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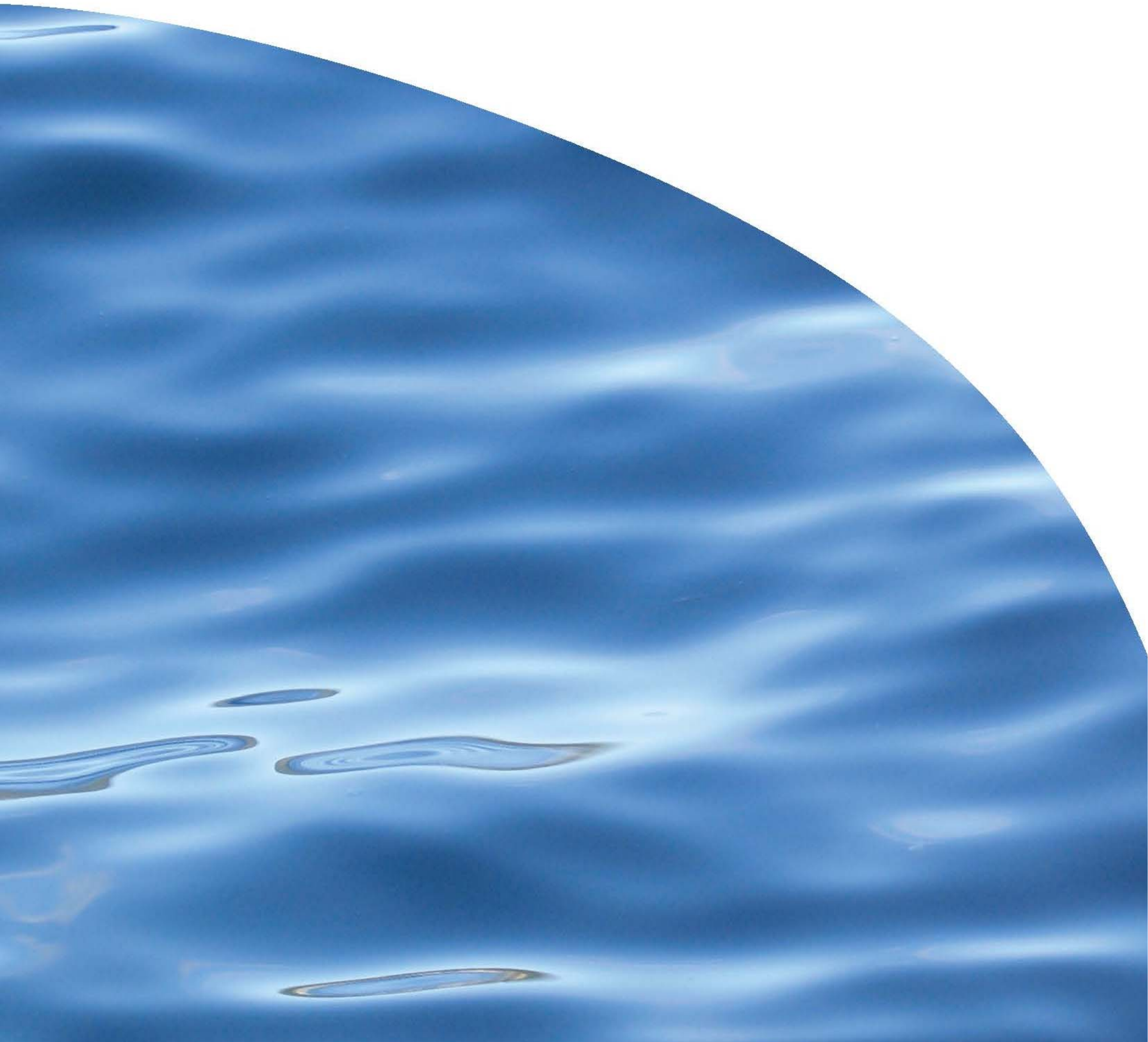
ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2015



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

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Prepared for The New Zealand King Salmon Co. Ltd.

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1. INTRODUCTION

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

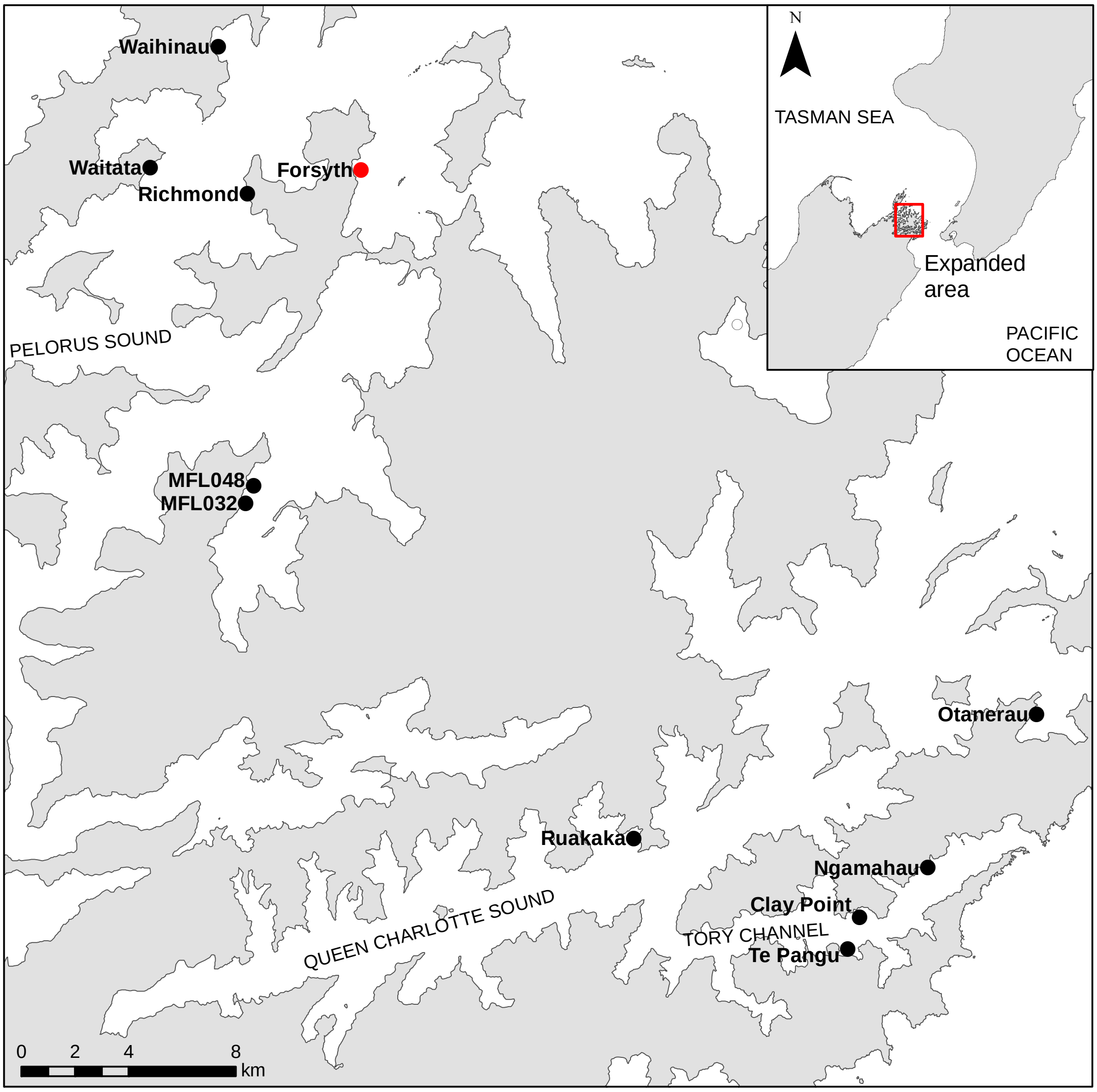

Figure 1. Map of the Marlborough Sounds area showing the location of the Forsyth Bay (FOR) salmon farm (red dot) along with NZ King Salmon's 10 other consented farm sites (black dots).

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

Consent conditions for all of the farms (with the exception of Waihinau) broadly require monitoring of the effects of deposition on the seabed, with particular regard to the seabed community composition and abundance, dissolved oxygen (DO) levels and water quality. The environmental monitoring results are used to determine whether the farms are compliant with the environmental quality standards (EQS) specified in the consent conditions for each farm. These are based on a seabed impact ‘zones concept’; an approach that provides an upper limit to the spatial extent and magnitude of seabed impacts (see Keeley 2012).

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

This report presents the 2015 annual monitoring results for the Forsyth Bay (FOR) salmon farm.

1.1. Site details and history of feed usage

The FOR farm site was established in 1994. Water depth at the farm site is around 32 m, and the average water current speed is around 3 cm/s, so it is considered a low-flow site.

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, and the site lay fallow at the time of the 2014 monitoring. A new farm containing smolt was temporarily installed at the site in the second quarter of 2015, with feed input commencing on 15 May 2015. This farm was operating during the 2015 monitoring.

Over the past decade, feed inputs at this farm have ranged from zero to 3,261 tonnes per annum (December through November; Figure 4). Between December 2013 and November 2014 (*i.e.* 12 months of occupation) the farm was fallowed with no feed input, and in the 12-month period prior to the 2015 survey (November 2014 through

October 2015), used a total of 769 tonnes (Figure 3)[1]. The first feed input was in May, when the smolt were introduced to the site. Monthly feed loadings then steadily increased, totalling 243 tonnes for the month of October, when monitoring was undertaken.

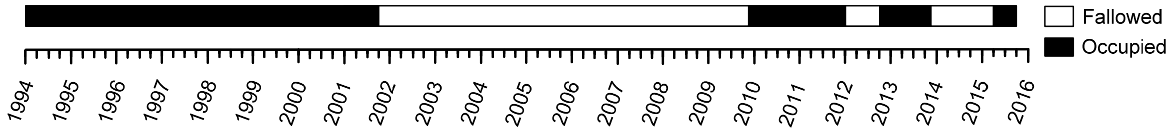

Figure 2. Operational state of the farm (occupied *vs*. fallowed) from 1994–2015. Year tick marks represents the start of the year.

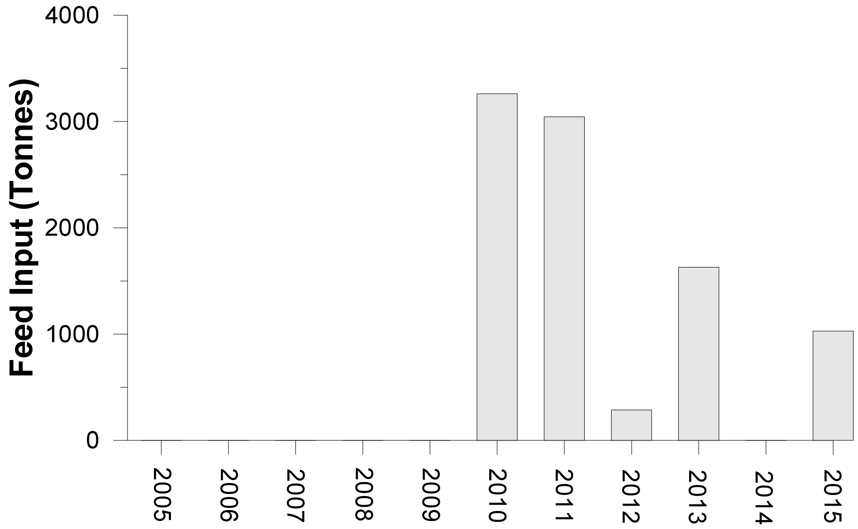

Figure 3. Annual feed inputs (December through November) at the Forsyth Bay (FOR) salmon farm, 2005–2015.

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

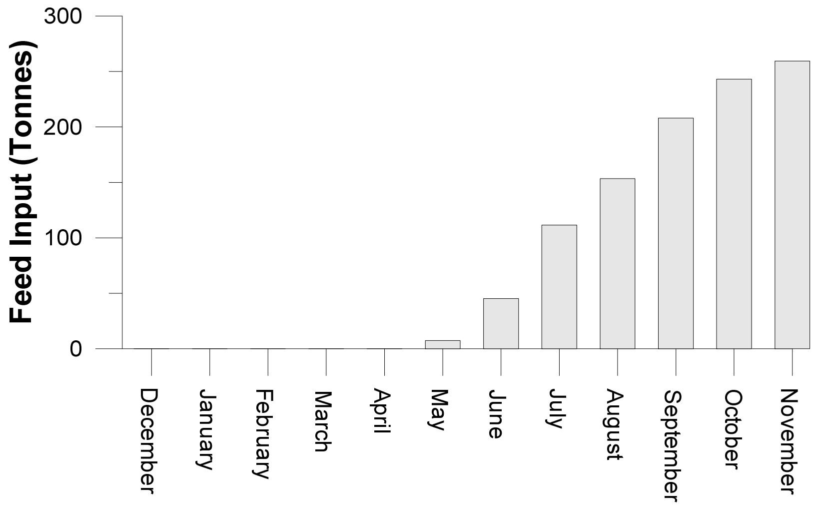

Figure 4. Monthly feed inputs at the Forsyth Bay (FOR) salmon farm from December 2014 to November 2015.

2. METHODS

Sampling for the FOR annual monitoring was undertaken on 30 October 2015. A condensed summary of the techniques that were used in the present survey is provided below. Detailed methods and rationale describing the sampling protocol for all of NZ King Salmon's farms can be found in the most recent MEMAMP (Elvines & Taylor 2015). Copies are held by MDC and NZ King Salmon. This plan is updated and modified annually to accommodate the most relevant and effective sampling methods. Further rationale and details related to the general monitoring procedures can be found in the BMP document (MPI 2015).

2.1. Soft-sediment habitats

2.1.1. Sampling locations

Sampling stations at the FOR farm are described as follows (also see Figure 5):

- Three net pen stations sampled at the outer edge of the pens (locations selected according to the net pen position [Figure 1] at the time of sampling): 'Pen 1', 'Pen 2' and 'Pen 3'.
- Two stations along a transect running perpendicular to the shoreline away from 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.

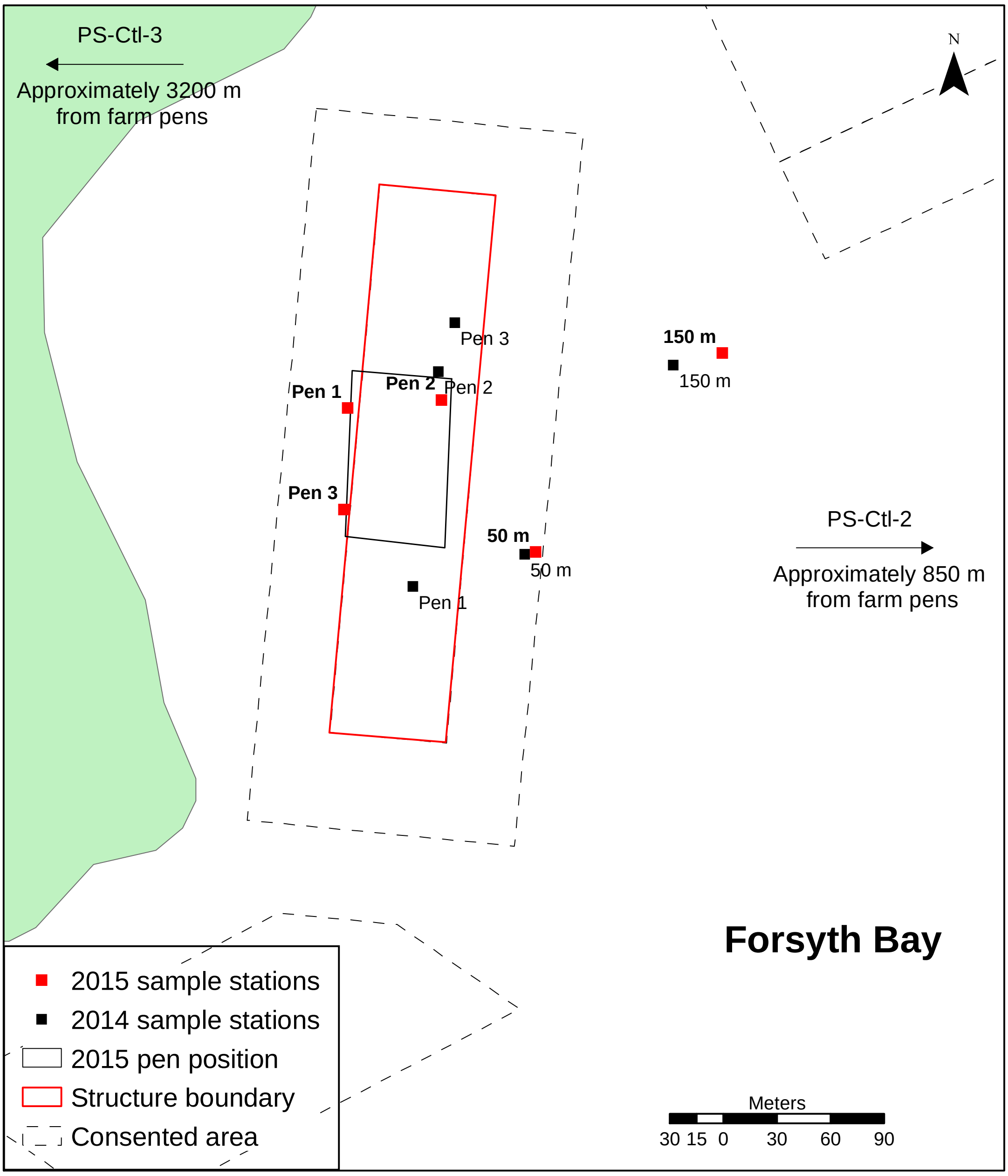

Figure 5. Soft-sediment sampling locations for the 2015 monitoring of the Forsyth Bay (FOR) salmon farm site. 'PS Ctl' = Pelorus Sound Control. Position accuracy is ± 5 m.

2.1.2. Environmental variables

Standard benthic monitoring

Three replicate sediment grab samples were collected at each sampling station using a van Veen grab. Each grab sample was examined for sediment colour, odour, texture and bacterial mat coverage. The top 3 cm of one sediment core (63 mm diameter) was analysed for organic content as % ash-free dry weight (AFDW), redox potential (Eh_{NHE}, mV), and total free sulphides (µM). Samples from two pen stations were analysed for copper and zinc concentrations (total recoverable and dilute-acid-extractable[2] in the < 250 µm grain size fraction[3]). In addition, a composited triplicate sample from the 50 m station was analysed for total recoverable copper and zinc concentrations. Laboratory analytical methods for sediment samples can be found in Appendix 2.

A separate core (130 mm diameter, about 100 mm deep) was collected from each grab for infauna identification and enumeration. The term 'infauna' describes the animals buried in the sediment. However, these samples do not reliably measure the larger animals living on the sediment surface (epifauna). Raw infauna data were further analysed to calculate the total abundance (N/core), total number of taxa (S/core), Shannon-Weiner diversity index (H'), Pielou's evenness index (J'), Margalef richness index (d), AMBI biotic coefficient (BC) and M-AMBI ecological quality ratio (EQR). Refer to MPI (2015) for an explanation of each of the biotic indices.

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

2.1.3. Assessment of enrichment stage

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to enrichment stage (ES). Each environmental result (raw data) was converted into an equivalent ES score using previously described relationships (MPI 2015). Average ES scores were then calculated for the sediment chemistry variables (redox and sulphides), the infauna composition variables (abundance, richness, evenness, diversity and biotic indices) and organic content (as % AFDW). The overall ES for a given sample was then calculated by determining the weighted average[4] of those three groups of variables. Finally, the overall ES for the sampling station was calculated from the average of the replicate samples with the degree of certainty reflected in the associated 95% confidence interval.

2.2. Water column

In-situ water column profiles of dissolved oxygen, turbidity, temperature, salinity, and chlorophyll-*a* were recorded at the net pen, and at the 50 m and 150 m sampling

[2] ANZECC threshold values are based on the bio-available fraction. For sediment particulates, the dilute-acid-extractable (1M HCl) fraction is used as a surrogate for bio-availability (ANZECC 2000).
[3] Because of historical exceedance of ISQG-High for zinc, the total recoverable and dilute-acid-extractable concentrations were analysed on the fine grain size fraction (<250µm) in the first instance to avoid chance inclusion of paint flakes that are often a cause for high concentrations at contaminated sites.
[4] Weighting used in 2015 was the same as that used in 2014: organic loading = 0.1, sediment chemistry = 0.2, infauna composition = 0.7)

stations, as well as a PS-CTL-3 for comparison. The information was collected by slowly raising a data-logging sensor array from the seabed to the surface.

2.3. Inshore habitats

The 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 2014 and the site is not due for this type of sampling again until the 2016 annual monitoring survey.

3. COMPLIANCE FRAMEWORK

The environmental quality standards (EQS) in the consent conditions (Table 1) do not set precise parameters for the allowable environmental states within the zones. This is particularly true when dealing with intermediate stages on the enrichment continuum. Consequently, it is not possible to report definitively on compliance with any particular consent condition. We note that a targeted working group has developed best management practice guidelines (MPI 2015) to address this issue.

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

Table 1. Environmental quality standards (EQS) for the Forsyth Bay (FOR) salmon farm described for each zone (taken from consent U040412) 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 MPI (2015) 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 and Pen 2 stations revealed soft dark muddy sediments with a consistent coverage of *Beggiatoa*-like bacteria. A layer of easily disturbed reddish-brown material, resembling feed pellets or fish faeces, was also apparent. The Pen 3 station was very similar to that observed at the other pen stations, but with less coverage (patchy only) of *Beggiatoa*-like bacteria, and slightly less easily disturbed feed pellet/faeces-like material. No bioturbation or epifauna was observed in the footage, and spotted wrasse (*Notolabrus celidotus*) were abundant.

The substrate at the 50 m and 150 m stations was similar to the control sites, exhibiting soft brown mud, lighter in colour than the pen stations. Some signs of bioturbation were evident in the form of burrow holes and trail-marks.

4.1.2. Physico-chemical characteristics

Sediment organic matter concentrations (measured as % AFDW) beneath the pens were variable. Two pen stations (Pen 1 and Pen 3) had anomalously low organic matter content (4.7–6.8%) that was reasonably comparable with concentrations from the control sites (4.9–5.2%) and the 50 m and 150 m stations (5.1–5.5%; Figure 6). However, the Pen 2 station had concentrations three times higher (13.9–17.5%) than those from the control sites. Organic content from all three pen stations were lower than recorded in 2014 (19.2%).

Pen station sediments all had negative and low average redox potentials (-79 to -166 Eh_{NHE}, MV). Of these, the Pen 3 station had the least impacted result (highest reading). Redox potentials at the 50 m and 150 m stations were positive, graduating upwards (95 Eh_{NHE} mV at 50 m, and 148 Eh_{NHE} mV at 150 m) with increasing distance from the pen (167 Eh_{NHE} mV and 242 Eh_{NHE} mV for PS-CTL-3 and PS-CTL-2 respectively). The 2015 redox potentials are lower overall than was recorded in 2014 at all stations.

Total free sulphide concentrations decreased with increasing distance from the pens. Average concentrations at the pen, 50 m and 150 m stations were 5,943 µM, 518 µM and 321 µM, respectively. Concentrations at the control stations were considerably lower (67 µM and 75 µM). Sample concentrations under the pens were high, and in some cases, extremely high, ranging from 1,568 to 9,939 µM. Pen stations had dark, gritty sediments with very strong sulphide odours. The presence of large and obvious patches of bacterial mat (Appendix 1 and Appendix 3) was consistent with the high sulphide levels recorded. Although average pen concentrations are higher than those recorded in 2014, comparatively lower sulphide concentrations were found at the 50 m and 150 m stations between these years.

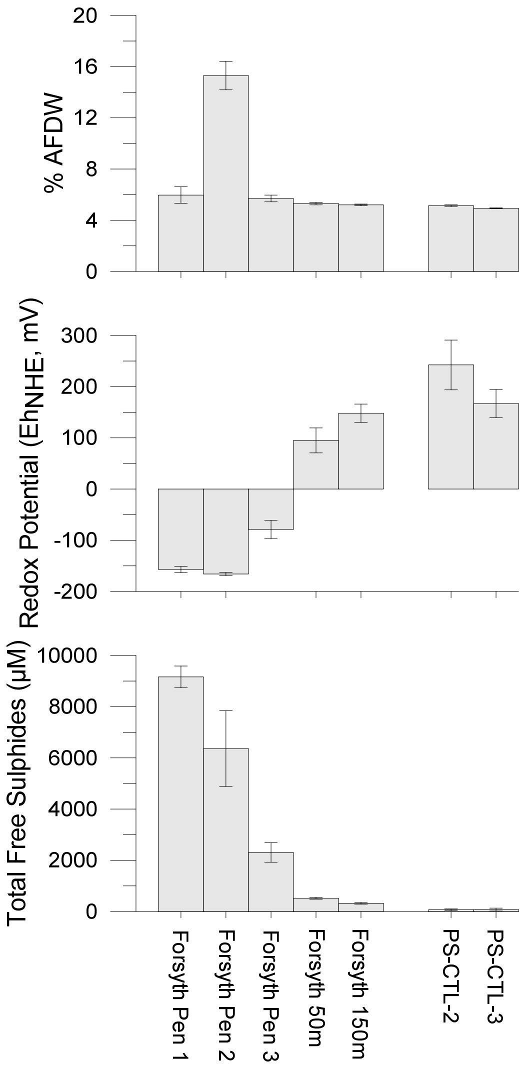

Figure 6. Sediment organic matter (% ash-free dry weight; AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) at Forsyth Bay farm (FOR) monitoring stations, 2015. Error bars = ± 1 SE, n = 3.

4.1.3. Biological communities

The infauna communities at the pen stations were very highly impacted. At the Pen 1 and Pen 2 stations, this was indicated by severely reduced numbers of taxa (2–4 per core), extremely low total abundances in some samples (as low as 2 per core), and subsequent reduced diversity and richness (Figure 7). The low taxa counts coupled with the low total abundances indicates post-peak of opportunist conditions that are now near azoic in some areas beneath the pens. Pen 3 had higher comparative total abundances (49 to 225 per core) spread across 5 taxa (overall at this station), but still indicated post-peak conditions that are approaching azoic. Communities at the pen stations were also characterised by lower diversity (H'), evenness (J'), richness (d) and ecological quality ratio (EQR) values compared with the control stations. Although the communities were post-peak in 2014, they have deteriorated further in the past 12 months.

Overall, the results suggest that although there is some element of patchiness in the communities beneath the net pens, at least some areas contain communities that are unable to effectively assimilate the current levels of organic input.

The 50 m and 150 m stations had total abundances (46 and 94 individuals per core, respectively) and taxonomic richness (15 and 25 taxa per core, respectively) indicative of a healthy and relatively diverse community, more similar to that of the control sites.

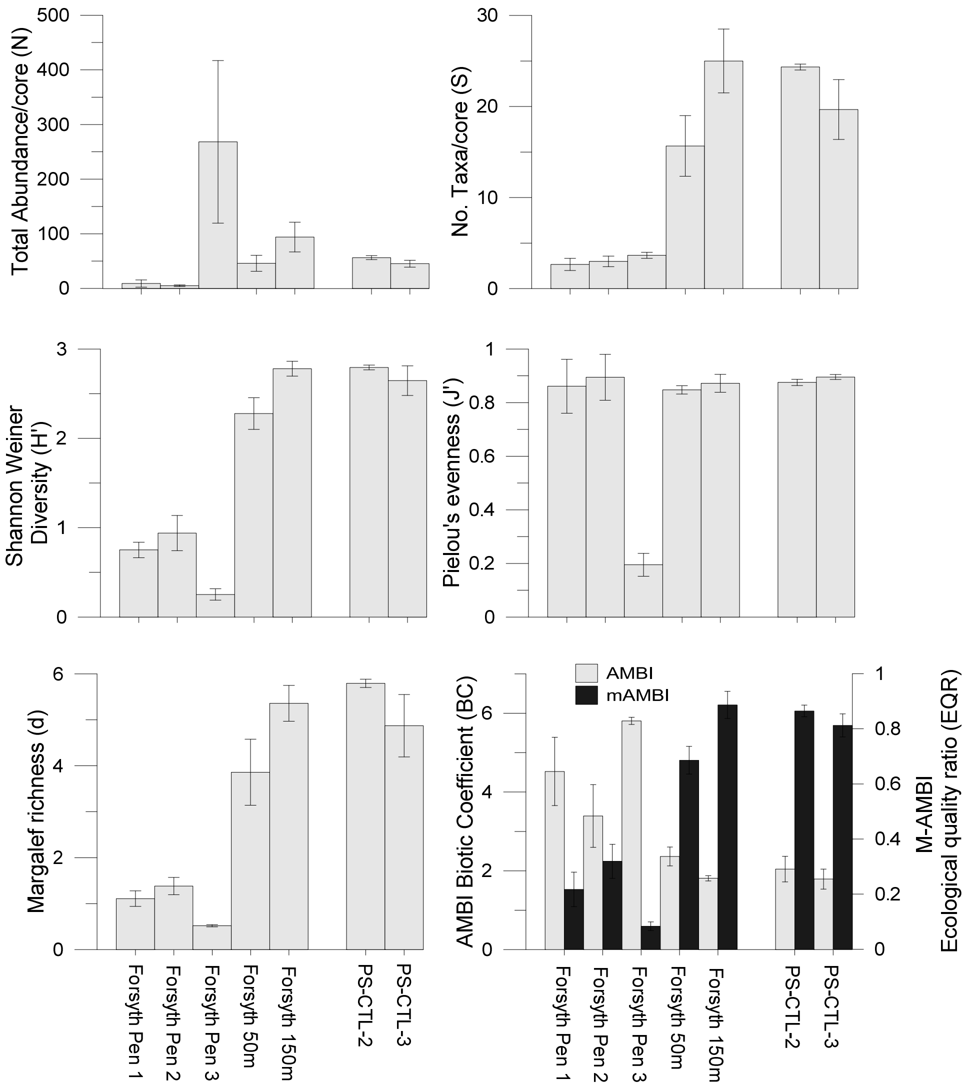

Figure 7. Infauna statistics for Forsyth Bay (FOR) salmon farm monitoring stations, 2015. Error bars = ± 1 SE, n = 3.

4.1.4. Copper and zinc concentrations

The combined average total recoverable zinc concentration across both pen stations (331 mg/kg, SE 60, n = 6) exceeded the ISQG-Low trigger level (200 mg/kg) for possible biological effects (Appendix 4; Figure A4.2). The concentration of the dilute-acid-extractable (DAE) fraction (a surrogate for the bio-available fraction: ANZECC 2000) was 259 mg/kg (SE 53 mg/kg). This was more than half the total recoverable concentration, and still over the ISQG-Low trigger level. Total recoverable zinc at the 50 m station was 93 mg/kg, less than half the ISQG-Low (Table 2).

The average total recoverable copper concentration across both pen stations (44.2 mg/kg, SE 7.1, n = 6) was below the ISQG-Low (65 mg/kg), and the DAE fraction was half as low again (22.0 mg/kg, SE 3.6). Total recoverable copper at the 50 m station was 13 mg/kg, well below the ISQG-Low (Table 2).

Historical comparisons[5] showed that concentrations of metals in the < 250 µm size fraction were substantially lower beneath the pens than recorded in bulk sediment in past monitoring surveys. This is likely because larger particulates (*i.e.* paint flake material) have been excluded from analysis in 2015 due to the size-specific methodological difference. In past years, larger particulates such as paint flakes have been the suspected cause of notably variable and high measurements of contaminants.

Sediment copper and zinc concentrations were not measured at the control stations in 2015 but average concentrations were less than 10 mg/kg and 50 mg/kg respectively in previous years (Appendix 4; Figure A4.2).

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

Sample		Total recoverable copper	Dilute-acid-extractable copper	Total recoverable zinc	Dilute-acid-extractable zinc
Pen 1	a	20	8	127	67*
	b	39	18	**210**	154
	c	**74**	35	**290**	**230**
Pen 2	a	43	22	**<u>440</u>**	**370**
	b	44	25	**<u>420</u>**	**340**
	c	45	24	**<u>500</u>**	**390**
50m		13		93	
ANZECC ISQG-Low		65		200	
ANZECC ISQG-High		270		410	

* Replicate analyses performed on this sample as part of the laboratory's in-house Quality Assurance procedures showed greater variation in this sample than would normally be expected. This may reflect the heterogeneity of the sample.

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

4.2. Water column

Water column profiling casts at the Forsyth Bay farm site (Figure 8) showed a well-mixed water column. Chlorophyll-*a* concentrations (a proxy for phytoplankton biomass) were greatest at depths below approximately 15 m. Concentrations of up to nearly 2.5 µg/L indicate productive conditions, but not to an extent that would suggest the onset of algal blooms.

Dissolved oxygen varied little throughout the water column except at the Pen 1 station, where midwater and surface reductions were apparent. This indicated an increase in oxygen demand, likely due to respiration by the salmon stock. DO levels remained at concentrations of greater than 6.5 mg/L, which constitutes a less than 20% reduction in DO concentration. Moreover, much less variability was apparent away from the pen, indicating a relatively minor and localised effect of the salmon farm on DO concentrations. Short-term fluctuations in DO concentration can occur dictated by the feeding regime and related respiratory activity of the salmon. Thus, single point in time measurements may not capture the full extent of periodic DO reduction events. A minor reduction in DO at the seabed may be related to benthic respiration, however concentrations were still quite high (7.7 mg/L), and similar to levels recorded throughout the water column at the control site. Therefore this reduction in DO does not indicate substantial effects of benthic enrichment.

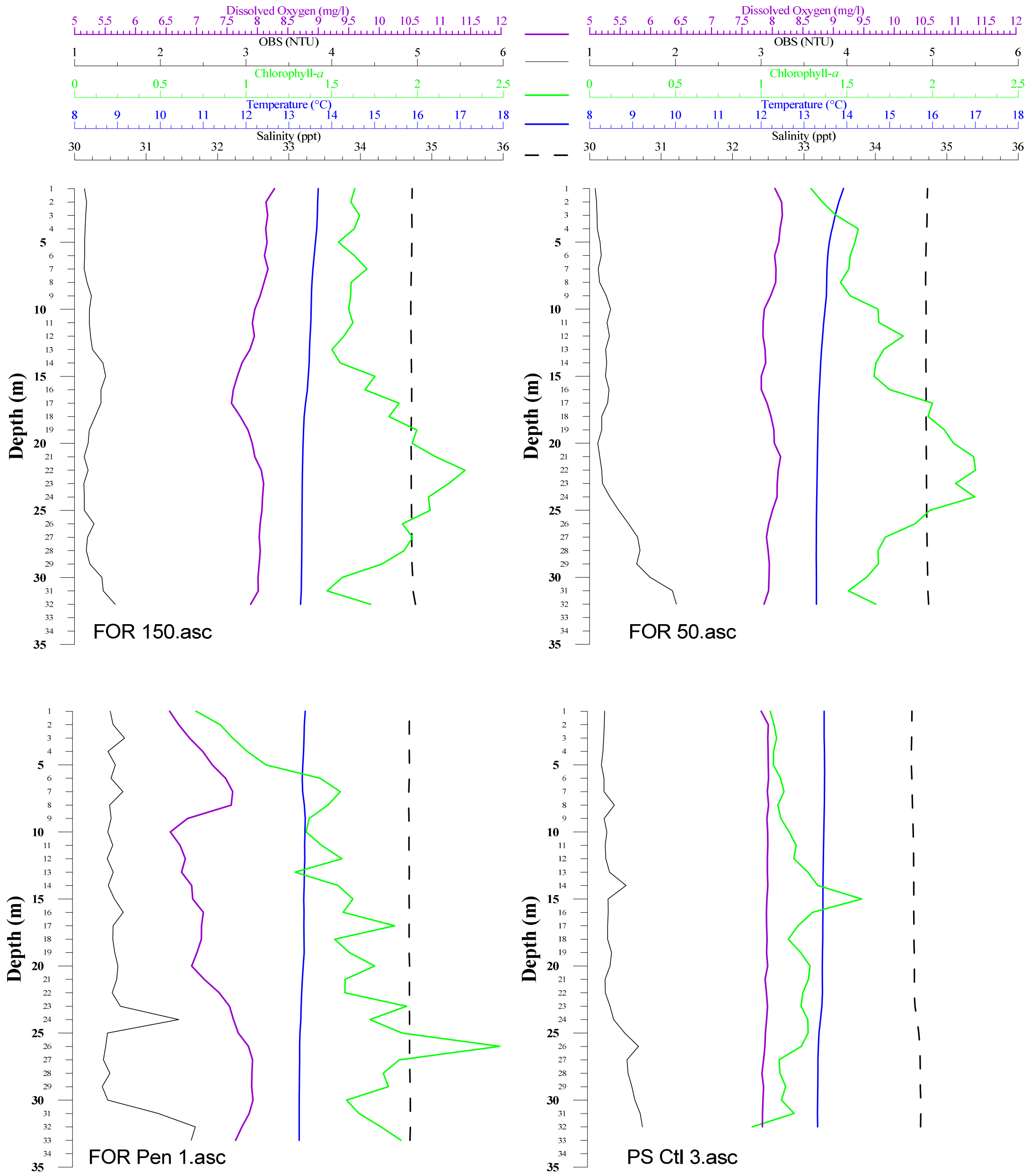

Figure 8. Dissolved oxygen, turbidity (optical back-scatter; OBS), chlorophyll-*a*, temperature, and salinity, as measured by an *in situ* sensor array raised through the water column, October 2015.

4.3. Results summary

Organic content and redox variables were slightly improved overall from the 2014 monitoring. However, the extremely elevated sulphide concentrations in some pen samples is evidence of recent deterioration. The presence of bacterial mats and strong odours associated with pen sediments is also consistent with deterioration.

Biological communities at the pen stations were indicative of highly enriched conditions, and had some samples indicating near azoic conditions. Pen communities were characterised by an extremely low taxa count (< 5 per core), low to moderate abundances of opportunistic infauna species, low species richness, evenness, diversity and EQR scores.

Zinc concentrations (both total recoverable, and DAE) exceeded ISQG-Low. Total recoverable copper concentrations were below ISQG-Low. High sediment metal concentrations found in 2014 apparently do not indicate a site-wide trend of sediment metal accumulation, and may have been due to samples containing flakes of paint.

Water column measurements did not indicate impacts of farming activities due to benthic enrichment-related processes (*e.g.*, unusually high chl-*a* concentrations or significant reduction of near-bottom DO). Mid-water reductions in DO were moderate and localised.

5. ASSESSMENT OF SEABED ENRICHMENT

5.1. Enrichment stage assessments for 2015

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

The overall ES at the pen stations was between 5.1–6.0. At Pen 2, the overall ES was 6.0, but the lower margin of the 95% confidence interval (5.7) was below the EQS (*i.e*. < 6.0). Under the BMP, this would elicit an ‘alert’ management response. The anomalously low organic matter concentrations at the Pen 1 and Pen 3 stations are driving lower overall ES average scores. The low OM at these stations may be a reflection of lower pre-existing organic matter levels at these stations prior to the introduction of the smolt earlier in 2015 (both Pen 1 and Pen 3 are located to the east [*i.e*. up-current] of the previous pen position), compared to Pen 2. Nonetheless, the strongly elevated sulphides coupled with the extremely low richness and abundance values at Pen 1 and 2 indicate clearly post-peak conditions, with macrofauna in most samples indicating near-azoic conditions (2 individuals per core). Relatively higher abundances at Pen 3 shows remnants of an assimilative community; however the species composition, absolute total abundance values and low numbers of taxa suggests conditions are also post-peak.

The Zone 1–2 (50 m) boundary appeared to be mildly enriched with an overall ES of 2.5, owing to slightly elevated sulphide concentrations. The Zone 2–3 (150 m) boundary had an overall ES of 2.0 and showed characteristics similar to background, again with the exception of slightly elevated sulphides.

[6] There are risks associated with placing emphasis on any individual indicator variables of ES. This is particularly true for chemical indicators, which tend to be more spatially and temporally variable. As such, the derived overall ES value is considered a more robust measure of the general seabed state.

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

	Summary of indicator variables		**ES (95%CI)**
Pen 1	%OM only slightly elevated; but redox strongly negative and sulphides extremely elevated. Number of taxa very low (< 5 per core), and total infauna abundance very low (2–22 per core). Post-peak conditions, near azoic.	Organic loading:	2.8 (0.5)
		Sediment chemistry:	6.2 (0.1)
		Infauna composition:	6.2 (0.7)
		Overall:	5.8 (0.4)
Pen 2	%OM high; redox strongly negative and sulphides highly elevated. Number of taxa very low (< 5 per core), and total infauna abundance very low (< 8 per core). Post-peak conditions, near azoic.	Organic loading:	5.5 (0.4)
		Sediment chemistry:	5.9 (0.4)
		Infauna composition:	6.2 (0.3)
		Overall:	6.0 (0.3)
Pen 3	%OM only slightly elevated; but redox moderately negative and sulphides elevated. Number of taxa very low (< 5 per core). Opportunistic taxa still present, but with post-peak abundances (49-552 per core).	Organic loading:	2.7 (0.2)
		Sediment chemistry:	4.7 (0.4)
		Infauna composition:	5.5 (0)
		Overall:	5.1 (0.1)
50 m (Zone 1–2 boundary)	Normal background conditions with the exception of mildly elevated sulphide concentrations.	Organic loading:	2.6 (0.1)
		Sediment chemistry:	3.1 (0.3)
		Infauna composition:	2.4 (0.4)
		Overall:	2.5 (0.4)
150 m (Zone 2–3 boundary)	Normal background conditions with the exception of mildly elevated sulphide concentrations.	Organic loading:	2.5 (0)
		Sediment chemistry:	2.6 (0.2)
		Infauna composition:	1.8 (0.1)
		Overall:	2 (0.1)
PS-Ctl 2	Normal background conditions. Infauna community composition indicative of background seabed conditions.	Organic loading:	2.5 (0.1)
		Sediment chemistry:	1.6 (0.5)
		Infauna composition:	1.8 (0.1)
		Overall:	1.8 (0.1)
PS-Ctl 3	Normal background conditions. Infauna community composition indicative of background seabed conditions.	Organic loading:	2.4 (0)
		Sediment chemistry:	1.9 (0.5)
		Infauna composition:	1.9 (0.2)
		Overall:	2 (0.1)

5.2. Historical comparison

A comparison of the last four monitoring assessments (conducted at roughly 12-monthly intervals) showed that after the relative stability from 2013–2014, the level of enrichment beneath the pens has increased from 2014 levels (when the site was fallowed) with the reintroduction of fish in May 2015, as would be expected (Table 4). Recovering sediments are thought to have a lower level of resilience (Keeley *et al*. 2015), and the sudden re-introduction of organic input at the site appears to have prompted a rapid deterioration of these communities into a near-azoic state.

Levels of enrichment at the Zone 1-2 and 3-4 boundaries have improved from 2014 to 2015. The apparent absence of any deterioration consistent with the pen stations is likely due to the very low flow, and therefore, non-dispersive site characteristics. However, it must also be noted that the 2014 results were derived from indicator monitoring (*i.e*. redox, sulphides and visual assessments only), and are not directly comparable to results derived from the full suite of variables that provides a more robust representation of conditions.

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

	Enrichment stage (s.e. and 95% CI for 2015)			
Station	**2012+**	**2013**	**2014+**	**2015**
Pen 1	3.76 (0.20)	5.6 (0.1)	5.6 (0)	**5.8 (0.4)**
Pen 2	4.25 (0.37)	5.5 (0.2)	5.6 (0)	**6.0 (0.3)**
Pen 3	4.80 (0.15)	5.6 (0.1)	4.9 (0) IM	**5.1 (0.1)**
50 m (Zone 1–2 boundary)	2.52 (0.06)	2.9 (0.1)	3.5 (0) IM	**2.5 (0.4)**
150 m (Zone 2–3 boundary)	2.29 (0.08)	2.2 (0.1)	3.0 (0.1) IM	**2.0 (0.1)**
PS-Ctl 2	1.84 (0.05)	1.8 (0.1)	2.0 (0)	**1.8 (0.1)**
PS-Ctl 3	1.59 (0.02)	1.7 (0)	1.8 (0)	**2.0 (0.1)**

+ Site was fallowed Dec 2011–Oct 2012, and again from Oct 2013–May 2015
IM = Indicator monitoring.

6. CONCLUSIONS AND RECOMMENDATIONS

Overall, the results at Forsyth show:

- No seabed enrichment effect related to farming was evident in the water-column profile.
- The levels of enrichment at the Zone 1–2 and Zone 3-4 boundary stations were consistent with the EQS.
- Two of the three pen stations were consistent with the stated EQS requirements (*i.e*. ES <6.0), despite near azoic state of some samples. However, the Pen 2 overall ES (6.0) elicits an 'alert' management response under the BMP (MPI 2015). Macrofauna beneath the pens was clearly post-peak abundance and the sulphide and macrofauna indicator ES values were both greater than ES 6.0, which is inconsistent with the BMP guidelines[7].
- No biological effects are expected from copper in the sediments. Zinc levels continue to exceed the threshold for possible biological effects.

  With the refined testing of sediment metals concentrations in 2015, it appears that a significant proportion of the high 2014 levels of zinc in the sediments beneath the net pens were probably bound as larger paint flake particulates. In addition, it does not appear that the elevated zinc levels are widespread (*i.e*. < 50 m from the net pens). Given these results, it is unlikely that high zinc levels are a result of continued accumulation of this metal across the pen site (*i.e*. more likely reflect chance inclusion of paint flakes in the samples).

6.1. Recommendation

Given the current highly enriched nature of sediments beneath the pens, continued long-term occupation of the site combined with the recent/current feed regime will likely have adverse implications for future compliance with the EQS for the site. However, the plans to fallow the farm (in January 2016) are likely to initiate the recovery of the seabed at the site. Nonetheless, it is recommended that at least the pen stations are considered for ES monitoring in the 2016 Marine Environmental Monitoring and Adaptive Management Plan (MEM-AMP).

[7] It must be noted that the BMP guidelines are yet to be applied to the management of this site as it is currently operating under a consent that pre-dates the BMP.

7. REFERENCES

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8. APPENDICES

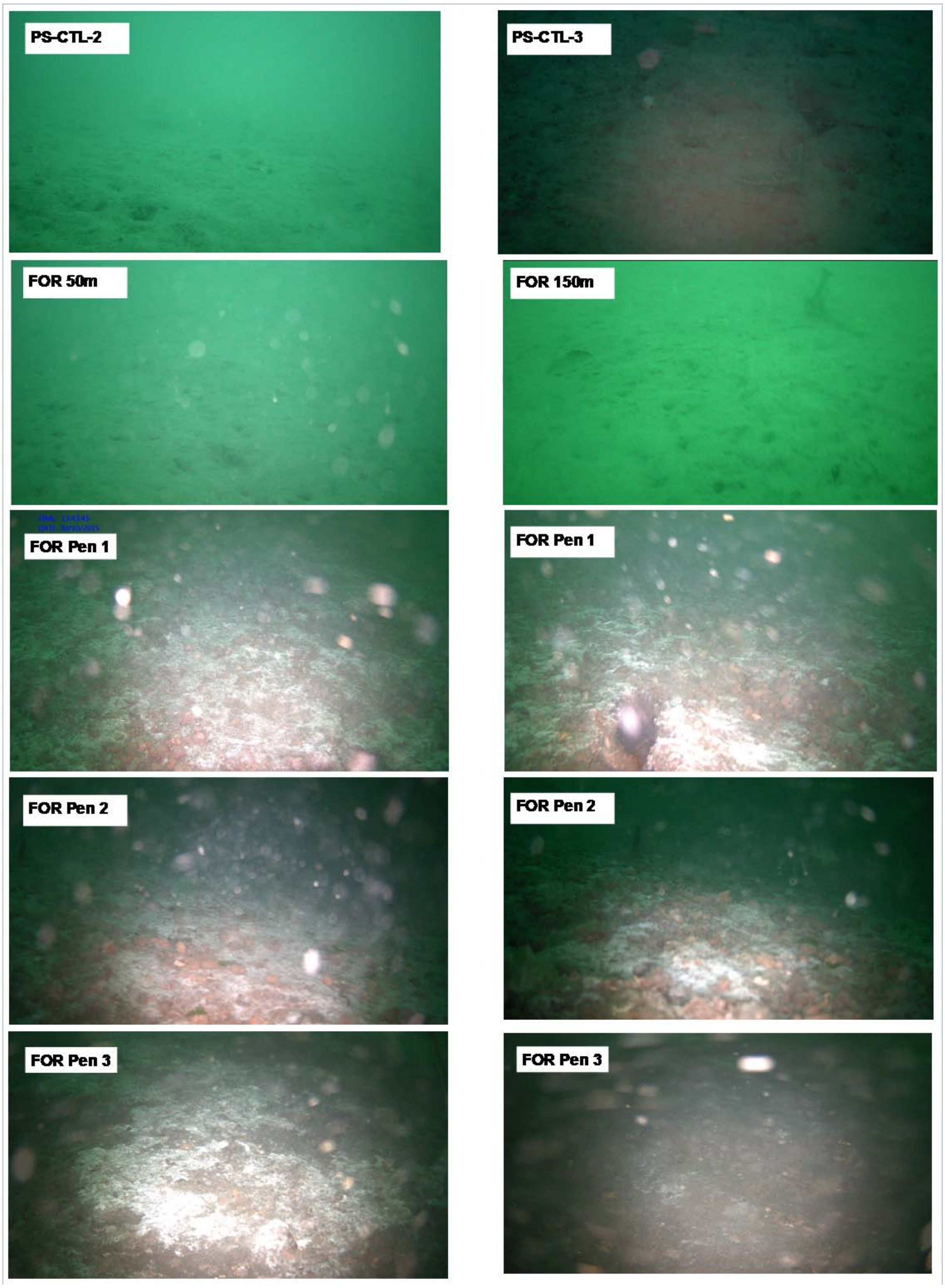
Appendix 1. Summary of the average (± SE) sediment physical and chemical properties, infauna variables and calculated indices for the Forsyth Bay (FOR) salmon farm stations during the 2015 monitoring survey. Summary of 2015 results.

	Station	Units	Pen-1	Pen 2	Pen 3	50 m	150 m	PS-Ctl-2	PS-Ctl-3
	Depth	m	33	31	31	31	31	30	37
Sediments	AFDW	%	6.0 (0.6)	15.3 (1.1)	5.7 (0.3)	5.3 (0.1)	5.2 (0.1)	5.1 (0.1)	4.9 (0)
	Redox	Eh_{NHE}, mV	-157.3 (6.2)	-166 (3.1)	-79 (18.1)	95 (24.4)	148 (17.9)	242.3 (48.5)	167 (27.5)
	Sulphides	µM	9161.8 (425.6)	6362.3 (1480.7)	2306.1 (383.9)	517.9 (34)	321.1 (31.1)	66.9 (34.5)	75.3 (56.4)
	Bacterial mat	-	Yes – consistent	Yes - consistent	Yes, patchy	None	None	None	None
	Out-gassing	-	None visible	None visible	None visible	No	No	No	No
	Odour	-	Strong	Strong	Strong	Mild	Mild	None	None
Infauna statistics	Abundance	No./core	9.0 (6.5)	5.0 (1.5)	268.3 (148.7)	46.0 (14.6)	94.0 (27.3)	56.3 (3.7)	45.3 (6.4)
	No. taxa	No./core	2.7 (0.7)	3.0 (0.6)	3.7 (0.3)	15.7 (3.3)	25.0 (3.5)	24.3 (0.3)	19.7 (3.3)
	Evenness	Stat.	0.9 (0.1)	0.9 (0.1)	0.2 (0)	0.8 (0)	0.9 (0)	0.9 (0)	0.9 (0)
	Richness	Stat.	1.1 (0.2)	1.4 (0.2)	0.5 (0)	3.9 (0.7)	5.4 (0.4)	5.8 (0.1)	4.9 (0.7)
	SWDI	Index	0.8 (0.1)	0.9 (0.2)	0.3 (0.1)	2.3 (0.2)	2.8 (0.1)	2.8 (0)	2.6 (0.2)
	AMBI	Index	4.5 (0.9)	3.4 (0.8)	5.8 (0.1)	2.4 (0.2)	1.8 (0.1)	2.0 (0.3)	1.8 (0.3)
	M-AMBI	Index	0.2 (0.1)	0.3 (0.1)	0.1 (0)	0.7 (0.1)	0.9 (0)	0.9 (0)	0.8 (0)
	BQI	Index	1.5 (0.7)	0.7 (0.1)	1.2 (0.1)	6.6 (0.5)	8.8 (0.6)	9.6 (1)	9.5 (0.6)

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

Analyte	Method	Default detection limit
Organic matter (as ash-free dry weight) [a]	APHA 2540 G 22nd ed. 2012.	0.04 g/100 g
1M HCl extractable copper & zinc [a]	< 250 µm sieved fraction. 1M HCl extraction, ICP-MS. CSIRO 2005.	1.2 mg/kg (copper) 3 mg/kg (zinc)
Total recoverable copper & zinc [a]	Bulk sediment and/or < 250 µm sieved fraction. Dried sample. nitric/ hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	0.2 - 2 mg/kg (copper) 0.4 - 4 mg/kg (zinc)
Total free sulphides [b]	Cawthron Protocol 60.102. Sample solubilised in high pH solution with chelating agent and anti-oxidant. Measured in millivolt (mV) using a sulphide specific electrode and calibrated using a sulphide standard.	

Appendix 3. Representative images of the seafloor at each station (2015).



Appendix 4. Historical comparisons.

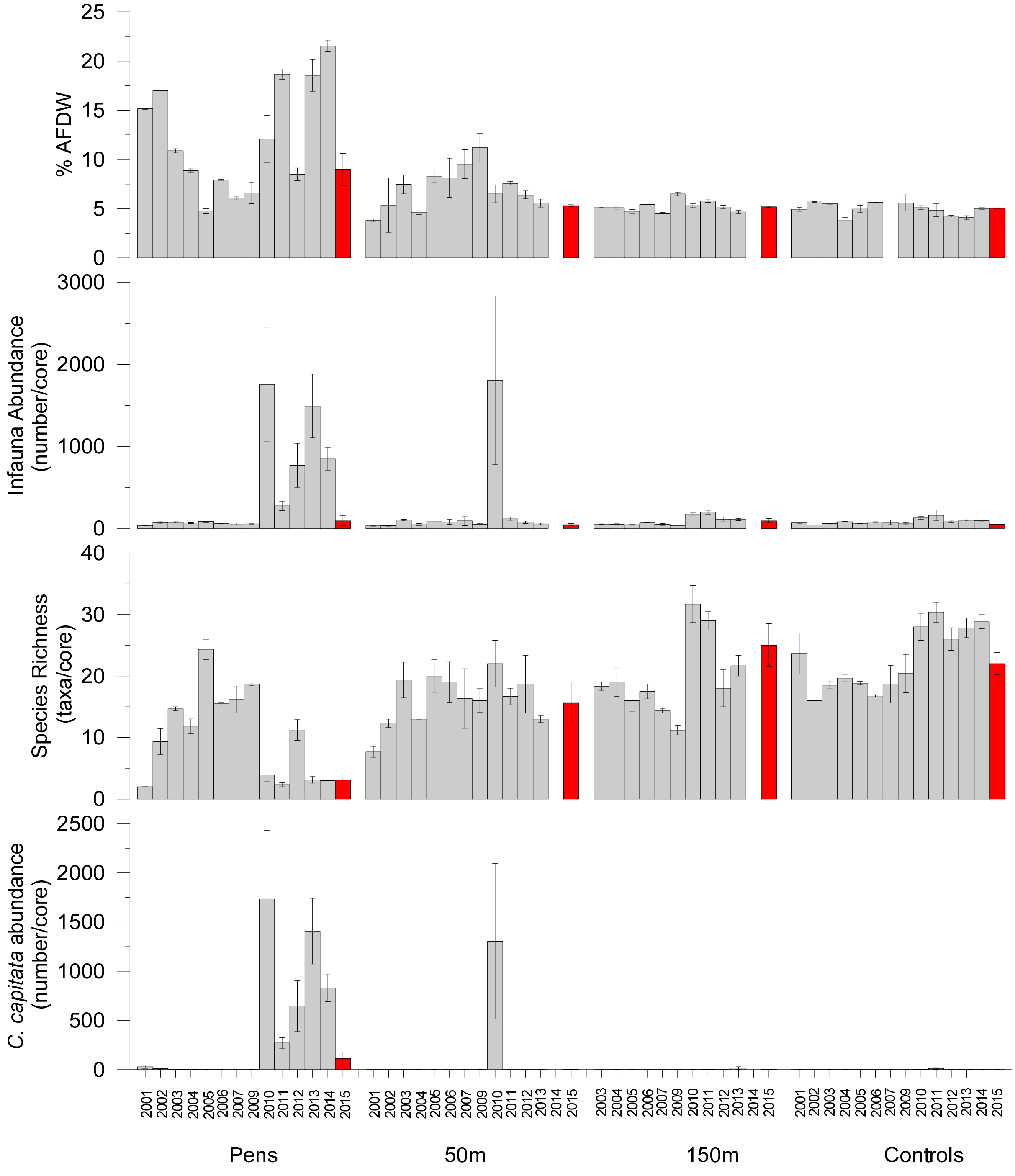


Figure A4.1. Comparison of annual monitoring of mean (± SE) ash-free dry weight (AFDW), infauna abundance and richness (no. taxa), and *Capitella capitata* densities recorded for Forsyth Bay (FOR) salmon farm annual monitoring since 2001. Densities of capitellid polychaetes of 1,000 individuals per m² (= 13 per 0.013 m² core) are typically considered high (ANZECC 2000 guidelines). 2015 results shown in red.

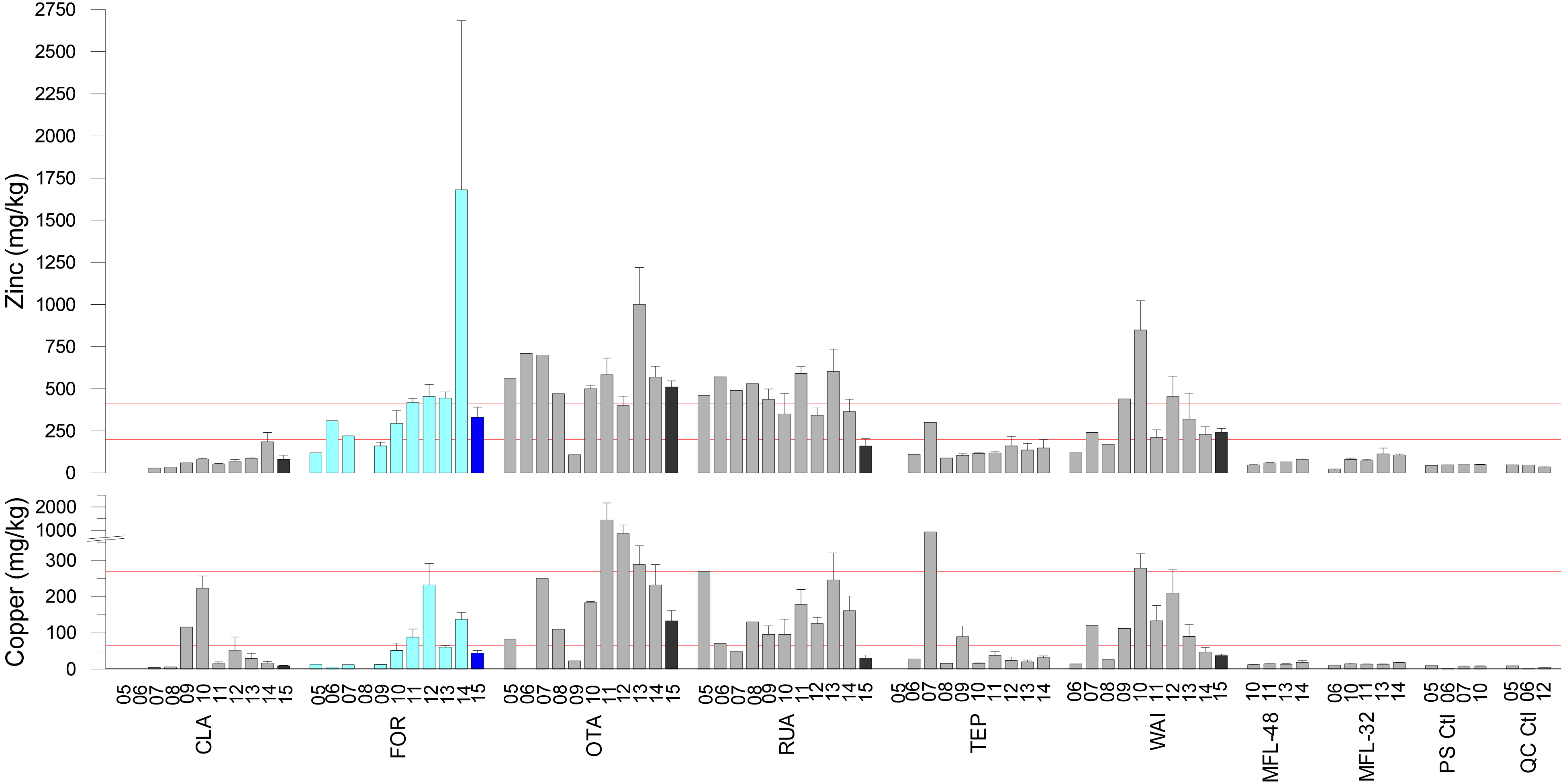


Figure A4.2. Comparison of the last 11 years of annual monitoring of sediment total recoverable copper and zinc concentrations beneath all eight NZ King Salmon farms and two control stations (PS = Pelorus Sound, QC = Queen Charlotte). Bars represent pen averages (± SE). Red lines indicate respective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

Appendix 5. Detailed enrichment stage (ES) calculations for each station at the Forsyth Bay (FOR) salmon farm, 2015. For details about how these values were calculated, see MPI (2015). Underlined text are cases where best professional judgement (BPJ; Keeley *et al.* 2012) was used.

SITE INFORMATION

Date: Oct-15

Farm/site: **Forsyth Bay**

Flow environment: **LF**

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

RAW DATA

Station:	Rep	TOM	Redox	TFS	N	S	j	d	Hloge	AMBI	M-AMBI	BQI
Forsyth Pen 1	A	4.7	-145	9073	2	2	1.0	1.4	0.7	3.0	0.3	2.7
Forsyth Pen 1	B	6.8	-164	9939	22	4	0.7	1.0	0.9	4.6	0.2	1.5
Forsyth Pen 1	C	6.4	-163	8473	3	2	0.9	0.9	0.6	6.0	0.1	0.3
Forsyth Pen 2	A	13.9	-170	9282	2	2	1.0	1.4	0.7	2.3	0.4	0.4
Forsyth Pen 2	B	17.5	-160	4475	7	3	0.7	1.0	0.8	4.9	0.2	0.8
Forsyth Pen 2	C	14.5	-168	5330	6	4	1.0	1.7	1.3	3.0	0.4	0.8
Forsyth Pen 3	A	6.1	-85	2493	49	3	0.2	0.5	0.2	5.9	0.1	1.0
Forsyth Pen 3	B	5.2	-45	1568	552	4	0.1	0.5	0.2	5.9	0.1	1.2
Forsyth Pen 3	C	5.8	-107	2858	204	4	0.3	0.6	0.4	5.6	0.1	1.3
Forsyth 50m	A	5.2	50	571	25	9	0.9	2.5	1.9	2.1	0.6	5.7
Forsyth 50m	B	5.2	101	454	39	19	0.8	4.9	2.5	2.8	0.7	6.8
Forsyth 50m	C	5.5	134	529	74	19	0.8	4.2	2.4	2.1	0.8	7.3
Forsyth 150m	A	5.2	113	351	114	29	0.9	5.9	2.9	1.8	0.9	9.0
Forsyth 150m	B	5.1	172	353	40	18	0.9	4.6	2.7	1.9	0.8	7.7
Forsyth 150m	C	5.3	159	259	128	28	0.8	5.6	2.7	1.7	0.9	9.8
PS-CTL-2	A	5.2	326	38	60	24	0.9	5.6	2.8	1.8	0.9	10.1
PS-CTL-2	B	5.2	243	136	60	25	0.9	5.9	2.7	2.7	0.8	7.8
PS-CTL-2	C	5	158	28	49	24	0.9	5.9	2.8	1.6	0.9	11.1
PS-CTL-3	A	4.9	139	17	40	18	0.9	4.6	2.6	1.5	0.8	9.3
PS-CTL-3	B	5	140	188	58	26	0.9	6.2	2.9	2.3	0.9	10.7
PS-CTL-3	C	4.9	222	21	38	15	0.9	3.8	2.4	1.6	0.7	8.7

ES equivalents

Station:	Rep	TOM	Redox	TFS	S	N	j	d	Hloge	AMBI	M-AMBI	BQI	Organic loading	Sediment chemistry	Macrofauna	Overall ES
Forsyth Pen 1	A	2.34	5.43	6.92	6	6		4.56	5.02	2.79	5.01	4.23	**2.34**	**6.18**	**6.5**	**6.02**
Forsyth Pen 1	B	3.14	5.61	7	6	5		5.18	4.63	3.96	5.32	5.47	**3.14**	**6.31**	**5.5**	**5.43**
Forsyth Pen 1	C	2.99	5.6	6.8	6	6		5.26	5.12	5.03	6.14	6.78	**2.99**	**6.2**	**6.5**	**6.09**
Forsyth Pen 2	A	5.19	5.66	6.96	6	6		4.56	5.02	2.23	4.74	6.63	**5.19**	**6.31**	**6.5**	**6.33**
Forsyth Pen 2	B	5.86	5.57	5.7	6	5.5		5.1	4.85	4.23	5.59	6.25	**5.86**	**5.64**	**6**	**5.91**
Forsyth Pen 2	C	5.32	5.64	5.99	6	5		4.28	3.93	2.79	4.49	6.2	**5.32**	**5.82**	**6**	**5.9**
Forsyth Pen 3	A	2.88	4.89	4.8	6	5.5		5.83	5.87	4.94	6.31	6.01	**2.88**	**4.85**	**5.5**	**5.11**
Forsyth Pen 3	B	2.54	4.53	4.15	5.5	5		5.88	5.91	4.97	6.28	5.71	**2.54**	**4.34**	**5.5**	**4.97**
Forsyth Pen 3	C	2.77	5.09	5	5.5	5		5.75	5.56	4.75	6.04	5.62	**2.77**	**5.05**	**5.5**	**5.14**
Forsyth 50m	A	2.54	3.68	2.93	2.5	3		3.39	2.91	2.12	3.49	2.22	**2.54**	**3.31**	**2.8**	**2.88**
Forsyth 50m	B	2.54	3.22	2.69	1.53	2.39		1.73	1.95	2.68	2.81	1.78	**2.54**	**2.96**	**2.12**	**2.33**
Forsyth 50m	C	2.66	2.92	2.85	2.08	2.39		2.08	2.05	2.15	2.59	1.62	**2.66**	**2.89**	**2.14**	**2.34**
Forsyth 150m	A	2.54	3.11	2.44	2.45	1.88		1.48	1.16	1.91	1.54	1.43	**2.54**	**2.78**	**1.69**	**1.99**
Forsyth 150m	B	2.5	2.58	2.44	1.55	2.51		1.86	1.61	1.98	2.4	1.55	**2.5**	**2.51**	**1.92**	**2.1**
Forsyth 150m	C	2.58	2.7	2.16	2.55	1.87		1.54	1.56	1.81	1.69	1.47	**2.58**	**2.43**	**1.78**	**1.99**
PS-CTL-2	A	2.54	1.2	1	1.9	1.96		1.53	1.41	1.92	1.94	1.51	**2.54**	**1.1**	**1.74**	**1.69**
PS-CTL-2	B	2.54	1.94	1.66	1.9	1.92		1.49	1.5	2.55	2.22	1.54	**2.54**	**1.8**	**1.87**	**1.92**
PS-CTL-2	C	2.46	2.71	0.9	1.73	1.96		1.48	1.34	1.76	1.83	1.74	**2.46**	**1.81**	**1.69**	**1.79**
PS-CTL-3	A	2.42	2.88	0.81	1.55	2.51		1.86	1.72	1.64	2.28	1.43	**2.42**	**1.85**	**1.86**	**1.91**
PS-CTL-3	B	2.46	2.87	1.9	1.87	1.89		1.45	1.15	2.26	1.89	1.63	**2.46**	**2.39**	**1.73**	**1.94**
PS-CTL-3	C	2.42	2.13	0.84	1.51	2.97		2.28	2.13	1.76	2.67	1.43	**2.42**	**1.49**	**2.11**	**2.02**