Chapter 1
Introduction and Thesis Approach

1.1 INTRODUCTION

Mussel farming is an important industry within New Zealand and, during the late 1990s and early 2000s, experienced rapid growth. Specifically, greenshell mussel (*Perna canaliculus*) export volumes doubled during the decade 1995-2005 to reach 100,000 tonnes (Ministry of Economic Development, 2007). Presently, the industry comprises numerous (~1100) individual farms of relatively small size (~3 ha each, Loyd, 2003; Ministry for the Environment, 2005) which have traditionally been located within relatively sheltered estuaries and bays close to the coast *e.g.* Firth of Thames and Marlborough Sounds. A combination of the rapid growth in the aquaculture industry, the near saturation of traditional sites, and recent advances in culture technologies (*e.g.* Thomson, 1996) has led the industry toward alternate environments; notably exposed offshore locations. Reflecting this, applications have been made recently for numerous large farms (~5000 Ha each) in open coast locations around New Zealand, including within the Bay of Plenty (pers. comm. Environment Bay of Plenty; Figure 1.1).

In many countries, the rapid expansion of the aquaculture industry has outpaced the development of management frameworks to control environmental impacts (Pitts, 1990; Burbidge *et al.*, 1993; Morrisey and Swales, 1997). Within New Zealand, the significant leap in scale of proposed development, along with the industry's progress toward alternate environments, has created a 'knowledge gap' with respect to potential impacts. This prompted the New Zealand government to initiate aquaculture specific legal reform during 2002-2004 with the goals of ensuring informed decision making, sustainable resource use, and informed management of any cumulative impacts. This thesis contributes to these efforts.

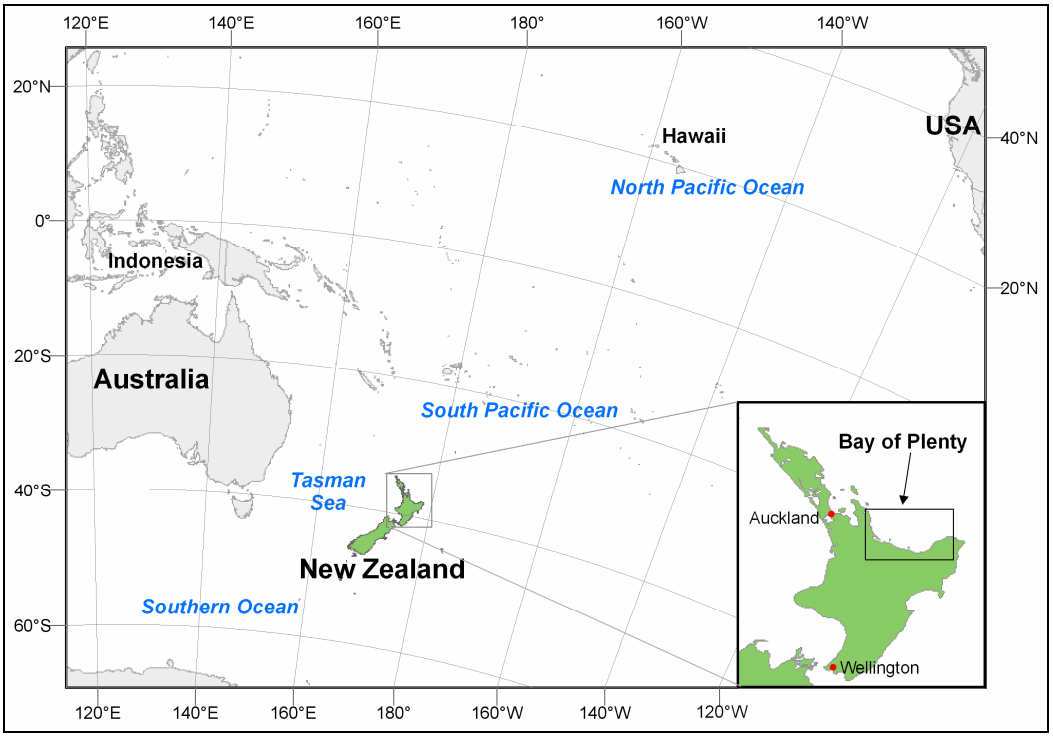

Figure 1.1 The Bay of Plenty, located on the north east coast of New Zealand's North Island in the South Pacific Ocean.

1.2 MOTIVATION FOR THE STUDY

Aquaculture modifies its receiving environment. There is real and significant potential for aquaculture-induced impacts across a variety of environmental components such as benthic nutrient and oxygen loads (Dahlback and Gunnarsson, 1981; Kaiser *et al.*, 1998), local biodiversity and species assemblages (Grant *et al.*, 1995; Stenton-Dozey *et al.*, 1999), pelagic communities (Davenport *et al.*, 2000; Grant and Bacher, 2001), and hydrodynamic conditions (Grant and Bacher, 2001; Plew *et al.*, 2005).

A sustainable aquaculture industry requires that environmental, economic, and social factors be considered (Figure 1.2). Here, the definition of Boyd and Schmittou (1999) can be applied where sustainable aquaculture is defined, '*where ecologic and economic viability persist indefinitely*'. This definition explicitly recognises that economic factors (*e.g.* productivity potential) must be considered within the overall 'sustainability equation' for their potential to improve efficiencies, reduce stocking densities and thereby reduce negative impacts (Figure 1.2).

Within an effective coastal-marine management framework, a strategy should be implemented to enhance the knowledge of appropriate aspects of the receiving environment (*e.g.* benthic habitats, nutrient delivery, productivity variability, Figure 1.2) along with the potential impacts of aquaculture upon them. Solutions to eliminate, minimise, or mitigate these effects can then be determined and implemented.

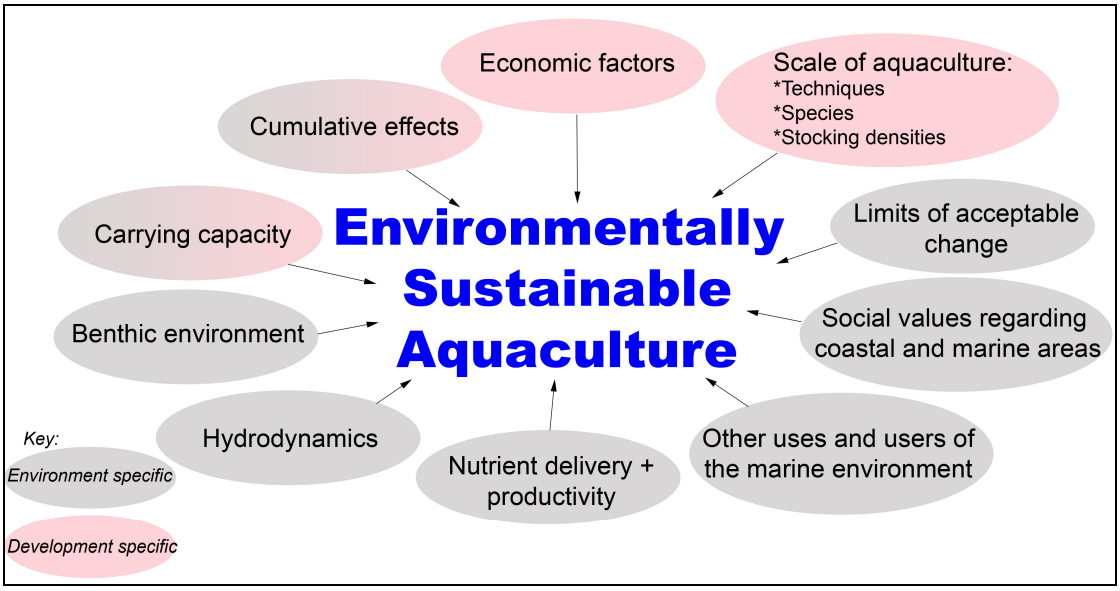

Figure 1.2 Development specific and environment specific factors influencing the potential for environmentally sustainable aquaculture within the marine environment.

Specific to the Bay of Plenty, while there are some relevant high quality data available, no detailed research has been undertaken which adequately considers the coupled dynamics and interactions of physical, ecological and bio-geochemical processes in terms of detailed hydrodynamics, nutrient supply and the productivity of the shelf waters. Additionally, many existing studies are locally focussed on specific issues and sites, failing to consider the regional environment and associated issues over larger scales, imperative for environmental managers during the planning stages to identify suitable sites and determine cumulative effects.

These issues create the need for a detailed study within the Bay of Plenty considering aspects relating to the planning for, and zoning of, sustainable Aquaculture Management Areas (AMAs). This thesis represents an expansion of a commissioned project to investigate the potential effects of offshore aquaculture on the Bay of Plenty marine environment.

1.3 AIMS AND OBJECTIVES

The overall goal of this study is to determine the potential for environmentally sustainable large-scale offshore mussel culture within the Bay of Plenty marine environment.

This aim is to be met by achieving the following objectives:

- determine potential impacts on the benthic environment and provide information to enable AMAs to be located such that negative impacts are minimised and mitigated efficiently;
- resolve forcing mechanisms and driving influences on shelf hydrodynamics and new nutrient supply within the Bay of Plenty;
- identify locations within the Bay of Plenty shelf where productive and sustainable AMAs can be located; and also locations which should be avoided; and
- determine the cumulative potential lower trophic level depletion effects of two large mussel proposed offshore mussel farms on the Bay of Plenty marine ecosystem.

To meet these objectives a significant data collection and modelling program was initiated with the goal of providing data focussed on:

- the benthic environment of the Bay of Plenty shelf;
- the water column structure and currents of the Bay of Plenty shelf;
- the nutrient status and lower ecosystem level character of the Bay of Plenty shelf;
- existing users and uses of, and societal values relating to, the Bay of Plenty shelf marine environment; and
- modelling to synthesise data and build tools to enable the assessment of suitable locations for sustainable aquaculture.

1.4 BENEFITS OF THE RESEARCH

Aquaculture development within the Bay of Plenty marine environment is currently hindered by a lack of information and knowledge relating to the impacts of large scale culture on open-coast locations, and also by a general paucity of data relating specifically to the Bay of Plenty shelf. This thesis endeavours to address these issues by overcoming the present uncertainties. In meeting its objectives, this work expects to fill knowledge gaps, predict impacts through modelling studies, and to define carrying capacities for use as a management tool.

The data collection program was designed to fill gaps, expand upon and create a more spatially intensive database of environmental parameters within the Bay. Through novel techniques and rigorous modelling simulations the work provides new insights into the physical and ecological workings of the Bay of Plenty marine environment.

1.5 THESIS STRUCTURE

1.5.1 CHAPTER 2 – BACKGROUND

Chapter 2 comprises a general background to the topics addressed within the thesis. Aquaculture techniques and practices, the New Zealand aquaculture experience and legislative reform are summarised. Local and international literature is reviewed to highlight potential impacts of aquaculture upon its receiving environment. The concepts of sustainability and carrying capacities for aquaculture development are introduced and investigated. Existing site specific oceanographic research is reviewed and summarised.

1.5.2 CHAPTER 3 – SEDIMENT HABITAT MAPPING

Previous research indicates that the benthic environment is vulnerable to aquaculture development (*e.g.* Dahlback and Gunnarsson, 1981; Kaspar *et al.*, 1985; Cranford *et al.*, 2003). Chapter 3 attempts to first identify and characterise the sedimentary habitats within the Bay of Plenty shelf, and subsequently to determine their relative suitability to be sited beneath an aquaculture development. The potential impacts of aquaculture on observed benthic habitats and associated species assemblages are considered as a strategy to minimise potential negative effects and maximise environmental sustainability.

1.5.3 CHAPTER 4 – UPWELLING MECHANISMS

Observations of shelf physical dynamics provide insights to how productivity is maintained in coastal regions. Presently, there is a distinct lack of research and understanding of the physical dynamics within the Bay of Plenty. Chapter 4 aims to characterise shelf water properties and the hydrodynamic environment from observations in order to resolve the influence of wind forcing and its subsequent water column responses. The identification of physical forcings and responses assists the discovery of upwelling based nutrient delivery mechanisms; such delivery mechanisms are important for aquaculture development as they stimulate primary production. A key outcome of this chapter is the measurement and characterisation of shelf water properties and dynamics to assist the identification of suitable sites for sustainable aquaculture.

1.5.4 CHAPTER 5 – HYDRODYNAMIC MODELLING

To identify the most suitable and sustainable sites for open-coast aquaculture a spatially comprehensive understanding of shelf hydrodynamics is essential. A calibrated hydrodynamic model can provide these data. Chapter 5 aims to set up, calibrate and run a 3-dimensional baroclinic model of continental shelf circulation within the Bay of Plenty. Such a model assists the identification of circulation patterns, the relative influence of tidal, wind, and oceanic forcings. A key outcome of this chapter is that the model can subsequently be used to identify the most suitable sites for sustainable aquaculture (Chapter 6) and to drive and ecological model to predict the lower trophic level depletion impacts of open-coast mussel aquaculture (Chapter 7).

1.5.5 CHAPTER 6 – SELECTING OPTIMALLY SUSTAINABLE SITES

A common reason for the economic failure and adverse environmental impacts of aquaculture projects is their location in/on inferior sites. Site selection is of significant importance in the sustainable management of aquaculture (Pillay, 2004). Chapter 6 builds upon and utilises previous work (*e.g.* benthic habitats from Chapter 3, water currents from Chapter 5), along with a variety of other datasets (*e.g.* productivity potential, existing uses and users of the environment). This work supports the decision making process to identify AMAs which are both productive and environmentally sustainable. A key result of this chapter is the identification of the most suitable open-coast sites for productive and sustainable aquaculture development.

1.5.6 CHAPTER 7 – ECOLOGICAL MODELLING

Cultured bivalves depend on the coastal ecosystem to supply their food. Through their feeding behaviour, they have the ability to compete with other animals and modify lower trophic level ecosystem functioning. Chapter 7 aims to quantify these lower trophic ecosystem level impacts of mussel culture through the development, calibration, and application of a numerical 3-dimensional bio-physical ecological model and mussel feeding sub-model. This work will allow the cumulative, ecosystem wide impacts of proposed mussel culture to be assessed in a predictive sense. A key result of the chapter is the comparison of predicted effects with those published from other locations both nationally and internationally allowing a confident assessment of ecosystem carrying capacity within the Bay of Plenty.

1.5.7 CHAPTER 8 – SUMMARY AND PROSPECTS FOR SUSTAINABLE AQUACULTURE

Chapter 8 summarises the thesis findings. With reference to the conclusions from the previous chapters, the potential for environmentally sustainable large-scale open coast mussel aquaculture within the Bay of Plenty is assessed. Recommendations are made on the location, size, and stocking densities of potential developments. Aspects of the research and areas of knowledge which would benefit from further investigation and research are highlighted.