

## 2 Introduction

Shellfish aquaculture is an important activity within the Firth of Thames and proposals are in place to significantly increase this activity. 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 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 individuals were growing slowly (because of unfavourable conditions, or because they have low intrinsic maximal growth rates), the depletion could extend several km beyond the farm's boundaries. 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, snapper populations could suffer.

The Firth of Thames opens onto the Hauraki Gulf. There is a wealth of data concerning plankton dynamics in the gulf, but very much less data for the Firth of Thames (particularly the southern and central firth). The data for both the gulf and the firth are reviewed in Broekhuizen et al. (2002). In summary, circulation patterns in the gulf and firth are both strongly influenced by the prevailing winds. The reader is referred to an accompanying report (Stephens, S.A. & Broekhuizen, N. 2003) for more details. During the summer, nitrate and ammonium concentrations in the gulf and northern firth drop to very low levels – such that phytoplankton growth is severely constrained. During El Nino conditions winds tend to blow from the west. This promotes offshore transport of the surface waters. These are replaced by water upwelling from the oceanic shelf. These waters tend to be richer in nutrients. In contrast, La Nina conditions are associated with winds blowing from the NE. These winds blow the surface waters onshore and prevent upwelling. Thus, El Nino conditions can be expected to promote greater phytoplankton growth than do La Nina conditions. There is substantial evidence that this is indeed the case (see the data review in Broekhuizen et al. (2002)). Furthermore, there is evidence that climatic variations influence not only the total abundance of phytoplankton, but also its species composition – with smaller species (phytoflagellates) and dinoflagellates being relatively more abundant during nutrient-limited times (summer and La Nina). There is also some evidence that the changes in phytoplankton abundance and species composition lead to changes in the abundance of the zooplankton communities, and possibly changes in the survival rates of young fish larvae.

In this report, we extend upon the preliminary depletion calculations referred to Broekhuizen et al. (2002). We used three different, simulation models to predict the magnitude and spatial extent of changes in plankton abundance under three different farm scenarios and six different wind/season scenarios. A limited number of parameter sensitivity simulations have also been undertaken in order to gain an indication of how robust the model predictions are. The three models are spatially explicit and include the effects of water-driven transport. Space and time-resolved currents (and temperature, salinity) were predicted using a separate model (see Stephens, S.A. & Broekhuizen, N. 2003).

One of the models used has been developed over several years within NIWA's "Ocean Ecosystems" program (and its predecessors). This program is funded by the Foundation for Research in Science and Technology (FRST). The existing model required relatively minor changes (to explicitly include mussel farms). The other two models were developed from scratch (though all of the transport-related code and much of the code associated with calculating the mussel feeding rates is shared with the first model). The mussel feeding sub-model that was adopted has been developed under another FRST funded NIWA program ("Sustainability and Enhancement of cultured and wild shellfisheries", and its predecessors). The models represent important extensions to the preliminary calculations presented in Broekhuizen et al. (2002) in several ways. They allow us to: (a) make spatially explicit predictions of impact, (b) make an assessment of both short-term (days) and seasonal-scale variations in the nature of the impact and (c) the biophysical model, takes explicit account of the stimulatory effect of mussel nitrogen excretion. There is a growing body of literature suggesting that when ambient nitrogen levels are low, the nitrogen excreted by mussels can promote sufficient additional phytoplankton growth to partially (or more than) offset the losses to mussel grazing (Ogilvie, S.C. et al. 2000, Prins, T.C. & Smaal, A.C. 1990, Rosenberg, R. & Loo, L.O. 1983). Since the mussels must retain at least some of the nitrogen that they consume, how can the phytoplankton biomass increase in the presence of mussels? The answer appears to be that mussels consume material other than phytoplankton (organic detritus, zooplankton etc.). Thus, their total nitrogen intake exceeds the quantity of phytoplankton nitrogen consumed. There is sufficient 'excess' nitrogen consumed (and then released) to offset the nitrogen losses suffered by the phytoplankton population. In effect, the mussels serve to speed up the natural process of remineralisation from detrital matter.

The report is broken into several sections. The Methods section describes each of the models used. The Results section summarises the results from each model. The results are described for each model in turn: snapper model, logistic plankton model, biophysical model. The Discussion section is used to make observations regarding the nature of each model, and the nature of the results; however, we make only brief reference to the ecological implications of the results at this stage.

## 2.1 Comparison with earlier results

This report supersedes a December 2003 draft. Since releasing the draft, the models have been modified in three distinct ways: (1) several minor bugs have been fixed; (2) within the biophysical model, the particle splitting rules have been modified to better maintain homogeneity of particle sizes; (3) the code has been modified to achieve more satisfactory reflection of the particles off the sea-floor and sea-surface; (4) in the empirical model, we have replaced the earlier, implicit assumption that the water is devoid of detrital organic particulates with a more realistic one (that there is a constant, non-depleting, 'background' concentration of organic particulates; the biophysical model already included an explicit, dynamic detrital pool); (5) in the empirical model, we have increased the relative vulnerability of plankton sub-class 2 to 1.0 since we consider that there is little evidence that plankton with maximum growth rates as high as those of this class are any less vulnerable to consumption by mussels than are faster-growing phytoplankton. All of the simulations presented in the draft have been re-run using the revised models. The results presented in this revised report are based upon the new simulation results.

Since we believe the revised models to be more robust, we do not recommend comparison with the earlier results. If such a comparison is made, it is important to note that we have chosen to revise the colour-scales of some of the plots for this revised report. Comparison reveals: (a) some changes in locations of depletion/enhancement plumes (most markedly in the biophysical model); (b) slightly reduced depletion, and reduced sensitivity to the 'relative vulnerability' parameters in the empirical model; (c) the spring-time surface-water DIN concentrations generated by the revised biophysical model are somewhat higher than those generated by the earlier model.

Despite the changes to the details of the results, we believe that the broad conclusions remain unchanged.

