Cawthron Report No. 1000

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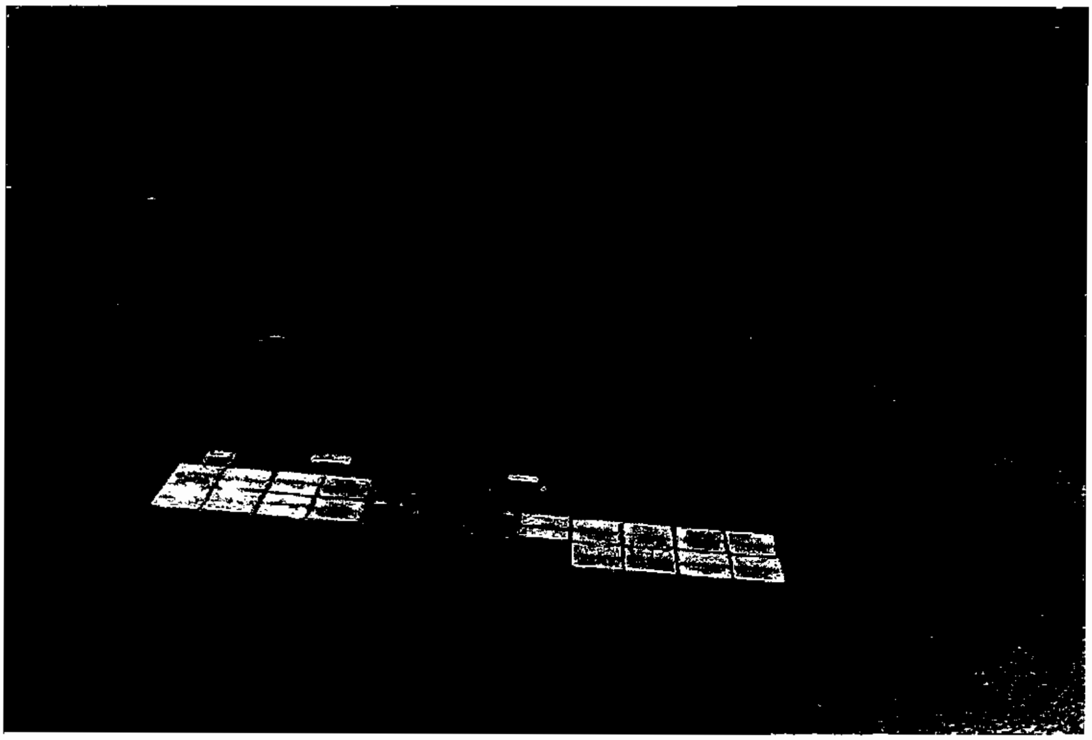
# Seabed Impacts of the Forsyth Bay Salmon Farm: Monitoring 2004



Prepared for

THE NEW ZEALAND
KING SALMON CO LTD

February 2005

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# Seabed Impacts of the Forsyth Bay Salmon Farm: Monitoring 2004

Prepared for

The New Zealand King Salmon Company Limited

by

Grant Hopkins, Murray Clarke
and Ralph Butcher

Cawthron Institute
98 Halifax Street East
Private Bag 2
NELSON
NEW ZEALAND

Phone: +64.3.548.2319
Fax: +64.3.546.9464
Email: info@cawthron.org.nz

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*Cover: Otanerau Bay salmon farm (Cawthron 2004)*

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Report reviewed by:

Paul A. Gillespie

Dr Paul Gillespie
Senior Scientist- Coastal Group

Approved for release by:

Dr Barry Robertson
Manager- Coastal Group

# 1 INTRODUCTION

The New Zealand King Salmon Company Limited (NZKS) currently farms Pacific King Salmon (*Oncorhynchus tshawytscha*) in sea cages at four sites in the Marlborough Sounds in waters ranging from around 25 to 40 m depth (Figure 1). An additional site in Forsyth Bay currently lies fallow after cages were moved to Waihinau Bay in November 2001. As part of their resource consent conditions, NZKS are required to undertake annual seabed (benthic) monitoring at these sites. These surveys also provide information about the need for, or success of, any mitigation measures implemented as part of the Company's operational practices. In September 2004, NZKS commissioned the Cawthron Institute (Cawthron) to monitor the seabed at the four operational salmon farm sites and at the fallowed site in Forsyth Bay. This report provides a summary of seabed monitoring undertaken at the Forsyth Bay salmon farm site.

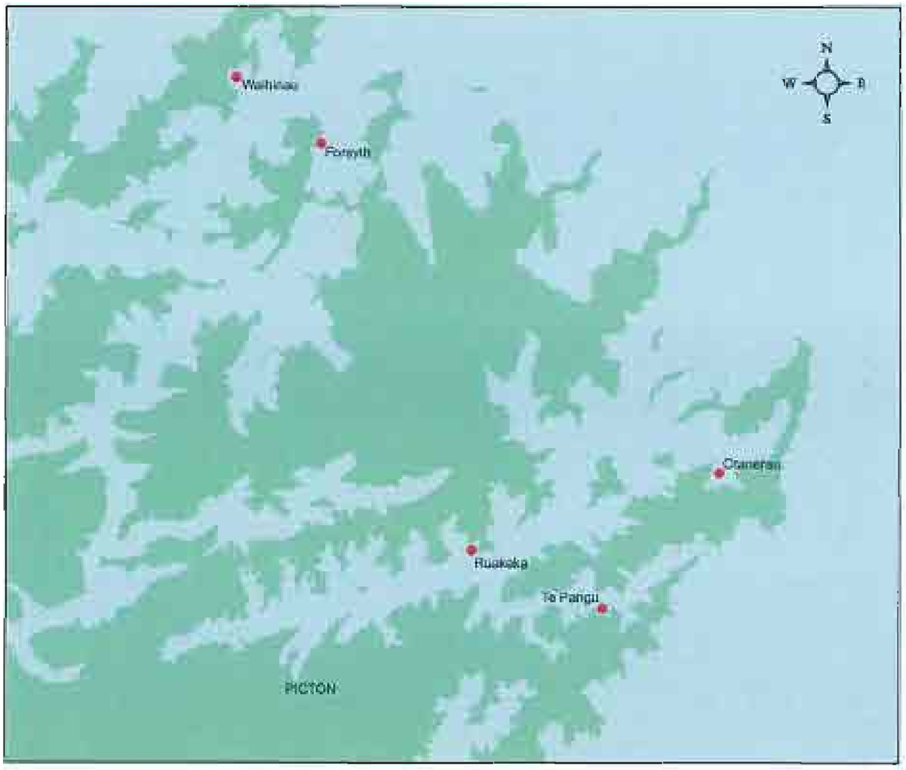

**Figure 1:** Location of the five NZKS salmon farm sites in the Marlborough Sounds. The Forsyth Bay site is not currently operational.

## 1.1 Background to salmon farming seabed impacts

The seabed impacts of the intensive sea cage rearing of salmon in relatively sheltered embayments have been well-documented (*e.g.* Gowen & Bradbury 1987; Brown *et al.* 1987, Findlay *et al.* 1995).

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 biodegradable organic wastes. Feed used by NZKS does not contain any antibiotics, vaccines, steroids or other growth enhancers.

**Table 1:** Main components of waste discharge from a marine farm (from Gowen & Bradbury 1987).

| Component of farm waste | Source | Impact to marine environment |
|---|---|---|
| Organic carbon and organic nitrogen | Largest components of faeces and waste | Organic enrichment of sediments |
| Ammonium and urea | Excretion by fish | 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 |
| Phosphate | Salmon feed | Unlikely to have a significant impact on the marine environment |
| Vitamins | Salmon feed | Poorly understood; but unlikely to be a significant environmental issue |

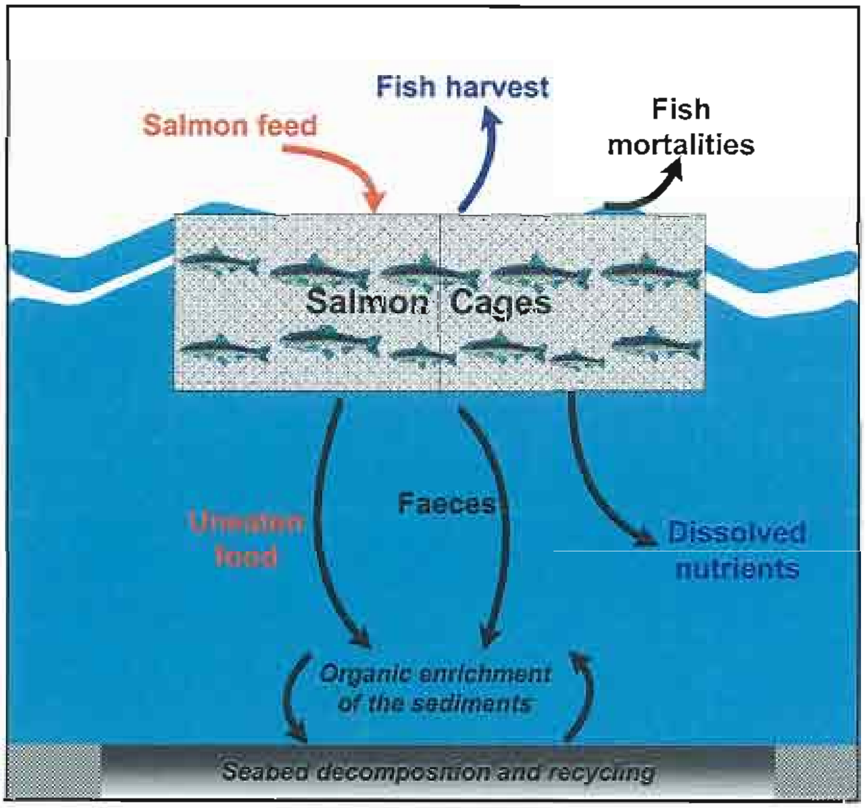

**Figure 2:** Simplified overview of major system inputs and outputs of nutrients in a typical salmon farm.

In addition to potential smothering effects of excessive sedimentation, microbial decay of the 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 species abundance (*e.g.* Forrest 2001; Hopkins 2003, 2004).

## 1.2 Seabed indicators of organic enrichment

Various physical, chemical and biological properties can be used as indicators of the level of seabed impact beneath a salmon farm site. The particular measures commonly used to assess salmon farm effects, which we have also adopted, are summarised in Table 2.

**Table 2:** Indicators of seabed impacts.

| Indicator type | Description |
|---|---|
| **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 the RPD layer | Un-enriched 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. |
| **2.** Sediment odour | Un-enriched sediments are typically relatively odourless, whereas excessively enriched and anoxic sediments have a strong 'rotten egg' smell of hydrogen sulphide ($H_2S$). |
| **3.** Out-gassing | Visible as bubbles rising to the sea surface, out-gassing is another symptom of excessive enrichment. 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). |
| **4.** Mat-forming filamentous bacteria (*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). |
| **5.** 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 (see below) to salmon farm effects (Crawford *et al.* 2001). |
| **6.** 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 such 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). |

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[1] Macrofauna are infauna retained on a 0.5 mm mesh sieve.

[2] Opportunistic species are typically characterised by a short life span, short development time to reach maturity, high death rate and many reproductive cycles per year (*e.g.* polychaetes, small bivalves and crustaceans).

## 2 SAMPLING METHODOLOGIES

In recent years, there have been several changes to the NZKS annual monitoring programme, reflecting the increased knowledge of the seabed environments beneath and adjacent to the farm sites and advances in sampling technology (*e.g.* remotely operated vehicles to collect samples). Additional sampling has also been undertaken to ensure that typically sensitive near-shore habitats have not been adversely affected by the marine farming activities.

Seabed sampling was undertaken at the fallowed Forsyth Bay salmon farm site during the 4-5th November 2004. Refer to Figure 3 for sampling locations and Appendix B for the complete species lists for each sampling station.

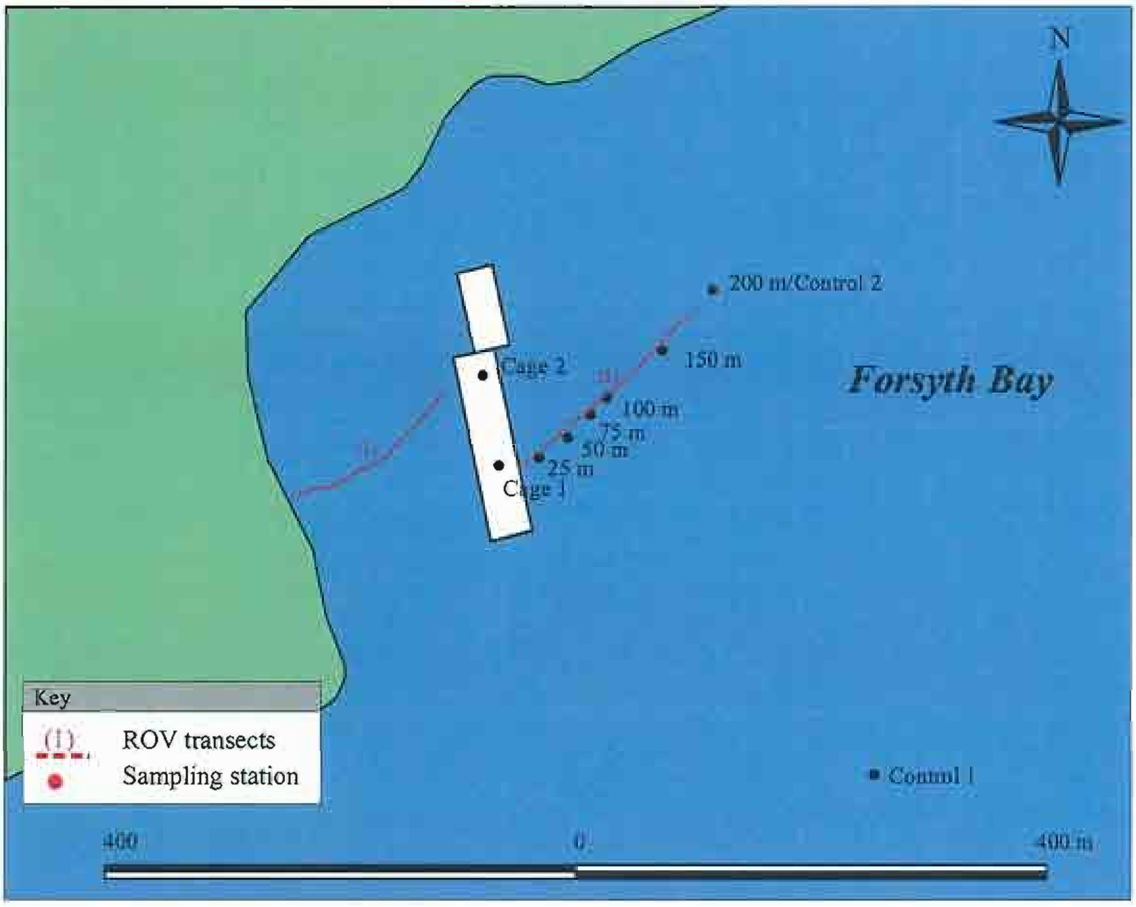

**Figure 3:** Site map of the fallowed Forsyth Bay farm site, indicating seabed sampling stations (dots) and ROV video transects (dotted lines).

## 2.1 Physical, chemical and biological properties of the sediments: sampling and analyses

The annual monitoring programme involved collecting replicate (three) sediment samples sites using either a van Veen grab sampler (where possible) or a ROV (equipped with a seabed sampling device) from seabed sites beneath and adjacent to the prior location of salmon cages at the Forsyth Bay farm site (refer Figure 3). Footage of the seabed at each sampling station was obtained by the ROV and was viewed on a TV monitor onboard the vessel, with the footage recorded to DVD. ROV transects were undertaken inshore of the prior location of farm cages to monitor potential seabed impacts to typically sensitive near-shore habitats, and to identify species/habitats that may require more regular surveillance. During each transect, the main seabed characteristics and the biota present were noted, along with the GPS coordinates (start/stop), time of sampling, DVD time, and water depth.

At each of the sampling sites, key indicators of seabed enrichment were assessed from visual observations as follows:

(i) From sediment cores, the depth of the RPD-layer from the sediment/water interface was measured and photographed

(ii) The coverage of mat-forming filamentous bacteria (referred to in this report as *Beggiatoa* sp.) was estimated from the ROV footage.

(iii) Epifaunal communities were described from ROV footage and diver observations.

(iv) The presence of out-gassing from the sediment was visually assessed.

(v) The presence of sulphide odours from sediment cores was noted.

A subset of the seabed samples collected were retained and transported to Cawthron for quantitative analyses, as follows:

- Sediment core sample (63 mm diameter): All cores were photographed and the top 25 mm of each was collected for analyses of sediment grain size and organic matter content. Grain size was determined gravimetrically by wet sieving after drying at 105°C, for gravel (≥2 mm), sand (≥63 µm - <2 mm) and silt/clay (<63 µm) size classes. Organic content was assessed by measuring the Ash Free Dry Weight (AFDW) of sediments following drying at 105°C, then ashing at 550°C to a constant weight (method modified from that of Luczak *et al.* 1996).
- Sediment zinc concentrations were determined from a composite of the cage site samples. This involved sample drying at 30°C, hot acid extraction (USEPA 2002 Modified), and analysis via

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) (analytical method APHA 1998 20th Ed 3120B).

- Macrofaunal core sample (130 mm diameter, approx. 100 mm deep): The core contents were gently sieved through a 0.5 mm mesh and animals retained were preserved in 70% ethanol in seawater, and transported back to Cawthron for identification and counting.

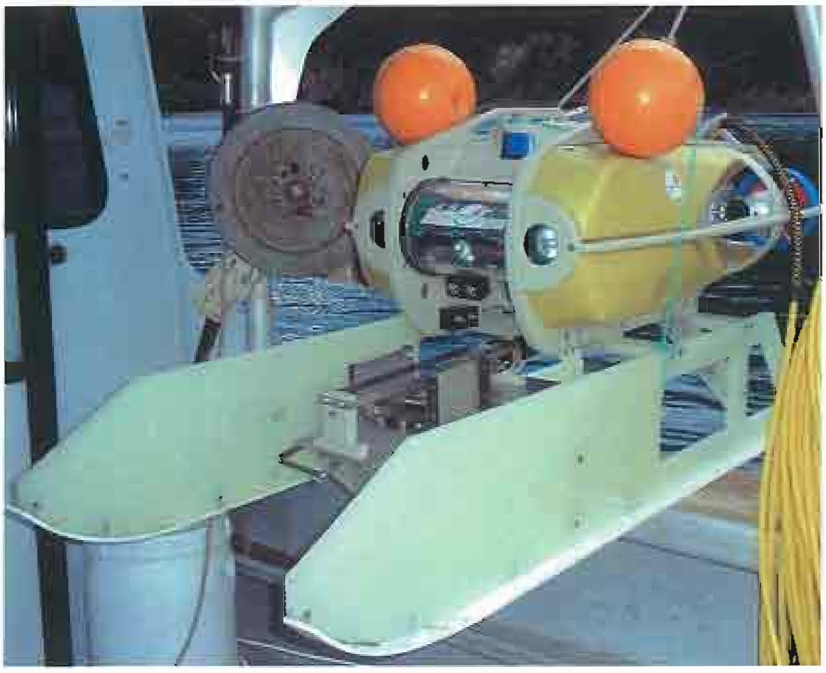

**Photo 1:** Remotely operated vehicle (ROV) at the surface prior to descending to the seabed. The ROV was equipped with purpose-built sediment sampler and a colour video camera and tethered to a TV/DVD recorded at the surface via an umbilical cord (right).

## 2.2 Assessing the significance of impacts

Table 3 presents the key indicators of seabed enrichment described above, and provides criteria by which the condition of each 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 classified, 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 "high impact" score of 20-30. 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 Ruakaka Bay salmon farm, and a more complete explanation of its derivation and use can be found in that report. One point that should be reiterated, however, is that the method is provisional and provides only a 'rough guide' to the severity of farm impacts. It was originally proposed as an operational guide for NZKS rather than a method for regulatory compliance or other purposes.

**Table 3:** 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) | Moderate impact (score=20) | 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 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 macro-fauna compared with control or baseline | Comparable | High dominance and/or reduced richness | Absent or greatly reduced in density & richness |

### *Data analyses*

In addition to the graphical presentation of data on macrofaunal densities and richness, a Bray-Curtis similarity matrix was constructed from fourth-root transformed[3] taxonomic data. From this, the relative similarity among sampling stations (in terms of the species present and their abundance) was depicted graphically with non-metric Multi Dimensional Scaling (MDS) and cluster analyses, using PRIMER 5 (Plymouth Laboratories) statistical software. Species that were characteristic of the infaunal communities present at different sampling stations ('clusters') were identified using a Similarity Percentage (SIMPER) analysis.

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[3] A fourth-root transformation effectively reduces the influence of species occurring in high numbers and increases the influence of species occurring in low numbers on the ordination plots.

# 3 SEABED MONITORING RESULTS & DISCUSSION

## 3.1 Physical, chemical and biological properties of the sediments

*Beneath the cages*

Sediments sampled from beneath the salmon farm cages showed signs of nutrient enrichment, despite being fallowed for three years at the time of sampling. Sediment cores were a dark grey/black gritty mud and produced a moderate hydrogen sulphide odour, indicating a degree of anoxic conditions (Table 4). Sediment RPD layers were at the sediment-water interface or quite shallow, with the top 80 mm of the cores composed of a black 'gritty' layer overlying dark grey, cohesive mud. Grain size analyses indicated that the sediments were composed largely of mud with a higher proportion of sands (with some shell material) at cage site 1, compared with cage site 2 (Figure 4). The organic content of the sediments beneath the prior location of the cages was elevated and high but variable, measuring on average 12 and 6% (AFDW) for cage sites 1 and 2, respectively (Figure 5).

The organic content of the sediments generally decreased with increasing distance from the farm; which is consistent with the enrichment gradient observed at the site immediately following fallowing. However, the 25 m site contained unexpectedly high levels (Figure 5), which is inconsistent with previous years' monitoring. Possible explanations include sampling within a localised 'hot-spot', or that sampling was undertaken 'offsite' (*i.e.* sampling undertaken on the seabed beneath the prior location of the cages rather than at 25 m from the farm boundaries). Due to the positional accuracy of GPS and the use of sonar to position the ROV, it is likely that a localised patch of highly enriched sediments was sampled.

**Table 4:** Summary of the physical and chemical properties of the sediments determined at the Forsyth Bay salmon farm during the 2004 monitoring survey.

| Site | Depth (m) | Sediment % silt/clay | Sediment % organic | Black zone depth (mm) | *Beggiatoa* (% cover) | Out-gassing (Y/N) | Feed %cover | Sulphide Odour |
|---|---|---|---|---|---|---|---|---|
| Cage 1 | 31.9 | 71 | 12 | Shallow (variable) | None | N | None | Low to Moderate |
| Cage 2 | 31.9 | 40 | 6 | 5-10 | None | N | None | Moderate |
| 50 m | 33.1 | 65 | 5 | 5-25 | None | N | None | Moderate |
| Control 1 | 32.5 | 83 | 4 | 40-60 | None | N | None | Slight/none |
| Control 2 | 32.1 | 79 | 4 | 30-70 | None | N | None | Slight/none |

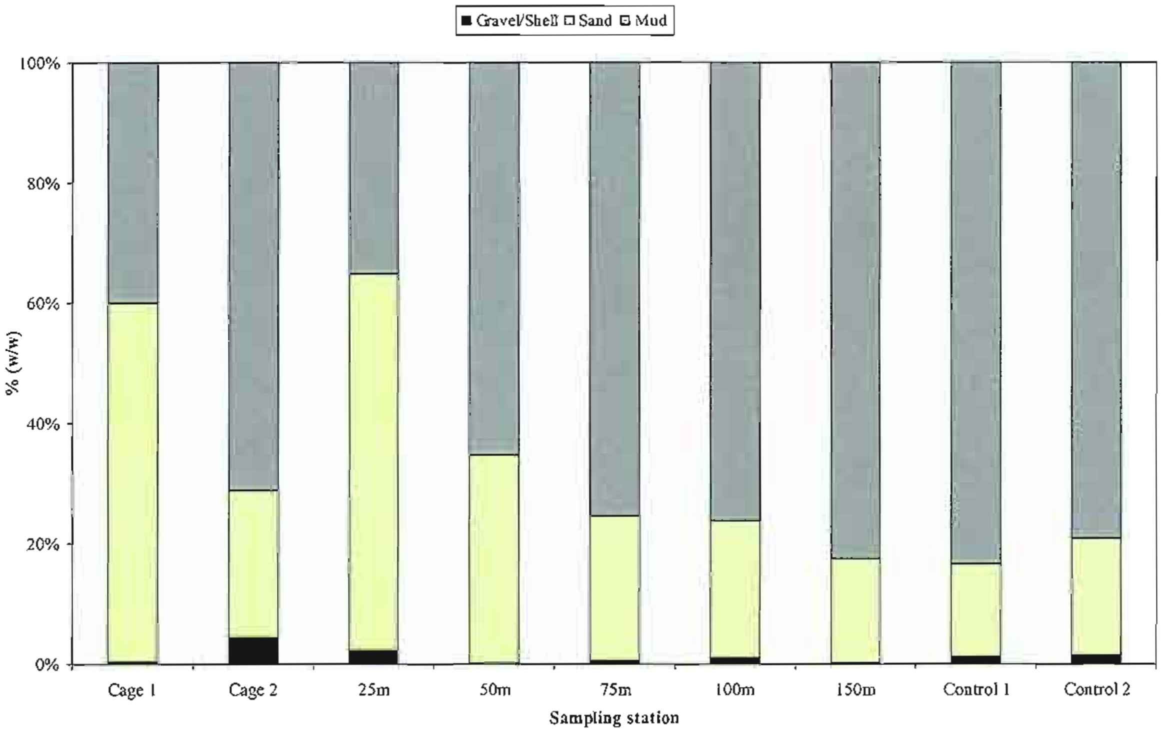

**Figure 4:** Grain size distribution of sediments collected from stations adjacent to the salmon farm cages at the Forsyth Bay salmon farm, and at the two control sites during the 2004 monitoring survey.

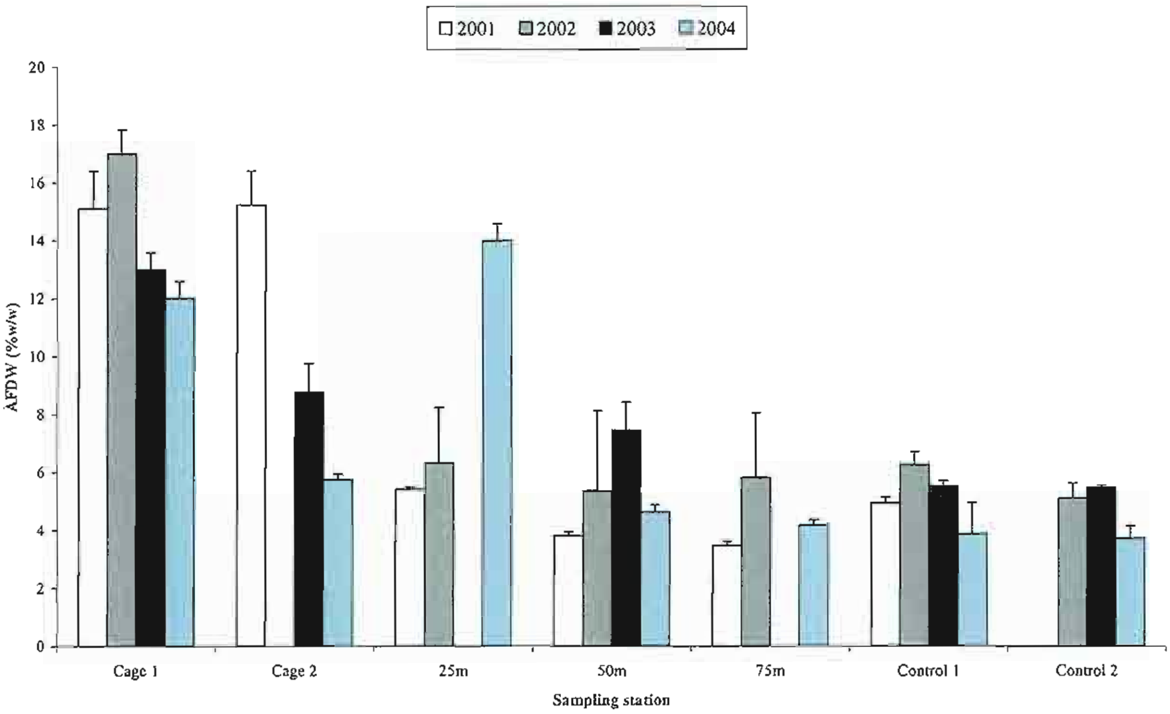

**Figure 5:** Organic matter content (AFDW) in sediments at the Forsyth Bay salmon farm monitoring sites from 2001-2004.

ROV footage of the seabed beneath the cages revealed sediments with a mottled appearance (typical of anaerobic sediments), with no obvious epibiota other than the occasional opal fish. Interestingly, there was no sign of the bacterial mat *Beggiatoa* sp. on the sediments, whereas it was observed in variable densities (5 to 90% cover) during the 2003 monitoring survey. With increasing distance from the farm, the mottled appearance diminished, with sediments at 150 m cages showing no obvious sign of impact. Worm holes and epifaunal taxa (*e.g.* cushion stars and the occasional scallop) became more abundant beyond 50-75 m from the farm.

Spatial patterns in the composition and dominance of the macrofaunal community were consistent with the succession model proposed by Pearson & Rosenberg (1978); with reduced species richness (number of taxa per core) and higher infaunal densities in the enriched sediments beneath the cages, with an increase in species richness and a slight decrease in animal densities with increasing distance from the farm. Infauna within the sediments at the cage sites were dominated by polychaetes (*e.g.* dorvilleids, *Prionospio* sp.), nematodes and small bivalves (*Theora lubrica*). Importantly, opportunistic polychaete species (in particular *Capitella capitata*) were present in very low abundance in only one of the cage site 1 samples. Interestingly, samples collected from the 25 m site had similar species composition to that measured at the cage 1 site (Figure 6), refer Appendix B for the taxonomic count data); indicating similarly high impacts at this site. This is consistent with the results of the physical/chemical properties of the sediments and visual observations (*e.g.* sediment colour, texture and odour).

Macrofaunal communities 50 m from the farm cages had similar species richness to that measured at the cage and 25 m sites; however, animal abundance for several taxa was lower (*e.g.* dovilleids, *Prionospio* sp.). Sites 75 m and further from the cage sites along the main transect had relatively similar species richness; however, animal abundance was higher at the 75 m, 100 m and control 2 sites than at the 150 m and control 1 sites (Figure 6). These results are consistent with last years' monitoring, indicating little or no noticeable recovery in seabed condition at the site over the past twelve months (Figure 8). A complete species list for each sampling station is given in Appendix B.

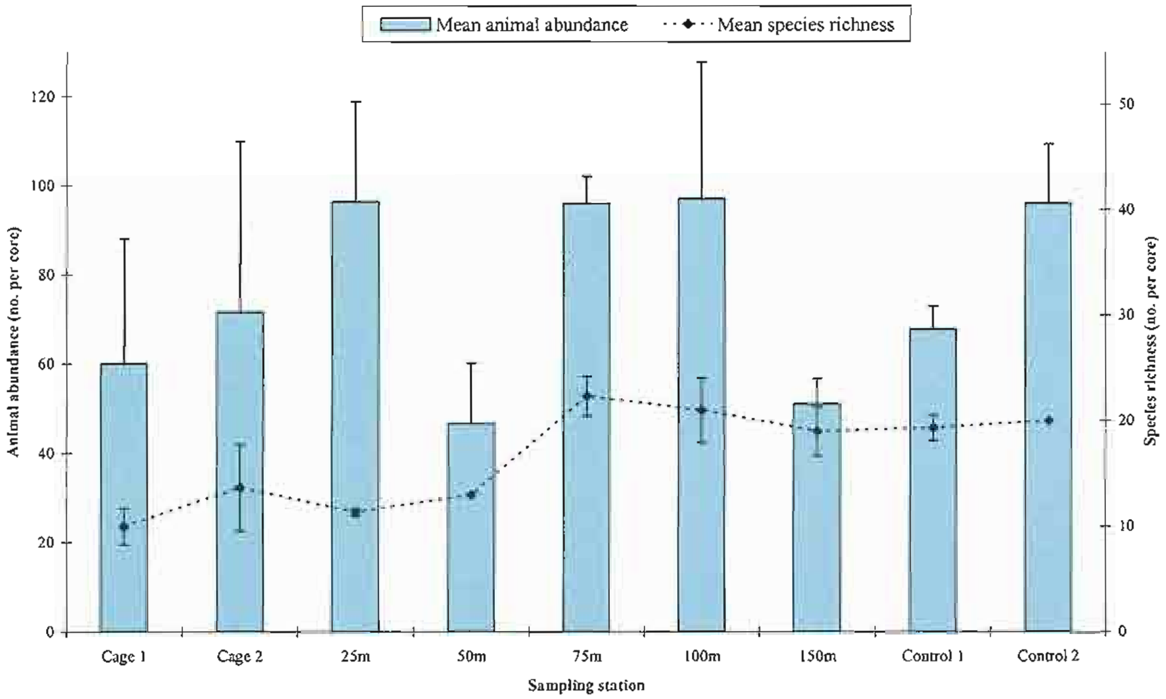

**Figure 6:** Mean animal abundance and species richness per sediment core (area=0.013m²) collected in 2004 from stations beneath and adjacent the prior location of salmon farm cages at the Forsyth Bay salmon farm, and at two control sites. Data are plotted as means (±1SE).

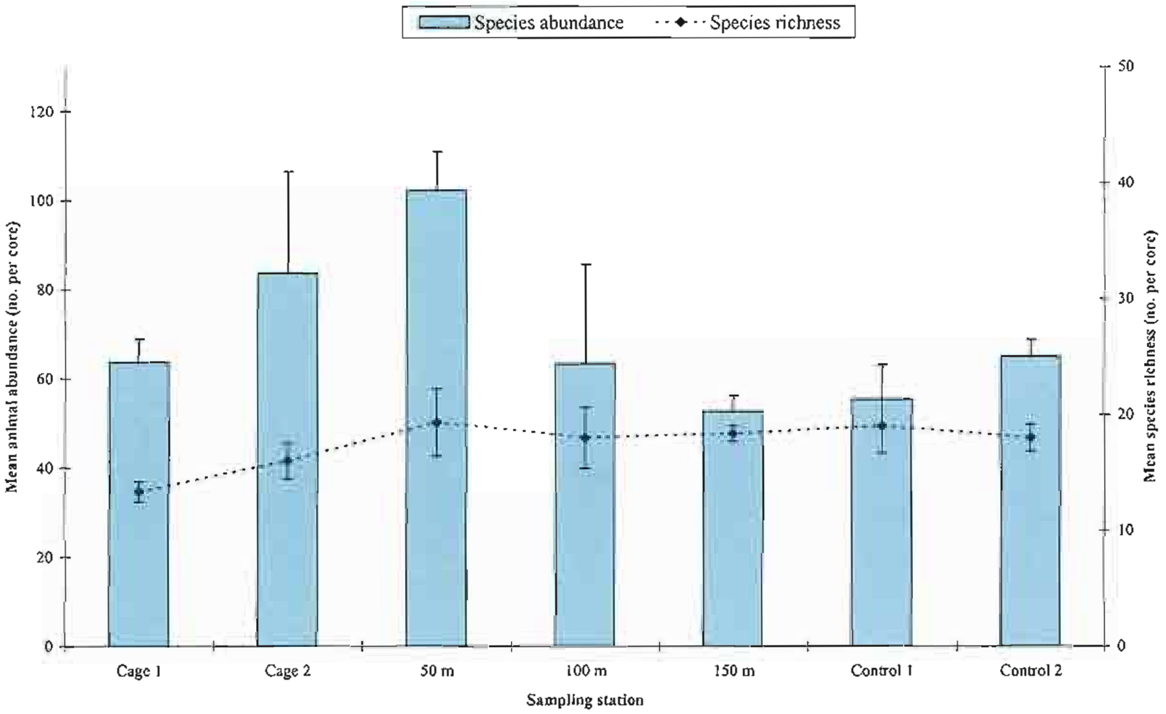

**Figure 7:** Mean animal abundance and species richness per sediment core (area=0.013m²) collected in 2003 from stations beneath and adjacent the prior location of salmon farm cages at the Forsyth Bay salmon farm, and at two control sites. Data are plotted as means (±1SE).

### 3.2 Differences amongst sampling stations

Multi-dimensional scaling (Figure 8) provides an indication of the 'similarity' amongst the sampling sites and outlines the key distinguishing biological characteristics responsible for the formation of these separate groupings (indicated by dotted lines). Nine distinct groups were formed, based on a 60% level of similarity. As Figure 8 shows, a gradient in seabed condition is evident based on the presence/absence and relative abundance of infaunal taxa, which is consistent with the results of physical/chemical analyses and visual observations of the seabed. The most impacted sediments (*i.e.* cage 1 and 25 m sites) formed Groups A and C, while the least impacted sites (*i.e.* Control and 150 m sites) also formed distinct groupings (Groups E and F) and were most distant (in terms of similarity) from the cage sites. Sites located down-current of the farm site formed several groupings, suggesting that an enrichment gradient still exists beyond 50 m from the prior location of the farm cages, which is consistent with the 2003 monitoring results.

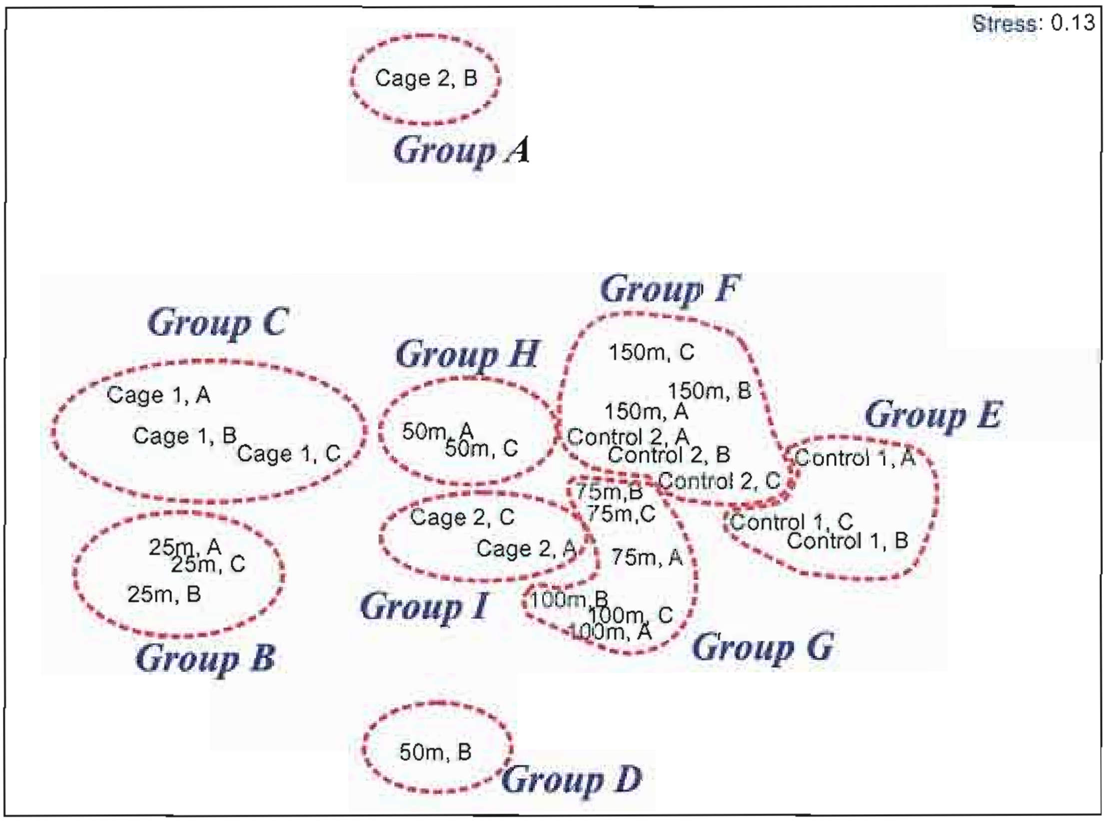

**Figure 8:** Multi-dimensional scaling plot of infauna samples collected from sampling stations beneath and adjacent to the former location of salmon farm cages at the Forsyth Bay salmon farm, and at two control sites. Data were fourth-root transformed (Stress=0.13). Groups (shown by dotted lines) were formed based on a 60% level of similarity.

### 3.3 Comparison with previous surveys at the Forsyth Bay salmon farm

Table 5 summarises the results of the 1993 baseline survey and the seabed monitoring conducted subsequently. Since post-development monitoring was initiated in 1998, consistently high impacts beneath the cages have been documented at the Forsyth Bay site. Survey results are somewhat inconsistent in that they suggest variability in the severity and spatial extent of impacts from year to year. While seabed monitoring is undertaken at about the same time each year and along a similar transect, the inherent variability that exists in the marine environment, as well as slight methodological changes over the years, means that some of the trends described in Table 5 are potentially explainable by sampling variation. Nevertheless, the noticeable improvement in seabed health over the last three years indicates that seabed recovery is occurring at this fallowed site.

#### *Seabed recovery with fallowing*

The Forsyth Bay site was fallowed in November 2001, which included the removal of all farming structures (*i.e.* cages, anchor warps, barges *etc*). The results of the 2004 monitoring revealed variable results in terms of seabed recovery at the site compared to the previous survey in 2003. Ecologically significant improvements in seabed health since fallowing include:

- An increase in the RPD depth at the sampling stations at 25 m, 50 m and 75 m away from the prior location of farm cages.
- A reduction in the organic matter content of the sediments beneath and adjacent to the prior location of salmon cages (Figure 5). However, over the past twelve months, the organic content in the sediments beneath the cages has remained on average the same (cage 1 was 13%, now 12%; cage 2 was 8.8%, now 6%).
- A large reduction in the number of opportunistic polychaetes, specifically *Capitella capitata,* in the sediments below and immediately adjacent to the cage positions (Figure 9).
- A general increase in species richness and animal abundance in the sediments below and immediately adjacent to the cage position. For example, several species of polychaete worms (*e.g.* Dorvilleid polychaetes, *Prionospio* sp.), brittle stars, small bivalves (*e.g. Theora lubrica*) and amphipods have returned to the sediments beneath the cages since fallowing in 2001.

The rate of recovery at the Forsyth Bay site is expected to increase over time, as the recolonisation of impacted sediments by burrowing infaunal species 'works the sediments over', thus increasing the flushing and oxygenation of the sediments (P. Gillespie, Cawthron, pers. comm.). However, the latest monitoring results indicate suggest that recovery may have slowed over the past twelve months. Future monitoring at the site will provide a better understanding of the recovery processes at the Forsyth Bay site.

The reduction in organic matter of sediments would be expected to decrease over time (*i.e.* concentrations would likely decrease sharply at first and then level off). The more recalcitrant materials may take many years to burn off. However, associated enrichment effects should continue to decrease independently of the slower decline of organic matter concentrations.

**Table 5:** Summary of the baseline survey and monitoring results of seabed condition at the Forsyth Bay salmon farm site between the 1993 baseline and 2004.

| Author (year) | Environmental Issues/Improvements |
|---|---|
| 1993<br>Roberts & Asher<br>***Baseline study*** | The seafloor was predominantly soft, grey well-oxygenated mud heavily littered with green shell 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<br>Brown (1999) | The sediments beneath the cages was 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<br>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 were slightly less than in previous years. |
| 2001<br>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 within less modified sediments (*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 cage sites) contained elevated densities of few opportunistic species (*e.g.* Capitellid polychaetes). |
| 2002<br>Hopkins (2003) | Some improvement of the seabed is apparent since 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 sites. Species richness and abundance had noticeably improved at the cage 1, 25 m, 50 m and 75 m sites, providing evidence the recovery process at these sites had begun. |
| 2003<br>Hopkins (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 north-easterly 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 is primarily in a north-easterly direction. Based on ROV footage and diver observations, impacts to the inshore habitat were limited to between 15-50 m from the cages. |
| 2004<br>Present study | 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 north-easterly direction. There has been little improvement in seabed health, with sediment organic contents and infaunal communities present that were similar to that determined during the 2003 monitoring survey. |

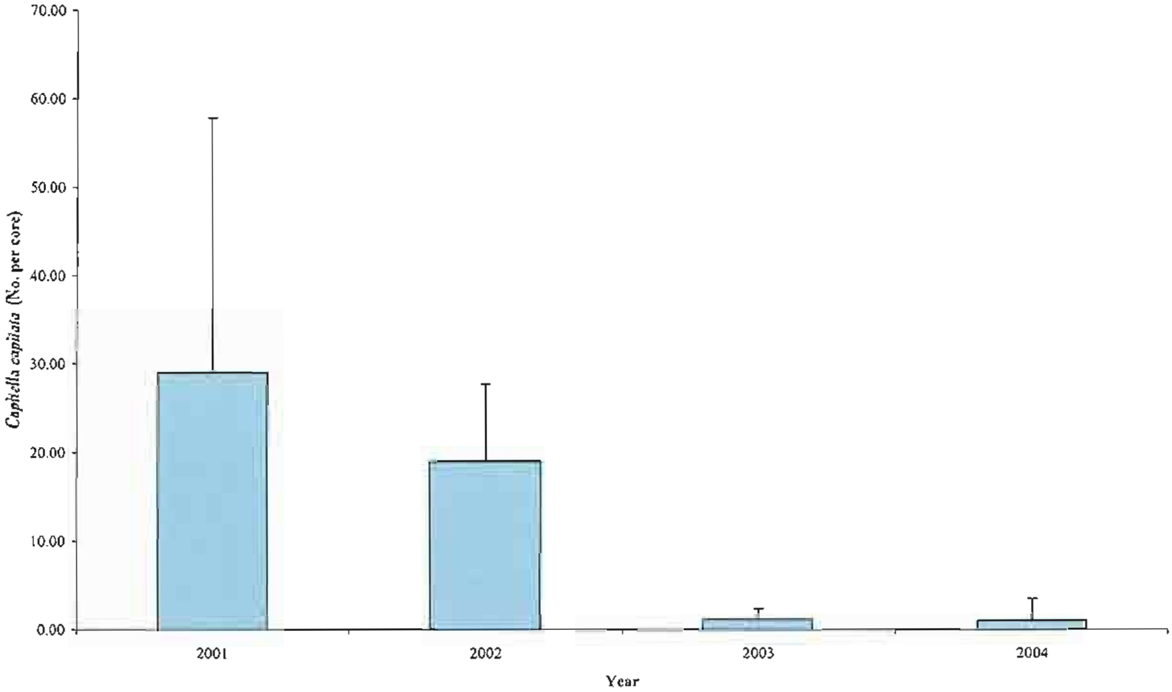

**Figure 9:** Mean number of *Capitella capitata* (an opportunistic polychaete) per core ($0.013m^2$) sampled beneath salmon cages (or former location) between 2001 and 2004 (±1SD). High densities of capitellid polychaetes are typically 1000 individuals/$m^2$ or greater (ANZECC 2000 guidelines).

There is relatively limited published information on the recovery rates of sediments beneath fish farms. Brooks *et al.* (2003) describe complete recovery rates, both in terms of chemical (*e.g.* organic content) and biological (*e.g.* infauna) properties following four to six months of fallow at salmon farm sites in British Columbia. Brooks *et al.* (2003) also describe studies that measured recovery times of up to two years at highly impacted sites. The latest monitoring results from the Forsyth Bay site show that both chemical and biological recovery is not yet complete following three years of fallow. This indicates that recovery rates of salmon farms in the Marlborough Sounds can potentially take several years, particularly if the sites are highly impacted prior to fallowing, and that recovery rates are probably controlled by environmental factors at the site (*e.g.* current velocities, sediment grain size *etc*). Refer to Section 7 for a discussion on the implications of the rate of recovery on using fallowing as a mitigation tool.

### 3.4 Sediment contaminants- Copper & 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 and zinc are both 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), and overseas studies have described environmentally significant levels in sediments beneath salmon cages (Morrisey *et al.* 2000; Solberg *et al.* 2002; Brooks *et al.* 2003).

Copper-based paints are needed since there is no practical way to mechanically clean the predator nets, and it is essential to prevent excessive bio-fouling so that water flow is maintained through the farm. In contrast to the overseas work, however, a cursory assessment at the NZKS farm sites in 2002 revealed copper levels in composite samples collected beneath the cages were well within the acceptable trigger value of 65 mg/kg recommended as a conservative interim sediment quality guideline (ISQG-low) by ANZECC (2000). This result suggests that the use of copper-based anti-fouling on the predator nets has not posed a significant environmental risk to date.

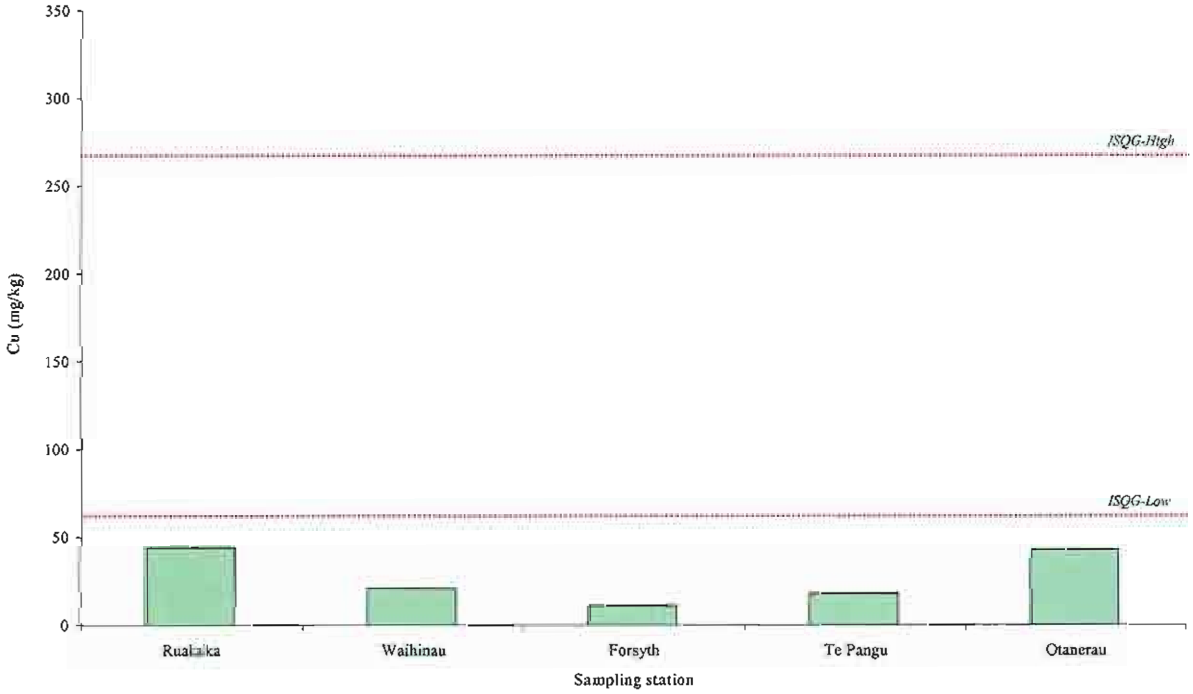

**Figure 10:** Copper concentrations within sediments collected beneath NZKS farm sites during the 2002 monitoring programme. ANZECC Interim Sediment Quality Guideline levels (ISQG-low and ISQG-High) are provided.

Morrisey *et al.* (2000) measured the concentration of zinc and copper within sediments beneath a poorly-flushed farm site in Big Glory Bay (Stewart Island) that had been fallowed for 12-months prior to sampling. Copper was shown to be variable, with some high concentrations detected, but overall the concentrations were relatively low and similar to the control site levels. However, zinc concentrations were consistently high at the site, and exceeded the ISQG-high trigger of 410 mg/kg (mean=665 mg/kg), indicating a 'probable' biological effect (ANZECC 2000). However, given the high levels of organic matter and sulphides beneath salmon farms, it is questionable that zinc would in fact be biologically available (Morrisey *et al.* 2000; Brooks *et al.* 2003).

Zinc is added to salmon feed as a supplement at concentrations between 100-200 mg/kg (pers. comm. Mark Gillard, NZKS). Zinc concentrations beneath the NZKS farm sites were measured during the 2004 monitoring survey. Concentrations ranged from 67 to 510 mg/kg (mean=381 mg/kg), and in most cases exceeded the ANZECC ISQG-High trigger (Figure 11). Sediments beneath the Te Pangu Bay site had the lowest concentration of zinc, which is most likely due to the environmental conditions at the site. Interestingly, studies at sites overseas located in similar depths and current regimes found at the NZKS farm sites demonstrated that zinc declined to background concentrations following 4-6 months of fallowing (Brooks *et al.* 2003). Surprisingly, zinc levels at the fallowed Forsyth Bay site are still above the ISQG-high threshold, despite being fallowed for three years at the time of sampling. These results suggest that long term monitoring of zinc levels would be justified, if future studies show that zinc concentrations measured beneath the NZKS farm sites are elevated with respect to background levels. In addition, investigating the biological availability of the enhanced zinc loadings would provide a better indication of the significance of the effects.

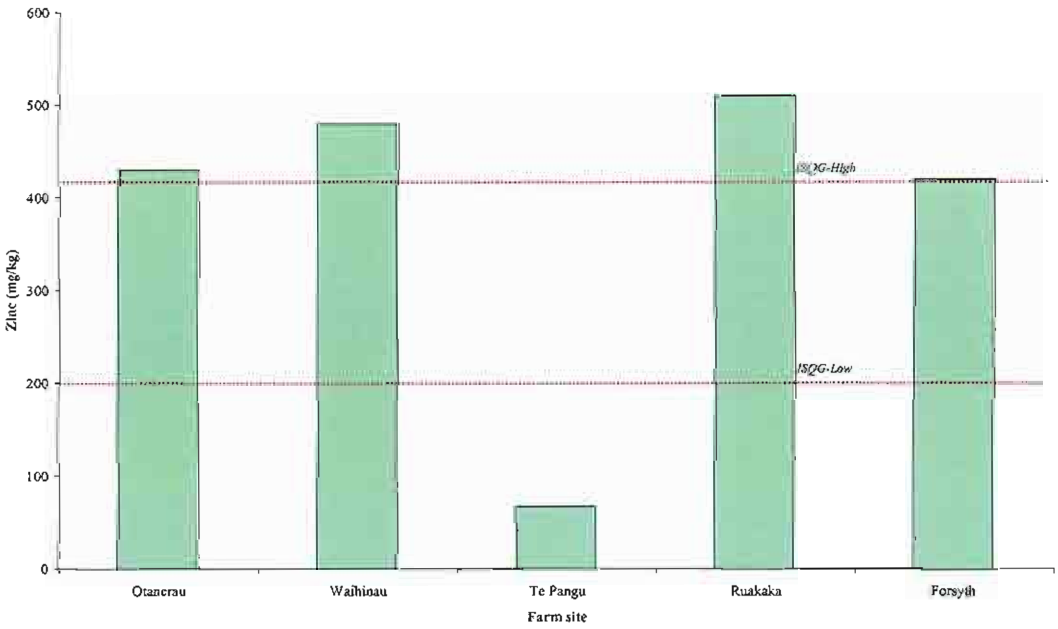

**Figure 11:** Zinc concentrations within sediments collected beneath NZKS farm sites during the 2004 monitoring programme. ANZECC Interim Sediment Quality Guideline levels (ISQG-low and ISQG-High) are provided.

# 4 SUMMARY

Cawthron has been monitoring seabed and water column environments in the vicinity of the Forsyth Bay site since the baseline monitoring survey (Roberts & Asher 1993) was undertaken. Listed below are some of the main lessons learned from the monitoring undertaken at this site during this time:

- The shape of the depositional "footprint" and the magnitude of seabed impacts can vary significantly from site to site, due to factors such as water currents and water depth. The predicted depositional footprint of Forsyth Bay farm site is smaller than that predicted for most other NZKS sites, due to the weaker currents operating at the Forsyth Bay site. However, monitoring has consistently found relatively localised, high level seabed impacts at this site. This has implications regarding the appropriate citing of future salmon farms in New Zealand's coastal waters.
- Results of the present study indicated that seabed impacts beneath and immediately adjacent to the Forsyth Bay salmon farm were moderate and lessened with increasing distance from the farm, with impacts extending to approximately 50 m to 100 m from the cages in a north-easterly direction. There has been little improvement in seabed health, with sediment organic contents and infaunal communities present that were similar to that determined during the 2003 monitoring survey. The rate of recovery at the Forsyth Bay site is expected to increase over time, as the recolonisation of impacted sediments by burrowing infaunal species 'works the sediments over', thus increasing the flushing and oxygenation of the sediments (P. Gillespie, Cawthron, pers. comm.). However, future monitoring at the site will provide a better understanding of the recovery processes at the Forsyth Bay site.
- Based on ongoing monitoring at the Forsyth Bay farm site, seabed recovery following the fallowing of a site may take several years. Conversely, observations made at the Waihinau Bay site suggest that seabed condition can quickly deteriorate once farming is resumed at the site, even if full recovery is achieved prior to restocking cages at the site. This has implications for the use of fallowing as a mitigation tool at NZKS sites.
- 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. At present, levels of copper beneath the Forsyth Bay salmon farm is within sediment quality criteria; however, zinc levels are elevated. Given the high levels of organic matter and sulphides within the sediments at this site, it is questionable that zinc would in fact be biologically available. Future monitoring will address this issue.

- 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 the phytoplankton and macroalgae enrichment, in particular toxic algal blooms. Synoptic water-column nutrient monitoring at several NZKS sites indicates that there is 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 relative 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 does not increase the frequency and magnitude of phytoplankton bloom events in the region.
- While overseas literature is useful in providing comparisons and in identifying potential environmental issues associated with finfish farming, the issues identified are not always directly applicable to New Zealand farming situations. For example, NZKS do not use antibiotics to control diseases, or use vaccines, steroids or other growth enhancers. Another major difference is that salmon farming intensity in the Marlborough Sounds is much less than that found in other countries (*e.g.* Scotland, Canada), and the industry operates under a different regulatory framework.

### 4.1 Comment on the monitoring programme

It is recommended that monitoring at the NZKS farm sites should continue on an annual basis, with the inclusion of copper and zinc comparisons beneath cages versus control sites if additional studies show that concentrations beneath the NZKS farm sites are elevated with respect to background levels. However, it is expected that further changes may be made to the monitoring programme in response to future monitoring results and/or changes in management practices.

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# Appendix A:

## Sampling coordinates

## **Appendix A:** Seabed sampling coordinates.

| **Station** | **NZMG_E** | **NZMG_N** |
|---|---|---|
| Cage site 1 | 2595662 | 6024346 |
| Cage site 2 | 2595652 | 6024431 |
| 25m site down-current | 2595698 | 6024355 |
| 50m site down-current | 2595716 | 6024369 |
| 75m site down-current | 2595738 | 6024392 |
| 100m site down-current | 2595760 | 6024419 |
| 150m site down-current | 2595789 | 6022620 |
| Control site 1 | 2595989 | 6024096 |
| 200m site/control site 2 | 2595834 | 6024524 |
| Inshore ROV transect#1 start | 2595631 | 6024372 |
| Inshore ROV transect#1 stop | 2595510 | 6024431 |
| Offshore ROV tansect#1 start | 2595687 | 6024347 |
| Offshore ROV tansect#1 stop | 2595820 | 6024514 |

# Appendix B

## Taxonomic Count Data (Monitoring 2004)

## **Appendix B:** Taxonomic count data.

| Taxa | Cage 1 A | Cage 1 B | Cage 1 C | Cage 2 A | Cage 2 B | Cage 2 C | 25m A | 25m B | 25m C | 50m A | 50m B | 50m C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nemertea | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Nematoda | 7 | 4 | 47 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 0 | 1 |
| Priapula | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sipuncula | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cadulus teliger* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Gastropoda (white rissoid like) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropoda unid. juv. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Philine auriformis* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Arthritica bifurca* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bassina yatei* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dosinia lambata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ennucula strangei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Leptomya retiaria retiaria* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| *Neilo australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nemocardium pulchellum* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Notocallista multistriata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nucula cf gallinacea* | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Serratina charlottae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Theora lubrica* | 6 | 6 | 14 | 0 | 1 | 3 | 14 | 20 | 12 | 3 | 0 | 2 |
| *Zenatia acinaces* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Ampharetidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cossura consimilis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| *Orbinia papillosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Paraonidae | 0 | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 7 |
| *Prionospio* sp. | 8 | 15 | 19 | 13 | 2 | 34 | 37 | 21 | 22 | 25 | 6 | 13 |
| Cirratulidae | 0 | 0 | 1 | 16 | 0 | 15 | 0 | 0 | 2 | 6 | 1 | 12 |
| *Capitella capitata* | 0 | 0 | 6 | 0 | 0 | 0 | 1 | 1 | 4 | 0 | 0 | 0 |
| *Heteromastus filiformis* | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| *Notomastus zeylanicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maldanidae | 0 | 0 | 0 | 3 | 1 | 5 | 0 | 0 | 0 | 0 | 1 | 0 |
| *Armandia maculata* | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 3 | 0 | 0 | 0 |
| Phyllodocidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Polynoidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sigalionidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hesionidae | 0 | 0 | 3 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Syllidae | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphaerosyllis hirsula* | 0 | 1 | 1 | 6 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| Glyceridae | 1 | 2 | 3 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 2 |
| *Aglaophamus macroura* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Onuphis aucklandensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lumbrineridae | 0 | 0 | 5 | 6 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 3 |
| Dorvilleidae | 4 | 3 | 12 | 8 | 0 | 39 | 74 | 22 | 18 | 3 | 2 | 8 |
| Flabelligeridae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Terebellidae | 0 | 1 | 3 | 0 | 0 | 3 | 3 | 0 | 2 | 1 | 1 | 0 |
| *Terebellides stroemi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sabellidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Nebalia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cumacea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 5 |
| *Tanaid* sp. | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Anthuridea* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Flabellifera | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gnathiidea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Amphipoda | 1 | 1 | 1 | 1 | 0 | 6 | 4 | 5 | 3 | 5 | 2 | 7 |
| *Macrophthalmus hirtipes* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| *Ostracoda* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Copepoda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| *Echinocardium cordatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ophiuroidea | 0 | 0 | 0 | 1 | 1 | 4 | 2 | 2 | 0 | 1 | 0 | 2 |
| *Heterothyone alba* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pentadactyla longidentis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aplidium phortax* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Corella eumyota* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total animal abundance** | **28** | **36** | **116** | **69** | **7** | **139** | **141** | **77** | **71** | **56** | **20** | **64** |
| **Total No. of species** | **7** | **10** | **13** | **15** | **6** | **20** | **11** | **11** | **12** | **13** | **13** | **13** |

**Appendix B (Continued):** Forsyth Bay salmon farm infauna species list.

| **Taxa** | **75m, A** | **75m, B** | **75m, C** | **100m, A** | **100m, B** | **100m, C** | **150m, A** | **150m, B** | **150m, C** |
|---|---|---|---|---|---|---|---|---|---|
| Nemertea | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Nematoda | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| Priapula | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sipuncula | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Cadulus teliger* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Gastropoda (white rissoid like) | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Gastropoda unid. juv. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Philine auriformis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Arthritica bifurca* | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| *Bassina yatei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dosinia lambata* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Ennucula strangei* | 1 | 2 | 2 | 0 | 0 | 0 | 3 | 4 | 2 |
| *Leptomya retiaria retiaria* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Neilo australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Nemocardium pulchellum* | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| *Notocallista multistriata* | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Nucula cf gallinacea* | 2 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 0 |
| *Serratina charlottae* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Theora lubrica* | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 1 | 1 |
| *Zenatia acinaces* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ampharetidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cossura consimilis* | 8 | 2 | 0 | 3 | 8 | 8 | 1 | 0 | 1 |
| *Orbinia papillosa* | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| Paraonidae | 8 | 4 | 12 | 4 | 13 | 3 | 5 | 1 | 6 |
| *Prionospio* sp. | 11 | 10 | 3 | 5 | 6 | 3 | 1 | 0 | 2 |
| Cirratulidae | 12 | 8 | 7 | 12 | 14 | 5 | 6 | 9 | 4 |
| *Capitella capitata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Heteromastus filiformis* | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Notomastus zeylanicus* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Maldanidae | 12 | 9 | 18 | 15 | 25 | 25 | 0 | 0 | 0 |
| *Armandia maculata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phyllodocidae | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Polynoidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sigalionidae | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 2 |
| Hesionidae | 1 | 2 | 1 | 3 | 0 | 4 | 1 | 1 | 1 |
| Syllidae | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Sphaerosyllis hirsula* | 1 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 |
| Glyceridae | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| *Aglaophamus macroura* | 0 | 3 | 1 | 0 | 2 | 0 | 1 | 1 | 0 |
| *Onuphis aucklandensis* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Lumbrineridae | 4 | 3 | 4 | 5 | 6 | 2 | 6 | 3 | 9 |
| Dorvilleidae | 6 | 4 | 10 | 13 | 9 | 15 | 0 | 1 | 0 |
| Flabelligeridae | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Terebellidae | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 |
| *Terebellides stroemi* | 2 | 4 | 0 | 7 | 5 | 2 | 0 | 0 | 0 |
| Sabellidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nebalia* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Cumacea | 7 | 10 | 14 | 2 | 3 | 1 | 4 | 3 | 1 |
| *Tanaid* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| *Anthuridea* sp. | 4 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | 1 |
| Flabellifera | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Gnathiidea | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| Amphipoda | 13 | 13 | 13 | 5 | 7 | 12 | 11 | 12 | 9 |
| *Macrophthalmus hirtipes* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ostracoda* | 1 | 0 | 1 | 2 | 0 | 1 | 8 | 3 | 0 |
| Copepoda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Echinocardium cordatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Ophiuroidea | 2 | 2 | 1 | 1 | 1 | 2 | 3 | 1 | 2 |
| *Heterothyone alba* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pentadactyla longidentis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aplidium phortax* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Corella eumyota* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **Total animal abundance** | **106** | **85** | **97** | **89** | **103** | **99** | **62** | **48** | **43** |
| **Total No. of species** | **26** | **21** | **20** | **23** | **15** | **25** | **23** | **19** | **15** |

**Appendix B (Continued):** Forsyth Bay salmon farm infauna species list.

| Taxa | Control 1, A | Control 1, B | Control 1, C | Control 2, A | Control 2, B | Control 2, C |
|---|---|---|---|---|---|---|
| Nemertea | 1 | 0 | 1 | 1 | 1 | 0 |
| Nematoda | 6 | 0 | 2 | 2 | 0 | 0 |
| Priapula | 1 | 0 | 2 | 0 | 0 | 0 |
| Sipuncula | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cadulus teliger* | 0 | 2 | 2 | 0 | 0 | 0 |
| Gastropoda (white rissoid like) | 0 | 0 | 0 | 0 | 0 | 1 |
| Gastropoda unid. juv. | 0 | 0 | 0 | 0 | 1 | 0 |
| *Philine auriformis* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Arthritica bifurca* | 0 | 0 | 0 | 1 | 0 | 0 |
| *Bassina yatei* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dosinia lambata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ennucula strangei* | 5 | 7 | 5 | 3 | 5 | 4 |
| *Leptomya retiaria retiaria* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Neilo australis* | 0 | 1 | 0 | 0 | 0 | 0 |
| *Nemocardium pulchellum* | 0 | 0 | 1 | 0 | 0 | 0 |
| *Notocallista multistriata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nucula cf gallinacea* | 2 | 1 | 2 | 2 | 1 | 8 |
| *Serratina charlottae* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Theora lubrica* | 0 | 0 | 0 | 2 | 1 | 0 |
| *Zenatia acinaces* | 0 | 0 | 0 | 0 | 0 | 0 |
| Ampharetidae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cossura consimilis* | 3 | 1 | 1 | 1 | 1 | 4 |
| *Orbinia papillosa* | 0 | 1 | 0 | 0 | 0 | 0 |
| Paraonidae | 1 | 2 | 7 | 10 | 3 | 2 |
| *Prionospio* sp. | 0 | 0 | 1 | 2 | 3 | 3 |
| Cirratulidae | 18 | 30 | 14 | 8 | 5 | 8 |
| *Capitella capitata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Heteromastus filiformis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Notomastus zeylanicus* | 0 | 0 | 0 | 0 | 0 | 0 |
| Maldanidae | 0 | 5 | 3 | 1 | 1 | 0 |
| *Armandia maculata* | 0 | 0 | 0 | 0 | 0 | 0 |
| Phyllodocidae | 0 | 0 | 0 | 0 | 0 | 0 |
| Polynoidae | 0 | 0 | 1 | 0 | 0 | 1 |
| Sigalionidae | 3 | 4 | 5 | 0 | 0 | 1 |
| Hesionidae | 1 | 0 | 0 | 3 | 0 | 10 |
| Syllidae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphaerosyllis hirsula* | 1 | 0 | 2 | 0 | 2 | 2 |
| Glyceridae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aglaophamus macroura* | 1 | 1 | 0 | 0 | 0 | 0 |
| *Onuphis aucklandensis* | 0 | 0 | 0 | 0 | 0 | 0 |
| Lumbrineridae | 0 | 0 | 0 | 8 | 8 | 10 |
| Dorvilleidae | 0 | 0 | 0 | 1 | 0 | 0 |
| Flabelligeridae | 0 | 1 | 2 | 0 | 0 | 1 |
| Terebellidae | 1 | 1 | 2 | 0 | 1 | 2 |
| *Terebellides stroemi* | 0 | 0 | 0 | 0 | 0 | 0 |
| Sabellidae | 0 | 0 | 0 | 2 | 0 | 0 |
| *Nebalia* sp. | 0 | 0 | 0 | 0 | 0 | 0 |
| Cumacea | 3 | 2 | 4 | 21 | 7 | 29 |
| *Tanaid sp.* | 1 | 0 | 0 | 0 | 1 | 1 |
| *Anthuridea* sp. | 0 | 0 | 0 | 0 | 0 | 0 |
| Flabellifera | 0 | 0 | 0 | 0 | 0 | 0 |
| Gnathiidea | 0 | 0 | 0 | 1 | 0 | 1 |
| Amphipoda | 1 | 2 | 6 | 12 | 22 | 8 |
| *Macrophthalmus hirtipes* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ostracoda* | 2 | 2 | 5 | 7 | 4 | 14 |
| Copepoda | 0 | 0 | 0 | 0 | 0 | 0 |
| *Echinocardium cordatum* | 0 | 0 | 0 | 0 | 1 | 0 |
| Ophiuroidea | 5 | 6 | 8 | 3 | 7 | 11 |
| *Heterothyone alba* | 1 | 0 | 0 | 0 | 0 | 0 |
| *Pentadactyla longidentis* | 1 | 0 | 0 | 0 | 0 | 0 |
| *Aplidium phortax* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Corella eumyota* | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total animal abundance** | **58** | **69** | **76** | **91** | **76** | **121** |
| **Total No. of species** | **20** | **17** | **21** | **20** | **20** | **20** |