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

RESEARCH BASED SOLUTIONS

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

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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 Otanerau 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).

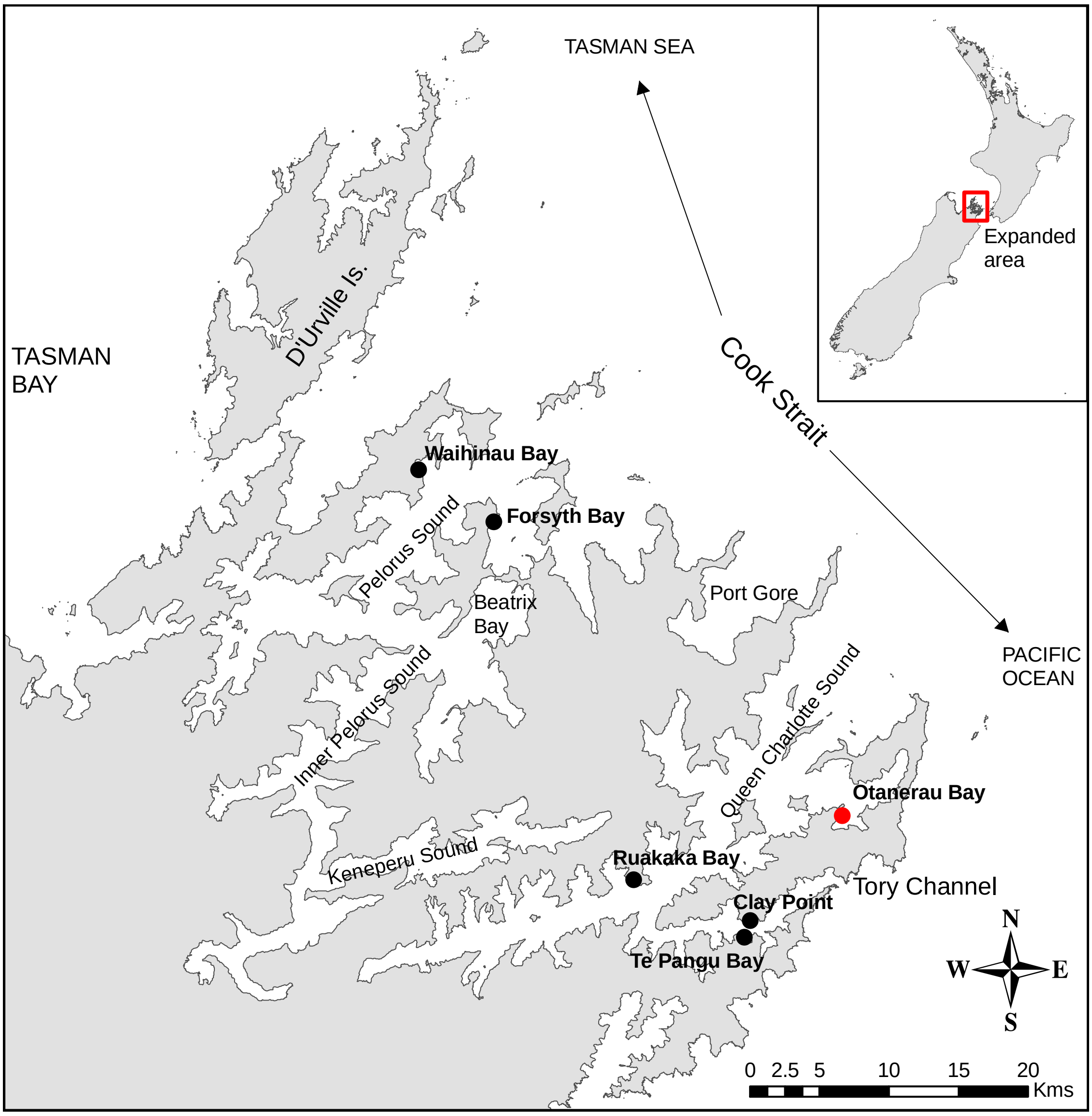

Figure 1. Map of Marlborough Sounds area showing the location of the OTA salmon farm (red dot) along with NZKS's five other farm sites (black dots).

1.2. 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 1640 to 2239 tonnes. Over the 12 month period leading up to this years monitoring (*i.e.* December 2009 to the end of November 2010) a total of 1925 tonnes of feed was used (Figure 2). 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 temporally 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.

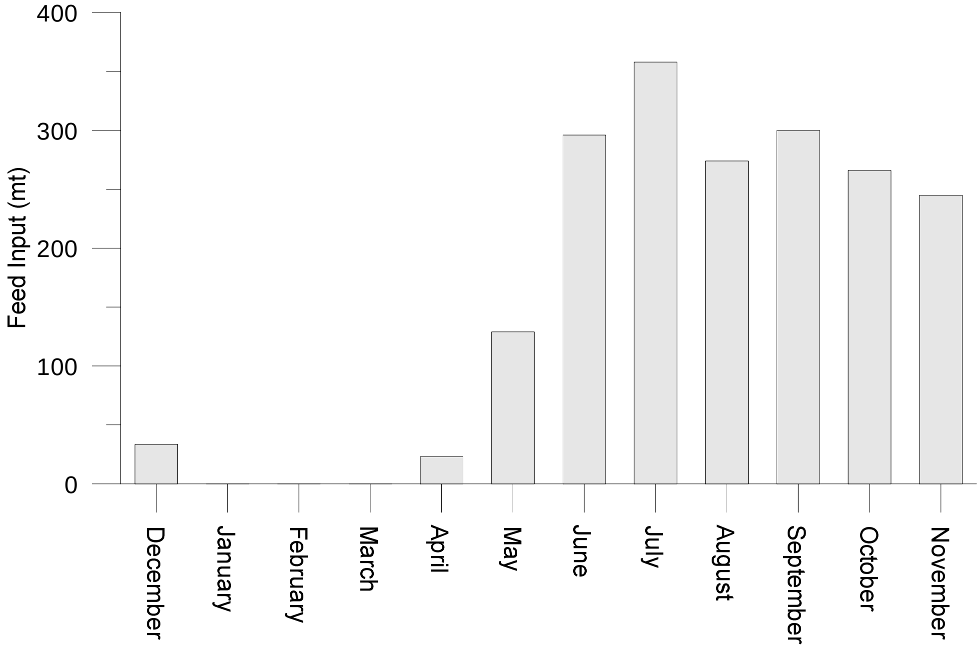

Figure 2. Monthly feed inputs at the Otanerau Bay farm from December 2009 to November 2010.

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 OTA salmon farm was monitored at two Cage stations (cage 2 only being inspected visually), two stations along a transect aligned in a down-current direction (from the farm) at distances that correspond to the zone 1-2 and 2-3 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 3). 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 is departs from the ideal orientation specified in the AMP (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).

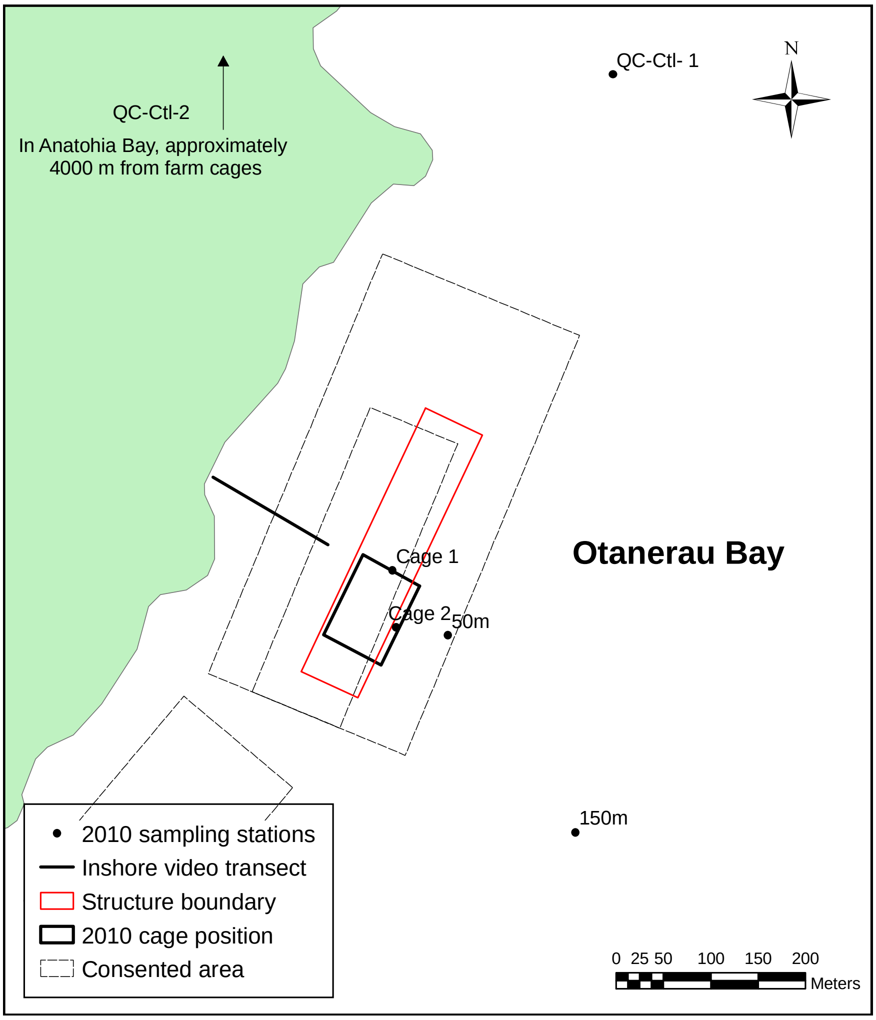

Figure 3. Soft sediment and inshore habitat sampling locations for OTA in 2010. 'Ctl' = Control.

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), AMBI and M-AMBI ecological statistics and indices.

2.2. Rocky habitats

The OTA salmon farm is considered a low- to moderate-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 reef habitat). Video footage is also compared to previous years. This was undertaken in 2011 (this survey). See Cawthron Report 1872 for further details on sampling methods and rationale.

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 are measured at one low-flow and one high-flow salmon farm each year; in 2010 this was undertaken at RUA and CLA. Water 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 4-5 times) beneath the cages compared to the '50m', '150m' and control stations (Figure 4). Organic matter was higher at QC-Ctl-1 than QC-Ctl-2 as well as the two stations closer to the farm boundary (*i.e.* 50 m and 150 m). The sampling station at the edge of the cages (Cage-1) also had a negative redox potential (-50 Eh_{NHE}, mV) and a particularly elevated level of total free sulphides. This was consistent with observations of out-gassing, evidenced by bubbles breaking at the surface upon disturbance (*i.e.* when the grab or drop-camera hits the seabed)

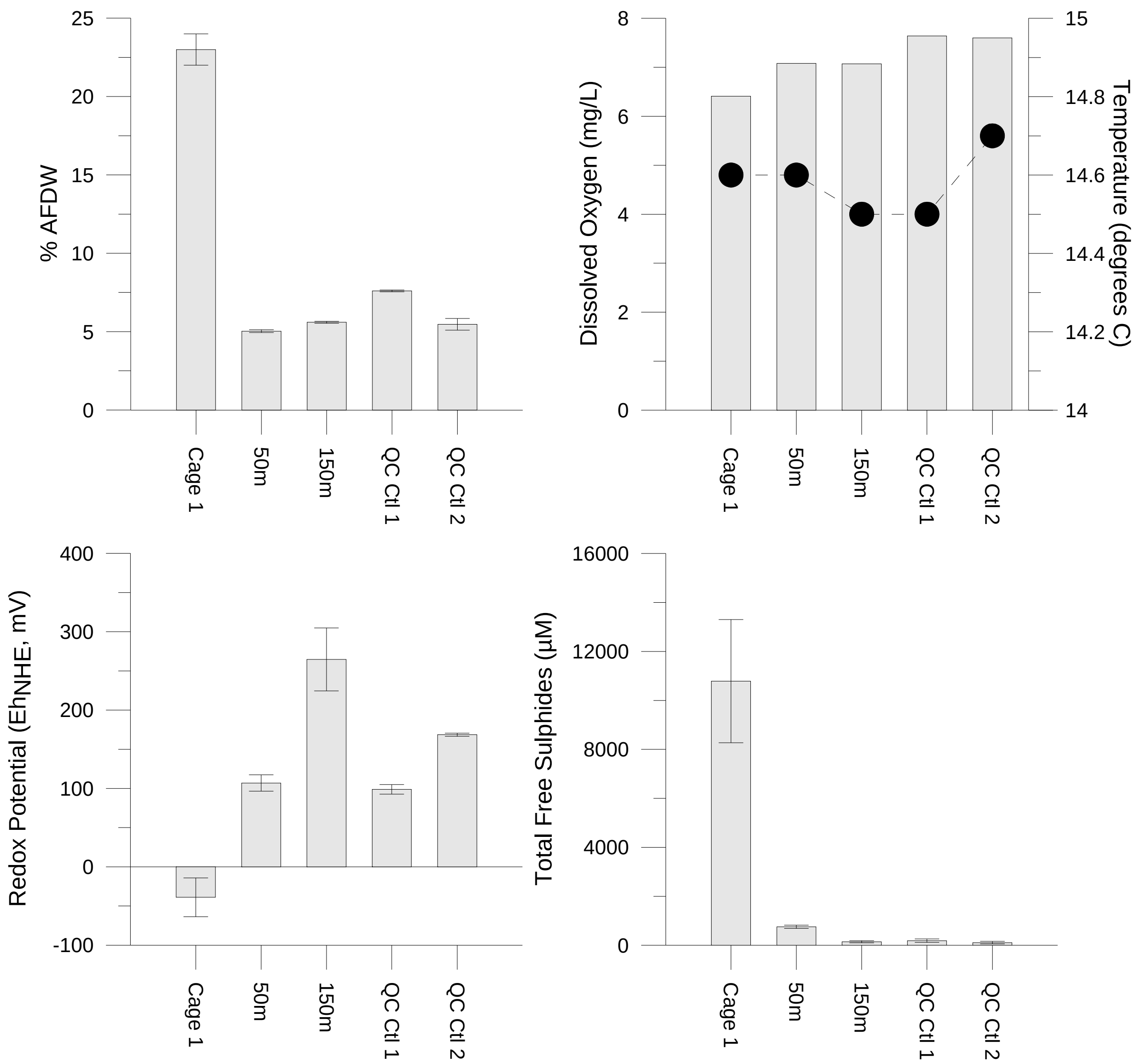

Figure 4. Multiplot of organic matter (as AFDW (% w/w)), redox potential (Eh_{NHE}, mV), total free sulphides (µM), near-bottom DO (mg/l) and water temperature (°C, indicated by black dots). Error bars = SE.

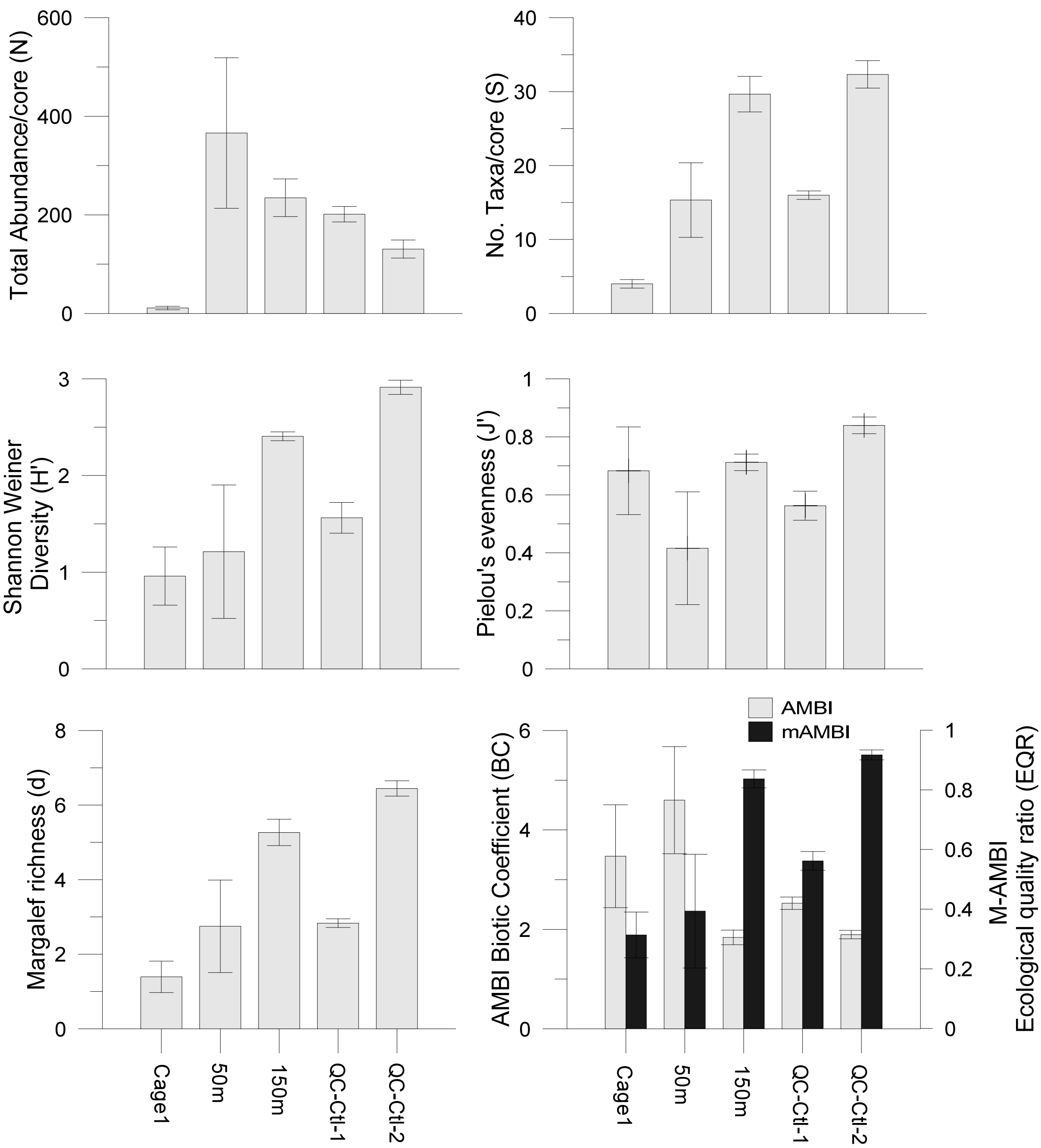

Figure 5. Multiplot of macrofauna statistics. Error bars = SE.

The infauna community at the cage station was severely compromised, as indicated by an average of four taxa and 11 individuals per core (Figure 5) and low Diversity (H'), Richness (d) and the Ecological quality ratio (EQR). Diversity was also somewhat reduced at '50 m' due to very high abundances of a few disturbance-tolerant, opportunistic taxa (especially *Capitella capitata* and nematode worms). The control 1 station (QC-Ctl-1) approximately 550 m north of the farm had a similar number of species to the 50 m station, but much lower densities.

3.1.1. Copper and zinc

Copper concentration in the sediments below the cages exceeded the ISQG-Low trigger level but was below the ISQG-High trigger level with an average of 183.3 mg/kg, (n=3) and zinc concentration exceeded the ISQG-High guidelines with an average of 500 mg/kg (n=3, Figure 8 in Appendix 2). This represents a 5-fold increase in zinc and a 9-fold increase in copper concentrations within the sediments since the 2009 annual monitoring.

3.2. Rocky habitats

Diver observation (and video footage) provide a description of habitats along a transect from the shallow subtidal area inshore of the western farm boundary, down the rocky cobble slope and out towards the cages. The larger cobbles and sand at the top of the slope between 5-12 m depth were largely barren of epibiota with a few sea cucumbers (*Stichopus* sp.), scattered tubeworms (*Galeolaria hystrix*) and small patches of *Ulva* sp. Between 12 m and 28 m depth (the end of the transect), a thick carpet of red macroalgae and tube worms covered the seabed. This band was composed of several different species of red algae, and high densities of tubeworms were observed to be living amongst the algae.

3.3. Water column

Near-bottom (water column) dissolved oxygen (DO) levels were slightly depressed (by ~16%) at the Cage station relative to the controls (Figure 4). DO levels at the 50 and 150m stations were approximately 8% lower than recorded at the control stations. Hence, near-bottom DO concentrations reduced with proximity to the farm. Near-bottom water temperatures remained relatively constant (±0.2 °C) regardless of station location. Water column nutrient levels were not analysed at Otanerau during the 2010 round of annual monitoring.

4. 2010 ASSESSMENT OF COMPLIANCE FOR OTA

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. OTA 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.

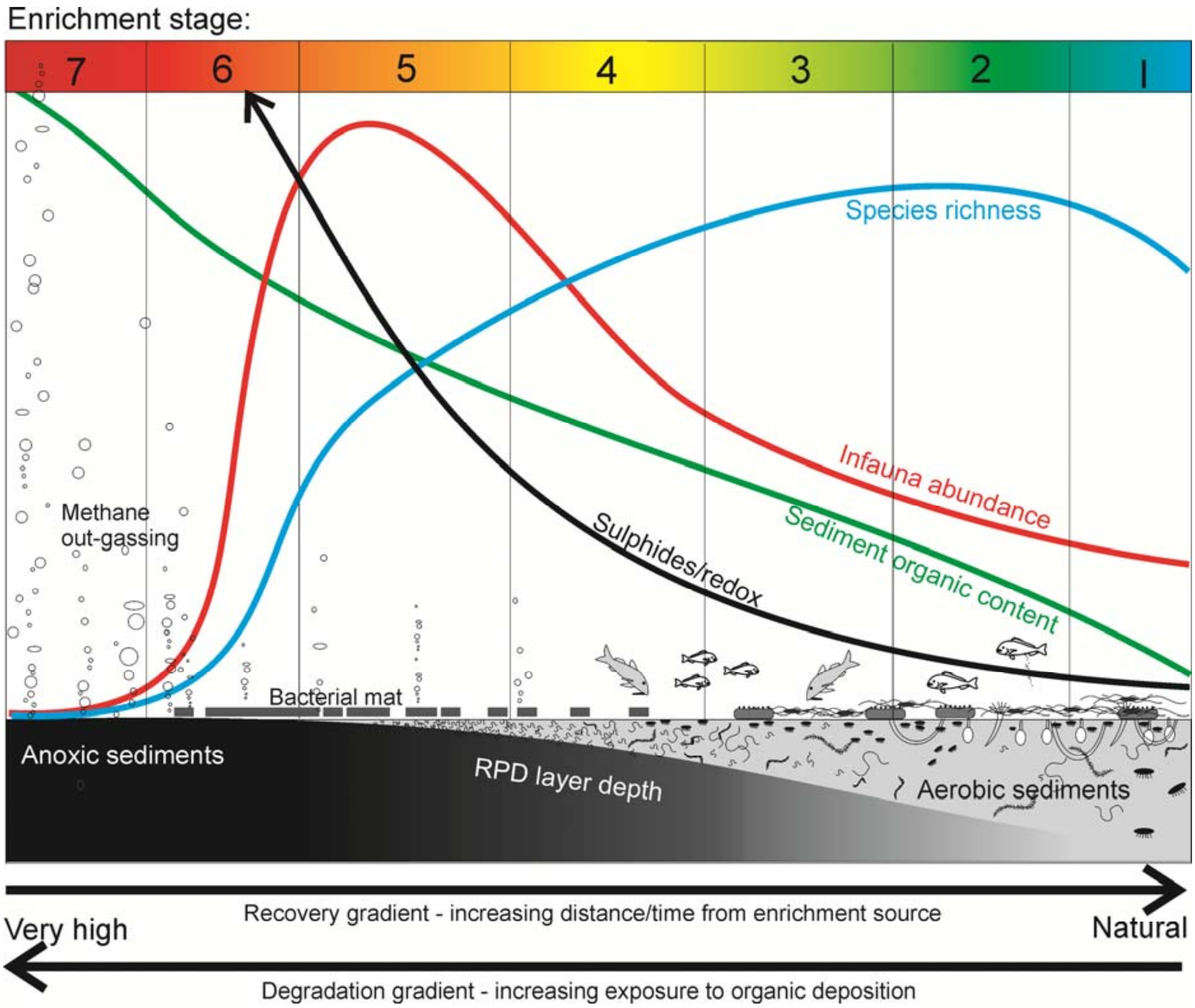

Figure 6. Stylised depiction of a typical enrichment stage (*ES*) gradient experienced at low-flow sites, showing generally understood responses in commonly measured environmental variables (species richness, infauna abundance, sediment organic content and sulphides and Redox). Apparent Redox Potential 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*
Spatial Zone	**Spatial extent**	**Comment**	**Description and bottom line**	**2010 AMP**
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 permitted *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 (as indicated by % AFDW) and the benthic macrofauna remains severely compromised.
- Conditions at the cage station are considered to be at the maximum accepted ES limit and there is a danger of exceeding these limits within a short time frame. While an *ES* 5.9 state is not technically 'azoic' it is a severely impacted state and beyond the specified maximum Zone 1 conditions defined by the point of peak infauna abundance and dominance of opportunists (*ES* 5).
- Copper concentrations in the sediments beneath the cages exceeded ISQG-Low (for possible biological effects) and zinc exceeded ISQG-High (for probable biological effects).
- Conditions at the zone 1 boundary ('50 m') station were also at the maximum accepted ES limit for this site with an *ES* of 3.5 (maximum permitted *ES* = 3), indicative of moderate-major effects, and there is a danger of exceeding these limits within a short time frame.
- The zone 2 boundary ('150 m') and control stations surveyed in the 2010 annual monitoring were within the acceptable ES limits for these stations.

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'	5.9	Mod	😐	Bacterial mats present, freely out-gassing with strong sulphide odours. Macrofauna severely compromised but not azoic. Extremely high sulphide levels.
'50 m' (Zone 1 Boundary)	3.5	High	😐	Very mild sulphide odours, infauna showing elevated densities of opportunistic, disturbance tolerant species.
'150 m' (Zone 2 Boundary)	1.5	V High	☺	Light brown coloured cohesive, clean muds with infauna communities similar to control 2 station.
Control 1	2.2	High	😐	Very mild sulphide odour in one sample and infauna communities indicating mild enrichment. Natural depositional area, possibly exacerbated by farm deposits.
Control 2	1.3	High	☺	"Pristine" Marlborough Sounds control station with healthy diverse infauna communities.

4.2. Rocky habitats

The wide band of dense red macroalgae (*Rhodymenia* sp.) and polychaete worm tubes (Maldanidae sp.) that was observed by divers along the transect inshore of the farm, has also been noted in previous inshore surveys. In 2010 the algal band appeared to be more extensive than in previous surveys, with the algae themselves appearing denser and healthier, and tubeworms apparently more prevalent. While it is likely that this community has been modified (*i.e.* more productive, resulting in greater biomass and abundances of some species) by farm-sourced nutrients and biodeposits, the impacts are not considered to be ecologically adverse. These habitats also seemed to be contained within the Zone 2 boundary (*i.e.* 150 m from cages), where moderate levels of benthic enrichment are tolerated under the existing consent conditions and according the AMP. A wider spatial study would be necessary in order to assess the degree to which the community has been altered by the farm versus that of natural temporal variability.

4.3. Water column

Near-bottom dissolved oxygen (DO) levels in the water reduced with proximity to the farm, suggesting a farm-related effect. However, the 16 % reduction in DO encountered beneath the cages (relative to the control stations) is unlikely to have been biologically 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.

5. CONCLUSION AND RECOMMENDATIONS

Overall, in December 2010, the Otanerau Bay farm was assessed to be at the maximum accepted ES limits, a management response is required to reduce the impacts. This finding is based on:

- The enrichment stage beneath the cages (*i.e. ES* 5.9) falling between what is and is not permitted for Zone 1 according to the consent conditions. Although not completely azoic, *ES* 5.9 is a highly impacted and biologically impoverished state and beyond the point at which wastes are maximally assimilated – and instead waste is likely to be accumulating.
- The '50 m' station (*i.e.* the Zone 1-2 boundary) was at the maximum acceptable limits of the enrichment that is permitted under the consent conditions for this zone.
- The copper and zinc concentrations beneath the cages exceeded the best available guideline thresholds for possible biological effects (ANZECC 2000, as concluded by Clement *et al.* 2010).

The recent deterioration in condition is likely to be related to the temporary relocation and addition of the Ruakaka farm to this site. 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 12 months (1925 t/yr) was still relatively low in comparison to historical levels. Hence, it would appear that the Otanerau site is impacted to a point where it is unlikely to recover to a compliant state without a prolonged period (*i.e.* years rather than months) of significantly reduced farming intensity.

Due to the elevated Cu and Zn levels, these should be assessed in triplicate at all stations (cage and down-current) in the 2011 monitoring. Additionally, serious consideration should be given to reducing inputs of these metals to the seabed.

6. REFERENCES

ANZECC 2000. Australian and New Zealand guidelines for fresh and marine water quality 2000 Volume 1. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

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. 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 Otanerau Bay stations during the 2009 monitoring survey. Bracketed values = SE. na = Not assessed - visual inspection only.

	Station	Units	Cage-1	Cage 2	50 m	150 m	QS-Ctl-1	QS-Ctl-2
	Depth	m	35.8	35.4	36	36.2	40	34.6
Sediments	AFDW	%	23	na	5	5.6	7.6	5.5
Sediments	Redox	Eh_{NHE}, mV	-38.9	na	106.9	264.7	98.8	168.6
Sediments	Sulphides	µM	10787.2	na	756.5	147.1	189.2	112.1
Sediments	Bacterial mat	% cover	~90	~80-90	0	0	0	0
Sediments	Out-gassing	-	Freely	Freely	None	None	None	None
Sediments	Odour	-	Very Strong	na	Mild	None	Faint	None
Macrofauna	Abundance	No./core	11.00 (3.61)	na	366 (152)	234 (38)	201 (15.)	130 (18)
Macrofauna	No. taxa	No./core	4.00 (0.58)	na	15.3 (5.0)	29.6 (2.4)	16.0 (0.5)	32.3 (1.8)
Macrofauna	Richness	Stat.	1.39 (0.42)	na	2.75 (1.24)	5.27 (0.35)	2.83 (0.12)	6.45 (0.21)
Macrofauna	Evenness	Stat.	0.68 (0.15)	na	0.42 (0.19)	0.71 (0.03)	0.56 (0.05)	0.84 (0.03)
Macrofauna	Shannon-Weiner	Index	0.96 (0.30)	na	1.21 (0.69)	2.41 (0.05)	1.56 (0.16)	2.91 (0.07)
Macrofauna	AMBI	Index	3.47 (1.03)	na	4.60 (1.08)	1.84 (0.15)	2.53 (0.12)	1.89 (0.08)
Macrofauna	M-AMBI	Index	0.31 (0.08)	na	0.39 (0.19)	0.84 (0.03)	0.56 (0.03)	0.92 (0.02)
	Near bottom DO	mg/l	6.41	na	7.08	7.56	7.64	7.07

Appendix 2. Historical comparisons.

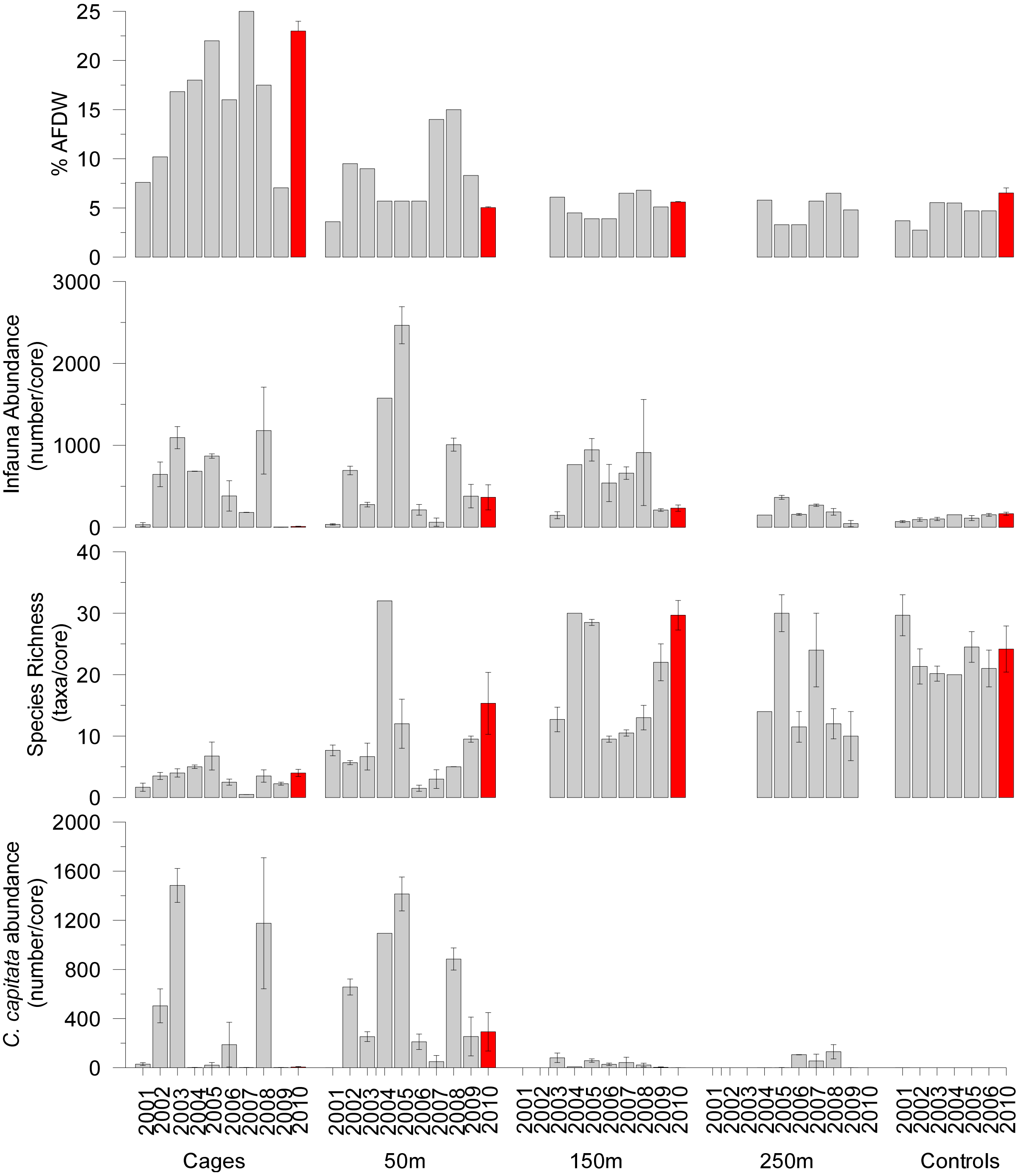

Figure 7. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and *C. capitata* densities recorded at Otanerau Bay since 2001. High densities of capitellid polychaetes are typically 1,000 individuals m^{-2} (=13 per 0.013 m² core) or greater (ANZECC 2000 guidelines). Note: 2009 cage and down-current stations were in different locations to previous years due changes in farm boundaries.

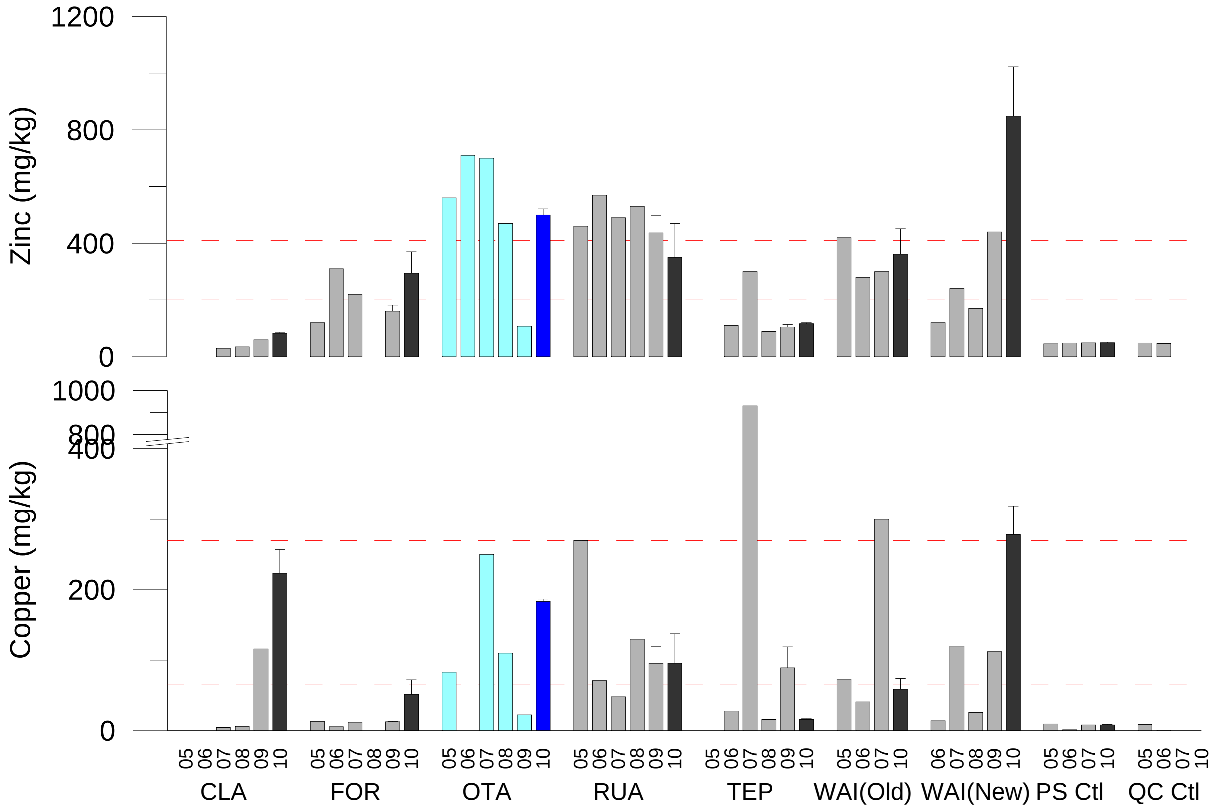

Figure 8. Comparison of the last six years of annual monitoring data for sediment copper and zinc concentrations beneath all six NZKS farms and two control stations (P.S. = Pelorus Sound, Q.C. = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG High and Low trigger levels. Otanerau data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

Table 7. 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.

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 these are calculated see Cawthron Report No. 1872).

Farm:	OTA	Year:	2010				
Site:	Cage1						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	7	Upper	7.25	2	14.5		
No. taxa	6	Central	6	2	12		
Abundance	6	Upper	6.25	2	12.5		
Shannon Div	5	Central	5	2	10		
M-AMBI	5	Central	5	3	15		
Redox	4	Lower	3.75	1	3.75		
Sulfides	7	Upper	7.25	1	7.25		
Outgassing	Freely	-	6	1	6		
Bacterial mat	Thick Mat	-	7	1	7		
		Count	9	15	88	Station:	*OTA-2010-Cage1*
				Mean score	5.9	Overall ES:	6
				SD	1.2	Certainty:	Moderate

Farm:	OTA						
Site:	50m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	2	Upper	2.25	2	4.5		
No. taxa	4	Central	4	2	8		
Abundance	3	Central	3	2	6		
Shannon Div	4	Lower	3.75	2	7.5		
M-AMBI	4	Central	4	3	12		
Redox	3	Lower	2.75	1	2.75		
pH							
DO							
Sulfides	3	Upper	3.25	1	3.25		
Outgassing	On disturbance	-	5	1	5		
Bacterial mat	Absent	-					
		Count	8	14	49	Station:	*OTA-2010-50m*
				Mean score	3.5	Overall ES:	3+
				SD	0.9	Certainty:	High

Farm:	OTA						
Site:	150m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	2	Central	2	2	4		
No. taxa	2	Upper	2.25	2	4.5		
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		
pH							
DO							
Sulfides	2	Upper	2.25	1	2.25		
Outgassing	None	-		1			
Bacterial mat	Absent	-		1			
		Count	7	15	23	Station:	*OTA-2010-150m*
				Mean score	1.5	Overall ES:	1+
				SD	0.4	Certainty:	Very High

Appendix 3. Cont.

Farm:	OTA				
Site:	QC Control 1				
	ES category	**Fit to category**	**Adj. ES**	**Weighting**	**Weighted score**
TOM	3	Central	3	2	6
No. taxa	3	Lower	2.75	2	5.5
Abundance	2	Central	2	2	4
Shannon Div	3	Central	3	2	6
M-AMBI	2	Upper	2.25	3	6.75
Redox	3	Central	3	1	3
pH					
DO					
Sulfides	2	Central	2	1	2
Outgassing	None	-		1	
Bacterial mat	Absent	-		1	
		Count	7	15	33.25
				Mean score	**2.2**
				SD	**0.5**

Station:	***OTA-2010-QC Control 1***
Overall ES:	**2**
Certainty:	High

Farm:	OTA				
Site:	QC Control 2				
	ES category	**Fit to category**	**Adj. ES**	**Weighting**	**Weighted score**
TOM	2	Central	2	2	4
No. taxa	1	Central	1	2	2
Abundance	1	Central	1	2	2
Shannon Div	1	Central	1	2	2
M-AMBI	1	Central	1	3	3
Redox	2	Upper	2.25	1	2.25
pH					
DO					
Sulfides	1	Upper	1.25	1	1.25
Outgassing	None	-			
Bacterial mat	Absent	-			
		Count	7	13	16.5
				Mean score	**1.3**
				SD	**0.5**

Station:	***OTA-2010-QC Control 2***
Overall ES:	**1+**
Certainty:	High