Environmentally Sustainable Aquaculture: An Eco-Physical Perspective

A thesis
submitted in partial fulfilment
of the requirements for the degree of

Doctor of Philosophy
at
The University of Waikato

by
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The University of Waikato
2007

ABSTRACT

The New Zealand aquaculture industry during the late 1990s and early 2000s experienced a significant and sustained period of growth. Greenshell mussels (*Perna canaliculus*) are proving to be a popular and valuable cultured species, with large domestic and international markets. Traditionally, these bivalves have been farmed within enclosed embayments and on relatively small scales (~3 Ha). The recent expansion of the industry coupled with the near saturation of existing 'traditional' sites and new culture technologies has led the industry toward alternate environments, notably exposed offshore sites. Initial proposals within the Bay of Plenty have included multiple farms of ~4500 Ha each. This novel approach to shellfish culture created uncertainty with respect to potential environmental impacts, cumulative effects, and sustainable carrying capacities within these exposed open-coast locations. In zoning for Aquaculture Management Areas (AMAs), environmental managers must be informed of each of these aspects to ensure the rational and sustainable use of the coastal-marine space.

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. The long term sustainability of aquaculture development on an open coast is a function of many influences which can vary in both time and space. The benthic environments of the Bay of Plenty exhibit great variability in their ability to assimilate waste inputs from suspended mussel culture; a direct function of the variability in sedimentary environments and benthic habitats within the region. Specifically, silty sediments with low natural organic contents, generally found between 40 and 100 m depths are the most suitable locations for sustainable mussel aquaculture from an environmental impact perspective. Both observations and model predictions indicate productivity potential within the region to be greatest within neritic zones of the western Bay of Plenty. Local wind forcing is the predominant mechanism forcing local shelf currents. Current meter data and numerical modelling tests from this study indicate that local winds explain the majority of water current variability on the shelf, generate the delivery of new nutrients to the shelf through upwelling, and hence create the variability in productivity potential. Complicating the AMA zoning process for environmental managers, however, are existing uses of, and societal values toward, the coastal-marine environment. GIS planning tools have been shown to be effective at minimising conflicts and maximising sustainability potential through informed site selection. Within the Bay of Plenty, these preferential sites are located on the mid-shelf (60-80 m depths) offshore from Pukehina, Matata, and Whakatane.

This study shows that the simulated cumulative lower trophic-level depletion impacts of two large (~5000 Ha) proposed offshore mussel farms vary seasonally as a result of subtle changes in ecosystem dynamics and mussel feeding patterns. At proposed stocking densities, largest relative impacts are expected during autumn and winter, when relative phytoplankton biomass is low and growth rates slow. During spring, while absolute impacts are greater than those during autumn/winter, greater phytoplankton-zooplankton biomass and faster growth rates result in quicker recovery times and reduced 'depletion halo' extents. Year-long predicted impacts are below those applied as 'acceptable limits of change', both within New Zealand and internationally, indicative of the ecological carrying capacity.

ACKNOWLEDGEMENTS

The completion of this work would not have been possible without the assistance and support of many individuals and organisations. First on the list of those who have been instrumental in their contribution are co-supervisors, Professor Terry Healy and Dr Kerry Black. I believe their enthusiasm for coastal science is without parallel within New Zealand. Together, they provided guidance, assistance, passion, motivation, and a good old fashioned kick up the backside when required. Both Terry and Kerry found time during a busy period during the year to review a draft version of this thesis in its entirety; their comments improved the readability of the thesis considerably. Thanks to you both, I hope I can return your efforts one day.

ASR Ltd and its managing directors Kerry and Shaw (and Joseph) created the foundations upon which this research was conducted. The project originates from their contacts, expertise, and initial efforts. Their contribution did not stop once I came on board. ASR Ltd continually provided infrastructural support, office space, and most importantly the combined knowledge of several 'old hands'. Environment Bay of Plenty (EBOP) particularly Stephen and Aileen have supported the project greatly, without their foresight and concern for the marine environment, the project would never have progressed.

The crew at the ASR office in Raglan were great work mates and surfing buddies: Andrew, Dave, Brett, Shaw, Peter, Shawn, Jose, and James, thanks for all the work discussions and for sharing the waves. Tim Haggit and his contacts with the Leigh Marine Laboratory were a great help, undertaking the biological analyses from the benthic survey. At the university Dirk Immenga was an essential component for his knowledge of all instruments, contacts within the NZ oceanographic community, boat handling skills, and most of all his general ability to actually get things done. Brad, Gegar, Kyle, Lauren and fellow students at the Coastal Marine Group were a great bunch of mates at Ruakura, on Terrys field trips and also on our conference trips. Also at the university, Meagan and Willem provided valuable support during the early planning stages where an abundant number of i's needed dotting, t's crossing, and general political palaver was required by certain 'regulations' when instigating a combined university-industry partnership. Sydney, as the day to day support person at the Department of Earth and Ocean Sciences, was always willing to go out of her way to help when needed, especially when I was located offshore and extra effort was required, cheers Sydney. I am also indebted to the university library staff, in particular the inter-loans department. They not only dealt with the massive quantity of inter-loans I requested from them, but assisted when I was based offshore by scanning and emailing these articles. I could not have worked productively in Qatar for over a year without this, huge gratitude to you all.

The Tertiary Education Commission supported this study initially through a Technology in Industry Fellowship (TIF) with ASR Ltd and subsequently through a Bright Future Top Achiever Doctoral scholarship (contract UOWX05006). This support has helped immensely and my appreciation for it, and also for the assistance of their UNIlink contact person, Carol Robinson, is huge.

My family have lived through this thesis with me. They have all experienced my frustrations, resentment, anger, excitement, and joy alongside me. Mum, Dad, Simon, and Anna, thanks for your love and support for the past 3½ years and into the future. Cassie, Bungle, Mercedes, and Shadow have given me an outlet to forget temporarily the issues of the work day and remember what life is really about. In the closing stages of this work my mum, Judi, acted as my NZ representative whilst I was working offshore. The thesis never would have made it to the printery, bindery, and finally the university without her huge efforts. Thanks mum!

Mel, my incandescent wife, we have been on a journey which often seemed like it had no end, yet we reached it in better shape than we started. You are everything to me.
Te Kotahitanga: together, we are strong in purpose and direction.

PREFACE

The main body of this thesis comprises five chapters (Chapters 3-7). At the time of submission Chapter 3 has been published in an international peer reviewed scientific journal, Chapter 4 has been accepted for publication, and Chapter 6 is undergoing the peer review process (see references below). I assumed responsibilities for field work, laboratory and data analysis, scientific reasoning, and thesis compilation. Except where referenced the material within this thesis was produced from my own ideas and work undertaken with the supervision of Professor Terry Healy and Dr Kerry Black.

Publications (published, accepted and submitted) to date include:

Chapter 3

Longdill, P.C., Healy, T.R., Black, K.P., and Mead, S.T., 2007. Integrated sediment habitat mapping for aquaculture zoning. *Journal of Coastal Research,* SI50 (ICS2007), 173-179.

Chapter 4

Longdill, P.C., Healy, T.R., Black, K.P. accepted for publication (2007). Transient coastal upwelling on a lee coast shelf with variable width and orientation. *New Zealand Journal of Marine and Freshwater Research*.

Chapter 6

Longdill, P.C., Black, K.P., Healy, T.R. 2006. Marine productive regions identified from satellite remotely sensed data and numerical model results. *In*: Woodroffe, C.D., Bruce, E.M., Poutinen, M., Furness, R.A. (eds), *GIS for the Coastal Zone: A Selection of Papers from CoastGIS 2006*, Wollongong Papers on Maritime Policy No. 16. pp 371-380.

Longdill, P.C., Healy, T.R., Black, K.P. in review (2007). An integrated GIS approach for sustainable aquaculture management area site selection. *Ocean and Coastal Management*.

This work builds upon a large consulting project undertaken by ASR Ltd (largely conducted by myself within the TIF program under the supervision of Dr Black and Professor Healy) for the regional council, Environment Bay of Plenty. This project was titled '*Choosing open coast AMAs to sustain the environment, kaimoana, and aquaculture industry*'. Throughout the project consulting reports were compiled and presented to them. This thesis combines several aspects of these reports and builds upon the concepts introduced within them. Without the deadlines of consulting work, this thesis has been able to expand upon and refine several of the techniques and methodologies used within the consulting reports; the general conclusions remain unchanged.

An attached CD-ROM inside the back cover includes digital copies of the following:

- This thesis;
- Papers published and conference presentations conducted during the work;
- Consulting reports arising from the work; and
- All raw data used within the thesis and the geo-referenced GIS benthic habitat map.

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AFDW	Ash Free Dry Weights
ADP	Acoustic Doppler Profiler
AMA	Aquaculture Management Area(s)
AVHRR	Advanced Very High Resolution Radiometer
Chl-a	Chlorophyll-a
CTD	Conductivity Temperature Depth (profiler)
CTW	Coastal Trapped Wave(s)
DGPS	Differential Global Positioning System
DN	Detrital Nitrogen
DO	Dissolved Oxygen
DP	Detrital Phosphorus
DRP	Dissolved Reactive Phosphorus
DSS	Decision Support System
DW	Dry Weight
EAC	East Australian Current
EAUC	East Auckland Current
EBOP	Environment Bay of Plenty
ECC	East Cape Current
ECE	East Cape Eddy
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El-Niño Southern Oscillation
GB	GigaByte
GIS	Geographic Information System(s)
GPS	Global Positioning System
GTSPP	Global Temperature-Salinity Profile Program
IB	Inverse Barometer
HOC	High Organic Carbon
ICZM	Integrated Coastal Zone Management
IDW	Inverse Distance Weighting
IOP	Inherent Optical Properties
LOC	Low Organic Carbon
LOI	Loss On Ignition
MCE	Multi Criteria Evaluation
MPA	Marine Protected Area(s)
MSL	Mean Sea Level
NCE	North Cape Eddy
NH3	Ammonium
NIWA	National Institute of Water and Atmospheric research
NPZ	Nutrient-Phytoplankton-Zooplankton
NOx	Oxidised Nntrogen as NO2 and NO3
NZMG	New Zealand Map Grid
NZPD	Nutrient-Zooplankton-Phytoplankton-Detritus
NZST	New Zealand Standard Time
NW	North Westerly
OCCAM	Ocean Circulation and Climate Advanced Modelling
OTIS	Oregon state university Tidal Inversion Software
PAR	Photosynthetically Active Radiation
PSSF	Parameter Specific Suitability Function(s)
RTK	Real Time Kinematics
SC	Southland Current
SDP	Science Data Product
SE	South Easterly
SeaWiFS	Sea-viewing Wide Field-of-view Sensor (satellite)
SI	Suitability Index
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
Sv	Sverdrups (10^6 $m^3.s^{-1}$)
TF	Tasman Front
WE	Wairarapa Eddy
WOD	World Ocean Database
XBT	eXpendable-Bathy-Thermograph

*equation constants defined within explanatory text