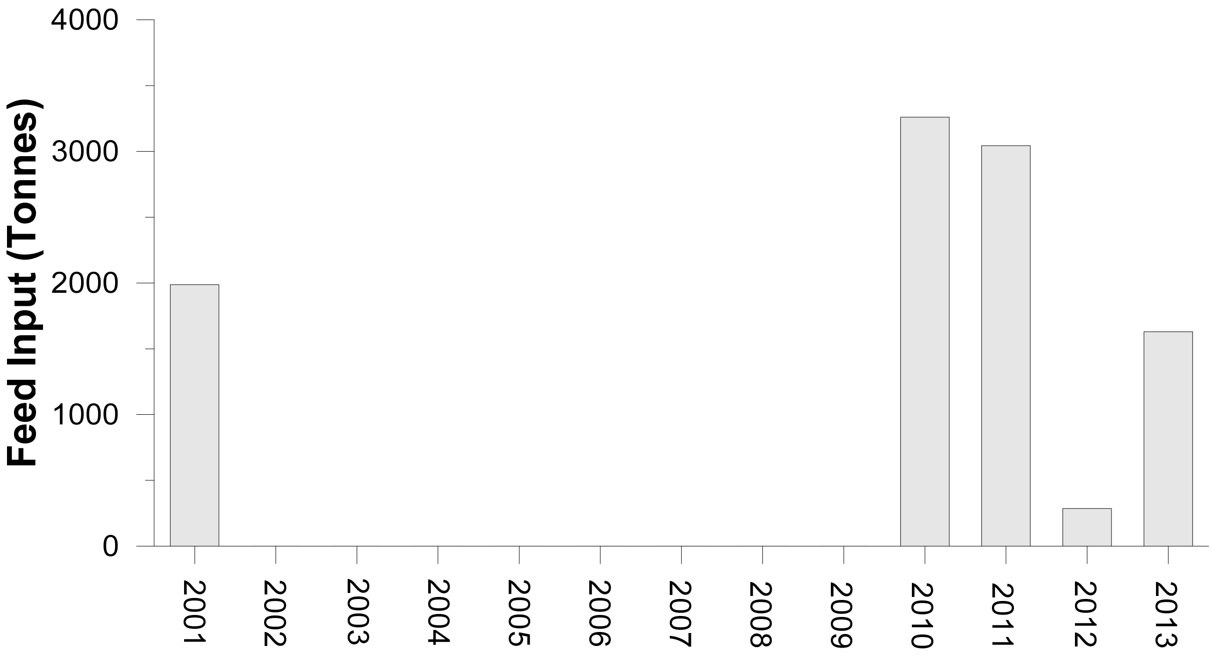

Figure 2. Annual feed inputs at the Forsyth Bay (FOR) salmon farm, 2001–2013.

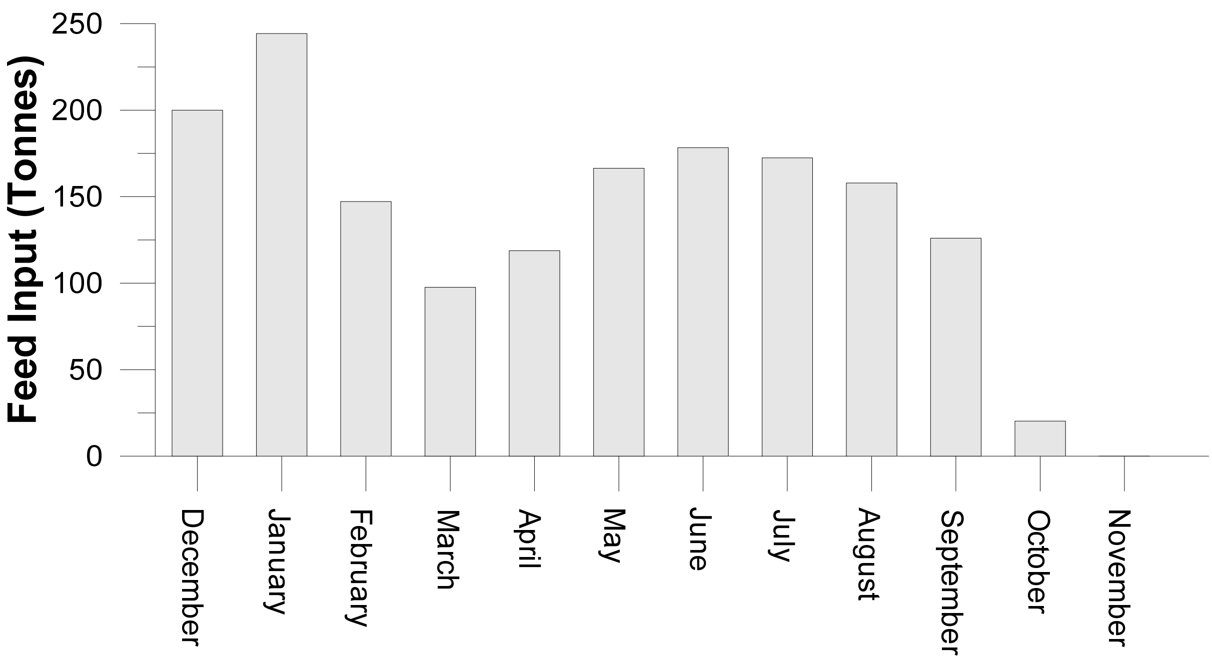

Figure 3. Monthly feed inputs at the Forsyth Bay (FOR) salmon farm from December 2012 to November 2013.

2. METHODS

Sampling at FOR was undertaken on 26 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 FOR salmon farm was monitored at the following locations:

- three net pen stations (at the edge of Zone 1)
- two stations along a transect aligned down-current from the pens at distances of 50 m (Zone 1–2 boundary) and 150 m (Zone 2–3 boundary) as specified under the zones concept.
- two reference or 'control' (*i.e.* Ctl-2 and Ctl-3) stations (Figure 4).

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

The net pen stations are normally sampled at the outer edge of the pens. At the time of sampling in 2013 however, as the FOR farm site was lying fallow pen stations were moved 10m inwards to avoid the mussel shell deposits at the outer edge of the farm. This allowed better collection of fully intact sediment samples almost free of shell material.

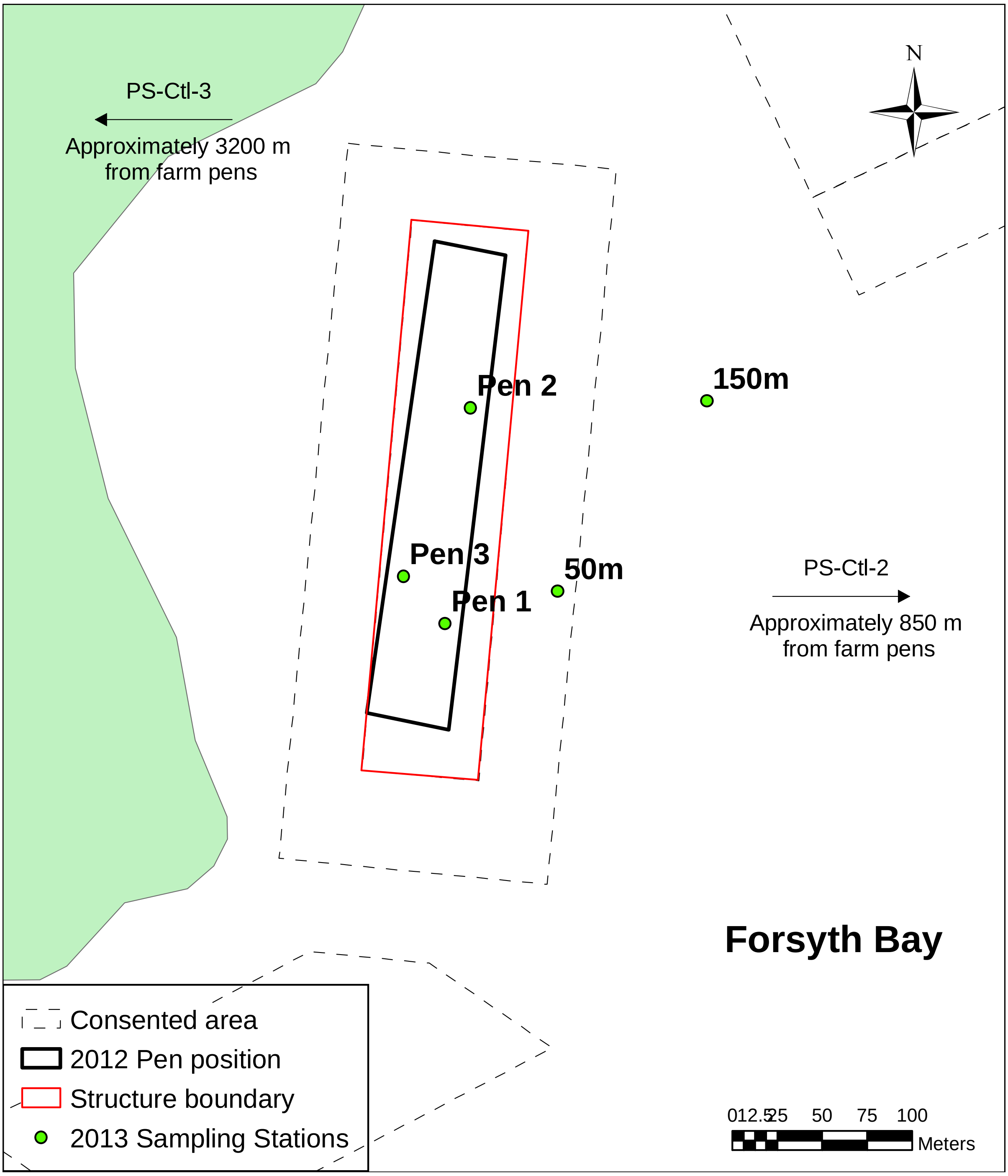

Figure 4. Soft sediment and inshore habitat sampling locations for the Forsyth Bay (FOR) site. 'Ctl' = Control. Position accuracy is ± 5 m.

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 outgassing 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). Refer to Keeley (2012) for an explanation of each of the biotic indices.

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[2] 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 total nitrogen (TN), nitrate-N (NO_3-N), nitrite-N (NO_2-N), ammoniacal-N (NH_4-N), dissolved reactive phosphorous (DRP) and total phosphorus (TP).

In situ water column profiles of dissolved oxygen, turbidity, temperature, salinity, and chlorophyll-*a*[3] were recorded at each FOR sampling station by slowly raising a data-logging sensor array from the seabed to the surface.

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

[3] 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 Forsyth Bay salmon 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. 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

Sediment organic matter levels were highly elevated (by 3.1–5.9 times) beneath the pens compared to the control stations (Figure 5), and generally showed a slight decreasing trend with increasing distance from the pens. Pen stations had average redox potentials of -28 to -139 Eh_{NHE}, MV. Average levels of total free sulphides under the pens (892–1,025 µM) were moderately elevated, consistent with observations of dark, gritty sediments that had moderate to strong sulphide odours (Appendix 1, Table A1.1). Redox potential at the 50 m station was positive (mean 62 Eh_{NHE} mV), although somewhat lower than 150 m and control stations (243, 146 Eh_{NHE} mV respectively). Average sulphide levels at the 50 m station were amost as high as pen stations (721 µM), and the 150 m station (209 µM), was elevated compared to the control stations (38 µM and 33 µM).

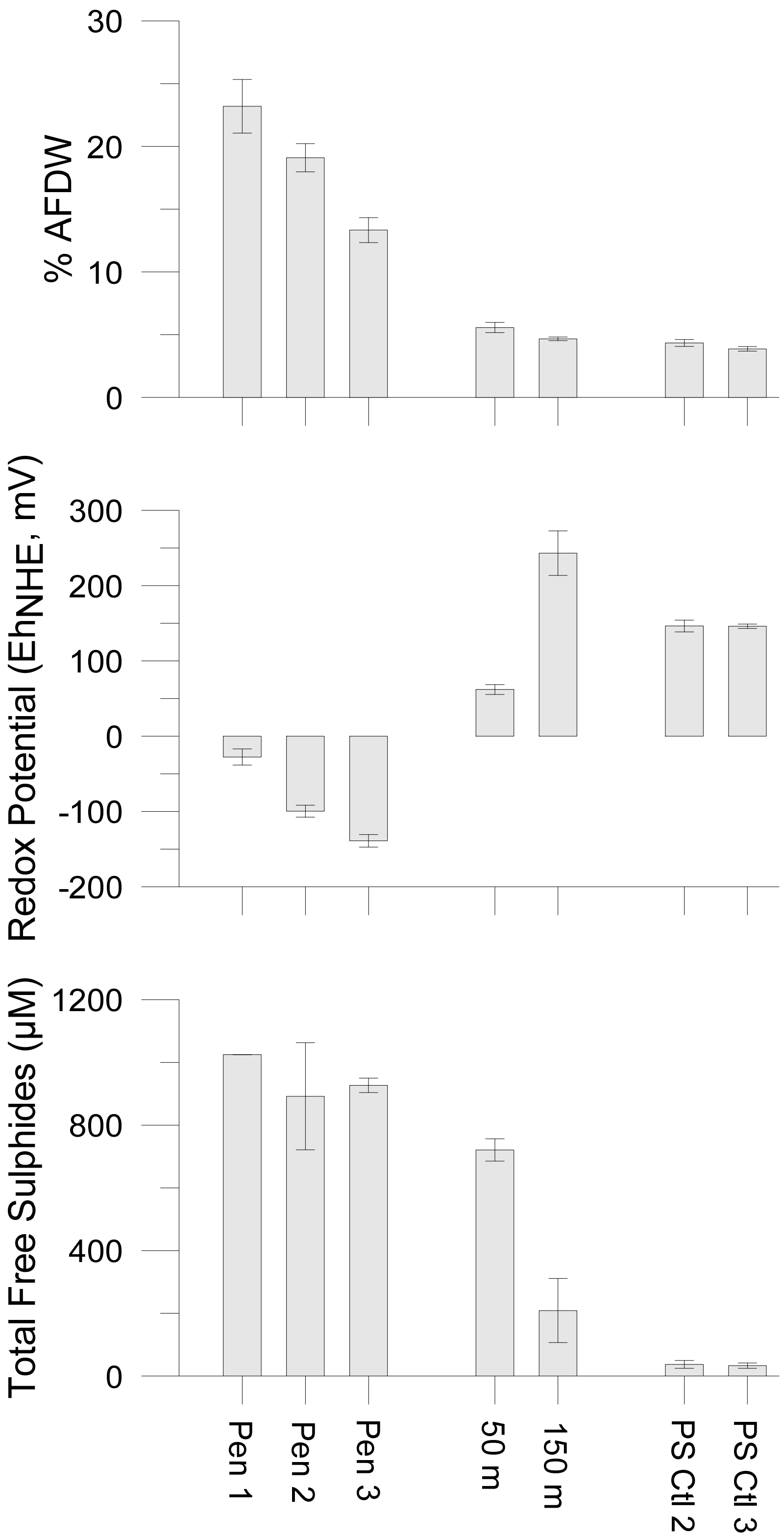

Figure 5. Organic matter (% AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM). Error bars = ±1 SE, n = 3. Samples with sulphide levels below the detection limit of 82 µM were assigned the detection level value.

3.1.2. Biological communities

The infauna communities at the pen stations were very highly impacted, as indicated by severely reduced numbers of taxa (~2–4 per core) and high total abundances (dominated by the opportunistic polychaete *Capitella capitata*) in comparison to the controls and down-current stations. Communities at the pen stations were characterised by lower diversity (H'), evenness (J'), richness (d) and ecological quality ratio (EQR) values compared with the 50 m, 150 m and control stations (Figure 5).. Total number of taxa, richness and ecological quality ratio (EQR) values were also reduced at the 50 m down-current station compared to the control stations. The Zone 3–4 boundary station (150 m) was comparable to the controls except that the number of taxa and richness was slightly reduced and AMBI was slightly elevated.

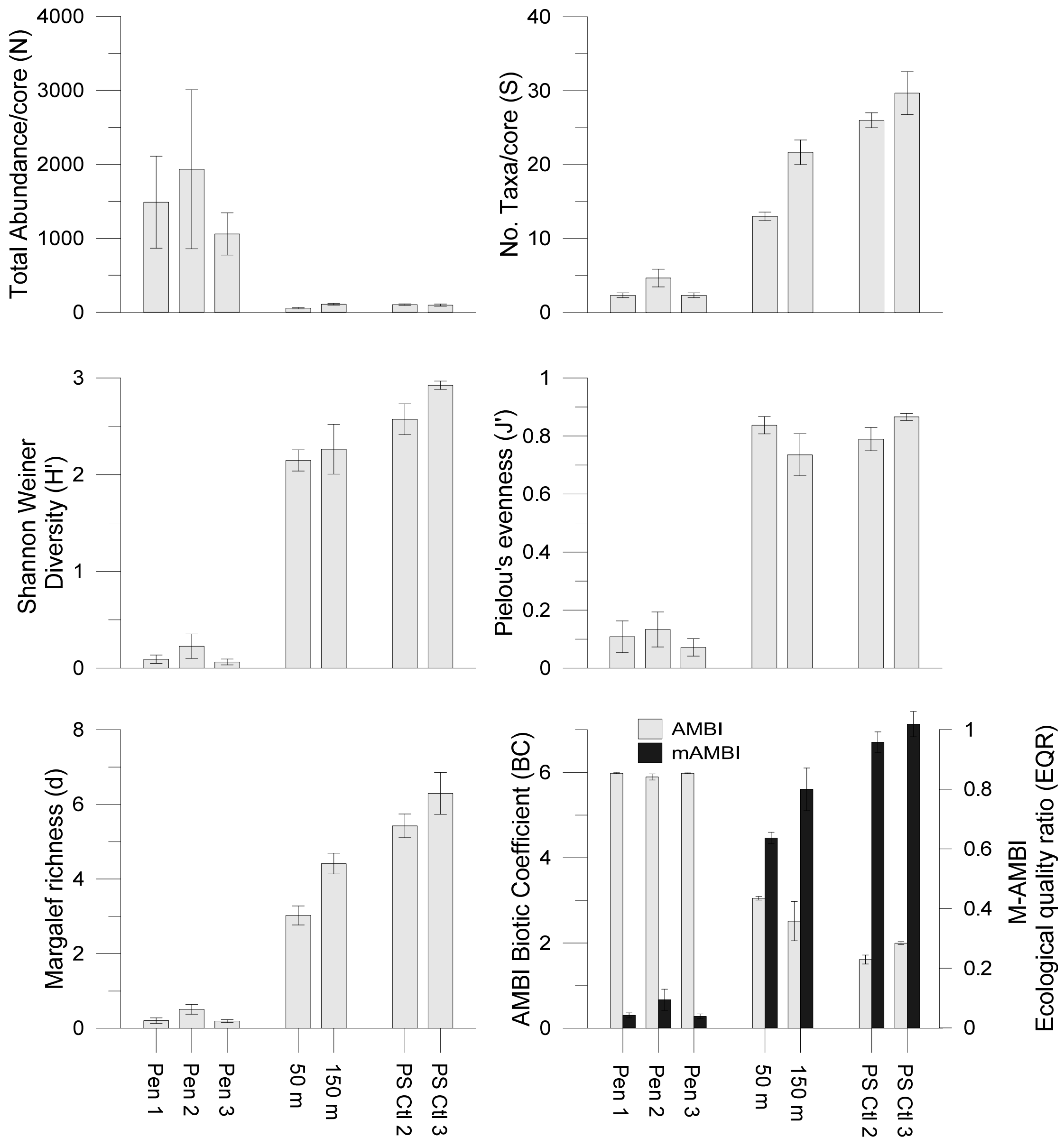

Figure 6. Infauna statistics. Error bars = ±1 SE, n = 3.

Video footage of the seabed from the pen stations revealed soft dark muddy sediments with some threads and patches of *Beggiatoa*-like bacteria. Also apparent was a surface layer of easily disturbed sedimentary material. Soft brown mud was featureless at the 50 m station, but shrimp or worm burrows were apparent at the 150 m station.

3.1.3. Copper and zinc concentrations

The combined average zinc concentration (across all pen stations) exceeded the ISQG-High trigger level for probably biological effects (410 mg/kg) with an average of 444 mg/kg (SE 36.8, n = 9) (Appendix 2, Figure A2.2). Average copper concentrations were just below the ISQG-Low trigger level for possible biological effects (65 mg/kg), with an average of 60.6 mg/kg (SE 4.3, n = 9). Average copper and zinc levels measured at control sites in past years have always been less than 10 mg/kg and 50 mg/kg respectively.

Zinc levels beneath the pens were very similar to those sampled in 2011 and 2012, but copper levels had decreased to be just over one quarter of the record high levels found in the sediments in 2012.

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	46	440
	2	88	490
	3	50	390
Pen 2	1	56	430
	2	62	610
	3	70	600
Pen 3	1	57	260
	2	51	370
	3	65	410

3.2. Water column

No potential effects of farming were detected in water column samples (Table 2).

Table 2. Water column sampling results at Forsyth Bay (FOR) salmon farm stations and the nearby Pelorus Sound (PS) Ctl-3 station. Values are averages in g/m^3, with 1 SE in brackets, n = 3 for all samples. Shaded boxes indicate that more than one replicate reading was below the analytical detection limits. Individual readings below the detection limit were assigned the detection limit value.

	Station			
	Pen 1	**50 m**	**150 m**	**PS-Ctl 3**
Nitrate-N (NO_3-N)	0.002 (0)	0.002 (0)	0.002 (0)	0.002 (0)
Nitrite-N (NO_2-N)	0.002 (0)	0.002 (0)	0.002 (0)	0.002 (0)
Ammonia (NH_4-N)	0.01 (0)	0.01 (0)	0.01 (0)	0.01 (0)
Total nitrogen (TN)	0.197 (0.007)	0.171 (0.015)	0.206 (0.018)	0.196 (0.013)
Dissolved reactive phosphorous (DRP)	0.004 (0)	0.004 (0)	0.004 (0.001)	0.005 (0.001)
Total phosphorus (TP)	0.006 (0.002)	0.008 (0.001)	0.008 (0.002)	0.019 (0.012)

Water column profiling casts at the Forsyth Bay farm site showed a stratified water column, with a notable decrease in temperature between 10 m and 15 m (Figure 7).

Chlorophyll-*a* concentrations (a proxy for phytoplankton biomass) were generally low in surface waters, but increased steadily below the thermocline to peak at around 25–30 m depth. Dissolved oxygen levels were similar across all stations, and showed the same pattern of a slight decrease in the very near-bottom waters, particularly at the net pen stations.

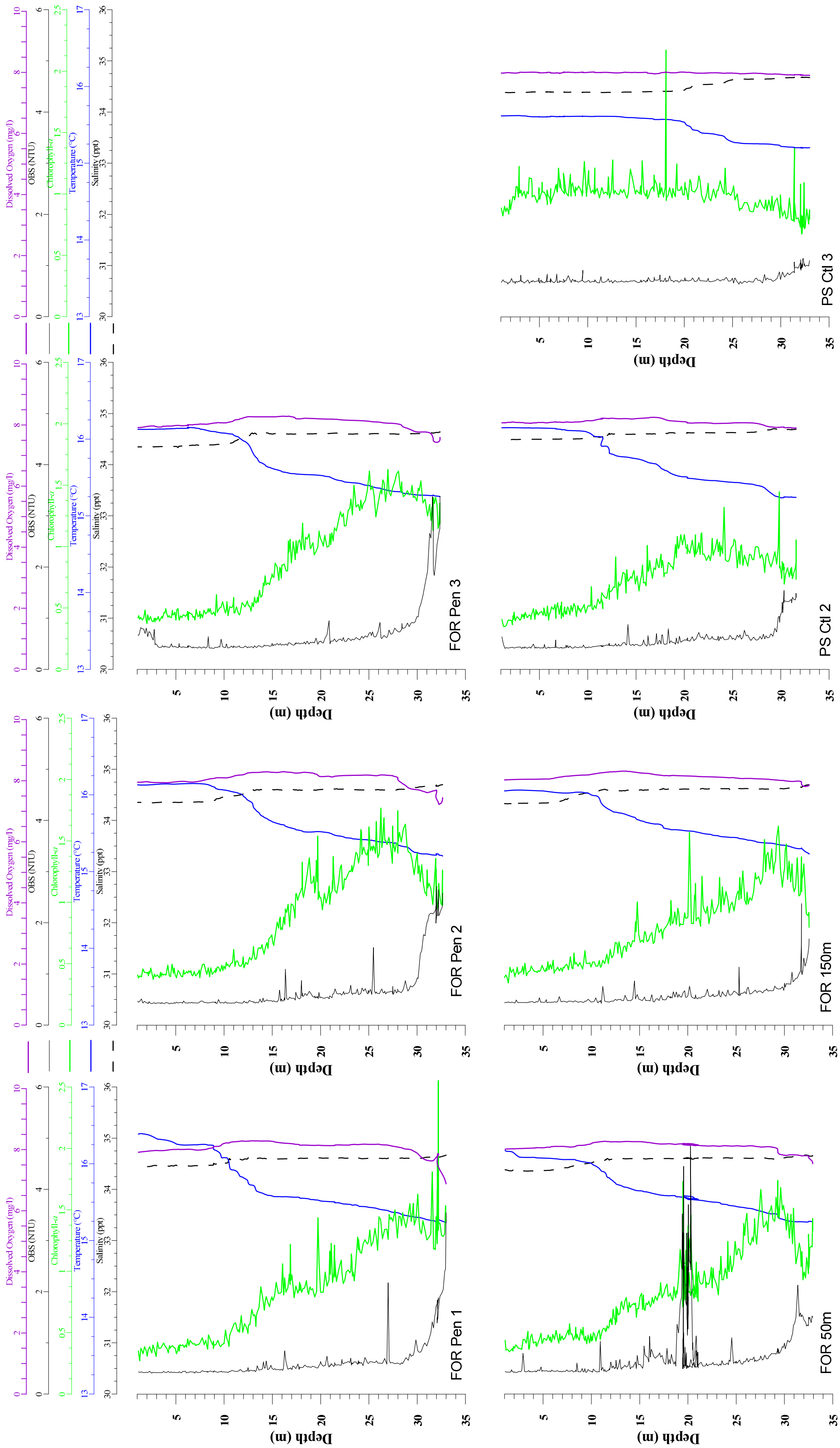

Figure 7. Dissolved oxygen, turbidity (optical backscatter), chlorophyll-*a*, temperature, and salinity, as measured by an *in situ* sensor array raised through the water column.

4. ASSESSMENT OF SEABED ENRICHMENT

4.1. Compliance framework

The 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, however, that this is an issue that is presently being addressed by a targeted working group and a new best management practice document is being developed for NZ King Salmon. This is likely to result in revised standards and consent conditions that may be introduced later in 2014.

However, Cawthron has previously endeavored 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. The current consent conditions and previously interpreted equivalent ES scores for the Forsyth Bay salmon farm are provided in Table 3.

Table 3. Environmental Quality Standards (EQS) for the Forsyth Bay (FOR) salmon farm described for each zone (taken from consent UO40412) and the 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 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*

Spatial zone	Spatial extent	Description and bottom line	Equivalent ES
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.

** In addition: Condition 15 specifies that the Zones can be distorted to allow for the effects of tidal currents.

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)[4] 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.

Station	Comments		ES (±SE)
Pen 1	%OM extremely elevated (~5xCtl's) redox just negative and sulphides moderately elevated. Total abundance high, number of taxa and richness very low (3 per core).	Organic loading:	6.3 (0.1)
		Sediment chemistry:	4 (0.1)
		Infauna composition:	6 (0.1)
		Overall:	**5.6 (0.1)**
Pen 2	%OM highly elevated (~4xCtl's) redox negative and sulphides moderately elevated. Total abundance high, number of taxa and richness very low (4.5 per core).	Organic loading:	6 (0.1)
		Sediment chemistry:	4.2 (0.1)
		Infauna composition:	5.7 (0.2)
		Overall:	**5.5 (0.2)**
Pen 3	%OM strongly elevated (~3xCtl's) redox strongly negative and sulphides moderately elevated. Total abundance high, number of taxa and richness very low (3 per core).	Organic loading:	5 (0.2)
		Sediment chemistry:	4.4 (0.1)
		Infauna composition:	6 (0.1)
		Overall:	**5.6 (0.1)**
50 m (Zone 1–2 boundary)	%OM slightly elevated, redox reduced and sulphides somewhat elevated. Total abundance normal, but number of taxa (50% of Ctl's) and richness reduced.	Organic loading:	2.7 (0.2)
		Sediment chemistry:	3.4 (0.1)
		Infauna composition:	2.8 (0.1)
		Overall:	**2.9 (0.1)**

[4] 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	Comments		ES (±SE)
150 m (Zone 2–3 boundary)	%OM normal, redox normal and sulphides slightly elevated. Total abundance diversity and evenness normal, number of taxa and richness slightly reduced.	Organic loading:	2.3 (0.1)
		Sediment chemistry:	1.9 (0.1)
		Infauna composition:	2.2 (0.2)
		Overall:	**2.2 (0.1)**
FS-Ctrl 1	Normal background conditions	Organic loading:	2.2 (0.1)
		Sediment chemistry:	1.9 (0.1)
		Infauna composition:	1.8 (0.1)
		Overall:	**1.8 (0.1)**
FS-Ctrl 3	Normal background conditions	Organic loading:	2 (0.1)
		Sediment chemistry:	1.9 (0)
		Infauna composition:	1.7 (0)
		Overall:	**1.7 (0)**

4.3. Historical comparison

A comparison of the last four monitoring assessments (conducted at 12-monthly intervals) showed that the ES score had increased substantially in the past year at all pen stations (Table 5). They were, however, still lower (less impacted) than 2011 levels. A minor increase occurred at 50 m from the pens, while ES scores from the 150 m station and controls had not changed markedly.

Table 4. Comparison of enrichment stage (ES) scores for assessments from monitoring in 2010–2013.

	Enrichment stage (s.e.)			
Station	**2010**	**2011**	**2012+**	**2013**
Pen 1	5.6	6.13 (0.13)	3.76 (0.20)	**5.6 (0.1)**
Pen 2	5.6	5.73 (0.13)	4.25 (0.37)	**5.5 (0.2)**
Pen 3	5.2	6.10 (0.15)	4.80 (0.15)	**5.6 (0.1)**
50 m (Zone 1–2 boundary)	3.6	3.03 (0.12)	2.52 (0.06)	**2.9 (0.1)**
150 m (Zone 2–3 boundary)	2.2	2.07 (0.12)	2.29 (0.08)	**2.2 (0.1)**
FS-Ctrl 1	1.8	2.13 (0.03)	1.84 (0.05)	**1.8 (0.1)**
FS-Ctrl 3	2.0	1.80 (0.10)	1.59 (0.02)	**1.7 (0)**

+ Site was fallowed Dec 2011–Oct 2012

5. SUMMARY AND CONCLUSIONS

5.1. Seabed enrichment

The macrofauna at the three pen stations consistently exhibited ES 5.5–6 conditions, where %OM was very high and opportunistic taxa were reasonably abundant, and the number of taxa and associated richness was very low. This is typical of an early post-peak abundance situation. Interestingly, the sediment chemistry results (sulphides and to a lesser extent, redox) indicated less impacted conditions; sediment chemistry ES ~4–4.5 equivalent. This is possibly because the farm had recently been fallowed and sediment chemistry tends to recover more rapidly than biological communities. The macrofauna was still highly impacted and the large amount of residual organic matter indicated that the seabed will remain heavily impacted for several months to come. Overall ES was 5.5 to 5.6.

The Zone 1–2 boundary station (50 m) was clearly moderately enriched with an overall ES of 2.9. The Zone 2–3 boundary station at 150 m did show very subtle signs of enrichment (due to slightly reduced number of taxa and richness and slightly elevated sulphides), but most of the indicators were within the range of normal background conditions.

In terms of consistency with the existing consent conditions, the absence of azoic conditions from any of the pen stations (even in individual replicate samples), suggested that the results are consistent with the assumed EQS. The Zone 1–2 and 2–3 boundary station conditions were also consistent with the assumed EQS. As the site has been fallowed, these considerations are not immediately relevant to farming operations, but should be considered for the future operation of the farm, and in particular regarding reinstatement of farming activity.

5.2. Water column

Water column information relates to a period when no salmon stocks were on site. No remnant impacts of farming activities (*e.g*. significant reduction of near-bottom DO or elevation of mid-water nutrient concentrations) due to benthic enrichment-related processes was detected.

5.3. Copper and zinc

Metal concentrations beneath the net pens were high; zinc levels exceeded the best available guideline threshold for probable biological effects (*i.e*. ANZECC ISQG-High) and copper levels were marginally below the threshold for possible biological effects (*i.e.* ANZECC ISQG-Low). In terms of a management response, the Forsyth site is presently fallowed and some seabed remediation experiments have been proposed for implementation during the upcoming months. As part of this work, copper and zinc concentrations will be reassessed at regular intervals during recovery.

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.

Borja A, Franco J, Muxika. I 2004. The biotic indices and the Water Framework Directive: the required consensus in the new benthic monitoring tools. Mar. Pollut. Bull. 48, 405-408.

Hargrave BT, Holmer M, Newcombe CP 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Mar. Pollut. Bull. 56, 810-824.

Keeley N. 2011. NZKS Annual Monitoring Plan (revised Oct 2010). Prepared for New Zealand King Salmon Company Ltd. Cawthron Report No. 1872. 28 p. plus appendices.

Keeley N. 2012. Assessment of Enrichment Stage and Compliance for Salmon Farms — 2011. Prepared for New Zealand King Salmon Company Limited. Report No. 2080. 15 p.

Keeley N 2013. New Zealand King Salmon Company Limited Annual Monitoring Programme and Methods: 2013. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2427. 15 p.

7. APPENDICES

Appendix 1. Summary of 2013 results.

Table A1.1. Summary of the physical and chemical properties of sediments from the Forsyth Bay (FOR) salmon farm stations during the 2013 monitoring survey. Bracketed values = 1 SE.

	Station	Units	Pen-1	Pen 2	Pen 3	50 m	150 m	PS-Ctl-2	PS-Ctl-3
	Depth	m	32	34	32	32	32	31	34
Sediments	AFDW	%	23.2 (2.1)	19.1 (1.1)	13.3 (1)	5.6 (0.4)	4.7 (0.1)	4.3 (0.3)	3.9 (0.2)
	Redox	Eh_{NHE}, mV	-27.7 (10.7)	-99.7 (7.9)	-139 (8.4)	62 (6.6)	243 (29.6)	146.3 (7.8)	146 (2.9)
	Sulphides	µM	1,025.1 (0)	892 (170.8)	926.9 (23.2)	720.8 (35.6)	209 (102.4)	37.5 (12.5)	33.3 (8.5)
	Bacterial mat	-	Yes	Yes	Yes	None	None	None	None
	Out-gassing	-	On disturbance	No	No	No	No	No	No
	Odour	-	Mild to moderate	Mild to moderate	Mild to moderate	Mild	None	None	None
Infauna statistics	Abundance	No./core	1,488.3 (621.5)	1,933.3 (1076)	1,059 (285.6)	56 (10)	109 (13.1)	102.3 (9.8)	96.7 (13.6)
	No. taxa	No./core	2.3 (0.3)	4.7 (1.2)	2.3 (0.3)	13 (0.6)	21.7 (1.7)	26 (1)	29.7 (2.9)
	Richness	Stat.	0.2 (0.1)	0.5 (0.1)	0.2 (0)	3 (0.3)	4.4 (0.3)	5.4 (0.3)	6.3 (0.6)
	Evenness	Stat.	0.1 (0.1)	0.1 (0.1)	0.1 (0)	0.8 (0)	0.7 (0.1)	0.8 (0)	0.9 (0)
	Shannon-Weiner	Index	0.1 (0)	0.2 (0.1)	0.1 (0)	2.1 (0.1)	2.3 (0.3)	2.6 (0.2)	2.9 (0)
	AMBI	Index	6 (0)	5.9 (0.1)	6 (0)	3 (0)	2.5 (0.5)	1.6 (0.1)	2 (0)
	M-AMBI	Index	0 (0)	0.1 (0)	0 (0)	0.6 (0)	0.8 (0.1)	1 (0)	1 (0)
	BQI	Index	0.9 (0.1)	1.3 (0.2)	0.9 (0.1)	4.3 (0.1)	7.2 (0.5)	10.2 (0.3)	8.9 (0.3)

Appendix 2. Historical comparisons.

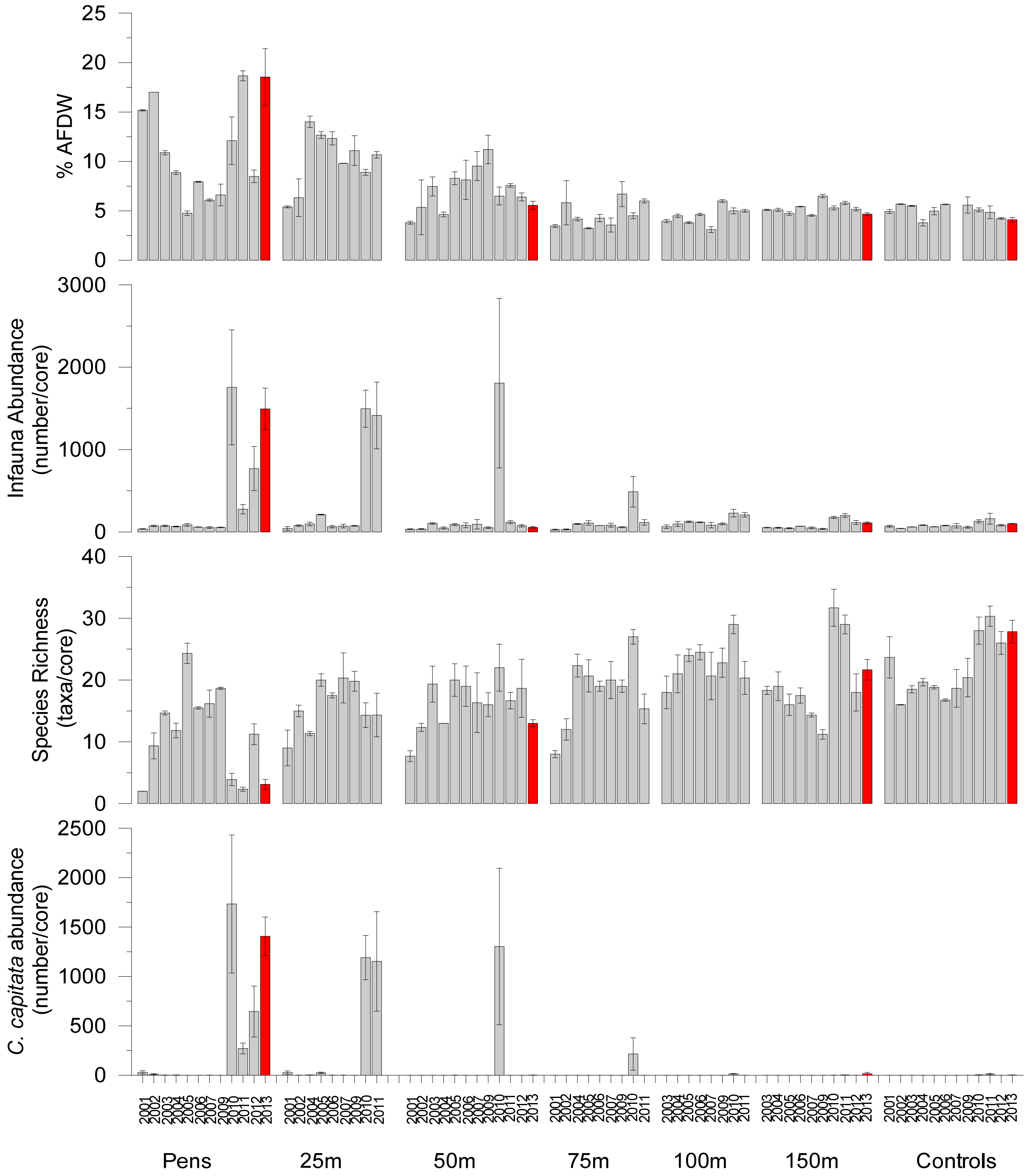

Figure A2.1. Comparison of mean ash-free dry weight (AFDW), infauna abundance and richness (No. taxa), and C. *capitata* densities recorded at Forsyth Bay (FOR) salmon farm since 2001. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000 guidelines). Error bars = ±1 SE.

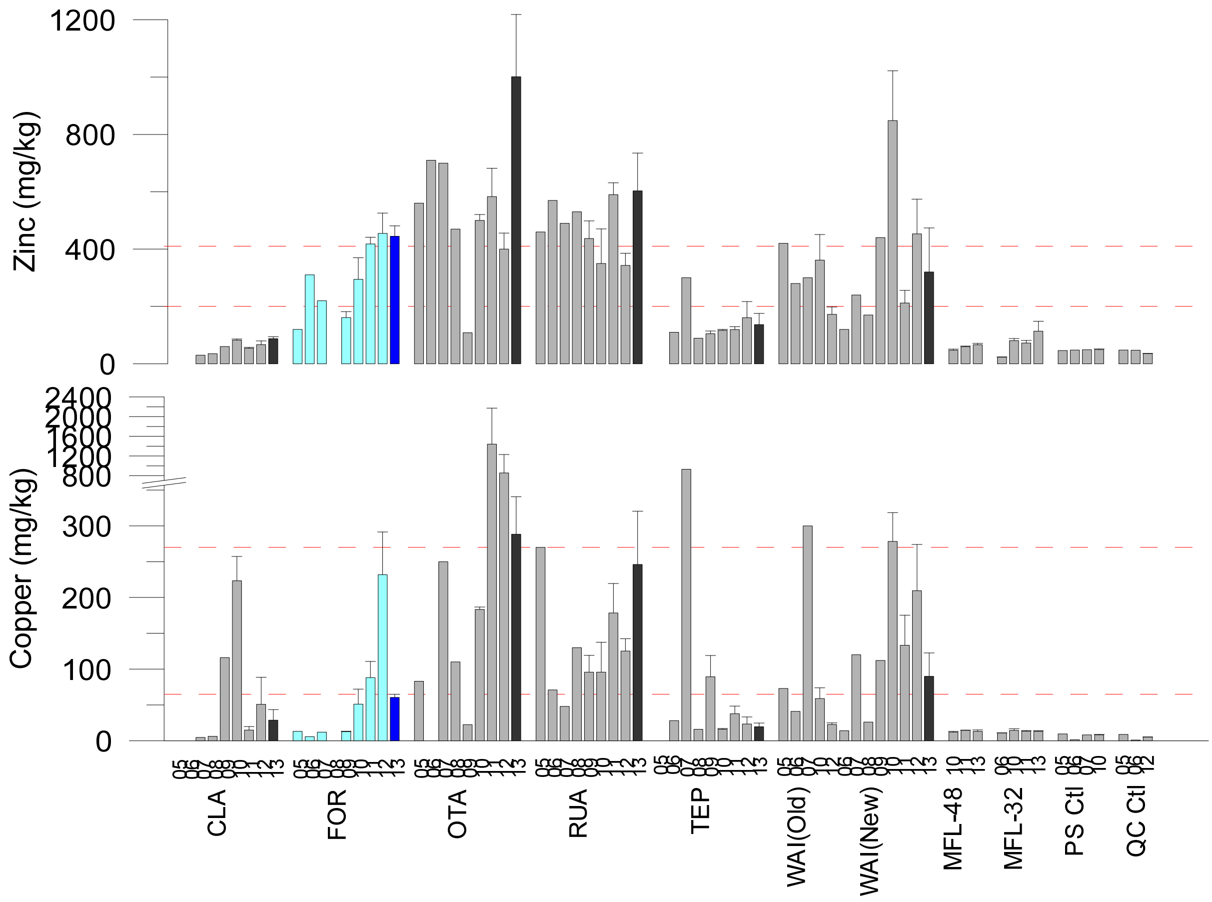

Figure A2.2. Comparison of the last nine years of annual monitoring data for sediment copper and zinc concentrations beneath all eight NZ King Salmon farms and two control stations (PS = Pelorus Sound, QC = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG-High and -Low trigger levels. Forsyth Bay (FOR) salmon farm data are in blue.

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

SITE INFORMATION
Date: Nov-13
Farm/site: Forsyth
Flow envi LF

RAW DATA (to be entered N S J' d H'(loge)

Station:	Repl.	TOM	Redox	Sulphides	Abundance	No. Taxa	P. evenness	Richness	SWDI	AMBI	M-AMBI	BQI
Pen 1	A	23	-15	1025.1	1798	2	0.01	0.13	0.00	6.00	0.03	0.83
Pen 1	B	27	-49	1025.1	291	3	0.12	0.35	0.14	5.99	0.06	1.06
Pen 1	C	19.6	-19	1025.1	2376	2	0.19	0.13	0.13	5.96	0.04	0.84
Pen 2	A	17.1	-115	602.1	3971	7	0.24	0.72	0.46	5.75	0.16	1.68
Pen 2	B	21	-95	880.5	315	4	0.13	0.52	0.18	5.94	0.08	1.22
Pen 2	C	19.2	-89	1193.3	1514	3	0.03	0.27	0.03	5.99	0.04	1.05
Pen 3	A	11.5	-125	880.5	965	2	0.01	0.15	0.01	6.00	0.03	0.83
Pen 3	B	13.6	-138	950.0	1594	3	0.10	0.27	0.11	5.97	0.05	1.06
Pen 3	C	14.9	-154	950.0	618	2	0.10	0.16	0.07	5.98	0.04	0.83
50 m	A	4.8	70	649.7	76	12	0.81	2.54	2.01	3.08	0.60	4.37
50 m	B	6.2	49	756.3	46	13	0.80	3.13	2.06	2.96	0.63	4.44
50 m	C	5.7	67	756.3	46	14	0.90	3.40	2.37	3.10	0.67	4.16
150 m	A	4.4	195	83.5	115	20	0.59	4.00	1.77	3.35	0.66	6.24
150 m	B	4.7	237	131.7	128	25	0.82	4.95	2.64	2.44	0.89	7.32
150 m	C	4.9	297	411.8	84	20	0.79	4.29	2.38	1.75	0.85	8.02
PSCTL2	A	3.8	159	31.1	88	27	0.85	5.81	2.79	1.72	0.99	9.60
PSCTL2	B	4.5	132	19.7	121	24	0.71	4.80	2.26	1.71	0.89	10.21
PSCTL2	C	4.7	148	61.6	98	27	0.81	5.67	2.67	1.40	1.00	10.79
PSCTL3	A	3.5	141	49.0	119	35	0.84	7.11	3.00	1.97	1.10	9.30
PSCTL3	B	4	146	19.7	99	25	0.89	5.22	2.85	1.95	0.95	9.10
PSCTL3	C	4.1	151	31.1	72	29	0.87	6.55	2.92	2.06	1.00	8.44

ES equivalents

Station:	Repl.	TOM	Redox	Sulphides	Abundance	No. Taxa	P. evenness	Richness	SWDI	AMBI	M-AMBI	BQI
Pen 1	A	6.38	4.26	3.6	6	6		6.41	6.21	5.03	6.52	6.16
Pen 1	B	6.39	4.57	3.6	6.5	6.5		6.07	5.98	5.02	6.36	5.9
Pen 1	C	6.12	4.3	3.6	5.04	6		6.41	5.98	5	6.42	6.15
Pen 2	A	5.79	5.16	2.98	5.48	5		5.52	5.42	4.85	5.78	5.23
Pen 2	B	6.26	4.98	3.42	6.5	6.5		5.81	5.9	4.98	6.24	5.72
Pen 2	C	6.08	4.93	3.79	6	6		6.19	6.16	5.02	6.43	5.91
Pen 3	A	4.61	5.25	3.42	6	6		6.39	6.2	5.03	6.52	6.16
Pen 3	B	5.12	5.37	3.51	6	6		6.19	6.02	5	6.37	5.9
Pen 3	C	5.4	5.52	3.51	6.5	6.5		6.37	6.09	5.02	6.47	6.16
50 m	A	2.38	3.5	3.07	2.1	3.55		3.34	2.76	2.85	3.4	2.95
50 m	B	2.92	3.69	3.24	1.67	3.34		2.8	2.67	2.76	3.25	2.91
50 m	C	2.73	3.53	3.24	1.67	3.15		2.6	2.15	2.86	3.04	3.09
150 m	A	2.22	2.37	1.36	2.46	2.28		2.18	3.17	3.05	3.1	1.97
150 m	B	2.34	2	1.64	2.55	1.92		1.72	1.68	2.37	1.85	1.63
150 m	C	2.42	1.46	2.59	2.19	2.28		2.02	2.12	1.86	2.09	1.49
PSCTL2	A	1.97	2.7	0.94	2.23	1.87		1.49	1.42	1.84	1.33	1.45
PSCTL2	B	2.26	2.94	0.83	2.5	1.96		1.78	2.33	1.83	1.87	1.53
PSCTL2	C	2.34	2.8	1.2	2.32	1.87		1.52	1.63	1.6	1.28	1.65
PSCTL3	A	1.85	2.86	1.1	2.48	2.21		1.5	1.06	2.02	1	1.43
PSCTL3	B	2.06	2.82	0.83	2.33	1.92		1.63	1.32	2.01	1.52	1.43
PSCTL3	C	2.1	2.77	0.94	2.06	1.88		1.45	1.2	2.09	1	1.45

SUMMARY ES SCORES

	Organic loading	Sediment chemistry	Macrofauna	Overall ES
Variable group weightings:	**0.1**	**0.2**	**0.7**	
Pen 1	**6.38**	**3.93**	**6.05**	**5.66**
Pen 1	**6.39**	**4.09**	**6.05**	**5.69**
Pen 1	**6.12**	**3.95**	**5.86**	**5.5**
Pen 2	**5.79**	**4.07**	**5.33**	**5.12**
Pen 2	**6.26**	**4.2**	**5.95**	**5.63**
Pen 2	**6.08**	**4.36**	**5.96**	**5.65**
Pen 3	**4.61**	**4.34**	**6.04**	**5.56**
Pen 3	**5.12**	**4.44**	**5.93**	**5.55**
Pen 3	**5.4**	**4.52**	**6.16**	**5.76**
50 m	**2.38**	**3.29**	**2.99**	**2.99**
50 m	**2.92**	**3.47**	**2.77**	**2.93**
50 m	**2.73**	**3.39**	**2.65**	**2.81**
150 m	**2.22**	**1.87**	**2.6**	**2.42**
150 m	**2.34**	**1.82**	**1.96**	**1.97**
150 m	**2.42**	**2.03**	**2.01**	**2.06**
PSCTL2	**1.97**	**1.82**	**1.66**	**1.72**
PSCTL2	**2.26**	**1.89**	**1.97**	**1.98**
PSCTL2	**2.34**	**2**	**1.7**	**1.82**
PSCTL3	**1.85**	**1.98**	**1.67**	**1.75**
PSCTL3	**2.06**	**1.83**	**1.74**	**1.79**
PSCTL3	**2.1**	**1.86**	**1.59**	**1.7**