CAWTHRON

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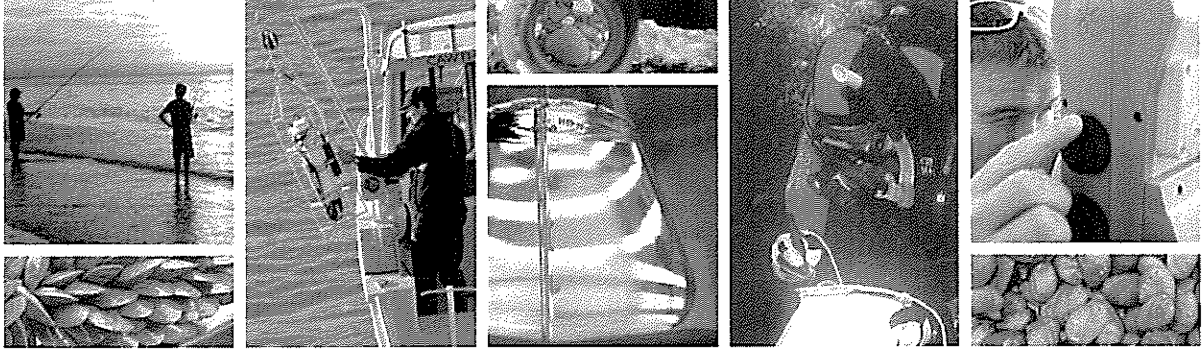
Environmental Impacts of the Te Pangu Bay Salmon Farm: Annual Monitoring 2010



RESEARCH BASED SOLUTIONS

CAWTHRON

Environmental Impacts of the Te Pangu 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 Te Pangu 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).

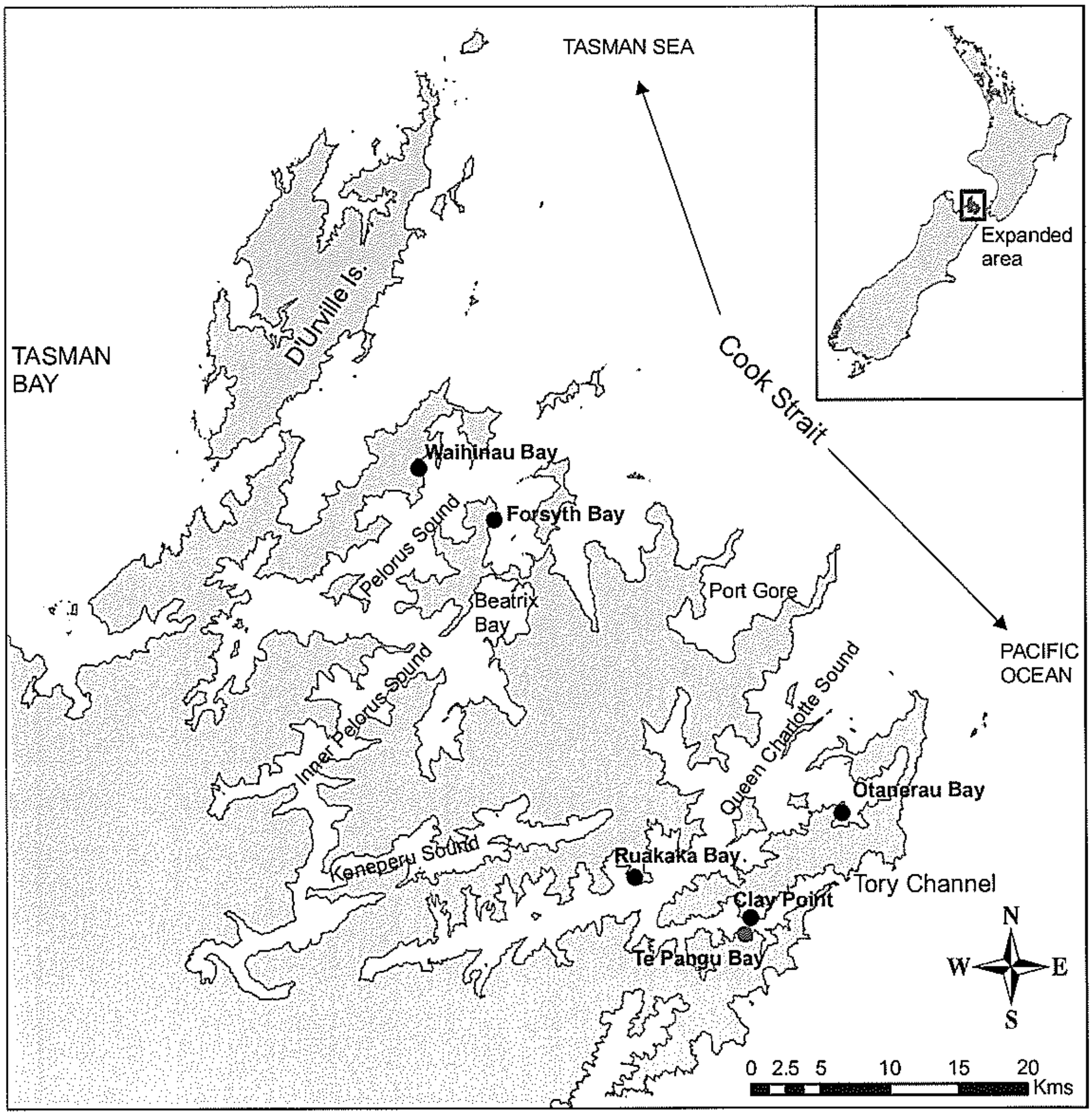

Figure 1. Map of Marlborough Sounds area showing the location of the TEP salmon farm (red dot) along with NZKS's five other farm sites (black dots).

1.2. Site details and history of feed usage

The Te Pangu Bay farm site was established in 1992, and, with average water current speeds of ~ 15 cm/s it is considered a high-flow site. Feed inputs at this farm have historically ranged from 2104 to 4120 tonnes per annum. Over the 12 month period leading up to this years monitoring (*i.e.* December 2009 to the end of November 2010) a total of 4,747 tonnes of feed was used (Figure 2).

In 2010 NZKS obtained resource consent to increase the total annual feed inputs at the Te Pangu Bay farm in a staged manner. The first increase was for an additional 1000 t/yr on top of the previous maximum of 4000 t/yr, with provision for a further 1000 T/yr the following year. The second 1000 t/yr feed increases was conditional upon the environmental monitoring results indicating that conditions had stabilised (as indicated by at least two comparable assessments in a row) and that the impacts had not exceeded the environmental quality standards set out in the AMP. The resource consent also required that benthic monitoring is conducted every six months (as opposed to annually at the other NZKS farms) and that the nearby reef communities are monitored quantitatively on an annual basis.

This study constitutes the first assessment since the first feed increase was implemented in 2010.

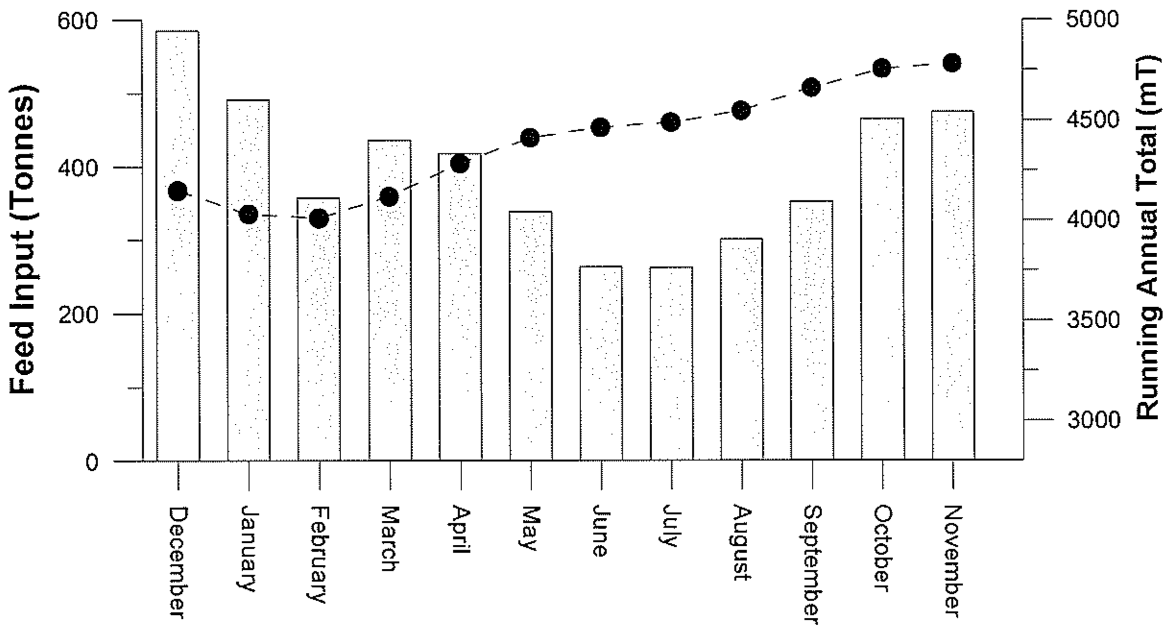

Figure 2. Monthly feed inputs and running annual 12 month total feed input at the Te Pangu Bay farm from December 2009 to November 2010.

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 the revised techniques that were adopted this year is provided below.

2.1. Soft sediment habitats

2.1.1. Sampling locations

The TEP 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 for sites with high current deformed zones (*i.e.* stations '60 m' and '200 m', respectively), and at two comparable reference or 'control' (*i.e.* 'TC-Ctl-2' and 'TC-Ctl-3') stations (Figure 3). For a full explanation of the zones concept, please refer to Keeley 2011. The position of the '200 m' station on the TEP transect sits somewhat out of the Te Pangu embayment and into the main part of Tory channel due to local substrate and bathymetry constraints. However, this station is still considered to be situated within the predominant down-current direction of flow from the longest axis of the farm.

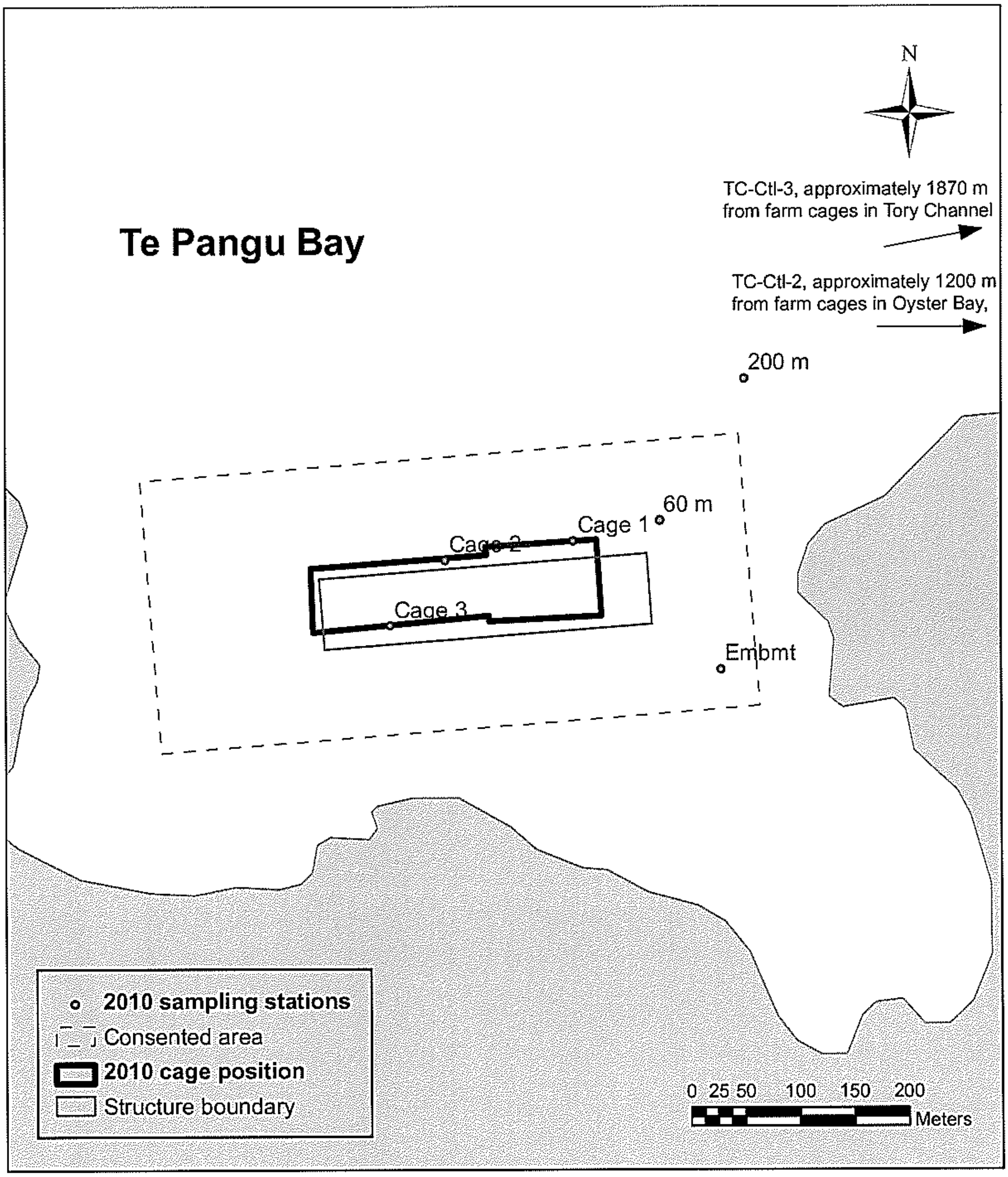

Figure 3. Soft sediment and inshore habitat sampling locations for TEP in 2010. 'Embmt' = Embayment.

2.1.2. Environmental variables

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

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

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

2.2. Rocky habitats

The TEP salmon farm is considered a high-flow site and there are significant reef habitats near the edges of the primary depositional footprint. Inshore habitats have been 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) and the video footage is compared to previous years. This was last undertaken in 2009, and since that survey, and in response to proposed feed increases, permanent monitoring quadrat stations have been installed for quantitative assessments at the two main rocky reef areas south and west of the farm. These stations are photographed every year by divers who are also then able to make observations on the general health of the reef areas. The methods and results from the 2010 reef surveys are reported separately in Cawthron Report 1922.

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. Nutrient samples were collected from mid-water using a van Dorn sampler and analysed in the laboratory for nutrients (nitrate-N, nitrite-N, ammoniacal-N and dissolved reactive phosphorous).

3. RESULTS

3.1. Soft sediment habitats

Sediment organic matter levels were twice as high beneath the cages compared to the '60 m' and '200 m' stations and around three times as high as control and embayment stations (Figure 4). Organic matter was higher at TC-Ctl-2 than at TC-Ctl-3 or the embayment station within Te Pangu Bay itself. The sampling station at the edge of the cages (Cage-1) also had a negative redox potential (-0.37 Eh_{NHE}, mV on average (n=3)) 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 hits the seabed) and the strong sulphide odour being emitted from the sediments retrieved by the grab sampler. Total free sulphide levels showed a trend of decreasing concentrations with increasing distance from the farm. Although the embayment station is situated physically closer to the farm, it sits to the side of the predominant current flow.

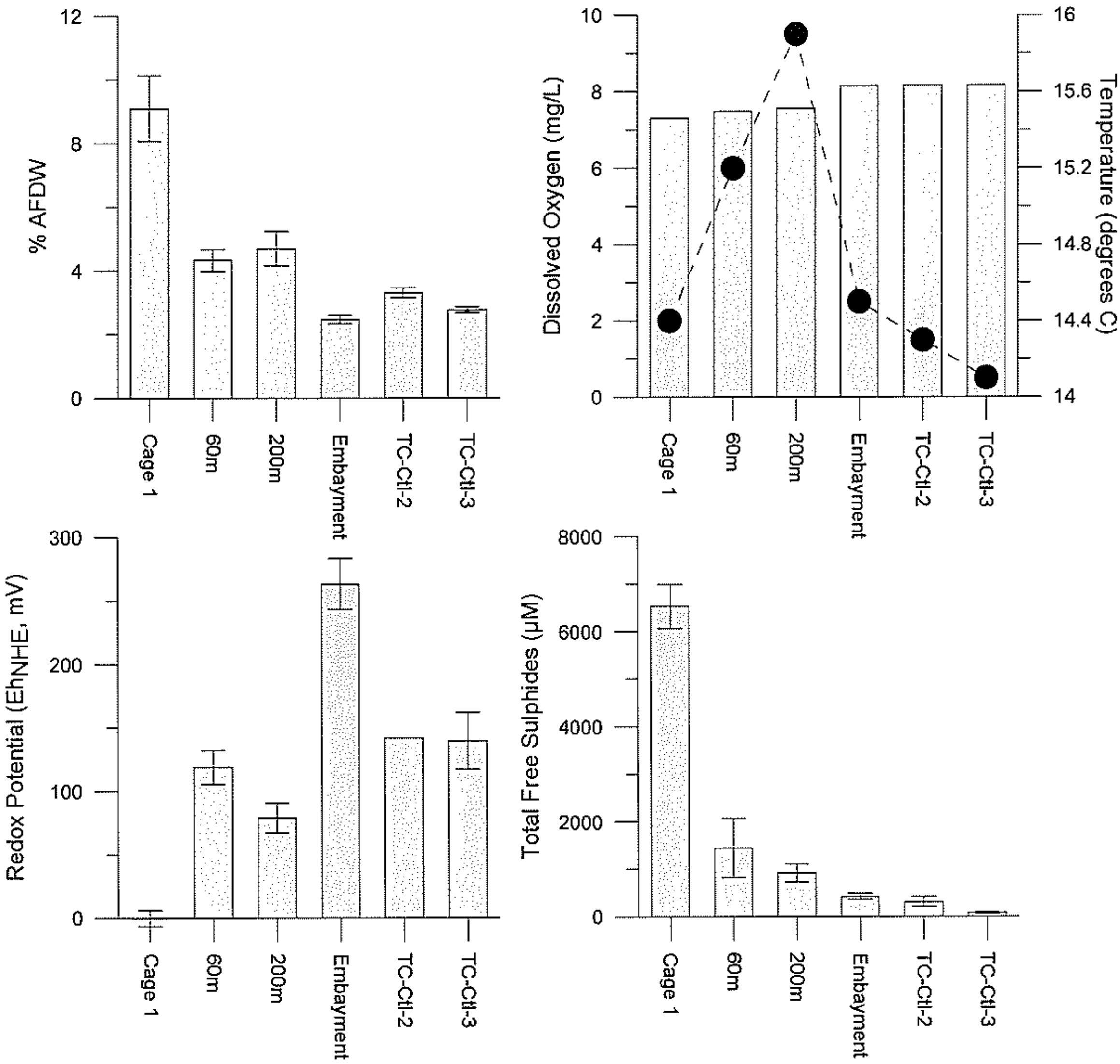

Figure 4. Multiplot of organic matter (as AFDW (% w/w)), redox potential (Eh_{NHE}, mV), total free sulphides (µM), near-bottom DO (mg/l) and water temperature (°C, indicated by black dots). Error bars = SE.

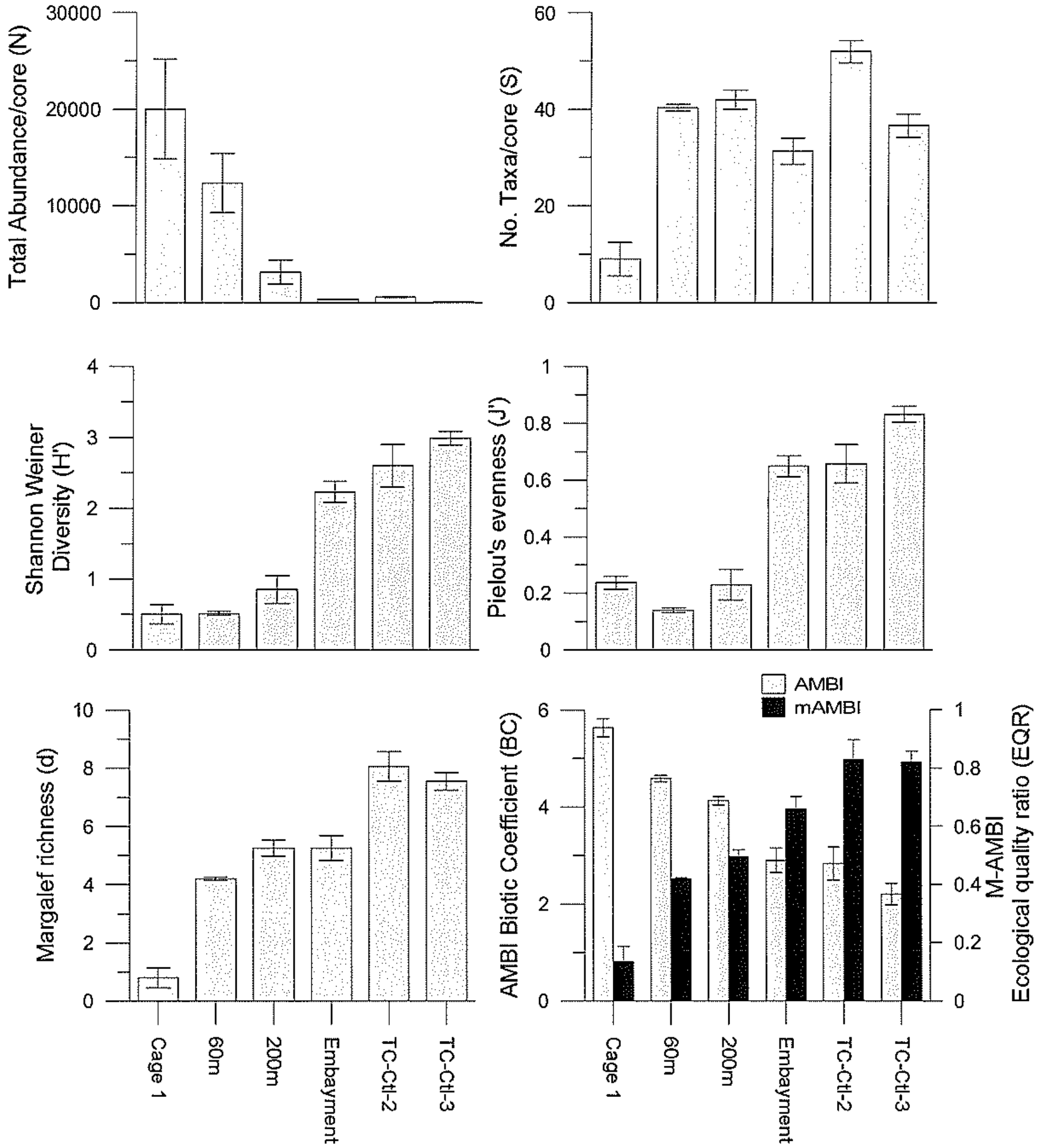

Figure 5. Multiplot of macrofauna statistics. Error bars = SE.

The infauna community at the cage station showed signs of severe enrichment with unprecedented total infauna abundances. Total abundances at the cage station reached over 20,000 individuals (Figure 5) with communities dominated by capitellid polychaetes and nematode worms. The nematodes formed thick mats on the sediment surface and due to their being smaller than the 0.5 mm mesh used in the sampling equipment, it is likely that numbers would have been even higher than those counted. Increased total abundances continued out to the 60 and 200 m stations, but were somewhat less elevated than at the cage station. The number of taxa recorded at the cage station was noticeably reduced (by 75%) compared to the control, embayment, 60 and 200 m stations. In addition, the number of true infauna taxa is likely to be less than reported, since at least two of the taxa identified in the cage and 60 m samples have most likely dropped from the cages or associated ropes, and are technically not recognised as infauna (the mussel *Mytilus edulis galloprovincialis*, and the tube worm *Phyllochaetopterus socialis*). Diversity (H'), Evenness (J) and the Ecological Quality Ratio (EQR) were also higher at the Embayment and control stations compared to cage and down-current stations.

The greatest number of species was found at the TC-Ctl-2 station and this was primarily due to the more complex nature of the sediments (larger particle grain size and significant amounts of large broken shell material) in this area providing a more heterogenous habitat.

3.1.1. Copper and zinc

Copper and zinc concentrations in the sediments below the cages were both below the ISQG-Low trigger levels for possible biological effects, with an average of 16 mg/kg copper, (n=3), and 116.7 mg/kg zinc (n=3) (Figure 8, Appendix 2). Compared with the previous survey conducted in 2009, the 2010 zinc levels were similar; however the copper levels were significantly lower.

3.2. Rocky habitats

Rocky reef habitats at the Te Pangu site were assessed quantitatively from permanent photo-quadrat monitoring stations and the results will be reported separately in Cawthron Report 1922.

3.3. Water column

Near-bottom (water column) dissolved oxygen (DO) levels were slightly depressed (by ~9%) at the cage and down-current stations relative to the control and embayment stations (Figure 4). Near-bottom water temperatures remained relatively constant (±0.2 °C) beneath the cages and at control and embayment stations, but were significantly warmer at the 60 m and 200 m stations. Although water temperature is known to affect the solubility of oxygen (and consequently DO concentrations) this was not seen as a significant factor in the observed DO variation between sites. Water column nutrient levels were not analysed at Te Pangu during the 2010 annual monitoring.

4. 2010 ASSESSMENT OF COMPLIANCE

4.1. Soft sediment habitats

4.1.1. Approach

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

Certain levels of enrichment (or 'states of impact') are permitted within set distances (*i.e.* at 'Cages', '50 m' and '150 m' stations) from the salmon cages (Table 3). The permitted conditions vary slightly depending on whether they pertain to a high- or low-flow site, as experience has indicated that they have inherently different benthic attributes and tend to respond differently to enrichment. TEP is treated as a high-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.

Assessment of the TEP farm differs slightly from that of the other five NZKS farms because the recent consent conditions associated with the feed discharge increases utilised a six stage enrichment gradient (impact stages I-VI), as opposed to the seven stage gradient described above that was used in the development of categorical environmental thresholds in the AMP. The main difference being that the seven stage gradient shifts the boundaries between stages V and VI back slightly (toward the stage V infaunal peak), and stage VI terminates prior to conditions becoming 'azoic', which defines stage VII. The target environmental quality standards also differ slightly from previous consents in that they specify:

- Cages to 50 m: "not be more than transitional between impact stages IV and V", *i.e.* a maximum *ES* of 4.5 instead of 5;
- 50 m-150 m: "not be more than transitional between impact stages III and IV", *i.e.* a maximum *ES* of 3.5 instead of 3;
- Beyond 150 m: "not be more than transitional between impact stages I and II", *i.e.* a maximum *ES* of 1.5 instead of 2;

Therefore conditions are more restrictive for Zone 1 (beneath the cages), less restrictive for the Zone 1-2 boundary and more restrictive for the Zone 2-3 boundary (Table). In the case of the

Zone 2-3 boundary, recent studies have indicated the *ES* 2 (very mild enrichment) can occur naturally within the Marlborough Sounds and therefore, an *ES* of 1.5 is probably an unreasonable 'natural conditions' target.

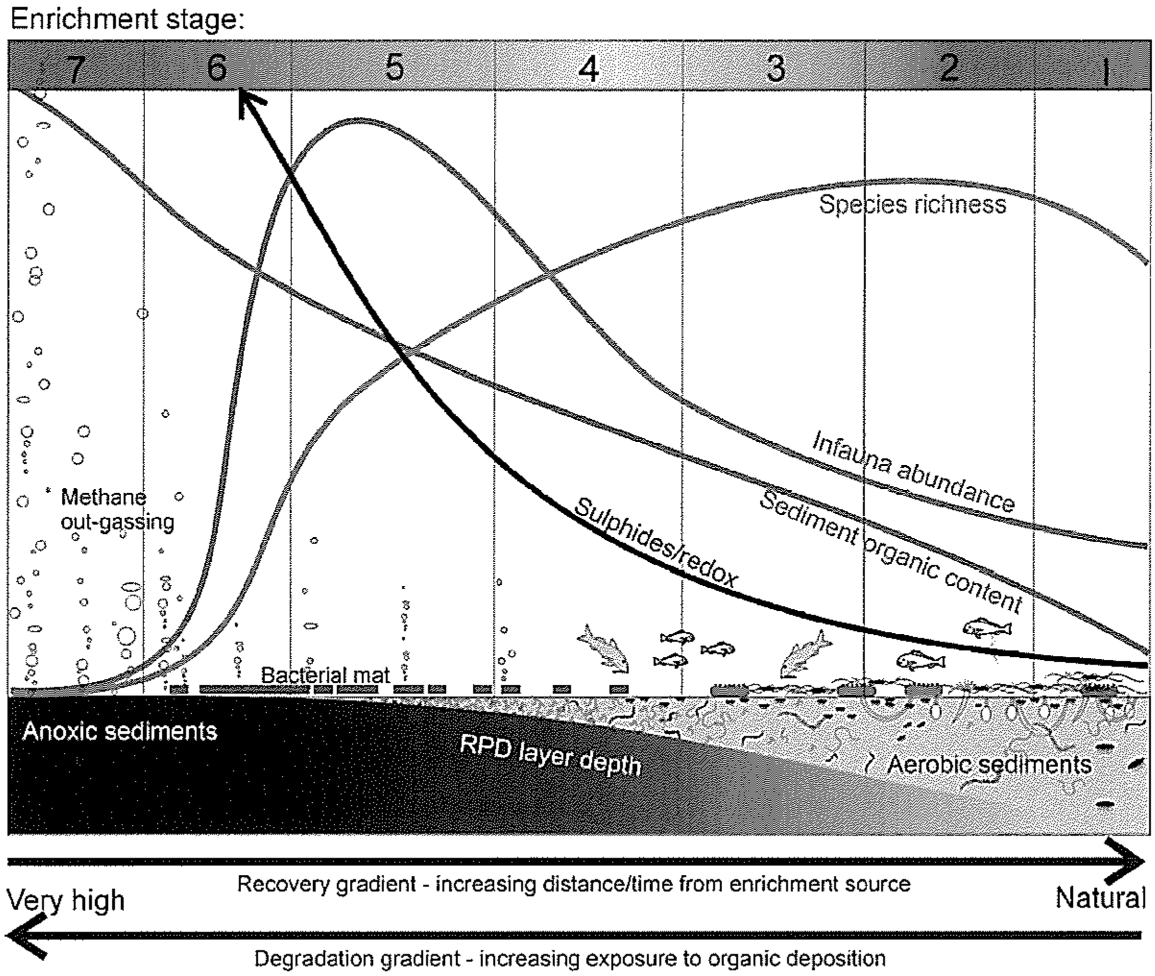

Figure 6. Stylised depiction of a typical enrichment stage (*ES*) gradient experienced at low flow sites, showing generally understood responses in commonly measured environmental variables (species richness, infauna abundance, sediment organic content and sulphides and Redox). Apparent Redox Potential 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 & 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 & 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 & 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. Bracketed values in 'Equivalent *ES*' column indicate *ES* value specified in recent feed increase consent for TEP and are the values that are used in this assessment.

Current Consent Conditions				Equivalent *ES*
Spatial Zone	**Spatial extent**	**Comment**	**Description & 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 (4.5 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 (3.5 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** (1.5 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).

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 (as indicated by % AFDW) beneath the cages and at the '60 m' station has increased significantly and the benthic macrofauna at these stations remain severely enriched.
- Conditions at the cage station scored *ES* 5.6 and were beyond what is permitted by the consent conditions associated with the feed increase permit (*i.e. ES* 4.5). If assessed according to the conditions that have been applied to the other farms, then the Cage site would be at the maximum permitted *ES* (*i.e.* between ES 5 and 6), rather than beyond it. Abundances of opportunist species were extremely high and unprecedented, the number of taxa recorded at the cage station was noticeably reduced (by 75%) and some significant organic accumulation was observed for the first time at a high flow site.
- Copper and zinc concentrations in the sediments beneath the cages were below the ISQG-Low levels (for possible biological effects).
- Conditions at the zone 1 boundary ('60 m') were beyond the acceptable *ES* for that station, and therefore in breach of consent conditions, with an *ES* of 4.1 (maximum permitted *ES* = 3.5), indicative of moderate to major effects. Abundances were significantly elevated compared to control stations and communities were dominated by nematodes and capitellid polychaetes.
- The zone 2 boundary ('200 m') were beyond the acceptable *ES* for that station, and therefore in breach of consent conditions, with an *ES* of 3.1 (maximum permitted *ES* = 1.5), indicative of moderate effects from the farm extending out to this distance. Total

infauna abundances were still elevated compared to control stations and communities remained dominated by nematodes and capitellids.

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

Station	*ES*	Certainty		Comments
'Cage'	5.6	High	☹	Bacterial mats present, out-gassing on disturbance with strong sulphide odours, high organic matter content. Macrofauna community highly enriched with extreme abundances of two disturbance tolerant taxa.
'60m' (Zone 1 Boundary)	4.1	Low	☹?	Mild-moderate sulphide odours, significantly elevated densities of opportunistic, disturbance tolerant species.
'200m' (Zone 2 Boundary)	3.1	Moderate	☹	Mild sulphide odours, increased total abundance dominated by opportunistic, disturbance tolerant species.
Control 1	1.3	High	☺	Particularly diverse infauna communities (over 50 different species), likely due to complex habitats on seabed, low organic matter content.
Control 2	1.2	High	☺	Healthy diverse infauna communities, low organic matter content and total free sulphide levels.

4.2. Rocky habitats

Rocky reef habitats at the Te Pangu site will be assessed separately in Cawthron Report 1872.

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 9% 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 Te Pangu Bay farm was assessed to be more impacted than permitted, and a management response is required. This finding is based on the following:

- Conditions at the cage site were beyond the environmental quality standards specified in the most recent set of conditions, which requires *ES* to be no greater than transitional between 4 and 5 (i.e. *ES* </= 4.5).
- The '60 m' (*i.e.* the Zone 1-2 boundary) and '200 m' (*i.e.* the Zone 2-3 boundary) stations were both assessed to be more enriched than is permitted under the consent conditions. Thus, the footprint is encompassing a bigger area than is presently permitted under the zones concept.

The assessment of the enrichment stage at the cage site was difficult in this instance because conditions were different to anything that we have encountered before and in the absence of this experience the environmental criteria beyond *ES* 5 for high flow sites are subject to ongoing development and revision. While some indicators, such as % organic matter, the AMBI index and sulphide levels, indicated an *ES* of 6 according to the established thresholds in the AMP, the very high infauna abundances clearly indicated an abundance peak, which has traditionally been the primary identifier of *ES* 5. It is conceivable that abundances could continue to increase in response to existing and/or increased feed levels, in which case the peak observed here may not yet represent a maximum possible peak for the site. Alternatively, further stressing through continued high feed levels may result in a collapse of the nematode and capitellid populations, which would then indicate that the present conditions were actually nearer to *ES* 6. Understanding if and where this collapse of infauna may occur in relation to feed loadings is fundamental to understanding the full enrichment gradient for high flow environments and would aid decision making and environmental management of high flow sites into the future.

We also note that the inner boundary ('60 m' or Zone 1-2) could justifiably be situated 10 m further away (*i.e.* at 70 m) as recommended in the recently revised AMP (refer Keeley 2011). The position of the Zone 1-2 station that was targeted in the 2010 survey was set based on an early estimate of deformity which has since been revised based on modelled depositional footprints. If this were the case then the Zone 1-2 boundary may be closer to being 'compliant'.

In terms of a recommended management response, continuation of existing feed levels, and potential for further increases (*i.e.* from 5000 t/yr to 6000 t/yr), are conditional upon the council being "satisfied that the subject stages are not individually or cumulatively creating any adverse effects". This report finds that the environmental footprint has now expanded beyond the area permitted under the zones concept and associated environmental quality standards; this is especially evident at the zone (2-3), where conditions are required to approximate background conditions. It is also apparent that conditions have deteriorated since last assessed in 2009 and are unlikely to be 'stable' with respect to the current annual feed input (which was 4747 t). Therefore, according to the present consent conditions, further increases are not appropriate and instead, they may need to be reduced. However, this assessment is due to be revisited in April 2011 as part of the required interim (6 monthly) monitoring assessment. It is recommended that current feed levels be maintained until the results of that assessment are available to allow the full effects to be evaluated for the purposes of future management.

We also recommend that this farm should be monitoring in accordance with the standard *ES* thresholds specified in the AMP; *i.e.* maximum of *ES* 5(6) for Cages, *ES* 3 for Zone 1-2 boundary, *ES* 2 for Zone 2-3 boundary and elsewhere. *ES* 5 is most appropriate beneath the cages because it is defined around a peak infauna abundance and therefore maximum organic assimilation capacity. *ES* 1.5 is not considered appropriate for the upper limit of natural conditions (*i.e.* at Zone 2-3 boundary and elsewhere) because pockets of mildly enriched sediments (*ES* ~2) are found naturally within the Marlborough Sounds. Lower *ES* triggers beneath the cages (*e.g.* 4 or 4.5) are normally only considered appropriate if a rotational fallowing approach has been adopted for the farm.

6. REFERENCES

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7. APPENDICES

Appendix 1. Summary of 2010 results.

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

	Station	Units	Cage-1	Cage 2	60 m	200 m	Embayment	TC-Ctl-2	TC-Ctl-3
	Depth	m	28.0	29.2	28.3	31.9	7.9	29.0	25.0
Sediments	AFDW	%	9.10	na	4.3	4.7	2.5	3.30	2.77
	Redox	Eh_{NHE}, mV	-0.4	na	118.7	79.0	263.2	142	139.4
	Sulphides	µM	6535.5	na	1449.4	923.8	425.8	319.7	79.7
	Bacterial mat	% cover	~50		0	0	0	0	0
	Out-gassing	-	On disturbance	On disturbance	None	None	None	None	None
	Odour	-	Very Strong	strong	Mild	Very mild	none	none	None
Macrofauna statistics	Abundance	No./core	20017 (5165)	na	12367 (3059)	3166(1240)	321(31)	575(78)	113(14)
	No. taxa	No./core	9(3.51)	na	40.33 (0.67)	42(2)	31.33(2.73)	52(2.31)	36.67(2.4)
	Richness	Stat.	0.81(0.34)	na	4.21(0.06)	5.26(0.26)	5.26(0.43)	8.07(0.5)	7.55(0.3)
	Evenness	Stat.	0.24(0.02)	na	0.14(0.01)	0.23(0.05)	0.65(0.04)	0.66(0.07)	0.83(0.03)
	Shannon-Weiner	Index	0.5 (0.1)	na	0.52(0.03)	0.86(0.2)	2.23(0.15)	2.6(0.3)	2.99(0.1)
	AMBI	Index	5.6 (0.2)	na	4.6 (0.1)	4.1 (0.1)	2.9 (0.2)	2.8 (0.3)	2.2 (0.2)
	M-AMBI	Index	0.1 (0.1)	na	0.4 (0)	0.5 (0)	0.7 (0)	0.8 (0.1)	0.8 (0)
	Near bottom DO	mg/l	7.30	na	7.48	7.56	8.15	8.16	8.17

Appendix 2. Historical comparisons.

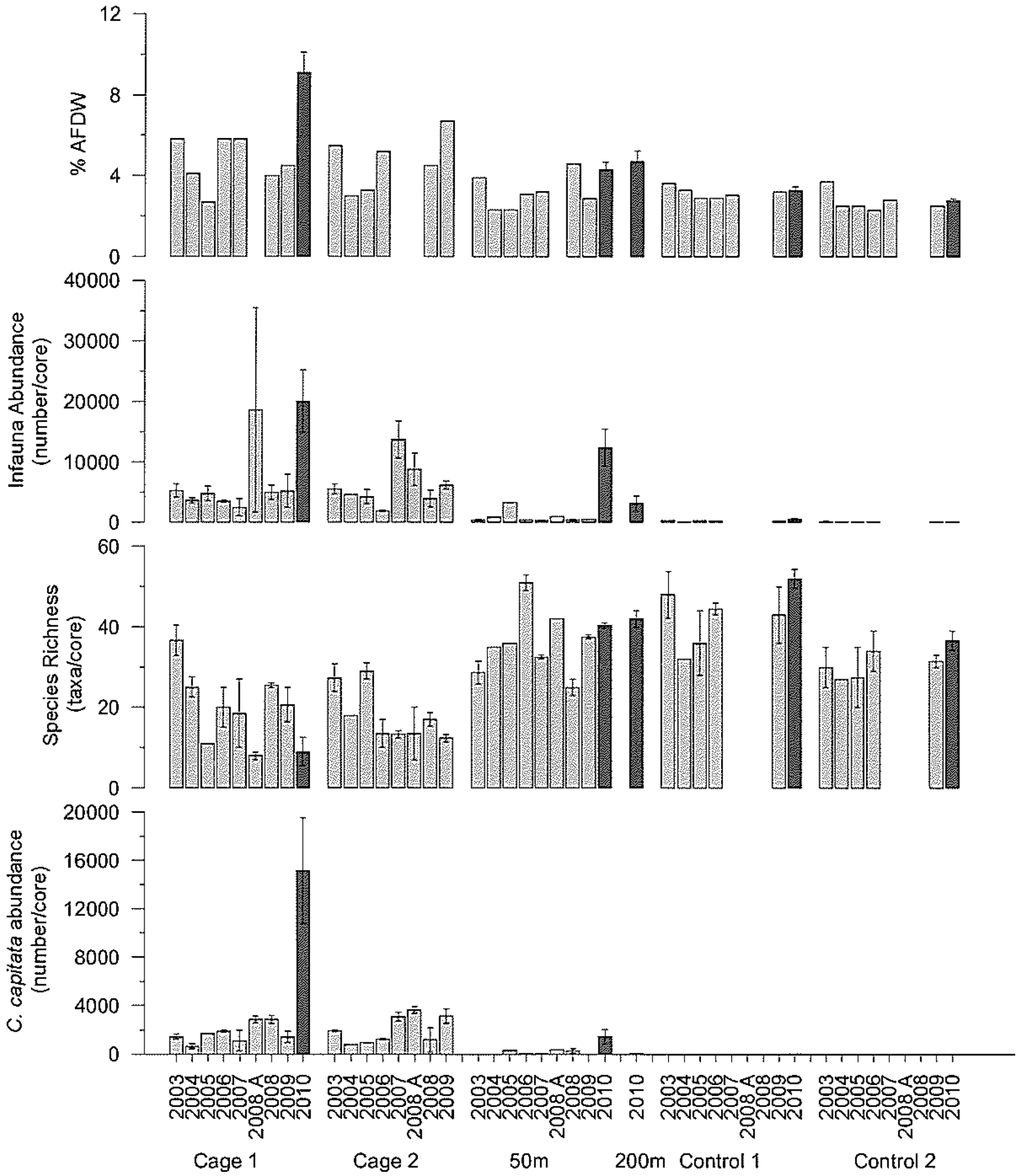

Figure 7. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and *C. capitata* densities recorded at Te Pangu Bay since 2003. High densities of capitellid polychaetes are typically 1,000 individuals m^{-2} (=13 per 0.013 m^2 core) or greater (ANZECC 2000 guidelines). Note that the 2010 50 m station was situated at 60 m from the cages.

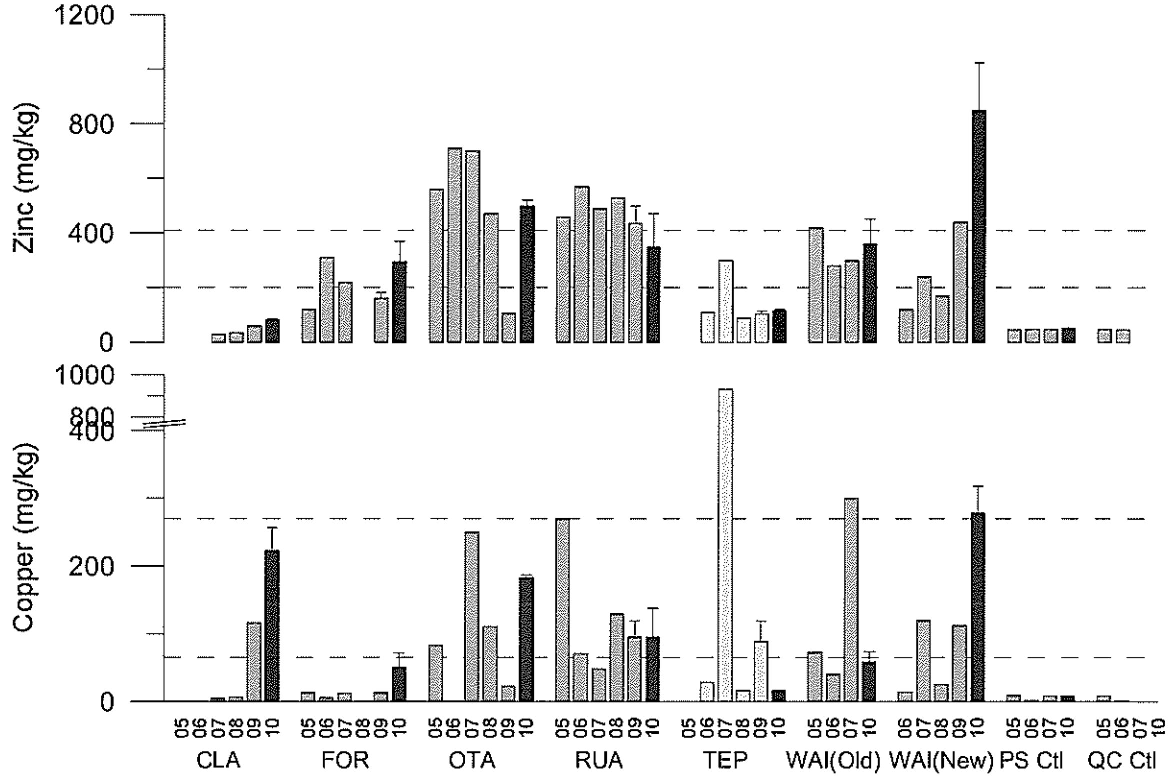

Figure 8. Comparison of the last six years of annual monitoring data for sediment copper and zinc concentrations beneath all six NZKS farms and two control stations (P.S. = Pelorus Sound, Q.C. = Queen Charlotte). Red dotted lines indicate respective ANZECC ISQG High and Low trigger levels. Te Pangu data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

Table 7. Summary of historical benthic impact levels at main stations situated beneath and down-current of the Te Pangu Bay farm. Assessed according to the ranking system provided in previous annual monitoring reports.

Survey	Cages	60 m	Embayment	Controls
2001			na	
2002			na	
2003			na	
2004				
2005				
2006				
2007				na
2008 A			na	na
2008 B				na
2009				

Impact Level		
	25.1-30	Very high
	20.1-25	High
	15.1-20	Moderate
	11-15	Low
	10	Natural

Appendix 3. Detailed *ES* calculations.

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

Farm:	TEP	Year: 2010					
Site:	Cage1						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	6	Upper	6.25	2	12.5		
No. taxa	6	Upper	6.25	2	12.5		
Abundance	5	Upper	5.25	2	10.5		
Shannon Div	5	Upper	5.25	2	10.5		
M-AMBI	6	Central	6	3	18		
Redox	4	Lower	3.75	1	3.75		
Sulfides	6	Lower	5.75	1	5.75		
Outgassing	On disturbance		5	1	5		
Bacterial mat	Thin Mat		6	1	6		
		Count	9	15	84.5	Station:	TEP-2010-Cage1
				Mean score	5.6	Overall ES:	6-
				SD	0.8	Certainty:	High

Farm:	TEP						
Site:	60m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	5	Central	5	2	10		
No. taxa	2	Upper	2.25	2	4.5		
Abundance	5	Upper	5.25	2	10.5		
Shannon Div	5	Upper	5.25	2	10.5		
M-AMBI	4	Central	4	3	12		
Redox	2	Upper	2.25	1	2.25		
Sulfides	3	Upper	3.25	1	3.25		
Outgassing	On disturbance		5	1	5		
Bacterial mat	Absent						
		Count	8	14	58	Station:	TEP-2010-60m
				Mean score	4.1	Overall ES:	4
				SD	1.3	Certainty:	Moderate

Farm:	TEP						
Site:	200m						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	5	Upper	5.25	2	10.5		
No. taxa	2	Upper	2.25	2	4.5		
Abundance	4	Central	4	2	8		
Shannon Div	4	Central	4	2	8		
M-AMBI	3	Central	3	3	9		
Redox	3	Lower	2.75	1	2.75		
pH							
DO							
Sulfides	3	Central	3	1	3		
Outgassing	None			1			
Bacterial mat	Absent			1			
		Count	7	15	45.75	Station:	TEP-2010-200m
				Mean score	3.1	Overall ES:	3
				SD	1	Certainty:	Moderate

Appendix 3. Cont.

Farm:	TEP						
Site:	TC Control 2						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	2	Central	2	2	4		
No. taxa	1	Lower	0.75	2	1.5		
Abundance	2	Central	2	2	4		
Shannon Div	2	Lower	1.75	2	3.5		
M-AMBI	1	Central	1	3	3		
Redox	2	Central	2	1	2		
pH							
DO							
Sulfides	2	Lower	1.75	1	1.75		
Outgassing	None			1			
Bacterial mat	Absent			1			
		Count	7	15	19.75	Station:	*TEP-2010-TC Control 2*
				Mean score	1.3	Overall ES:	1+
				SD	0.5	Certainty:	High

Farm:	TEP						
Site:	TC Control 3						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	1	Lower	0.75	2	1.5		
No. taxa	2	Central	2	2	4		
Abundance	1	Lower	0.75	2	1.5		
Shannon Div	1	Central	1	2	2		
M-AMBI	1	Central	1	3	3		
Redox	2	Central	2	1	2		
pH							
DO							
Sulfides	1	Central	1	1	1		
Outgassing	None						
Bacterial mat	Absent						
		Count	7	13	15	Station:	*TEP-2010-TC Control 3*
				Mean score	1.2	Overall ES:	1
				SD	0.5	Certainty:	High

Farm:	TEP						
Site:	Embayment						
	ES category	Fit to category	Adj. ES	Weighting	Weighted score		
TOM	1	Lower	0.75	2	1.5		
No. taxa	3	Lower	2.75	2	5.5		
Abundance	1	Central	1	2	2		
Shannon Div	2	Central	2	2	4		
M-AMBI	2	Central	2	3	6		
Redox	1	Central	1	1	1		
pH							
DO							
Sulfides	2	Lower	1.75	1	1.75		
Outgassing	None	-					
Bacterial mat	Absent	-					
		Count	7	13	21.75	Station:	*TEP-2010-Embayment*
				Mean score	1.7	Overall ES:	2-
				SD	0.7	Certainty:	High