Cawthron Report No. 1758
April 2010

CAWTHRON

Seabed Impacts of the Forsyth Bay Salmon Farm: Annual Monitoring 2009

RESEARCH BASED SOLUTIONS

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Seabed Impacts of the Forsyth Bay Salmon Farm: Annual Monitoring 2009

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Reviewed by: Paul Gillespie

Approved for release by: Rowan Strickland

Recommended citation:
Forrest R, Dunmore R, Keeley N 2010. Seabed Impacts of the Forsyth Bay Salmon Farm: Annual Monitoring 2009. Prepared for The New Zealand King Salmon Company Limited. Cawthron Report No. 1758. 31 p.

EXECUTIVE SUMMARY

This report presents the results of the annual seabed monitoring at the New Zealand King Salmon Company Limited farm operating at Forsyth Bay as required by Resource Consent (U040412). The farm was operational from 1994 until 2001, when it was fallowed and the cages were removed. Cawthron has monitored the seabed and surrounding environment since the baseline survey in 1993. The results of the 2009 survey of sediment physico-chemical and biological properties are reported and discussed in the context of previous monitoring rounds and special consideration is given to the present state of 'recovery' in relation to background or baseline conditions.

Results indicated that the remaining seabed impacts beneath and immediately adjacent to the former Forsyth Bay salmon farm were low. Seabed health had generally improved very slightly since the 2008 survey, with reductions in sulphide odours and zinc concentrations, and the absence of apparent redox potential discontinuity layers at all but two of the stations (one cage and the 25 m station).

Some of the 'enrichment indicators' were assessed to be indicative of background conditions, while others still indicated remnant habitat modification. Infauna composition, for example, approximated that of unimpacted natural sediments. Species richness and abundances were relatively 'normal' and enrichment-indicating opportunistic species were nearly absent. However, the sediments in the general vicinity of the historical cage site had not yet fully returned to pre-farm baseline levels. Despite a trend of decreasing organic content in sediments under the cages, ash-free dry weights were elevated at the 25 and 50 m stations, with a trend of increasing levels at the 50 m station. In addition, sediment zinc concentrations under the cages were elevated in comparison to background levels (but were below ISQG-Low levels). Thus, although the infaunal community had re-established, the recovery throughout the sediment profile was not yet complete.

We make the precautionary note that rates of re-impact subsequent to the cages being reinstated as of November 2009 are likely to be influenced by the historical state of the sediments. Any residual level of impact is likely to affect the process and timeline over which this occurs. Furthermore, observations made at the Waihinau Bay site, for example (Keeley & Govier 2008), suggest that seabed condition can quickly deteriorate once farming is resumed, even if full recovery is achieved prior to restocking cages. Little is known about precisely how the rate of 're-impact' relates to different stages along the recovery continuum, and in all reality, this is likely to be site-specific. The extent to which the rate of re-impact is affected is the subject of a Cawthron internally funded study, which aims to help inform the efficacy of fallowing practices for the future.

The apparent slow rate of organic matter return to normal "background" levels may be due to the recalcitrant nature of the remaining waste materials and/or the cohesive nature of the sediments which resists the infiltration of oxygenated wastes from above. This being the case, there may be some potential for enhancement of the latter stages of organic matter removal through physical mixing of the deep sediment layers and/or seeding the seabed with an appropriate microbial inoculum.

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1. INTRODUCTION

The New Zealand King Salmon Company Limited (NZKS) farms Pacific king salmon (*Oncorhynchus tshawytscha*) in sea cages at five sites in the Marlborough Sounds (Figure 1). NZKS are required to undertake annual seabed (benthic) monitoring beneath each site as part of the conditions for Resource Consents. These surveys also provide information about the need for, or success of, any mitigation measures implemented as part of the NZKS's operational practices.

In September 2009, NZKS commissioned Cawthron Institute (Cawthron) to monitor the seabed beneath all six of their sites. This report provides a summary of seabed monitoring undertaken at the fallowed Forsyth Bay salmon farm site, and is the last monitoring prior to the farm becoming operational again in November 2009.

1.1. Farm history

The Forsyth Bay farm was in operation from 1994 until November 2001, when its farm structures were shifted to Waihinau Bay and the site was fallowed for eight years (until November 2009). Annual monitoring has continued at Forsyth Bay despite it being fallowed in order to track seabed 'recovery'. In the last five years of operation prior to fallowing (1997–2001), feed levels ranged from ~1,500 to 2,400 tonnes/year, with an average of 1,867 tonnes. Although current data has not been obtained for this farm, it is generally considered a low-flow site.

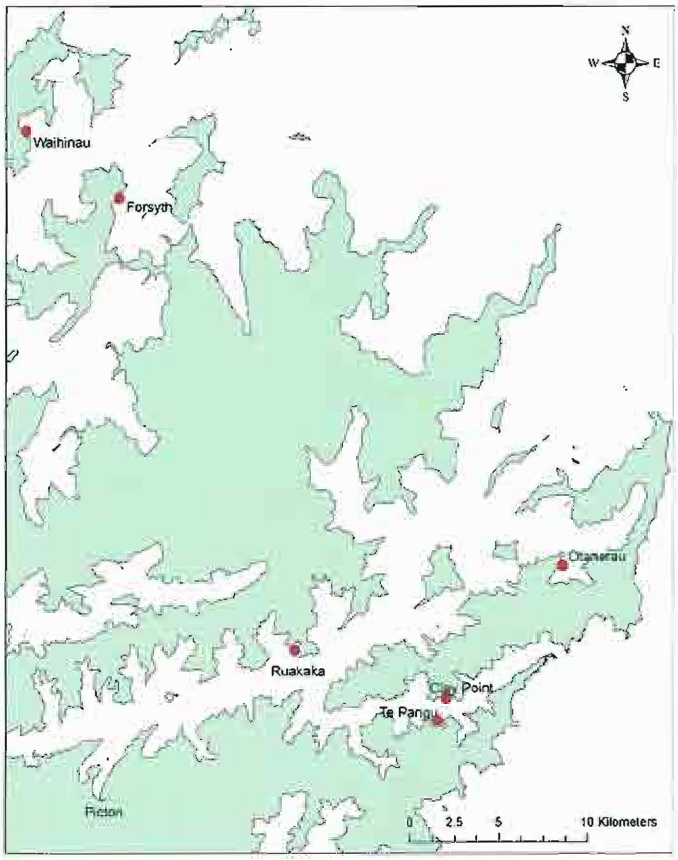


Figure 1. Location of the six NZKS salmon farm sites in the Marlborough Sounds.

1.2. Overview of typical salmon farming impacts

Seabed impacts of the intensive sea cage rearing of salmon in relatively sheltered embayments have been well-documented (*e.g.* Brown *et al.* 1987; Gowen & Bradbury 1987; Findlay *et al.* 1995) and a detailed synopsis for New Zealand farms can be found in Forrest *et al.* 2007. These impacts result directly from the sedimentation of organic-rich particulate wastes. Organic wastes discharged from salmon farms come from two main sources; excretory by-products from the cultured fish, and uneaten salmon feed (refer Table 1). A schematic diagram of the main salmon farm inputs and outputs is given in Figure 2. Excretory by-products comprise of particulate material (faeces) and dissolved excretory products (mainly ammoniacal nitrogen). These are largely biodegradable organic wastes. Feed used by NZKS does contain zinc additives, but does not contain any added antibiotics, vaccines, steroids or other organic growth enhancers.

In addition to potential smothering effects of excessive sedimentation, microbial decay of accumulated waste material can dramatically alter the chemistry and ecology of seafloor sediments. Salmon farm discharges can change well irrigated and species-rich soft-sediment habitats into anaerobic (oxygen depleted) zones that are either devoid of animal life or dominated by only one or a few tolerant species. Previous monitoring surveys at the NZKS farm sites have shown that the ecosystem response to these impacts is variable, ranging from moderate to severe reduction in species diversity, and in some cases elevated abundance of opportunistic species (Keeley & Govier 2007 a-e; Keeley *et al.* 2007).

The effects of salmon farming on the water column are not yet fully understood, but the discharge of nutrients to the coastal environment raises issues regarding phytoplankton and macroalgal enrichment; in particular toxic algal blooms. Synoptic water column nutrient surveys at several NZKS sites indicated localised enrichment of the water column. The effect of this localised enrichment is unknown, but is unlikely to pose an environmental risk due to the relatively small contribution of nutrients compared to oceanic and riverine inputs, and water column mixing processes that would likely reduce the elevated nutrient concentrations to near-background (ambient) conditions within a period of hours. This is supported by a review of phytoplankton data collected from NZKS farm sites as part of their routine phytoplankton monitoring, which suggests that the presence of salmon farms has not increased the frequency and magnitude of phytoplankton bloom events in the region (Keeley *et al.* 2008).

Table 1. Components of waste discharge from a typical NZKS salmon farm and potential environmental concerns.

Component of farm waste	Source	Potential impact to marine environment
Organic carbon, nitrogen & phosphorus	Major components of faeces and waste feed	Organic enrichment of sediments
Ammonium and urea	Excretion by fish Sediment mineralisation	Hypernutrification (= excessive nutrient enrichment) of the water column
Bicarbonate	By-product of respiration, excreted via the gills	Unlikely to have a significant impact on the marine environment
Vitamins	Salmon feed	Poorly understood; but unlikely to be a significant environmental issue
Trace metals	Salmon feed, anti-foulants	Poorly understood, but possible ecological effects to seabed biota.

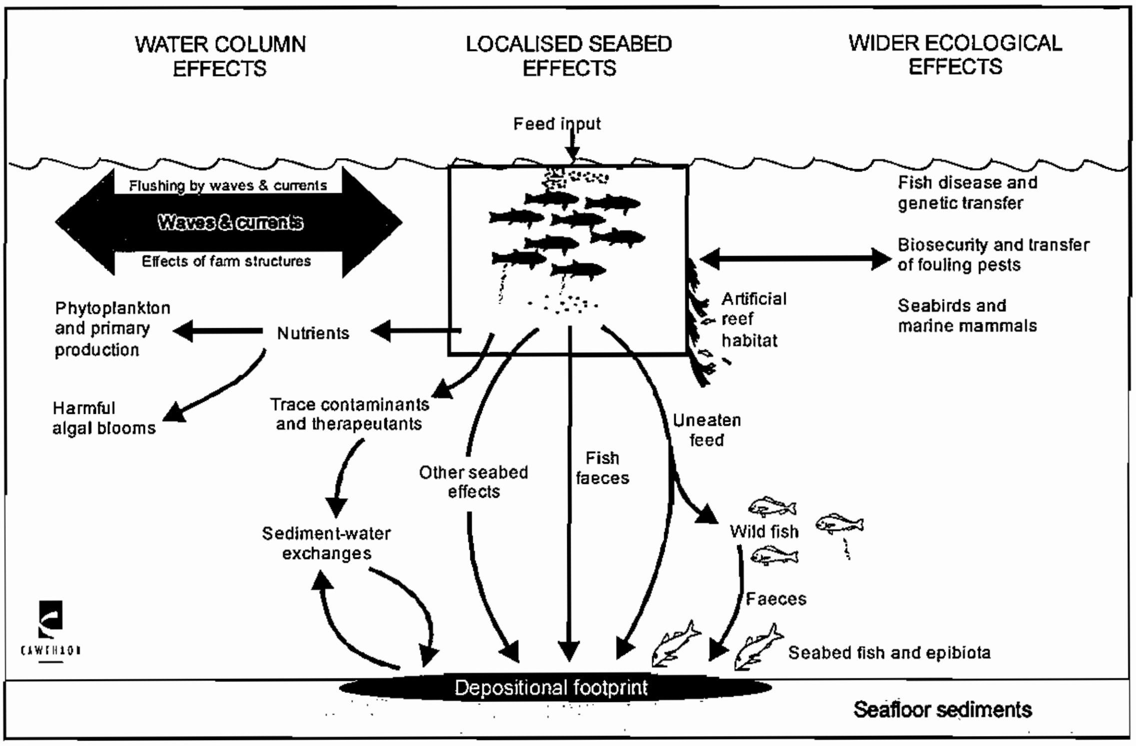


Figure 2. Overview of actual and potential ecological effects from a typical salmon farm.

1.3. Seabed indicators of organic enrichment

Various physical, chemical and biological properties can be used as indicators of the level of seabed impact from a salmon farm. The particular measures adopted here are commonly used to assess salmon farm effects. These are summarised in Table 2 and Figure 3.

Table 2. Commonly used indicators of seabed impacts beneath marine farms.

Indicator type	Description/Rationale
1. Sediment organic content and grain size distribution	These measures are used to provide an indication of the extent of sedimentation and organic loading from waste salmon food and faecal material.
2. Sediment colour and depth of RPD layer	Unenriched sediments are typically grey/brown, whereas excessively enriched and anoxic sediments can be black. The boundary between these zones is often termed the redox potential discontinuity (RPD) layer. As the level of enrichment increases and the sediment becomes increasingly anoxic, the RPD moves closer towards the sediment surface.
3. Sediment odour	Unenriched sediments are typically odourless, whereas excessively enriched and anoxic sediments have a strong 'rotten egg' smell of hydrogen sulphide (H_2S).
4. Out-gassing	Out-gassing is another symptom of excessive enrichment and is visible as bubbles rising to the sea surface. The gas bubbles are primarily methane, since this compound is relatively insoluble (Iwama 1991). Other products of excessive enrichment such as ammonia, hydrogen sulphide, and carbon dioxide tend to dissolve

	readily in seawater (Samuelsen *et al.* 1988).
5. Mat-forming filamentous bacteria (*e.g. Beggiatoa* sp.)	These bacteria metabolise sulphide but require oxygen to live. Their presence, therefore, provides an indication that the sediments are highly anaerobic and sulphide-rich at the sediment surface, but that the overlying water column still contains some oxygen (Findlay *et al.* 1995).
6. Epibiota	Animals and seaweeds inhabiting the sediment surface (*e.g.* starfish, marine snails) can be used as coarse indicators of impact, but are generally considered less sensitive than infauna to salmon farm effects (Crawford *et al.* 2001).
7. Infauna	Infauna are animals living within the sediment matrix (*e.g.* polychaete worms, bivalves) whose presence/absence, diversity and abundance collectively provide an indication of seabed health. A subset of the infaunal community, termed the macrofauna[1], is commonly analysed as an indicator. The macrofaunal assemblage found within unmodified subtidal sediments in wave-sheltered habitats is typically characterised by a high diversity of co-dominant species, whereas enriched or impacted sediments generally contain high densities of a few 'opportunistic'[2] species (Pearson & Rosenberg 1978).

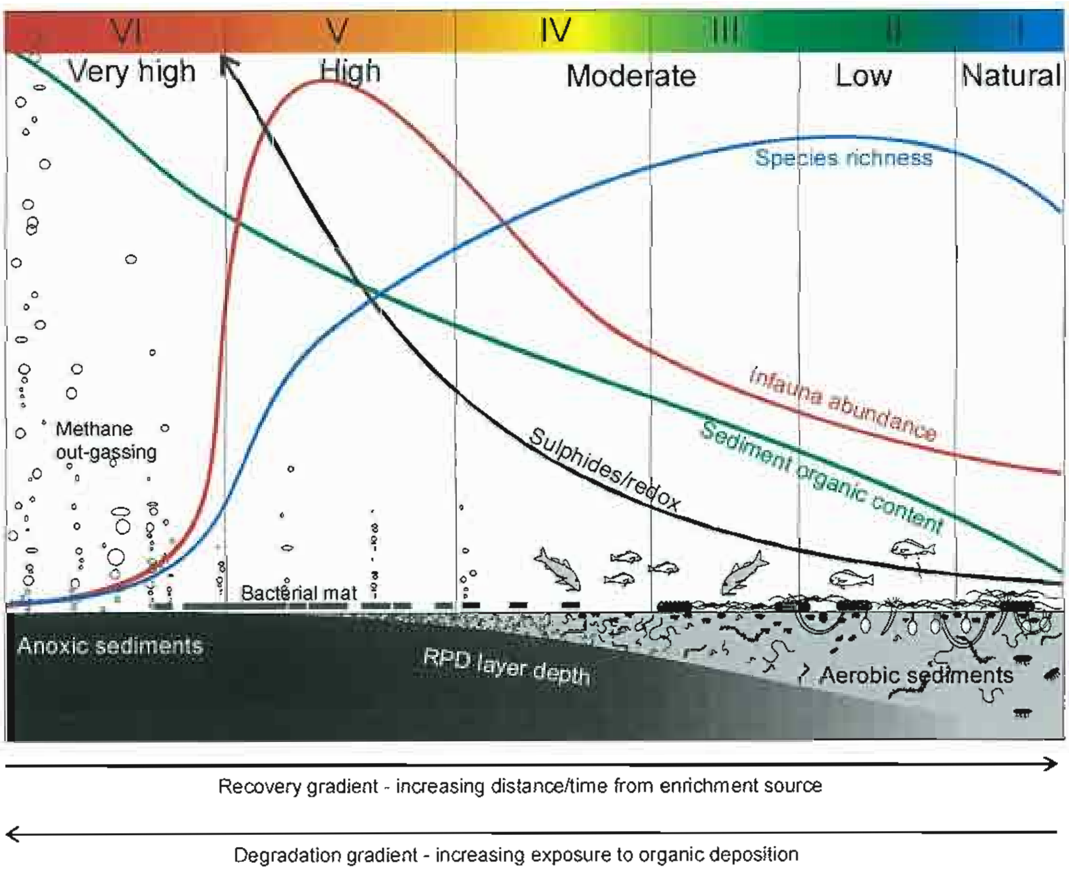


Figure 3. Stylised diagram of typical enrichment gradient indicating stages of enrichment and corresponding zone threshold (see Section 2.3).

[1] Macrofauna are infauna retained on a 0.5 mm mesh sieve.
[2] Opportunistic species are typically characterised by a small size, short life span, short development time to reach maturity, and many reproductive cycles per year (*e.g.* polychaetes, small bivalves and crustaceans).

1.4. Sediment contaminants – copper and zinc

Based on the recent scientific literature and information provided by NZKS, the potential toxicant-related risks at NZKS farms primarily appear to be from the application of copper-based anti-fouling paints on the predator exclusion nets that surround the cages and the presence of zinc in salmon feed. Copper-based paints are required since there is no practical way to mechanically clean predator nets. This is essential to prevent excessive bio-fouling so that adequate water flow is maintained through the farm. Zinc is added to salmon feed as a supplement at concentrations between 100-200 mg kg^{-1} (Mark Gillard, NZKS, pers. comm.).

Copper (Cu) and zinc (Zn) both occur naturally in coastal sediments and are also ubiquitous trace contaminants found in sediments from urban areas, ports and marinas (*e.g.* Forrest *et al.* 1997; Conradi & Depledge 1998; Fichet *et al.* 1998). Most of the copper found in sediments is thought to be derived from antifouling paint, and can be present as small flakes, which can cause high inter-sample variability. New Zealand and overseas studies have repeatedly identified elevated levels of these trace metals in sediments beneath salmon cages (Morrisey *et al.* 2000; Solberg *et al.* 2002; Brooks *et al.* 2003), however the environmental significance is not well understood (Forrest *et al.* 2007). Elevated zinc concentrations do not necessarily indicate adverse ecological effects (ANZECC 2000; Forrest *et al.* 2007) because the bioavailability of zinc is likely to be limited by high sediment sulphide levels that occur under anaerobic conditions. This results in the formation of zinc sulphide which is largely insoluble and therefore not available for biological uptake.

2. METHODS

In recent years, there have been several changes to the NZKS annual monitoring programme reflecting the increased knowledge of seabed environments beneath and adjacent to the farm sites and methods of sampling are continually evolving. Additional sampling has also been undertaken over the past six years to ensure that typically sensitive near-shore habitats have not been adversely affected by the marine farming activities. Annual monitoring of the six NZKS sites was undertaken in October 2009, and the Forsyth Bay site (Figure 4) was sampled on 30 October 2009.

2.1. Monitoring sites

The Forsyth Bay monitoring sites (Figure 4) were situated along a transect running northeast of the previous farm location in line consistent with the dominant direction of current flow. During the 2009 annual monitoring (prior to cages being re-installed at the site), there were eleven sites in total, with three controls, three sites beneath the cages and five positioned at 25 m intervals along the transect. Control 2 was positioned ~200 m northeast of the cages, Control 1 was ~1200 m to the east, and Control 3 was located in Ketu Bay (Figure 4).

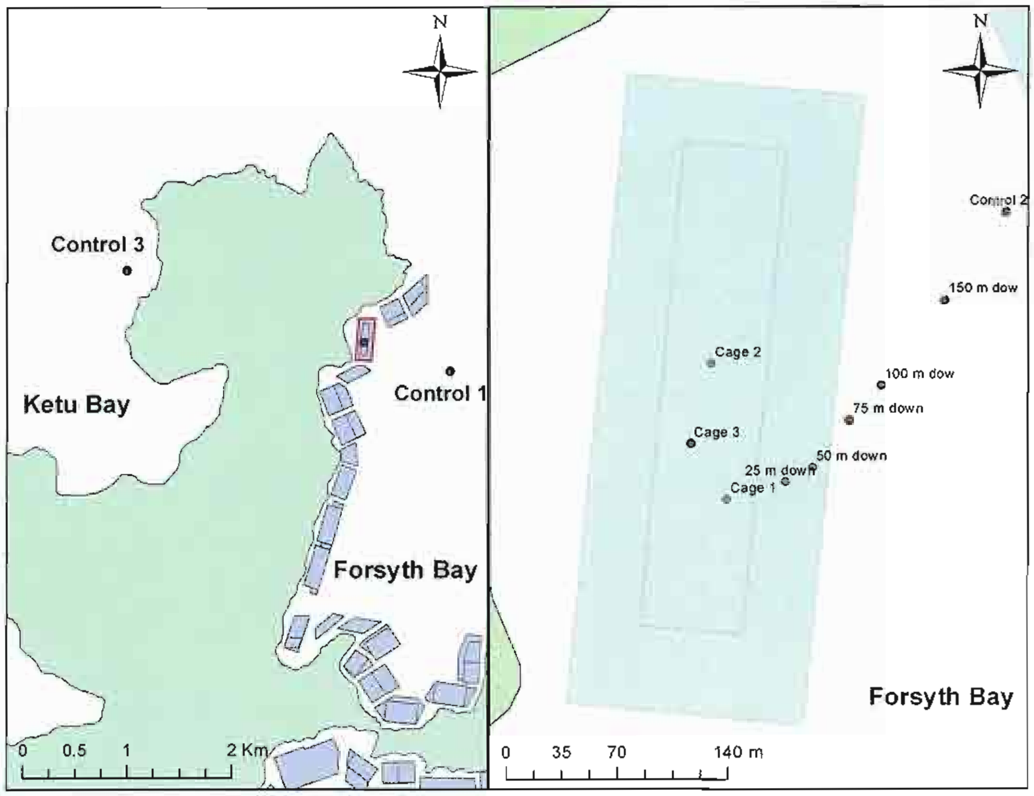


Figure 4. Site maps of Forsyth Bay indicating farm location and seabed sampling stations.

2.2. Field observations and sample collection

Key indicators of seabed enrichment/sedimentation effects were assessed at each of the Forsyth Bay monitoring sites using a variety of quantitative and qualitative procedures, as summarised in Table 3.

Table 3. Summary of seabed sampling methods.

Effect indicators	Method	Replicates
Visual assessment of the seabed (including epifauna communities)	Diver observations and video footage	1 previous cage site
Coverage of mat-forming filamentous bacteria	% cover estimated from diver observations and video footage	1 cage site
Sediment out-gassing	Surface and diver observations and video footage	1 cage site
Sediment grain size, organic (AFDW) & trace metal (zinc, copper) content	~150mm sediment cores taken with perspex corers from a Van-Veen grab or taken manually by divers. The top 25 mm of each core was collected for analysis.	Triplicate at cages and control sites Composite of 3 samples at other sites
Visual assessment of the sediment profiles, sediment colour & aRPD* layer depth	Collected as above and then cores were photographed and analysed immediately onboard the vessel.	2-3
Sulphide odours	Assessment of the sediments from grabs.	2-3
Infauna communities	130 mm diameter infauna cores were pushed 100 mm into the sediment taken by van-Veen grab or directly into the seabed by divers. The sampled material was partially washed through 0.5 mm nylon mesh and the remaining material was preserved with 70% ethanol and 1% glyoxylate as a fixative for later processing.	3
Sensitive habitats (*e.g.* hydroid habitats)	Diver observations and video footage	N/A
Near-bottom dissolved oxygen (DO)	Water samples collected 1 m above the seabed and analysed for DO concentration using a portable YSI oxygen meter (Appendix 1)	1

*aRPD = apparent Redox Potential Discontinuity

2.3. Assessing the significance of impacts

Table 4 provides the criteria by which each effects indicator can be scored to assess the severity of seabed impacts beneath NZKS salmon farm cages and adjacent sites. The seabed at each site was scored, with respect to each indicator, as showing a low, medium, or high impact, and assigned a score of 10, 20, or 30 points, respectively. A mean score for each site was then calculated by dividing the total score by the number of indicators used. Thus, mean scores can theoretically range from a "low impact" score of 10 to a "very high impact" score of 30. This provides an easily understood index of the relative severity of seabed impacts between sites and over time. This index was first proposed by Forrest (1998) as a means of summarising the effects of the NZKS Ruakaka Bay salmon farm on the benthic environment, and a detailed explanation of its derivation and use can be found in that report. One point that is emphasised, however, is that this assessment was originally proposed as an operational guide for NZKS rather than a method for regulatory compliance or other purposes, and should be treated only as a 'rough-guide' to the severity of farm impacts on the seabed environment.

Table 4. Criteria for ranking of seabed impacts based on conditions at salmon cages and adjacent sites.

Seabed Impact Indicator	Seabed Impact Scoring Criteria: No impact to low impact (score=10)	Low-Moderate impact (score=20)	High-Very High impact (score=30)
Percent increase in organic matter compared with control or baseline	<50%	50-90%	>90%
Depth of black zone compared with control or baseline	<50% shallower	50-90% shallower	At surface or >90% shallower
Bacterial mat coverage of seabed	Absent	Trace to <25%	25-100%
Gas bubbles	None	Slight	Freely released from sediment
Salmon feed (coverage of seabed)	Absent	Trace to ≤10%	>10%
Conspicuous epibenthic species compared with control or baseline	Comparable	Present but clearly impacted	Absent
Sediment-dwelling macrofauna compared with control or baseline	Comparable	High dominance and/or reduced richness	Absent or greatly reduced in density & richness

	Mean score interpretation				
Impact level	**None**	**Low**	**Moderate**	**High**	**V. High**
Mean impact ranking	**10**	**15**	**20**	**25**	**30**

2.4. Data analyses

The sediment properties of the sites were plotted to facilitate interpretation of spatial gradients and comparison with the control samples. Sediment organic content (AFDW) and trace metal (Cu and Zn) concentrations were also compared against the results from the previous years.

Trace metals concentrations were compared against national sediment quality criteria (ANZECC 2000). These guidelines aim to predict 'acceptable' levels of contaminants in sediment, above which adverse ecological effects may occur. The criteria are defined as Interim Sediment Quality Guideline-Low (ISQG-Low) and Interim Sediment Quality Guideline-High (ISQG-High) representing two distinct threshold levels above which biological effects are predicted. The criteria are based on statistical models of toxicity data to give a level of probability of detecting adverse effects at particular contaminant levels. The lower threshold (ISQG-Low) indicates a possible biological effect and acts as a trigger for further investigation, while the upper threshold (ISQG-High) indicates a probable biological effect. The guidelines acknowledge, however, that actual thresholds for biological effects can be strongly affected by a variety of environmental characteristics (*e.g.* the sensitivity of the existing biological community and the ionic state of the metal).

The number of taxa and their abundance (*i.e.* density) were calculated for each sample station. The infauna assemblages recorded at the various sites were then contrasted using non-metric multidimensional scaling or MDS (Kruskal & Wish 1978) and ordination and cluster diagrams based on Bray-Curtis similarities (Clarke & Warwick 1994). Abundance data were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each group formed at a 50% level of similarity were identified using analysis of similarities (SIMPER; Clarke & Warwick 1994). All multivariate analyses were performed with PRIMER v6 software. The distribution and grouping of samples within the MDS for the current monitoring year can then be compared with that of previous years.

2.5. Determining compliance with the 'Zones Concept'

Environmental 'bottom lines' have been developed and adopted for monitoring of the seabed at all NZKS farm sites (refer to Hopkins *et al.* 2004). This approach provides transparency and certainty to all parties (*i.e.* consent applicants, objectors and regulators), and a framework for assessing compliance. It is based around a conceptual model that identifies an acceptable level of seabed impact, both in terms of severity and spatial extent, in accordance with environmental quality standards. The model identifies three zones around a salmon farm (Brown *et al.* 1987) with associated acceptable impact criteria, as shown in Table 5 and depicted in Figure 3. Zone shapes may be modified to reflect site-specific conditions (*e.g.* water currents), while ensuring that the inshore habitats (such as cobble/rocky areas) are protected. This would involve an alteration to the shape of the impact zones to recognise the dispersion pattern of farm wastes, while still ensuring that the total area of seabed affected within each zone is no more than would be allowed under the conceptual approach.

Table 5. Proposed impact zones model (based on a 2.0 ha farm).

Zone	Spatial extent	Maximum area affected in each zone (ha)	Acceptable impact criteria
2	Beneath the cages and out to 50 m from their outside edge	5.8	Low species diversity dominated by opportunistic species (*e.g.* polychaete worms)
3	From 50 to 150 m from the outside edge of the cages	12.2	Transitional between Zone 2 and unimpacted Zone 4
4	Beyond 150 m from the outside edge of the cages	0	Normal conditions (*i.e.* reference or control)

3. RESULTS

3.1. 2009 Survey Data

The physical and chemical properties of the sediments at the Forsyth Bay stations are summarised in Table 6, and the sediment grain size distributions and AFDW results are also depicted in Figure 5. Photographs of the cores are presented in Appendix 3.

3.1.1. Seabed observations

Footage of the seabed where the sea cages used to be positioned showed sediments were composed of soft muds, thickly littered with dead scallop and mussel shells, presumably as a result of the marine farms that have existed historically at this site. No conspicuous finfish species were observed by the divers, although several "sea cucumbers" (*Australostichopus mollis*) were seen throughout the area. A bacterial mat was not observed (Table 6).

3.1.2. Grainsize and Ash-Free Dry Weight

Analysis of sediment samples showed that the organic component was highest at the 25 and 50 m sites (~11% AFDW, Table 6 & Figure 5), and were also slightly elevated at one of the cage stations (Cage 1: 7.6%). Other stations had levels comparable to controls. aRPD layers were evident at one cage and the 25 m stations, but were not present at any of the other sites. Slight sulphide odours were present at the 25 and 50 m stations.

Grainsize analyses showed control sediments to be the most mud dominated (~90% mud). Down-current transect sediments contained higher proportions of sand, but there was no clear gradient in grainsize from near the cages towards the end of the transect.

3.1.3. Zinc and copper

Mean copper concentrations beneath the cages in 2009 were 14.3 mg kg^{-1} at Cage 1, 11.7 mg kg^{-1} at Cage 2 and 12 mg kg^{-1} at Cage 3, and there was low variability between samples. These levels were well below the ISQG-Low criteria (65 mg kg^{-1}) for possible biological effects.

Zinc concentrations averaged 240 mg kg^{-1} at Cage 1, exceeding the ISQG-Low criteria of 200 mg kg^{-1} for possible biological effects. Sediments from Cages 2 and 3 averaged 109.7 and 133.3 mg kg^{-1} respectively, which is below the ISQG-Low criteria. Concentrations varied from 220 to 280 mg kg^{-1} at Cage 1, 99-120 mg kg^{-1} at Cage 2 and 120-140 mg kg^{-1} at Cage 3.

The concentrations of both metals are compared with those from previous years and other NZKS farm sites in Section 3.2.

3.1.4. Near-bottom Dissolved Oxygen

Dissolved Oxygen (DO) concentrations were only slightly reduced beneath the cages (84.4-87%) in comparison with other sites (86.6-90.3%) (Table 6). However, this was not to a degree that would have been ecologically significant. More detailed analysis of the vertical profile of DO concentration in near-bottom waters and its variation over time would be required to evaluate potential water column effects.

Table 6. Summary of the physical and chemical properties of sediments from the Forsyth Bay sites during the 2009 monitoring survey. Note: *Italicized* responses assessed from cores only.

Site	Depth (m)	Silt/clay (%)	AFDW (%)	RPD depth (mm)	Near bottom DO (%)	Bacterial mat (cover)	Out-gassing (Y/N)	Feed cover (%)	Sulphide odour
Cage 1	33.6	79.6	7.6	No distinct layer	87	None	N	None	No odour
Cage 2	32.5	87.1	6.7	No distinct layer	86.4	None	N	None	No odour
Cage 3	33.1	81.6	5.4	~ 29 mm	84.4	*None*	*N*	*None*	No odour
25 m	33.5	66.7	11.1	~ 60 mm	86.9	*None*	*N*	*None*	Slight
50 m	33.0	70.8	11.2	No distinct layer	90.3	*None*	*N*	*None*	Slight
75 m	33.0	88.0	6.7	No distinct layer	87.0	*None*	*N*	*None*	None
100 m	32.6	71.1	6.0	No distinct layer	87.6	*None*	*N*	*None*	None
150 m	33.0	72.9	6.5	No distinct layer	88.5	*None*	*N*	*None*	None
Control 1	32.3	91.4	6.3	No distinct layer	87.3	*None*	*N*	*None*	None
Control 2	33.2	95.6	4.5	No distinct layer	86.6	*None*	*N*	*None*	None
Control 3	34.0	86.4	5.9	*	89	*None*	*N*	*None*	None

* = No sample result.

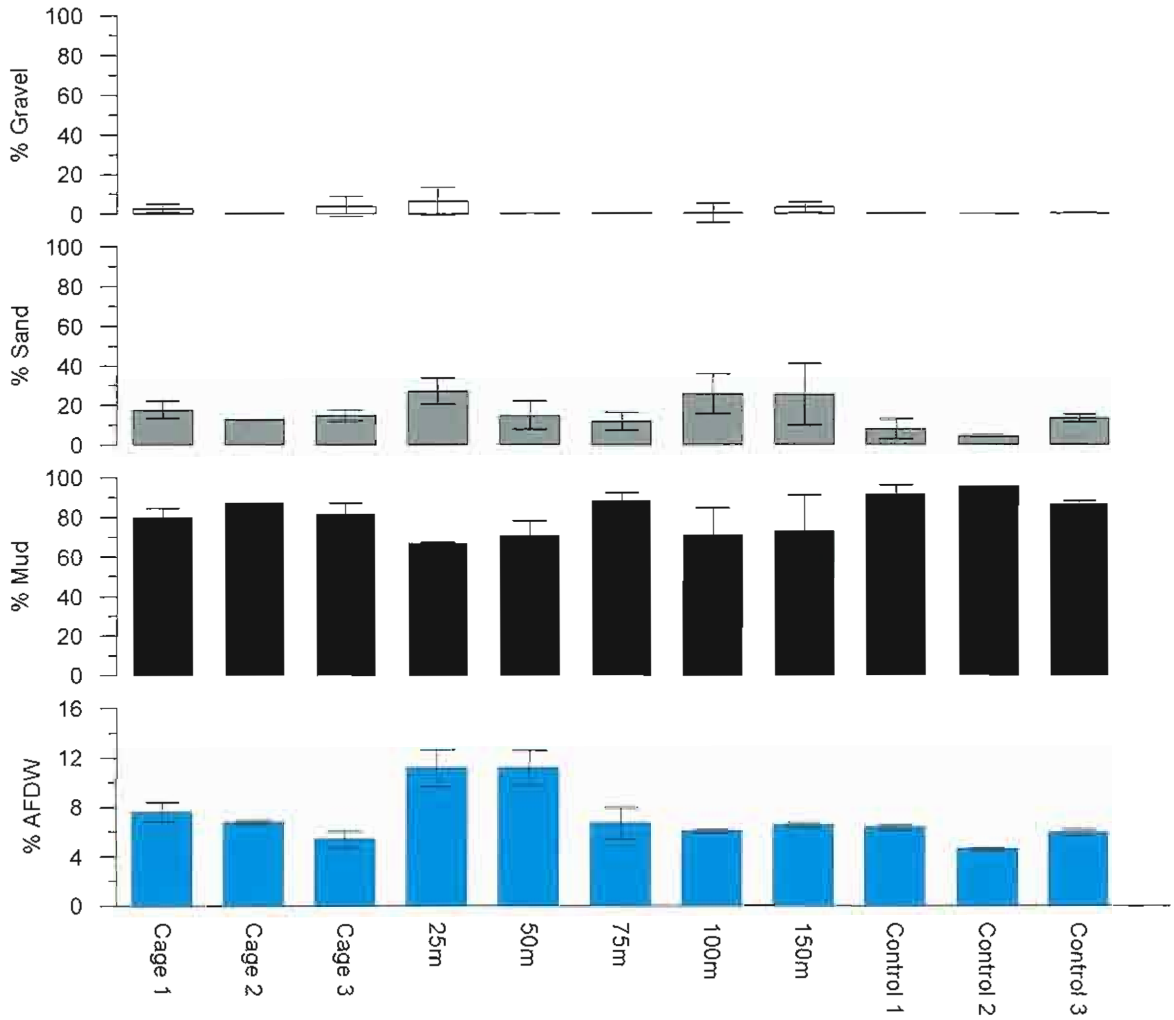


Figure 5. Sediment grain size distribution and AFDW content from Forsyth Bay sites.

3.1.5. Infauna

Mean infauna densities recorded across all of the stations ranged from 51 to 98 individuals per core. The 100 m station had noticeably elevated densities relative to the other stations and controls, and the 25 m station had slightly elevated densities, but spatial trends with distance were not evident.

Species richness varied from 16 to 24 taxa per core with no obvious gradient of decreasing species richness with distance from the historical salmon cage site (Figure 6). The lowest species richness was found at the 50 m station (16 individuals per core), but this was not significantly different from Control 2 (18 individuals per core). The full set of infauna data are presented in Appendix 2.

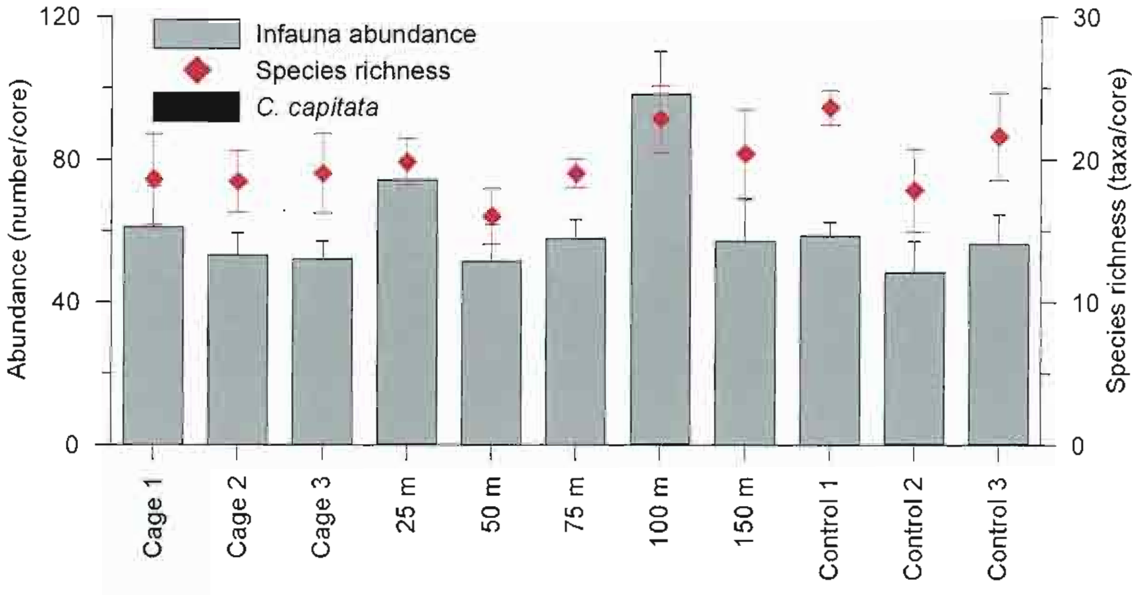
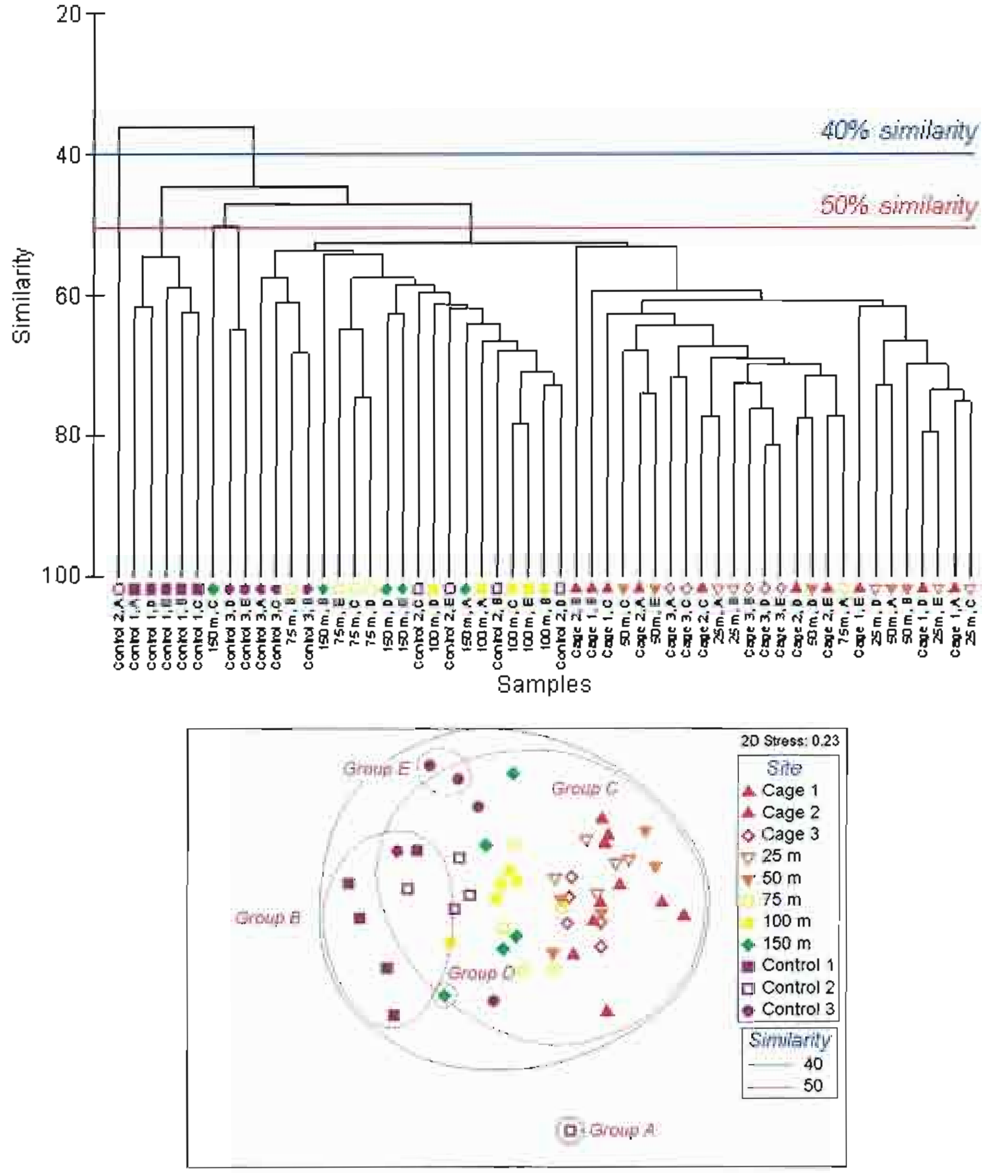


Figure 6. Mean sediment infauna abundance and species richness at the Forsyth Bay sites.

Most of the infauna samples collected from the Forsyth Bay sites shared a reasonable degree of similarity (*i.e.* Group C, Figure 7, ~57%) and were typically characterised by amphipod 'b', Paraonidae, Cirratulidae, Lumbrineridae and *Prionospio aucklandica* polychaetes, and cumaceans (Table 7). Interestingly, this group comprised samples from all of the sites (cages, down-current stations and controls), indicating the sites close to the farm were comparable to those further away, including the controls. However, there was still a subtle gradient in the data when presented in a 2-dimensional MDS plot, with cage sites predominantly on the right, progressing left to mainly down-current stations, and then to predominantly control sites on the left (Figure 7). This is evidence of the persistence of a weak farm impact-related gradient.

At a 50% level of similarity, some of the control samples separated into three groups (A, B and E), and one 150 m sample formed a fifth group (D). Group A comprised a sample from Control 2, and was distinguished from all others because it had low taxa abundance and richness, and consequently many of the species present in other groups were absent from this sample. Group B comprised all of the Control 1 samples, and separated from the main group (C) primarily because it had fewer amphipod 'b', and more Priapula worms and Maldanidae polychaetes. Two Control 3 samples were in Group E, and this group differed from the main group primarily due to higher numbers of nematodes and the absence of the polychaete *Prionospio aucklandica*. The 150 m sample (Group D) was distinguished from Group C due to the absence of amphipod 'a' and *P. aucklandica*.



Group	Key distinguishing biological characteristics
A	Low taxa abundance and richness. Generally only 1-2 individuals of each taxa.
B	Moderate to high species diversity. Characterised by several polychaete species (*e.g.* Maldanidae, Paraonidae, *Cossura consimilis*, Cirratulidae), Priapulan worms, the bivalve *Ennucula strangei* and amphipod 'c'.
C	Moderate to high species diversity. Several species of polychaete (Paraonidae, Cirratulidae, Lumbrineridae, *Prionospio aucklandica* and Maldanidae), amphipod 'a' and 'c', and cumaceans common. More of amphipod 'b' and less Priapulids than Group B.
D	Moderate species diversity. Characterised by Lumbrineridae, *C. consimilis*, *E. strangei*, and cumaceans. Differed from Group B primarily due to the absence of Priapulids, amphipod 'c' or ostracods. Differed from Group C primarily due to the absence of amphipod 'a' and *P. aucklandica*.
E	High species diversity. Paraonidae polychaetes and nematodes common. Also characterised by amphipod 'b', *C. consimilis*, *E. strangei*, *Goniada* sp. and Cirratulidae. Differed from Group C primarily due to higher numbers of nematodes, and the absence of *P. aucklandica*

Figure 7. Cluster diagram and multi-dimensional scaling of infauna species and abundance data from the Forsyth Bay sites. Data were fourth-root transformed (2D Stress=0.23). Groups (shown by dashed lines) were formed based on 40% and 50% levels of similarity.

Table 7. Average abundance (per core) and similarity of like-groups of benthic infauna species at the Forsyth Bay sites. Species contributing >60% of the total similarity are listed. Percentage contributions are based on a fourth-root transformation, average abundances are raw data. Groups A and D had less than two samples.

Site	Species	Average Abundance	Average Similarity	% Contribution	% Cumulative
Group B	**Average similarity: 56.72**				
	Maldanidae	19.2	7.45	13.13	13.13
	Priapula	2.2	4.12	7.26	20.39
	Paraonidae	3.0	4.09	7.21	27.6
	Ennucula strangei	2.4	4.07	7.18	34.78
	Amphipoda c	1.4	3.74	6.59	41.37
	Cossura consimilis	2.6	2.93	5.16	46.53
	Cirratulidae	2.4	2.75	4.84	51.37
	Ostracoda	2.6	2.65	4.67	56.04
	Prionospio aucklandica	1.6	2.60	4.59	60.63
Group C	**Average similarity: 56.76**				
	Paraonidae	5.52	5.11	9.00	9.00
	Cirratulidae	4.74	5.04	8.88	17.88
	Amphipoda b	6.57	4.85	8.54	26.42
	Cumacea	5.37	4.79	8.45	34.86
	Lumbrineridae	3.41	4.52	7.96	42.83
	Prionospio aucklandica	4.98	3.77	6.64	49.46
	Maldanidae	4.72	3.14	5.54	55.00
	Amphipoda a	2.33	3.02	5.32	60.32
Group E	**Average similarity: 64.75**				
	Paraonidae	9.5	5.50	8.50	8.50
	Nematoda	11.5	5.32	8.22	16.71
	Amphipoda b	5.0	4.63	7.14	23.86
	Cossura consimilis	4.5	4.30	6.65	30.51
	Ennucula strangei	2.5	3.89	6.01	36.51
	Goniada sp.	2.5	3.89	6.01	42.52
	Cirratulidae	3.5	3.89	6.01	48.53
	Asellota	2.0	3.89	6.01	54.54
	Prionospio multicristata	2.5	3.27	5.05	59.59
	Maldanidae	1.5	3.27	5.05	64.64

3.2. Comparison to previous surveys and guideline levels

Appendix 4 summarises the key environmental issues relating to the seabed condition at the Forsyth Bay salmon farm site as determined by monitoring in 1993-2009.

3.2.1. Cage stations

Organic content of the sediments beneath the historical cage sites were still slightly elevated relative to the control sites and slightly higher than in 2007 (Figure 8). However, the level was noticeably lower than those measured at these sites when the farm was last actively used over eight years ago. The remaining state of organic enrichment was relatively minor and may have been partially clouded by natural variation.

Both copper and zinc concentrations in sediments below the cages had decreased in 2009 compared to 2007, with zinc below the ISQG-Low threshold for 'possible' biological effects and copper remaining well below the threshold (Figure 9).

Infauna abundance had remained at similar levels since 2006, and diversity had increased slightly since 2006 (Figure 8). *C. capitata*, which is generally abundant in the presence of elevated concentrations of labile organic matter, was not present in the samples, which was consistent with 2005 and 2006 results. *C. capitata* has not been present at elevated levels since 2002.

3.2.2. 25 m station

Sediments sampled 25 m down-current of the previous location of salmon cages appeared more impacted than sediments from the cage sites, with higher organic content (11.1%) than in 2007 and slight hydrogen sulphide odours. This apparent increase is difficult to explain. Sediments were composed of soft brown mud above an aRPD layer of black mud approximately 60 mm beneath the surface.

Infaunal abundance has remained at a similar level since 2006 and diversity has remained at a comparable level since 2005 (Figure 8). Only one *C. capitata* was found within the infaunal samples; low densities of *C. capitata* have been present in samples in previous years, but not at elevated densities since 2005. Nematodes, which were observed prior to the 2006 monitoring, were absent.

3.2.3. Down-current stations

Organic enrichment was also detectable at the 50 m down-current station (*i.e.* elevated AFDW, slight H_2S odour *etc.* Table 6), but beyond this, there were no H_2S odours and the composition of the sediments became indistinguishable from the control sites. This finding is consistent with previous years. Despite this, AFDW had increased in 2009 at all down-current sites. The 50 m station in particular has had a trend of increasing organic matter since 2001.

Infaunal abundances and richness were generally comparable to results from 2005 onwards. An exception to this was richness at the 150 m station, which has generally had a declining trend since 2003. Only individual *C. capitata* were present in one 100 m sample, and two control samples.

3.2.4. Control stations

The results obtained from the control sites have remained relatively consistent over time. Sediments were largely soft brown muds with no apparent RPD layers. Organic contents similar to other un-impacted sediments in the Marlborough sounds (~5%). Species richness and diversity at the control sites were similar to previous years, and although not significantly different between years, there seems to have been a trend of increasing richness and slowly decreasing abundance at the control sites over the past three rounds of monitoring. Seabed conditions at the control sites were generally consistent with what would be expected for "natural" un-impacted seabed habitats within the Marlborough Sounds region.

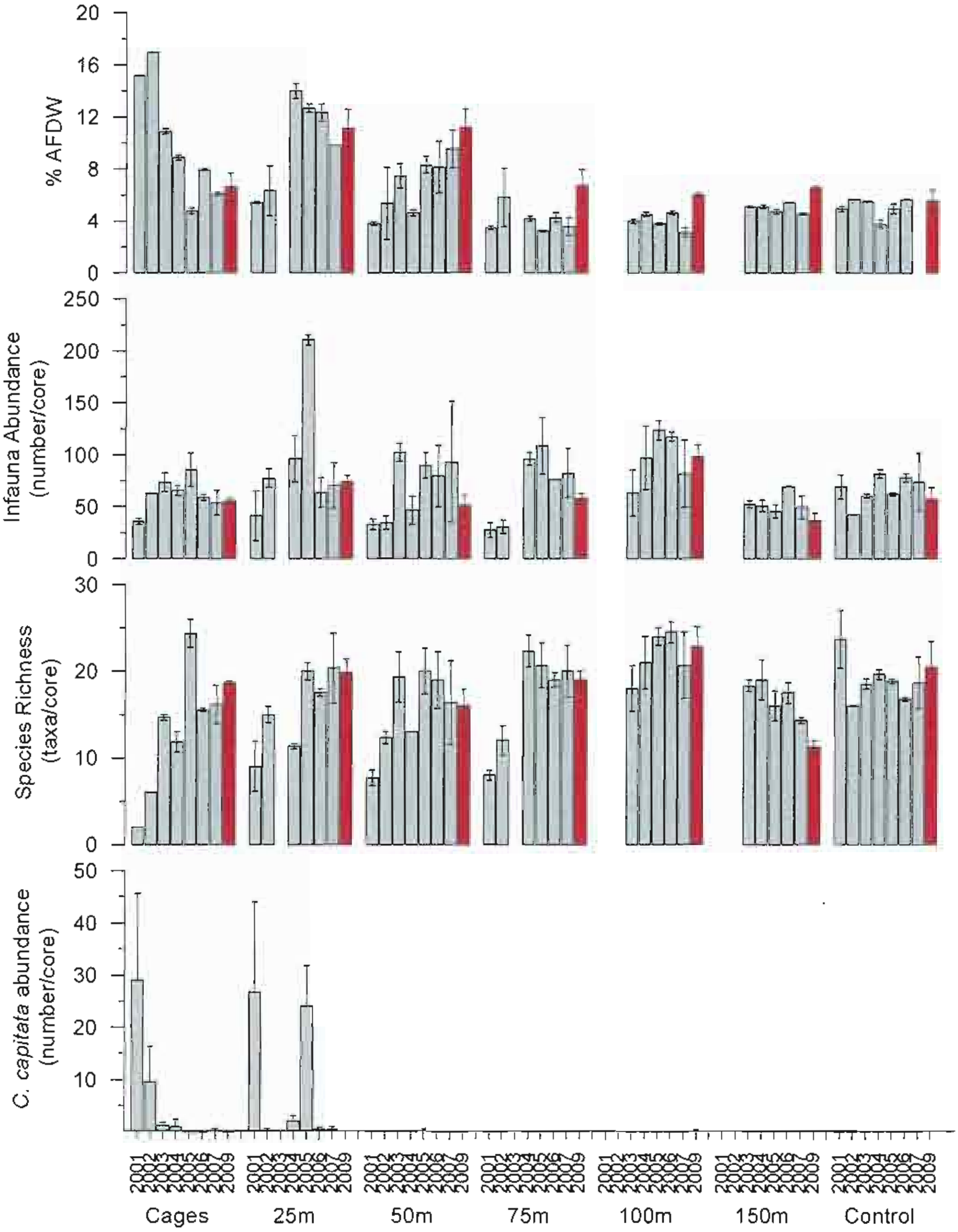


Figure 8. Comparison of mean AFDW, infauna abundance and richness (No. taxa), and *C. capitata* densities recorded at Forsyth Bay since 2001. High densities of capitellid polychaetes are typically 1,000 individuals m^{-2} (=13 per 0.013 m^{-2} core) or greater (ANZECC 2000 guidelines).

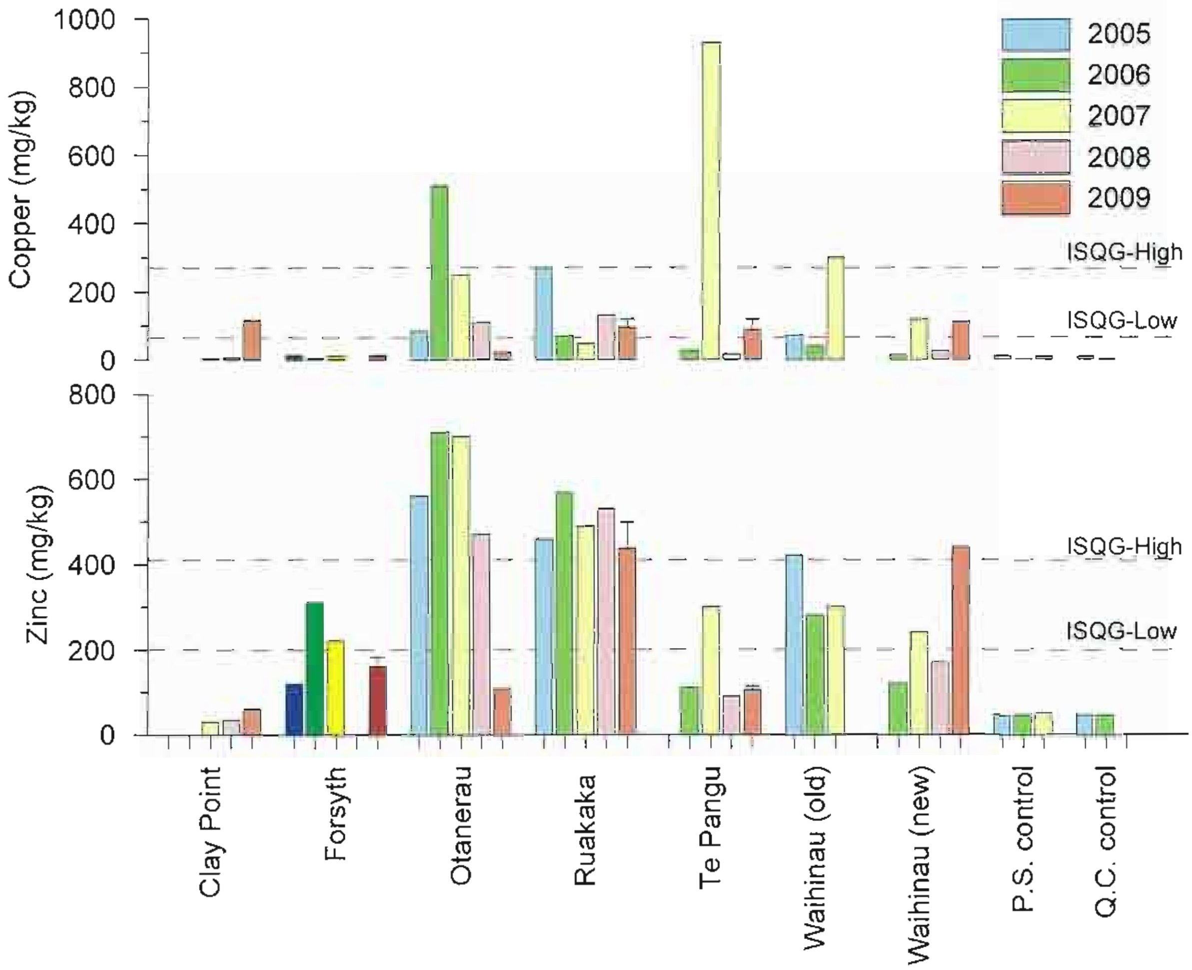


Figure 9. Comparison of the last five years of annual monitoring data for sediment copper and zinc concentrations beneath all six NZKS farms and two control sites. P.S. = Pelorus Sound, Q.C. = Queen Charlotte. Red dotted lines indicate respective ANZECC ISQG trigger levels. Forsyth Bay data are bolded.

4. ASSESSMENT OF RECOVERY

The Forsyth Bay farm site was fallowed in November 2001, which included the removal of all farming structures (*i.e.* cages, anchor warps, barges *etc.*). At the time of fallowing, the seabed beneath the cages was considered highly enriched to the point of being nearly azoic (Hopkins 2001). The organic content of the sediments was around 16%, the infauna limited to a few dominant opportunistic species and the epibiota primarily comprised a white bacterial mat indicating strongly reduced oxygen concentrations.

Conditions began to improve soon after the cessation of farming. Within 12 months the bacterial mat had almost disappeared and infauna abundances began to increase. However, the composition of sediments has been slower to recover than anticipated. The aRPD layer remained at or near the surface until 2003, and in 2007 it was still apparent and approximately 50-60% nearer to the sediment surface compared to the control sites. In 2009, aRPD layers were observed in sediments from one cage station, and the 25 m station. Although the organic content of the sediments beneath the cages has been improving, AFDW at 25 and 50 m have been elevated in comparison to background levels, and levels at the 50 m site have been increasing since 2001. The reasons for this are unclear, but may be related to the dispersion of surface sediments with high organic matter away from the cage stations. Site hydrodynamics may support a slow net transportation of easily suspended organic deposits to the northeast (following the bathymetry), resulting in high AFDW at the 25m and 50m stations, but this has not been proven. Previously, we have also observed mussel farms in the vicinity of this site during fallowing which may be contributing to the organic deposition. However, mussel farms are not normally associated with sediment organic contents as high as 11% (Keeley *et al.* 2009).

The apparent slow rate of organic matter return to normal "background" levels may be due to the recalcitrant nature of the remaining waste materials and/or the cohesive nature of the sediments which resists the infiltration of oxygenated water from above. Lower impacts due to oxygen depletion (*e.g.* infauna composition, sulphide odours, aRPD layers) suggest reduced rates of microbial decomposition which is consistent with this explanation. This being the case, there may be some potential for enhancement of the latter stages of organic matter removal through physical mixing of the deep sediment layers and/or seeding the seabed with an appropriate microbial inoculum (*e.g.* Vezzulli *et al.* 2004).

Nevertheless, the 2009 survey indicates that seabed conditions continued to improve, albeit at a slower rate than previously observed. The most notable improvements to condition are as follows:

- Absence of sediment odour at most sites, and the absence of a bacterial mat (*e.g. Beggiatoa* sp.).
- The absence of aRPD layers in the sediments from two of three cage stations and all down-current sampling stations except 25 m.
- A reduction in sediment organic matter content at the cage stations to levels comparable to background levels.
- An improvement in infauna communities, with none of the opportunistic, enrichment-tolerant polychaete *Capitella capitata* present at the cage stations, and only individuals present in a few other samples.

Appendix 5 summarises the key environmental issues relating to seabed conditions at the Forsyth Bay salmon farm site since the baseline survey in 1993, and the start of annual seabed monitoring in 1999.

4.1. Compliance with 'Zones Concept' and recommendations for management and mitigation

Based on the results of the 2009 monitoring programme, it appears that seabed impacts at the Forsyth Bay salmon farm are well within the limits of 'acceptable impact criteria' outlined in Table 5 for Zones 2 and 3. Infauna communities have re-established to the point of being naturally diverse and productive. However, recovery is not complete, with some indications of enrichment in the general vicinity of the historical cage site and some areas remaining significantly enriched in terms of sediment organic content and zinc concentrations. These residual effects may influence the re-impact timeline now that the farm has been reinstated (as of November 2009). The extent to which the rate of re-impact is affected is the subject of a Cawthron internally funded study, which aims to help inform the efficacy of fallowing practices for the future.

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6. APPENDICES

Appendix 1. Seabed sampling coordinates

Sampling station	WGS84_Lat	WGS84_Long	NZMG_E	NZMG_N
Cage 1	-40° 58.980'	174° 01.088'	2595662	6024346
Cage 2	-40° 58.934'	174° 01.080'	2595652	6024432
Cage 3	-40 58.96117	174 01.07088	2595634	6024381
25 m	-40° 58.974'	174° 01.114'	2595699	6024357
50 m	-40° 58.969'	174° 01.126'	2595716	6024366
75 m	-40° 58.952'	174° 01.142'	2595739	6024396
100 m	-40° 58.940'	174° 01.156'	2595759	6024418
150 m	-40° 58.911'	174° 01.184'	2595799	6024472
Control 1	-40° 59.108'	174° 01.332'	2596002	6024106
Control 2	-40° 58.880'	174° 01.211'	2595838	6024528
Control 3	-40° 58.600'	173° 59.455'	2593381	6025075

Appendix 2. Taxonomic count data

TAXA	COMMON NAME	Cage 1, A	Cage 1, B	Cage 1, C	Cage 1, D	Cage 1, E	Cage 2, A	Cage 2, B	Cage 2, C	Cage 2, D	Cage 2, E	Cage 3, A	Cage 3, B	Cage 3, C	Cage 3, D	Cage 3, E
ANTHOZOA																
Edwardsia sp.	Burrowing anemone															
NEMERTEA	Proboscis worms						1	1		1		1		1		
NEMATODA	Roundworm															
PRIAPULA	Priapularins															
Sipuncula	Peanut Worm															
GASTROPODA																
Gastropoda (white rissoid-like)	Unidentified gastropod															
Struthiolaria papulosa	(Kaikai-karoro)															
Zeacolpus sp.	Turret shell								1							
Zegalerus tenuis																
OPISTHOBRANCHIA																
Opisthobranchia unid.																
Philine auriformis	White Slug															
BIVALVIA																
Arthritica bifurca	Small bivalve			1				1								
Dosinia lambata	Silky biscuit shell															
Ennucula strangei							1						1	1		1
Leptomya retiaria retiaria					1											
Maorithyas marama					1											
Melliteryx parva																
Neilo australis			1										1			
Nemocardium pulchellum	Strawberry cockle					1										
Notocallista multistriata	Oblong cockle shell		1													
Nucula gallinacea	Nut shell								1		1	1		2		
Nucula nitidula	Nut shell															
Saccela bellula																
Tellinota edgari			1													
Theora lubrica	Window shell		1	2	2		2	1	1	2	3	5	1	2	1	2
Thracia sp.	Bivalve															
POLYCHAETA																
Sphaerodoropsis sp.	Small polychaete worm															
Orbinia papillosa					1					1						
Scoloplos cylindrifer	Polychaete worm															
Paraonidae	Polychaete worm	1	5	4	4	1	4	3	7	4	4	2	3	1	5	5
Cossura consimilis			1	1	1		2	2	3	2		3	1	3	1	2
Prionospio aucklandica		2	12	12	33	9	3	6	13	5	2	6	2	10	7	4
Prionospio multicristata																
Prionospio yuriel			3		2			1	1			1				
Spiophanes kroyeri																
Phyllochaetopterus socialis	Parchment worm															
Capitella capitata																
Capitellethus zeylanicus										1		1		1		
Heteromastus filiformis			2	1	5		5		3	3	1	2	1		1	
Maldanidae	Bamboo Worms	1	2		1					2	3	1		2	2	2
Armandia maculata		1	1		1											
Phyllodocidae	Paddle worms								1							
Polynoidae	Scale worms															
Sigalionidae																

TAXA	25 m, A	25 m, B	25 m, C	25 m, D	25 m, E	50 m, A	50 m, B	50 m, C	50 m, D	50 m, E	75 m, A	75 m, B	75 m, C	75 m, D	75 m, E	100 m, A	100 m, B	100 m, C	100 m, D	100 m, E
ANTHOZOA																				
Edwardsia sp.																			1	1
NEMERTEA								1	1		1		1	1					1	
NEMATODA																			1	
PRIAPULA															2				1	
Sipuncula												1			2				1	1
GASTROPODA																				
Gastropoda (white rissoid-like)																				
Struthiolaria papulosa																				
Zeacolpus sp.																				
Zegalerus tenuis																				
OPISTHOBRANCHIA																				
Opisthobranchia unid.																				
Philine auriformis																				
BIVALVIA																				
Arthritica bifurca				1								1								
Dosinia lambata																				
Ennucula strangei		1						1		2	3	2	5	1	1	3	3	6	4	3
Leptomya retiaria retiaria			1										1							
Maorithyas marama						1										1		1		1
Melliteryx parva																				
Neilo australis					1			1												
Nemocardium pulchellum																				
Notocallista multistriata																				
Nucula gallinacea	3																			
Nucula nitidula																				
Saccela bellula																				
Tellinota edgari	1							1												
Theora lubrica	4	1	2	3	8	9	13	2	1	1	3	1	2	1	2	4	1	1	1	3
Thracia sp.																				
POLYCHAETA																				
Sphaerodoropsis sp.																1				
Orbinia papillosa																				
Scoloplos cylindrifer																				
Paraonidae	10	10	11	4	8	3	11	5	4	3	3	6	15	10	4	11	13	12	11	11
Cossura consimilis	1	3						2	5	2	3	3				3	10	8	12	15	11
Prionospio aucklandica	13	7	9	8	3	7	18	1	2	1	4	1		4	1	6		3	3	1
Prionospio multicristata																				
Prionospio yuriel		1																		
Spiophanes kroyeri																				
Phyllochaetopterus socialis																				
Capitella capitata			1														1			
Capitellethus zeylanicus													1	1	2			1		
Heteromastus filiformis	1	2	2	3	2	2	3	2	3	3	1	1	1			1	1	1		1
Maldanidae	3	1	1	1	2	1			1		2	7	9	2	6	21	10	18	21	17
Armandia maculata					1											1	1			
Phyllodocidae	1													1						
Polynoidae																				
Sigalionidae													2			1		1	2	1

TAXA	150 m, A	150 m, B	150 m, C	150 m, D	150 m, E	Control 1, A	Control 1, B	Control 1, C	Control 1, D	Control 1, E	Control 2, A	Control 2, B	Control 2, C	Control 2, D	Control 2, E	Control 3, A	Control 3, B	Control 3, C	Control 3, D	Control 3, E
ANTHOZOA																				
Edwardsia sp.							1	1												
NEMERTEA					1	2		1	2		1		1		1					
NEMATODA								1		1						1		3	7	16
PRIAPULA				1		2	3	2	1	3										1
Sipuncula									1											
GASTROPODA																				
Gastropoda (white rissoid-like)	1					1						1								
Struthiolaria papulosa																			1	
Zeacolpus sp.																				
Zegalerus tenuis							1													
OPISTHOBRANCHIA																				
Opisthobranchia unid.												1								
Philine auriformis		1																		1
BIVALVIA																				
Arthritica bifurca		1								1		1				1	1	2	1	
Dosinia lambata										1										
Ennucula strangei	7	4	3	3	11	2	2	2	1	5		4	2	4	3	1	2	3	3	2
Leptomya retiaria retiaria																				
Maorithyas marama								1				1							2	
Melliteryx parva			1																	
Neilo australis	3			1			2				1	1					1	1		1
Nemocardium pulchellum											1									
Notocallista multistriata																				
Nucula gallinacea										1						1				
Nucula nitidula	1																		5	
Saccela bellula	1										1									
Tellinota edgari			1																	
Theora lubrica	1			1										1				1		1
Thracia sp.							1	1	1	1										
POLYCHAETA																				
Sphaerodoropsis sp.				1																
Orbinia papillosa																				
Scoloplos cylindrifer						1							1	1		1				
Paraonidae	3	2	1	1	1	2	2	1	2	8		5	3	6		7		8	8	11
Cossura consimilis	1		3	2	1	3	3		4	3		5	6	4	8	5	1	8	3	6
Prionospio aucklandica	1				1	2		2	2	2			5		1	1	2			
Prionospio multicristata	2																		4	1
Prionospio yuriel	1																			1
Spiophanes kroyeri						1	2	1	1											
Phyllochaetopterus socialis				1																
Capitella capitata													1					1		
Capitellethus zeylanicus	1																			1
Heteromastus filiformis	3	4	1	1	3			1		2			3				1	2		2
Maldanidae	9	2	2	6	3	15	21	22	16	22	5	9	1	13	22	4	3	6	1	2
Armandia maculata																				
Phyllodocidae								1											1	
Polynoidae	1									1									1	
Sigalionidae	1					3	1		1	2				1	1					

TAXA	COMMON NAME	Cage1, A	Cage1, B	Cage1, C	Cage1, D	Cage1, E	Cage2, A	Cage2, B	Cage2, C	Cage2, D	Cage2, E	Cage3, A	Cage3, B	Cage3, C	Cage3, D	Cage3, E
POLYCHAETA																
Hesionidae		2			1		1	1								
Syllidae												1				
Sphaerosyllis sp.		3			2	1			1			1		1		
Nereidae	Rag worms															
Glyceridae		2	3			1										
Goniada sp.													1			
Aglaophamus sp.												1				
Onuphis aucklandensis				1	2				1							
Lumbrineridae		3		1	4	4	5	7	4	5	2	2	1		4	4
Dorvilleidae		1			1							1	1			
Myriochele sp.		1	2	8	5	2	1		1	2	1	2	2	1	1	3
Ampharetidae																
Cirratulidae		4	7		2	1	3	7	1	1	3	5	3	2	1	5
Flabelligeridae	Polychaete worm															
Sternapsis scutata																
Sternaspis scutata																
Terebellidae		1	1		1				1	1		1				
Terebellides stroemi							1	1					1		1	
Sabellidae	Umbrella worms															
Euchone pallida	Fan worm															
MYSIDACEA	Mysid shrimp															
CUMACEA	Cumaceans	1	5	2	1	3	4	6	5	6	4	6	8	8	7	10
TANAIDACEA																
Tanaid sp.	Tanaid Shrimp	9		4	8	12		1	8	3		2	2	1	2	4
ISOPODA																
Munna schauinslandii	Isopod										1	2		3		
Natatolana pellucida	Fish lice								1	1						
Asellota	Isopod						1	2	4		2	7	4	1	3	5
Gnathiidea																
Valvifera																
AMPHIPODA																
Amphipoda a	Amphipods	3	3	1	3	1	2	9	3	3	3	3	1			
Amphipoda b	Amphipods	6	7	7	14	3	2		6	16	8	5	3	18	5	2
Amphipoda c	Amphipods	2	6	1	1				3	2		2		1		1
Amphipoda d	Amphipods															
Amphipoda e	Amphipods						1									
DECAPODA																
Ebalia laevis	Nut Crab															
Notomithrax minor																
OSTRACODA	Ostracods	2	1	3	7	1			2	1	3		2	2	1	1
Echinoidea																
Echinocardium cordatum	Heart Urchin			1				2								
OPHIUROIDEA																
Ophiuroidea	Brittle stars	1									1			2	1	
ASCIDIACEA																
Cnemidocarpa bicornuta	Saddle squirt															
Didemnum sp. (white)	Encrusting white didemnum															
Molgula sp.																
	Taxa abundance	**46**	**65**	**50**	**104**	**40**	**39**	**51**	**72**	**62**	**42**	**64**	**39**	**63**	**43**	**51**
	Taxa richness	**19**	**20**	**16**	**25**	**13**	**17**	**16**	**23**	**20**	**16**	**25**	**19**	**20**	**16**	**15**

TAXA	COMMON NAME	25 m, A	25 m, B	25 m, C	25 m, D	25 m, E	50 m, A	50 m, B	50 m, C	50 m, D	50 m, E	75 m, A	75 m, B	75 m, C	75 m, D	75 m, E	100 m, A	100 m, B	100 m, C	100 m, D	100 m, E	150 m, A	150 m, B	150 m, C	150 m, D	150 m, E
POLYCHAETA																										
Hesionidae			2	1		1		3					1					2	1		1			1		
Syllidae			1		1		1						1							1				1		
Sphaerosyllis sp.		2	5	2	2	8	4	4	3					3				1	5	2	1	3	2			
Nereidae	Rag worms																									
Glyceridae		1		1																					1	
Goniada sp.						1			1	1			1								1	1				
Aglaophamus sp.																3	1						1			
Onuphis aucklandensis						2		2				2														
Lumbrineridae		7	4	5	1	1	2	4	8	3	3	5	1	2	6	4	8	3	2	3	1	7	4	4	2	7
Dorvilleidae			2	3		3	1	1					2				3	1					1	2		
Myriochele sp.		1	1	2	2	4	2	3		1		1												1	1	
Ampharetidae															1	1			1							
Cirratulidae		4	8	3	2	10		2	3	3	5	5	3	7	5	6	10	4	7	12	10	7	9	2	4	4
Flabelligeridae	Polychaete worm																1		1			3		1	1	1
Sternapsis scutata														1		1										
Sternaspis scutata																										
Terebellidae					2	1		2				1	1				1	1		1	1	1	1			1
Terebellides stroemi																										
Sabellidae	Umbrella worms																									
Euchone pallida	Fan worm																					1	1			
MYSIDACEA	Mysid shrimp																									
CUMACEA	Cumaceans	5	4	1		1	3		7	1	2	8	4	3	9	4	30	8	7	5	3	17		3	10	12
TANAIDACEA																										
Tanaid sp.	Tanaid Shrimp	11	13	5	1	5	6	11	1	3		3					1									1
ISOPODA																										
Munna schauinslandii	Isopod			1			1		1			1							3							1
Natatolana pellucida	Fish lice							1																		
Asellota	Isopod	1	1									1		2	4		1	1	2	5	3	8	3	2	3	2
Gnathiidea																	1									1
Valvifera																	1									
AMPHIPODA																										
Amphipoda a	Amphipods	3		1	1	10	1		2	2	2	8		3	3	6	5	1	1	4	2	3	2		1	5
Amphipoda b	Amphipods	5	7	13	19	16	11	3	6	7	1	18	6	2	2	5	12	8	11		5	6	2		9	5
Amphipoda c	Amphipods					1					2		1			2	3								1	
Amphipoda d	Amphipods																									
Amphipoda e	Amphipods																									
DECAPODA																										
Ebalia laevis	Nut Crab																						1			
Notomithrax minor																			1		1					
OSTRACODA	Ostracods	2	4	2	3	2		3	1			1	1	1	1	2	2	1	2		3	5	2			
Echinoidea																										
Echinocardium cordatum	Heart Urchin																									1
OPHIUROIDEA																										
Ophiuroidea	Brittle stars			1				1				1		1	1		1							1		
ASCIDIACEA																										
Cnemidocarpa bicornuta	Saddle squirt																		1							
Didemnum sp. (white)	Encrusting white didemnum																		1							
Molgula sp.																										
	Taxa abundance	**79**	**78**	**68**	**54**	**91**	**55**	**87**	**52**	**35**	**28**	**75**	**42**	**62**	**53**	**57**	**141**	**69**	**102**	**95**	**83**	**99**	**43**	**30**	**51**	**62**
	Taxa richness	**20**	**20**	**21**	**16**	**22**	**16**	**18**	**19**	**15**	**12**	**21**	**19**	**19**	**17**	**19**	**27**	**19**	**25**	**20**	**23**	**28**	**18**	**17**	**20**	**19**

TAXA	COMMON NAME	Control1, A	Control1, B	Control1, C	Control1, D	Control1, E	Control2, A	Control2, B	Control2, C	Control2, D	Control2, E	Control3, A	Control3, B	Control3, C	Control3, D	Control3, E
POLYCHAETA																
Hesionidae					2		1	1			1	1	2	2		
Syllidae		1		1	2							1	1		2	
Sphaerosyllis sp.			1	1		1		1	1	1	1		1		2	
Nereidae	Rag worms	1														
Glyceridae				1					1							
Goniada sp.			1							2	1		1	2	2	3
Aglaophamus sp.		1													3	1
Onuphis aucklandensis								2			1					
Lumbrineridae		1	1		4	1	1	2	1	4	1	3	7		5	1
Dorvilleidae		1		2		1		4	2	1	1			2	1	1
Myriochele sp.																
Ampharetidae															1	1
Cirratulidae			2	3	3	4		6	7	6	6	7	2	6	2	5
Flabelligeridae	Polychaete worm	1	3	1		1		2	1	1	1					
Sternapsis scutata																
Sternaspis scutata			1	1										1	1	1
Terebellidae		1	1					3	1		1		1	1		
Terebellides stroemi																
Sabellidae	Umbrella worms	1			1											
Euchone pallida	Fan worm															
MYSIDACEA	Mysid shrimp													1		
CUMACEA	Cumaceans	4	1	5		2	2	4	1	4	8	2	3	5	4	1
TANAIDACEA																
Tanaid sp.	Tanaid Shrimp					2										
ISOPODA																
Munna schauinslandii	Isopod													1		
Natatolana pellucida	Fish lice															
Asellota	Isopod	1	1		1			1	1	1					2	2
Gnathiidea			1	1		1				1	1		1	2		
Valvifera																
AMPHIPODA																
Amphipoda a	Amphipods	1		2			1	1		2		2		1	1	
Amphipoda b	Amphipods					2	2	4		1	4	2		10	4	6
Amphipoda c	Amphipods	1	2	1	1	2							2			1
Amphipoda d	Amphipods											1				
Amphipoda e	Amphipods															
DECAPODA																
Ebalia laevis	Nut Crab															
Notomithrax minor																
OSTRACODA	Ostracods	1	4	5	3		2	4	1	3				1		
Echinoidea																
Echinocardium cordatum	Heart Urchin															
OPHIUROIDEA																
Ophiuroidea	Brittle stars				2										1	1
ASCIDIACEA																
Cnemidocarpa bicornuta	Saddle squirt					2										
Didemnum sp. (white)	Encrusting white didemnum															
Molgula sp.					1											
	Taxa abundance	**50**	**58**	**61**	**52**	**72**	**18**	**63**	**40**	**57**	**63**	**41**	**32**	**70**	**68**	**70**
	Taxa richness	**24**	**23**	**25**	**21**	**25**	**11**	**22**	**19**	**19**	**18**	**17**	**17**	**23**	**26**	**25**

Appendix 3. Sediment core photos

Cage 1

Cage 2

Cage 3

Control 1

Control 2

25 m

50 m

75 m

100 m

Control 1

Control 2

Appendix 4. Summary of the baseline and monitoring survey results of seabed condition at the Forsyth Bay salmon farm from 1993 to 2009

Author (year)	Environmental Issues/Improvements
1993 Roberts & Asher ***Baseline study***	The seafloor was predominantly soft, grey well-oxygenated mud, heavily littered with green-lipped mussels from the mussel long lines, with no evidence of seabed enrichment due to the deposition of faeces and pseudofaeces. The organic content of surficial sediments ranged from 3.2-6.2%. The wide range of taxa found at the site, and the lack of very high densities of any species suggest the macrofaunal communities were in a relatively undisturbed state.
1999 Brown (1999)	The sediments beneath the cages were highly enriched, as evidenced by a *Beggiatoa* sp. mat coverage of ~80%, an organic content of ~19%, a very strong hydrogen sulphide odour, out-gassing from the sediments, and a very low species abundance and diversity. Salmon feed was observed beneath the cages, a factor most likely contributing to the high enrichment. Sites located 25, 75, and 125 m away from the cages in the direction of the prevailing current had organic matter levels comparable to the control site. However the macrofaunal community structure found at all three sites was characterised by a low-moderate level of species diversity and increased numbers of few "opportunistic" species, which indicated a moderate level of enrichment.
2000 Forrest (2001)	The sediments beneath the cages were highly enriched. The sediments had a *Beggiatoa* sp. mat coverage of ~75%, an organic content of ~14%, a very strong hydrogen sulphide odour, out-gassing from the sediments. Salmon feed was observed beneath the cages. Impacts 50 m from the cages were low and impacts overall were slightly less than in previous years.
2001 Hopkins (2002)	At time of sampling the Forsyth Bay salmon farm had been partially relocated to Waihinau Bay. The seabed beneath the cages showed signs of high nutrient enrichment, as evidenced by a *Beggiatoa* sp. mat coverage of between 10-75%. No salmon feed present on the seabed at the time of sampling. The macrofaunal assemblages found at less impacted stations (*i.e.* 50 m, 75 m, 100 m and control sites) were characterised by a high diversity of co-dominant species; whereas enriched or impacted sediments (*i.e.* 25 m and cage stations) contained elevated densities of few opportunistic species (*e.g.* capitellid polychaetes).
2002 Hopkins (2003)	Some improvement of the seabed was apparent following the fallowing of the site 12 months prior. However, organic content at the cage sites had not declined and was still relatively high (mean=17%). The RPD depth remained at the sediment/water interface. However, it appeared that the RPD depth had increased at the 25 m site and possibly the 50 m and 75 m stations. Species richness and abundance had noticeably improved at the Cage 1, 25 m, 50 m and 75 m stations, providing evidence the recovery process at these stations had begun.
2003 Hopkins *et al.* (2004)	Seabed impacts beneath and immediately adjacent to the salmon farm were moderate and lessened with increasing distance from the farm, with impacts extending to approximately 50 to 100 m from the cages in a northeasterly direction. Seabed impacts inshore and to the south of the salmon farm were relatively low at 50 m from the cages, confirming observations that dispersion by currents from the farm was primarily in a northeasterly direction. Based on ROV footage and diver observations, impacts to the inshore habitat were limited to between 15-50 m from the cages.
2004 Hopkins *et al.* (2005)	Seabed impacts beneath and immediately adjacent to the salmon farm were moderate and lessened with increasing distance from the farm, with impacts extending to approximately 50 to 100 m from the cages in a northeasterly direction. There has been little improvement in seabed health, with sediment organic contents and infaunal communities similar to that determined during the 2003 monitoring survey.
2005 Hopkins *et al.* 2006	Seabed impacts beneath and immediately adjacent to the salmon farm were moderate and variable, and lessened with increasing distance from the farm, with impacts extending to approximately 50 m in a northeasterly direction. There has been some improvement in seabed health, with sediment organic contents showing a considerable decrease at Cage 1 and an increase in species richness at impacted sites, compared with the 2004 survey. Organic contents were highest at the 25 m site (12.7%), which corresponded with elevated densities of opportunistic taxa (*e.g.* Dorvilleids, capitellids, *Prionospio* sp. polychaetes).

2006 Govier & Bennett 2007	Seabed impacts beneath and immediately adjacent to the previous salmon farm was moderate and variable, and lessened with increasing distance from the farm, with impacts extending to approximately 25 m in a northeasterly direction. There were some improvements in seabed health, where the cage stations are grouped in with the down-current stations identifying that the stations are becoming similar. However there was an increase in sediment organic contents at Cage 1 and 2 sites, although this has not been farmed since 2001 it is likely to be through variability in the sediments. Species richness was similar to 2005 results for all sites except at the Cage 1 site which decreased. Organic contents were highest at the 25 m site (12.3%), although there were no elevated densities of opportunistic taxa present (*e.g.* Dorvilleids, capitellids, *Prionospio* sp. and polychaetes).
2007 Govier and Keeley 2008	Samples collected from beneath the historical cage sites indicate moderate and variable levels of impact with low to moderate (mean=6.1%) organic content. Infaunal community composition at beneath and near to (*i.e.* 25 m) the cage sites were comparable to background conditions. However, dark patches within the sediments and a mild hydrogen sulphide odour still indicate a moderate impact. Opportunistic species (nematodes and *C. capitata*) were virtually absent. Sediments at the 25 and 50 m down-current stations also showed slight nutrient enrichment; evidenced by slight hydrogen sulphide odours, sediment colour and high organic contents (9.8% and 9.5% respectively). General area still mildly impacted however conditions have improved significantly since fallowing in 2001 and slightly since 2006. Infauna communities nearly fully recovered.
2009 Present Study	Organic content was slightly elevated at one cage station, but similar to background conditions at the other two stations. Organic content was elevated at the 25 and 50 m stations (~11%). Infaunal abundance and richness under the cages and at down-current stations were comparable to control stations, but community composition was slightly different to some of the control communities. Opportunistic species (nematodes and *C. capitata*) were virtually absent. Copper and zinc levels averaged across all of the cage stations were below ISQG-Low levels, but one cage station had an average zinc concentration that was above the ISQG-Low level.