Chapter 8
Summary and Conclusions: Prospects for Sustainable Aquaculture

8.1 PROSPECTS FOR SUSTAINABLE AQUACULTURE WITHIN THE BAY OF PLENTY

This thesis has identified significant variability within the Bay of Plenty with respect to the potential for sustainable open coast suspended mussel culture.

This variability is a direct function of variability in both environmental and anthropogenic factors including:

i. the benthic environment (sediments, organisms, reef areas, etc.) (Chapter 3);
ii. existing and conflicting uses and users of the coastal marine environment (Chapter 6);
iii. hydrodynamic regime (Chapters 4, 5, and 6);
iv. nutrient delivery mechanisms (Chapter 4);
v. ecosystem dynamics (Chapter 7);
vi. the interactions of cultured mussels with their receiving environment (Chapter 7); and
vii. societal values toward the coast and marine areas (Chapter 6).

Observed and predicted productivity potential within the Bay of Plenty is greatest in neritic zones between Tauranga and Whakatane and lowest in oceanic regions and the eastern Bay of Plenty. Within the Bay of Plenty, the most suitable benthic areas to efficiently assimilate potential inputs from offshore suspended mussel aquaculture are silty sediments with relatively low natural organic contents. These sediments generally exist between 40-100 m depths. GIS approaches have indicated that high existing use, along with societal values toward specific areas of the Bay of Plenty considerably restricts the zoning potential for AMAs. This zoning potential is further restricted by environmental conditions which vary throughout the region and act to influence the magnitude of aquaculture induced impacts and hence its environmental sustainability. The rationalisation of these factors has allowed the identification of areas which show the greatest potential for sustainable aquaculture production. These areas are located on the mid-shelf (60-80 m) offshore from Pukehina, Matata, and Whakatane.

The western Bay of Plenty shelf is highly responsive to wind forcing, with the response varying spatially with coastline and shelf edge orientation. The dynamic response of the shelf to this wind forcing is responsible for significant new nutrient delivery through upwelling and infrequently shows strong potential for generating conditions leading to toxic algal blooms. The identification of this pattern has significant implications for any aquaculture development in the region. These implications include the prediction of both positive and negative growth conditions, and also the identification of poor harvest conditions (when the shellfish may be affected by harmful algae), thus potentially allowing a delayed harvest and significant savings.

Nested modelling studies have indicated that the mean EAUC flow field has little impact upon mid-shelf currents within the Bay of Plenty. Additionally, detailed analyses of long-term records from two open coast tide gauges, one within the Bay of Plenty and another from farther outside the study region, failed to find any evidence of CTWs originating or propagating though the Bay of Plenty. This finding can not be held as definitive, however, as a more thorough analysis would involve multiple (>4) concurrent current meter deployments across a wider geographic region.

At predicted stocking densities, two proposed large offshore mussel farms create low level changes to phytoplankton, zooplankton, and nutrient concentrations. These simulated cumulative lower trophic level impacts are below those applied as 'acceptable limits of change', indicative of the ecological carrying capacities, within New Zealand and internationally.

8.2 IMPLICATIONS FOR ENVIRONMENTAL MANAGERS

Environmental managers, within an integrated coastal-marine zone management framework, normally strive to ensure the rational use of coastal space. Managers must balance the needs and desires of industry with environmental concerns and societal values. To optimise use of the costal-marine space aquaculture developments should be sited were adverse impacts and conflict with existing users and societal values are minimised, while also considering the production potential of the cultured species. GIS tools have been shown to be effective in the integration of the diverse datasets required to optimise AMA site selection (Chapter 6).

Environmental managers must also consider the cumulative effects of multiple developments when assigning planning consents. This requires regional scale calibrated numerical models. Currently, there are no 'hard and fast' guidelines on which to base decisions regarding the levels of development induced change which are sustainable for a given environment; guidance must be taken from case studies around the world. Within the Bay of Plenty, model predictions indicate that the proposed scale of development induces changes which are of lesser magnitude and extent than those deemed sustainable in these national and international case studies (Chapter 7).

8.3 IMPLICATIONS FOR THE AQUACULTURE INDUSTRY

Optimal siting of aquaculture development maximises profits. The siting of aquaculture in highly productive areas maximises potential food for cultured species ensuring rapid growth. Siting in areas where negative environmental impacts are minimised and away from conflicting users and uses of the marine space reduces the costs of environmental remediation, consultation, and possible compensation. GIS tools have been effective in the identification of such sites (Chapter 6).

Within the Bay of Plenty, new nutrient supply occurs primarily through wind driven coastal upwelling (Chapters 4 and 5). This results in variability in productivity potential throughout the Bay. Aquaculture induced effects on nutrients and lower trophic levels of the food web are limited in magnitude and are below those observed at other locations around the world (for development specifics as tested, Chapter 7). However, low level changes can extend some distance from the farms themselves. This effect is potentially greater than that for the more traditional receiving environments of enclosed embayments as the level of hydrodynamism on the open coast is typically much higher, providing an efficient dispersal mechanism. Thus, it is important to consider cumulative effects when planning for open coast aquaculture.

8.4 NOVEL ASPECTS AND ADVANCEMENTS

This thesis represents a significant advancement in the scientific knowledge of Bay of Plenty physical dynamics and in the potential for sustainable mussel aquaculture within an open-coast environment. A substantial data collection program represents the first large-scale multi-disciplinary investigation of the Bay of Plenty continental shelf. These data have allowed the identification, description, and modelling of the region and processes occurring within it such as coastal upwelling; previously these features and processes were either unknown or based on anecdotal evidence. Previously existing datasets from within the region are characterised by narrow foci and restricted spatial extents. The dataset gathered for this thesis has enabled the identification of regional continental shelf benthic habitats and their suitability to assimilate aquaculture wastes (Chapter 3), shelf water column properties and wind driven upwelling dynamics (Chapter 4). Modelling studies, adopting several novel aspects, such as data assimilation and offshore boundary condition specification, identified the relative roles of local wind forcing, oceanic currents, and CTWs on shelf circulation within the Bay of Plenty (Chapter 5); all of which were previously unknown.

Several novel concepts were introduced in the GIS analysis to determine sustainable AMA sites (Chapter 6). The application of marine productive regions, identified from remotely sensed SST and Chl-a anomalies, along with benthic suitability indices and shore normal components of residual currents expand upon and advance existing methodologies and customise them for open coast sites.

The representation of non-simplified hydrodynamics and non-generalised environmental forcings in full 3-dimensional space within the ecosystem model (Chapter 7) is a significant advancement over most regional aquaculture depletion studies. This has allowed the cumulative consideration of aquaculture effects at various spatial scales and an evolution of the sustainable depletion curve concept (magnitude-extent combinations).

8.5 PROSPECTS FOR FURTHER RESEARCH

This thesis has highlighted several potential impacts of open-coast aquaculture development.

Nested farm scale or intra-farm scale ecological modelling would be an interesting development of the work in this thesis (particularly Chapter 7). A general weakness highlighted in the scientific literature of ecological models for aquaculture is a lack of realistic boundary conditions with appropriate temporal and spatial complexity (Chapter 7). The nesting of finer resolution models within a larger regional model such as that presented here could solve these problems.

The potential for large scale aquaculture to periodically provide additional nutrients to the marine system has previously been theorised (Smaal *et al.*, 2001); the model used within this thesis supports these postulations. Further work could investigate in more detail this possibility. An important feature of any such work would be the identification of any successional effects on the spring phytoplankton blooms and implications that this may have for the phytoplankton species composition. This is an important are to focus on as the possibility exists for Harmful Algal Blooms (HABs). The present model lacked this layer of complexity.

The main overriding unanswered question brought forward, however, is:

"*What are the specific levels of aquaculture induced changes which are sustainable over the long-term?*'

These levels are likely to be environment specific, creating further complexity given the proposed transition of the New Zealand aquaculture industry from enclosed embayments towards the open coast. While additional complexity could be added to the present work *e.g.* expanded benthic surveys, spatially extensive current meter arrays, more temporally expansive modelling of the EAUC, variable stoichiometry

NPZD models, additional phytoplankton and zooplankton groups within the NZPD model, additional calibration data for the NPZD model, the same problem still presents itself. Additional techniques could even be employed, such as food web modelling to determine the higher tophic level impacts of aquaculture development; we are still left asking the same question.

Progress towards finding a solution to this problem is likely to be slow due to the complexity and enormity of both the question and the ecosystem. Presently, numerical modelling can, as in this case, provide an indication of the level of change expected; it cannot, as a whole, determine threshold levels for each and every ecosystem component which relies on constituents directly or indirectly altered by aquaculture. Currently, the best approach is to use case studies; however, this in turn leads to potential issues as a result of ecosystem and species level variability between sites.

A solution is to determine and catalogue the specific environmental requirements for each 'significant' ecosystem component *e.g.* dissolved oxygen, nutrient, phytoplankton, and zooplankton requirements for coastal shellfish or finfish; this represents a substantial challenge. In the absence of these requirements and definitive threshold values detailed monitoring will be required of any development which takes place.

8.6 CLOSING REMARKS

This thesis has shown that there is high potential for sustainable open-coast culture of mussels on large scales provided it is located appropriately. However, there is a need to be informed about environmental and development issues to ensure that informed decision making can take place. The most significant question to ask once development proposals have been made is not necessarily '*What level of change will aquaculture will aquaculture development induce?*', but '*What level of change is sustainable?*'.