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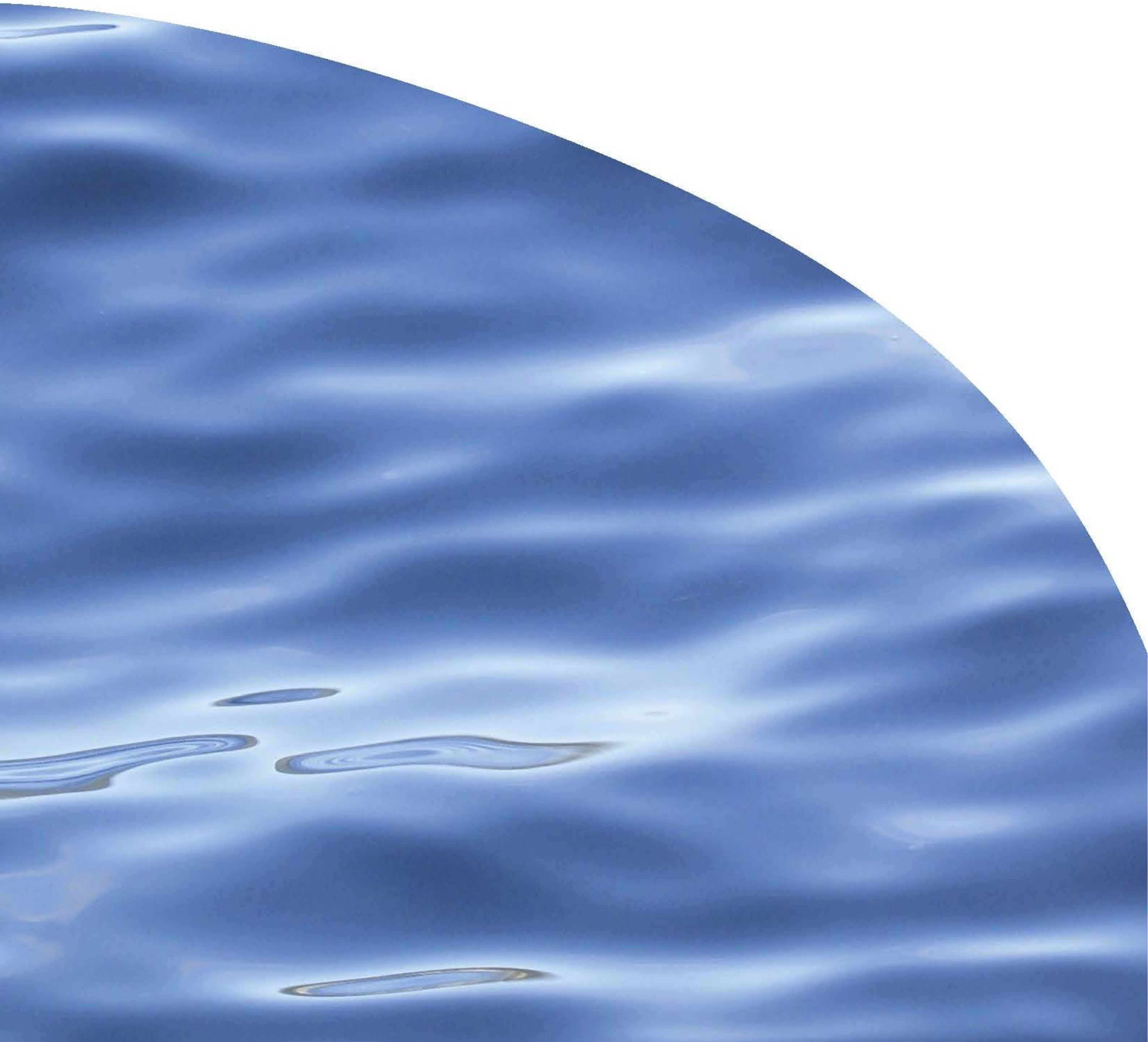
ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2014



ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2014

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Prepared for The New Zealand King Salmon Co. Limited.

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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), eight of which were farmed prior to and/or during 2014: 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). However, MFL-48, MFL-32, and FOR were not farmed during 2014.

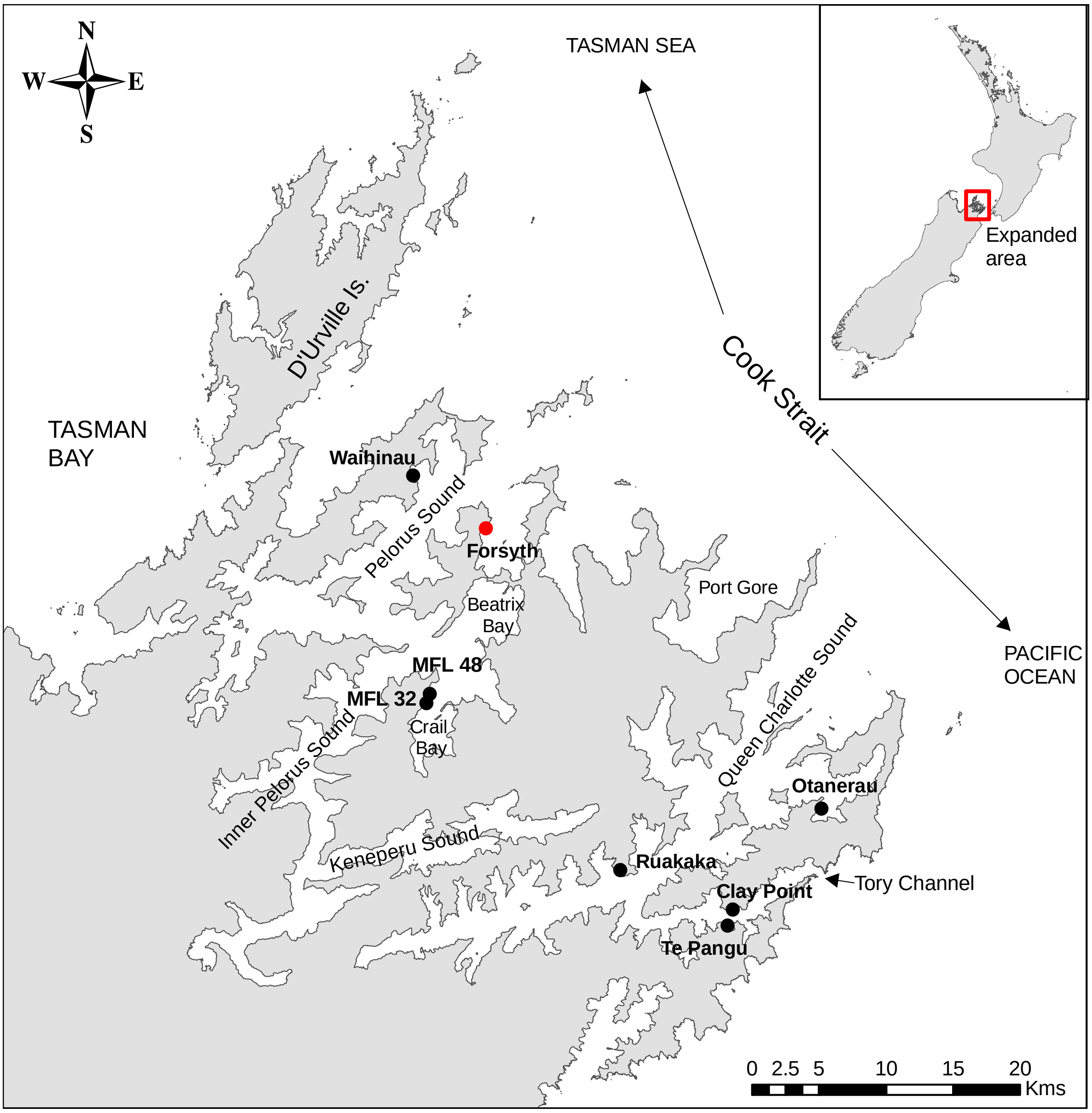

Figure 1. Map of the Marlborough Sounds area showing the location of the Forsyth Bay (FOR) salmon farm (red dot) along with NZ King Salmon's seven other operational farm sites (black dots).

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 (Keeley 2014) 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, water column monitoring was undertaken at all NZ King Salmon farm sites using *in situ* water column profiling generally at pen edge and down-current stations. Both TEP and CLA have adjacent rocky reef communities that are also monitored. The present report presents the 2014 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. There is an average water current speeds of ~ 3 cm/s, so it is considered a low-flow site. Water depth at the farm site is ~33 m.

The FOR site has been managed on a rotational/fallowing basis with the Waihinau Bay site (Figure 2). The site has been fallowed three times since its establishment, most recently in in October 2013. As such, the FOR site lay fallow at the time of the November 2014 monitoring.

Feed inputs at this farm have historically ranged from 1,987 to 3,261 tonnes per annum (since 2001, Figure 3). 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].

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

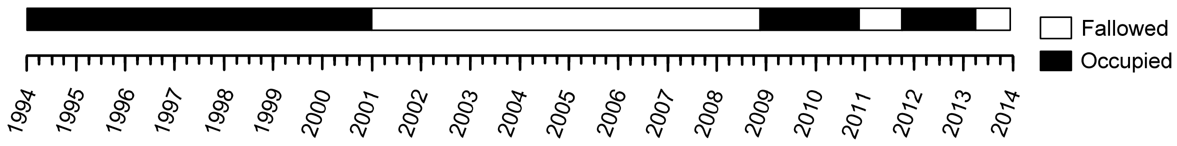

Figure 2. Operational state of the farm (occupied *vs*. fallowed) from 1994–2014.

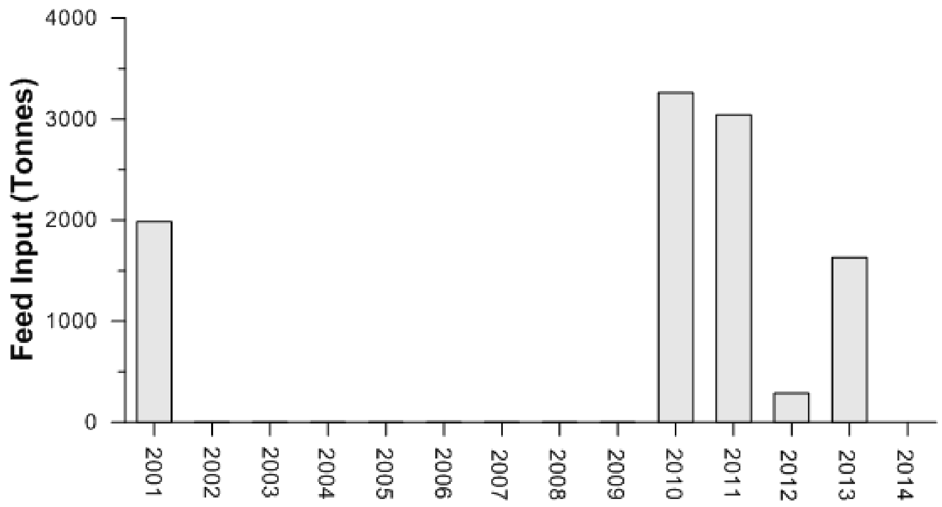

Figure 3. Annual feed inputs at the Forsyth Bay (FOR) salmon farm, 2001–2014.

2. METHODS

Sampling for the FOR annual monitoring was undertaken on 5 November 2014. 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 2014). 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.

Monitoring was reduced from that undertaken in the 2013 survey (see Section 2.1). Some stations had only a subset (*i.e.* sediment chemistry indicators) of variables sampled (hereafter 'indicator monitoring'), instead of the full suite. This was rationalised because the site had been fallowed for 12 months prior to sampling in 2014. In addition, a seabed remediation study was undertaken at the site in March–August 2014 (Keeley *et al.* in press). These March results have been used in this report to supplement the reduced annual monitoring dataset.

2.1. Soft-sediment habitats

2.1.1. Sampling locations

Depths at the FOR salmon farm monitoring stations ranged from 29–33 m (Appendix 1). Stations are described as follows (also see Figure 4):

- Three net pen stations; Pen 1, Pen 2 and Pen 3.
- Two stations along a transect aligned down-current of the pens; 50 m (Zone 1–2 boundary) and 150 m (Zone 2–3 boundary).
- Two reference or 'control' stations; PS Ctl-2 and PS Ctl-3.

The net pen stations are normally sampled at the outer edge of the pens. However, the time of sampling in 2014, the site was lying fallow (so there were no pens). As such, pen station samples were collected inside the old pen edge boundary. In addition, a mussel farm was located over the 2013 Pen 3 sampling location, and the Pen 3 station was therefore relocated to the north of the Pen 2 station.

The standard sampling regime (see Section 2.1.2) was undertaken at all stations except at the 150 m, 50 m and Pen 3 stations in 2013, where indicator monitoring was carried out. Supplementary data from the March 2014 sampling (Keeley *et al.* in press) included eight pen stations (HA, IR, RE and UT) and two control stations (Ctl1 and Ctl2; Figure 4)**.** The March control stations differ from the annual monitoring control stations.

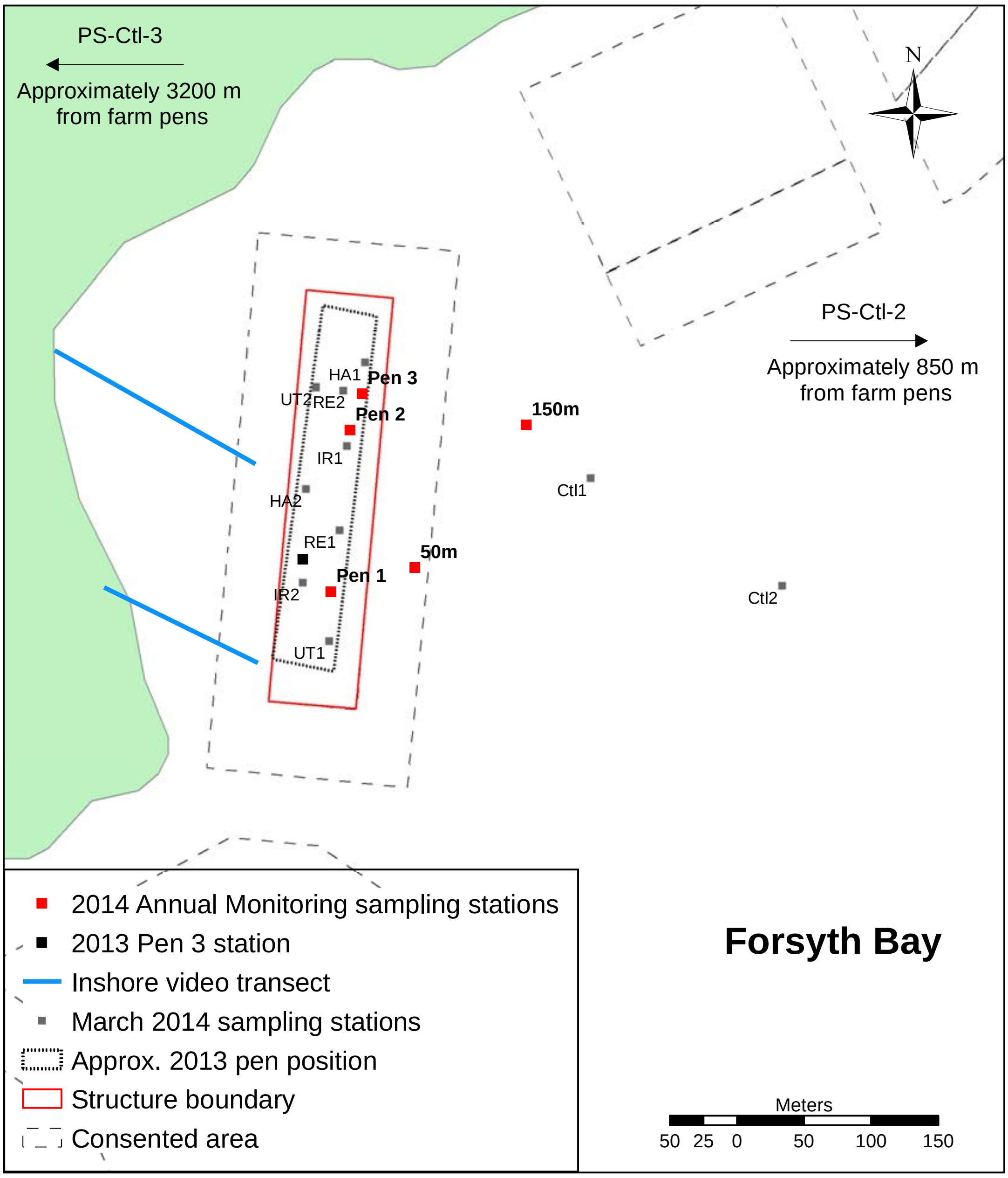

Figure 4. Soft-sediment and inshore habitat sampling locations for the November 2014 monitoring of the Forsyth Bay (FOR) salmon farm site. 'PS Ctl' = Pelorus Sound Control. Position accuracy is ± 5 m. Note: only an approximate indication has been provided for the perimeter of the 2013 pen position. This is because the pens were moved before the 2013 sampling, and the position was therefore unable to be plotted.

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). In addition, pen samples were analysed for copper and zinc concentrations (total recoverable and dilute-acid-extractable[2]). Laboratory analytical methods for sediment samples can be found in Appendix 2.

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/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 Keeley (2012) for an explanation of each of the biotic indices.

Sediment photo-quadrats and / or video footage were 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 noted.

Benthic indicator monitoring

Replicates from stations where indicator monitoring was undertaken were assessed only for sediment colour, odour, and texture, redox potential and total-free sulphides. This is a subset of the full suite of parameters assessed for standard benthic monitoring (described above), so does not include sampling for infauna, organic content or metals.

Sediment photo-quadrats and/or video footage were also taken at each of these stations 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.

Supplementary data

Supplementary data was collected on 20, 21 and 22 March 2014 for a separate study. Parameters assessed (*i.e*. redox potential, total free sulphides, and infauna composition) and methodology used for sample collection and data analyses was similar to what was used for the 2014 annual monitoring. The only modifications to these methods were that samples were collected by a diver, rather than a grab sampler, and the Perspex core size was 55 mm diameter, with the top 40 mm retained (Keeley *et al.* in press).

[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).

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 2014). 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). Enrichment stages were also calculated from the March 2014 data (Appendix 1; Figure A1.1). 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

In situ water column profiles of dissolved oxygen, turbidity, temperature, salinity, and chlorophyll-a were recorded at all FOR sampling stations that weren't nominated for indicator monitoring. The information was collected by slowly raising a data-logging sensor array from the seabed to the surface.

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 and any obvious changes in visual characteristics over time. The last visual assessment was undertaken in 2012, so was repeated during this 2014 annual monitoring survey. Video footage was collected along two transects using a remotely operable video sled (ROVS). Both transects ran from the shallow sub-tidal to ~30 m depth; one running east to mid-point of the farms western edge, the second also running east but to the south-western corner of the farm.

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

[3] Weighting used in 2014 was the same as that used in 2013: organic loading = 0.1, sediment chemistry = 0.2, infauna composition = 0.7)

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 (Keeley *et al.* 2014) to address this issue. This work is likely to result in some revised standards and consent conditions from 2015 onwards.

Cawthron has endeavoured to interpret the existing conditions in a quantitative manner for 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 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*
All zones	These conditions are not permitted beneath any NZKS 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 of consent U040412 specifies that the zones can be distorted to allow for the effects of tidal currents.

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 1 station revealed soft dark muddy sediments with some threads and patches of *Beggiatoa*-like bacteria, as well as patches of mussel shell. Also apparent was a surface layer of easily-disturbed sedimentary material. The substrate at Pen 2 and 3 stations was soft brown, featureless mud with patches of mussel shell. No bioturbation or epifauna was observed in the footage. The substrate at the 50 m and 150 m stations was more similar to the control sites, whereby the substrate was soft brown mud lighter in colour than the pen stations and some signs of bioturbation were evident, in the form of burrow holes and trail-marks. There was also evidence of significant microalgal (diatom) mat development, but only at the control stations.

4.1.2. Physico-chemical characteristics

Sediment organic matter concentrations (measured as % AFDW) in samples from beneath the pens (20–23%) were five times higher than those from the control stations (~5 %;Figure 5). Results from March 2014 showed a similar relationship between the pen and control sites (Appendix 1; Figure A1.2).

Pen station sediments had comparatively lower average redox potentials (-8.2 to -67.7 Eh_{NHE}, MV) than all other stations. Redox potentials for the 50 m, 150 m and control stations were all positive and reasonably similar amongst those stations. Average values were 106 Eh_{NHE} mV, 109 Eh_{NHE} mV and 110 to150 Eh_{NHE} mV, respectively.

Overall, sediment organic content and redox potential at the pen stations showed little temporal difference to previous annual monitoring results and March 2014 results (Appendix 3).

Total free sulphide concentrations decreased with increasing distance from the pens. Average concentrations at the pen, 50 m and 150 m stations were 2,826 µM, 1,263 µM and 568 µM, respectively. Concentrations at the control stations were considerably lower (70 µM and 178 µM). Average concentrations under the pens were high, ranging from 2,724 to 3,160 µM and were within the range recorded from below the pen sites in March 2014 (1,056–4,067 µM; Appendix 1; Figure A1.2). However, both 2014 datasets showed average pen (and control station) sulphide levels to be higher than recorded in 2013. Pen samples in November 2014 were elevated by 2–3 times, and control site levels were elevated by 1.9–4.7 times compared to 2013 levels. Pen stations had dark, gritty sediments that had mild to strong sulphide odours. The presence of bacterial mats (Appendix 1; Appendix A1.1) was consistent with the high sulphide levels recorded.

In contrast to the relatively unchanged organic content and redox potential, total free sulphides were higher in 2014 than those recorded in 2013. These elevated sulphide levels were recorded at pen stations in both March and November 2014. While sulphide levels decreased with increasing distance from the pen, sulphides at the 50 m, 150 m and control stations, were also higher than those recorded in 2013.

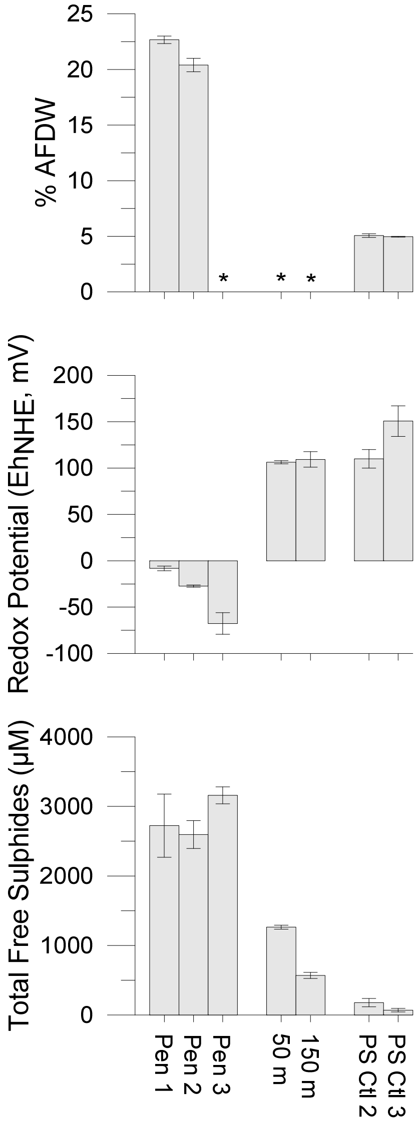

Figure 5. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) at Forsyth Bay farm (FOR) monitoring stations, November 2014. Error bars = ± 1 SE, n = 3. Sites that were sampled for indicator monitoring are denoted with an asterisk.

Summary—physico-chemical characteristics

Organic content and redox variables indicate environmental conditions have remained relatively unchanged in the past 12 months. However, the increase in total free sulphide levels in 2014, suggests that the physico-chemical conditions of the sediments at the site have deteriorated.

4.1.3. Biological communities

The infauna communities at the pen stations were very highly impacted. This was indicated by severely reduced numbers of taxa (3 per core) and high total abundances (316–1,248 per core) in comparison to the control stations (77–116 per core) (Figure 6). Average taxa abundances in pen station samples during March 2014 and November 2014 surveys were lower than 2013, but similar to findings in 2012 (Appendix 4; Figure A4.1). However, the number of taxa remained relatively similar to 2013. The continued dominance by the opportunistic polychaete *Capitella capitata*, was a further indication that highly-enriched conditions remain at the site.

Communities at the pen stations were characterised by lower diversity (H'), evenness (J'), richness (d) and ecological quality ratio (EQR) values compared with the control stations. These community results are very similar to those observed during the 2012, 2013 and March 2014 surveys, and continue to indicate conditions of high organic enrichment.

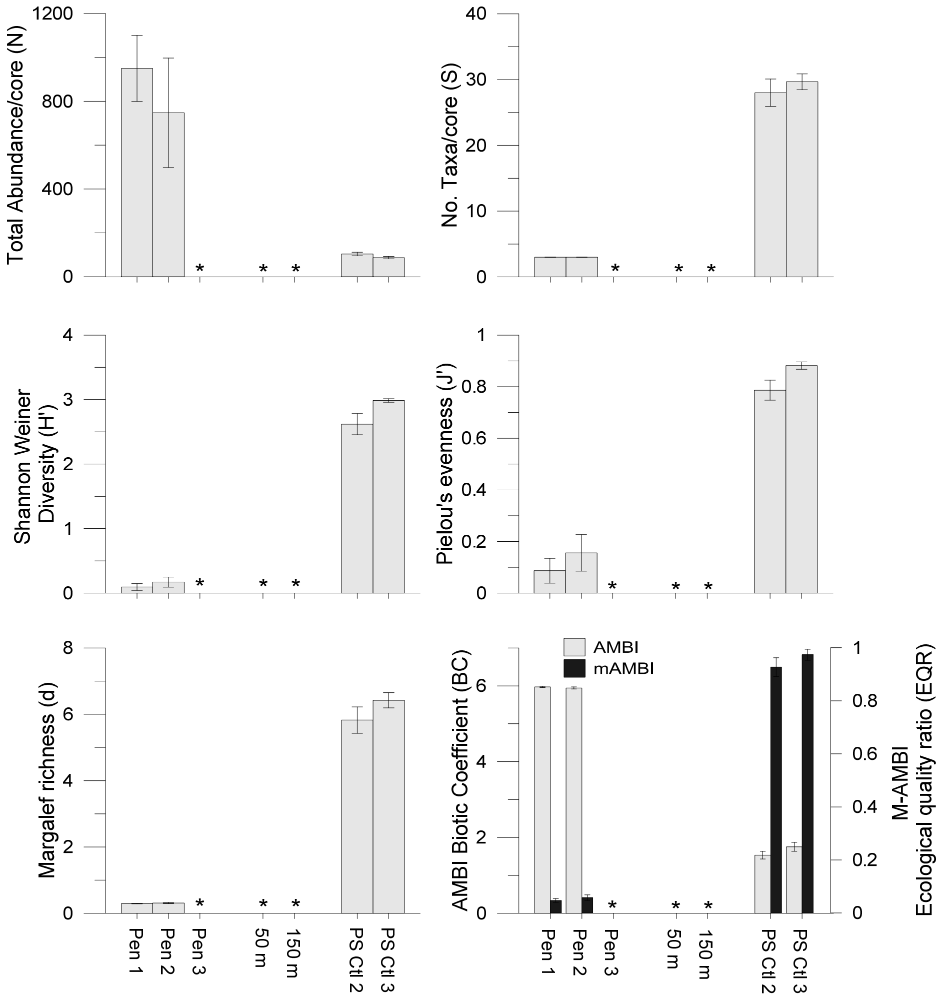

Figure 6. Infauna statistics for Forsyth Bay (FOR) salmon farm monitoring stations, November 2014. Error bars = ± 1 SE, n = 3. Sites that were sampled for indicator monitoring are denoted with an asterisk.

Summary—biological communities

Biological communities at the pen stations were indicative of highly enriched conditions, with high abundances of opportunistic infauna species (polychaete worms), lower species richness, evenness, diversity and EQR scores compared to control stations.

4.1.4. Copper and zinc concentrations

The combined average total recoverable zinc concentration across both pen stations (1,680 mg/kg; SE 1,004, n = 6) exceeded the ISQG-High trigger level (410 mg/kg) for probable biological effects (Appendix 4; Figure A4.2). The concentration of the dilute-acid-extractable fraction (a surrogate for the bio-available fraction: ANZECC 2000; Sneddon *et al.* 2012) was 652 mg/kg (SE 69 mg/kg). This was less than half the total recoverable concentration, but still well over the ISQG-High trigger level (Table 2).

The zinc concentrations were highly variable amongst replicates due to an outlying value of 6,700 in replicate 'b' at the Pen 2 station. However, this sample was not notably high in bio-available zinc indicating that particulate material (*e.g*. a paint flake) may have been present in this sample.

The average total recoverable copper concentration across both pen stations (137.2 mg/kg; SE 18.7, n = 6) was above the ISQG-Low trigger level for possible biological effects (65 mg/kg). However, the average bio-available copper concentration (37.3 mg/kg; SE 2.8) was below the ISQG-Low trigger level.

Historical comparisons showed that total recoverable zinc concentrations beneath the pens had been high but relatively stable from 2011 to 2013. However, the average total recoverable zinc concentrations at FOR in 2014 were the highest recorded since sampling for metals analyses began at all NZ King Salmon farmed sites in 2004. Total recoverable copper concentrations in the sediments were at record high levels in 2012, and had decreased substantially in 2013. In 2014 concentrations were higher than the 2013 levels, but still well below the 2012 peak. Sediment copper and zinc concentrations were not measured at the control stations in 2014 but average concentrations were less than 10 mg/kg and 50 mg/kg respectively in all previous years (Appendix 4; Figure A4.2).

Table 2. Copper and zinc concentrations in sediments, mg/kg dry weight (raw data); November 2014. 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	60	29	<u>**770**</u>	<u>**510**</u>
	b	**127**	35	<u>**580**</u>	<u>**460**</u>
	c	**135**	33	<u>**620**</u>	<u>**590**</u>
Pen 2	a	**183**	43	<u>**680**</u>	<u>**760**</u>
	b	**185**	36	<u>**6,700**</u>	<u>**920**</u>
	c	**133**	48	<u>**730**</u>	<u>**670**</u>
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

Summary—copper and zinc

Zinc and copper concentrations beneath the net pens were high. Zinc levels (both total recoverable zinc, and weak acid extractable zinc) substantially exceeded the best available guideline threshold for probable biological effects (*i.e*. ANZECC ISQG-High) and despite the site being fallowed, were substantially higher than the previous year.

Total recoverable copper concentrations were above the threshold for possible biological effects (*i.e.* ANZECC ISQG-Low), but the bio-available fraction was below this threshold.

Sediment metal concentrations have increased at the Forsyth site despite it being fallowed. Further sampling would be required to determine if this is a site-wide trend of sediment metal accumulation, or if it is due to anomalous samples containing flakes of paint.

4.2. Water column

Water column profiling casts at the Forsyth Bay farm site (Figure 7) showed a well-mixed water column. Chlorophyll-a concentrations (a proxy for phytoplankton biomass) were generally low, particularly from the surface to a depth of approximately 15 m. The sampling unit disturbed the sediment around the Pen 2 station, so DO levels near the seafloor were reduced as a result. The disturbance was also apparent as an increase in turbidity (optical back-scatter; OBS) near the seafloor.

Water column measurements did not indicate remnant impacts of farming activities due to benthic enrichment-related processes (*e.g*. significant reduction of near-bottom DO).

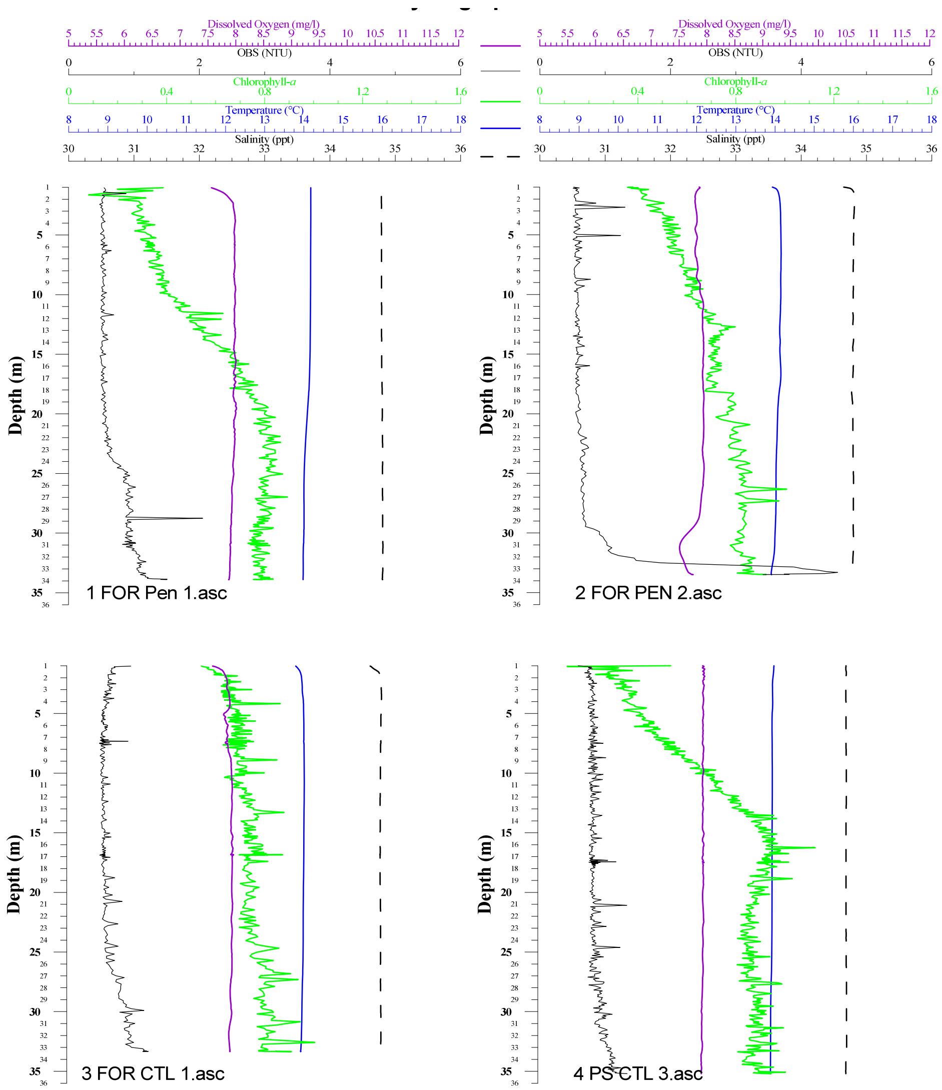

Figure 7. Dissolved oxygen, turbidity (optical back-scatter; OBS), chlorophyll-a, temperature, and salinity, as measured by an *in situ* sensor array raised through the water column, November 2014.

4.3. Inshore habitats

The video footage described below is held at Cawthron for future reference. On both video transects, a cobble seafloor was observed in the shallows grading to gravel and coarse sand in the mid-depths, and shell hash (mussel, cockle, and turret shells) and finer sediments from 20–30 m. The presence of epifauna was rare. Identifiable taxa included; starfish (*Coscinasterias muricata)*, sea cucumbers (*Stichopus mollis)*, horse mussels (*Atrina zelandica)* and solitary ascidians (*Cnemidocarpa* sp). Spotties (*Notolabrus celidotus*) and triplefins (probably *Forsterygion lapillum*) were the most common fish, although blue cod (*Parapercis colias*) and flatfish (unidentified species) were also observed in low numbers. No large seaweeds were apparent along either transect.

5. ASSESSMENT OF SEABED ENRICHMENT

5.1. Enrichment stage assessments for 2014

The November 2014 assessment of soft-sediment conditions references a selection of informative chemical and biological indicator variables[4]. 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. The March 2014 results are summarised in Figure 8 (see Appendix 5 for full results with raw data values).

The overall ES was 5.6 at both pen stations, similar to (or even slightly lower than) ES scores from March 2014. The macrofauna at the Pen 1 and 2 stations exhibited equivalent ES 5.7–5.8 conditions. Organic matter at these stations was very high, opportunistic taxa were reasonably abundant, and the number of taxa and associated richness was very low. The large amount of residual organic matter (equivalent ES 6.2–6.4) suggests that the seabed is still heavily impacted.

Interestingly, and despite the high sulphide levels, the sediment chemistry equivalent ES scores indicated less impacted conditions at the pen stations; sediment chemistry equivalent ES ~4.6–4.9. Lower infauna abundances and elevated sulphides compared to 2013 suggest that the seabed remains highly enriched. Given the unchanged organic matter and redox potential, normal DO profile in the water column, as well as the absence of farm-related inputs, this indicates that the site is in a state of slow recovery.

Zone 1–2 (50 m) and Zone 2–3 (150 m) stations appeared to be moderately enriched, with sediment chemistry averages equivalent ES of 3.5 and 3 respectively. This is mainly due to elevated sulphide levels.

It is important to note that the ES scores at the Pen 3, 50 m and 150 m stations were derived from sediment chemistry indicators (redox and sulphides) only. Indicator-only ES scores do not have the same robustness of the weighted approach typically used, and should be interpreted with appropriate caution.

4 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 (± 1 SE) calculated for indicator variables, and overall, for each Forsyth Bay (FOR) farm sampling station; November 2014. For full breakdown of indicator variable contributions see Appendix 1.

	Summary of indicator variables		ES (± SE)
Pen 1	%OM extremely elevated (~5 × Ctls); redox all marginally negative and sulphides highly elevated. Total infauna abundance high, number of taxa (3 per core) and richness very low.	Organic loading:	6.4 (0)
		Sediment chemistry:	4.6 (0.1)
		Infauna composition:	5.8 (0)
		Overall:	**5.6 (0)**
Pen 2	%OM extremely elevated (~5 × Ctls) redox negative (but marginally) and sulphides highly elevated. Total abundance high but variable, number of taxa and richness very low (3 per core).	Organic loading:	6.2 (0.1)
		Sediment chemistry:	4.6 (0.1)
		Infauna composition:	5.8 (0)
		Overall:	**5.6 (0)**
Pen 3	Indicator monitoring only. Redox marginally negative but sulphides extremely elevated.	Organic loading:	ns
		Sediment chemistry:	4.9 (0)
		Infauna composition:	ns
		Overall:	-
50 m (Zone 1–2 boundary)	Indicator monitoring only. Redox positive. Sulphides highly elevated.	Organic loading:	ns
		Sediment chemistry:	3.5 (0)
		Infauna composition:	ns
		Overall:	-
150 m (Zone 2–3 boundary)	Indicator monitoring only. Redox positive, sulphides moderately elevated.	Organic loading:	ns
		Sediment chemistry:	3 (0.1)
		Infauna composition:	ns
		Overall:	-
PS-Ctrl 2	Normal background conditions. Infauna community composition indicative to background seabed conditions.	Organic loading:	2.5 (0.1)
		Sediment chemistry:	2.5 (0.1)
		Infauna composition:	1.8 (0.1)
		Overall:	**2 (0)**
PS-Ctrl 3	Normal background conditions. Infauna community composition indicative to background seabed conditions.	Organic loading:	2.4 (0)
		Sediment chemistry:	2 (0.2)
		Infauna composition:	1.6 (0)
		Overall:	**1.8 (0)**

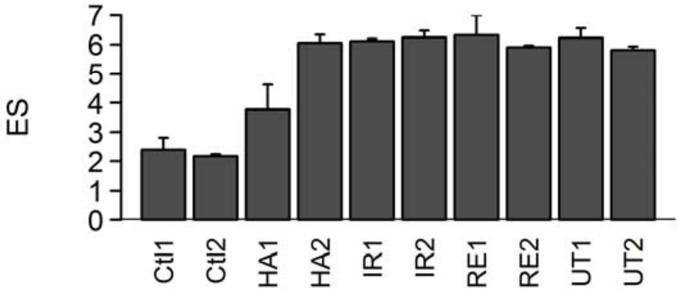

Figure 8. Enrichment stage (ES) values for sediment samples prior to treatment in the seabed remediation study in March 2014 (Keeley *et al.* in press). Ctl = Control stations; HA, IR, RE and UT = pen stations (see Figure 3 for locations). Error bars = ± 1 SE, n = 3.

5.2. Historical comparison

A comparison of the last four monitoring assessments (conducted at 12-monthly intervals) showed that the ES score have remained similarly enriched at the pen stations apart from a substantial, but temporary, reduction observed in 2012 (Table 4). Interestingly, higher sulphide levels and lower infaunal richness and abundances resulted in higher ES scores at non-pen sites in 2014 compared to 2013. Although, because ES scores for the 50 m and 100 m sites were calculated using only sediment chemistry indicators, comparing these scores directly with previous years should be done with appropriate caution.

Table 4. Comparison of enrichment stage (ES) scores for assessments from monitoring in 2011–2014.

Station	Enrichment stage (s.e.)			
	2011	2012+	2013	2014
Pen 1	6.13 (0.13)	3.76 (0.20)	5.6 (0.1)	5.6 (0)
Pen 2	5.73 (0.13)	4.25 (0.37)	5.5 (0.2)	5.6 (0)
Pen 3	6.10 (0.15)	4.80 (0.15)	5.6 (0.1)	4.9 (0) IM
50 m (Zone 1–2 boundary)	3.03 (0.12)	2.52 (0.06)	2.9 (0.1)	3.5 (0) IM
150 m (Zone 2–3 boundary)	2.07 (0.12)	2.29 (0.08)	2.2 (0.1)	3 (0.1) IM
PS-Ctl 2	2.13 (0.03)	1.84 (0.05)	1.8 (0.1)	2 (0)
PS-Ctl 3	1.80 (0.10)	1.59 (0.02)	1.7 (0)	1.8 (0)

+ Site was fallowed Dec 2011–Oct 2012
IM = Indicator monitoring.

6. CONCLUSIONS AND RECOMMENDATIONS

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 2014 results were consistent with the stated EQS requirements.

The Zone 1–2 boundary station conditions were also consistent with the EQS. However, the ES scores at the outer Zone 2–3 boundary exceeded the EQS. It is important to note that these results were determined by indicator monitoring, so should be interpreted with caution. Standard monitoring, with a full suite of ES indicator variables, would be required to determine if this was a true estimate of seabed state.

Determining whether the increased sediment metal concentrations observed, particularly the very high levels of zinc, are indicative of accumulation across the site, or are simply the result of some anomalous samples, would also require more targeted sampling. However, the results of the seabed remediation study in March 2014 suggest that removal of the surface layer beneath the pens may be an effective method of reducing sediment metal concentrations in the longer term (Keeley *et al*. in press). As the site has been fallowed, these considerations are not immediately relevant to farming operations. They should, however, be considered in the 2015 Marine Environmental Monitoring and Adaptive Management Plan (MEM-AMP; *i.e.* standard monitoring for ES across the site) and in the reinstatement of farming activity at the site.

7. REFERENCES

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8. APPENDICES

Appendix 1. Summary of 2014 results.

Table A1.1. Summary of the average (± SE) sediment physical and chemical properties, infauna variables and calculated indices for the Forsyth Bay (FOR) salmon farm stations during the November 2014 monitoring survey.

	Station	Units	Pen-1	Pen 2	Pen 3	50 m	150 m	PS-Ctl-2	PS-Ctl-3
	Depth	m	33	33	31	33	33	33	29
Sediments	AFDW	%	22.7 (± 0.3)	20.4 (± 0.6)	ns	ns	ns	5.1 (± 0.2)	5 (± 0)
	Redox	Eh_{NHE}, mV	-8.2 (± 2.4)	-27.3 (± 1.2)	-67.7 (± 11.6)	106.3 (± 1.8)	109.3 (± 8.4)	110 (± 10.1)	150.7 (± 16.5)
	Sulphides	µM	2,723.6 (± 455.4)	2,596.2 (± 200.4)	3,160 (± 122.2)	1,263.5 (± 28.5)	568.8 (± 44.3)	177.9 (± 60.3)	70.2 (± 24.9)
	Bacterial mat	-	No	Yes, patchy	No	None	None	None	None
	Out-gassing	-	No	No	No	No	No	No	No
	Odour	-	Mild to strong	Moderate	Strong	Mild	None	None	None
Infauna statistics	Abundance	No./core	950 (± 150.8)	747.3 (± 249.7)	ns	ns	ns	103.3 (± 8.2)	87 (± 5.3)
	No. taxa	No./core	3 (± 0)	3 (± 0)	ns	ns	ns	28 (± 2.1)	29.7 (± 1.2)
	Richness	Stat.	0.3 (± 0)	0.3 (± 0)	ns	ns	ns	5.8 (± 0.4)	6.4 (± 0.2)
	Evenness	Stat.	0.1 (± 0)	0.2 (± 0.1)	ns	ns	ns	0.8 (± 0)	0.9 (± 0)
	SWDI	Index	0.1 (± 0.1)	0.2 (± 0.1)	ns	ns	ns	2.6 (± 0.2)	3 (± 0)
	AMBI	Index	6 (± 0)	5.9 (± 0)	ns	ns	ns	1.5 (± 0.1)	1.8 (± 0.1)
	M-AMBI	Index	0 (± 0)	0.1 (± 0)	ns	ns	ns	0.9 (± 0)	1 (± 0.1)
	BQI	Index	1.1 (± 0)	1.1 (± 0)	ns	ns	ns	10.6 (± 0.2)	9.8 (± 0.5)

Table A1.2. Summary of the physical and chemical properties of sediments from the supplementary data at Forsyth Bay (FOR) during the March 2014 seabed remediation study (see Figure 3 for site locations). Bracketed values = 1 SE.

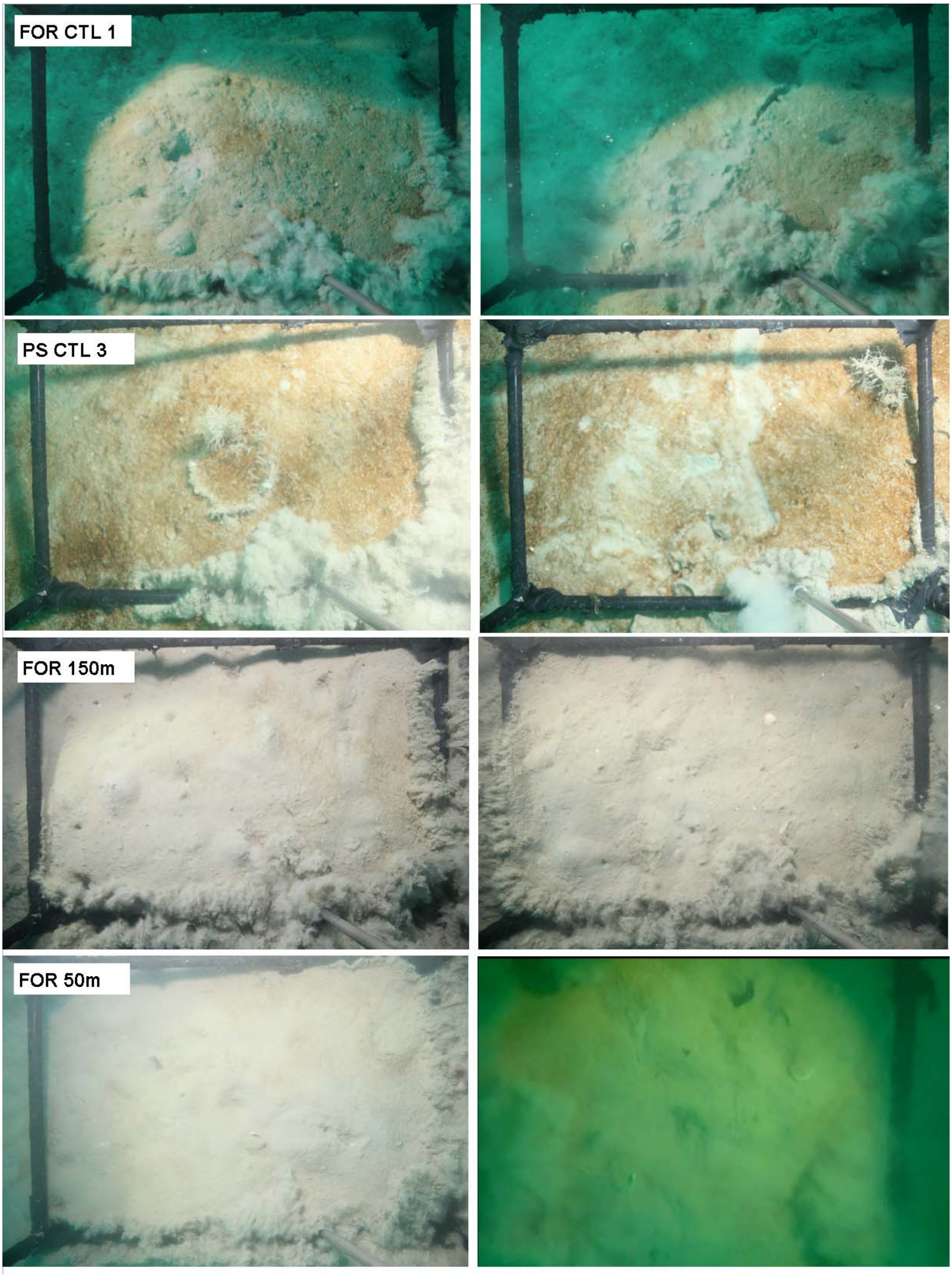
	Units	HA1	HA2	IR1	IR2	PL1	PL2
AFDW	%	6.9	20.5	0	16.5	0	0
Redox	Eh_{NHE}, mV	-162.6 (± 20.8)	-195.3 (± 18.7)	-155.8 (± 4.2)	-176.3 (± 6)	-145.2 (± 17.8)	-125.3 (± 16.3)
Sulphides	µM	1,850.6 (± 53.7)	2,419 (± 155.9)	2,526.2 (± 403.4)	4,067.3 (± 514)	2,050.1 (± 150.7)	1,416 (± 395.3)
Abundance	No./core	104 (± 52.7)	69 (± 25.5)	49.3 (± 8.3)	146 (± 69.1)	6.7 (± 3.8)	735 (± 228.4)
No. Taxa	No./core	20.3 (± 8.3)	3.7 (± 1.2)	2.7 (± 0.7)	3 (± 1)	1.3 (± 0.7)	2.7 (± 0.3)
Richness	Stat.	4.2 (± 1.3)	0.7 (± 0.4)	0.4 (± 0.2)	0.4 (± 0.2)	0.3 (± 0.2)	0.3 (± 0.1)
Evenness	Stat.	0.9 (± 0)	0.4 (± 0.1)	0.4 (± 0)	0.2 (± 0.1)	0.6 (± 0.3)	0.2 (± 0)
Shannon-Weiner	Index	2.4 (± 0.3)	0.5 (± 0.2)	0.4 (± 0.1)	0.3 (± 0.2)	0.4 (± 0.2)	0.2 (± 0.1)
AMBI	Index	2.8 (± 0.1)	5.7 (± 0.1)	5.8 (± 0)	5.9 (± 0.1)	5.4 (± 0.3)	6 (± 0)
BQI	Index	4.9 (± 1)	1.2 (± 0.2)	0.9 (± 0.2)	1 (± 0.3)	0.7 (± 0)	1 (± 0.1)
ES	Index	3.8 (± 0.4)	6.1 (± 0.1)	6.1 (± 0)	6.3 (± 0.1)	6.3 (± 0.3)	5.9 (± 0)

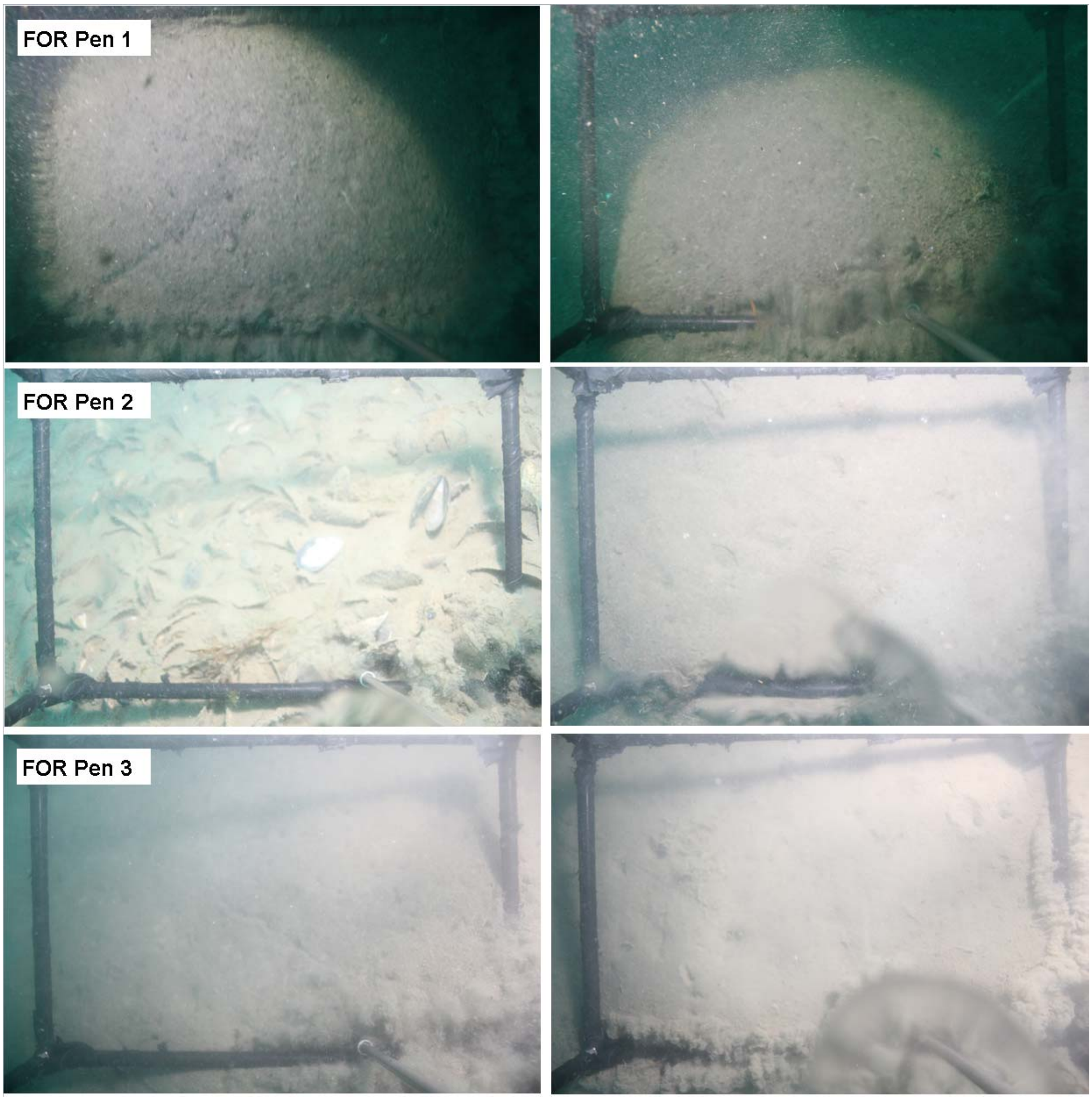
	Units	UT1	UT2	PL1-PP	Ctl1	Ctl2
AFDW	%	16.3	21	7.5	0	5.5
Redox	Eh_{NHE}, mV	-163.2 (± 14.7)	-94.8 (± 1)	-166 (± 16.1)	187.3 (± 14)	171.2 (± 9)
Sulphides	µM	1,846.7 (± 145.2)	1,056.1 (± 96.7)	2,273.2 (± 251)	218.3 (± 27.3)	175.2 (± 45.7)
Abundance	No./core	19.7 (± 16.2)	599.3 (± 81.2)	59 (± 35.9)	110.7 (± 23.8)	88.7 (± 7.5)
No. Taxa	No./core	1.7 (± 0.7)	3.3 (± 0.9)	1.7 (± 0.3)	24 (± 1.5)	24.7 (± 0.9)
Richness	Stat.	0.2 (± 0.2)	0.4 (± 0.1)	0.4 (± 0.3)	5 (± 0.3)	5.3 (± 0.1)
Evenness	Stat.	0.2 (± 0.2)	0.1 (± 0)	0.4 (± 0.3)	0.8 (± 0.1)	0.8 (± 0)
Shannon-Weiner	Index	0.2 (± 0.2)	0.1 (± 0)	0.3 (± 0.2)	2.6 (± 0.2)	2.5 (± 0.1)
AMBI	Index	5.9 (± 0.1)	6 (± 0)	4.6 (± 1.3)	2 (± 0.4)	1.7 (± 0.1)
BQI	Index	0.5 (± 0.3)	1.1 (± 0.2)	0.8 (± 0.2)	9.1 (± 0.5)	10.1 (± 0.5)
ES	Index	6.2 (± 0.2)	5.8 (± 0.1)	6.1 (± 0.2)	2.4 (± 0.2)	2.2 (± 0)

Appendix 2. Laboratory analytical methods for sediment samples (November 2014) processed by either Hill Laboratories (a) or Cawthron Institute Analytical Services (b).

Analyte	Method	Default detection limit
Organic matter (as ash-free dry weight) [a]	APHA 2540 G 22nd ed. 2012.	0.04 g/100 g
1M HCl extractable copper & zinc [a]	< 2 mm sieved fraction. 1M HCl extraction, ICP-MS.	1.2 mg/kg (copper) 3 mg/kg (zinc)
Total recoverable copper & zinc [a]	Dried sample. nitric/ hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	2 mg/kg (copper) 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 obtained by drop-camera or video (November 2014).




FOR Pen 1
FOR Pen 2
FOR Pen 3

Appendix 4. Historical comparisons.

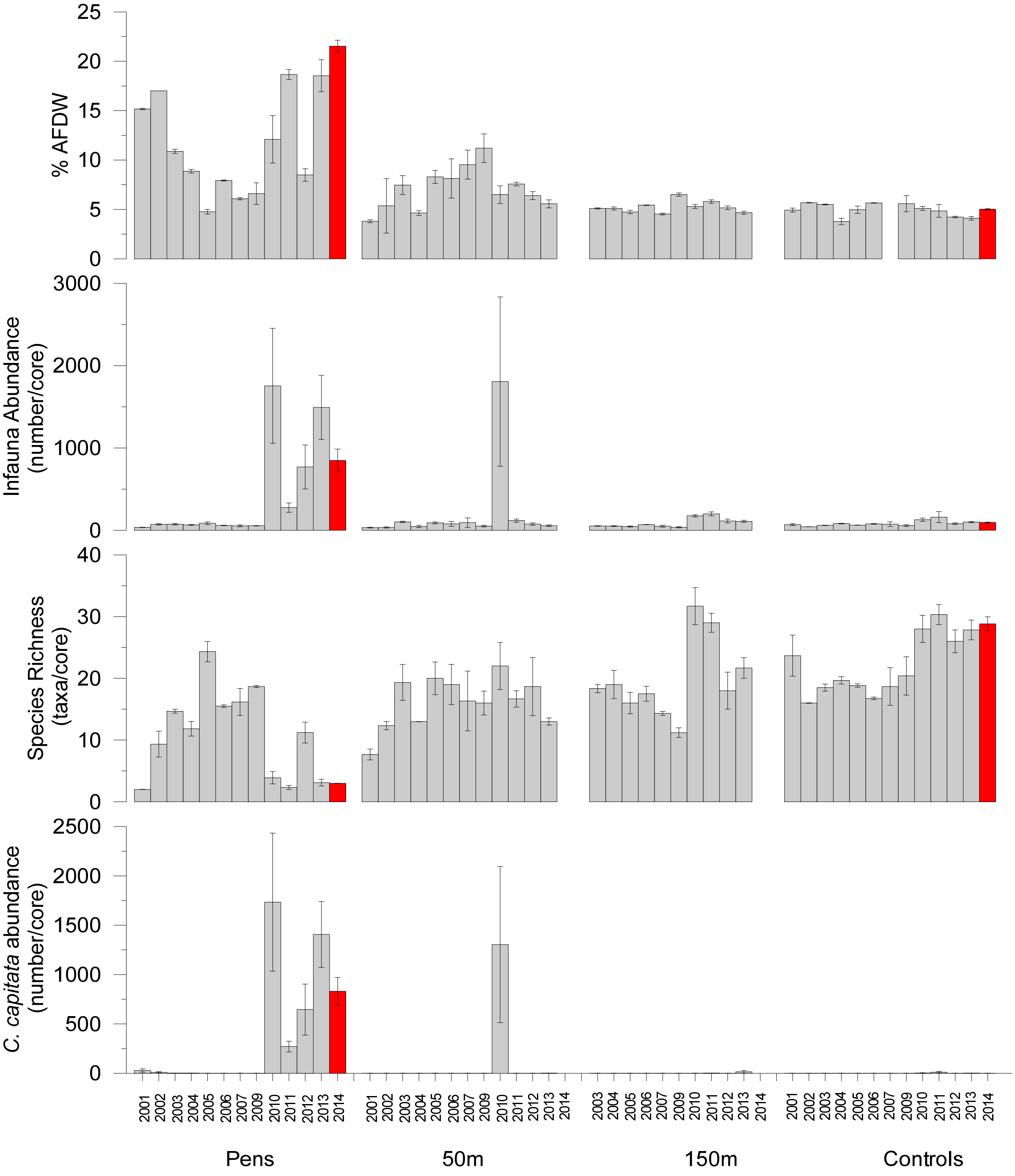


Figure A4.1. Comparison of annual monitoring of mean (± SE) ash-free dry weight (AFDW), infauna abundance and richness (No. taxa), and *Capitella capitata* densities recorded for Forsyth Bay (FOR) salmon farm annual monitoring since 2001. Densities of capitellid polychaetes of 1,000 individuals per m²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

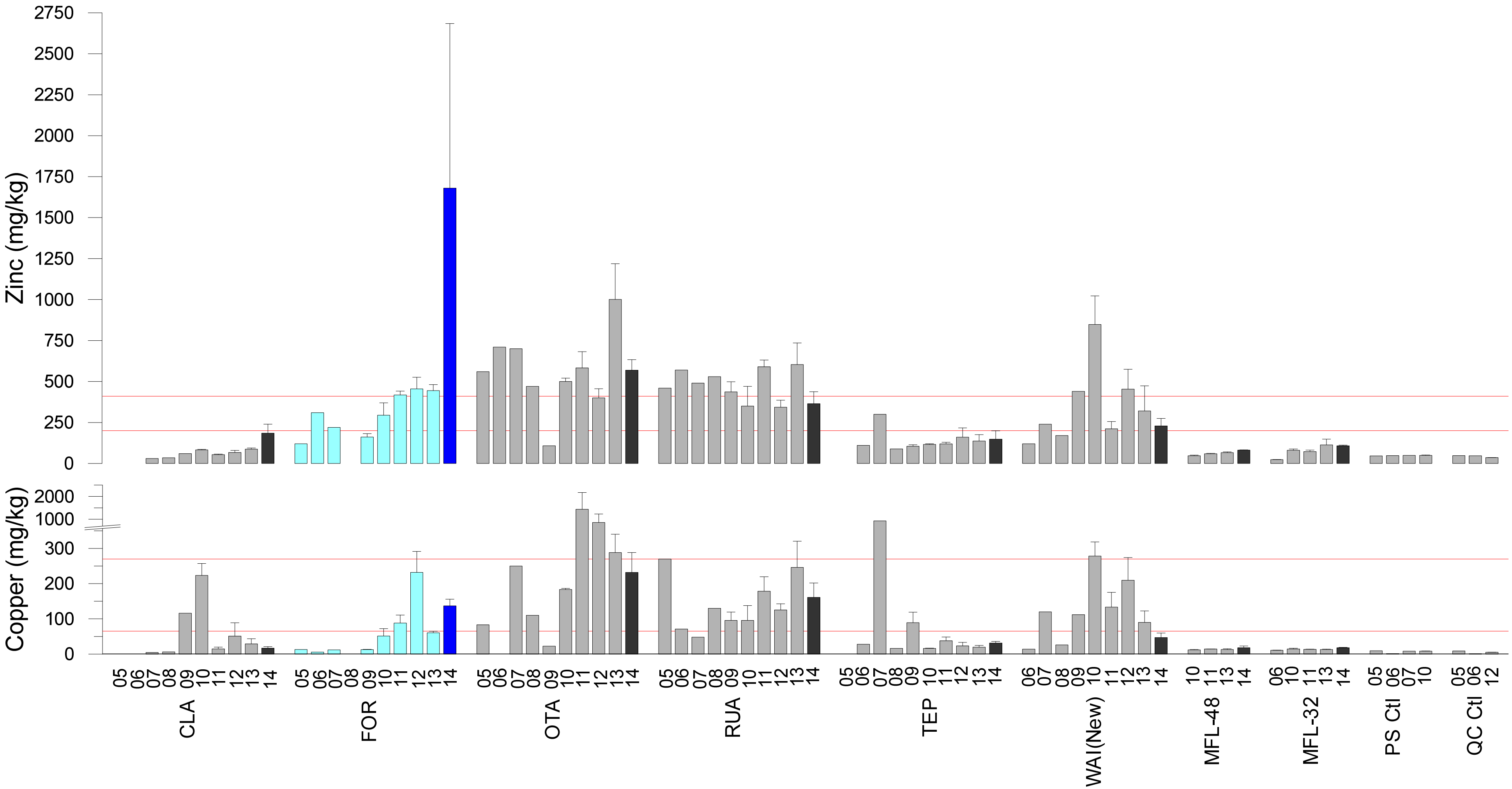


Figure A4.2. Comparison of the last 10 years of annual monitoring of sediment total recoverable copper and zinc concentrations beneath all eight NZ King Salmon farms and two control stations (PS = Pelorus Sound, QC = Queen Charlotte). Bars represent pen averages (± SE). Red lines indicate respective ANZECC ISQG-High and -Low trigger levels. Forsyth Bay (FOR) salmon farm data are in blue.

Appendix 5. Detailed enrichment stage (ES) calculations for each station at the Forsyth Bay (FOR) salmon farm, November 2014. For details about how these values were calculated, see Keeley 2012. Red text highlights cases where best professional judgement (BPJ; Keeley 2014) was used.

SITE INFORMATION
Date: Nov-14
Farm/site: Forsyth
Flow envir(LF

Variable group weightings: 0.1 0.2 0.7

Station:	Repl.	TOM	Redox	Sulphides	N Abundance	S No. Taxa	J' P. evenness	d Richness	H'(loge) SWDI	AMBI	M-AMBI	BQI	ES equivalents TOM	Redox	Sulphides	Abundance	No. Taxa	even ne	Richness	SWDI	AMBI	M-AMBI	BQI	SUMMARY ES SCORES	Organic loading	nt chemistry	Macrofauna	Overall ES
Pen 1	A	22	-6.7	3373.94	841.00	3.00	0.18	0.30	0.20	5.94	0.06	1.06	6.33	4.19	5.26	5.50	5.50		6.15	5.88	4.98	6.33	5.90	**Pen 1**	6.33	4.73	5.75	**5.6**
Pen 1	B	23	-5	2950.82	761.00	3.00	0.02	0.30	0.02	6.00	0.04	1.05	6.38	4.17	5.05	5.50	5.50		6.15	6.18	5.03	6.46	5.91	**Pen 1**	6.38	4.61	5.82	**5.63**
Pen 1	C	23	-13	1846.11	1248.00	3.00	0.06	0.28	0.07	5.98	0.04	1.05	6.38	4.25	4.37	5.50	5.50		6.18	6.09	5.02	6.43	5.91	**Pen 1**	6.38	4.31	5.80	**5.56**
Pen 2	A	19.2	-25	2580.75	316.00	3.00	0.25	0.35	0.28	5.91	0.07	1.06	6.08	4.35	4.85	5.50	5.50		6.08	5.74	4.96	6.27	5.90	**Pen 2**	6.08	4.60	5.71	**5.53**
Pen 2	B	21	-29	2950.82	745.00	3.00	0.20	0.30	0.22	5.93	0.06	1.07	6.26	4.39	5.05	5.50	5.50		6.14	5.84	4.98	6.32	5.90	**Pen 2**	6.26	4.72	5.74	**5.59**
Pen 2	C	21	-28	2257.10	1181.00	3.00	0.02	0.28	0.02	6.00	0.04	1.05	6.26	4.38	4.66	5.50	5.50		6.17	6.18	5.03	6.46	5.91	**Pen 2**	6.26	4.52	5.82	**5.6**
Pen 3	A		-89	3155.29										4.93	5.15									**Pen 3**		5.04		**1.01**
Pen 3	B		-49	3373.94										4.57	5.26									**Pen 3**		4.92		**0.98**
Pen 3	C		-65	2950.82										4.71	5.05									**Pen 3**		4.88		**0.98**
50 m	A		109	1320.59										3.15	3.92									**50 m**		3.54		**0.71**
50 m	B		103	1235.01										3.20	3.83									**50 m**		3.52		**0.7**
50 m	C		107	1235.01										3.17	3.83									**50 m**		3.50		**0.7**
150 m	A		126	591.01										3.00	2.96									**150 m**		2.98		**0.6**
150 m	B		102	483.40										3.21	2.75									**150 m**		2.98		**0.6**
150 m	C		100	631.97										3.23	3.04									**150 m**		3.14		**0.63**
PS CTL 2	A	4.9	102	74.06	106.00	25.00	0.71	5.15	2.29	1.35	0.87	10.14	2.42	3.21	1.29	2.39	1.92		1.65	2.28	1.56	1.98	1.52	**PS CTL 2**	2.42	2.25	1.90	**2.02**
PS CTL 2	B	4.9	98	282.83	116.00	32.00	0.80	6.52	2.78	1.56	0.99	10.98	2.42	3.25	2.24	2.46	1.98		1.45	1.44	1.72	1.32	1.70	**PS CTL 2**	2.42	2.75	1.72	**2**
PS CTL 2	C	5.4	130	176.94	88.00	27.00	0.84	5.81	2.78	1.69	0.92	10.60	2.62	2.96	1.85	2.23	1.87		1.49	1.44	1.82	1.68	1.61	**PS CTL 2**	2.62	2.41	1.73	**1.96**
PS CTL 3	A	4.9	153	35.44	89.00	28.00	0.89	6.02	2.96	1.99	0.94	9.07	2.42	2.75	0.98	2.24	1.87		1.47	1.14	2.03	1.62	1.43	**PS CTL 3**	2.42	1.87	1.69	**1.8**
PS CTL 3	B	5	121	118.37	95.00	32.00	0.85	6.81	2.96	1.61	1.01	10.63	2.46	3.04	1.57	2.29	1.98		1.46	1.13	1.76	1.00	1.61	**PS CTL 3**	2.46	2.31	1.60	**1.83**
PS CTL 3	C	5	178	56.65	77.00	29.00	0.90	6.45	3.04	1.66	0.98	9.73	2.46	2.53	1.16	2.11	1.88		1.45	0.99	1.79	1.38	1.46	**PS CTL 3**	2.46	1.85	1.58	**1.72**