Review of Monitoring the Environmental Effects of Salmon Farming in Tasmania

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Introduction
Salmon aquaculture in the D’Entrecasteaux Channel and Huon Estuary can have serious ecological and social impacts which may get worse as the industry expands. As the effects of climate change become greater, there is a need to increase natural areas’ resilience and therefore it becomes all the more important to reduce anthropogenic causes of environmental stress. In a salmon cage the highest density allowed for the fish is 25/m$^3$. Up to 50,000 salmon can be put in one circular cage. A long-term increase in phytoplankton (microalgal) biomass across the region, and periodic blooms of the introduced and toxic microalga *Gymnodinium catenatum* were reported by Parsons (2012a).

The current monitoring program was based on the recommendations of research studies undertaken by Volkman et al. (2009) and Thompson et al. (2008), which investigated the cumulative effects of aquaculture operations on the local aquatic environment. It carried out measurement of water column parameters (dissolved nutrients, dissolved oxygen and phytoplankton biomass and community composition) (Parsons, 2012a).

There are concerns about the current monitoring, and whether all receiving habitats and anticipated impacts are adequately monitored and reported. This report examines current monitoring, the possible impacts of increased salmon farming in the D’Entrecasteaux Channel and
Huon Estuary and the transparency of data to the stakeholders. It also recommends some changes to the monitoring programme.

Parsons (2012a) suggested there was some evidence of environmental degradation determined on the basis of applicable national guidelines (e.g. dissolved oxygen) or comparative assessments, including: localised oxygen depletion and nutrient enrichment in bottom waters of the Huon Estuary, a long-term increase in phytoplankton (microalgal) biomass across the region, and periodic blooms of the introduced and toxic microalga Gymnodinium catenatum.

High resolution hydrodynamic models were also developed to investigate the mixing zone characteristics around a fish farm cage. These analyses revealed that a continuous release of tracer from the cage results in a plume emanating from the cage in the form of a long narrow ribbon. The position and concentration of the plume is dependent on the in situ flow conditions, and possesses large variability in space and time. It is possible for a plume having concentration of 10% (i.e. 10:1 dilution) of the source concentration to exist up to 0.5 km from the cage on occasion (Volkman et al, 2009).

**Current Monitoring**

Approximately 85% of the 5% of total salmon feed entering the environment is released as dissolved nitrogen. This is the fraction used to estimate total permissible dissolved nitrogen (TPDN). Nitrogen released into the environment by fish farms is regulated (since 2009) via caps on output TPDNO. The other 15% of nitrogen is particulate nitrogen also released at cages. Fish farms are the most significant source of ammonium, a form of soluble nitrogen, in many marine areas due to the bacterial mineralization of faeces and feed (Ross and Macleod, 2012).

Monitoring is carried out on an annual basis with specific environmental standards recording and reporting requirements. Production data (the amount of feed used by each salmon farm on a monthly basis, fish inputs, production, planning & food conversion rates) is to be supplied as routine quarterly reporting. Underwater video of sediment is required annually or in accordance with stocking and fallowing. A compliance monitoring site is established 35 m outside the lease boundary.

Performance based monitoring for individual lease areas may be adjusted by increasing the frequency and intensity of monitoring depending on the level of compliance and monitoring history of the farm.

**Water quality**

In marine coastal waters dissolved nitrogen compounds promote algae. There are a number of sources of dissolved nitrogen entering the Channel and Huon Estuary. Total nutrient budgets for the D’Entrecasteaux Channel and Huon Estuary in 2002–2003 including the load crossing the ocean boundaries were estimated by Volkman et al. (2009). Estimates of labile and refractory nitrogen inputs from ocean waters for 2002–2003 were approximately 2000 and 1000 tonnes p.a. respectively; most of which was delivered in winter. This represented approximately
60% of the nitrogen load to the system. Runoff from agricultural land and sewage also provides nitrate and ammonium that are available to plants and added to the available nitrogen in the farming area.

The Broadscale Environmental Monitoring Program (BEMP) is a system wide water quality and sediment monitoring program in the D’Entrecasteaux Channel and Huon Estuary, required by the Department of Primary Industries Parks Water and Environment (DPIPWE) and undertaken by the salmon aquaculture industry (who contract out the monitoring). Samples to test water quality are taken regularly (usually monthly) throughout the year at multiple sites, which are located outside marine farm leases and are distributed across different areas of the Channel and lower Huon Estuary. Sampling is undertaken to measure and assess the following indicators of water quality:
- water column nutrients
- dissolved oxygen levels
- temperature
- salinity and
- phytoplankton community structure (using both taxonomic and biochemical measures) and abundance.

**Sediment quality**

The BEMP also contains a sediment monitoring program in the D’Entrecasteaux Channel and Huon Estuary, required by DPIPWE and undertaken by the salmon aquaculture industry (who contract out the monitoring). It specifies that benthic environmental conditions be monitored within a 35 m radius from the licence boundaries and at control sites. This monitoring consists of underwater videos for sediment health undertaken annually, or in accordance with the stocking and fallowing regimes in the cages.

Benthic infaunal evaluation was the most useful indicator of both degradation and recovery (Macleod and Forbes, 2004). Unimpacted and impacted (farmed) sediments indicated significant differences between the benthic infaunal communities. To determine recovery and provide an indication of the potential resilience of the system, an understanding of the community composition prior to farming is essential (Table 1). The benthic community results also clearly showed that when sediment conditions were degraded polychaete worms were the dominant faunal group, both in terms of abundance and diversity. Capitellid polychaetes (distinctive, red, opportunistic worms) were strongly indicative of the moderate and major impact stages (Macleod and Forbes, 2004).

**Recommended Monitoring and Data Handling**

It is relevant and timely to review and revise the present monitoring system. Implementing an indicative monitoring system that will answer the questions of whether fish farming is harming the environment, what is the carrying capacity of Tasmanian waters for available nitrogen and what level of damage are managers of the marine environment willing to tolerate, would be appropriate.
As long as appropriate quality control and quality assurance (QA&QC) measures are adopted a range of techniques is likely to be suitable. Volkman et al. (2009) advocate for QA&QC procedures to be implemented at the outset of any monitoring and this is done for water quality. Guidelines for QA&QC are provided in Appendix 10 in Thompson et al. (2008).

Clearly, additional research is urgently needed to assess impact and recovery of benthic ecosystems over time. Such analysis should include investigation of broad-scale change over the past few years, a period of accelerating transformation in local benthic communities. The plans should monitor the system-wide impacts of increased marine farming in the Channel. There seems to be a lack of adequate reference sites to use as control sites for comparisons.

Tasmanian marine farm regulations require that any impacts extending from farm lease are measured at compliance locations 35 m outside the farm lease boundary. Current regulations are thus at the evidentiary end of the continuum from a need for clear evidence of farm impacts to a precautionary approach. Changes at compliance sites must be similar or greater than mean values observed immediately adjacent to cages to be considered unacceptable (Edgar et al., 2005).

What are the triggers for these data? Research should also be implemented to determine the frequency of monitoring. What are the triggers for remediation and what are the capacities of water bodies to hold nutrients and associated waste from salmon cages? It is not clear as to the period an impacted area takes to recover, nor at what level of deterioration remediation is possible.

Monitoring should be designed from a water movement model, as a result of current understanding of the hydrology. The current BEMP should provide data that could be compared with the baselines or trigger values relevant for the identification of change in ecological function.

Macleod and Forbes (2004) recommended that video assessment be adopted as the main approach for farm based monitoring. Video footage should be obtained relatively frequently (at least monthly but preferably fortnightly) up to 35 m beyond the boundaries of the lease, towards the end of the stocking cycle and over the fallow period, and this should be compared with footage from reference positions taken at the same times.

The current frequency of video samples--annually--seems inadequate for a meaningful assessment of impacts on sediment under cages. These video images and transects should be made monthly. After two or three years of data, the frequency may be revised. Annual monitoring will not alert managers to impacts that may do permanent damage to the benthos. Triggers for action must be carefully determined and actions to reduce them documented so that there is certainty of all remedial actions.

Because algal blooms in regions with fish farming operations are occurring more frequently, it follows then that the more finfish aquaculture expands, the greater the impacts will be. These impacts include anoxic water, turbidity and the possibility of toxic algal blooms. Sampling is
undertaken on a monthly basis from May through January, and fortnightly in February, March and April. The chlorophyll a data from the region should be assessed for irregular changes and these analysed to determine sources.

A regional planning review should be undertaken to cover all uses of the waterway resources and conservation of the environment. This "strategic plan" will establish how the waterway is planned and managed.

The monitoring program was based on the recommendations of research studies undertaken by Volkman et al. (2009) and Thompson et al. (2008). Thompson et al. (2008) chose phytoplankton biomass, frequency of algal blooms, the concentration of dissolved oxygen, changes in nutrient cycling as manifest by the increase in concentrations of NH4+, organic enrichment of the sediments, increases in bacteria involved in the remineralization of the organic matter, and pathogenic bacteria as indicator parameters to monitor (Volkman et al, 2009).

**Water Quality**

Water quality should continue to be monitored outside the lease areas. The range of this monitoring can be determined by reviewing previous monitoring to determine the detection limit of the water quality parameters attributed to salmon farming.

Research should also be implemented to determine the frequency of monitoring. What are the triggers for remediation and what are the capacities of water bodies to hold nutrients and associated waste from salmon cages? Annual samples may be too late to remediate or stop the impact.

No results were available for water quality for this report so little can be said of annual, seasonal or event variability.

**Sediment Quality**

Sampling for sediment condition (sediment biogeochemistry) is undertaken annually from 15 sites, and infaunal samples are assessed every four years. It is difficult to understand what the use of this data is and waiting four years between samples appears to have very little use.

Although a sediment quality, biogeochemical assessment and measuring the sediment grain size was conducted annually, little can be reported from the analyses because of the infrequency of monitoring (Macleod and Forbes, 2004).

They tested the microbiological and biological responses of sediments under salmon cages by using quantitative video assessment. They decided that this was the most effective approach for simple farm-based assessment of sediment condition. This approach was capable of discerning the broadest range of impact stages and was particularly useful in evaluating recovery over time. Video footage should be obtained relatively frequently (at least monthly but preferably fortnightly)
from cages within the farm, towards the end of the stocking cycle and over the fallow period, and this should be compared with footage from reference positions taken at the same times.

What are the triggers for remediation and what are the capacities of benthic communities to withstand the waste from salmon cages. Annual samples may be too late to remediate or stop the impact.

Table 1A. General characterisation of impact/recovery stages based on main infaunal community, key faunal indicators and functional changes. Shaded area indicates period when cage was stocked (Macleod and Forbes, 2004).

<table>
<thead>
<tr>
<th>Stage</th>
<th>General Indicators</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No evidence of farm impact; unimpacted indicator species present</td>
<td>Site specific Range of functions</td>
</tr>
<tr>
<td>II</td>
<td>Larger; long lived species &amp; unimpacted indicators absent. Diversity may be greater than pristine (zone of enhancement).</td>
<td>Site specific Site Specific</td>
</tr>
<tr>
<td>III</td>
<td>Rapid change in community mix; deposit feeding polychaetes / opportunists dominate. Filter / suspension feeders absent; Polychaetes dominant (Annelid abundance x20 ref); Number of Species &gt;50% of ref Capitella, Nebalia - Deposit feeders</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Opportunists (esp. Capitellids) characterise community Capitella, Nebalia - Deposit feeders</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Infaunal opportunists (esp. Capitellids) dominate Annelid abundance x50 ref; Patchy Beggiatoa / outgassing on disturbance; Number of Species &lt;50% ref Polychaetes highly dominant; Capitella, Nebalia - Deposit feeders</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>No Fauna Sediments &amp; bottom waters anoxic</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Opportunists (Capitellids) still dominate but no.s dropping &amp; other species colonising</td>
<td>Capitella, Nebalia - Deposit feeders</td>
</tr>
<tr>
<td>VIII</td>
<td>Transitional species prevalent - notable increase in epibenthic opportunists</td>
<td>Capitella Site specific</td>
</tr>
<tr>
<td>IX</td>
<td>Diversification of community but absence of climax / long lived species</td>
<td>Site specific Range of functions</td>
</tr>
</tbody>
</table>

An important element in the design of the current BEMP monitoring program was the need to provide data that could be compared with the baselines or trigger values proposed by Thompson et al. (2008) as being relevant for the identification of change in ecological function.. Table 2 compares the 2009–2012 BEMP water column assessment data in relation to the recommended trigger levels (Thompson et al., 2008). It is difficult to determine, from available reports, what is
being monitored. The standard or baseline values were not found so it is not clear what evaluation is being made of the data. Trigger levels for sediment biota, seagrass and macrophyte health and sediment chemistry are not monitored or have not been made available for scrutiny, nor are these data compared with a baseline. No triggers have been set for this set of proposed parameters.

Table 2. Three proposed trigger levels for various parameters (Ross and Macleod, 2013).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard or Baseline value</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment biota</td>
<td>Huon Estuary</td>
<td>D’Entrecasteaux Channel (low risk)</td>
<td>Significant change over time since start of assessments at one or more sites + other indicators TBD</td>
<td>Significant change in multivariate community structure at 1 site since last assessment + other indicators TBD</td>
</tr>
<tr>
<td>(infauna)</td>
<td>To be determined TBD</td>
<td>To be determined TBD</td>
<td>Significant change over time since start of assessments at one or more sites + other indicators TBD</td>
<td>Significant change in multivariate community structure at 2 or more sites since last assessment + other indicators TBD</td>
</tr>
<tr>
<td>Seagrass and other macrophytes</td>
<td>TBD</td>
<td>Significant change over time or relative to control site</td>
<td>As level 1 + TBD</td>
<td>As level 1 + TBD</td>
</tr>
<tr>
<td>Sediment chemistry</td>
<td>ANZECC guidelines for metals and TBD</td>
<td>Significant change over time at one site.TBD</td>
<td>Significant change at 2 sites in ≥ 2 indicators. Exceeds ANZECC guidelines for low metal concentrations. TBD</td>
<td>Significant change at ≥ 3 sites in ≥ 2 indicators. Exceeds ANZECC guidelines for high metal concentrations. TBD</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Summer NH₄⁺ surface = 0.32 µM, Bottom = 0.42 µM</td>
<td>summer mean up 25%, or 3 successive annual means &gt; baseline, or mean for any one site +50%</td>
<td>summer mean up 50%, or 8/10 annual means &gt; baseline for any site, or mean for any single site up 200%</td>
<td>Summer mean +100%, or summer mean &gt; 1 µM (~ ANZECC)</td>
</tr>
<tr>
<td>chlorophyll a</td>
<td>sites 10 to 14 annual = 1.4 µg/L. Summer = 1.7 µg/L</td>
<td>Any site; annual mean +100%; or average summer mean +50%</td>
<td>Any site: annual mean +200%; or average summer mean +100%; or average annual mean +50%</td>
<td>Any site: annual mean +400%; or average summer mean +200%; or average annual mean +100%</td>
</tr>
<tr>
<td>Phytoplankton blooms</td>
<td>7% obs. &gt;3x median chla</td>
<td>% obs. &gt;3x median rise 50%</td>
<td>% obs. &gt;3x median rise 100%</td>
<td>% obs. &gt;3x median rise 200%</td>
</tr>
<tr>
<td>Harmful Phytolankton G. catenatum</td>
<td>TSQAP data from areas 1997-2007</td>
<td># of days 7 areas are closed to shellfish harvest due to HAB &gt;226 days</td>
<td># of days 7 areas are closed to shellfish harvest due to HAB &gt;336 days</td>
<td>Not defined</td>
</tr>
<tr>
<td>Absolute DO³</td>
<td>Channel mean &gt;6 ppm. Bay mean &gt;5 ppm</td>
<td>Any 2 channel observations ≤6 ppm. Any 2 bay observations ≤5 ppm</td>
<td>50% of channel observations ≤6 ppm. 50% of bayobservations ≤ 5 ppm. Any 2 observations ≤ 2 ppm</td>
<td>Channel mean ≤6 ppm. Bay mean ≤ 5 ppm. Any 2 measurements &lt; 1 ppm</td>
</tr>
<tr>
<td>Relative DO³ (percent saturation)</td>
<td>Set at 20th percentile from 1st year of observations</td>
<td>Number of observations below baseline increases 50%</td>
<td>Number of observations below baseline increases 100%</td>
<td>Mean falls 10% from baseline (~ ANZECC)</td>
</tr>
</tbody>
</table>

From available reports and information there is a lack of an adequate reference site to use as a control site. Comparisons and triggers can only be understood if there is a non-affected control site or sites.
Sensitive Habitats
Reefs and seagrass beds are part of the ecosystem in the D’Entrecasteaux Channel and Huon Estuary. There are no data available for the effect of nutrients or cage detritus on reefs. While there are no reef habitats within the proposed lease areas, marine vegetation on adjacent fringing reef has the potential to be influenced by soluble nutrients and detritus arising from fish farm activities. Such impacts were expected by Tassal (2002) to be localised, i.e. between 100 m to 400 m from the lease boundary, and limited to increased abundance of opportunistic species (filamentous and other opportunistic green algae). Its assessment may not be correct and no investigation on the detrital fallout on reefs has been attempted. Recent studies show impacts of nutrients on macroalgal communities are occurring hundreds of metres away from salmon farms (Oh, 2009). It should be noted that accepted sediment impacts are legally limited to just 35m from the lease area.

Research to assess potential nutrient response criteria for sub-tidal macroalgal communities in south east Tasmania will assist a monitoring programme. Reef Life Survey has well defined monitoring methods and would be useful to use seasonally (http://reeflifesurvey.com/).

More nitrogen in the sheltered water habitats in the southern D’Entrecasteaux Channel could result in significant environmental effects on marine vegetation communities within the broader southern D’Entrecasteaux Channel and Great Taylors Bay region. The more exposed locations will have more dilution and dispersion of soluble emissions and may be better places for licenses.

It has been difficult to fully review the effects of salmon cages on the marine environment as no raw data are readily available.

References

