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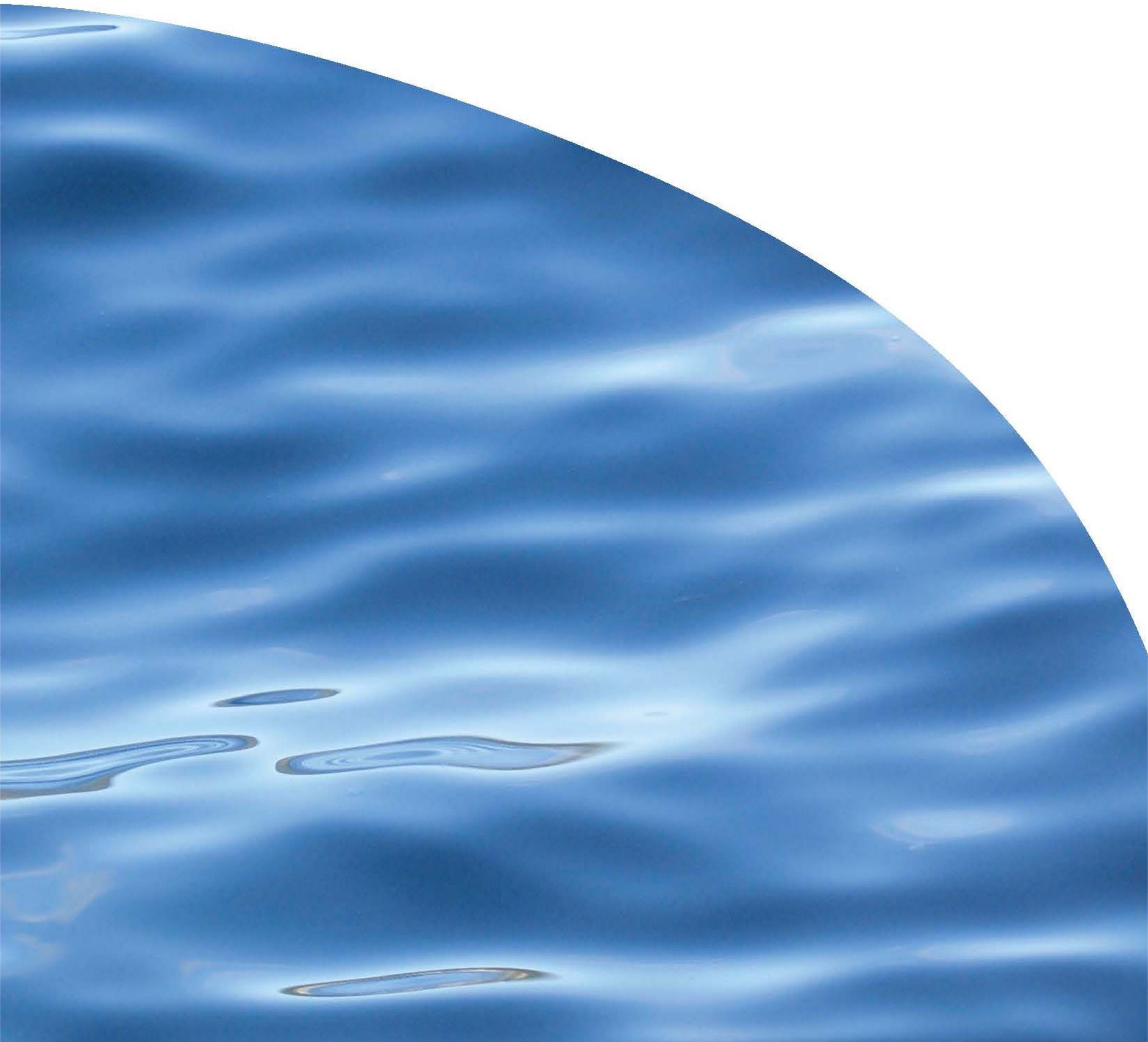
ENVIRONMENTAL IMPACTS OF THE OTANERAU BAY SALMON FARM: ANNUAL MONITORING 2011



ENVIRONMENTAL IMPACTS OF THE OTANERAU 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).

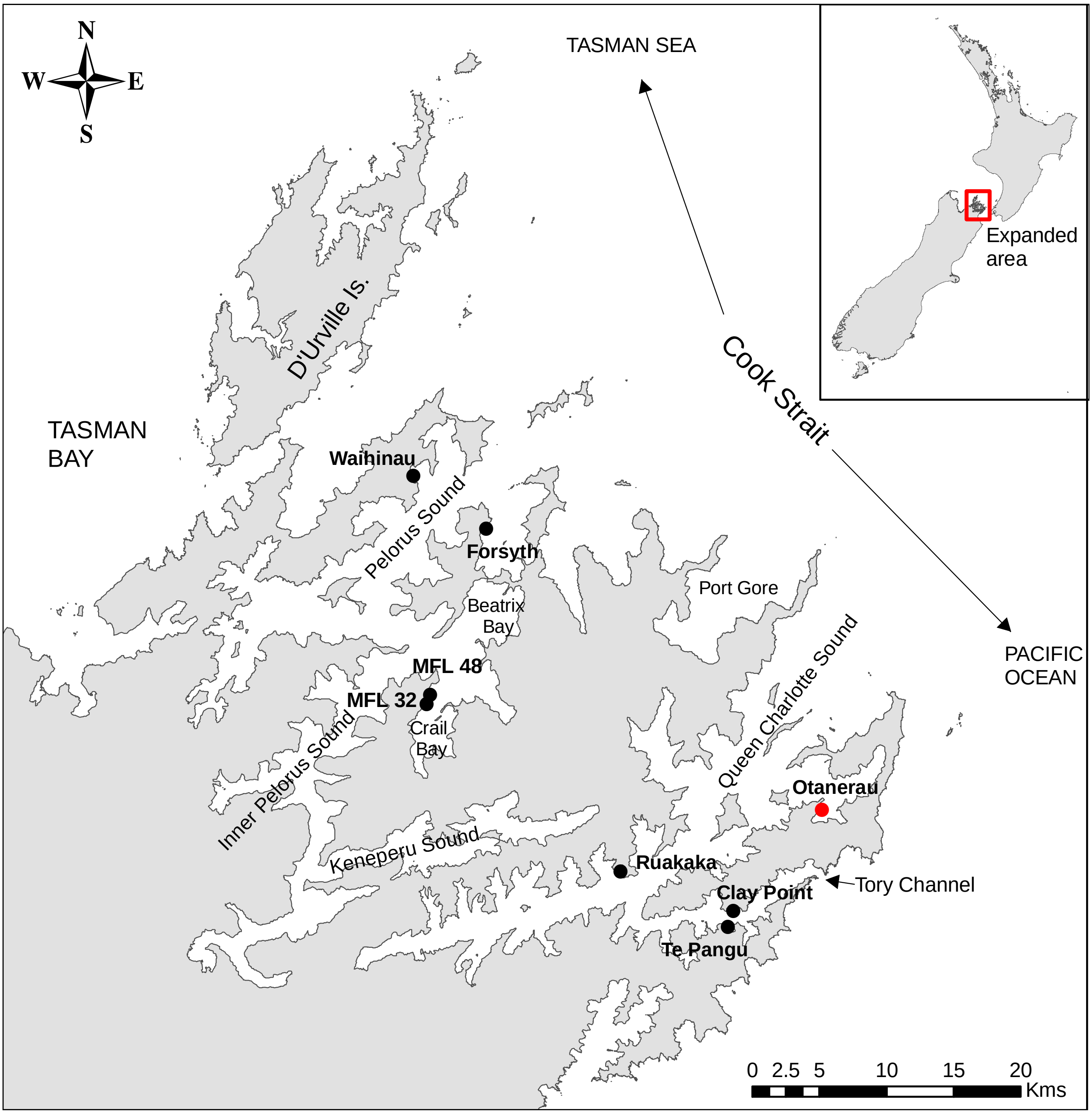

Figure 1. Map of Marlborough Sounds area showing the location of the OTA salmon farm (red dot) along with NZKS's seven other farm sites (black dots).

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 Otanerau Bay salmon farm.

1.1. Site details and history of feed usage

The Otanerau Bay farm site was established in 1990 and, with average water current speeds of ~ 6 cm/s, it is considered a low-moderate flow site. Feed inputs at this farm have historically ranged from 1501 to 2568 tonnes (since 2001, Figure 2). 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 1346 tonnes of feed was used (Figure 3). The majority of this feed input occurred in May to November 2011.

In 2009 the Otanerau Bay farm was significantly reduced in size as cages were removed from this farm and shifted to a number of other farm sites. A harmful algal bloom affecting the inner Marlborough Sounds forced the Ruakaka Bay salmon farm to be temporarily relocated to some spare space on the northern end of the Otanerau Bay farm for 3.5 months, between 12 June and 2 October 2010. Hence, the Otanerau Bay site was more intensively utilised (while the Ruakaka Bay site lay fallow) over this period than at other times of the year.

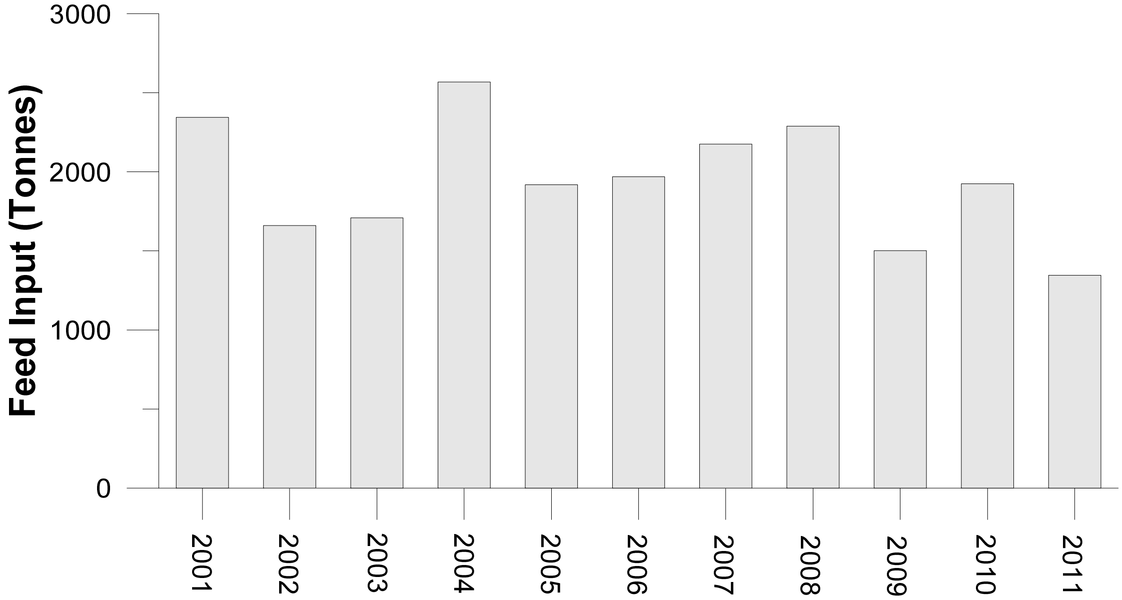

Figure 2. Annual feed inputs at the Otanerau Bay farm, 2001-2011.

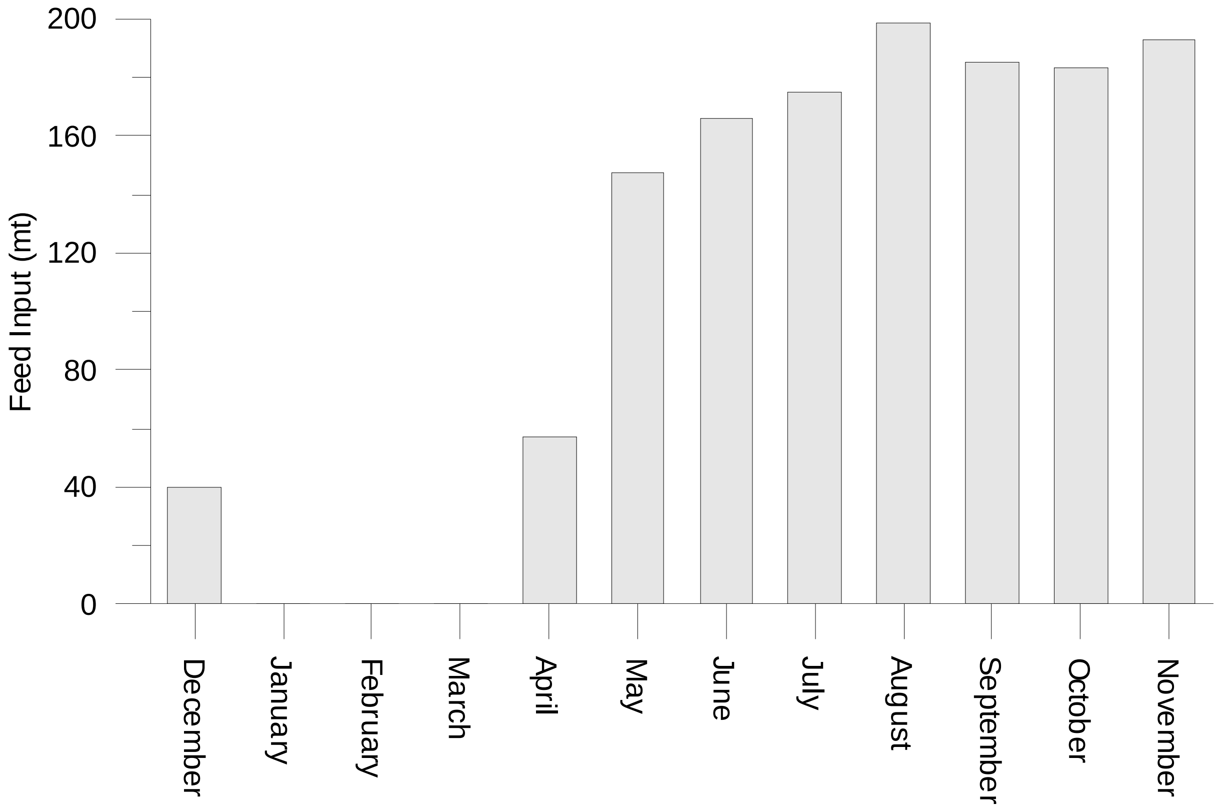

Figure 3. Monthly feed inputs at the Otanerau Bay farm from December 2010 to November 2011.

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 OTA occurred on 22 November 2011

2.1. Soft sediment habitats

2.1.1. Sampling locations

The OTA salmon farm was monitored at two cage stations (at the edge of Zone 1), two stations along a transect aligned in a down-current direction (from the cages) at distances that correspond to the Zone 2-3 and 3-4 boundaries specified under the zones concept (*i.e.* stations '50 m' and '150 m', respectively) and at two comparable reference or 'control' (*i.e.* 'Ctl-1' and 'Ctl-2') stations (Figure 4). For a full explanation of the zones concept, please refer to Keeley 2011. The orientation of the OTA transect was altered from previous years, and now runs perpendicular to the longest axis of the site and the predominant direction of flow. This departs from the ideal orientation specified in the AEMP (which is in a down-current orientation), but was considered necessary to avoid the 'down-current' stations being situated within the consented boundaries, in an area that was recently farmed (cages are presently at one end of what is a long, narrow site).

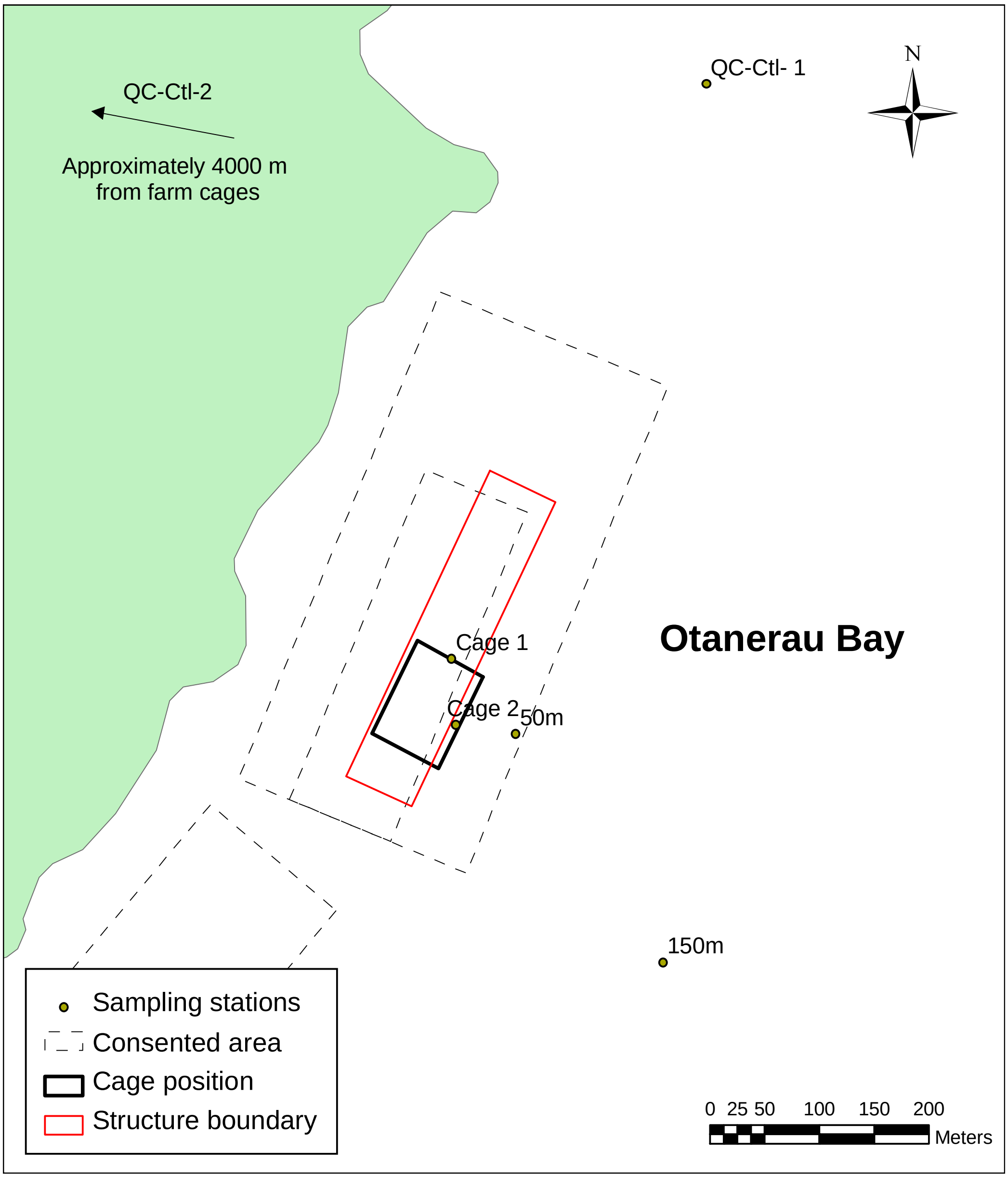

Figure 4. Soft sediment and inshore habitat sampling locations for OTA in 2011. 'Ctl' = Control.

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 Otanerau Bay salmon farm is a low- to moderate-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 OTA, the results from RUA low-flow site are considered to be generally representative.

3. RESULTS

3.1. Soft sediment habitats

Average sediment organic matter levels were elevated (by ~ 2.3 times) beneath the cages compared to the down-current and control stations, which had similar levels (Figure 5). Sediments at the cages also had negative redox potentials (average -106 Eh_{NHE}, mV) and highly elevated levels of total free sulphides, particularly at Cage 1. This was consistent with observations of sediments freely out-gassing, evidenced by bubbles breaking at the sea surface, and very strong sulphide odours (Appendix 1).

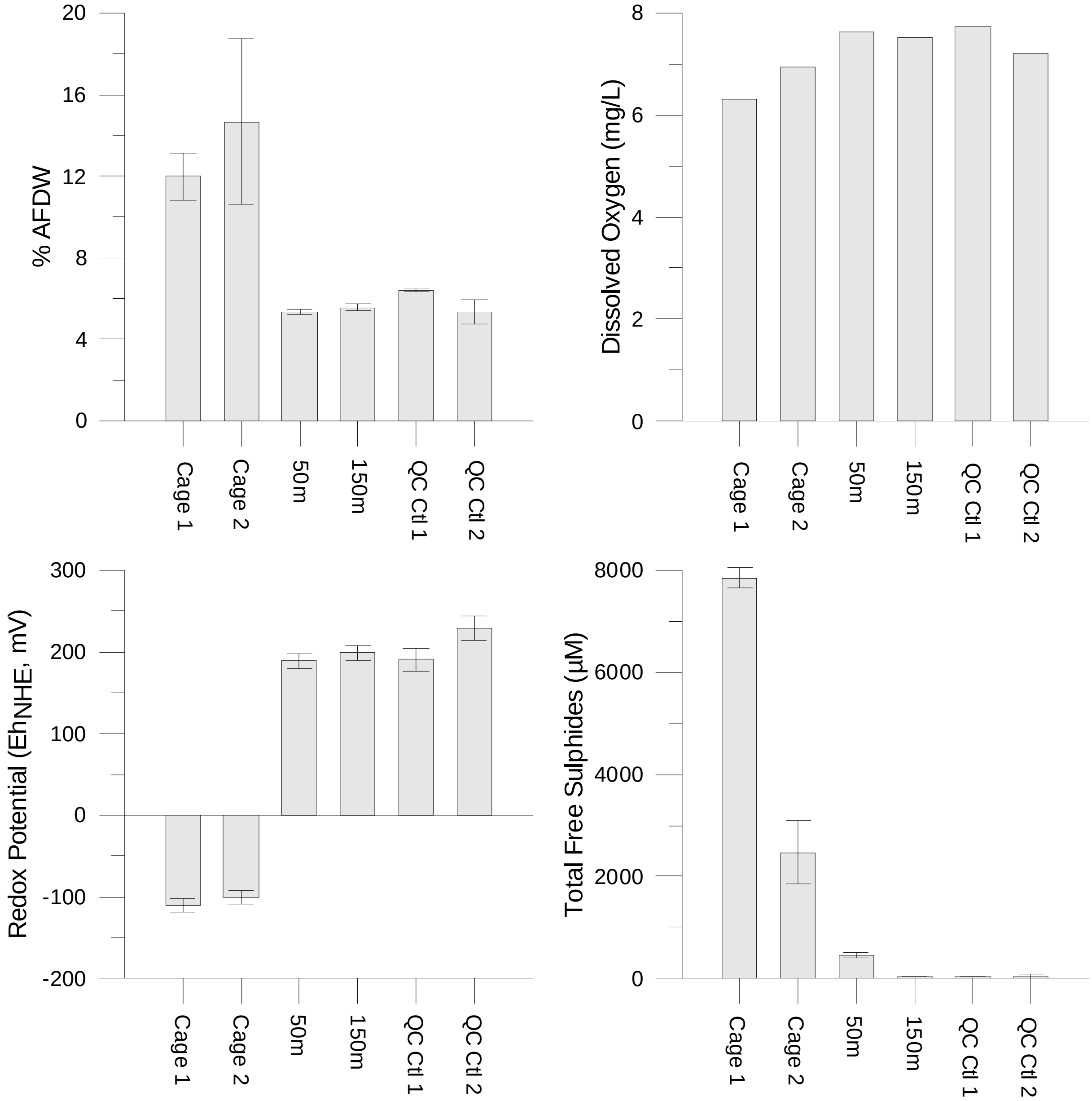

Figure 5. Multiplot of organic matter (as % AFDW), redox potential (Eh_{NHE}, mV), total free sulphides (µM) and near-bottom DO (mg/l). Error bars = SE, n=3.

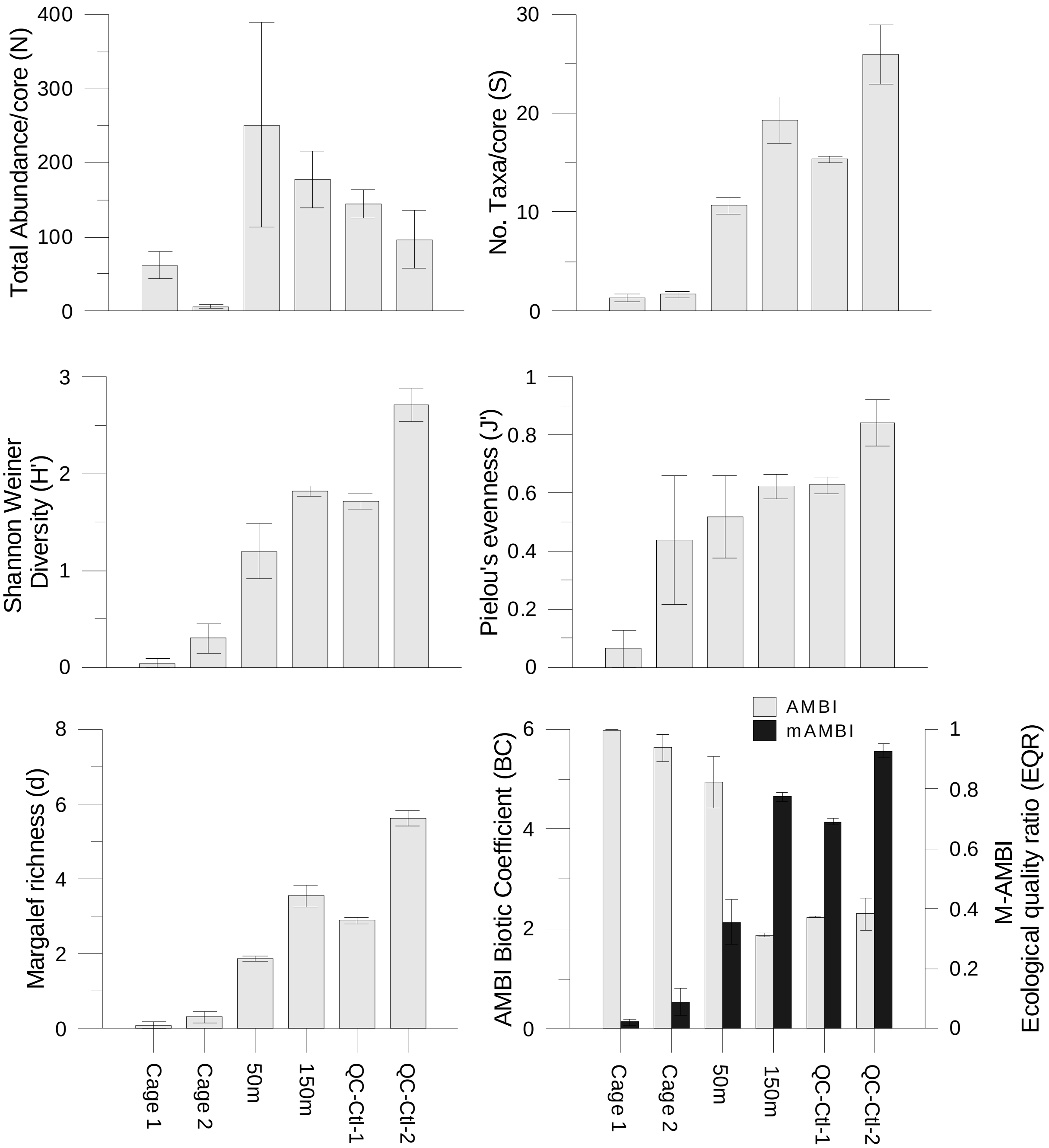

Figure 6. Multiplot of infauna statistics. Error bars = SE, n=3.

The infauna communities at the cage stations were severely impoverished, as indicated by an average of 1.5 taxa and 34 individuals per core (Figure 5) and low diversity (H'), richness (d) and ecological quality ratio (EQR). Samples from the Cage 2 station were particularly impacted; one replicate was virtually azoic and contained only one capitellid worm. Diversity was also somewhat reduced at '50 m' due to relatively high abundances of a few disturbance-tolerant, opportunistic taxa (especially *Capitella capitata*). The 150 m station infauna had similar abundance, richness and diversity to the Control 1 station (QC-Ctl-1), approximately 550 m north of the farm.

3.1.1. Copper and zinc

Copper concentration in the sediments below the cages exceeded the ISQG-High trigger level with an average of 1440 mg/kg (SE 731, n = 6) and zinc concentration also exceeded the ISQG-High guidelines with an average of 583 mg/kg (SE 93, n = 6, Appendix 2, Figure 2.2). Zinc levels were slightly elevated in comparison to 2010, but have increased by 5.4-fold since 2009. Copper concentrations had increased by and 64- and 7.9-fold in comparison to 2009 and 2010 respectively.

3.2. Water column

Near-bottom (water column) dissolved oxygen (DO) levels were slightly depressed (by ~12%) at the cage stations relative to the controls (Figure 5). DO levels at the 50 and 150 m stations were similar to those recorded at the control stations.

Water column nutrient levels were not analysed at Otanerau during the 2011 annual monitoring, but results from the RUA survey 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 (as indicated by % AFDW) beneath the cages was high, particularly at Cage 2, and the benthic infauna remained severely compromised.
- Conditions at the cage station were considered to be at the maximum accepted ES limit. While an average ES 5.9 state is not technically ‘azoic’, one of the cage stations was virtually azoic with only trace numbers of opportunistic taxa. Hence, it is a severely impacted state and beyond the preferred Zone 1 conditions; defined by the point of peak infauna abundance and dominance of opportunists (ES 5).
- Both copper and zinc concentrations in the sediments beneath the cages exceeded ISQG-High (for probable biological effects).
- Conditions at the Zone 2-3 boundary (‘50 m’) station were within the maximum accepted ES limit for this site with an ES of 3.1 (maximum permitted ES = 3.5), indicative of moderate effects.
- The Zone 3-4 boundary (‘150 m’) and control stations surveyed in the 2011 annual monitoring were within the acceptable ES limits for these stations and comparable to the control sites.

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:**	4.71 (0.29) 5.87 (0.06) 6.16 (0.05) **5.77 (0.03)**	Sediments freely outgassing with very strong sulphide odours and high organic matter content. Very low redox values, and high sulphides. Infauna community severely impoverished, with only capitellid polychaetes present, and one nematode in one sample.
Cage 2	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	5.03 (0.80) 5.19 (0.18) 6.71 (0.08) **5.93 (0.14)**	Bacterial mats present, sediments freely outgassing with very strong sulphide odours and high organic matter content. Very low redox values, and high sulphides. Infauna community nearly azoic, with an average of only six individuals and 1.7 taxa per core.
50 m (Zone 2-3 Boundary)	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	1.50 (0.00) 2.65 (0.09) 3.98 (0.27) **3.10 (0.15)**	Moderate sulphide odours, elevated sulphides, elevated densities of opportunistic, enrichment-tolerant species.
150 m (Zone 3-4 Boundary)	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	1.50 (0.00) 1.71 (0.08) 2.54 (0.06) **2.10 (0.06)**	Sediment chemistry and infauna community characteristics similar to Control 1.
Control 1	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	2.52 (0.51) 1.78 (0.03) 2.83 (0.07) **2.47 (0.09)**	Diverse infauna communities, low organic matter content and total free sulphide levels.
Control 2	Organic loading: Sediment chemistry: Infauna composition: **Overall:**	2.01 (0.51) 1.76 (0.19) 1.87 (0.16) **1.83 (0.14)**	Very 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 were reduced at the cage stations, suggesting a farm-related effect. However, the 12 % reduction in DO encountered beneath the cages (relative to the control stations) is unlikely to have been ecologically significant. 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 Ruakaka farm 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. CONCLUSIONS AND RECOMMENDATIONS

In November 2011, the Otanerau 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 (ES 5.9) was close to ES 6, which is an undesirable state. Although not completely azoic, ES 5.9 is a highly impacted and biologically impoverished state and beyond the point at which wastes are efficiently assimilated – and instead waste is likely to be accumulating.
- The copper and zinc concentrations beneath the cages exceeded the best available guideline thresholds for probable biological effects (ANZECC 2000, as concluded by Clement *et al.* 2010).

The deterioration in conditions is likely to be related to the temporary relocation and addition of the Ruakaka farm to this site in 2010 and the fact that most of the feed usage (and production) occurred in the seven months prior to monitoring. The reduction in farm size, and subsequently feed inputs, since mid 2009 would likely otherwise have enabled further recovery from this state. However, the total feed input during the last 24 months (1925 and 1346 t/yr in 2010 and 2011 respectively) was still relatively low in comparison to historical levels. Hence, it would appear that the Otanerau site is impacted to a point where the infauna is severely compromised and farming intensity would need to be reduced for some recovery to occur. We note that NZKS have recently started using feed containing organic zinc, which is likely to reduce zinc inputs to the seabed. 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. Summary of 2011 results.

Table 1.1. Summary of the physical and chemical properties of sediments from the Otanerau Bay stations during the 2011 monitoring survey. Bracketed values = SE.

	Station	Units	Cage-1	Cage 2	50 m	150 m	QS-Ctl-1	QS-Ctl-2
	Depth	m	35.5	35.1	36.3	36.6	40.3	37.1
Sediments	AFDW	%	12.0	14.7	5.4	5.6	6.4	5.3
	Redox	Eh_{NHE}, mV	-110.4	-100.6	189.2	198.7	190.8	229.1
	Sulphides	µM	7656.3	3652.7	544.8	46.9	54.8	106.7
	Bacterial mat	-		present				
	Out-gassing	-	Freely	Freely	None	None	None	None
	Odour	-	Very Strong	Very Strong	Moderate	None	None	None
Infauna statistics	Abundance	No./core	61(18.1)	6(2.65)	251(137.82)	178(37.62)	145(18.82)	97(38.94)
	No. taxa	No./core	1.33(0.33)	1.67(0.33)	10.67(0.88)	19.33(2.33)	15.33(0.33)	26(3)
	Richness	Stat.	0.10(0.10)	0.32(0.16)	1.87(0.06)	3.55(0.3)	2.89(0.09)	5.63(0.22)
	Evenness	Stat.	0.07(0.07)	0.44(0.22)	0.52(0.14)	0.62(0.04)	0.63(0.03)	0.84(0.08)
	Shannon-Weiner	Index	0.05(0.05)	0.30(0.15)	1.20(0.29)	1.83(0.05)	1.71(0.08)	2.71(0.17)
	AMBI	Index	5.98(0.02)	5.63(0.27)	4.94(0.52)	1.88(0.05)	2.24(0.01)	2.30(0.33)
	M-AMBI	Index	0.02(0.01)	0.09(0.04)	0.36(0.07)	0.77(0.02)	0.69(0.01)	0.93(0.02)
	Near bottom DO	mg/l	6.31	6.94	7.63	7.52	7.73	7.2

Appendix 2. Historical comparisons.

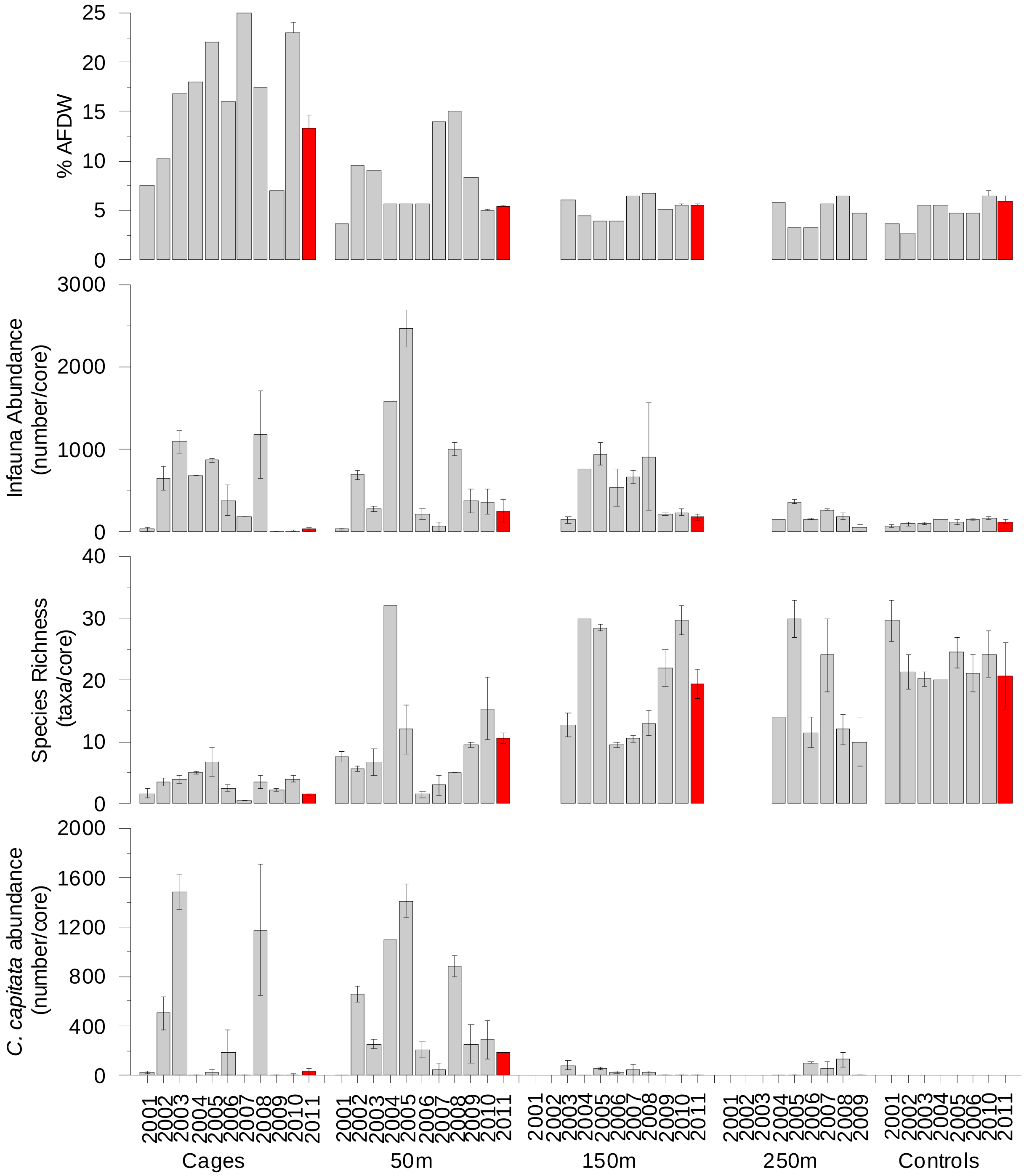

Figure 2.1. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and C. capitata densities recorded at Otanerau Bay since 2001. High densities of capitellid polychaetes are typically 1,000 individuals m-2 (=13 per 0.013 m² core) or greater (ANZECC 2000 guidelines). Note: 2009 cage and down-current stations were in different locations to previous years due changes in farm boundaries.

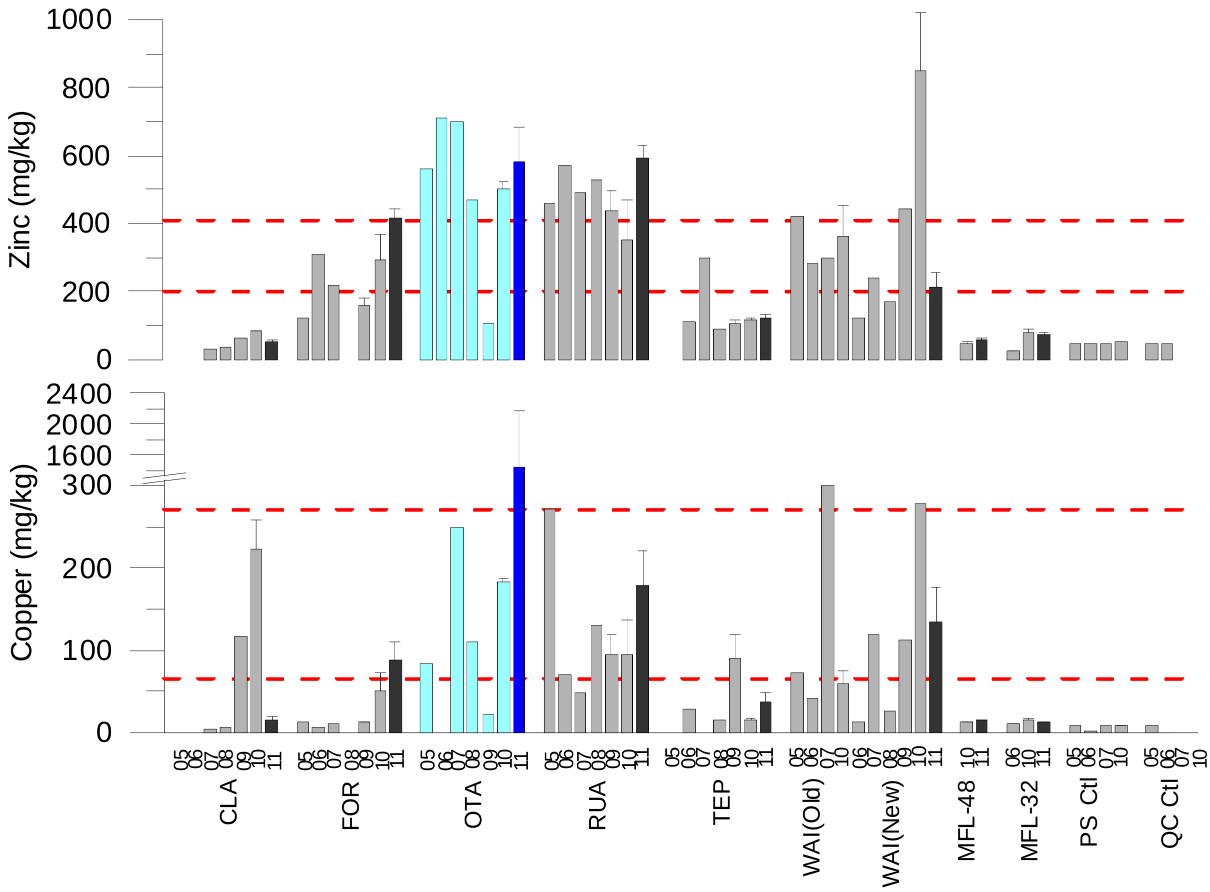

Figure 2.2. Comparison of the last seven years of annual monitoring data for sediment copper and zinc concentrations beneath all eight NZKS farms and two control stations (P.S. = Pelorus Sound, Q.C. = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG High and Low trigger levels. Otanerau data are in blue. Note break in y-axis and change in scale in copper graph (OTA 2011 average copper concentration was 1440 mg/kg).

Table 2.1. Summary of historical benthic impact levels at main stations situated beneath and down-current of the Otanerau Bay farm. Assessed according to the ranking system provided in previous annual monitoring reports. This comparison does not include recent monitoring years because the classification system was changed in 2010 to a quantitative method.

Survey	Cages	50 m	150 m	250 m	Controls
2001	(yellow)	(blue)	na	na	(blue)
2002	(orange)	(yellow)	na	na	(blue)
2003	(orange)	(green)	(green)	(blue)	(blue)
2004	(orange)	(yellow)	(green)	(blue)	(blue)
2005	(orange)	(yellow)	(green)	(green)	(blue)
2006	(orange)	(yellow)	(green)	(green)	(blue)
2007	(red)	(red)	(yellow)	(green)	(blue)
2008	(orange)	(orange)	(yellow)	(green)	
2009	(orange)	(orange)	(green)	(green)	

Impact Level		
(red)	25.1-30	Very high
(orange)	20.1-25	High
(yellow)	15.1-20	Moderate
(green)	11-15	Low
(blue)	10	Natural

Appendix 3. Detailed ES calculations.

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

Flow environment: LF
Farm OTA
Site Cage1

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	14	12	10				12	2	3	1.15
Redox	-116.6	-121	-93.7				-110.4	14.66	3	8.46
Sulphides	7851	7851	7267				7656.3	336.75	3	194.42
Abundance	33	95	56				61.333	31.34	3	18.09
No. Taxa	2	1	1				1.3333	0.58	3	0.33
P. evenness	0.1959	0	0				0.0653	0.11	3	0.06
Richness	0.286	0	0				0.0953	0.17	3	0.1
SWDI	0.1358	0	0				0.0453	0.08	3	0.05
AMBI	5.9545	6	6				5.9848	0.03	3	0.02
M-AMBI	0.0416	0.0094	0.0094				0.0201	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	5.21	4.74	4.19				4.7133	0.51	3	0.29
Redox	5.18	5.22	4.97				5.1233	0.13	3	0.08
Sulphides	6.66	6.66	6.52				6.6133	0.08	3	0.05
Abundance	6	6	6				6	0	3	0
No. Taxa	6	6	6				6	0	3	0
P. evenness										
Richness	6.17	6.62	6.62				6.47	0.26	3	0.15
SWDI										
AMBI										
M-AMBI										

	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	5.21	4.74	4.19			0.2	4.71	0.51	3	0.29
Sediment chemistry	5.92	5.94	5.745			0.3	5.87	0.11	3	0.06
Infauna composition	6.0567	6.2067	6.2067			0.5	6.16	0.09	3	0.05
Overall ES	5.8	5.8	5.7				5.77	0.06	3	0.03

Flow environment: LF
OTA
Site Cage2

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	22	14	8				14.667	7.02	3	4.05
Redox	-83.8	-108	-110				-100.6	14.58	3	8.42
Sulphides	2466	3919	4573				3652.7	1078.5	3	622.67
Abundance	1	7	10				6	4.58	3	2.64
No. Taxa	1	2	2				1.6667	0.58	3	0.33
P. evenness	0	0.5917	0.7219				0.4379	0.38	3	0.22
Richness	0	0.5139	0.4343				0.3161	0.28	3	0.16
SWDI	0	0.4101	0.5004				0.3035	0.27	3	0.16
AMBI	6	5.7857	5.1				5.6286	0.47	3	0.27
M-AMBI	0.0094	0.0938	0.1624				0.0885	0.08	3	0.05

ES equivalents (do not touch)

Variable	Repl 1	Repl 2	Repl 3	Repl 4	Repl 5		Ave	SD	n	SE
TOM	6.33	5.21	3.56				5.0333	1.39	3	0.8
Redox	4.88	5.1	5.12				5.0333	0.13	3	0.08
Sulphides	4.78	5.49	5.74				5.3367	0.5	3	0.29
Abundance	7	7	7				7	0	3	0
No. Taxa	7	7	7				7	0	3	0
P. evenness										
Richness	6.62	5.83	5.94				6.13	0.43	3	0.25
SWDI										
AMBI										
M-AMBI										

	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	6.33	5.21	3.56			0.2	5.03	1.39	3	0.8
Sediment chemistry	4.83	5.295	5.43			0.3	5.19	0.31	3	0.18
Infauna compositior	6.8733	6.61	6.6467			0.5	6.71	0.14	3	0.08
Overall ES	6.2	5.9	5.7				5.93	0.25	3	0.14

Flow environmen	
	LF
	OTA
	50m

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	5.2	5.6	5.3				5.3667	0.21	3	0.12
Redox	206.2	187.4	174.1				189.23	16.13	3	9.31
Sulphides	451	569	614				544.84	84.22	3	48.62
Abundance	164	68	521				251	238.7	3	137.81
No. Taxa	11	9	12				10.667	1.53	3	0.88
P. evenness	0.4939	0.7744	0.2867				0.5183	0.24	3	0.14
Richness	1.961	1.896	1.758				1.8717	0.1	3	0.06
SWDI	1.184	1.702	0.7124				1.1995	0.49	3	0.28
AMBI	5.2043	3.9265	5.6833				4.938	0.91	3	0.53
M-AMBI	0.3344	0.4924	0.2386				0.3551	0.13	3	0.08

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	2.27	2.44	2.56				2.4233	0.15	3	0.09
Sulphides	2.68	2.92	3.01				2.87	0.17	3	0.1
Abundance	2.76	2.01	3.74				2.8367	0.87	3	0.5
No. Taxa	3.77	4.24	3.55				3.8533	0.35	3	0.2
P. evenness										
Richness	3.95	4.02	4.18				4.05	0.12	3	0.07
SWDI	4.18	3.29	4.99				4.1533	0.85	3	0.49
AMBI	4.44	3.48	4.79				4.2367	0.68	3	0.39
M-AMBI	4.86	4	5.37				4.7433	0.69	3	0.4
	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	2.475	2.68	2.785			0.3	2.65	0.16	3	0.09
Infauna composit	3.9933	3.5067	4.4367			0.5	3.98	0.47	3	0.27
Overall ES	3	2.9	3.4				3.1	0.26	3	0.15

Flow environmen	
	LF
	OTA
	150m

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	5.3	5.6	5.8				5.5667	0.25	3	0.14
Redox	214.9	183.1	198.2				198.73	15.91	3	9.19
Sulphides	33	56	52				46.924	12.5	3	7.22
Abundance	240	110	183				177.67	65.16	3	37.62
No. Taxa	23	15	20				19.333	4.04	3	2.33
P. evenness	0.5486	0.6967	0.6235				0.6229	0.07	3	0.04
Richness	4.014	2.978	3.647				3.5463	0.53	3	0.31
SWDI	1.72	1.887	1.868				1.825	0.09	3	0.05
AMBI	1.8138	1.8578	1.9698				1.8805	0.08	3	0.05
M-AMBI	0.7992	0.7437	0.779				0.7739	0.03	3	0.02

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	2.19	2.48	2.35				2.34	0.15	3	0.09
Sulphides	0.95	1.16	1.12				1.0767	0.11	3	0.06
Abundance	3.08	2.42	2.85				2.7833	0.34	3	0.2
No. Taxa	2.02	2.97	2.28				2.4233	0.49	3	0.28
P. evenness										
Richness	2.18	2.94	2.41				2.51	0.39	3	0.23
SWDI	3.26	2.97	3.01				3.08	0.16	3	0.09
AMBI	1.91	1.94	2.02				1.9567	0.06	3	0.03
M-AMBI	2.35	2.65	2.46				2.4867	0.15	3	0.09
	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	1.57	1.82	1.735			0.3	1.71	0.13	3	0.08
Infauna composit	2.4667	2.6483	2.505			0.5	2.54	0.1	3	0.06
Overall ES	2	2.2	2.1				2.1	0.1	3	0.06

Flow environmen	LF
	OTA
	Control 1

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	6.5	6.3	6.5				6.4333	0.12	3	0.07
Redox	162.3	203	207.2				190.83	24.8	3	14.32
Sulphides	38	61	65				54.758	14.59	3	8.42
Abundance	148	176	111				145	32.6	3	18.82
No. Taxa	16	15	15				15.333	0.58	3	0.33
P. evenness	0.6273	0.5774	0.6785				0.6277	0.05	3	0.03
Richness	3.002	2.708	2.973				2.8943	0.16	3	0.09
SWDI	1.739	1.564	1.837				1.7133	0.14	3	0.08
AMBI	2.2653	2.2414	2.2162				2.241	0.02	3	0.01
M-AMBI	0.6991	0.6671	0.7075				0.6912	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	3.03	1.5	3.03				2.52	0.88	3	0.51
Redox	2.67	2.3	2.26				2.41	0.23	3	0.13
Sulphides	1	1.19	1.23				1.14	0.12	3	0.07
Abundance	2.67	2.82	2.42				2.6367	0.2	3	0.12
No. Taxa	2.8	2.97	2.97				2.9133	0.1	3	0.06
P. evenness										
Richness	2.92	3.18	2.94				3.0133	0.14	3	0.08
SWDI	3.23	3.53	3.06				3.2733	0.24	3	0.14
AMBI	2.24	2.22	2.21				2.2233	0.02	3	0.01
M-AMBI	2.89	3.06	2.84				2.93	0.12	3	0.07
	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	3.03	1.5	3.03			0.2	2.52	0.88	3	0.51
Sediment chemis	1.835	1.745	1.745			0.3	1.78	0.05	3	0.03
Infauna composit	2.7917	2.9633	2.74			0.5	2.83	0.12	3	0.07
Overall ES	2.6	2.3	2.5				2.47	0.15	3	0.09

Flow environmen	LF
	OTA
	Control 2

Raw data (Input table)

Variable	Grab1	Grab2	Grab3	Grab4	Grab5		Ave	SD	n	SE
TOM	5	4.5	6.5				5.3333	1.04	3	0.6
Redox	239.3	249.6	198.4				229.1	27.08	3	15.63
Sulphides	45	83	193				106.7	77.13	3	44.53
Abundance	174	50	66				96.667	67.45	3	38.94
No. Taxa	32	23	23				26	5.2	3	3
P. evenness	0.6853	0.9369	0.9007				0.841	0.14	3	0.08
Richness	6.009	5.624	5.251				5.628	0.38	3	0.22
SWDI	2.375	2.938	2.824				2.7123	0.3	3	0.17
AMBI	2.9371	1.8438	2.1048				2.2952	0.57	3	0.33
M-AMBI	0.8839	0.9674	0.9301				0.9271	0.04	3	0.02

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	3.03				2.01	0.88	3	0.51
Redox	1.98	1.88	2.34				2.0667	0.24	3	0.14
Sulphides	1.06	1.35	1.92				1.4433	0.44	3	0.25
Abundance	2.81	1.74	1.98				2.1767	0.56	3	0.32
No. Taxa	1.98	2.02	2.02				2.0067	0.02	3	0.01
P. evenness										
Richness	1.47	1.53	1.62				1.54	0.08	3	0.05
SWDI	2.14	1.17	1.36				1.5567	0.51	3	0.29
AMBI	2.74	1.93	2.12				2.2633	0.42	3	0.24
M-AMBI	1.89	1.44	1.64				1.6567	0.23	3	0.13
	Grab1	Grab2	Grab3	Grab4	Grab5	Wt	Ave	SD	n	SE
Organic loading	1.5	1.5	3.03			0.2	2.01	0.88	3	0.51
Sediment chemis	1.52	1.615	2.13			0.3	1.76	0.33	3	0.19
Infauna composit	2.1717	1.6383	1.79			0.5	1.87	0.27	3	0.16
Overall ES	1.8	1.6	2.1				1.83	0.25	3	0.14