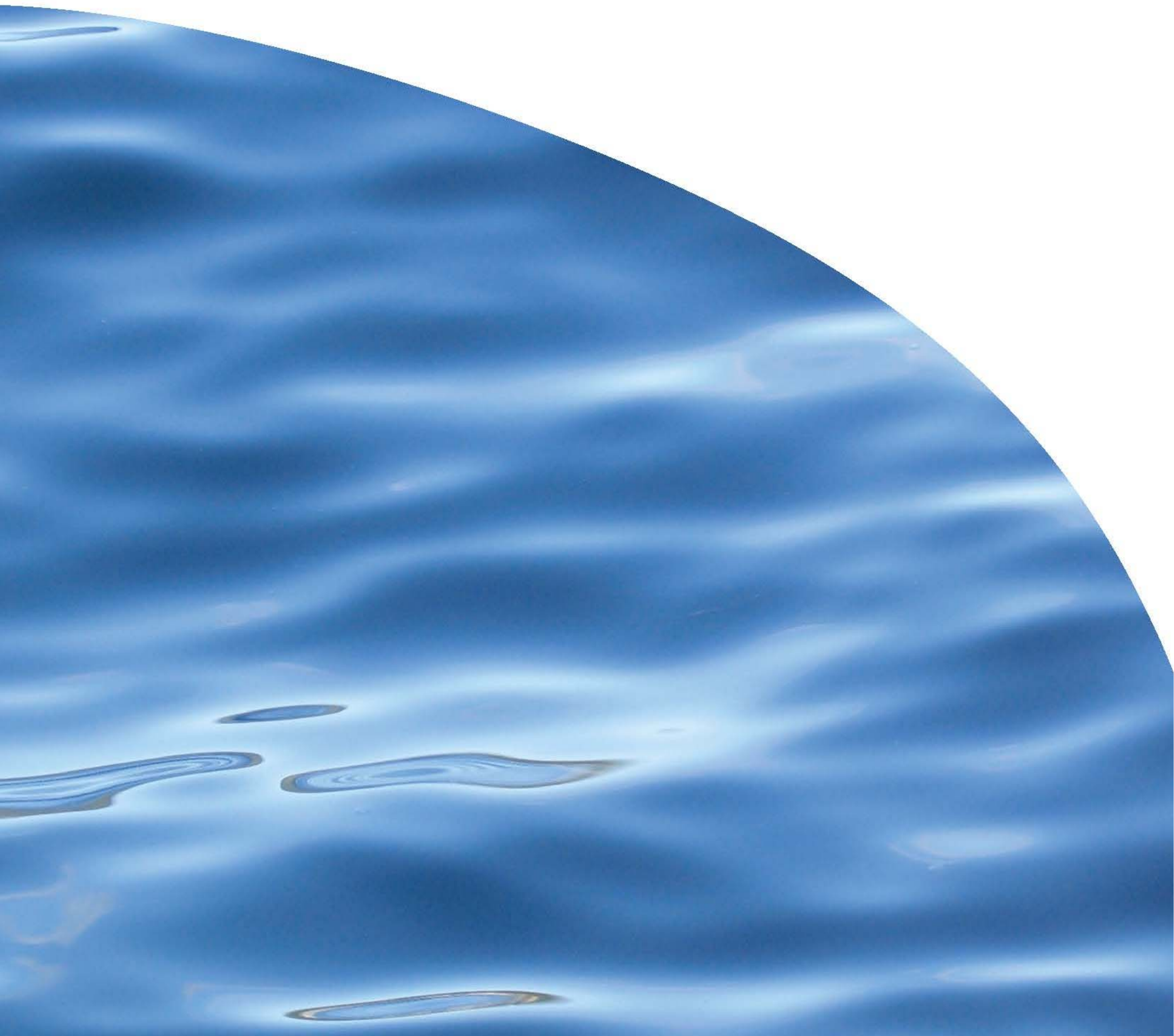
CAWTHRON INSTITUTE

REPORT NO. 2427

# NEW ZEALAND KING SALMON COMPANY LIMITED ANNUAL MONITORING PROGRAMME AND METHODS: 2013



# NEW ZEALAND KING SALMON COMPANY LIMITED ANNUAL MONITORING PROGRAMME AND METHODS: 2013

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ISSUE DATE: 13 November 2013

RECOMMENDED CITATION: Keeley N 2013. New Zealand King Salmon Company Limited Annual Monitoring Programme and Methods: 2013. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2427. 15 p.

# 1. INTRODUCTION

The New Zealand King Salmon Company Limited (NZ King Salmon) operates eight consented farm sites in the Marlborough Sounds. Each of those farms is monitored annually pursuant to a monitoring programme. NZ King Salmon has requested that Cawthron Institute (Cawthron) provide an overview of the monitoring that will be undertaken at each farm site in November 2013 in order to provide clarity for interested parties. Monitoring will be consistent with that undertaken in 2012, except for the alterations that this report outlines. Hence, this report constitutes an Annual Monitoring Plan for 2013 and is an addendum to Cawthron Report No. 2080 (Keeley Et al. 2012), which outlines the original methods for calculating Enrichment Stage (ES). This report is not intended to be a complete or comprehensive methods document.

# 2. PROPOSED MONITORING PROGRAMME FOR 2013

## 2.1. Overview

Table 1 summarises the types and levels of monitoring that will be conducted at each of the eight farm sites during the 2013 monitoring. For some sites, additional reef and water column monitoring is required; either due to the farms proximity to potentially sensitive reef habitats or because it is one of the farms that was designated for local-scale water column monitoring.

Less intensive, indicator monitoring is proposed for the two Crail Bay farms (MFL-32 and -48) because they have not been utilised (de-stocked) and were easily compliant with the farm-specific EQS for the last two years.

Table 1. Summary of 'type' of local seabed monitoring (normal / indictor) and 'level' of copper (Cu) and zinc (Zn) monitoring (refer Sneddon *et al.* 2012) for the upcoming year for each farm.

| Site | Survey type | Cu & Zn | Reefs | Water column |
|---|---|---|---|---|
| TEP | Normal | Tier 1 | 4 stations | Yes |
| CLA | Normal | Tier 1 | 4 stations | Yes |
| OTA | Normal | Tier 2 | - | Yes |
| RUA | Normal | Tier 2 | - | Yes |
| WAI | Normal | Tier 2 | - | No |
| FOR | Normal | Tier 2 | - | Yes |
| MFL-32 | Indicator | Tier 1 | - | Yes — net pen only |
| MFL-48 | Indicator | Tier 1 | - | Yes — net pen only |

## 2.2. Evaluating seabed enrichment

### *2.2.1. Proposed sampling locations for 2013*

The proposed sampling locations for the upcoming year are detailed in Table 2 and are discussed further in Table 3.

Table 2. Summary of proposed benthic monitoring stations for each farm during the 2013 annual monitoring surveys. FF = Far field

| Farm | Transect(s) | Sampling stations: Pens (or 1/2 if 4-Zone) | Zone 1/2 (or 2/3 if 4-Zone) | Zone 2/3 (or 3/4 if 4-Zone) | Other | Ref-near | Ref-FF |
|---|---|---|---|---|---|---|---|
| **TEP** | NE<br>NW | Pen1<br>Pen2 | 75 m<br>75 m | 300 m<br>300 m | 90 m<br>90 m<br>Embayment | TC-Ctl-2 | TC-Ctl-3 |
| **CLA** | E<br>W<br>N | Pen1<br>Pen2 | 75 m<br>75 m | 300 m<br>300 m | 90 m<br>90 m<br>Inshore | TC-Ctl-1<br>TC-Ctl-4 | |
| **OTA** | E | Pen1<br>Pen2<br>Pen3 | 50 m | 150 m | | QC-Ctl-1 | QC-Ctl-2 |
| **RUA** | S | Pen1<br>Pen2 | 50 m | 150 m | | QC-Ctl-3 | QC-Ctl-4 |
| **WAI** | SE | Pen1<br>Pen2 | 60 m | 180 m | | PS-Ctl-1 | PS-Ctl-3 |
| **FOR** | NE | Pen1<br>Pen2<br>Pen3 | 50 m | 150 m | | PS-Ctl-2 | |
| **MFL-32** | E | Pen1<br>Pen2 | 50 m | 150 m | | CB-Ctl-1 | |
| **MFL-48** | E | Pen1<br>Pen2 | 50 m | 150 m | | | |

Table 3. Description of transect alignments and proposed sampling adjustments for the 2013 annual monitoring.

| |
|---|
| **Te Pangu**<br>• The north-east transect is the traditional down-current (worst-case) direction and the additional north-west transect is aligned in a direction perpendicular to the predominant current direction. The direction of the second NW transect was also selected because it is aligned with the secondary, down-current direction.<br>• The down current transects will be sampled at 75 and 300 m, as opposed to the 50 m and 200 m specified in the consent as an assumed deformity of 50% has been applied. The distances along the perpendicular transect are shorted accordingly, to the same degree.<br>• The down-current transects will also be sampled at 90 m in anticipation of the upcoming s 127 application, in which it will be proposed that the Zone 2/3 boundary be extended, consistent with Clay Point. This will enable us to check the appropriateness of that distance.<br>• The Embayment sample has traditionally been sampled (voluntarily) to monitor for potential enrichment in the inshore embayment. |
| **Clay Point**<br>• The Clay Point farm is monitored along the east and west transects because these down-current directions were selected from predictive modelling and subsequent effects monitoring. For the first three years after farm establishment a NE transect was also monitored, but this was discontinued in 2009.<br>• Sampling is conducted at 75 m and 300 m as opposed to the 50 m and 250 m specified in the consent conditions because deformity is permitted in down-current directions. The 50 m station is deformed to a standard 50%, whilst the deformity of the 250 m stations is constrained to 300 m due to substrate and bathymetry.<br>• The 90 m site is consistent with the distances applied for under a s 127 application (90 m and 300 m), for which a decision is likely around the time of monitoring.<br>• The s 127 application also proposes establishing additional monitoring stations in a neighbouring far-field location and at an inshore site (locations to be determined). This is a precautionary measure in response to a temporary increase in feed and the removal of the EQS requiring that conditions at the Zone 3/4 boundary are ‘comparable to natural’. |
| **Otanerau**<br>• The Otanerau farm is sampled along an eastern transect, as opposed to the northern down-current direction because the farm structures are occasionally extended or contracted in the north direction. Sampling is required to be oriented in relation to the net pen edge and therefore the 50 m site would otherwise often be either situated in recovering sediments (beneath where the |

| | |
|---|---|
| | pens had recently been) or further away in an area that has had very little recent deposition. Being a low-flow site, deformity is not a great issue and therefore a perpendicular transect was selected to overcome the problem posed by altering pen configurations. |
| **Ruakaka** | |
| | • This farm is monitored in primary down-current (southern) direction. |
| **Waihinau** | |
| | • There are no existing benthic environmental quality standards at this site and it is monitored on a voluntary basis. Sampling occurs in the SE direction, consistent with the main down-current direction. It is proposed that monitoring takes place at 60 m and 180 m (as opposed to the traditional 50 m and 150 m for low-flow sites) from the pen edge, because the site has a low to moderate flow regime, with potential for some deformity / footprint expansion (relative to traditional low-flow sites). |
| **Forsyth** | |
| | • Forsyth is monitored in these locations for reasons of bathymetry and proximity to neighbouring mussel farms. It is a very low-flow site, therefore the direction is not particularly critical. |
| **MFL-32** | |
| | • Monitored on an eastern transect perpendicular to shore for reasons of bathymetry and proximity to neighbouring mussel farms — north and south.<br>• Reduced monitoring is proposed because the farm not been utilised (de-stocked) and was easily compliant with the farm-specific EQS for the last two years. |
| **MFL-48** | |
| | • Monitored on an eastern transect perpendicular to shore for reasons of bathymetry and proximity to neighbouring mussel farms — to the north and south.<br>• Reduced monitoring is proposed because the farm not been utilised (de-stocked) and was easily compliant with the farm-specific EQS for the last two years. |

### 2.2.2. Standard sampling protocol

At each sampling station, sediment samples will be collected using a suitable boat-operated grab. Each successful (full) grab will constitute a replicate (*i.e.* three independent grabs are required when sampling in triplicate) that will be sub-sampled for the required parameters.

For monitoring at all farms other than Crail Bay, the following sub-sampling will occur:

- A **sediment core** sample (63 mm diameter): each core will be qualitatively assessed for sediment colour, odour and texture. The top 30 mm of each sample will be quantitatively analysed for organic content as ash-free dry weight (AFDW), and copper and zinc concentrations (see Sneddon *et al.* 2012 for Cu and Zn sampling protocol).
- **Redox and sulphides:** Redox potential will be measured directly from the grab at 1 cm depth using a probe, and total free sulphides will be ascertained from a 5 ml syringe driven at 45º angle into the surface sediment.
- A **macrofaunal core** sample (130 mm diameter, approx. 100 mm deep): the core contents will be gently sieved through a 0.5 mm mesh and animals retained will be preserved, identified and counted under a microscope by a suitably trained taxonomist. From these data, animal abundance and species richness will be determined, and biotic indices calculated (*e.g.* Shannon-Weiner diversity index, Pielou's evenness, Margalef's richness, AZTI Marine Biotic Index (AMBI), Multivariate-AMBI and Benthic Quality Index).

Replicate **sediment photo-quadrats** or video footage will also be taken at each benthic monitoring site and at a second pen site to assess bacterial mat coverage, general seabed condition and presence of sediment out-gassing.

For monitoring at the Crail Bay farms, the following sub-sampling will occur:

- A **sediment core** sample (63 mm diameter): each core will be qualitatively assessed, sediment colour, odour and texture and quantitatively sampled for, redox potential and total free sulphides (as described above).

Replicate **sediment photo-quadrats** or video footage will also be taken at each benthic monitoring site and at a second pen site to assess bacterial mat coverage, general seabed condition and presence of sediment out-gassing.

### 2.2.3. Calculating overall Enrichment Stage

Changes along the enrichment gradient (from ES1–7) have been numerically defined for a suite of widely used benthic environmental indicators and biotic indices (for definitions, see Table 4) based on a meta-analysis of historical data from beneath fish farms in the Marlborough Sounds (Keeley *et al.* 2012). The results have also been compared to international studies that have quantified similar gradients for other regions. Through this process, the relationships between ES and the following enrichment-indicating variables have been numerically described: infauna statistics (including: No. taxa, abundance, evenness, Shannon diversity, AMBI, M-AMBI, BQI), sediment organic content, redox, and total free sulphide levels (Figures 1 & 2). Enrichment responses have also been categorised for the following qualitative variables: level of out-gassing and bacterial mat coverage. As a result, any subset or combination of these variables can be used to quantitatively assign ES scores to sampling stations. Some variables are better predictors of ES than others (*i.e.* exhibit a tighter (as indicated by $R^2$) and a more linear relationship) and this has been accounted for in the selection and subsequent weighting of the variables in the overall calculation.

Using the appropriate polynomial, each environmental result (raw data) is converted into an equivalent ES score. Average ES scores are then calculated for the sediment chemistry variables (redox and sulphides), the 'infauna composition' variables (abundance, richness, H', AMBI and BQI) and for %OM, representing 'organic loading' for each sample/ grab. The 'overall ES' for a sample is given by the weighted average of those three groups of variables (weighting for 2013 will be the same as for 2012: organic loading = 0.1, sediment chemistry = 0.2 and infauna composition = 0.7).

The overall ES for a sampling station is given by the average of the (usually three) replicate samples and the variability between samples is reflected in the associated standard error; also reported. As with previous years, results will be reported for each individual station.

Table 4. Definitions of selected biological indicators.

| Indicator | Calculation and description | Source reference |
|---|---|---|
| N | Sum (n)<br><br>Total infauna abundance = number of individuals per 13 cm diameter core | - |
| S | Count (taxa)<br><br>Taxa richness = number of taxa per 13 cm diameter core | - |
| *d* | (S-1) / log N<br><br>Margalef's diversity index. Ranges from 0 (very low diversity) to ~12 (very high diversity) | Margalef (1958) |
| *J'* | *H'* / log S<br><br>Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can range from 0.00 to 1.00, a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa. | Pielou (1966) |
| *H'* | $- \sum_i p_i \log(p_i)$<br>where p is the proportion of the total count arising from the *i*th species<br><br>Shannon-Weiner diversity index (SWDI). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values for communities containing many species with each represented by a small number of individuals. | - |
| AMBI | = [(0 × %GI + 1.5 × %GII + 3 × %GIII + 4.5 × % GIV + 6 × %GV)]/100<br>where GI, GII, GIII, GIV and GV are ecological groups (see Section 2.3).<br><br>Azites Marine Biotic Index: relies on the distribution of individual abundances of soft-bottom communities according to five Ecological Groups (GI-GV). GI being species sensitive to organic pollution and present under unpolluted conditions, whereas, at the other end of the spectrum, GV species are first order opportunists adapted to pronounced unbalanced situations (*e.g. Capitella capitata*). Index values are between 1 (normal) and 6 (extremely disturbed) | Borja *et al.* (2000) |
| M-AMBI | Uses AMBI, S and H', combined with factor analysis and discriminant analysis (see source reference).<br><br>Multivariate-AMBI. Integrates the AMBI with measures of species richness and SWDI using discriminant analysis (DA) and factorial analysis (FA) techniques. Utilises reference conditions for each parameter (based on 'pristine conditions') that allows the index to be tailored to accommodate environments with different base ecological characteristics. Scores are from 1 (high ecological quality) to 0 (low ecological quality). | Muxika *et al.* (2007) |
| BQI | $= (\sum_{i=1}^{n}(\frac{A_i}{totA} \times \mathrm{ES50}_{0.05i})) \times {}^{10}\log(S+1)$<br>Where ES50 = expected number of species as per Hurlbert (1971)<br>And, $\mathrm{ES50}_{0.05}$ the species tolerance value, given here as the $5^{th}$ percentile of the ES50 scores for the given taxa as per Rosenberg *et al.* (2004).<br><br>Benthic quality index: uses species specific tolerance scores ($\mathrm{ES50}_{0.05}$), abundance and diversity factors. Results can range from 0 (being highly impacted) and 20 (reference conditions). | Rosenberg *et al.* (2004) |

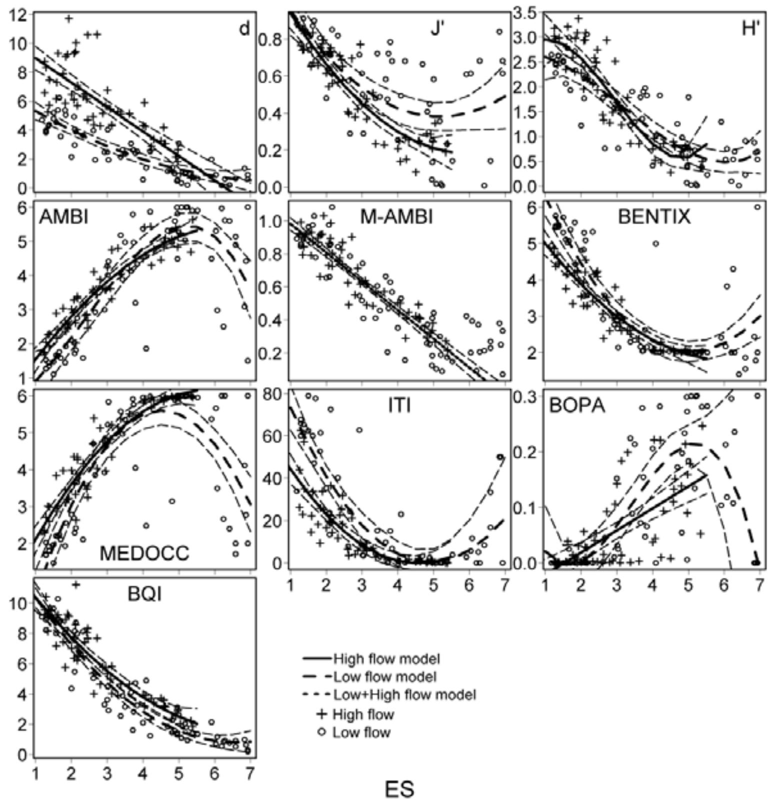


Figure 1. Scatterplots displaying optimum models with 95% confidence intervals for 10 biotic indices in relation to Enrichment Stage (From Keeley *et al.* 2012).

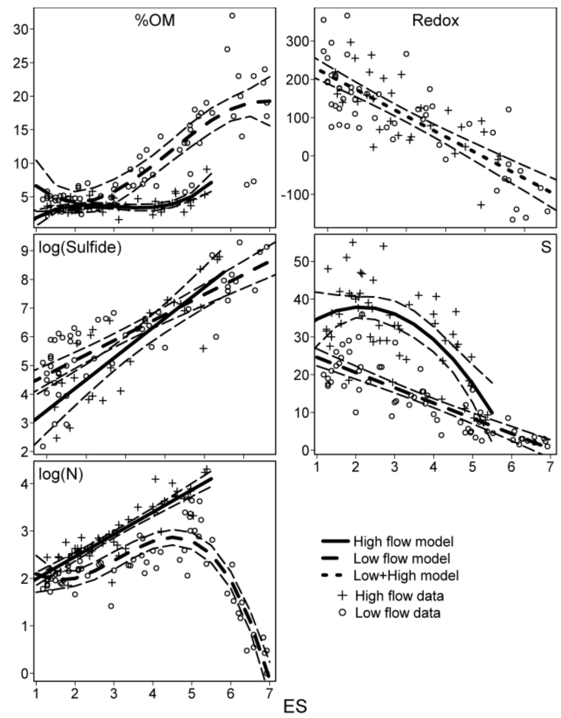


Figure 2. Scatterplots displaying optimum models with 95% confidence intervals for each of the physicochemical and biological indicators in relation to Enrichment Stage (From Keeley *et al.* 2012).

### 2.2.4. The role of best professional judgement

While the quantitative method of determining ES described above works well for results that are within the 'normal' or expected range at NZ King Salmon sites, and hence removes much of the subjectivity in the assessment, there are still situations where professional judgement is required. For example, ES scores >5.5 are poorly accommodated by most biotic indices (Keeley *et al.* 2012). Additionally, some variables have a 'C-shaped' relationship with ES, meaning that a single Y-value can have two X-values (*i.e.* ES scores, *e.g.* log(N), Figures 1 and 2). Therefore, there remains a role for best professional judgment to correct or override potentially erroneous / misleading ES scores.

The following are general rules that will be implemented to accommodate some of the more common issues:

1. Numerical bounds for the range of responses that were well described and therefore the relationship between ES and each variable is considered reliable, were determined from the plots. These bounds are referenced such that a 'best professional judgment' warning is triggered if the value is outside of the reliable range. This forces a manual allocation of the equivalent ES.
2. Total number of Taxa and %OM are both poor predictors of ES at low to moderate levels of enrichment **at high flow sites**. The following rules are to be applied:
    a. For No. taxa, a null result will be returned for the ranges over which the variable was non-responsive. Hence, the regression is used to calculate ES only for samples with < 20 taxa.
    b. For %OM a look-up table will be created with the following categorical equivalencies for %OM to ES: 2% = ES 1, 3.5% = ES 2, 4% = ES 3, 6.5% = ES 4, 8% = ES 5, 12% = ES 6 and 16% = ES 7. The %OM result is also down-weighted in the calculation of overall ES (to 10%).

The 'azoic' state that typifies ES 7 is virtually impossible to achieve in the strictest sense because the samples will almost always contain one or two individuals. The significance of these individuals with regard to ES is questionable as they could be from cross-contamination, or transient surface dwelling taxa, in which case the sample is still essentially 'azoic'. As this region of enrichment is poorly dealt with by most of the diversity measures it is manually assessed when abundance (N) < 800 and No. taxa (S) < 5 (true infauna). In which case the ES score is to be manually assigned to total abundance (N) and No. taxa (S).

### 2.2.5. Interpretation of zones and compliance

Benthic enrichment is monitored pursuant to a 7-stage ES scale as outlined in Cawthron Report 2080 (Keeley et al. 2012). Permitted levels of seabed effect are 'zoned' around each farm pursuant to pre-specified, and generally narrative, environmental quality standards (EQS) that relate to both the magnitude (or 'severity') and spatial extent of effects. Cawthron and NZ King Salmon accept there is some ambiguity around how EQS should be translated on the ES scale and this is going to be a subject for discussions during the upcoming workshop (in December 2013).

## 2.3. Copper and zinc

While the monitoring of copper and zinc sediment concentrations will be conducted in conjunction with the routine annual seabed monitoring, it is considered separately because it is generally monitored in the worst affected area (*i.e.* beneath the pens) and has its own adaptive management decision tree (refer Sneddon *et al.* 2012).

### 2.3.1. Environmental Quality Standards

The available information suggests that the ANZECC (2000) ISQG-Low criteria for copper and zinc are the most appropriate trigger values for sediments beneath farms (Sneddon & Tremblay 2011), and therefore should be used as the first tier trigger level for further actions (Table 5). For more information regarding the ecological effects of copper and zinc and the rationale for selecting the ANZECC guidelines as the EQS, see Sneddon and Tremblay (2011).

Table 5. ANZECC (2000) Interim Sediment Quality Guideline concentrations for copper and zinc (mg/kg).

| | ISQG-Low | ISQG-High |
|---|---|---|
| Copper | 65 | 270 |
| Zinc | 200 | 410 |

### 2.3.2. Sampling protocol

Varying levels of sampling intensity and investigation for Cu and Zn will be conducted, dependent on the results of the 2012 annual monitoring (see Sneddon *et al.* 2012 for decision tree). In terms of the implications for sampling, this mainly concerns how the samples are analysed once collected. The Tier 1 sampling protocol utilises single composite samples (made up of triplicate sub-samples) collected from beneath or at the downstream edge of the farm pens. Sub-samples will be retained for immediate individual follow-up analyses in case the composite result exceeds ISQG-Low for either copper or zinc.

Tier 2 sampling will involve the individual triplicate sub-samples being analysed separately, and it is recommended that Tier 2 sediment samples be split into fine (<250 μm) and coarse (250 μm–2 mm) fractions prior to separate analysis. This will allow the fine fraction to be standardized to facilitate the analysis of temporal trends and also minimise the inclusion of large paint flakes or other metal-rich particulates.

Based on the results of the 2012 annual monitoring, and recommendations from Cawthron scientists within the individual farm reports, Tier 2 sampling for Cu and Zn would occur at all farm sites except for MFL-32 and MFL-48, which would remain at Tier 1 sampling.

## 2.4. Water column effects monitoring

As specified in the consent conditions, and agreed upon with Marlborough District Council (MDC) and NZ King Salmon, fine-scale water column monitoring during 2013 will be undertaken at all of the currently operational farm sites , while the fallowed sites in Crail Bay (MFL-32 and- 48) will have a lower intensity of sampling

Stations will be selected along transects orientated according to the tidally reversing current flows. Sampling stations will be coordinated with benthic monitoring stations at the zone boundaries as outlined in Section 2.2. A full list of the sampling stations is detailed in Table 7, but the sampling design is based on monitoring the ‘worst-case scenario’ at the pen edges, and then along the anticipated gradient at the zone 2/3 and 3/4 boundaries (*e.g.* 50 m and 150 m down-current for the RUA farm) to evaluate near-farm mixing. Seawater concentrations of nutrients (TP, DRP, $NH_4$-N, $NO_3$-N, $NO_2$-N and TN) will be analysed in discrete, remotely-collected samples from mid-water depths at each station (Table 6). Depth profiles of salinity, temperature, chlorophyll *a*, turbidity and dissolved oxygen will be measured *in situ* at the same stations using a submersible sensor array (CTD: conductivity, temperature and depth).

Monitoring results will be used to quantify the effect of individual farms on the surrounding near-field water quality where the potential for detecting change / effects is greatest.

Table 6. Summary of farm-scale water quality monitoring methods for 2013.

| | | |
|---|---|---|
| **Timing:** | Annual survey to be coordinated with annual benthic monitoring surveys | |
| **Location:** | Full scale at currently operational farms, reduced number of stations at fallowed sites. | |
| **Sampling stations:** | Pen site, Zone 2/3 boundary (*i.e.* 50 m), Zone 3/4 boundary (*i.e.* 150 m), Reference sites may be shared by farms located in close proximity, *e.g.* TEP and CLA, FOR and WAI. | |
| **Sampling methods:** | **Sampling** | **Parameters** |
| | • Triplicate discrete samples at mid-water (mid-pen) depths | • Nutrients (TP, DRP, $NH_4$-N, $NO_3$-N, $NO_2$-N, TN) |
| | • *In situ* profiling throughout water column | • Salinity, temperature, chl-*a*, turbidity, DO |

Table 7. Location of water column monitoring locations to be sampled during the 2013 annual monitoring survey.

| Farm sites | | | | | | | |
|---|---|---|---|---|---|---|---|
| **TEP** | **CLA** | **RUA** | **OTA** | **FOR** | **WAI** | **MFL-32** | **MFL-48** |
| Pen 1 | Pen 1 | Pen 1 | Pen 1 | Pen 1 | Pen 1 | Pen 1 | Pen 1 |
| 90 m NE | 90 m W | 50 m | 50 m | 50 m | 60 m | | |
| 300 m NE | 300 m W | 150 m | 150 m | 150 m | 180 m | | |
| TC Ctl 2 | | QC Ctl 3 | QC Ctl 2 | PS Ctl 3 | PS Ctl 1 | | CB Ctl 1 |

## 2.5. Reporting and revisions

The annual monitoring reports will be provided to Council as soon as practically possible following the completion of the monitoring (within 3-4 months). The timing and frequency of the different forms of marine environmental monitoring is summarised in Table 8. The reports will include the following as per the consent conditions:[1]

1. Presentation and interpretation of the monitoring results.
2. A comprehensive and integrated report on the effects of the development and operation of the farm to date; this includes incorporating data on the maximum biomass of fish and feed volumes for the past year into farm operations to date.
3. An assessment as to whether or not the farm is having a significant adverse effect on the environment (and is operating within the 'Zones Concept').
4. Recommendations to avoid, mitigate or remedy environmental effects (if required).
5. Comments on the adequacy of the monitoring program and any recommendations relating to changes and/or improvements (*e.g.* frequency, parameters to be measured *etc.*).

Table 8. Summary of different types of environmental monitoring strategies and associated timing, frequencies and sampling design requirements for 2013.

| Monitoring component | Seabed | Rocky reef | Water column |
|---|---|---|---|
| **Scale** | Local (0–300 m) | Local / regional | Local or 'fine-scale' (0–300 m) |
| **Frequency and duration** | Annually, on-going | Annually | Annually, on-going at some level |
| **Timing** | November | Early October | November — synchronised with Seabed monitoring |
| **Key parameters** | Redox, $S^{2-}$, %OM, Infauna statistics, ES, Cu, Zn | Photo-quadrats (% cover, size & abundance) | Nutrients, CTD |
| **Sampling stations** | Tiered sampling, per-farm basis | 8 Existing Tory Channel sites (5 'farm' sites, 3 'ref' sites) | Down-current transect (as for benthic sites) |
| **Response / management** | Comparison to defined EQS. | BACI-type Multivariate analysis / Qualitative evaluation | Spatial gradient, univariate statistics. |
| **Baseline** | Yes: One-off, pre-farm | Yes: One-off, pre-farm | No |

[1] NZ King Salmon acknowledges the consents at Forsyth, Otanerau, Ruakaka, MFL-032 and MFL-048 require some additional reporting.

# 3. REFERENCES


Borja A, Franco J, Perez V (2000) A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar Pollut Bull 40:1100-1114

Dunmore R, Keeley N, Forrest R 2011. Reef environmental monitoring results for the Clay Point and Te Pangu salmon farms: 2010. Prepared for New Zealand King Salmon Ltd. Cawthron Report No. 1922. 22 p. plus appendices

Ervik A, Hansen PK, Aure J, Stigebrandt A, Johannessen P, Jahnsen T 1997. Regulating the local environmental impact of intensive marine fish farming I. the concept of the MOM system (modelling - ongrowing fish farms - monitoring). Aquaculture 158, 85-94.

Hansen PK, Ervik A, Schaanning M, Johannessen P, Aure J, Jahnsen T, Stigebrandt A 2001. Regulating the local environmental impact of intensive, marine fish farming II. The monitoring programme of the MOM system (Modelling-Ongrowing fish farms-Monitoring). Aquaculture 194, 75-92.

Keeley N, Forrest B, Crawford C, MacLeod C 2012. Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. Ecological Indicators 23: 453-466.

Keeley N, Forrest B, MacLeod C 2013. Novel observations of benthic enrichment in contrasting flow regimes with implications marine farm management. Mar. Pollut. Bull. 66, 105-116.

Keeley N. 2012. Assessment of Enrichment Stage and Compliance for Salmon Farms - 2011. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2080. 15 p.

Keeley, N 2011 NZKS Annual Monitoring Plan (revised Oct 2010). Prepared for New Zealand King Salmon Ltd. Report No. 1872. 26 p. plus appendices.

Margalef R (1958) Information theory in ecology. General Systems 3:36-71

Muxika I, Borja A, Bald J (2007) Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status according to the European Water Framework Directive. Mar Pollut Bull 55:16-29

Pielou EC (1966) The measurement of diversity in different types of biological collections. J Theor Biol 13:131-144

Rosenberg R, Blomqvist M, C Nilsson H, Cederwall H, Dimming A (2004) Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. Mar Pollut Bull 49:728-739

Sneddon R, Tremblay L 2011. The New Zealand King Salmon Company Limited: Assessment of Environmental Effects - Copper and Zinc. Prepared for New Zealand King Salmon Company Ltd. Cawthron Report No. 1984. 53 p plus appendices.

Sneddon R, Tremblay L, Stringer T 2012. Investigation of potential copper and zinc bioavailability and ecotoxicological status of sediments beneath salmon farms. Prepared for New Zealand King Salmon Ltd. Cawthron Report No. 2033. 31 p. plus appendices.

Wilson A, Magill S, Black KD 2009. Review of environmental impact assessment and monitoring in salmon aquaculture., Environmental impact assessment and monitoring in aquaculture. FAO, pp. 455-535.