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Environmental Impacts of the Forsyth Bay Salmon Farm: Annual Monitoring 2010

RESEARCH BASED SOLUTIONS

Environmental Impacts of the Forsyth Bay Salmon Farm: Annual Monitoring 2010

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

New Zealand King Salmon Ltd (NZKS) is the largest finfish farming company in New Zealand and has a long history in the Marlborough Sounds. NZKS is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The monitoring is conducted under an annual monitoring plan (AMP) that is prepared by Cawthron and submitted to NZKS and the Marlborough District Council (the Council) for approval prior to implementation in October-November of each year. The specific methods of the AMP were revised in 2010 to accommodate improvements in knowledge and techniques as described in Keeley (2011).

This report presents the 2010 annual monitoring results for the Forsyth Bay salmon farm.

1.1. Background

New Zealand King Salmon (NZKS) has six consented farms in the Marlborough Sounds (Figure 1): Te Pangu Bay (TEP), Ruakaka Bay (RUA), Otanerau Bay (OTA), Waihinau Bay (WAI), Forsyth Bay (FOR) and Clay Point (CLA). Five of these are currently farmed, while one (WAI) is presently unstocked (*i.e.* lies fallow). The six farms are situated in comparable depths (30-45 m) and over similar seabed substrates, but vary in terms of their flow regimes (Table 1). The differences in flow rates (and flushing) have ramifications for how each farm is monitored. TEP and CLA are considered high-flow sites, WAI and OTA low- to moderate-flow and FOR and RUA are low-current sites.

The environmental monitoring determines whether the farms are compliant with the seabed impact zones concept; a model, which provides an upper limit to the spatial extent and magnitude of seabed impacts. The Waihinau Bay salmon farm site is the only exception to this, as it is not required to apply the zones concept under its consent conditions. However, conditions for all of the farms broadly require monitoring of the effects of deposition on the seabed, with particular regard to the benthic community composition and abundance, and dissolved oxygen levels. Consents for four of the farms (CLA, WAI, TEP and OTA) also require some form of water column monitoring, and TEP and CLA have adjacent rocky reef communities that are also monitored as a precautionary measure due to their proximity to the farms and proposed feed increases.

Table 1. Summary of farm ages, historical feed ranges and physical attributes (depth and flow).

Farm	Established	Age (yrs)	Feed inputs t/yr	Site depth (m)	Flow Category	Current spd. (cm/s)* Ave	Max
Clay Point	2007	3	2631-3150	30-40	High	19.6	109
Te Pangu Bay	1992	18	2104-4120	27-31	High	15	55.9
Waihinau Bay	1989	21	2171-3918^{+}	28-30	Low-Moderate	8.4	33.7
Otanerau Bay	1990	20	1640-2239	37-39	Low-Moderate	6	34.6
Forsyth Bay	1994	16	100-2264^{+}	34-35	Low	3.1	11.8
Ruakaka Bay	1985	25	2510-3289	34-35	Low	3.7	17.5

*Average at 20 m depth.
$^{+}$When in production (as opposed to fallow).

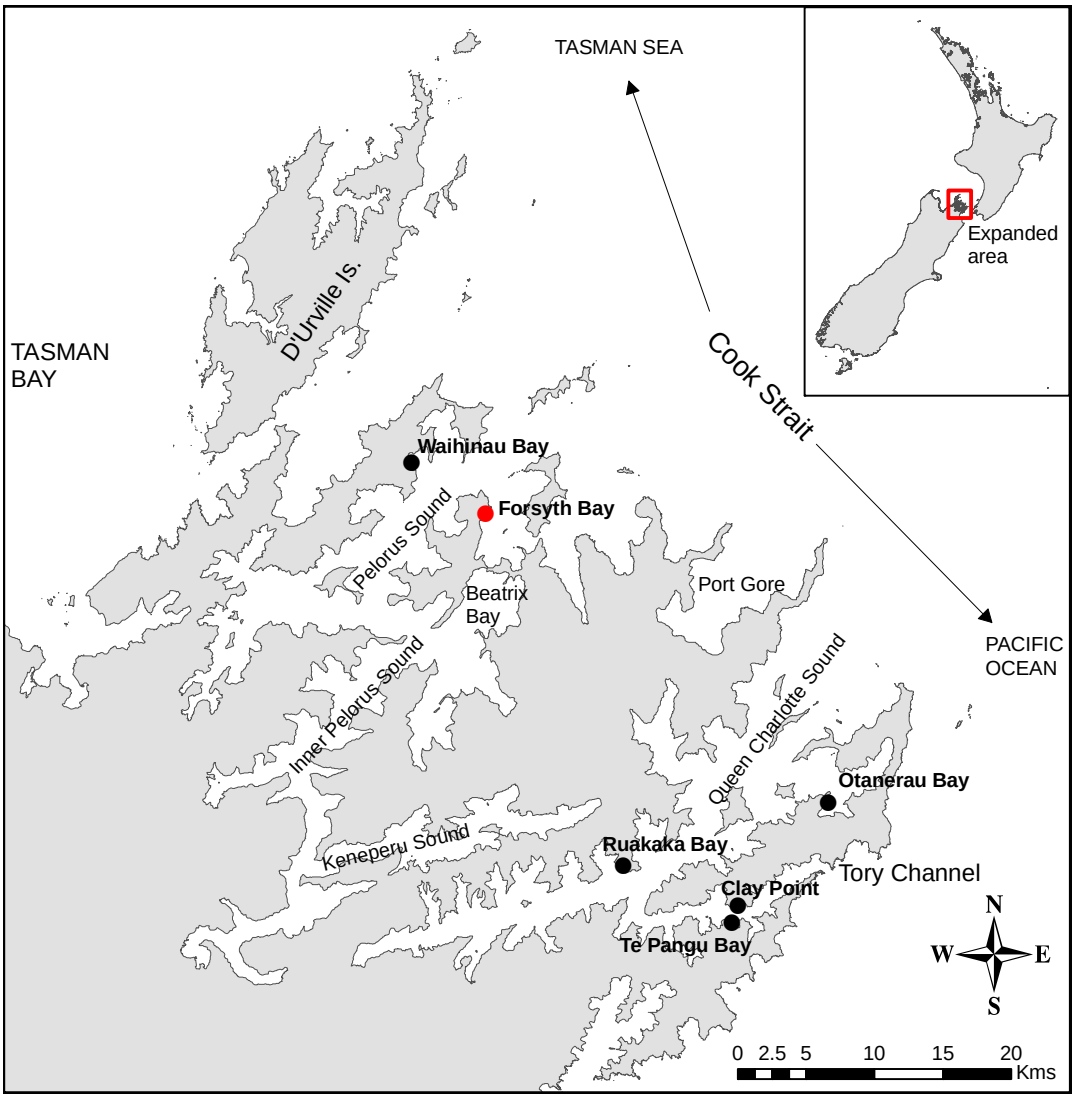

Figure 1. Map of Marlborough Sounds area showing the location of the FOR salmon farm (red dot) along with NZKS's five other farm sites (black dots).

1.2. Site details and history of feed usage

The Forsyth Bay farm site was established in 1994 and, with average water current speeds of ~ 3 cm/s, it is considered a low-flow site (Table 1). Feed inputs at this farm have historically ranged from 100 to 2264 tonnes, however, the site was fallowed (*i.e.* farm removed and no feed input) for nine 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 nearly fully recovered. Over the 12 month period leading up to this years monitoring (*i.e.* December 2009 to the end of November 2010), a total of 3261 tonnes of feed was used (Figure 2).

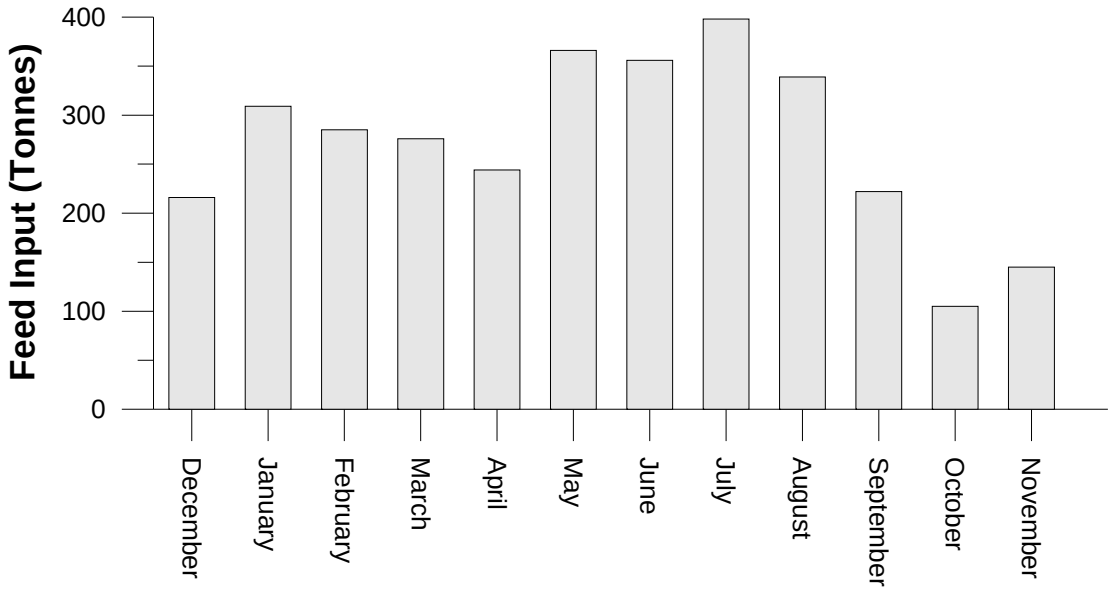

Figure 2. Monthly feed inputs at the Forsyth Bay farm from December 2009 to November 2010.

2. METHODS

Detailed methods and rationale describing the sampling protocol for all of NZKSs' farms can be found in the most recent Annual Environmental Monitoring Plan (AEMP, Cawthron Report 1872). Copies are held by MDC and NZKS. This plan is updated and modified routinely to accommodate the most relevant and effective sampling methods. A condensed summary of sample techniques that were adopted this year is provided below.

2.1. Soft sediment habitats

2.1.1. Sampling locations

The FOR salmon farm was monitored in a manner that was consistent with the previous three surveys, which includes three cage stations, five stations along a transect aligned in a down-current direction and three comparable reference or 'control' (*i.e.* 'Ctl-1', 'Ctl-2' and 'Ctl-3') stations (Figure 3). The additional stations were adopted at this site temporarily for the purposes of describing how it responded to farm reintroduction after nine years of fallowing. Stations '50 m' and '150 m' are appropriately situated for use as indicators of conditions at the zone 1-2 and 2-3 boundaries, as required under the zones concept. For a full explanation of the zones concept, please refer to Keeley 2011.

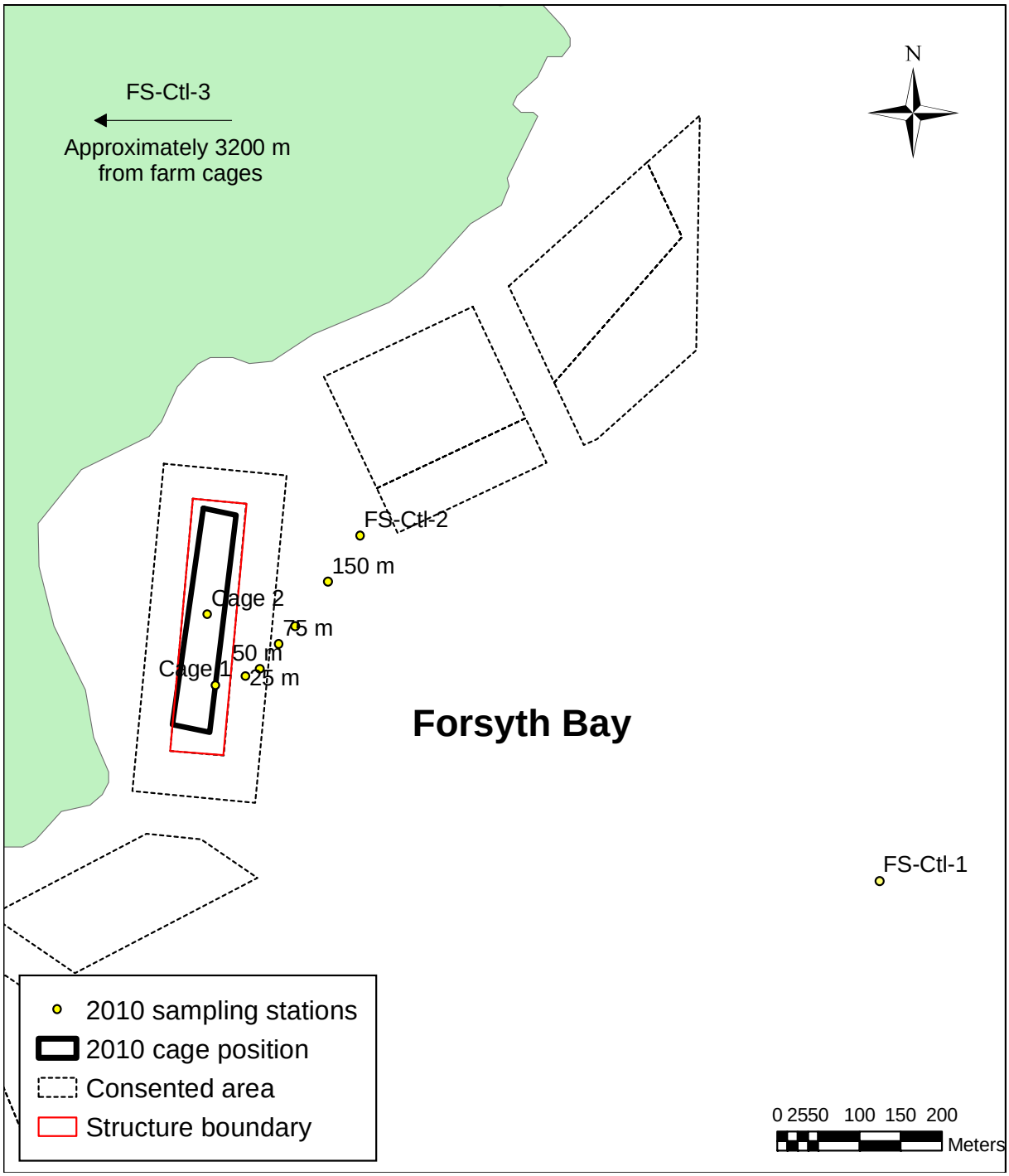

Figure 3. Soft sediment and inshore habitat sampling locations for FOR in 2010. 'Ctl' = Control.

2.1.2. Environmental variables

Three replicate sediment (modified van Veen) grab samples were collected at each sampling station. Each grab was examined for sediment odour and texture and the top 3 cm of a sediment core (63 mm diameter) was analysed for organic content (as AFDW, % w/w), redox potential (Eh_{NHE}, mV), and total free sulphides (µM). 'Cage' samples were additionally analysed for copper and zinc concentrations. A separate core (130 mm diameter, approx. 100

mm deep) was collected from each grab for macrofauna identification and enumeration. A minimum of three replicate seabed photo-quadrats were assessed at each benthic monitoring station to assesses the prevalence (none/patchy/complete coverage) of bacterial (*Beggiatoa*-like) mat and sediment out-gassing, and to evaluate the general seabed condition.

Raw macrofauna data were further analysed to calculate the total abundance (N), total number of taxa (S), Shannon-Weiner Diversity (H'), Pielou's evenness (J'), Margalef richness (d), and AMBI and M-AMBI ecological statistics and indices.

2.2. Rocky habitats

The FOR salmon farm is considered a low-flow site and there are no significant reef habitats within the primary depositional footprint. Inshore habitats are therefore visually inspected qualitatively every second year for general health and any signs of excessive organic deposition (indicated by any unusual build-up on rocky habitats) and the video footage is compared to previous years. This was undertaken during the survey for this year's annual monitoring.

2.3. Water column

Near bottom dissolved oxygen (DO) concentrations were measured at each of the benthic sampling stations by collecting water ~ 1 m from the seabed with a van Dorn sampling bottle and measuring with a calibrated, on-board DO meter.

Nutrients were measured at one low-flow and one high-flow salmon farm each year; in 2010 this was undertaken at RUA and CLA. Nutrient samples were collected from mid-water using a van Dorn sampler and analysed in the laboratory for nutrients (nitrate-N, nitrite-N, ammoniacal-N and dissolved reactive phosphorous).

3. RESULTS

3.1. Soft sediment habitats

Sediment organic matter levels were significantly elevated (*i.e.* by 2-3 times) beneath the cages compared to the control stations (Figure 4), and showed a decreasing trend with increasing distance from the cages. Sediment organic contents were similar at all three control stations as well as the 150, 100 and 75 m down-current stations. The sampling stations at the edge of the cages had negative redox potentials (-50 Eh_{NHE}, mV) and levels of total free sulphides that were twice as high as the next closest station to the cage edge (25 m). These results were consistent with observations of out-gassing, evidenced by bubbles breaking at the surface both freely and upon disturbance (*i.e.* when the grab or drop-camera hits the seabed).

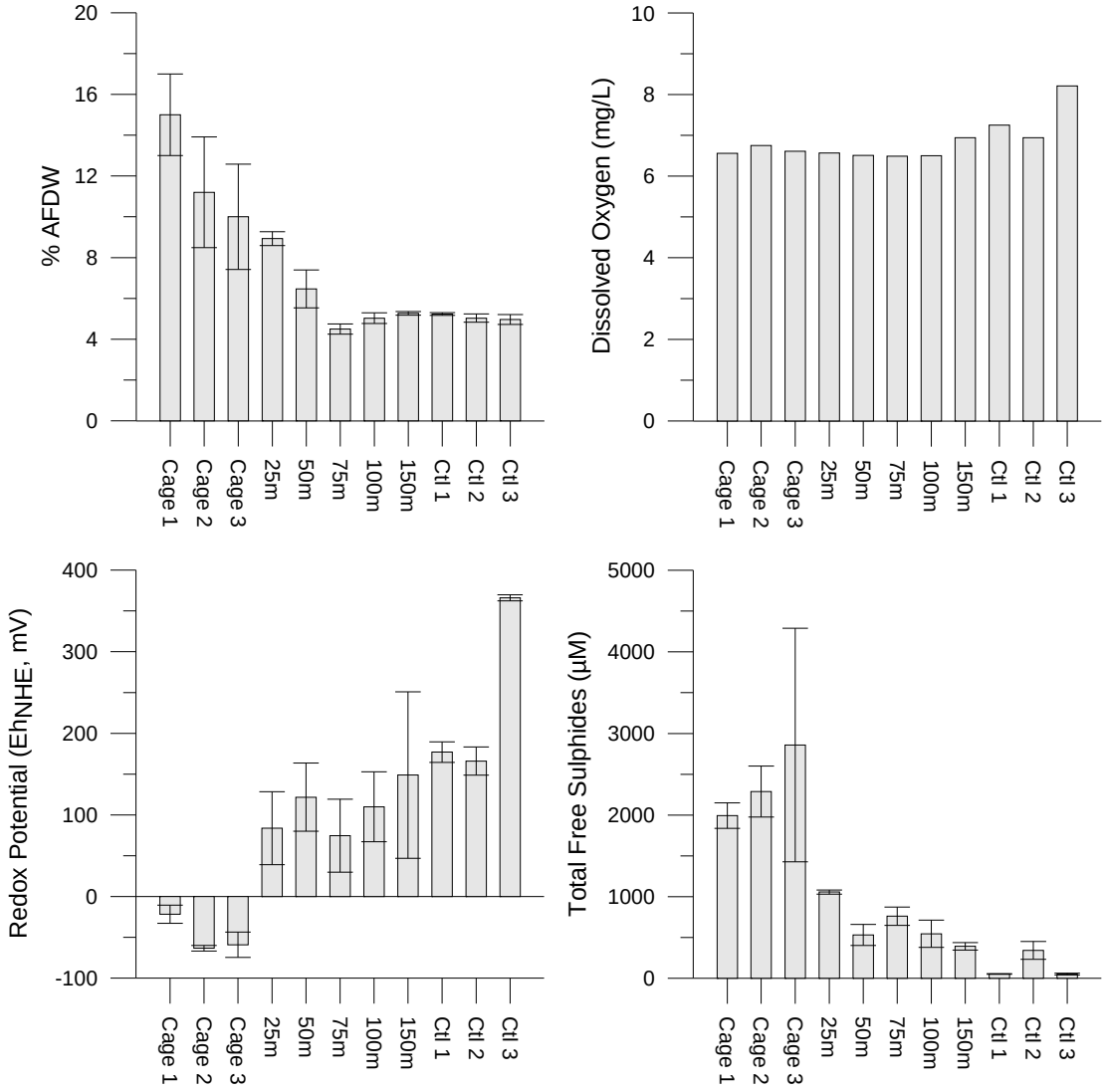

Figure 4. Multiplot of organic matter (as AFDW (% w/w)), redox potential (Eh_{NHE}, mV), total free sulphides (µM), near-bottom DO (mg/l) and water temperature (°C, indicated by black dots). Error bars = SE.

The infauna communities at the cage stations were compromised, as indicated by an average of four taxa and increased total abundances dominated by disturbance tolerant, opportunistic taxa. In addition, communities were characterised by low Diversity (H'), Richness (d) and Ecological Quality Ratio (EQR) values (Figure 5). Total taxa numbers were also reduced at the '50 m' station compared to controls, and together with diversity, evenness and richness showed a positive trend with distance from the cage edge due to very high abundances of a few disturbance tolerant, opportunistic taxa (especially *Capitella capitata* and nematode worms). The control stations showed similar biological community properties to the 100 and 150 m down-current stations.

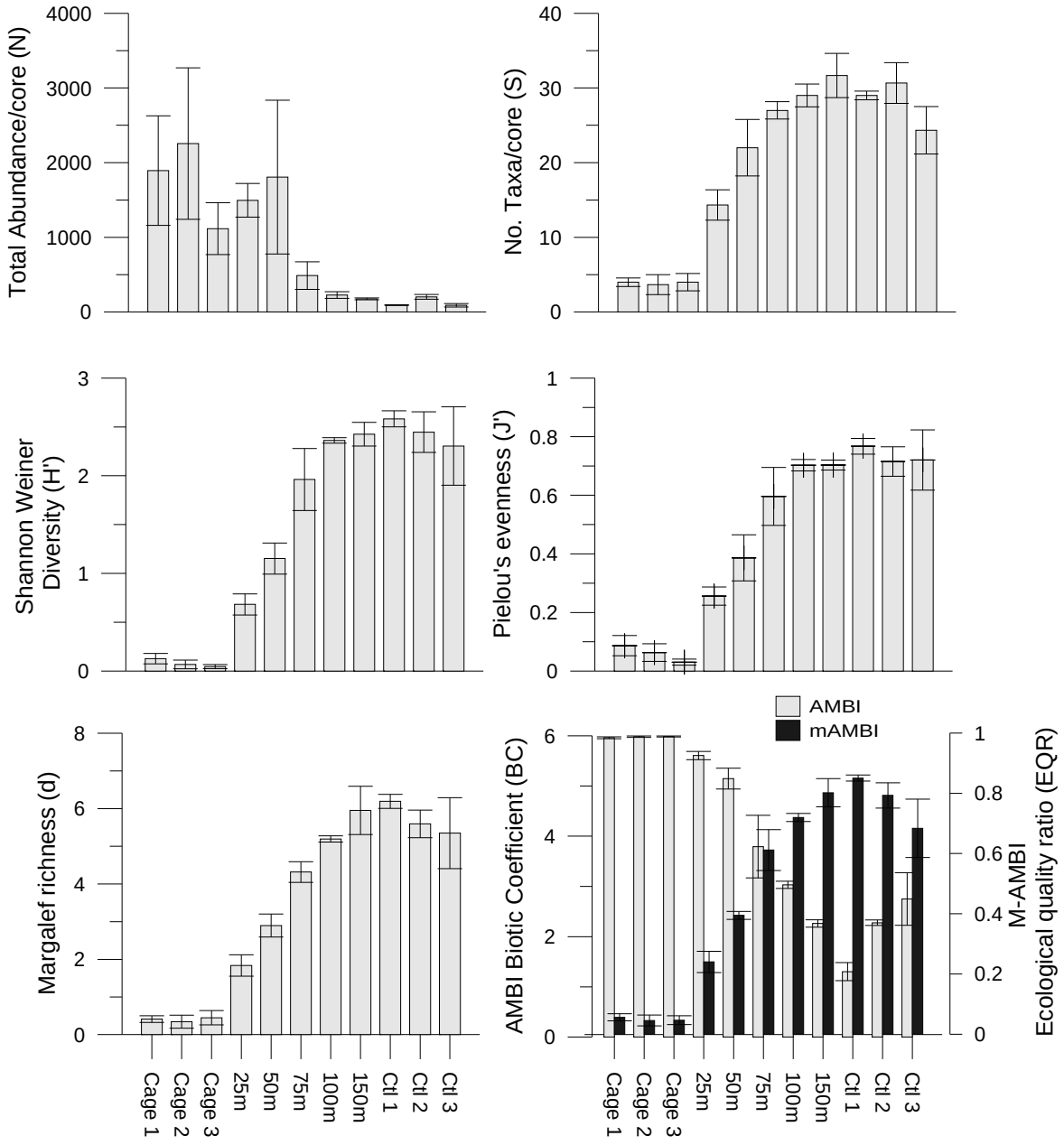

Figure 5. Multiplot of macrofauna statistics. Error bars = SE.

3.1.1. Copper and zinc

Zinc concentrations in the sediments below the cages exceeded the ISQG-Low trigger levels with an average of 294.4 mg/kg across all three cage stations (n = 9), while average copper concentrations were below the low trigger level (Figure 8 in Appendix 2). These results represent noticeable increases in both copper and zinc since the previous monitoring in 2009, and concentrations below the cages are around six times higher than background levels in the outer Pelorus Sound.

3.2. Rocky habitats

Diver observations and video footage provided a description of habitats along two transects from the shallow subtidal area inshore of the south-western and north-western corner of the farm boundary, down the rocky cobble slope and out towards the cages. The south-west transect showed a cobble and sand slope that flattened to sandy mud at around 20 m with occasional horse mussels, sea-cucumbers, 11-armed sea stars and small scallops. Blue mussels were present in some large beds at the base of the slope at around 18-19 m depth. Off the north-western corner of the cages the exposed bedrock in the shallows is covered with the brown algae *Carpophyllum* sp. Below this the cobble and sand seabed sloped down to 22 m with numerous 11-armed sea-stars, gray sponges, sea cucumbers and abundant blue mussels. Out on the flatter seabed nearer the edge of the cages the benthos was covered with a thick layer of mussel shells with an overlying layer of fine, easily disturbed material. A large amount of rope remains on the seabed near one of the mooring blocks off the north-western corner of the farm.

3.3. Water column

Near-bottom (water column) dissolved oxygen (DO) levels were similar at all stations beneath the cages and along the down-current transect, apart from the 150 m station. The 150 m and control stations had an average near bottom DO level that was ~ 10% higher than the down-current and cage stations. Water column nutrient levels were not analysed at Forsyth during the 2010 round of annual monitoring.

4. 2011 ASSESSMENT OF COMPLIANCE

4.1. Soft sediment habitats

4.1.1. Approach

Compliance is assessed by comparing the environmental results to predefined environmental quality standards (Appendix 3, Keeley 2011). These standards define stages (from 1-7) along an enrichment stage (*ES*) gradient, as depicted in Figure 6 and described in Table 2. An overall *ES* score is calculated for each station based on the individual scores that are assessed for each of the environmental variables (by comparing against the environmental quality standards; as detailed in Appendix 3). 'Certainty' reflects the degree of certainty in the overall *ES* score and is calculated from the level of variability (or agreement) between the scores for the different variables.

Certain levels of enrichment (or 'states of impact') are permitted within set distances (*i.e.* at 'Cages', '50 m' and '150 m' stations) from the salmon cages (Table 3). The permitted conditions vary slightly depending on whether they pertain to a high- or low-flow site, as experience has indicated that they have inherently different benthic attributes and tend to respond differently to enrichment. FOR is treated as a low-flow site. If the overall *ES* score for any of the stations is greater than the equivalent *ES* specified in Table 3, then the farm is considered more impacted than is permitted by the consent conditions. The state of compliance, coupled with the certainty around the assessment, is then used to identify the type of management response, if any, that is required (Table 4). Further details pertaining to the rationale for, and development of, the environmental quality standards and thresholds are provided in Cawthron Report 1872.

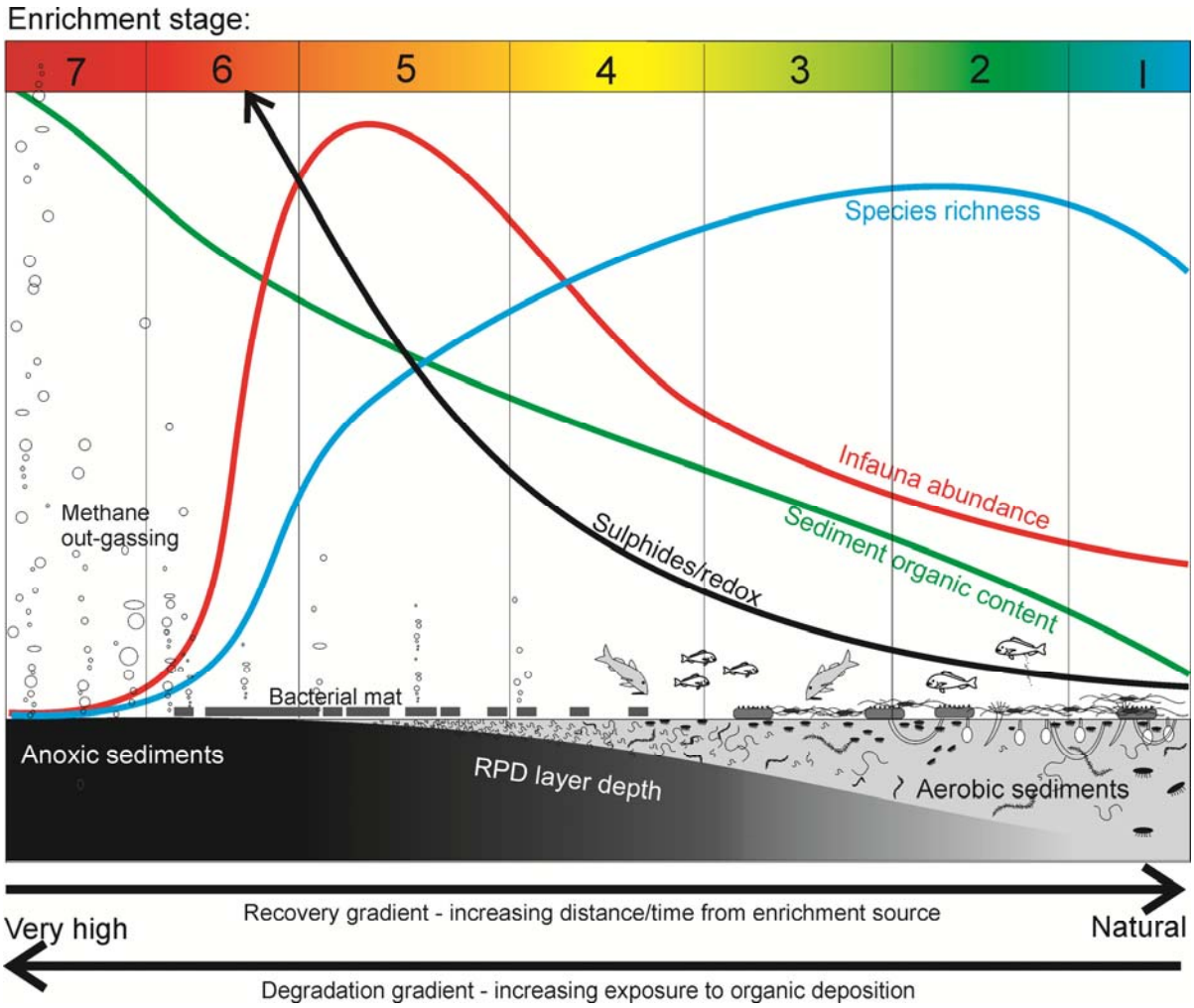

Figure 6. Stylised depiction of a typical enrichment stage (*ES*) gradient experienced at low-flow sites, showing generally understood responses in commonly measured environmental variables (species richness, infauna abundance, sediment organic content and sulphides and Redox). Apparent Redox Potential Discontinuity (RPD) depth and prevalence of bacterial mats and sediment out-gassing are also indicated. The gradient spans from natural or pristine conditions on the right (*ES* = 1) to highly enriched azoic conditions on the left (*ES* = 7). This is based on previously described classical disturbance gradients (Pearson & Rosenberg 1978) and modified accordingly to reflect more recent studies (MacLeod 2004; Macleod *et al.* 2004; Hargrave *et al.* 2008; Hargrave 2010) and the present day understanding of specific farm effects in the Marlborough Sounds.

Table 2. General qualitative descriptions of the seven *ES* categories with a narrative description of the associated environmental quality standards. LF = Low-flow sites, HF = High-flow sites.

ES	Effect category	Farm type	General description	Benthic characteristics that typify ES
1	**Pristine/reference conditions**	LF	As expected for natural/pristine unmodified conditions within the region. Used as permanent 'reference' conditions.	Longer lived, pristine indicator species usually present.
		HF	As above	As above
2	**Mild enrichment/ reference**	LF	Low level enrichment. Can occur naturally or from other diffuse anthropogenic sources. 'Enhanced zone'.	Larger, long lived species and pristine indicators may be reduced. Richness usually greater than for reference conditions. Zone of 'enhancement'. Mainly compositional change. Sediment chemistry unaffected or with only very minor effects.
		HF	As above. Less likely to be natural state at sandy site.	As above
3	**Moderate enrichment**	LF	Clearly enriched and impacted. Significant community change - diversity adversely affected.	Diversity usually lower than reference. Community composition significantly altered; opportunists begin to dominate. Filter/suspension feeders absent. Sediment chemistry affected.
		HF	As above	As above
4	**Major effects 1**	LF	Transitional state between moderate effects and peak infauna abundance. Major community change.	Diversity further reduced, abundance usually very high, but clearly sub-maximum. Dominance of one or a few opportunistic species, but few semi-enrichment tolerant species still evident. Major sediment chemistry changes.
		HF	As above	As above, but richness and diversity not necessarily reduced.
5	**Major effects 2**	LF	Highly enriched. State of peak infauna abundance.	Very high numbers of only a few opportunistic species. Bacteria mat usually evident. H_2S out-gassing on disturbance.
		HF	As above	Total abundances can be extreme. Richness and diversity significantly reduced but not as low as for LF sites. Organic content usually slightly elevated.
6	**Major effects 3**	LF	Post-peak conditions. Opportunistic taxa dying out.	Transitional state between peak and azoic. Richness and diversity very low. Abundances of opportunistic species severely reduced from peak, but not azoic. Total abundance low but can be comparable to reference.
		HF	Not previously observed	Not previously observed
7	**Severe effects/ Azoic**	LF	Azoic/abiotic; sediments no longer capable of supporting infauna. Organics accumulating.	None, or only trace numbers of infauna remain. Some cores with 0 or only 1 taxa. Usually spontaneous out-gassing. Bacterial mat may be absent.
		HF	Not previously observed	Not previously observed

Table 3. Example of EQS described for each zone (taken from recent NZKS farm consent conditions) and their equivalent *ES* for compliance.

Current Consent Conditions				Equivalent *ES* 2010 AMP
Spatial Zone	**Spatial extent**	**Comment**	**Description & bottom line**	
1	Beneath the cages and out to 50 m from their outside edge	Low species diversity dominated by opportunistic species (*e.g.* polychaete worms)	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 cages.	5 or less (*ES* 6 is permitted but undesirable)*
2	From 50 to 150 m from the outside edge of the cages	Transitional between Zone 2 and un-impacted Zone 4	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 or less
3	Beyond 150 m from the outside edge of the cages	Normal conditions (*i.e.* reference or control)	Normal conditions (*i.e.* background or control conditions).	2 or less**
All zones	These conditions are not permitted beneath any NZKS farm		Sediments that are anoxic and azoic (*i.e.* no life present).	7

*Although *ES* 6 is technically a 'permitted state' (as it is not quite azoic), it is past the point of peak abundance and conditions could deteriorate to *ES* 7 in a relatively short time period (*i.e.* months). *ES* 6 is therefore considered an undesirable state at the ES limit and a management response is recommended.

**Up to *ES* 2 permitted so long as conditions also comparable to reference site, *i.e.*: if conditions at relevant reference site is *ES* 1.0, then the maximum *ES* at the Zone 2 boundary is 1.5. Thus, the maximum permitted difference is 0.5 greater than the highest *ES* score for a relevant reference site.

Table 4. Suggested management responses associated with assessment of *ES* (and assessment certainty) in relation to specified environmental bottom lines. *Note: 'at maximum' relates to *ES* >5-6 at Cages (within Zone 1), *ES* 3-3.5 at Zone 1-2 boundary, and ranges from *ES* 1.5-2.5 at Zone 2-3 boundary dependant on conditions at the relevant reference sites (see Table Table **3**).

Assessment for given station	**Certainty**	**Suggested management response**	
Less impacted than permitted *ES*	Moderate to Very high	None required.	☺
	Low, Very low	Check elevated variables. Consider management response.	☺?
At maximum *ES* *	Moderate to Very high	Management response recommended following consultation with MDC and research providers	😐
	Low, Very low	Check elevated variables. Consider management response.	😐?
More impacted than permitted *ES*	Moderate to Very high	Management response required.	☹
	Low, Very low	Management response recommended following consultation with MDC and research providers.	☹?

4.1.2. Assessment

The 2010 assessment of soft-sediment conditions, in terms of compliance with the zones concept and associated conditions, are summarised below and in Table 5.

- Organic loading beneath the cages has increased significantly (as indicated by % AFDW), since 2009. Over the same period, taxa richness of the benthic macrofauna communities beneath the cages decreased markedly, while total abundances increased.
- Conditions at the cage stations are considered to be at the maximum accepted ES with a score of 5.6. However, *ES* 5.6 is a severely impacted state, typically beyond the specified maximum zone 1 conditions defined by the point of peak infauna abundance and dominance of opportunists (*ES* 5).
- Zinc concentrations in the sediments beneath the cages exceeded ISQG-Low trigger levels (for possible biological effects).
- Conditions at the Zone 1-2 boundary ('50 m') station were at the maximum accepted ES with an *ES* of 3.3 (maximum permitted *ES* = 3 (+/- 0.5), indicative of moderate effects. Abundances of *C. capitata* were approaching numbers observed beneath the cages.
- The zone 2-3 boundary ('150 m') station surveyed in the 2010 annual monitoring was less impacted than the permitted ES, although a very mild sulphide odour was present.
- Conditions at the Ctl-2 station were slightly enriched, likely due to this station's close proximity to a mussel farm, rather than from material coming down-current from the salmon farm.

Table 5. Seabed effects score card summarising compliance and requirement of management responses. Refer to Appendix 3 for a more detailed breakdown of how overall enrichment state (*ES*) was calculated from each environmental variable for each sampling station.

Station	*ES*	Certainty		Comments
'Cage'	5.6	Mod	😐	Bacterial mats present, out-gassing on disturbance, strong sulphide odours. Macrofauna severely compromised but not azoic, highly opportunist dominated.
'50 m' (Zone 1 Boundary)	3.3	Mod	😐	Very mild sulphide odours, infauna showing somewhat elevated densities of opportunistic, disturbance tolerant species.
'150 m' (Zone 2 Boundary)	1.4	High	☺	Light brown muds with diverse infauna communities similar to control stations. Somewhat elevated organic matter compared to controls.
Control 1	1.3	High	☺	Representative Marlborough Sounds control station with healthy diverse infauna communities.
Control 2	1.6	Very High	☺	High infauna diversity, although somewhat elevated total abundances compared to other control stations, and increase numbers of disturbance tolerant opportunists.
Control 3	1.5	Very High	☺	Representative Marlborough Sounds control station with healthy diverse infauna communities.

4.2. Rocky habitats

The large area of dead and broken mussel shell material observed by divers off of the north-western corner of the cages in 2010 was also observed in 2009, while the site was still laying fallow. There does however appear to be more fine, easily disturbed material covering the seabed in this area near the cages, than in 2009.

A wider spatial study would be necessary in order to assess whether this material is a result of the re-establishment of the farm at the Forsyth Bay site or simply due natural movements of fine sediments in the area.

4.3. Water column

Near-bottom dissolved oxygen (DO) levels in the water beneath and nearby to the farm were reduced, possibly suggesting a farm-related effect. However, the ~10 % reduction in DO encountered beneath and close by the cages (relative to the 150 m and control stations) is unlikely to have been biologically significant and there did not appear to be a systematic decrease in DO with proximity to the farm. If, as suspected, the oxygen demand is coming from organic waste material on the seabed, then it is likely that DO levels would be further reduced nearer to the surface of the seabed.

5. CONCLUSION AND RECOMMENDATIONS

Overall, in December 2010, the Forsyth Bay farm was assessed to at the maximum acceptable ES limits, and a management response is recommended following consultation with MDC and research providers to reduce the impacts. This finding is based on:

- The enrichment stage beneath the cages (*i.e. ES* 5.6) falling on the borderline of what is and is not permitted for Zone 1 according to the consent conditions. In this case, although there was still a pronounced peak in infauna abundances beneath the cages, the overall assessment of *ES* 5.6 (based on several variables) suggests the population tended toward the 'down side' of the peak (towards being azoic). Continued feed loading at this level would likely result in azoic conditions.
- The '50 m' station (*i.e.* the Zone 1-2 boundary) being at the maximum acceptable ES limit of 3 (+/- 0.5). While not exceeding consent conditions, this state showed there to be significant enrichment of opportunistic, disturbance tolerant infauna species and suggests recent spreading of the farm footprint.
- The zinc concentrations beneath the cages exceeded ISGQ-Low guideline threshold for possible biological effects (ANZECC 2000).

The obvious deterioration in seabed conditions beneath the Forsyth Bay farm from *ES* 2-3 in 2009 to *ES* 5.6 after only 12 months of being recommissioned, indicates that the recent level of

feed inputs are beyond the assimilation capacity of the site and therefore unsustainable long-term. We note that the total annual feed input that was used prior to Dec 2010 was almost 1000 t higher than has been used in the past at this site.

Due to the elevated Zn levels, metals samples should again be assessed in triplicate at all stations (Cage, 50 m, 150 m) in the 2011 monitoring.

6. REFERENCES

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Clement D, Keeley N, Sneddon R 2010. Ecological Relevance of Copper (Cu) and Zinc (Zn) in Sediments Beneath Fish Farms in New Zealand. Prepared for Marlborough District Council. Report No. 1805. 48 p. plus appendices.

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

7. APPENDICES

Appendix 1. Summary of 2010 results.

Table 6. Summary of the physical and chemical properties of sediments from the Forsyth Bay stations during the 2010 monitoring survey. Bracketed values = SE. na = Not assessed - visual inspection only.

	Station	Units	Cage 1	Cage 2	Cage 3	25 m	50 m	75 m	100 m	150 m	Ctl 1	Ctl 2	Ctl 3
Sediments	Depth	m	31.8	30.4	29.2	32.0	32.1	32.2	32.4	32.9	34.2	33.0	34.6
	AFDW	%	15	11.2	10.0	8.9	6.5	4.5	5.0	5.3	5.2	5.0	5.0
	Redox	Eh_{NHE}, mV	-21.6	-63.2	-59.1	83.8	121.8	74.7	110.1	148.9	177.0	166.0	366.1
	Sulphides	µM	1993.6	2288.8	2858.8	1057.2	530.7	760.6	545.4	392.0	53.2	342.1	51.5
	Bacterial mat	% cover	na	na	na	na	na	na	na	na	na	na	na
	Out-gassing	-	On disturbance	On disturbance	On disturbance	None	None	None	None	None	None	None	None
	Odour	-	Very Strong	Very Strong	Very Strong	Strong	Mild-Mod	Mild	Faint	Very Faint	None	Very mild	None
Macrofauna	Abundance	No./core	1894.7 (733.2)	2255.7 (1013.7)	1116.3 (347.3)	1495.7 (225.6)	1807 (1029.1)	487.7 (185)	228 (45.7)	176 (13.6)	92.3 (4.4)	203 (31.4)	91 (23.1)
	No. taxa	No./core	4 (0.6)	3.7 (1.3)	4 (1.2)	14.3 (2)	22 (3.8)	27 (1.2)	29 (1.5)	31.7 (3)	29 (0.6)	30.7 (2.7)	24.3 (3.2)
	Richness	Stat.	0.4 (0.1)	0.3 (0.2)	0.4 (0.2)	1.8 (0.3)	2.9 (0.3)	4.3 (0.3)	5.2 (0.1)	6 (0.6)	6.2 (0.2)	5.6 (0.4)	5.3 (0.9)
	Evenness	Stat.	0.1 (0)	0.1 (0)	0 (0)	0.3 (0)	0.4 (0.1)	0.6 (0.1)	0.7 (0)	0.7 (0)	0.8 (0)	0.7 (0.1)	0.7 (0.1)
	Shannon-Weiner	Index	0.1 (0.1)	0.1 (0)	0 (0)	0.7 (0.1)	1.2 (0.2)	2 (0.3)	2.4 (0)	2.4 (0.1)	2.6 (0.1)	2.4 (0.2)	2.3 (0.4)
	AMBI	Index	6 (0)	6 (0)	6 (0)	5.6 (0.1)	5.1 (0.2)	3.8 (0.6)	3 (0.1)	2.3 (0.1)	1.3 (0.2)	2.3 (0.1)	2.7 (0.5)
	M-AMBI	Index	0.1 (0)	0 (0)	0 (0)	0.2 (0)	0.4 (0)	0.6 (0.1)	0.7 (0)	0.8 (0)	0.9 (0)	0.8 (0)	0.7 (0.1)
	Near bottom DO	mg/l	6.6	6.8	6.6	6.6	6.5	6.5	6.5	6.9	7.3	6.9	8.2

Appendix 2. Historical comparisons.

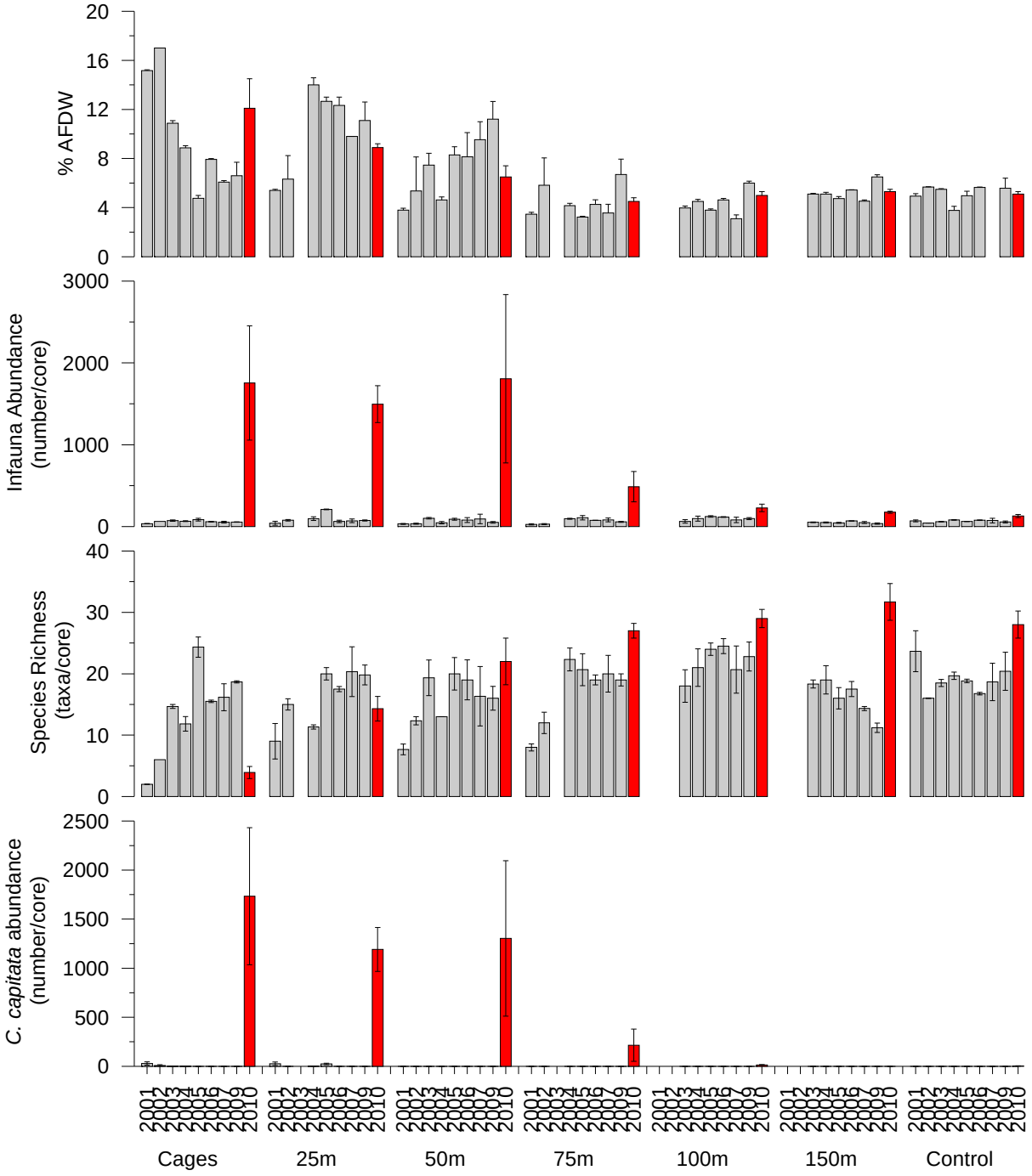

Figure 7. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and *C. capitata* densities recorded at Forsyth Bay since 2001. High densities of capitellid polychaetes are typically 1,000 individuals m^{-2} (=13 per 0.013 m^2 core) or greater (ANZECC 2000 guidelines).

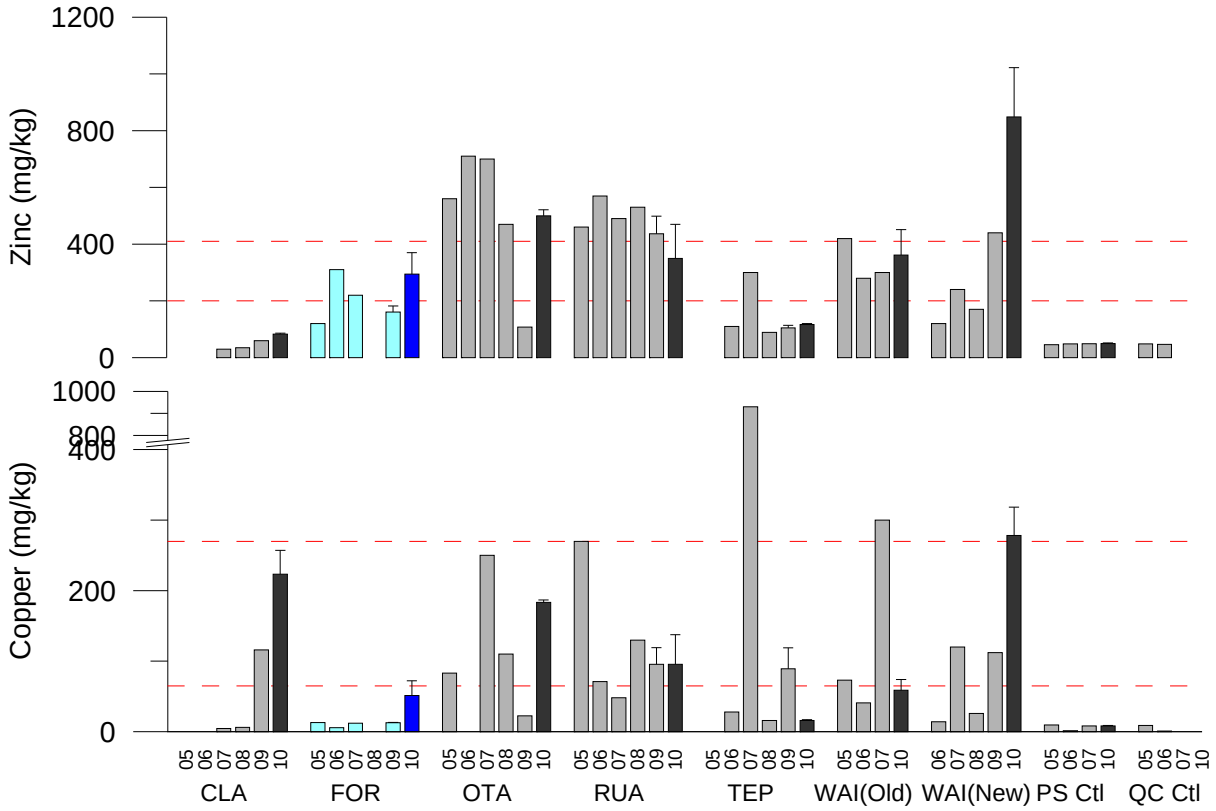

Figure 8. Comparison of the last six years of annual monitoring data for sediment copper and zinc concentrations beneath all six NZKS farms and two control stations (P.S. = Pelorus Sound, Q.C. = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG High and Low trigger levels. Forsyth data in blue.

Appendix 3. Detailed *ES* calculations.

(For details pertaining to how these are calculated see Cawthron Report No. 1872)

Farm:	FOR	Year:	2010				
Site:	Cage1						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	6	Central	6	2	12		
No. taxa	6	Upper	6.25	2	12.5		
Abundance	5	Central	5	2	10		
Shannon Div	6	Central	6	2	12		
M-AMBI	6	Central	6	3	18		
Redox	4	Lower	3.75	1	3.75		
Sulfides	4	Central	4	1	4		
Outgassing	On disturbance		5	1	5		
Bacterial mat	Thick Mat		7	1	7		
		Count	9	15	84.25	Station:	*FOR-2010-Cage1*
				Mean score	5.6	Overall ES:	6-
				SD	1.1	Certainty:	Moderate

Farm:	FOR						
Site:	50m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	3	Central	3	2	6		
No. taxa	3	Central	3	2	6		
Abundance	5	Lower	4.75	2	9.5		
Shannon Div	4	Upper	4.25	2	8.5		
M-AMBI	4	Central	4	3	12		
Redox	2	Central	2	1	2		
Sulfides	2	Upper	2.25	1	2.25		
Outgassing	None			1			
Bacterial mat	Absent						
		Count	7	14	46.25	Station:	*FOR-2010-50m*
				Mean score	3.3	Overall ES:	3+
				SD	1	Certainty:	Moderate

Farm:	FOR						
Site:	150m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	2	Upper	2.25	2	4.5		
No. taxa	2	Upper	2.25	2	4.5		
Abundance	2	Lower	1.75	2	3.5		
Shannon Div	1	Upper	1.25	2	2.5		
M-AMBI	1	Central	1	3	3		
Redox	1	Upper	1.25	1	1.25		
Sulfides	2	Central	2	1	2		
Outgassing	None			1			
Bacterial mat	Absent			1			
		Count	7	15	21.25	Station:	*FOR-2010-150m*
				Mean score	1.4	Overall ES:	1+
				SD	0.5	Certainty:	High

Appendix 3: Cont.

Farm:	FOR						
Site:	Ctl 1						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	1	Upper	1.25	2	2.5		
No. taxa	2	Upper	2.25	2	4.5		
Abundance	2	Lower	1.75	2	3.5		
Shannon Div	1	Upper	1.25	2	2.5		
M-AMBI	1	Central	1	3	3		
Redox	2	Central	2	1	2		
Sulfides	1	Lower	0.75	1	0.75		
Outgassing	None			1			
Bacterial mat	Absent			1			
		Count	7	15	18.75	Station:	*FOR-2010-Ctl 1*
				Mean score	1.3	Overall ES:	1+
				SD	0.5	Certainty:	High

Farm:	FOR						
Site:	Ctl 2						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	1	Upper	1.25	2	2.5		
No. taxa	2	Central	2	2	4		
Abundance	2	Central	2	2	4		
Shannon Div	1	Upper	1.25	2	2.5		
M-AMBI	1	Upper	1.25	3	3.75		
Redox	2	Central	2	1	2		
Sulfides	2	Lower	1.75	1	1.75		
Outgassing	None						
Bacterial mat	Absent						
		Count	7	13	20.5	Station:	*FOR-2010-Ctl 2*
				Mean score	1.6	Overall ES:	2-
				SD	0.4	Certainty:	Very High

Farm:	FOR						
Site:	Ctl 3						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	1	Upper	1.25	2	2.5		
No. taxa	2	Lower	1.75	2	3.5		
Abundance	2	Lower	1.75	2	3.5		
Shannon Div	1	Upper	1.25	2	2.5		
M-AMBI	2	Lower	1.75	3	5.25		
Redox	1	Central	1	1	1		
Sulfides	1	Lower	0.75	1	0.75		
Outgassing	None	-					
Bacterial mat	Absent	-					
		Count	7	13	19	Station:	*FOR-2010-Ctl 3*
				Mean score	1.5	Overall ES:	1+
				SD	0.4	Certainty:	Very High