7 Conclusions & Recommendations

Perhaps one of the most important findings of this study is that, when measured over scales of several weeks, seasonal influences are the dominant influence upon the qualitative nature of any of the model results. That is, the magnitude and location of any (time-averaged) depletion/enhancement is more strongly influenced by seasonal changes in water-column stability, circulation patterns, mussel feeding rates and plankton production rates, than they are by the exact details of the winds blowing during the period of the simulation. This suggests that our results have general applicability, rather than being restricted only to the particular conditions that we chose to simulate.

We have stated that for the specific assumptions of the models, there are reasons to believe that all three of our models will over-estimate the quantity of material that mussels remove from the water-column. For this reason, our predictions are likely to be 'worst-case'. The results from the modelling suggest that if large-scale aquaculture does proceed within the firth:

- if snapper eggs/larvae are not resistant to mussel predation, they will suffer additional mortality. The extent of this additional mortality and affects on adult stock is difficult to assess because:
    - the factors governing natural mortality rates and recruitment rates in snapper are poorly known;
    - the degree to which snapper eggs/larvae are vulnerable to predation by mussels is unknown.
- Phytoplankton populations are likely to become depleted during times when temperature and/or light levels limit cell-growth rates (late autumn, winter & early spring). During times when phytoplankton growth rates are limited by nitrate/ammonium concentrations, the ammonium released by the mussels will enhance phytoplankton growth rates – perhaps to the extent that phytoplankton populations attain concentrations greater than would otherwise be likely to occur at that time of year. The depletion can be ~30% within the farms. Transport processes imply that depletion plumes will extend beyond the farm's perimeters, but also imply that depletion within the upstream areas of farms will be minimal. Thus, the total area in which depletion is evident will usually be offset somewhat from the farm, but will not exceed the area of the farm itself by a large margin. These modelling results are consistent with experimental and field observations. In contrast to the situation for snapper, we are therefore more confident of the qualitative nature of these conclusions.
- The predicted impacts upon slow growing (but relatively invulnerable) zooplankton are very sensitive to the choice of growth rate and vulnerability parameters. Depending on these factors and the parameters used, the

depletion may be of small magnitude and localised or in a worst-case scenario the predicted impacts could be large and extend over much of the central firth.

Perhaps the most important thing to note is that historic data for the Hauraki Gulf, Firth of Thames and other regions (such as the Marlborough Sounds) indicate that there is enormous variability in plankton systems – whether one considers time-scales of days, weeks, or years. In comparison with the natural range of variability, the predicted impacts are small – particularly in the far-field. This implies that they will be extremely difficult to identify with any certainty in field data.

Whilst the biophysical model is predicting DIN and chlorophyll concentrations that are consistent with measured values, this model has not undergone a formal verification process. The same is true of the snapper and logistic models. Whilst we believe the models' predictions to be robust, we consider that all of the models will be over-predicting mussel consumption rates (hence magnitude and spatial extent of depletion). Though it would necessarily be restricted to the near-field, a formal verification of the model against detailed field data from around a large farm would enable us to gain a greater appreciation of the models' strengths and weaknesses.

Our biophysical model suggests that the influence of farms upon phytoplankton are dependent upon the ambient DIN concentrations. Aside from riverine and oceanic inputs of DIN, there is a further source of dissolved inorganic nitrogen: remineralised nitrogen stemming from sedimented organic matter. Whilst the biophysical model does include a crude description of this process (including denitrification losses), this description takes no account of the documented influences that mussel farms have upon benthic remineralisation processes. For example, Kaspar et al. (1985) reported elevated denitrification rates below mussel farms. Thus, if sufficiently extensive (and intensive), it is conceivable that mussel farming could increase the nitrogen deficit within the firth in the long term. The substantial oceanic and riverine inputs would buffer any such tendency but a more detailed model of benthic remineralisation processes would help to assess the importance of this issue.

The magnitude of mussel impacts upon zooplankton are uncertain. Further experimental work may help to reduce this uncertainty but there is also a need to incorporate a dynamic description of zooplankton into the biophysical model. This would allow us to better assess the beneficial (to phytoplankton recovery) effects of zooplankton depletion, and the beneficial (to zooplankton recovery) effects of phytoplankton enhancement.