Ecological sustainability assessment for Firth of Thames shellfish aquaculture:

Tasks 2-4 – Biological Modelling

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N. Broekhuizen
J. Ren
J. Zeldis
S. Stevens

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Auckland Regional Council
Environment Waikato
Western Firth of Thames Mussel Industry Consortium

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Contents

1 Executive Summary

Shellfish aquaculture is an important activity within the Firth of Thames and there are proposals to increase this activity substantially. At present there are in excess of 2000 ha of existing and approved farms within the firth. The largest of these is the Wilson Bay development on the eastern side of the firth. There are pending applications for approximately 6000 ha of farms on the western side of the firth.

In an earlier report (Broekhuizen, N. et al. 2002) into the possible ecological impacts of large-scale shellfish aquaculture in the firth, preliminary simple calculations suggested that whilst moderate depletion of plankton was possible within large farms, this would be unlikely to extend much beyond the farm boundaries if the plankton cells were growing rapidly. On the other hand, if the cells were growing slowly (because of unfavourable conditions, or because they have low intrinsic maximal growth rates), the depletion could extend several km beyond the boundaries of a large farm. The report also emphasized that the northern Firth of Thames is the major spawning ground for New Zealand's largest snapper fishery. It suggested that, if mussels were to consume a sufficiently large fraction of the eggs/young larvae due to large-scale operations then snapper populations could suffer.

Following the earlier report, NIWA were engaged by the Auckland Regional Council, Environment Waikato and the Western Firth Mussel Consortium to make quantitative predictions of the degree to which large-scale mussel farming in the western firth would influence: (a) snapper egg/larval survival and (b) plankton abundance and spatial distribution. In doing so, NIWA was to take explicit account of existing (operating and approved-but-not-yet-operating) mussel farms in order to gauge the degree to which cumulative (in area) effects might occur. It was recognised that plankton growth rates within the firth vary on both seasonal and inter-annual time-scales. Thus, the analysis was to include consideration of seasonal and interannual variations in environmental conditions. Initially, it was planned to make spring- and summertime predictions under El Nino and La Nina conditions. Unfortunately, this proved impossible for two reasons. Firstly, there was a lack of data with which to formulate initial and boundary conditions (particularly for El Nino conditions). Secondly, whilst El Nino and La Nina conditions are associated with changes in the prevailing wind fields (and hence, circulation patterns within the firth), these changes are evident only over long time-scales (months-years). Over shorter time-scales, the dominant signal is the seasonal one. Rather than persisting with the original plan, it was agreed that NIWA would search the entire wind-record and identify month-long periods in which the wind-rose approximated the long-term (multi-decadal) average El Nino or La Nina pattern, and then use those records as inputs to our hydrodynamic model (retaining spring or summer insolation, river flows etc. as appropriate).

In this report, we use three separate simulation models to make an assessment of how the current and modelled AMA farms may be influencing the abundance of: (a) snapper eggs & larvae, (b) phytoplankton and (c) zooplankton. In each case, we consider three distinct farm scenarios (no farms, existing farms and existing farms plus a maximal modelled western firth AMA). Henceforth, these will be referred to as scenarios NF, 0 and 1 respectively. For each farm scenario, we made simulations under six distinct hydrodynamic conditions. These correspond to: (i) September 1999, (ii) March 2000, (iii) spring, prevailing winds from ENE, (iv) summer, prevailing winds from ENE, (v) spring, prevailing winds from WSW, (vi) summer, prevailing winds from WSW. For reasons discussed in the report, our simulations are likely to over-estimate depletion, but we are uncertain of the extent of over-estimation.

The true vulnerability of Snapper eggs and larvae to predation by mussels is unknown, but we have assumed that the larvae become invulnerable at age 8 days post-spawn. This criterion was chosen on the basis that larvae begin to swim shortly before this age and are likely to become increasingly invulnerable to predation thereafter. Our simulations indicate that, if Snapper eggs and larvae (to age 8 d post-spawn) are assumed to be no less vulnerable to predation than phytoplankton, then under the existing farm scenario, the firth-wide numbers of snapper larvae surviving to age 8 days post-spawn may be reduced by 2-6% relative to scenario NF and by 2.5-15% under scenario 1. If the relative vulnerability of snapper eggs and young larvae proves to be lower than that of phytoplankton, these figures will be over-estimates. The depletion estimates are not strongly influenced by changes to the assumed buoyancy driver ascent speed of the non-motile eggs/larvae.

We use two distinct models to examine the influence of mussel farming upon the true plankton (phytoplankton and zooplankton). The first of these (the 'logistic model') adopts a very simple characterisation of plankton growth, aiming only to reproduce observed growth rates in an empirical manner. The second 'biophysical model' adopts a more mechanistic description of phytoplankton growth processes. The logistic model ignores any mechanisms which may lead to farms to augment phytoplankton abundance. The logistic model suggests that the concentrations of fast growing plankton (growth rates of ~ 2 d^{-1}) will be reduced by much less than 10% within the farms and that this depletion will not extend appreciably beyond the farms. Slow growing (0.2 d^{-1}), but vulnerable plankton (nutrient, light or temperature limited phytoplankton, food or temperature limited protozoa) are predicted to suffer depletion of >20% within the farm, and the depletion halos may extend several km beyond the farms. Slower growing zooplankton (growth rates of 0.025 – 0.05 d^{-1}) will tend to be less vulnerable to predation (being larger and more mobile). Depending upon how much less vulnerable they are, their abundances may be more or less adversely affected than those of the slow-growing, vulnerable plankton.

The biophysical model takes explicit account of nutrient-regeneration by mussels (which may stimulate greater phytoplankton growth); however it contains no dynamic description of zooplankton populations (their impacts upon phytoplankton are implicitly represented as a part of a first-order mortality term). This model indicates that farms will tend to suppress total phytoplankton abundance during spring (when phytoplankton growth rates are temperature and light limited). Depletion is predicted to approach 30% within the farms and to extend several km beyond the farm boundaries in a downstream direction; however there is little depletion in the upstream regions of the farm. Though somewhat offset from the farm, the total area over which depletion is evident is usually not substantially greater than the area of the farm itself. The model suggests that, if mussels excrete dissolved inorganic nitrogen (DIN) at experimentally observed rates, the farms may lead to enhancement of fast growing phytoplankton taxa (diatoms, phytoflagellates) downstream of the farms in the summer – when the mussel-generated DIN fertilizes the water – reducing the degree of N-limitation suffered by the phytoplankton. Enhancement is typically circa 20%, but can exceed 100%. The degree of phytoplankton enhancement is sensitive to the assumed rate of DIN production by mussels and there is a possibility that the experimentally determined mussel excretion rates used in the 'default' simulations were artificially high, stress-induced rates rather than 'basal' rates. If we adopt a theoretical minimum excretion rate in place of experimentally determined values summertime enhancement is replaced by depletion.

The modelled western Firth AMA is predicted to have larger impacts than any of the existing farms. This reflects its larger size, the fact that it will occupy shallower water than most of the existing farms, and the fact that current speeds are lower in the region that this AMA would occupy.