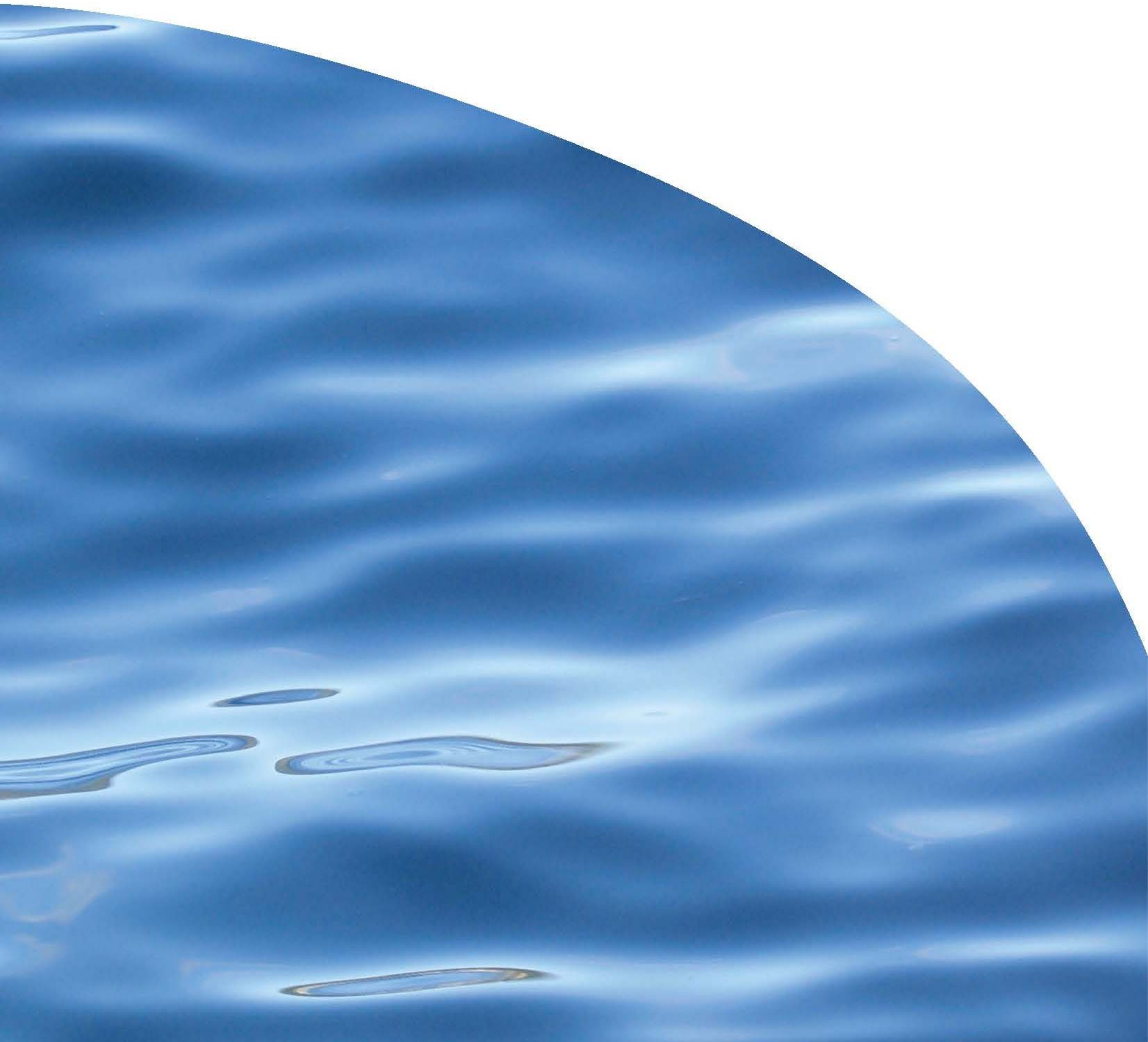
REPORT NO. 2073

ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2011



ENVIRONMENTAL IMPACTS OF THE FORSYTH BAY SALMON FARM: ANNUAL MONITORING 2011

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Prepared for New Zealand King Salmon Company Limited.

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1. INTRODUCTION

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

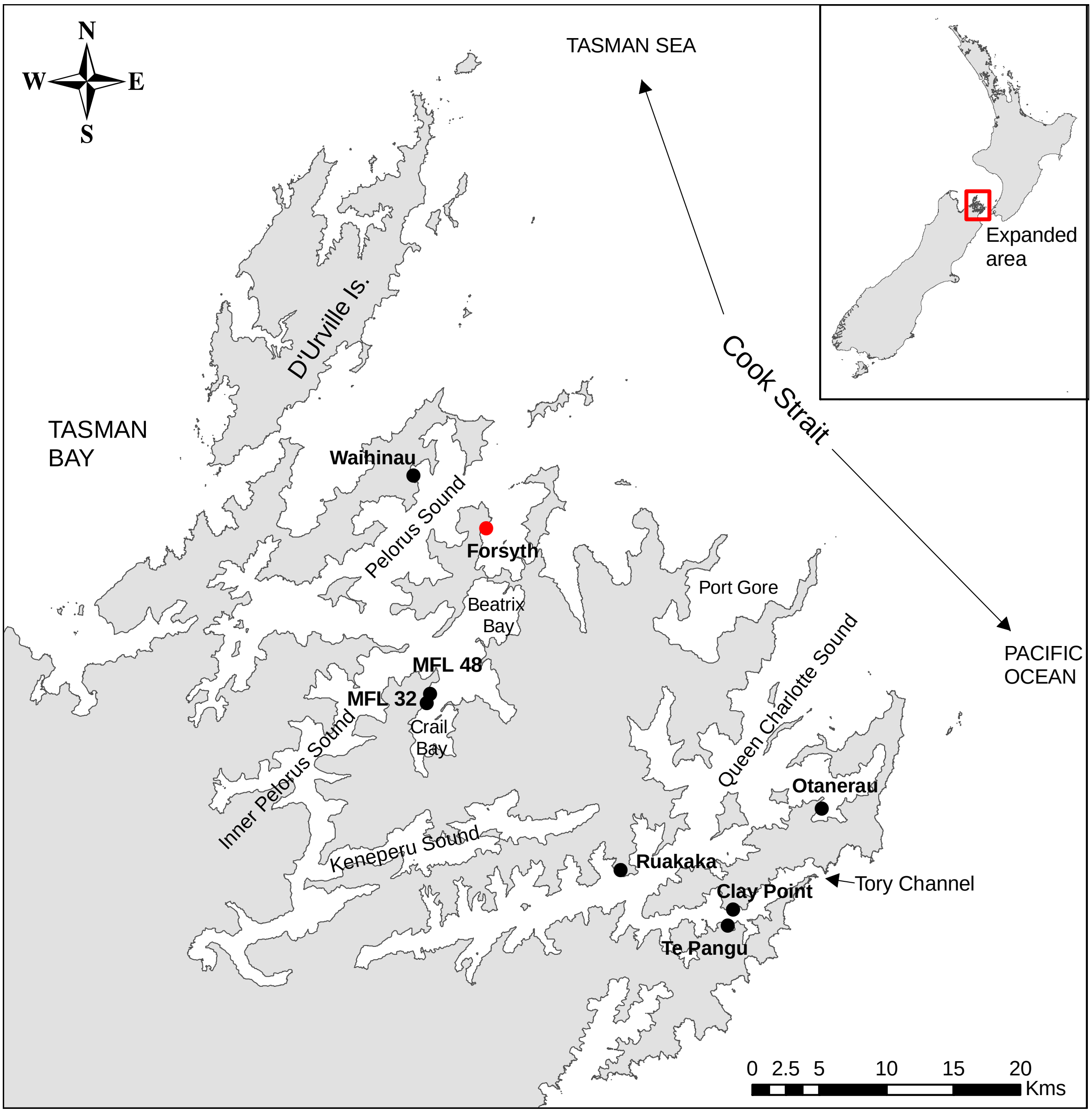

Figure 1. Map of Marlborough Sounds area showing the location of the FOR salmon farm (red dot) along with NZKS's seven other farm sites (black dots).

NZKS is required to undertake environmental monitoring and reporting in accordance with its marine farm consents. The monitoring is conducted under an annual environmental monitoring plan (AEMP) that is prepared by Cawthron on behalf of NZKS. The specific methods of the plan were revised in 2010 to accommodate improvements in knowledge and techniques as described in Keeley (2011). Detailed methods and rationale relating to this year's monitoring can be found in Keeley 2012.

Consent 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 (DO) levels. The environmental monitoring results determine 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 (see Keeley 2012). In addition, water column monitoring (measuring nutrients and chlorophyll-*a*) is undertaken each year at one low-flow and one high-flow farm, and TEP and CLA have adjacent rocky reef communities that are monitored. This report presents the 2011 annual monitoring results for the Forsyth Bay salmon farm.

1.1. 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. Feed inputs at this farm have historically ranged from 1987 to 3261 tonnes (since 2001, Figure 1), however, the site was fallowed (*i.e.* farm removed and no feed input) for eight years prior to December 2009. During this period the seabed was able to recover considerably from what was a highly impacted state in 2001. By November 2009 the site was described as being almost fully recovered. Over the 12-month period leading up to this year's monitoring (*i.e.* December 2010 to the end of November 2011), a total of 3044 tonnes of feed was used. The feed loading was relatively low during the two months prior to sampling (Figure 3). This farm is presently managed on a rotational/fallowing basis with the Waihinau Bay site, and was reinstated to Waihinau Bay shortly after this year's monitoring was conducted.

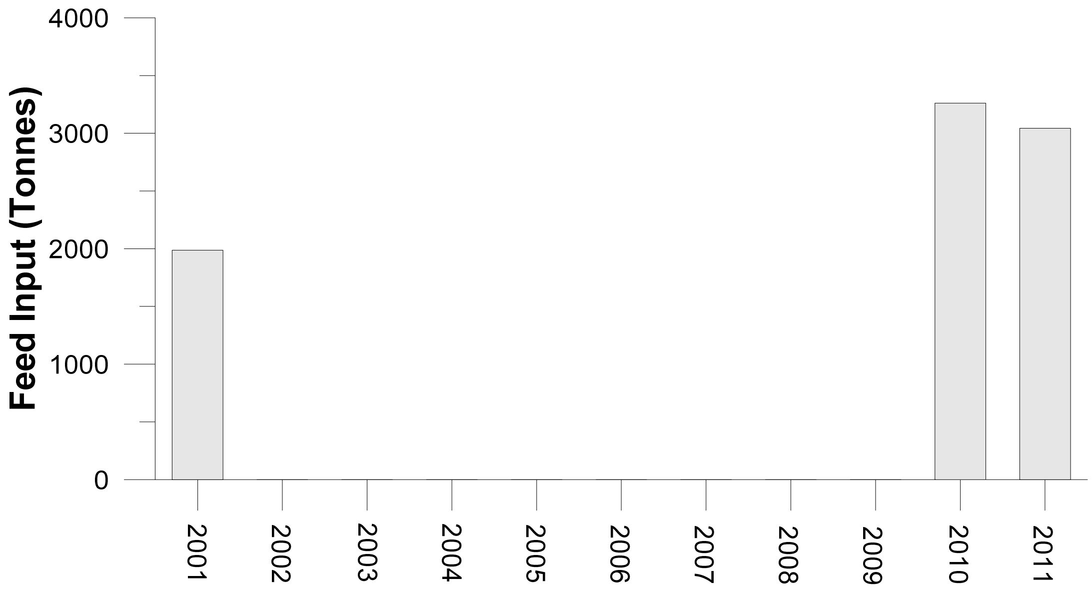

Figure 2. Annual feed inputs at the Forsyth Bay farm, 2001-2011.

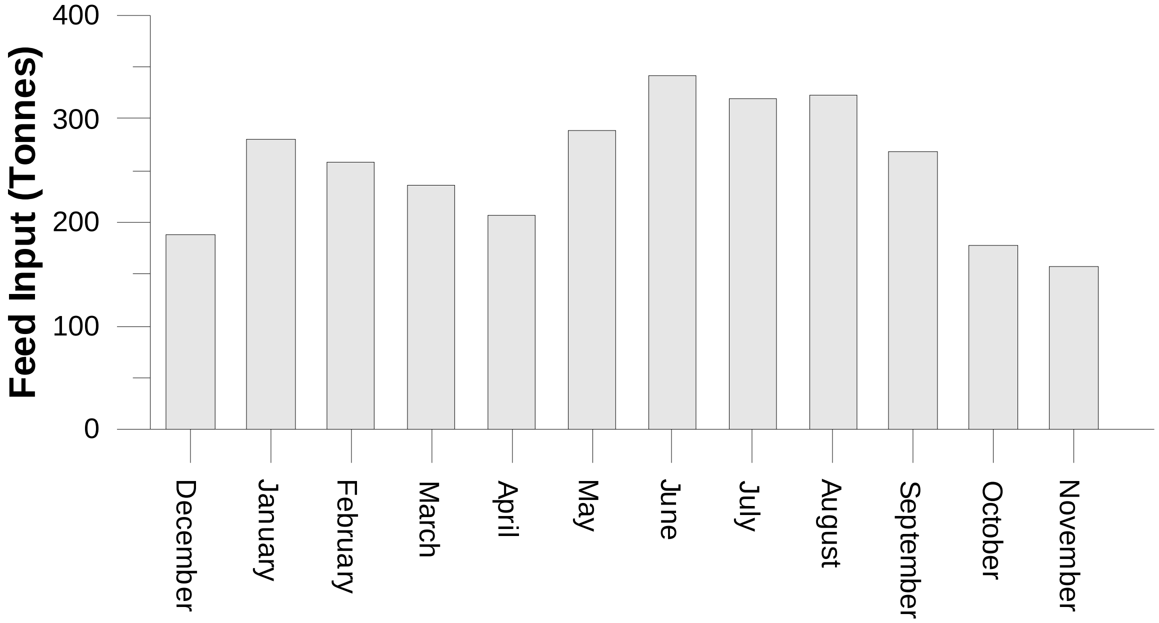

Figure 3. Monthly feed inputs at the Forsyth Bay farm from December 2010 to November 2011.

2. METHODS

The eight NZKS farms are situated at depths generally ~ 25-35 m and over similar seabed substrates, but they vary in terms of their flow regimes. The differences in flow rates (and flushing) have ramifications for how each farm is monitored due to the associated differences in how the various environmental variables respond. TEP and CLA are considered high-flow sites, WAI and OTA low- to moderate-flow and FOR, RUA, MFL-48 and MFL-32 are low-current sites. Detailed methods and rationale describing the sampling protocol for all of NZKS's farms can be found in the most recent Annual Environmental Monitoring Plan (AEMP, Cawthron Report 1872). Copies are held by Marlborough District Council (MDC) and NZKS. This plan is updated and modified routinely to accommodate the most relevant and effective sampling methods. A condensed summary of the revised techniques that were adopted this year is provided below.
Sampling at FOR occurred on 24 November 2011.

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). Ctl-2 is a historical control site that is situated 250 m from the salmon cages (along the transect) and near to a mussel farm, and therefore effectively represents a '250 m' impact site, hence the need for the additional, more spatially isolated control sites. Stations '50 m' and '150 m' are appropriately situated for use as indicators of conditions at the Zone 2-3 and 3-4 boundaries, as required under the zones concept. For a full explanation of the zones concept, please refer to Keeley 2011.

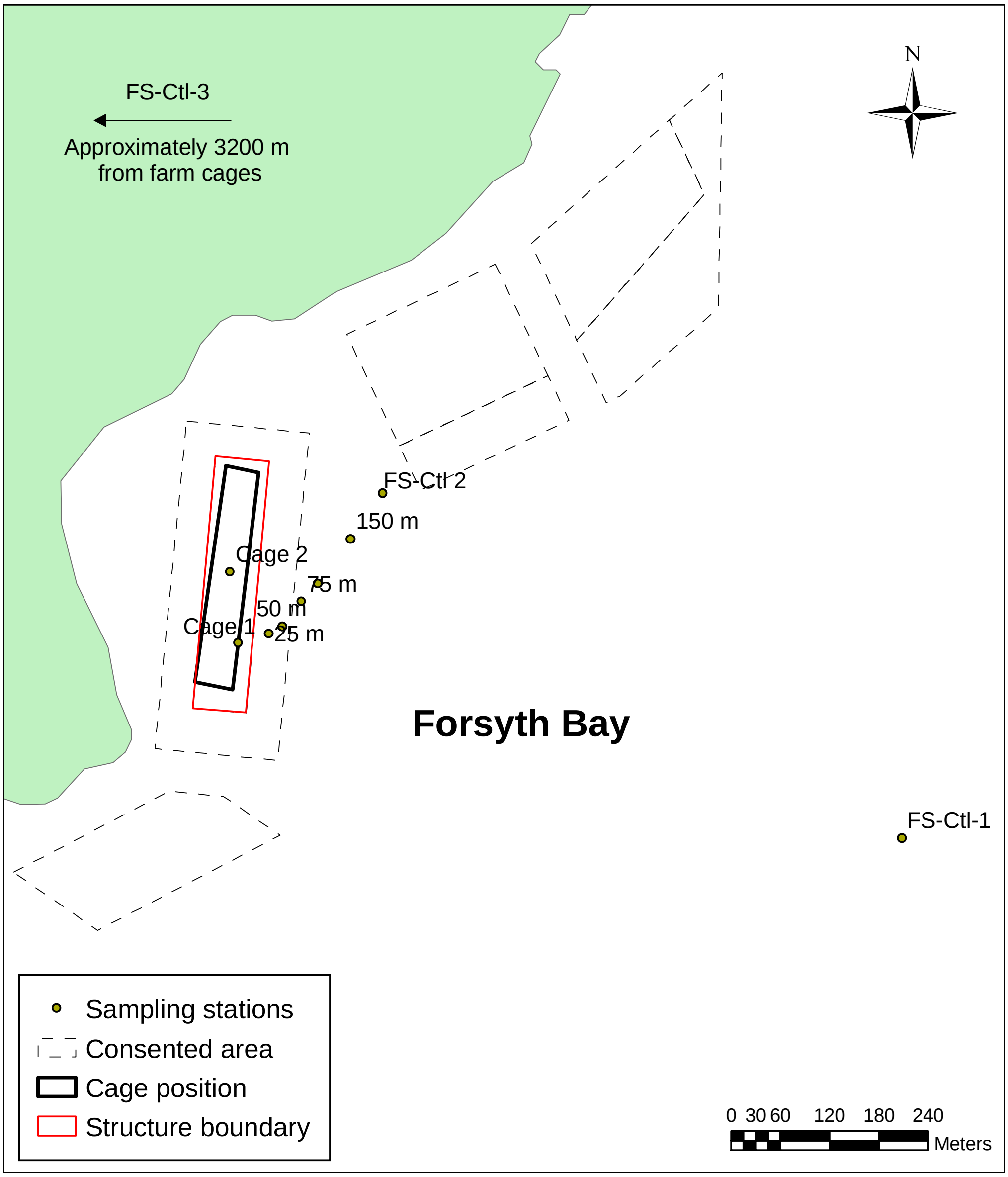

Figure 4. Soft sediment and inshore habitat sampling locations for FOR in 2011. 'Ctl' = Control.

2.1.2. Environmental variables

Three replicate sediment (modified van Veen) grab samples were collected at each sampling station. Each grab sample was examined for sediment odour, texture, bacterial mat coverage and the top 3 cm of one sediment core (63 mm diameter) was analysed for organic content (as % AFDW), redox potential (Eh_{NHE}, mV), and total free sulphides (µM). In addition, 'cage' samples were analysed for copper and zinc concentrations. 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 within the sediment matrix and does not adequately represent the epifauna component (animals living on the sediment surface). Observations of sediment out-gassing visible at the surface were also made.

Raw infauna data were further analysed to calculate the total abundance (N), total number of taxa (S), Shannon-Weiner diversity index (H'), Pielou's evenness index (J'), Margalef richness index (d), AMBI biotic coefficient (BC) and M-AMBI ecological quality ratio (EQR). Refer to Keeley 2012 for an explanation of each of the biotic indices.

2.2. Rocky habitats

The Forsyth Bay salmon farm is a low-flow site which contains no significant reef habitats within the primary depositional footprint. Inshore habitats are visually inspected qualitatively every second year for assessment of general health with respect to any signs of excessive organic deposition. Video footage is collected on each scheduled occasion and archived for assessment of any obvious changes of visual characteristics over time. This assessment was undertaken during 2010 monitoring survey and consequently was not repeated during the present 2011 survey.

2.3. Water column

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 are measured at one low-flow and one high-flow salmon farm each year; in 2011 this was undertaken at RUA and CLA. Samples were collected from mid-water using a van Dorn sampler and analysed in the laboratory for nitrate-N (NO_3-N), nitrite-N (NO_2-N), ammoniacal-N (NH_4-N), dissolved reactive phosphorous (DRP) and chlorophyll-*a* (Chl-*a*). Although these measurements were not undertaken at FOR, the results from RUA low-flow site are considered to be generally representative.

3. RESULTS

3.1. Soft sediment habitats

Sediment organic matter levels were significantly elevated (*i.e.* by 3-4 times) beneath the cages compared to the control stations (Figure 5), and generally showed a decreasing trend with increasing distance from the cages. Average sediment organic content at the 75 m, 100 m, 150 m and Ctl-2 and -3 stations were similar (ranging between 5.3 and 6.0 %), and levels were slightly lower at the Ctl-1 station (average 3.6%). The sampling stations at the edge of the cages and at 25 m had negative redox potentials (cages with an average of -159 Eh_{NHE}, mV) and levels of total free sulphides that were at least 6.5 times as high as the next closest station to the cage edge (25 m). These results were consistent with observations of very dark sediments that had strong sulphide odours (Appendix 1, Table 1.1).

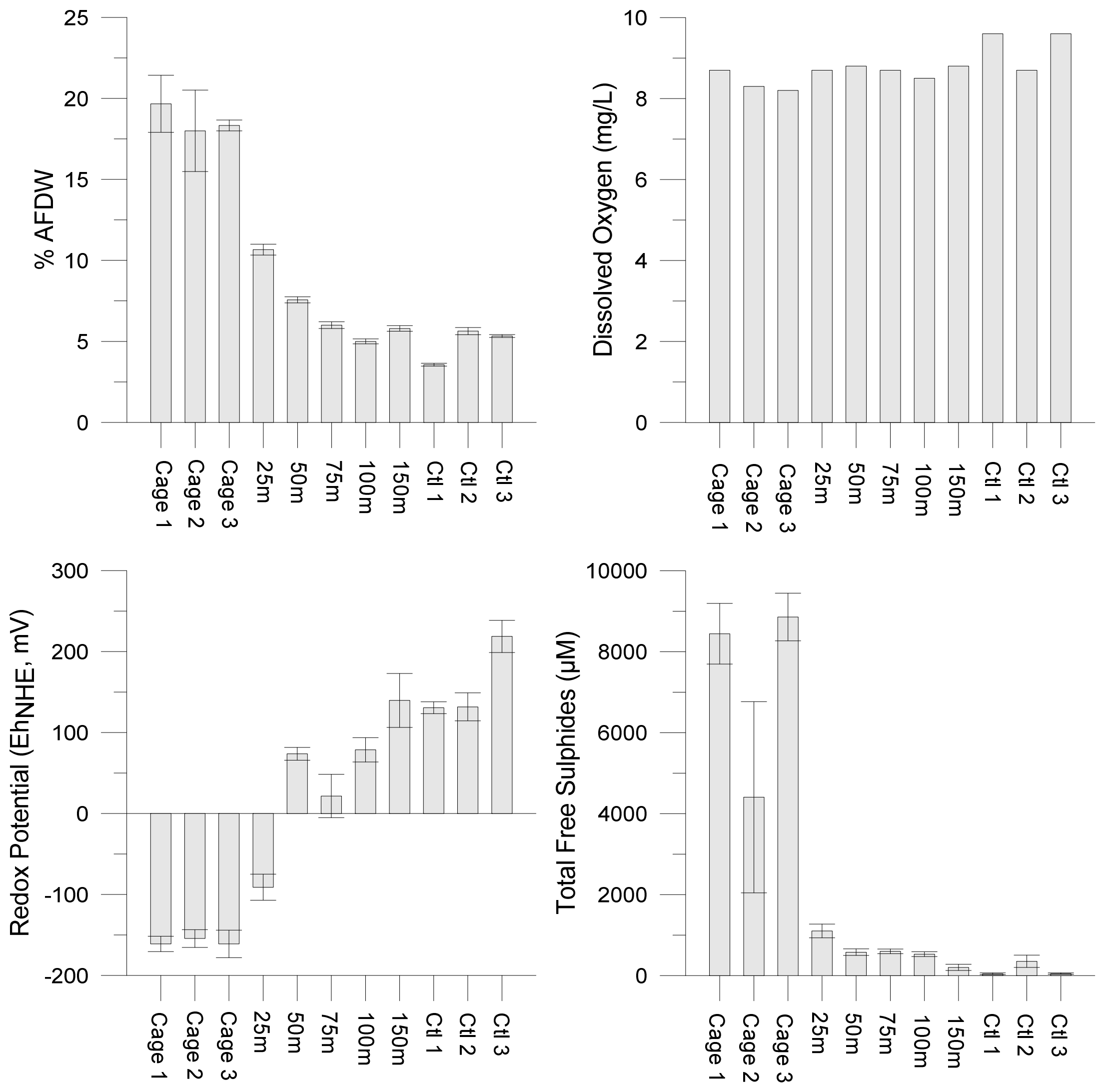

Figure 5. Multiplot of organic matter (as % AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and near-bottom DO (mg/l). Error bars = SE, n=3.

The infauna communities at the cage stations were very highly impacted, as indicated by a range of only 1-4 taxa/core (mean 2.3, n=9) and total abundances that were beyond peak capacity. This represents a dramatic reduction in comparison to the adjacent ‘25 m’ site, and the previous years ‘Cage’ sites results (Appendix 2, Figure 2.1). All three cage sites had similar results, and three of the nine replicate cores were virtually azoic. In addition, communities were characterised by very low diversity (H’), richness (d) and ecological quality ratio (EQR) values (Figure 5). Total taxa numbers were also reduced at down-current stations out to 100 m, by way of comparison to the 150 m and control stations. Diversity, richness and EQR values showed a positive trend with distance from the cages.

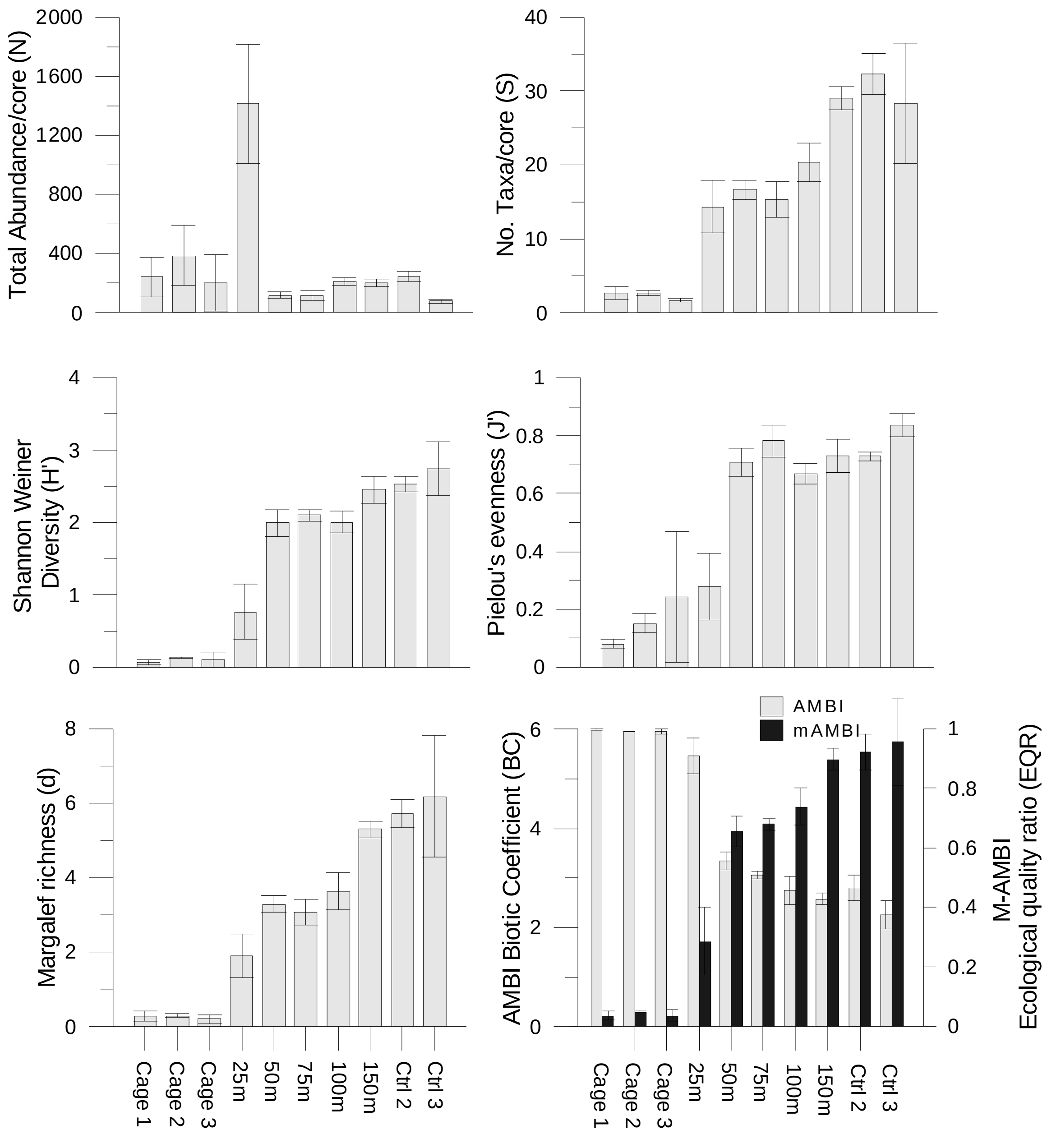

Figure 6. Multiplot of infauna statistics. Error bars = SE, n=3.

3.1.1. *Copper and zinc*

Zinc concentrations in the sediments below the cages exceeded the ISQG-High trigger levels with an average of 418 mg/kg (SE 23.4, n=9) across all three cage stations (Appendix 2, Figure 2.2). Average copper concentrations were above the low trigger level, with an average of 88 mg/kg (SE 22.5, n=9). These results represent noticeable increases in both copper and zinc since 2009 (after an eight year fallowing period) and 2010 (after one year of operation).

3.2. Water column

Near-bottom (water column) dissolved oxygen (DO) levels were slightly lower (by ~5%) at the Cage 2 and 3 stations, in comparison to Cage 1. Average DO levels at the cages were depressed by ~10% in comparison to the average level at the controls, but were similar to Control 2. Down-current stations were 5-9% lower than the average control levels.

Water column nutrient levels were not analysed at FOR during the 2011 round of annual monitoring, but results from monitoring at the low-flow Ruakaka farm showed that chl-*a* was reduced and NH_4-N was elevated with proximity to the farm (Dunmore and Keeley 2012a). DRP, NO_3-N and NO_2-N levels were similar across all stations.

4. SUMMARY OF FINDINGS: ASSESSMENT OF ENRICHMENT STAGE AND COMPLIANCE

Enrichment stage (ES) was calculated by converting each environmental result (raw data) into an equivalent ES score using the appropriate linear model. 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 for total organic matter (TOM), representing 'organic loading' for each sample/ grab. The 'overall ES' for a given sample was calculated by determining the weighted average of those three groups of variables. Finally, the overall ES for the sampling station was equated to the average of the replicate samples with the degree of certainty reflected in the associated standard error. To determine compliance, the overall ES for each station was compared to predefined environmental quality standards under the zones concept. The methods and rationale for quantifying ES and assessing environmental compliance at the NZKS sites in 2011 are described in Keeley 2012.

4.1. Seabed habitats

The 2011 assessment of soft-sediment conditions, in terms of compliance with the zones concept and associated conditions, are summarised below and in Table 1.

- Organic loading beneath the cages had increased significantly (as indicated by % AFDW), since 2009. Over the same period, taxa richness of the benthic infauna communities beneath the cages decreased. Most notably, total abundances had decreased markedly since the peak in 2010 and compared to the adjacent 25 m station.
- Conditions at the cage stations were considered to be at the maximum accepted ES with an average score of 6.0. However, ES 6.0 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-High trigger levels (for probable biological effects), and copper concentrations exceeded ISQG-Low trigger levels (for possible biological effects).
- Conditions at the Zone 2-3 boundary ('50 m') station were below the maximum accepted ES with an ES of 3.0 (maximum permitted ES = 3.5), indicative of moderate effects.
- The Zone 3-4 boundary ('150 m') station surveyed in the 2011 annual monitoring was less impacted than the permitted ES.
- Conditions at the Control 1 and 3 stations had ES scores of 2.1 and 1.8 respectively.

Table 1. Seabed effects score card summarising compliance and requirement for management responses. Refer to Appendix 3 for detailed enrichment stage (ES) calculations, and refer to Keeley 2012 for a more detailed breakdown of how overall ES was calculated from each environmental variable for each sampling station.

Station		ES (±SE)	Comments
Cage 1	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	6.07 (0.17) 6.21 (0.07) 6.07 (0.17) **6.13 (0.13)**	Sediments with strong sulphide odours, very high organic content, very low redox values, and high sulphides. Infauna community post-peak abundance, with an average of 243 individuals and less than three taxa per core. One core was near-azoic, with only seven capitellid polychaetes.
Cage 2	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	5.80 (0.29) 5.41 (0.48) 5.90 (0.03) **5.73 (0.13)**	Sediments with strong sulphide odours, very high organic content, very low redox values, and high sulphides. Infauna community post-peak abundance, with an average of 387 individuals and less than three taxa per core.
Cage 3	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	5.97 (0.05) 6.23 (0.14) 6.07 (0.22) **6.10 (0.15)**	Sediments with strong sulphide odours, very high organic content, very low redox values and high sulphides. Infauna community post-peak abundance, with an average of only 198 individuals and less than two taxa per core. Two cores were near-azoic, with only five and 10 individuals.
50 m (Zone 2-3 Boundary)	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	3.41 (0.06) 3.20 (0.11) 2.81 (0.18) **3.03 (0.12)**	Mild sulphide odours, low redox values and slightly elevated sulphides. Slightly elevated organic matter content. Numbers of taxa reduced, but abundances not elevated in comparison to controls.
150 m (Zone 3-4 Boundary)	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	1.50 (0.00) 2.38 (0.28) 2.12 (0.12) **2.07 (0.12)**	No sulphide odours. Organic matter content, redox values and sulphide levels generally similar to controls. Diverse infauna communities.
FS- Ctrl 2	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	1.50 (0.00) 2.64 (0.15) 2.15 (0.10) **2.13 (0.03)**	Diverse infauna communities, low organic matter content. Slightly higher total free sulphide levels than controls and 150 m stations.
FS- Ctrl 3	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	1.50 (0.00) 1.63 (0.12) 2.01 (0.28) **1.80 (0.10)**	Diverse infauna communities, low organic matter content and total free sulphide levels.

4.2. Water column

Near-bottom dissolved oxygen (DO) levels in the water beneath and nearby to the farm were slightly reduced, possibly suggesting a farm-related effect. However, the ~10 % reduction in DO encountered at the cages (relative to the 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.

Monitoring of chl-*a* at the low-flow farm Ruakaka showed that concentrations were lower closer to the farm, but were within levels observed naturally in the Marlborough Sounds (Dunmore and Keeley 2012a). Chl-*a* concentrations can be temporally and spatially variable, and the difference observed between near-farm levels and control levels was less than that observed over a tidal cycle in Pelorus Sound (Gibbs *et al.* 1992). The difference observed at RUA is not considered to be ecologically significant.

NH_4-N concentrations at Ruakaka were slightly elevated with proximity to the farm, indicating localised low-level enrichment (Dunmore and Keeley 2012a). However, levels were not outside the range previously reported for the wider Marlborough Sounds environment (Gibbs *et al.* 1992). Elevated NH_4-N levels were also reported for this farm in 1998 and 2002 (Hopkins and Forrest 2002), and for other fish farming sites (La Rosa *et al.* 2002, Hopkins 2004, Dunmore and Keeley 2012b). It has been concluded that localised elevated NH_4-N concentrations of similar magnitude observed around the farms are unlikely to have significant adverse effects on the wider Marlborough Sounds ecosystem (Hopkins and Forrest 2002). This conclusion is consistent with the expected flushing rate and consequent dilution as the water is transported away from the farm (Gillespie *et al.* 2011).

5. CONCLUSION AND RECOMMENDATIONS

In November 2011, the Forsyth Bay farm was assessed overall to be 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 6.0) falls on the borderline of what is and is not permitted for Zone 1 according to the consent conditions. In this case, there has been a marked decrease in the abundance of infauna, and the number of taxa was very low. The population was assessed to be clearly post-peak (towards being azoic), and continued feed loading at this level would likely result in azoic conditions.
- The zinc concentrations beneath the cages exceeded ISGQ-High guideline threshold for probable biological effects (ANZECC 2000) and copper concentrations exceeded ISQG-Low trigger levels for possible biological effects.

The obvious deterioration in seabed conditions beneath the Forsyth Bay farm after only two years 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 December 2010 and December 2011 was ~ 800 t and ~ 600 t respectively higher than has been used in the past at this site. NZKS manage this site on a two-year rotational/fallowing basis with the Waihinau Bay site, and the farm cages have been shifted to Waihinau Bay as scheduled. NZKS have recently started using feed containing organic zinc, which is likely to reduce zinc inputs to the seabed when the farm is reinstated. In addition, copper-based antifouling is no longer used on the nets and therefore inputs of copper to the environment should be substantially reduced.

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7. APPENDICES

Appendix 1. Historical comparisons.

Table 1.1. Summary of the physical and chemical properties of sediments from the Forsyth Bay stations during the 2011 monitoring survey. Bracketed values = SE. Note: Control 1 infauna was not sampled in 2011.

	Station	Units	Cage 1	Cage 2	Cage 3	25 m	50 m	75 m	100 m	150 m	Ctl 1	Ctl 2	Ctl 3
	Depth	m	8.7	8.3	8.2	8.7	8.8	8.7	8.5	8.8	9.6	8.7	9.6
Sediments	AFDW	%	33.5	33.6	32.9	33.2	33.4	33.4	33.2	33.2	32.5	33.2	32.4
	Redox	Eh_{NHE}, mV	19.7	18.0	18.3	10.7	7.6	6.0	5.0	5.8	3.6	5.6	5.3
	Sulphides	µM	-161.0	-154.3	-161.0	-91.0	73.7	21.7	78.7	139.7	130.7	131.7	218.7
	Bacterial mat	% cover	8442.2	4405.3	8857.2	1103.7	578.5	600.8	530.8	203.4	45.0	354.2	50.2
	Out-gassing	-	None	None	None	None	None	None	None	None	None	None	None
	Odour	-	None	None	None	None	None	None	None	None	None	None	None
Infauna statistics	Abundance	No./core	243(133)	387(201)	198(191)	1414(404)	118(19)	115(33)	208(28)	199(24)		242(34)	78(13)
	No. taxa	No./core	2.7(0.9)	2.7(0.3)	1.7(0.3)	14.3(3.5)	16.7(1.3)	15.3(2.4)	20.3(2.7)	29(1.5)		32.3(2.7)	28.3(8.1)
	Richness	Stat.	0.28(0.15)	0.29(0.05)	0.2(0.13)	1.9(0.58)	3.3(0.23)	3.06(0.34)	3.63(0.49)	5.3(0.22)		5.72(0.37)	6.19(1.64)
	Evenness	Stat.	0.08(0.02)	0.15(0.03)	0.24(0.23)	0.28(0.12)	0.71(0.05)	0.78(0.05)	0.67(0.04)	0.73(0.06)		0.73(0.02)	0.84(0.04)
	Shannon-Weiner	Index	0.07(0.04)	0.14(0.01)	0.11(0.11)	0.76(0.38)	1.99(0.19)	2.1(0.08)	2.01(0.15)	2.45(0.19)		2.53(0.11)	2.75(0.38)
	AMBI	Index	6(0)	6(0)	5.9(0)	5.5(0.4)	3.3(0.2)	3.1(0.1)	2.7(0.3)	2.6(0.1)		2.8(0.3)	2.3(0.3)
	M-AMBI	Index	0(0)	0(0)	0(0)	0.3(0.1)	0.7(0.1)	0.7(0)	0.7(0.1)	0.9(0)		0.9(0.1)	1(0.1)
	Near bottom DO	mg/l	8.7	8.3	8.2	8.7	8.8	8.7	8.5	8.8	9.6	8.7	9.6

Appendix 2. Historical comparisons.

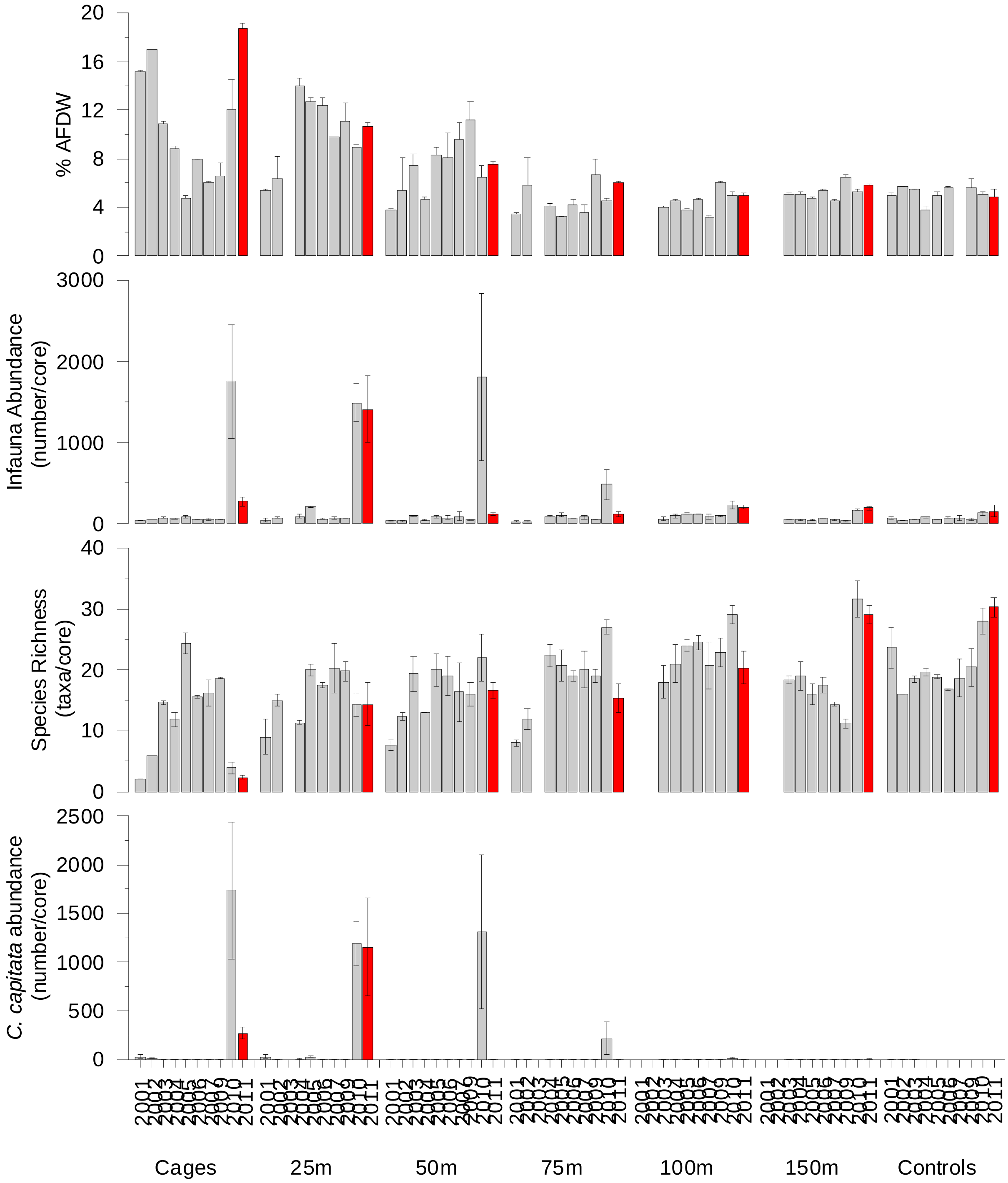

Figure 2.1. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and C. *capitata* densities recorded at Forsyth Bay since 2001. High densities of capitellid polychaetes are typically 1,000 individuals m-2 (=13 per 0.013 m² core) or greater (ANZECC 2000 guidelines).

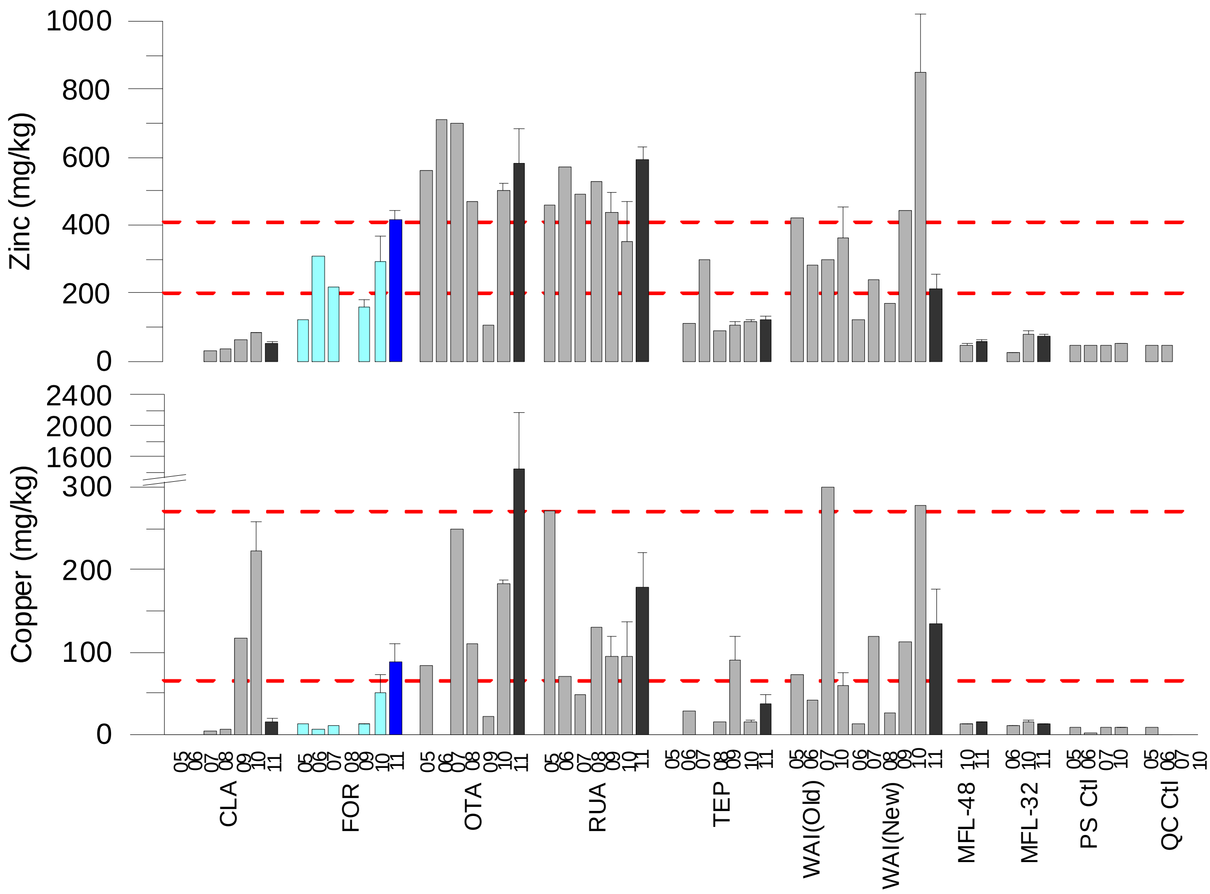

Figure 2.2. Comparison of the last seven years of annual monitoring data for sediment copper and zinc concentrations beneath all eight NZKS farms and two control stations (P.S. = Pelorus Sound, Q.C. = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG High and Low trigger levels. Forsyth data are in blue.

Appendix 3. Detailed ES calculations.

For details pertaining to how the figures in these tables were calculated, see Keeley 2012.

Flow environment:	LF
Farm	FOR
Site	Cage1

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	23	19	17				19.667	3.06	3	1.77
Redox	-170	-171	-142				-161	16.46	3	9.5
Sulphides	9770.3	7180.4	8375.8				8442.2	1296.3	3	748.4
Abundance	7	254	468.00				243	230.7	3	133.19
No. Taxa	1	3	4				2.6667	1.53	3	0.88
P. evenness	****	0.0653	0.10				0.0807	0.02	2	0.01
Richness	0	0.3612	0.49				0.283	0.25	3	0.14
SWDI	0	0.0717	0.13				0.0684	0.07	3	0.04
AMBI	6	5.9823	5.97				5.9834	0.02	3	0.01
M-AMBI	0.0094	0.0397	0.0589				0.036	0.02	3	0.01

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5		Ave	SD	n	SE
TOM	6.38	6.06	5.78				6.0733	0.3	3	0.17
Redox	5.66	5.67	5.41				5.58	0.15	3	0.09
Sulphides	7	6.5	7				6.8333	0.29	3	0.17
Abundance	7	6	6				6.3333	0.58	3	0.33
No. Taxa	7	6	6				6.3333	0.58	3	0.33
P. evenness										
Richness	6.62	6.05	5.86				6.1767	0.4	3	0.23
SWDI	6.21	6.09	5.98				6.0933	0.12	3	0.07
AMBI	5.03	5.02	5.01				5.02	0.01	3	0.01
M-AMBI	6.61	6.45	6.34				6.4667	0.14	3	0.08

	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	6.38	6.06	5.78			0.2	6.07	0.3	3	0.17
Sediment chemistry	6.33	6.085	6.205			0.3	6.21	0.12	3	0.07
Infauna composition	6.4117	5.935	5.865			0.5	6.07	0.3	3	0.17
Overall ES	6.4	6	6				6.13	0.23	3	0.13

Flow environment:	LF
	FOR
Site	Cage2

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	23	15	16				18	4.36	3	2.52
Redox	-133	-169	-161				-154.3	18.9	3	10.91
Sulphides	1319.6	2850.1	9046.2				4405.3	4091.4	3	2362.2
Abundance	230	786	145				387	348.15	3	201
No. Taxa	3	3	2				2.6667	0.58	3	0.33
P. evenness	0.1207	0.1167	0.2164				0.1513	0.06	3	0.03
Richness	0.3678	0.3	0.2009				0.2896	0.08	3	0.05
SWDI	0.1326	0.1283	0.15				0.137	0.01	3	0.01
AMBI	5.9672	5.9599	5.9483				5.9585	0.01	3	0.01
M-AMBI	0.0495	0.0495	0.0441				0.0477	0	3	0

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5		Ave	SD	n	SE
TOM	6.38	5.42	5.61				5.8033	0.51	3	0.29
Redox	5.33	5.65	5.58				5.52	0.17	3	0.1
Sulphides	3.92	5	7				5.3067	1.56	3	0.9
Abundance	6	5.5	6				5.8333	0.29	3	0.17
No. Taxa	6	6	6				6	0	3	0
P. evenness										
Richness	6.04	6.15	6.3				6.1633	0.13	3	0.08
SWDI	5.99	5.99	5.96				5.98	0.02	3	0.01
AMBI	5.01	5	4.99				5	0.01	3	0.01
M-AMBI	6.39	6.39	6.42				6.4	0.02	3	0.01

	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	6.38	5.42	5.61			0.2	5.8	0.51	3	0.29
Sediment chemistry	4.625	5.325	6.29			0.3	5.41	0.84	3	0.48
Infauna compositior	5.905	5.8383	5.945			0.5	5.9	0.05	3	0.03
Overall ES	5.6	5.6	6				5.73	0.23	3	0.13

Flow environment	LF
	FOR
	Cage3

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5	Ave	SD	n	SE
TOM	19	18	18			18.333	0.58	3	0.33
Redox	-127	-179	-177			-161	29.46	3	17.01
Sulphides	7755.1	9046.2	9770.3			8857.2	1020.8	3	589.38
Abundance	580.00	10.00	5.00			198.33	330.54	3	190.84
No. Taxa	2	2	1			1.6667	0.58	3	0.33
P. evenness	0.02	0.47	****			0.2437	0.32	2	0.23
Richness	0.16	0.43	0.00			0.1972	0.22	3	0.13
SWDI	0.01	0.33	0.00			0.1126	0.18	3	0.1
AMBI	6.00	5.85	6.00			5.9491	0.09	3	0.05
M-AMBI	0.0208	0.0766	0.0094			0.0356	0.04	3	0.02

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5	Wt	Ave	SD	n	SE
TOM	6.06	5.93	5.93				5.9733	0.08	3	0.05
Redox	5.27	5.74	5.72				5.5767	0.27	3	0.16
Sulphides	6.64	7	7				6.88	0.21	3	0.12
Abundance	3.84	7	7				5.9467	1.82	3	1.05
No. Taxa	6	7	7				6.6667	0.58	3	0.33
P. evenness										
Richness	6.37	5.94	6.62				6.31	0.34	3	0.2
SWDI	6.19	5.66	6.21				6.02	0.31	3	0.18
AMBI	5.03	4.92	5.03				4.9933	0.06	3	0.03
M-AMBI	6.55	6.25	6.61				6.47	0.19	3	0.11
	Grab1	**Grab2**	**Grab3**	**Grab4**	**Grab5**	**Wt**	**Ave**	**SD**	**n**	**SE**
Organic loading	**6.06**	**5.93**	**5.93**			0.2	**5.97**	0.08	3	0.05
Sediment chemis	**5.955**	**6.37**	**6.36**			0.3	**6.23**	0.24	3	0.14
Infauna composit	**5.6633**	**6.1283**	**6.4117**			0.5	**6.07**	0.38	3	0.22
Overall ES	5.8	6.2	6.3				**6.1**	0.26	3	0.15

Flow environment	LF
	FOR
	50m

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5	Ave	SD	n	SE
TOM	7.2	7.7	7.8			7.5667	0.32	3	0.18
Redox	59	86	76			73.667	13.65	3	7.88
Sulphides	659.91	415.76	659.91			578.53	140.96	3	81.38
Abundance	94.00	105.00	155.00			118	32.51	3	18.77
No. Taxa	14	18	18			16.667	2.31	3	1.33
P. evenness	0.62	0.79	0.71			0.7068	0.09	3	0.05
Richness	2.86	3.65	3.37			3.295	0.4	3	0.23
SWDI	1.64	2.29	2.05			1.9913	0.33	3	0.19
AMBI	3.58	3.00	3.45			3.3451	0.31	3	0.18
M-AMBI	0.5585	0.7348	0.6644			0.6525	0.09	3	0.05

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5	Wt	Ave	SD	n	SE
TOM	3.28	3.45	3.49				3.4067	0.11	3	0.06
Redox	3.6	3.36	3.45				3.47	0.12	3	0.07
Sulphides	3.08	2.6	3.08				2.92	0.28	3	0.16
Abundance	2.28	2.38	2.71				2.4567	0.23	3	0.13
No. Taxa	3.15	2.51	2.51				2.7233	0.37	3	0.21
P. evenness										
Richness	3.04	2.41	2.62				2.69	0.32	3	0.18
SWDI	3.4	2.29	2.69				2.7933	0.56	3	0.32
AMBI	3.22	2.79	3.13				3.0467	0.23	3	0.13
M-AMBI	3.65	2.7	3.08				3.1433	0.48	3	0.28
	Grab1	**Grab2**	**Grab3**	**Grab4**	**Grab5**	**Wt**	**Ave**	**SD**	**n**	**SE**
Organic loading	**3.28**	**3.45**	**3.49**			0.2	**3.41**	0.11	3	0.06
Sediment chemis	**3.34**	**2.98**	**3.265**			0.3	**3.2**	0.19	3	0.11
Infauna composit	**3.1233**	**2.5133**	**2.79**			0.5	**2.81**	0.31	3	0.18
Overall ES	3.2	2.8	3.1				**3.03**	0.21	3	0.12

Flow environmen	
	LF
	FOR
	150m

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	5.8	6.1	5.5				5.8	0.3	3	0.17
Redox	199	84	136				139.67	57.59	3	33.25
Sulphides	112.29	356.42	141.47				203.39	133.32	3	76.97
Abundance	152	222	224				199.33	41	3	23.67
No. Taxa	27	28	32				29	2.65	3	1.53
P. evenness	0.8293	0.6301	0.728				0.7291	0.1	3	0.06
Richness	5.175	4.998	5.728				5.3003	0.38	3	0.22
SWDI	2.733	2.1	2.523				2.452	0.32	3	0.18
AMBI	2.3897	2.7558	2.5977				2.5811	0.18	3	0.1
M-AMBI	0.9318	0.8225	0.9324				0.8956	0.06	3	0.03

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5		Ave	SD	n	SE
TOM	1.5	1.5	1.5				1.5	0	3	0
Redox	2.34	3.37	2.91				2.8733	0.52	3	0.3
Sulphides	1.53	2.45	1.69				1.89	0.49	3	0.28
Abundance	2.69	3.02	3.02				2.91	0.19	3	0.11
No. Taxa	1.87	1.87	1.98				1.9067	0.06	3	0.03
P. evenness										
Richness	1.64	1.7	1.51				1.6167	0.1	3	0.06
SWDI	1.52	2.61	1.88				2.0033	0.56	3	0.32
AMBI	2.34	2.61	2.49				2.48	0.14	3	0.08
M-AMBI	1.63	2.22	1.63				1.8267	0.34	3	0.2
	Grab1	**Grab2**	**Grab3**	**Grab4**	**Grab5**	Wt	**Ave**	**SD**	**n**	**SE**
Organic loading	**1.5**	**1.5**	**1.5**			0.2	**1.5**	0	3	0
Sediment chemis	**1.935**	**2.91**	**2.3**			0.3	**2.38**	0.49	3	0.28
Infauna composit	**1.9483**	**2.3383**	**2.085**			0.5	**2.12**	0.2	3	0.12
Overall ES	1.9	2.3	2				**2.07**	0.21	3	0.12

Flow environmen	
	LF
	FOR
	Control 2

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	5.9	5.8	5.2				5.6333	0.38	3	0.22
Redox	158	99	138				131.67	30.01	3	17.33
Sulphides	659.91	224.55	178.24				354.23	265.74	3	153.43
Abundance	259	176	291				242	59.35	3	34.27
No. Taxa	36	27	34				32.333	4.73	3	2.73
P. evenness	0.761	0.715	0.7111				0.729	0.03	3	0.02
Richness	6.299	5.029	5.817				5.715	0.64	3	0.37
SWDI	2.727	2.357	2.507				2.5303	0.19	3	0.11
AMBI	2.3415	3.2219	2.8404				2.8013	0.44	3	0.25
M-AMBI	1.0195	0.8111	0.9292				0.9199	0.1	3	0.06

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5		Ave	SD	n	SE
TOM	1.5	1.5	1.5				1.5	0	3	0
Redox	2.71	3.24	2.89				2.9467	0.27	3	0.16
Sulphides	3.08	2.04	1.86				2.3267	0.66	3	0.38
Abundance	3.15	2.82	3.25				3.0733	0.23	3	0.13
No. Taxa	2.31	1.87	2.12				2.1	0.22	3	0.13
P. evenness										
Richness	1.45	1.69	1.49				1.5433	0.13	3	0.08
SWDI	1.53	2.17	1.91				1.87	0.32	3	0.18
AMBI	2.3	2.96	2.67				2.6433	0.33	3	0.19
M-AMBI	1	2.29	1.65				1.6467	0.65	3	0.38
	Grab1	**Grab2**	**Grab3**	**Grab4**	**Grab5**	Wt	**Ave**	**SD**	**n**	**SE**
Organic loading	**1.5**	**1.5**	**1.5**			0.2	**1.5**	0	3	0
Sediment chemis	**2.895**	**2.64**	**2.375**			0.3	**2.64**	0.26	3	0.15
Infauna composit	**1.9567**	**2.3**	**2.1817**			0.5	**2.15**	0.17	3	0.1
Overall ES	2.1	2.2	2.1				**2.13**	0.06	3	0.03

Flow environmen	LF									
	FOR									
	Control 3									
Raw data (Input table)										
Variable	**Grab1**	**Grab2**	**Grab3**	**Grab4**	**Grab5**		**Ave**	**SD**	**n**	**SE**
TOM	5.2	5.3	5.5				5.3333	0.15	3	0.09
Redox	208	257	191				218.67	34.27	3	19.79
Sulphides	82.525	35.379	32.757				50.22	28.01	3	16.17
Abundance	97	54	84				78.333	22.05	3	12.73
No. Taxa	43	15	27				28.333	14.05	3	8.11
P. evenness	0.9143	0.7891	0.8067				0.8367	0.07	3	0.04
Richness	9.181	3.51	5.868				6.1863	2.85	3	1.65
SWDI	3.439	2.137	2.659				2.745	0.66	3	0.38
AMBI	2.0063	2.8125	1.9688				2.2625	0.48	3	0.28
M-AMBI	1.2125	0.7008	0.9557				0.9563	0.26	3	0.15
ES equivalents (do not touch)										
Variable	**Repl 1**	**Repl 2**	**Repl 3**	**Repl 4**	**Repl 5**		**Ave**	**SD**	**n**	**SE**
TOM	1.5	1.5	1.5				1.5	0	3	0
Redox	2.26	1.82	2.41				2.1633	0.31	3	0.18
Sulphides	1.35	0.98	0.95				1.0933	0.22	3	0.13
Abundance	2.31	1.81	2.19				2.1033	0.26	3	0.15
No. Taxa	3.41	2.97	1.87				2.75	0.79	3	0.46
P. evenness										
Richness	1	2.51	1.48				1.6633	0.77	3	0.44
SWDI	0.31	2.54	1.65				1.5	1.12	3	0.65
AMBI	2.05	2.65	2.02				2.24	0.36	3	0.21
M-AMBI	1	2.88	1.5				1.7933	0.97	3	0.56
	Grab1	**Grab2**	**Grab3**	**Grab4**	**Grab5**	Wt	**Ave**	**SD**	**n**	**SE**
Organic loading	**1.5**	**1.5**	**1.5**			0.2	**1.5**	0	3	0
Sediment chemis	**1.805**	**1.4**	**1.68**			0.3	**1.63**	0.21	3	0.12
Infauna composit	**1.68**	**2.56**	**1.785**			0.5	**2.01**	0.48	3	0.28
Overall ES	1.7	2	1.7				**1.8**	0.17	3	0.1