SALMON FARM LOCATION IN THE BROUGHTON ARCHIPELAGO,

BRITISH COLUMBIA: A QUANTITATIVE ANALYSIS

by

ZOFIA BIRGIT BORNIK

B.Sc., McGill University, 2002

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Resource Management and Environmental Studies)

THE UNIVERSITY OF BRITISH COLUMBIA

April, 2005

ABSTRACT

The Broughton Archipelago on the northeast coast of Vancouver Island has the highest density of salmon aquaculture in the province of British Columbia, with 27 farms operating in an area of 117 km². The Archipelago has been a focus region for early developments of spatial resource databases; it was the site selected for conducting the 1997 Salmon Aquaculture Review; and it has been the origin of recent controversies over the (mis)use of local ecological knowledge of First Nations and other interest groups. Many of the studies conducted in this area have focussed on the impacts of salmon farming on the local ecology. However, to date, little attention has been paid to what drives the industry at the regional level. By examining the distribution of salmon farms within the Archipelago and their spatial relationship to five different factors, this thesis aims to shed light on how and why the salmon aquaculture industry in the Broughton Archipelago has evolved over the last 20 years.

This work examines the effectiveness of current siting guidelines in minimizing the impacts of salmon farming and protecting the long-term sustainability of B.C.'s coastal ecology. Geographic Information Systems and spatial data analysis are used in combination to test the validity of five hypotheses on the potential drivers of the location of salmon farms in the Broughton Archipelago. Temporal analysis is used to compare the intended versus actual use of three spatial databases in shaping the development of the industry along the coast. Salmon farms in this region are found to be clustered by company, and located in areas of high biophysical capability where coastal resource interests and activities are also concentrated. These sites are not selected for their

proximity to processing plants, hatchery facilities, or labour. Salmon farms, as currently distributed, are equally likely to be found in areas that meet the existing siting criteria as those that fail to do so. The findings of this research will be of fundamental importance as the province of B.C. faces the decision of whether to continue expanding the industry balancing risks with economic rewards, or to limit expansion until more is known about the costs and long-term impacts.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Equations

List of Abbreviations

BCAS – British Columbia Aquaculture System

BC OAG – British Columbia Office of the Auditor General

Canada OAG – Canada Office of the Auditor General

CDF – Cumulative Density Function

CMPB - Coast and Marine Planning Branch

CRIMS - Coastal Resource Information Management System

CRIS – Coastal Resource Interest Study

DFO – Department of Fisheries and Oceans

EAO – Environmental Assessment Office

GIS – Geographic Information Systems

LUCO – Land Use and Coordination Office

LWBC – Land and Water British Columbia Ltd.

MAFF – Ministry of Agriculture Food and Fisheries

MELP – Ministry of Environment, Lands and Parks

MSRM - Ministry of Sustainable Resource Management

MWLAP – Ministry of Water, Land, and Air Protection

NIS – North Island Straits

NNI – Nearest Neighbour Index

Acknowledgements

Financial support from the Centre for the Integrated Study of Human Dimensions of Global Change at Carnegie Mellon University, the R. Howard Webster Foundation and the University of British Columbia is greatly appreciated. Special thanks to Hadi Dowlatabadi for his supervision and ability to see what others don't. Thanks also to my committee members, Tim McDaniels, Ed Levy, and Brian Klinkenberg for their advice. Acknowledgements for data assistance to Rob Paynter, Rick Deegan, Heather Russell, Brenda Williams, David Weir, Jose Aparicio, Steven F. Cross, Jeff Ardon and Daniel Galland. Finally, many thanks to Alexandra Morton, Brendan Connors, Marty Krkosek for their kind hospitality, to Matt Brown for his patience and Friday night dinners, and to my family for their positive thoughts.

CHAPTER I Introduction

1.1 Context

Salmon aquaculture in British Columbia has evolved rapidly over the last 30 years: from a small-scale industry in the 1970s, exclusively raising Pacific salmon; to an entrepreneurial industry of over 100 companies in the 1980s, concentrated in and around the Sunshine Coast, raising predominantly Atlantic salmon; to a consolidated industry in the 1990s, operated by 23 national and multinational firms, with farms located over a broader range around and north of Vancouver Island, in areas such as the Johnstone Strait and the Broughton Archipelago.

British Columbia now produces approximately 3-4% of the world's farmed salmon. In 2003, the harvest of farmed fish accounted for 65% of salmon production in B.C., with an annual wholesale value of $260 million per year (BC MAFF, 2003). Much of the production is exported, with the bulk going to the U.S. market. Direct and indirect industry employment is estimated at 4,100 jobs. Employment in hatchery operations, processing facilities and feed operations has contributed to the economic well-being of a number of coastal communities. Salmon aquaculture also benefits support industries such as transportation and veterinary services. It is believed that farmed salmon is, in dollar terms, B.C.'s highest value legal agricultural export crop (Gardner and Pederson, 2003).

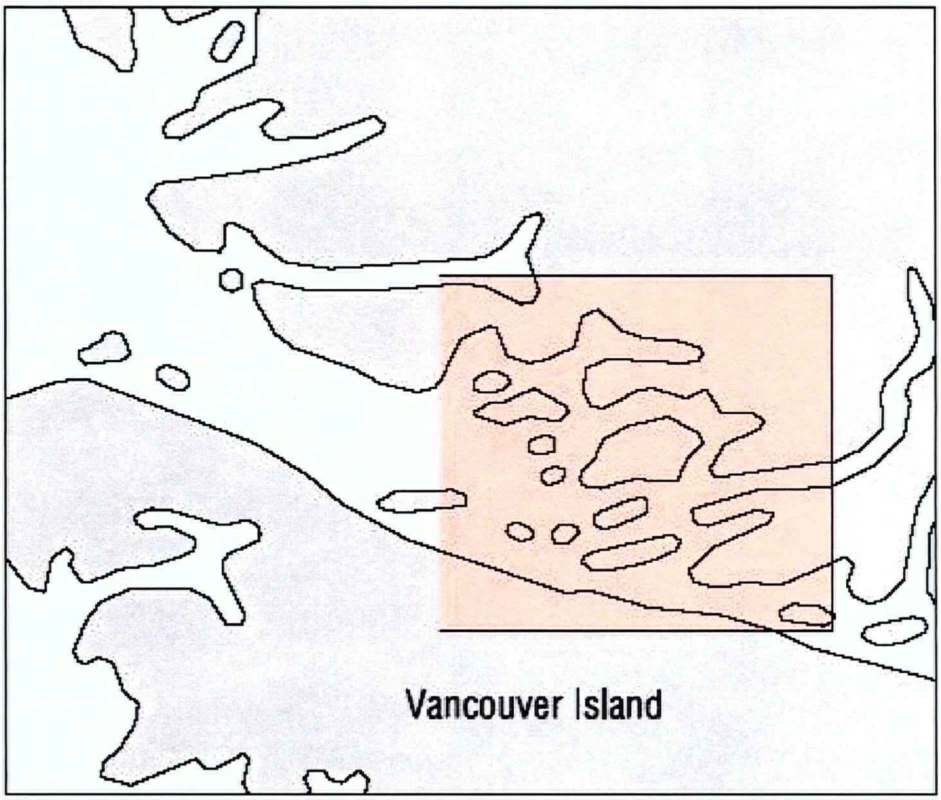
The rapid growth of the B.C. salmon farming industry in the 1980s was accompanied by increasing public concerns about impacts of the industry on the local marine ecology and on other coastal users. Since the Gillespie Inquiry of 1986, there have been many more inquiries, reports, reviews, and studies on the sustainability of the industry. Key issues central to the controversy have included impacts of escaped farm salmon on wild stocks, disease in wild and farmed fish, waste impacts on the benthic environment, impacts of farms on coastal mammals and other species, and siting of salmon farms. This thesis focuses on the last of these issues, examining the location of salmon farms in the Broughton Archipelago, B.C. with respect to five potential determinants ranging from factors of commercial success to other factors protecting the local coastal ecology.

1.2 Motivation

The Broughton Archipelago on the northeast coast of Vancouver Island has the highest density of salmon aquaculture in the province, with 27 farms operating in an area of 117 km^2. The Archipelago has been a focus region for early developments of spatial resource databases (eg. Coastal Resource Interest Studies, British Columbia Aquaculture System); it was the site selected for conducting the 1997 Salmon Aquaculture Review; and it has been the origin of recent controversies over the (mis)use of traditional ecological knowledge of the local First Nations in the siting of salmon farms. These factors make the Broughton Archipelago an ideal region on which to focus, both in terms of availability of data, and timely relevance.

In September, 2002, the B.C. government lifted the moratorium on issuance of new salmon farm licences, which had been in effect since 1995, opening the doors for "responsible" expansion of the salmon aquaculture industry. Production had been increasing during the period of the moratorium, from 23.8 million gross tonnes in 1995 to 49.5 million tonnes in 2000, as operators increased stocking in the area within their licensed tenures. The salmon farming industry is now projected to quadruple production over the next 10 years, with an average of 10-15 new farms added each year (Gardner and Pederson, 2003).

Figure 1.1 Broughton Archipelago



(Source: BC MSRM, 2002)

Recent studies conducted in the Broughton Archipelago have focussed on the impacts of salmon farming on the local coastal ecology (Brooks *et al.* 2004, Morton *et al.* 2004, Morton and Symonds 2002, Sutherland *et al.* 2001). However, to date, little attention has been paid to the 'driver' end of the process: what are the underlying factors shaping the industry? By examining the distribution of salmon farms within the Archipelago and their spatial relation to five different factors, this thesis aims to shed light on how and why the salmon aquaculture industry in the Broughton Archipelago has evolved in the manner that it has over the last 20 years.

The work examines the effectiveness of current siting guidelines in minimizing the impacts of salmon farming and protecting the long-term sustainability of B.C.'s coastal ecology. It tests, quantitatively, five hypotheses on the potential drivers of the location of salmon farms in the Broughton Archipelago. This thesis also compares the intended versus actual use of three spatial databases in shaping the development of the industry along the coast. This information will be of fundamental importance as the province decides whether to continue expanding the industry balancing risks with economic rewards, or to limit expansion until more is known about its costs and long-term impacts.

1.3 Multiple Testable Hypotheses

The thesis begins with a description of the salmon farm siting and approval process as it has emerged in British Columbia over the last twenty years. Chapter 2 delves into the evolution of siting criteria and a comprehensive finfish aquaculture application process, involving multiple levels of government each with their own mandate. Recent dynamics are discussed, including termination of the moratorium and development of the salmon aquaculture policy framework, along with challenges put forth by the latest Auditor Generals' reports. Chapter 3 describes four different spatial guides to finfish aquaculture siting for B.C., in terms of the data sources, intended use, and ultimate product. They are: the British Columbia Aquaculture System, Coastal Resource Interest Studies, Aquaculture Opportunity Maps, and the North Island Straits Coastal Plan. Chapter 4 outlines the methodological framework for analysis, including a literature review of the uses (and limitations) of Geographic Information Systems and spatio-temporal analysis for natural resource management. The specific spatial statistical approach applied to each hypothesis is detailed in the methodology and results section, Chapter 5.

The null and five tested hypotheses regarding the determinants of salmon farm location in the Broughton Archipelago are as follows:

- H0: Salmon farms are randomly located along the coast
- H1: Salmon farms are clustered by company
- H2: Salmon farms are located in biophysically capable areas
- H3: Salmon farms are located to be close to processing plants
- H4: Salmon farms are located to protect coastal resource interests
- H5: Located to meet current siting criteria

The results lead to either a rejection, or failure to reject, the hypothesis in question. The implications of each finding are discussed in Chapter V (Results) and Chapter VI (Conclusion and Recommendations), with regards to the effectiveness of spatial databases and salmon farm siting policy in protecting the long-term sustainability of B.C.'s coast.

References:

British Columbia Ministry of Agriculture, Food and Fisheries (2003) Fisheries Statistics. http://www.agf.gov.bc.ca/fish_stats/statistics.htm. Accessed: December 15, 2004.

British Columbia Ministry of Sustainable Resource Management, Business Solutions Division (2002) Salmon Aquaculture Relocation Process: Finfish Aquaculture Opportunity Map, North Island Straights. ftp://ftp.gis.luco.gov.bc.ca/pub/coastal/nis/pdf/map9e.pdf. Accessed December 08, 2004.

Brooks, K.M., A.R. Stiems, C. Backman (2004) Seven year remediation study at the Carrie Bay Atlantic salmon (Salmo salar) farm in the Broughton Archipelago, British Columbia, Canada. Aquaculture 239, pp. 81-123.

Gardner, J. and D.L. Peterson (2003) Making sense of the salmon aquaculture debate: Analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council.

Morton A., R. Routledge, C. Peet, A. Ladwig (2004). Sea lice (Lepeophtheirus salmonis) infection rates on juvenile pink (Oncorhynchus gorbuscha) and chum (Oncorhynchus keta) salmon in the nearshore marine environment of British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 61(2), pp. 147-157.

Morton A.B. and H.K. Symonds (2002). Displacement of Orcinus orca (L.) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science 59(1), pp. 71-80.

Sutherland T.F., A.J. Martin, C.D. Levings (2001). Characterization of suspended particulate matter surrounding a salmonid net-pen in the Broughton Archipelago, British Columbia. ICES Journal of Marine Science 58(2), pp. 404-410.

CHAPTER II Salmon Farm Siting and Approval Process

2.1 Evolution of siting criteria

In April 1995, the B.C. government placed a moratorium on the issuance of new salmon farm tenures, and launched an Action Plan for Provincial Salmon Aquaculture, identifying the need for a definitive review of environmental issues and of provincial salmon aquaculture policies. The resulting Salmon Aquaculture Review was conducted by the B.C. Environmental Assessment Office (EAO), with its report being delivered in August of 1997. The EAO identified five issues as central to the controversy over the aquaculture industry, one of which was salmon farm siting. A Technical Advisory Team of experts prepared comprehensive discussion papers on the five issues, and a final report was submitted to the Minister of Environment, Lands and Parks and the Minister of Agriculture, Fisheries and Food, including 49 recommendations for improving current methods and processes.

In its review of salmon farm siting, the EAO concluded that much of the existing distrust around the siting of salmon farms stemmed from the 1980s, when the industry was rapidly expanding and regulatory systems had little chance to develop.

> The qualities that make a site suitable for salmon farming—good marine water quality, accessible shoreline, access to supplies of fresh water, safe moorage and proximity to population centres—are similarly attractive for other activities. The appearance of salmon farms in areas of the coast where several other activities already exist or where other new activities (marine tourism) are growing have frequently led to conflict with other users.
>
> (EAO, 1997a).

Ten recommendations were made regarding salmon farm siting, addressing problems with 1) the location of sites that were approved under former policies and 2) the effectiveness of licensing arrangements (see Appendix 1 for the complete list of recommendations).

Recommendation 4, with the aim to reducing negative impacts and conflicts, recommends that a list of siting criteria be established to define minimum distances (buffers) separating farms sites from other uses and resource values. A preliminary list of criteria for siting new aquaculture facilities was developed in 1997, and later modified in March 2000. The siting criteria have now been fully incorporated into the marine finfish aquaculture application process, taking the place of any previous farm siting criteria, including Coastal Resource Interests Studies (see Section 3.2). Application guidelines require that applicants meet the siting criteria, as well provide detailed local resource maps identifying habitat, wildlife, social, navigational or environmental resources in the area, and documenting methods used to identify these features.

Criteria for siting new finfish aquaculture facilities

The following criteria have been in place since March 2000 and have been used to evaluate proposals for new commercial finfish aquaculture tenures. They remain effective until further notice. They may be adjusted over time by the province in consultation with industry and stakeholders in response to new information and the results of new technology.

These criteria take the place of any previous farm siting criteria, including the Coastal Resource Interests Study guidelines and the Salmon Aquaculture Review's recommended salmon farm siting criteria (on which these criteria are based). Earlier siting criteria may continue to be consulted by agencies in making siting decisions.

These criteria apply to the siting of new tenures only. They do not apply to the evaluation of existing tenures that were granted prior to October 2000. Information on siting requirements for existing tenures is separate and is available from MAFF upon request.

Proposals for new salmon farms must meet the following requirements and minimum separation distances.

Sites must be located:
1. At least 1 km in all directions from a First Nations reserve (unless consent is received from the First Nation).
2. At least 1 km from the mouth of a salmonid-bearing stream determined as significant in consultation with DFO and the province.
3. At least 1 km from herring spawning areas designated as having "vital", "major" or "high" importance.

4. At least 300 m from inter-tidal shellfish beds that are exposed to water flow from a salmon farm and which have regular or traditional use by First Nations, recreational, or commercial fisheries.
5. At least 125 m from all other wild shellfish beds and commercial shellfish growing operations.
6. An appropriate distance from areas of "sensitive fish habitat", as determined by DFO and the province.
7. An appropriate distance from the areas used extensively by marine mammals, as determined by DFO and the province.
8. At least 30 m from the edge of the approach channel to a small craft harbor, federal wharf or dock.
9. At least 1 km from ecological reserves smaller than 1000ha or approved proposals for ecological reserves smaller than 1000 ha.
10. Not within a 1km line of sight from existing federal, provincial or regional parks or marine protected areas (or approved proposals for these).
11. In order to not infringe on the riparian rights of an upland owner, without consent, for the term of the tenure licence.
12. Not in areas that would pre-empt important Aboriginal, commercial or recreational fisheries as determined by the province in consultation with First Nations and DFO.
13. Not in areas of cultural or heritage significance as determined in the Heritage Conservation Act.
14. Consistent with approved local government bylaws for land use planning and zoning.
15. At least 3 km from any existing finfish aquaculture site, or in accordance with a local area plan or Coastal Zone Management Plan.

Source: (BC MAFF, 2000)

2.2 Marine finfish aquaculture application process

To apply for a permit authorizing a new salmon aquaculture site, the operator is required to submit a detailed proposal describing all aspects of the proposed site and facility. Preparing the application is a demanding process, and requires extensive on-site surveys of the proposed area. A complete Marine Finfish Aquaculture Application will include:

- a detailed description and map of the site location
- a planned layout of intensive use areas (net cages, docks and other structures) and extensive use areas (anchorage structures)
- the proposed production levels and species to be cultured
- information about, and proof of correspondence with local First Nations
- a local resources map identifying nearby environmental resources and human activities (conforming to siting criteria)
- characterization of the marine habitat and seabed under the farm

- a map of nearby streams, indicating the presence or absence of anadromous salmonids at various times throughout the year
- detailed information on weather (eg. winds, waves) and oceanography (eg. depth, tides)
- domestic waste management plans

Source: (BC MAFF, 2003a)

In the Guide to Information Requirements for Marine Finfish Aquaculture Applications, the Ministry provides resources and contact information to operators in order to assist with their generating of the required components. However, the extent to which these standard data sources are used, to generate capability and suitability information for a proposed site, is unknown. Many salmon farm operators hire private consultants to carry out the necessary on-site investigations and to produce maps for the application. The same consultants are often called upon by government regulatory agencies to revisit specific aspects of the application and proposed site (Cross, personal communication). Aquametrix Research Ltd., one of the oldest aquaculture consultants in the province, uses government coastal zoning and land use plans to determine whether there could be any large-scale resource conflicts in the proposed area; however, they generate the rest of their data through detailed site surveys (1:50 resolution).

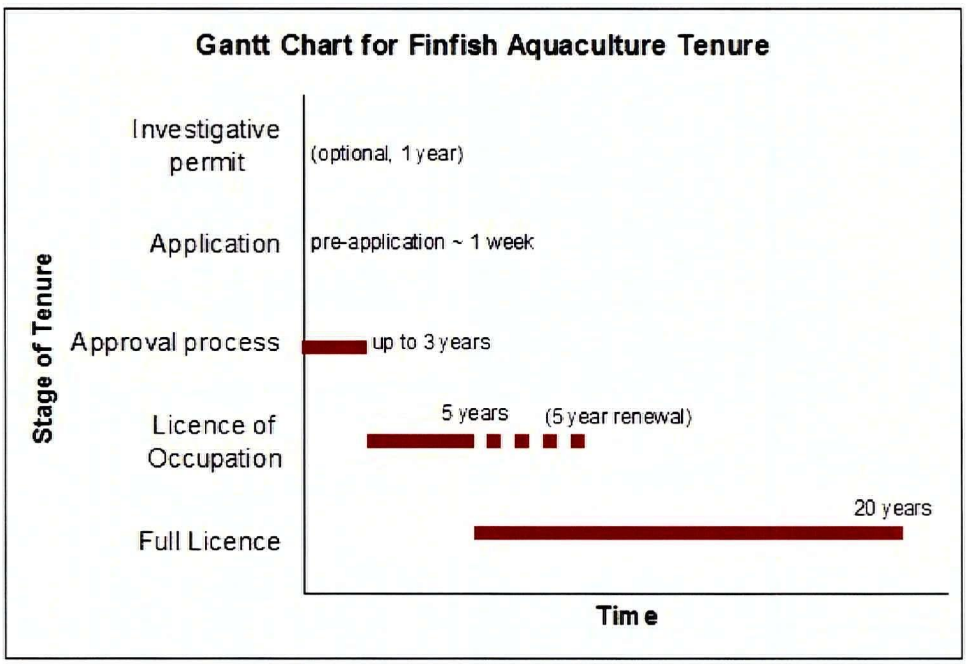
There are half a dozen consulting firms operating in British Columbia, with very little coordination among them unless they are providing complementary services (Cross, personal communication). Firms may interpret finfish aquaculture requirements differently, making an objective evaluation of current siting and approval processes difficult to achieve. Examining the procedures followed by such agencies in siting salmon farms may not be sufficient to determine what drives their collective location. Additional insight may be gained from analyzing the spatial patterns of salmon farm location with respect to various other indicators (biophysical, ecological, socio-economic data). Throughout the remainder of the thesis, I will combine these two approaches in an attempt to paint a fuller picture of the evolving salmon aquaculture industry on the B.C. coast.

2.3 Assessment and approval process

All three formal levels of government – federal, provincial and municipal – have a role in regulating the salmon aquaculture industry. The federal government, under the leadership of the Department of Fisheries and Oceans (DFO), has a mandate to "benefit Canadians through the culture of aquatic organisms while upholding the ecological and socio-economic values associated with Canada's oceans and inland waters" (DFO, 2004). As such, DFO has regulatory authority over the health of farmed fish, food and public health safety, conservation and protection of wild fish stocks and habitat, and protection of navigable waters. The provincial government's primary mandate is to foster sustainable development of the aquaculture industry by "acknowledging aquaculture as a legitimate user of coastal resources, and basing decisions on sound science and ensuring sustainable practices" (BC MAFF, 2004a). Provincial jurisdiction includes location, size and development of farms, siting requirements, and standards for design, construction and layout.

The provincial government's lead agency in dealing with the federal government on aquaculture issues is the Ministry of Agriculture, Fisheries and Food (MAFF). Under the authority of the provincial *Fisheries Act,* MAFF is responsible for evaluating the suitability of aquaculture proposals and for issuing tenures (refer to Figure 2.1 for forms of tenure and average application timeline). In addition to the *Fisheries Act,* aquaculture operations are subject to the conditions of other provincial legislation, including: the *Aquaculture Regulation,* the *Waste Management Act*, the *Finfish Aquaculture Waste Control Regulation,* the *Water Act*, the *Land Act*, the *Wildlife Act*, and the *Right to Farm Act.*

Figure 2.1 Gantt chart depicting average timeline for finfish aquaculture application and tenure in British Columbia



(Data source: LWBC, 2003)

Land and Water B.C. (LWBC) is the provincial agency that provides tenure rights to Crown land, foreshore and aquatic Crown land, and processes water licence applications. Since 2002, LWBC has acted as the one-window through which salmon aquaculture applications are received and distributed to reviewing agencies. The strategic shift of responsibility was part of the new government's Core Service Review, leading to the development of the joint agency Service Agreement between: (1) LWBC, (2) the Ministry of Water, Land and Air Protection (MWLAP), and (3) the Ministry of Sustainable Resource Management (MSRM). MAFF, as the leading agency on salmon aquaculture, coordinates responsibilities amongst the three agencies to reduce duplication of effort, enhance administrative fairness, increase transparency, and demonstrate an accountable compliance and enforcement regime. Under this agreement, MAFF inspection staff are responsible for assessing "compliance" of the industry with awareness activities, education, monitoring, and inspection. "Enforcement" activities are carried out by MWLAP and include verifying and substantiating alleged offences and implementing the necessary enforcement responses (MAFF, 2003b).

2.4 Recent dynamics

The Core Service Review, along with several other regulatory developments, coincided with the end of the B.C. government's moratorium on new licences in September 2002, allowing for "responsible" expansion of the salmon aquaculture industry. The decision to lift the moratorium and begin accepting applications for new finfish aquaculture sites was a direct result of work done under the Salmon Aquaculture Policy Framework initiated in 1999 (MAFF 2004b). The Policy Framework addressed the outstanding concerns of the Environmental Assessment Office's Salmon Aquaculture Review, and set strict environmental standards on prevention of escapes, waste management, disease prevention, siting and relocation. At the time the moratorium was lifted, Minister of Agriculture, Food and Fisheries John van Dongen (2002) touted B.C.

as having "one of the most comprehensive regulatory frameworks in the world, including science-based standards to protect the environment."

However, issues surrounding the joint federal-provincial responsibility for managing salmon aquaculture were not resolved in the Salmon Aquaculture Policy Framework, and remain problematic. Conflicting mandates and a lack of coordination between the two levels of government have resulted in a frustrating, redundant and inefficient application process in the view of many salmon farm operators. While the current B.C. Liberal government tried to streamline its review process in 2002, they blame the federal government for stalling the aquaculture approval process with its inaction and red tape (Globe and Mail, 2004).

The need for better collaboration between federal and provincial government was most recently highlighted in this year's Auditor General's report on salmon stocks, habitat and aquaculture. The report was part of a unique tri-partite project between the federal Auditor-General, and the Auditors-General of British Columbia and New Brunswick, released on October 26, 2004. B.C.'s Auditor General, Wayne Strelioff, reported a lack of clear vision within the provincial government to guide priority-setting. The Auditor's key recommendation was for the province to overcome differing views with the DFO, and to come up with a common strategy for the management of wild salmon and salmon aquaculture (BC OAG, 2004). The Federal Commissioner of the Environment and Sustainable Development, Johanne Gelinas, also emphasized the need for cooperation in managing fish habitat, sharing information, and approving aquaculture site applications. On salmon farm location, the Commissioner emphasized the need for better assessing cumulative effects of each site's operations, and better monitoring of salmon aquaculture operations to prevent harmful destruction of fish habitat (Canada OAG, 2004).

With the re-issuance of new salmon farm licences, the salmon farming industry is now projected to quadruple production over the next 10 years, with an additional $1 billion in new investments, 9 000-12 000 direct jobs, and around 10-15 new farms sited each year (Gardner and Pederson, 2003). In addition, four salmon farms are in the process of being relocated and an additional 25 sites have been identified for amended operational practices or future relocation (MAFF, 2002). The way in which the regulatory environment responds to the findings of the Auditor Generals' reports in the next few years will be critical to determining whether the salmon aquaculture industry in B.C. develops around an economically driven mandate or one that protects the long-term sustainability of the coastal ecology. The findings of this research will also have important implications for the future shape of the industry, by shedding light on the factors and values that currently carry the most weight in the decision-making process on the siting and relocation of salmon farms.

References:

(2003). "B.C. Liberals vote to fast-track fish farms", Globe and Mail.com. Friday November 05, 2004. http://www.theglobeandmail.com/national/. Accessed: November 06, 2004.

British Columbia Environmental Assessment Office (1997a). Salmon Aquaculture Review Final Report. Summary Report. Victoria, British Columbia Environmental Assessment Office. http://www.intrafish.com/laws-and-regulations/report_bc/v1sum.htm. Accessed: September 21, 2004.

British Columbia Environmental Assessment Office (1997b). Salmon Aquaculture Review Final Report. Volume 1, Chapter 4: Salmon Farm Siting. Victoria, British Columbia Environmental Assessment Office. http://www.intrafish.com/laws-and-regulations/report_bc/v1chp4.htm. Accessed: July 03, 2004.

British Columbia Environmental Assessment Office (1997c). Salmon Aquaculture Review Final Report. Volume 3, Part F: Siting of Salmon Farms. Victoria, British Columbia Environmental Assessment Office. http://www.intrafish.com/laws-and-regulations/report_bc/vol3-f.htm. Accessed: November 18, 2004.

British Columbia Ministry of Agriculture Food and Fisheries, Aquaculture Development Branch (2000). Criteria for siting new finfish aquaculture facilities. http://www.agf.gov.bc.ca/fisheries/Finfish/Provincial_Siting_Criteria_March_2000.pdf. Accessed: October 23, 2003.

British Columbia Ministry of Agriculture Food and Fisheries, Aquaculture Development Branch (2002). B.C. Salmon Aquaculture Policy Backgrounder. http://www.agf.gov.bc.ca/fisheries/reports/aqua_backgrounder.pdf. Accessed: December 03, 2003.

British Columbia Ministry of Agriculture Food and Fisheries, Aquaculture Development Branch (2003a). Guide to information requirements for marine finfish aquaculture applications. http://www.agf.gov.bc.ca/fisheries/Finfish/MFF_Guide_BW_single-sided.pdf. Accessed: January 27, 2004.

British Columbia Ministry of Agriculture Food and Fisheries, Fisheries and Aquaculture (2003b). 4th Annual Inspection Report on Marine Finfish Aquaculture Sites, Executive Summary. http://www.agf.gov.bc.ca/fisheries/aqua_report/Exec_Summary.pdf. Accessed: December 07, 2004.

British Columbia Ministry of Agriculture Food and Fisheries, Fisheries and Aquaculture (2004a). Finfish aquaculture. http://www.agf.gov.bc.ca/fisheries/Finfish_main.htm. Accessed: December 02, 2004.

British Columbia Ministry of Agriculture Food and Fisheries, Fisheries and Aquaculture

(2004b). Salmon Aquaculture Policy Framework. http://www.agf.gov.bc.ca/fisheries/salmon_aqua_policy.htm. Accessed December 06, 2004.

British Columbia Office of the Auditor General (2004). Salmon Forever: An Assessment of the Provincial Role in Sustaining Wild Salmon. http://www.bcauditor.com/PUBS/2004-05/Report5/salmon1.pdf. Accessed: November 16, 2004.

Canada Department of Fisheries and Oceans, Aquaculture (2004). Sustainable Aquaculture: The Vision. http://www.dfo-mpo.gc.ca/aquaculture/Vision/index_e.htm. Accessed: December 02, 2004.

Canada Office of the Auditor General (2004). Report of the Commissioner of the Environment and Sustainable Development. Chapter 5: Fisheries and Oceans Canada – Salmon Stocks, Habitat and Aquaculture. http://www.oag-bvg.gc.ca/domino/reports.nsf/html/c20041005ce.html. Accessed: November 16, 2004.

Cross, S.F., President Aquametrix Research Ltd. Courtenay, British Columbia. Personal communication: June 04, 2004.

Gardner, J. and Peterson, D. (2003) Making Sense of the Salmon Aquaculture Debate: Analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council.

Land and Water British Columbia Inc. (2003) Land-Use Programs, Agricultural and Aquacultural Land-Use. Volume 3, Chapter 3: Aquaculture Land Use Policy. Amendment No: 1/03.09.13.

Van Dongen, J., Minister of Agriculture, Food and Fisheries (2002) "Why B.C. Lifted the Moratorium on Fish Farms." Government of British Columbia Opinion-Editorial. http://www2.news.gov.bc.ca/nrm_news_releases/2002AGF0020-000827.htm# Accessed: November 10, 2004

CHAPTER III Spatial guides to finish aquaculture siting

3.1 British Columbia Aquaculture System

Mapping and Geographic Information Systems have long been used in B.C. for the purposes of land-use planning and resource management, and more recently for the purpose of guiding the location of salmon farms. Studies conducted over the last two decades have focused on a range of suitability indicators along the coast, including ecological and biophysical factors and local resource interests. In 1987, the Ministry of Agriculture, Fisheries and Food (MAFF) began documenting biophysical resource information to show the finfish aquaculture industry where water bodies with good sites might be found. Over the next few years, analytical methods were developed to rate individual sites as well as larger coastal areas for finfish and shellfish aquaculture, based on biophysical capability. Ratings were based on quantitative estimates of physical and biological parameters that determined site capability for rearing or culturing of specific species (eg. salmonid species, shellfish). Socio-economic, market, transportation or other non-environmental factors were not taken into account.

These early studies led to the development, in 1996, of a fully integrated information system called the British Columbia Aquaculture System (BCAS), in which GIS played a central role. The BCAS includes a range of inventories (eg. aquaculture sites, kelp beds, marine mammal habitat) compiled by the aquaculture and commercial fisheries branch of MAFF, and interfaces with digital data on biophysical and land use variables from B.C.'s Land Use and Coordination Office (LUCO). Within BCAS, biophysical variables *only* are used to estimate capability indices for finfish aquaculture, rating coastal areas as good, medium or poor for salmonid culture. Table 3.1 details the source layers of biophysical criteria and the rating process used to evaluate capability. The evident emphasis in BCAS on site "capability" over site "suitability" also appears in public government literature on fisheries and aquaculture. See for example MAFF's current online list defining of what makes a good aquaculture site (Appendix 2).

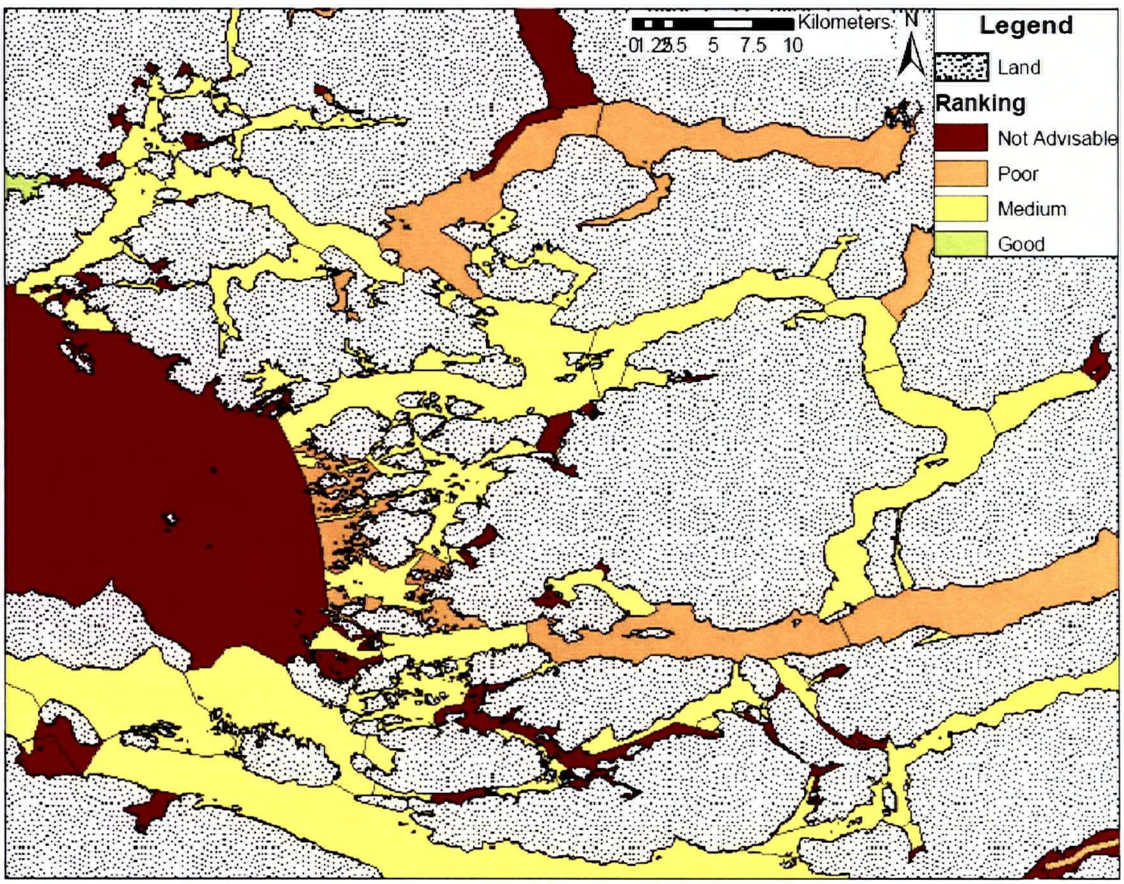
Table 3.1 Source layers for biophysical criteria and ratings used in BCAS to evaluate the capability of waterways to support salmonid cage culture.

Source layer	Rating		
	Good	Medium	Poor
Temperature (°C)			
Summer	10–15	16-21	>21
Winter	>7	5–7	<4
Dissolved oxygen (% saturation)	100%	79	57
Salinity (ppt)	>24	15–24	<15
Plankton	No record of harmful blooms	Infrequent harmful blooms	Frequent and lethal blooms
Pollution	No sources nearby	Nearby, low level sources	Within high pollution areas
Currents (cm s^{-1})			
Slack water	10–15	2–10	<2
Peak flows	10–50	50–100	100–200
Low tide depth (m)	>50	20–49	10–19
Site Physiography			
Slope	>30°	15–30°	<15°
Substrate	Rock, sand or gravel	Sand or mixed rock	Mud or organic ooze
Hydrology (freshwater lens depth in m)	<1	1–4	>4
Predators	None	Close to sea lion haulouts with many avian/mammal predators	Nearby sea lion rookeries and haulouts; bird colonies nearby and many mammal predators
Marine plants and fouling organisms	Low levels of fouling organisms; no kelp	Moderate levels of fouling organisms; kelp nearby	High levels of fouling organisms; kelp onsite
Winds and waves/snowfall and freeze over	Site not exposed to polar outflows; wave height <0.6 m	Partial exposure to polar outflows; wave height 0.6–1.0 m	Complete exposure to polar outflows; wave height >1.2 m

(Source: Carswell, cited in Nath *et al.* 2000)

The original intention of the BCAS was to generate marine aquaculture information that would be of use for the development of policies at the provincial level. According to Nath *et al.* (2000), use of the system has now evolved to include local governments in B.C., consultants, and individual farmers in identifying suitable sites for aquaculture. However, personal communication with Aquametrix Research, a long-established Vancouver Island consulting firm, suggests that the scale of the inventory (1:250 000 – 1:40 000) is far too large to provide the necessary detail for assessing the capability of a potential farming area. Consultants and aquaculture companies will tend to perform their own on-site investigations rather than relying on the database system (Cross, 2004).

Figure 3.1 British Columbia Aquaculture System biophysical capability rankings for the Broughton Archipelago. Biophysical criteria are used to rate areas as Good (green), Medium (yellow), Poor (orange) or Not Advisable (red) for salmonid culture.



Created by Zosia Bornik, Nov. 09, 2004
Projection: BC Albers Equal Area Conic
Data Source: BC MAFF

3.2 Coastal Resource Interest Studies

Concurrent to the development of BCAS, the B.C. Ministry of Crown Lands was investigating the significance of potential land use conflicts between aquaculture operations and other interest groups. Coastal Resource Interest Studies (CRIS), undertaken in the late 1980s, were a response to the Gillesepie Inquiry (1986) recommendation that areas of high value to coastal users be identified so that finfish aquaculture activities should be directed *away* from such areas. In other words, CRIS studies aimed at identifying areas of site suitability (as opposed to capability) for finfish aquaculture. The Broughton Archipelago CRIS was the fifth study of its kind, and took place from September to December 1989. Participants included regional government agencies, coastal resource industries (fishing, forestry and marine transportation) as well as public outdoor recreation and environmental interest groups. Recruitment focussed on organizations that had participated in previous CRIS studies, as well as local groups identified by the Regional District of Mount Waddington. Out of 43 invitations, 31 organizations participated directly, of which 26 supplied mapped information (see Appendix 3 for a list of organizations by submission format).

Participant groups were asked to:

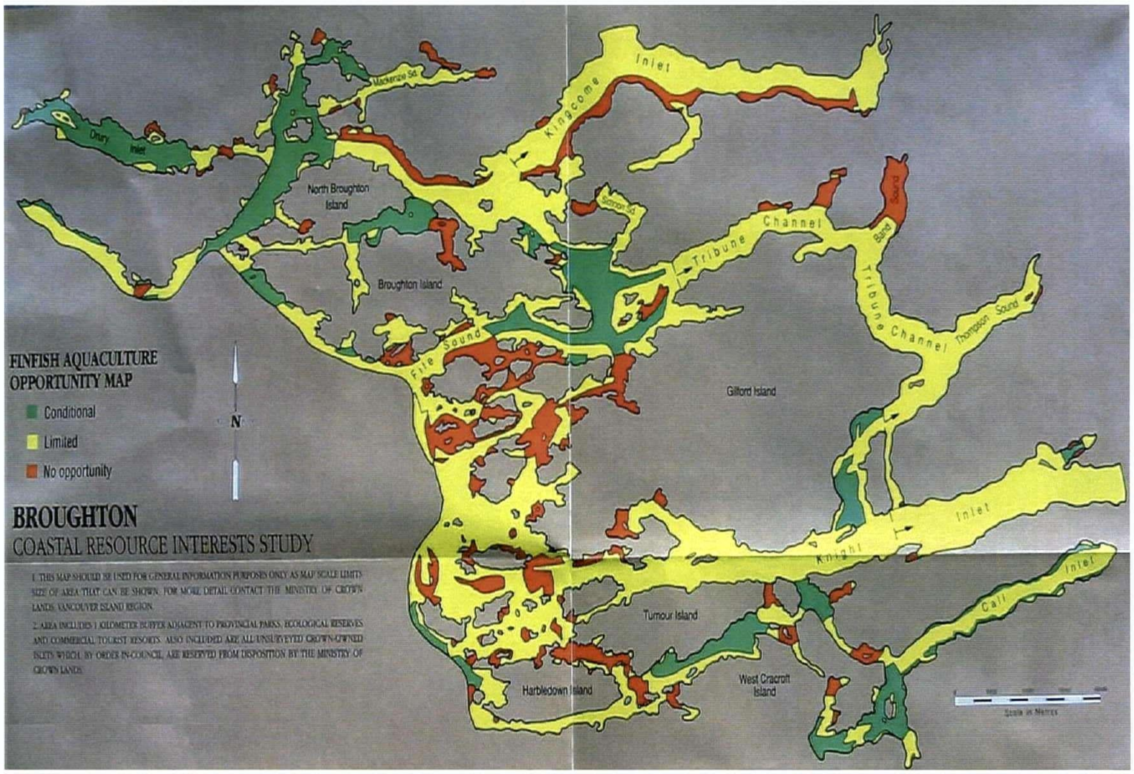
1) Map their "high value" areas, defined as "areas with characteristics or features that are particularly attractive or necessary for your activity/interest"
2) Rank high value areas as Critical ("C") – areas so essential that the activity/interest should take precedence over other activities, or Important ("I") – areas where, under certain management conditions, the activity/interest could co-exist with other activities.

Overlay mapping was used to build a composite map identifying Critical and Important areas for all the groups. The most specific and group maps were traced first; designations by other groups in the same general area were then adapted to the more accurate outlines already on the map. According to documentation on composite mapping procedures, "to the degree that lines were adjusted for greater accuracy, there was *some degree of interpretation* in the mapping procedure" (Catherine Berris Associates Inc, 1990). Participant groups that were familiar or had previous experience with mapping procedures were likely able to produce more detailed submissions, and therefore may have had more influence when the composite map for the area was generated. Most participating government agencies provided information based on existing information files and field inspection data. Other organizations, in particular native peoples' groups who attended open houses and made written submissions but did not produce maps, may have been under-represented in the final composite product.

The composite map identified on one sheet the locations of concern to all groups. This sheet was used to develop a finfish aquaculture opportunity map (known locally as the "Red-Yellow-Green Map") as a basis for evaluating and processing future aquaculture applications. Red areas were designated as No Opportunity, or high conflict: aquaculture applications would not be considered for these areas. Yellow areas had Limited Opportunity: applications would be accepted only after interests identified on the composite map were addressed through consultation with the relevant groups.

Applications falling into Green, Conditional Opportunity areas would be considered using normal procedures for notification and referral. The opportunity map was presented at two separate public open houses (Port McNeil and Alert Bay), and written comments collected from participants. Criteria for the finfish aquaculture opportunity map were revised accordingly, and a final map and report were produced by Catherine Berris Associates Inc.

Figure 3.2 CRIS Finfish Aquaculture Opportunity Map for the Broughton Archipelago. Coastal resource interests are used to designate areas as having Conditional (green), Limited (yellow) or No (red) opportunity for finfish aquaculture.



(Source: Ardon, personal communication)

The purpose of the CRIS study was to compile information on coastal resources and uses, and to evolve an aquaculture opportunities map with appropriate review procedures to guide the assessment of new applications. However, applications for licences of occupation and tenure renewals already initiated at the time of the study release were 'grandparented', *i.e.* they were not subject to CRIS limitations.

In the year that followed the publication of CRIS, many local participants complained that there were more salmon farms in the Red zones than any other zone. Some felt that their knowledge of local "hotspots" had been used against them, conspiracy theories developed, and the issue drew significant media attention. Summarizing the series of events, local activist/scientist Alexandra Morton wrote, "in a breach of public trust, fishermen's hard-won knowledge [was] used by the salmon farmers to find the places their fish would survive the best" (Morton, 2002).

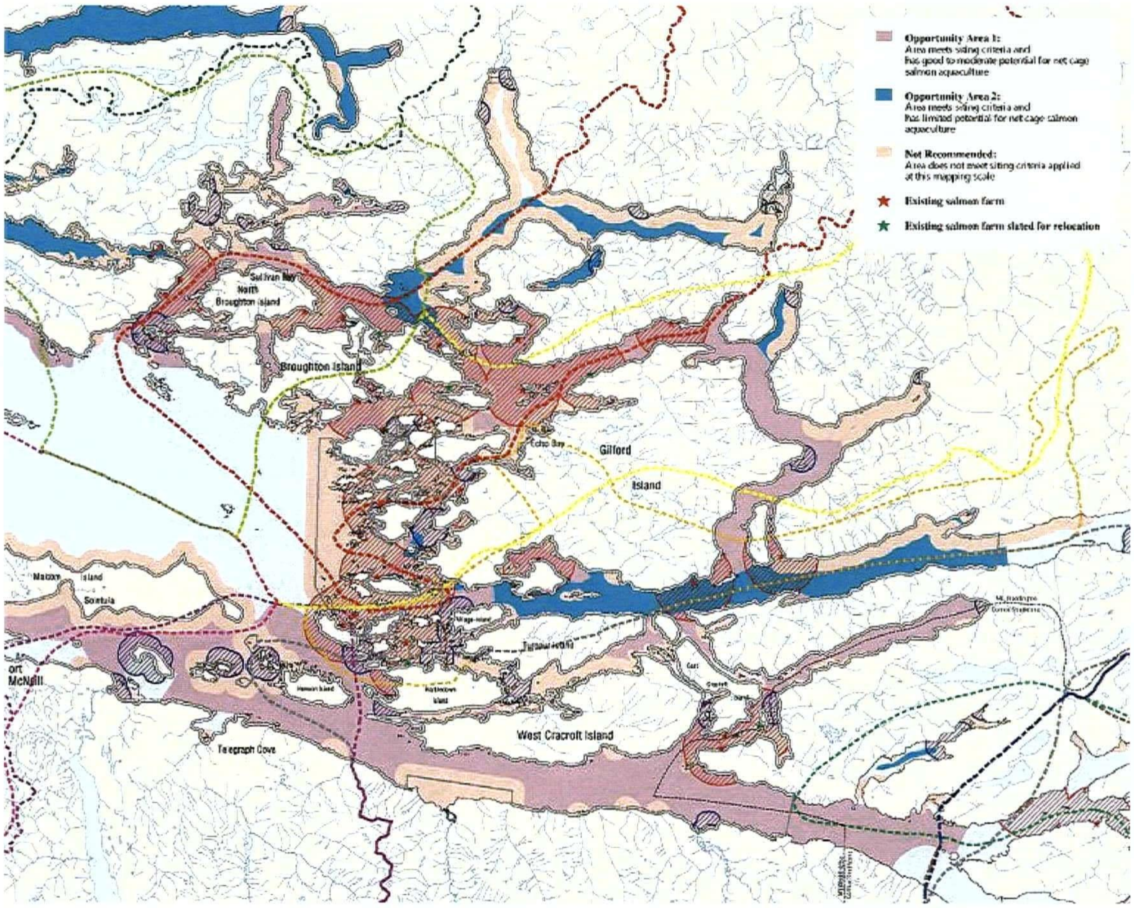
During the moratorium on salmon farm tenures, the Technical Advisory Team for Salmon Farm Siting of the Salmon Aquaculture Review (1997) examined in depth the relationship between fish farm sites in the Broughton and CRIS Red zones. They found 6 out of 28 farms to be located partially or completely in No Opportunity areas; 5 of these site applications had been filed prior to the release of CRIS. The Advisory Team concluded that "the approval process prior to the CRIS studies did not adequately address resource use conflicts, and this impact was extended because of the grandparenting of applications" (EAO, 1997, pp. 8).

3.3 Aquaculture Opportunity Maps

In response to the controversies of the 1990s, and recommendations arising from the Salmon Aquaculture Review (1997), the British Columbia government recently initiated a new round of aquaculture opportunity studies, with the aim of minimizing environmental and social impacts of fish farms while supporting local economies in coastal communities. These are the first studies of their kind to bring together information on both site capability (biophysical attributes) and site suitability (conflict with other local resources or activities) (BC MSRM, 2002a). Aquaculture Opportunity Studies (AOS) are one aspect of the broader Salmon Aquaculture Policy Framework (1999) which outlines strict standards for environmental sustainability, technological development and communities consultation. AOS maps are to assist in the relocation of some 25 poorly sited salmon farms into areas where they will have a reasonable chance of success, and where habitat considerations, social conflicts or other related issues will not be barriers (BC MSRM, 2004).

The Aquaculture Opportunity Study process is being led by technical staff from the Ministries of Sustainable Resource Management (MSRM), and Land and Water British Columbia Inc. (LWBC). AOS maps are compiled from biophysical capability studies (the same used to generate the BCAS for salmon aquaculture), and mapped siting criteria from the Commercial Finfish Aquaculture Management Plan (BC MAFF, 2000), including buffering from existing farms, salmon streams, shellfish beds, and other resource values (see Section 2.1). Opportunity Areas 1 (OA1) represent areas of "good" or "medium" biophysical ratings that meet the salmon farm siting criteria, while Opportunity Areas 2 (OA2) represent areas of "limited" biophysical capability rating that also meet salmon farm siting criteria. Areas that are Not Recommended do not meet the siting criteria. Through community consultation, AOS maps are also being labelled to reflect areas where First Nations and local government support for relocating farms is confirmed. To date, five such studies have been completed, including one for the North Island Straits, which encompasses the Broughton Archipelago (Figure 3.3).

Figure 3.3 North Island Straits Aquaculture Opportunity Map. Biophysical capability and siting criteria are used to designate areas as: OA1 (purple), meeting the siting criteria with "good" or "medium" biophysical capability; OA2, meeting the siting criteria with "limited" biophysical capability; and Not Recommended for aquaculture due to a failure to meet siting criteria. For complete map legend, please see Appendix 4.



(Source: BC MSRM, 2002b)

Due to the large, generalized scale of the biophysical studies used as input to the AOS (1:125,000), and the patchy nature of spatial data available for certain siting criteria (eg. salmonid bearing streams, eelgrass, kelp and shellfish beds), the Ministry recommends that OA1 and OA2 categories be used only as a "general indication" of capability, asserting that some high potential localized opportunities can and do exist in areas generally classified as poor. In fact, the AOS map explicitly advises users not to use good and poor categories for the purposes of limiting the scope of salmon aquaculture tenure applications (see AOS Map Notes, Appendix 5). This seems to contradict the intended use of the AOS Study, to act as a guideline for the identification and relocation of poorly sited salmon farms. Furthermore, the uncertainty in map designations raises questions about MAFF's justification for terminating B.C.'s moratorium on new farm licences based on existing 'science-based standards', suggesting perhaps that our knowledge base remains limited with regards to coastal resources.

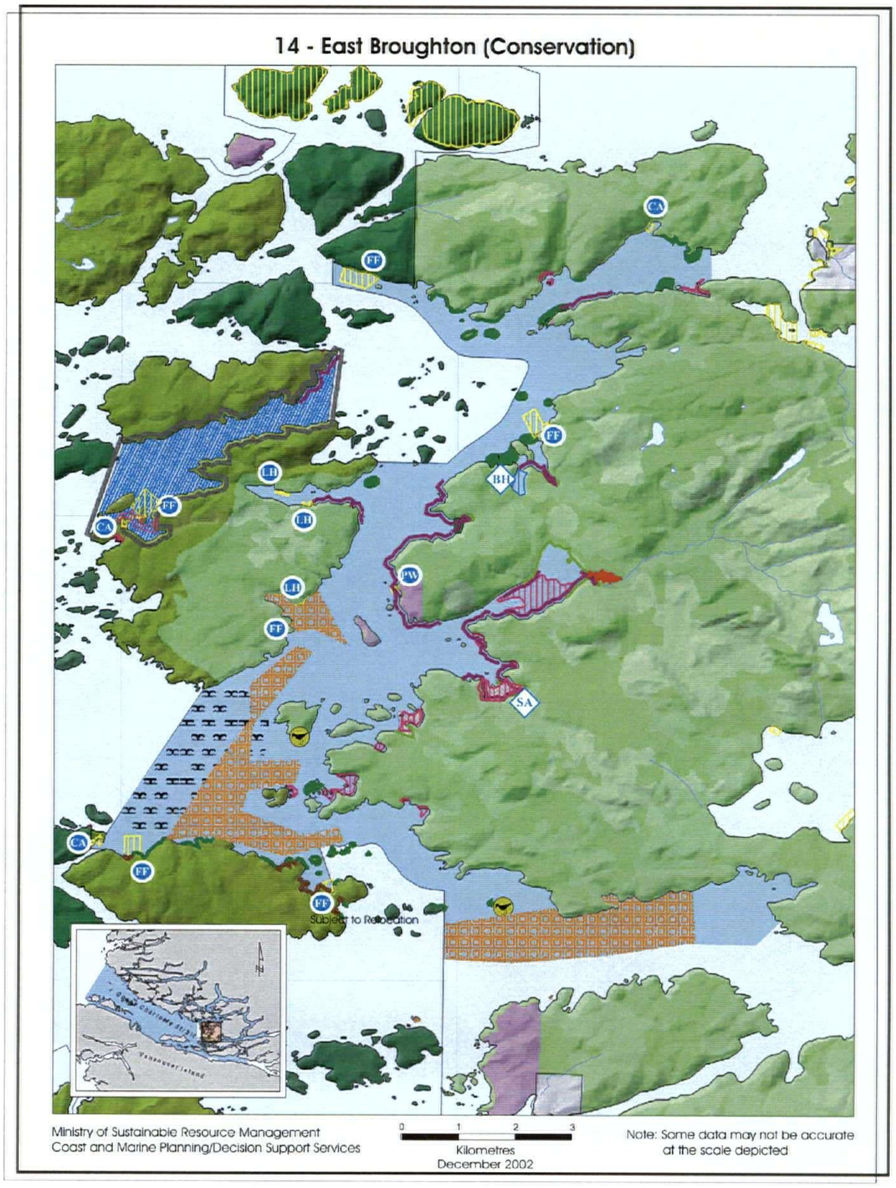
Subsequent initiatives by MSRM, such as Integrated Coastal Zone Planning, employ a more cautious approach to designating areas for salmon aquaculture, taking into account existing tenured and non-tenured activities, and mapping biological resources at more feasible (higher resolution) scales. In certain areas, such as the Broughton Archipelago, zone designations for aquaculture differ from and may supercede the AOS study. The MSRM integrated coastal planning approach is discussed in more detail in the following section.

3.4 North Island Straits Coastal Plan

In recent years, integrated coastal zone planning has become a priority for the Ministry of Sustainable Resource Management. The plans, under the jurisdiction of the Coast and Marine Planning Branch (CMPB), are intended to support informed decision-making in coastal areas, focussing on economic development and diversification, environmental risk, land and resource conflicts, and First Nations issues. Coastal zone planning currently occurs at two distinct levels: Strategic level coastal plans, designed to identify broad goals, objectives and strategies for coastal and marine resources; and local level coastal plans, designed to identify new land tenure opportunities, manage for specific types of uses or areas, and guide issue resolution.

Several zoning plans specific to shellfish culture have already been developed for the coast, including the Baynes Sound and Cortes Island Shellfish Aquaculture Plans. In contrast, the North Island Straits (NIS) Coastal Plan, completed in December 2002, is a *multiple use* coastal plan identifying key resource activities in the area in addition to salmon aquaculture. The NIS covers the area from the Johnson Strait to the Queen Charlotte Strait, including the Broughton Archipelago. The NIS plan is intended as a guide to assessing specific Crown land applications made within the region, and will serve as a prototype for future multiple-use plans to be completed by MSRM. The NIS plan area is divided into 66 smaller planning units for which information was assembled on upland ownership, tenures and ongoing activities; biological resources, environmental values and recreational uses; and capability for shellfish and salmon aquaculture (for Map Legend, see Appendix 6). For each unit area, a description and map was produced using existing resource data, subject to consultation with public and interest groups.

Figure 3.4 North Island Straits Coastal Plan sample study unit. Circles represent tenured uses, diamonds represent non-tenured uses, solid or striped colours represent land status (purple = Indian reserve, pink = private, green = protected area) and coastal biological resources (purple stripe = clam beach, green = clam bed, purple line = herring spawn, brown line = eelgrass). For complete legend, see Appendix 6.



(Source: BC MSRM, 2002c)

While these coastal plans identify AO1 and AO2 designated areas (from previous Aquaculture Opportunity Studies), they also include layers of coastal resource uses, biological resource and designated areas at a much finer scale of resolution than earlier studies. For example, Aquaculture Opportunity Studies, constrained by an earlier generalization of base data sources, mapped salmon farm siting criteria at a scale of 1:250 000, whereas the NIS plan maps the same data at a scale of 1:50 000 – 1:5 000. This significant difference in scale influences the usability of the two databases in terms of their likelihood to guide decision-making on salmon farm siting.

For each study unit, the NIS plan recommends that future use and related economic development be given one of four emphases: conservation, recreation, community or general marine. The designation is based on an assessment of the predominant activity in the area, compatibility of activities, preferred future uses and available management mechanisms. Regarding salmon farming, study unit descriptions also rank finfish aquaculture on a four-point scale of acceptability, ranging from acceptable/appropriate to inappropriate, where applications for tenure in such areas should not be accepted for processing and evaluation.

Land and Water B.C. Inc., however, has its own procedures and criteria to follow when evaluating salmon aquaculture applications (see Section 2.3), and the NIS plan does not guarantee that a site will be approved or rejected based on its acceptability ranking in a specific study unit. While many of the unit areas in the Broughton Archipelago are considered by the NIS to be inappropriate or appropriate only at current levels for salmon farming, professional judgement suggests that over the next few years, at least an additional 4-6 finfish farms will be granted tenure in the region (BC MSRM, 2002c). The success of the aquaculture industry will depend on farms being environmentally sustainable and socially acceptable, as well as being economically viable. The NIS plan is a first step towards integrating these three types of data at similar spatial scales in a Geographic Information System to provide valuable input to coastal management decisions.

References:

Ardon, J., GIS Manager, Living Oceans Society. Sointula, British Columbia. Personal communication: June 25, 2004.

British Columbia Environmental Assessment Office (1997). Salmon Aquaculture Review Final Report. Volume 3, Part F: Siting of Salmon Farms. Victoria, British Columbia Environmental Assessment Office. http://www.intrafish.com/laws-and-regulations/report_bc/vol3-f.htm Accessed: May 20, 2004.

British Columbia Ministry of Agriculture Food and Fisheries, Aquaculture Development Branch (2000). Criteria for siting new finfish aquaculture facilities. http://www.agf.gov.bc.ca/fisheries/Finfish/Provincial_Siting_Criteria_March_2000.pdf. Accessed: October 23, 2003.

British Columbia Ministry of Sustainable Resource Management, Business Solutions Division (2004) Salmon Aquaculture Relocation Process: Aquaculture Opportunity Studies for Salmon Farming in British Columbia. http://srmwww.gov.bc.ca/dss/projects/sarp/index.htm. Accessed December 08, 2004.

British Columbia Ministry of Sustainable Resource Management, Fisheries and Aquaculture (2003) Finfish Aquaculture: What Makes a Good Aquaculture Site. http://www.agf.gov. bc.ca/fisheries/siting_reloc/what.htm. Accessed January 16, 2004.

British Columbia Ministry of Sustainable Resource Management, Business Solutions Division (2002a) Salmon Aquaculture Relocation Process: Methodology and Aquaculture Opportunity Summary. http://srmwww.gov.bc.ca/dss/projects/sarp/documents/031902_AOS_Summary_QAs.pdf. Accessed December 08, 2004.

British Columbia Ministry of Sustainable Resource Management, Business Solutions Division (2002b) Salmon Aquaculture Relocation Process: Finfish Aquaculture Opportunity Map, North Island Straights. ftp://ftp.gis.luco.gov.bc.ca/pub/coastal/nis/pdf/map9e.pdf. Accessed December 08, 2004.

British Columbia Ministry of Sustainable Resource Management, Coast and Marine Planning (2002c) North Island Straits Coastal Plan, Final Version: December 2002. http://srmwww. gov.bc.ca/rmd/coastal/north_island/nis/docs/NIS_Final.pdf Accessed: August 12, 2004.

British Columbia Ministry of Sustainable Resource Management (1995), Resource Analysis Guidelines for Land and Resource Management Planning in B.C. Section 7.3: Aquaculture. http://srmwww.gov.bc.ca/rmd/rpts/raguide/rag-toc.htm. Accessed: Nov 12, 2004.

Carswell, B. (1998). BCAS: an information system for aquaculture and marine resource planning. Ministry of Agriculture, Fisheries and Food, British Columbia. Unpublished report, cited in Nath, S.S., J.P. Bolte, L.G. Ross, J. Aguilar-Manjarrez (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering 23, pp. 233-278.

Catherine Berris Associates Inc., 1990. Broughton Coastal Resource Interests Study. Ministry of Crown Lands, Province of British Columbia.

Cross, S.F., President Aquametrix Research Ltd. Courtenay, British Columbia. Personal communication: June 04, 2004.

Morton, A. (2002) "What is wrong with salmon farming?" Raincoast Research Society. Simmom Sound, B.C. http://www.raincoastresearch.org/pdf/Salmon_farming.pdf Accessed November 26, 2004.

Morton, A., Raincoast Research Society. Simoom Sound, British Columbia. Personal communication: June 03, 2004.

Nath, S.S., J.P. Bolte, L.G. Ross, J. Aguilar-Manjarrez (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering 23, pp. 233-278.

CHAPTER IV Methodological framework

4.1 Geographic Information Systems and Natural Resource Management

A Geographic Information System (GIS) is a set of computer tools designed to efficiently capture, store, update, manipulate, analyze and display many forms of geographically referenced information (ESRI, 2004). A GIS pulls together data sets from different sources, using geo-referencing to link data based on their spatial coordinates. The power of a GIS lies in its ability to represent maps as data layers that can be studied in greater depth, and to perform analyses. There are many GIS software products on the market, ranging from private/commercial to public domain, each designed with the capability to answer user-driven questions on spatial identification, spatial trends, and spatial patterns for the study region of interest.

The applications of GIS to natural resource management are diverse, due to the inherently spatial aspect of atmospheric, terrestrial and aquatic resources. GIS has been used to assess levels of environmental degradation over space and time (Kalivas *et al.* 2003) and determine priority areas for conservation/restoration purposes (Gkarveli *et al.* 2004, Bayliss *et al.* 2003, Lee *et al.* 2002, Brown *et al.* 1998). GIS has also been used to model future scenarios in determining where best to site specific resource activities, ranging from aquaculture facilities (Perez *et al.* 2003, Nath *et al.* 2002) to agricultural land use (Munier *et al.* 2004). Recent trends suggest that natural resource management is moving towards GIS-based approaches to participatory decision-making (eg. BC MSRM 2002, Bojorquez-Tapia *et al.* 2001).

Other GIS applications include data visualization and interactive web pages for decision support and public education. An example of the latter is what was formerly called the Aquaculture Wizard, and is now B.C.'s Coastal Resource Information Management System (CRIMS). Designed and managed by the Ministry of Sustainable Resource Management, the CRIMS is an internet-based interactive map for viewing a wide variety of coastal and marine data, including shoreline classification, aquaculture, selected fisheries and offshore oil and gas information (BC MSRM, 2004). Specific to salmon aquaculture, the CRIMS allows users to map the location of farms, processing plants, and aquaculture capability rankings. However, the tool is designed for data visualization purposes only, and individual layers cannot be extracted for analysis.

With regards to siting analysis, examples from the literature tend to focus on urban public facilities such as hazardous waste sites, and the spatial distribution of costs and benefits of such facilities (Morello-Frosch *et al.* 2002, DeVerteuil 2000, Farber 1998, Lober 1995) rather than natural resources. Two studies uniquely applied spatial and temporal analysis to test hypotheses about processes driving the evolution of an industry: Feitelson's (2000) study on the proximity among noxious facilities and residential areas of Tel-Aviv, found the siting pattern to be the outcome of more complex processes than previously thought, with residential developments encroaching upon facilities rather than the other way around; Lidskog and Sundqvist (2004) examined Sweden's nuclear waste management throughout its formative phases of development, describing the industry as "an active adaptation to demands from different stakeholders", rather than evolving in par with scientific findings. No such approaches have been applied to natural resources or their related industries. This thesis attempts to address this gap, focussing on salmon aquaculture in British Columbia.

4.2 Spatial data analysis and GIS

Data visualization is the simplest form of spatial data analysis, considered a pre-requisite for further exploration (Unwin, 1996). The goal of visualization is to give an initial impression of the shape of the study region and of any obvious patterns that may be present in the data. Once the data are mapped, the analyst can begin to explore the spatial distribution of points (whether they are clustered, randomly or regularly distributed), and any patterns of spatial association with particular attributes of the data.

Geographic Information Systems contain powerful tools for both data visualization and what Bailey (1994) calls spatial *summarization*: the select retrieval of spatial information within a defined area of interest and the computation, tabulation or mapping of various basic summary statistics of that information. However, GIS are limited in their capacity for spatial *analysis*: investigating relationships between patterns and other attributes of the study region, and modelling relationships for the purpose of understanding or predicting. This is due to the fact that (1) many early statistical methods of geographic interest were developed before the availability of geographic information systems, and are no longer relevant in the GIS era, and (2) aspatial statistical methods designed for randomly sampled survey data do not address many of the key features of spatial data, such as spatial dependency and modifiable areal unit effects.

Over the last decade, a debate has emerged as to the best way to link new spatial analytical functions to standard GIS. On the one hand, as long as the data is called from, and ends within, a GIS environment, it should be irrelevant whether the statistical methods are accessed from within the GIS package or not. In an era of open, distributed, heterogeneous computing, there is no longer a need for every step of the analysis to be contained within the same interface. On the other hand, raw statistical methods and technologically advanced packages are difficult to understand for the majority of system-users (including the author!) There is a need for spatial analysis technology that is easy to use and understand, while at the same time fostering meaningfully interpretation of the results. Goodchild (1992) identifies three major approaches that have been taken towards coupling spatial data analysis and GIS:

a) Full integration of spatial analytic procedures within the GIS.
b) Close coupling between statistical spatial data analysis software and GIS.
c) Loose coupling where an independent spatial data-analysis module relies on a GIS for its input data, and for functions such as graphic display, via the import and export of data in common format.

The first and second approaches have the advantages of well-documented software, vendor support and availability to a range of users, however due to lack of market demand, integration of spatial analysis techniques with GIS have not yet been fully realized. The third approach has been the most widely adopted strategy to date, and is the methodological framework employed in this thesis to explore the location of salmon farms in the Broughton Archipelago, B.C. The approach employs ArcGIS 8.1 for visualization and summarization of various spatial data sets, but takes output from GIS in standard data format into the software packages EXCEL and SPSS for more sophisticated statistical analysis.

4.3 Spatial data analysis for point processes

Spatial data analysis for point processes is referred to as point pattern analysis. It explores either first order properties - the density of point events within a unit area, or second order properties - spatial dependence between points (Bailey and Gatrell, 1995). In this study, the null hypothesis (H0: salmon farms are randomly located along the coast) and H1 (H1: Salmon farms are clustered by company), are concerned with the former. First order properties can be examined using either area-based or distance-based techniques to estimate how the intensity, $\lambda(s)$, of a point process varies over the study region, R. Mathematically, this can be described as a limit:

Equation 4.1 Intensity of a point process

$$\lambda(s) = \lim_{ds \to 0} \left\{ \frac{E(Y(ds))}{ds} \right\}$$

(Source: Bailey and Gatrell, 1995)

where ds is a small region around the point s, $E(Y(ds))$ is the expected number of events in this small region operator and ds is the area of this region.

Selecting an appropriate test for point density in H0 and H1 depends on several factors, including the number of observed events (N), the scale of analysis and the nature of the area of interest. Given the small sample size in this study (27 salmon farms), area-based techniques such as quadrat analysis were not ideal for point pattern analysis of salmon farms in the Broughton Archipelago. Nearest neighbour analysis was found to be a better suited method for analyzing the pattern at a fine scale, where the sample size was also small. The irregular nature of the Archipelago study region, comprising ocean, islands and mainland, further discouraged the use of quadrat analysis, and complicated the use of distance-based techniques. These issues and how they were addressed are discussed in more detail in Chapter 5.0 Methodology and Results.

H2 through H5 are concerned not with the point process itself, but with testing for spatial correlation between the point pattern and other potentially explanatory variables: biophysical suitability, processing plants, coastal resource interests, and siting criteria. Data was visualized using map overlay in ArcGIS to determine how the locational attributes of salmon farms (coordinate data) related to the locational attributes of the zone designations of interest. The results were normalized to account for zone area differences for each variable, and are presented in further detail in Chapter 5.0.

References:

Bailey, T. and A. Gatrell (1995). Interactive Spatial Data Analysis. Essex, England, Longman Group Limited.

Bailey, T. (1994) A review of statistical spatial analysis in geographical information systems. In Spatial Analysis and GIS (eds, Fotheringham, S. and Rogerson, P.) Taylor & Francis Inc., Bristol, PA.

Bayiss, J., A. Helyar, J.T. Lee, S. Thompson (2003) A multi-criteria targeting approach to neutral grassland conservation. Journal of Environmental Management 67(2), pp. 145-160.

Bojorquez-Tapia, L.A., S. Diaz-Mondragon, and E. Ezcurra (2000) GIS-based approach for participatory decision making and land suitability assessment. International Journal of Geographical Information Science 15(2), pp. 129-151.

British Columbia Ministry of Sustainable Resource Management (2004). Coastal Resource Information Management System. http://srmwww.gov.bc.ca/dss/coastal/crimsindex.htm. Accessed: December 02, 2004

British Columbia Ministry of Sustainable Resource Management, Coast and Marine Planning (2002) North Island Straits Coastal Plan, Final Version: December 2002. http://srmwww. gov.bc.ca/rmd/coastal/north_island/nis/docs/NIS_Final.pdf Accessed: August 12, 2004.

Brown, N.J., R.D. Swetnam, J.R. Treweek, J.O. Mountford, R.W.G. Caldow, S.J. Manchester, T.R. Stamp, D.J.G. Gowing, D.R. Soloman, A.C. Armstrong (1998) Issues in GIS development: adapting to research and policy-needs for management of wet grasslands in an Environmentally Sensitive Area. International Journal of Geographical Information Science 12(5), pp. 465-478.

DeVerteuil, G. (2000) Reconsidering the legacy of urban public facility location theory in human geography. Progress in Human Geography 24(1), pp. 47-69.

ESRI Dictionary Online. http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&search=true&searchTerm=GIS. Accessed: Dec 06 2004

Farber, S. (1998) Undesirable facilities and property values: A summary of empirical studies. Ecological Economics 24(1), pp. 1-14.

Feitelson, E. (2000) Malicious siting or unrecognized processes? A spatio-temporal analysis of environmental conflicts in Tel-Aviv. Urban Studies 38(7), pp. 1143-1159.

Gkaraveli, A. J.E.G. Good, J.H. Williams (2004) Determining priority areas for native woodland expansion and restoration in the Snowdonia National Park, Wales. Biological Conservation 115(3), pp. 395-402.

Goodchild, M. (1992) Integrating GIS and spatial data analysis: Problems and possibilities. International Journal of Geographical Information Systems 6(5), pp. 407-23.

Kalivas, D.P., V.J. Killias, G. Karantounias (2003) A GIS for the assessment of the spatio-temporal changes of the Kotychi Lagoon, western Peloponnese, Greece. Water Resource Management 17(1), pp. 19-36.

Lee, J.T., N. Bailey, S. Thompson (2002) Using geographical information systems to identify and target sites for creation and restoration of native woodlands: A case study of the Chiltern Hills, UK. Journal of Environmental Management 64(1), pp. 25-34.

Lidskog, R. and G. Sundqvist (2004) On the right track? Technology, geology and society in Swedish nuclear waste management. Journal of Risk Research 7(2), pp. 251-268.

Lober, D.J. (1995) Resolving the siting impass. Journal of the American Planning Association 61(4).

Morello-Frosch, R., M. Pastor, C. Porras, J. Sadd (2002) Environmental justic and regional inequality in southern California: Implications for future research. Environmental Health Perspectives 110, pp. 149-154.

Munier, B., K. Birr-Pedersen and J.S. Schou (2004) Combined ecological and economic modelling in agricultural land use scenarios. Ecological Modelling 174(1-2), pp. 5-18.

Nath, S.S., J.P. Bolte, L.G. Ross, J. Aguilar-Manjarrez (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering 23, pp. 233-278.

Perez, O.M., L.G. Ross, T.C. Telfer, L.M.D. Barquin (2003) Water quality requirements for marine fish cage site selection in Tenerife (Canary Islands): predictive modelling and analysis using GIS. Aquaculture 224(1-4), pp. 51-68.

Unwin, D. J. (1996) GIS, spatial analysis and spatial statistics. Progress in Human Geography 20, pp. 540-551.

Walker, P.A. and M.D. Young (1997) Using integrated economic and ecological information to improve government policy. International Journal of Geographical Information Science 11(7), pp. 619-632.

CHAPTER V Methodology and Results

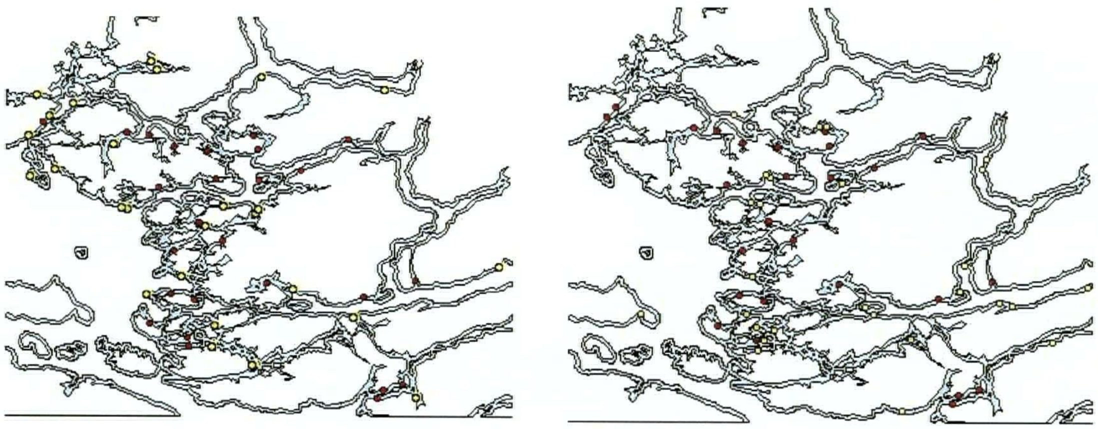
The analytical component of this thesis tests the five hypotheses presented in Chapter 1 regarding the factors that may shape the distribution of salmon farms within the Broughton Archipelago. Each hypothesis considers a potential correlation between the locational attributes of the response variable (X and Y coordinates of the salmon farm point data) and locational attributes of the potential explanatory variable (eg. biophysical capability, coastal resource interests). The methodology selected to test the hypotheses differed, depending on the nature of the data. Both quantitative and qualitative data were used. Results are presented below.

5.1 H0: Salmon farms are randomly located along the coast? *Reject.*

A critical first step in attempting to explain an observed spatial pattern is to test the null hypothesis, that salmon farms in the Broughton Archipelago are completely random in their spatial locations. This test used a nearest neighbor analysis, comparing the cumulative density function (CDF) of randomly generated point-to-nearest farm distances with the CDF of farm-to-nearest farm distances. The extent of the study area was defined so as to maintain consistency with earlier studies of the Broughton Archipelago conducted by MAFF (1996) and Living Oceans Society (2003). A region of salmon farm siting potential, *R*, was defined as the area of water within the Broughton Archipelago that was up to 475m distance from the coast, based on government estimates of salmon aquaculture site location and size (intensive and extensive use) (BC MAFF, 2003a). A polygon shapefile for *R* was created using the ArcGIS geoprocessing tools "clip", "dissolve", and "buffer", and saving the buffer as a new polygon layer.

At the time of the analysis, there were twenty-seven salmon farm tenures located within the Broughton Archipelago; the farms were plotted in the region of salmon farm siting potential, *R*. Fifty samples of 27 random points each were then generated in uniform random distribution within the area *R* (see Figure 5.1). This was accomplished using Random Point Generator, v. 1.27, an extension for Arcview 3.x written by Jenness Enterprises (2004a). The program allows for generating a specified number of random points within a select input feature (polygon *R*), and outputs data results in a standard format, easily transferable to EXCEL/SPSS for statistical analysis.

Figure 5.1. Randomly generated points in two different samples (H0) Red dots are observed salmon farm tenures (events), yellow dots are randomly generated points.



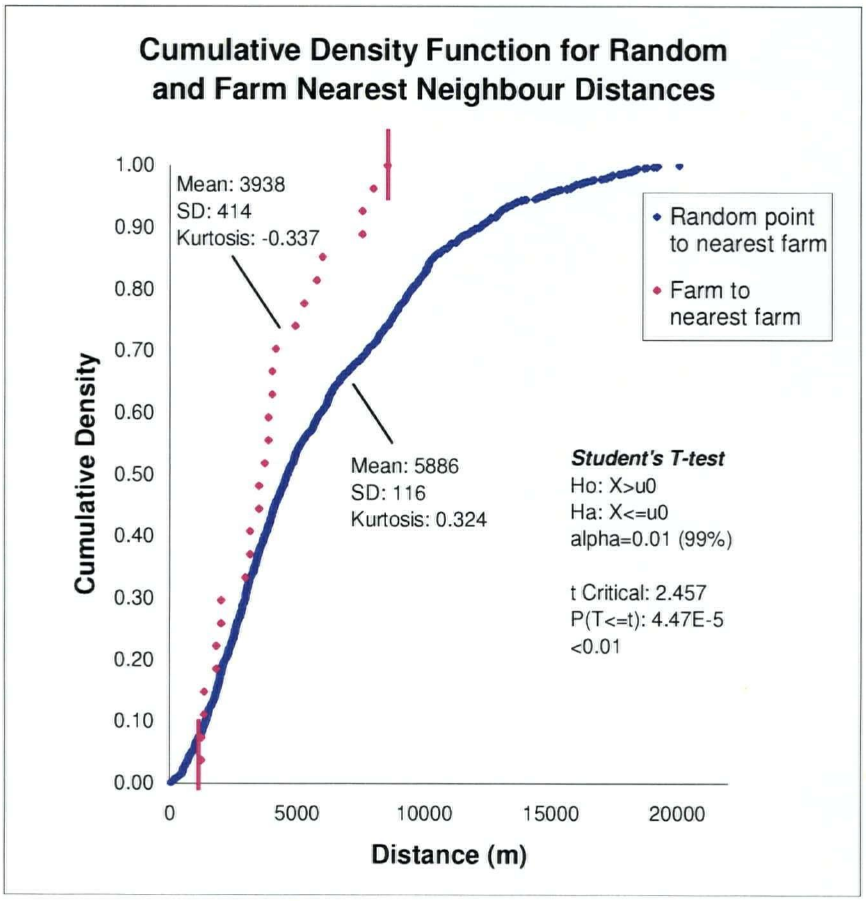
Nearest neighbour distances were calculated for salmon farms, and for each of the fifty random samples. The process was automated using Nearest Features, v3.7 for Arcview 3.x (Jenness, 2004b). One major limitation to the program was its calculation of straight line distances from point to nearest neighbour, regardless of the definitional attributes (water, land) of the study region. For example, it is not very useful to calculate the distance "as the crow flies" from one salmon farm to the nearest farm, because transportation in the salmon aquaculture industry is almost all marine. The nearest salmon farm by land may not be the nearest farm by water. This limitation impeded the accurate characterization of salmon farm distribution as a stand-alone point process. However, the hypothesis aims to test for significant differences between salmon farm distribution and uniform random distribution. As long as the same *R* and methodology are used to describe the two point processes being compared, the approach can still provide useful information for testing the null hypothesis.

Table 5.1 Descriptive statistics for cumulative density functions (H0)

Farm to nearest farm		**Random point to nearest farm**	
Mean	3940	Mean	5890
Standard Error	415	Standard Error	116
Median	3715	Median	4629
Standard Deviation	2156	Standard Deviation	4257
Sample Variance	4646740	Sample Variance	18119520
Kurtosis	-0.337	Kurtosis	0.324
Skewness	0.695	Skewness	0.971
Range	7303	Range	20030
Minimum	1246	Minimum	35.6
Maximum	8549	Maximum	20070
Sum	1063340	Sum	7946480
Count	27	Count	1350

Cumulative density functions of nearest neighbour distances were plotted and characterized for salmon farms, and for each of the fifty random samples. Because both N and variance differed between samples, a heteroscedastic independent samples T-test was used to determine whether there was a significant difference between the two distribution means (assuming proximity to normal).

Figure 5.2 Cumulative density functions for "Farm to nearest farm" and "Random point to nearest farm" (H0)



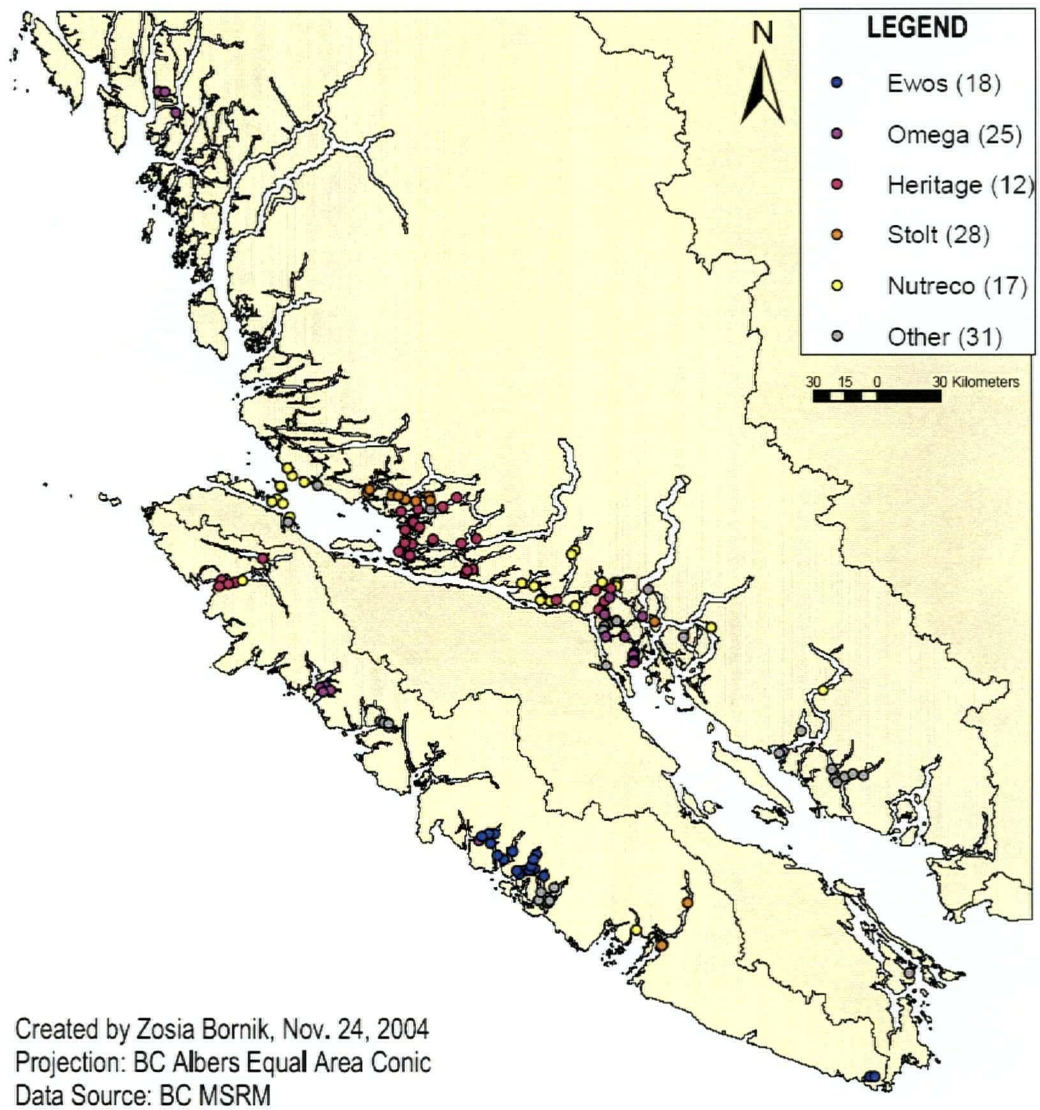
The CDF for salmon farms indicates that salmon farms in the Broughton Archipelago are never closer than 1.2 km to each other and never farther than 8.5km. This finding suggests that there may indeed be a form of spatial arrangement among sites, with underlying factors constraining the proximity of farms on the lower bound, and different factors favouring clustering on the upper bound. The results of the T-test indicate that at the 99% confidence level there is a significant difference between the uniform random point distribution and salmon farm distribution in the Broughton Archipelago. Thus, the null hypothesis, that salmon farms are randomly located along the coast, is rejected, and provides incentive for exploring the potential influence of five factors related to salmon farm siting. In consecutive order, they are: ownership, biophysical suitability, proximity to processing sites, coastal resource interests, and finfish aquaculture siting criteria.

5.2 H1: Salmon farms are clustered by company? *Fail to reject.*

H1 was motivated by mapping salmon farm data at a larger scale than would eventually be analyzed, that is, along the entire coast of British Columbia. Visualization revealed that, at this scale, salmon farms tenures appeared to be clustered in certain pockets of the coast, rather than uniformly or randomly distributed. (Non-random distribution had already been tested in H0 for the Broughton Archipelago, but not for B.C.) There are five major salmon aquaculture firms currently operating in British Columbia who collectively own 75% of the salmon farms. Thematic symbol tools in ArcGIS were used to display point salmon farm data in different colours, based on their ownership code. Firms that did not belong to one of the major five were categorized as "Other". The resulting map, Figure 5.3, shows a distinct clustering of salmon farms by company (some more than others), suggesting a relationship between salmon farm location and ownership. Clustering may reflect a combination strategic siting, as well as acquisition of farms as the salmon aquaculture industry consolidated into fewer hands.

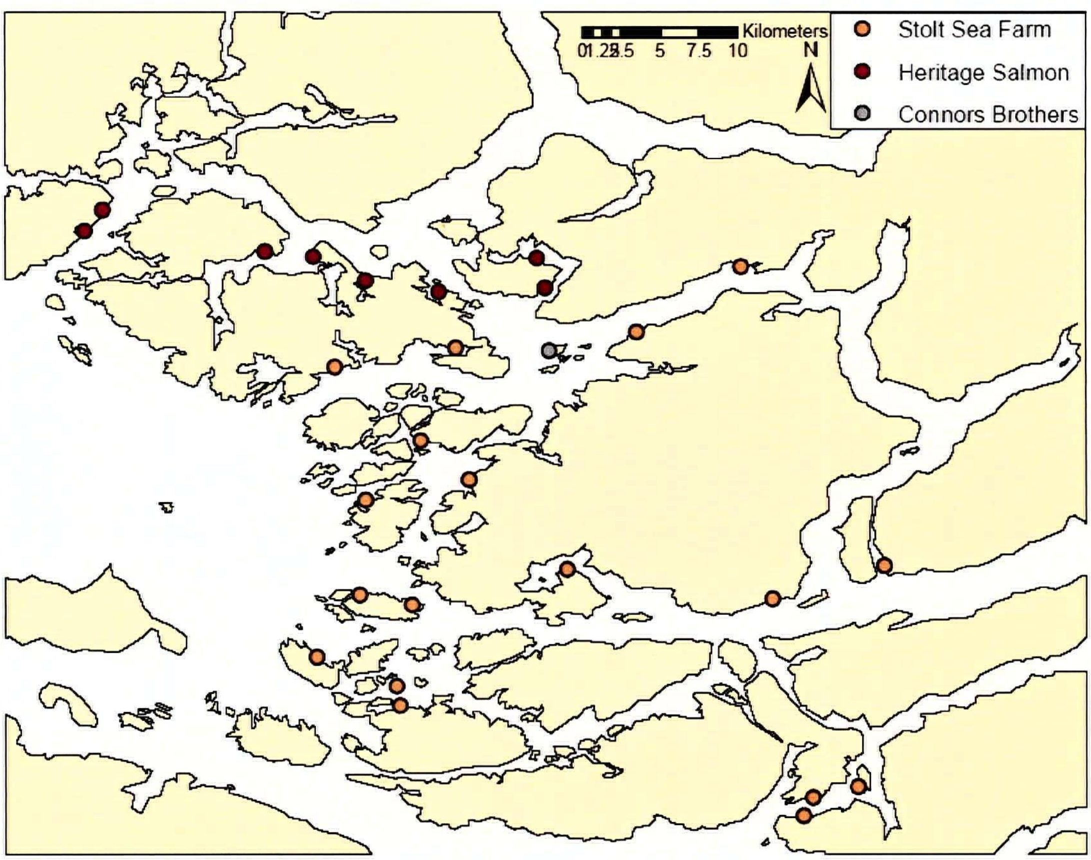
While siting company farms near one another may seem logical for the five major companies in the industry, it is interesting to note some degree of clustering among independently owned farms (classified as "Other" on the map). Clustering occurs particularly along the Pacific Rim Coast of Vancouver Island and the Sunshine Coast of the mainland. The Pacific Rim Coast is best known for its pristine beaches, whale watching, wilderness camping, good fishing and winter storms, rather than for its salmon aquaculture potential. The Sunshine Coast has largely been vacated by the major salmon aquaculture firms due to summer warming of waters in this area. Hence, companies now running salmon farm operations in these two areas tend to be smaller-scale, and independently owned. They can also be considered experimental or risk-takers in terms of employing new aquaculture technologies, raising Pacific (as opposed

Figure 5.3. Salmon farms by company in British Columbia (H1). Brightly coloured dots represent major companies, while grey dots represent small-scale, independently owned farms.



to Atlantic) salmon, and moving towards certified organic production (eg. Creative Salmon Company Ltd. and Mainstream Canada). The distribution of salmon farms by company suggests that experimental, risk-taking companies are more likely to locate near other such companies than close to multinational firms or on their own. While this finding is beyond the scope of this thesis, the presence of such a spatial relationship merits further exploration.

Figure 5.4 Salmon farms by company in the Broughton Archipelago (H1). Orange dots are farms owned by Stolt Sea Farm, pink dots are owned by Heritage Salmon, and grey is Connors Brothers. Notice that Heritage farms are concentrated in the northwestern quadrat while Stolt farms are more widely distributed throughout the Archipelago. This may reflect different siting as well as acquisition strategies.



Created by Zosia Bornik, Nov. 23, 2004
Projection: BC Albers Equal Area Conic
Data Source: BC MSRM

At the scale of interest, salmon farms can similarly be mapped to visually explore their distribution by company in the Broughton Archipelago (Figure 5.4). There are two main firms with ownership in the area: Heritage Salmon Limited and Stolt Sea Farm Inc. Displaying salmon farm point data by company suggests that Heritage salmon farms are clustered together in the northern areas of the Archipelago, while Stolt farms are more widely distributed among central and southern islands. In order to test for clustering of farms by company, first order properties were examined for both Heritage and Stolt salmon farm point data, and compared to the intensity, $\lambda(s)$, of all salmon farms in the study region, R_2. Due to the small N and irregular nature of R_2, nearest neighbour analysis was used to test this hypothesis. The ESRI ArcScript Nearest Neighbour Program (Sawada, 2002) was installed in ArcGIS 8.1. This script has the ability to select any point layer in the data frame for analysis, select any polygon layer that contains the points being analyzed[1], and calculate a nearest neighbour index. The nearest neighbour index (NNI) is based on the average nearest neighbour distance between all points (salmon farms) in a given study region, R_2, and is defined as:

Equation 5.1 Nearest Neighbour Index

$$NNI = \frac{\bar{d}}{E(\bar{d})}$$

[1] A key difference between Sawada's (2002) nearest neighbour program used in H1 and Jenness' program (2004) used in H0, was the option of inputting a specific polygon as the study region (water) as opposed to calculating distance and area across the entire region (land and water). As a result, the programs returned different values for the expected average nearest neighbour distance of salmon farms. The next step would be to test the significance of this difference by applying both scripts to the same hypothesis.

where $\bar{d}$ is the average nearest neighbour distance, and $E(\bar{d})$ is the expected average nearest neighbour distance.

Equation 5.2 Average Nearest Neighbour Distance

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$$

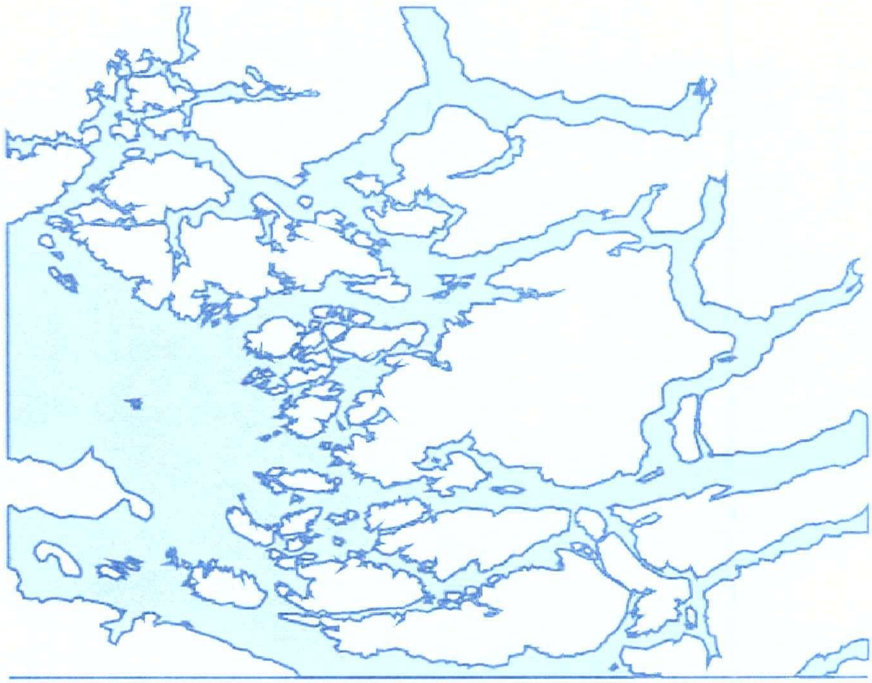
Equation 5.3 Expected Average Nearest Neighbour Distance

$$E(\bar{d}) = 0.5\sqrt{\frac{A}{n}}$$

Source: (Sawada, 2002)

In general, NNI is not the best index to use for characterizing point-patterns because of its sensitivity to the polygon size and shape, and map projection. Like the Nearest Features Program (Jenness, 2004) used in testing H0, Sawada's Nearest Neighbour Program also calculated straight line distances between neighbours, which perhaps lead to exaggerated NN Indices, suggesting a greater clustering effect than pattern exhibited. However the purpose of the test was not to accurately characterize each sample point process, but rather to compare first order properties for Heritage and Stolt salmon farm point data, and all salmon farms in the study region. As such, NNI was a useful measure of intensity for testing H1, assuming the same R_2 and methodology is used for all three samples.

Figure 5.5. Map of the study region, R_2, for nearest neighbor analysis, defined as all areas of water within the Broughton Archipelago (H1).



The study region, R_2, was defined as all areas of water (not land) within the Broughton Archipelago (Figure 5.5). A single polygon was created to represent the desired area, using the ArcGIS geoprocessing tools "clip" and "union", and saving multiple select features as one polygon layer. R_2 was found to have an area of 1,355 km^2, and was used as the input polygon used for nearest neighbor analysis.

Table 5.2. Nearest neighbor analysis for Heritage Salmon farm point data, Stolt Sea Farm point data, and all salmon farm points in the Broughton Archipelago (H1).

Sample	NN Index	Average Distance (m)	Expected average distance (m)	Standard Deviation	Sample size, n
Heritage Salmon	0.43	2820	21470	3890	8
Stolt Sea Farm	1.11	4820	10500	1450	18
All salmon farms	1.11	3940	7530	885	27

The program performed a nearest neighbor analysis for three samples of salmon farm point data (Table 5.2). Salmon farms owned by Heritage Salmon had a NN Index of less than 1, which indicates clustering in this sample. Salmon farms owned by Stolt Sea Farm had an NN Index of greater than one, which is very close to the NNI for all salmon farms and suggests a random to uniform point distribution (random distribution NNI = 1, uniform NNI >1). More importantly, a comparison of the three samples confirms what was earlier inferred: Heritage salmon farms are significantly closer to one another than they are to other farms in the region, and closer than Stolt salmon farms are to one another.

When mapped, Heritage salmon farms were found to be concentrated in the north-western section of the Broughton Archipelago, while Stolt farms were more widely distributed throughout the region. Two competing factors shaping the distribution of salmon farms by company are: economics, favouring the concentration farms, and risk-management, favouring a wider dispersion of farms. The results suggest that Heritage and Stolt weighed these two factors differently when choosing where to site their farms. We fail to reject H1 for Heritage Salmon Limited and conclude that salmon farms are clustered by company, some more than others.

A closer examination of the table reveals that the average distance for all salmon farms in the Archipelago, 3940m, was identical to the mean farm-to-nearest farm distance in H0 (Table 5.1). In contrast, the expected average distance in H1, 7530m, was significantly larger than the mean random point-to-nearest farm distance in H0, 5890m. This supports the theory that nearest neighbor approaches are extremely sensitive to area and shape of the study region. This region was defined in H0 as a thin buffer extending

475m out from the coast, and in H1 as the entire body of water in the Broughton Archipelago. Both Sawada's and Jenness' programs measured straight line nearest neighbor distances, over land and water. (Sawada's nearest neighbor program used the 'input' polygon to calculate the expected average distance only (Equation 5.3), and not the average nearest neighbor distance (Equation 5.2)). Therefore, the difference in expected average distance between H0 and H1 was due to a difference in area of potential salmon farm location, which was significantly larger in H1 than H0.

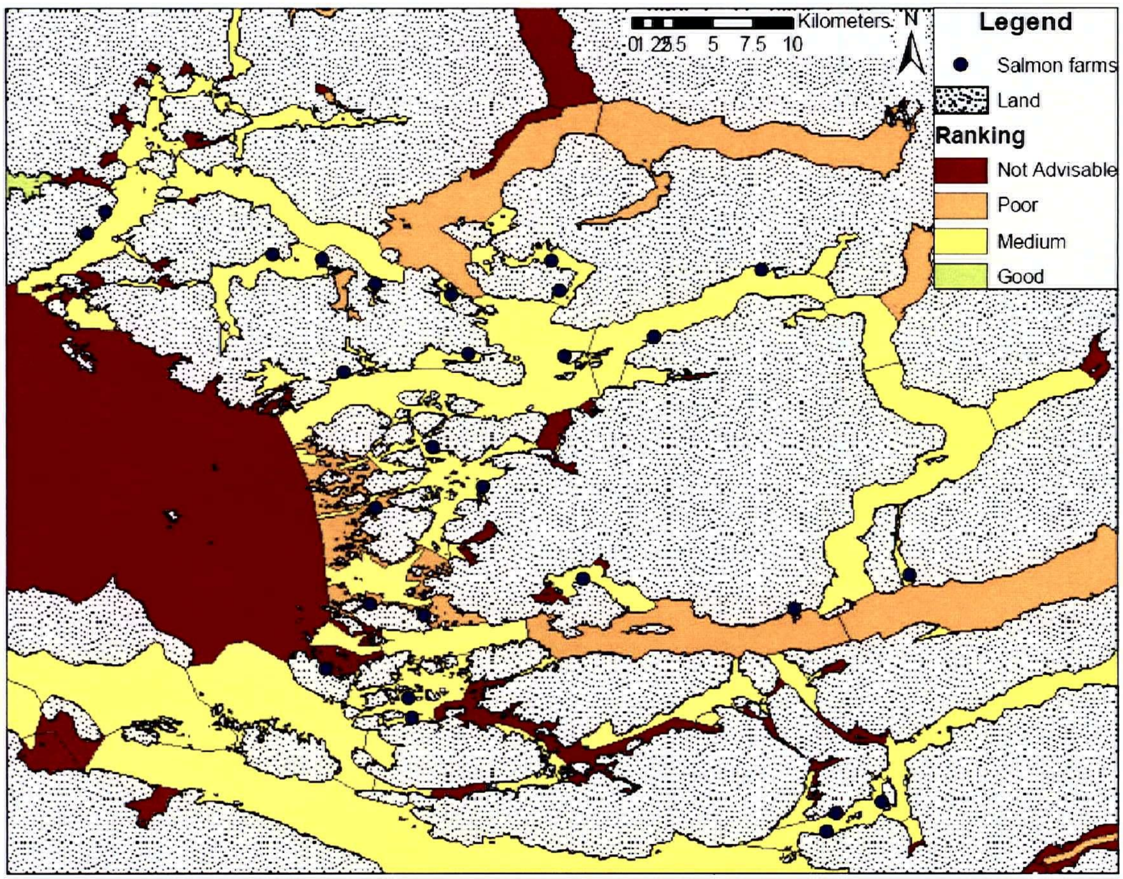
5.3 H2: Salmon farms are located in biophysically capable areas? *Fail to reject.*

Biophysical capability for salmon aquaculture was first defined and mapped for the province under the British Columbia Aquaculture System (BCAS) (MAFF, 1996). The hypothesis is concerned with testing whether biophysical capability, as defined in the BCAS, has had an influence on siting of salmon farms. In other words, is there a correlation between salmon farm point data and the locational attributes of areas rated in the BCAS as good or medium for salmonid culture (as opposed to poor or non advisable)? Should this be the case, one would expect farms to be preferentially sited in coastal areas reported to have high dissolved oxygen levels, moderate year-round temperatures, rocky substrate, adequate depth, protection from wind, waves, etc.

Map overlay techniques in ArcGIS were used to compare salmon farm locality with biophysical capability ratings for the Broughton Archipelago. As seen in Figure 5.6, many of the farms appear to be located in yellow or "medium" rated zones. Areas for the four biophysical capability zones were obtained by summarizing layer attribute data in ArcGIS, and normalized to generate the expected probability of siting farms in each zone

(Red = 0.31, Orange = 0.19, Yellow = 0.5, Green = 0.002). Salmon farm count data was similarly normalized to generate the actual probability of farms as located in each zone (Red = 0.04, Orange = 0.15, Yellow = 0.82, Green = 0). Odds ratios were obtained by dividing actual by expected probabilities and results are presented in Figure 5.7.

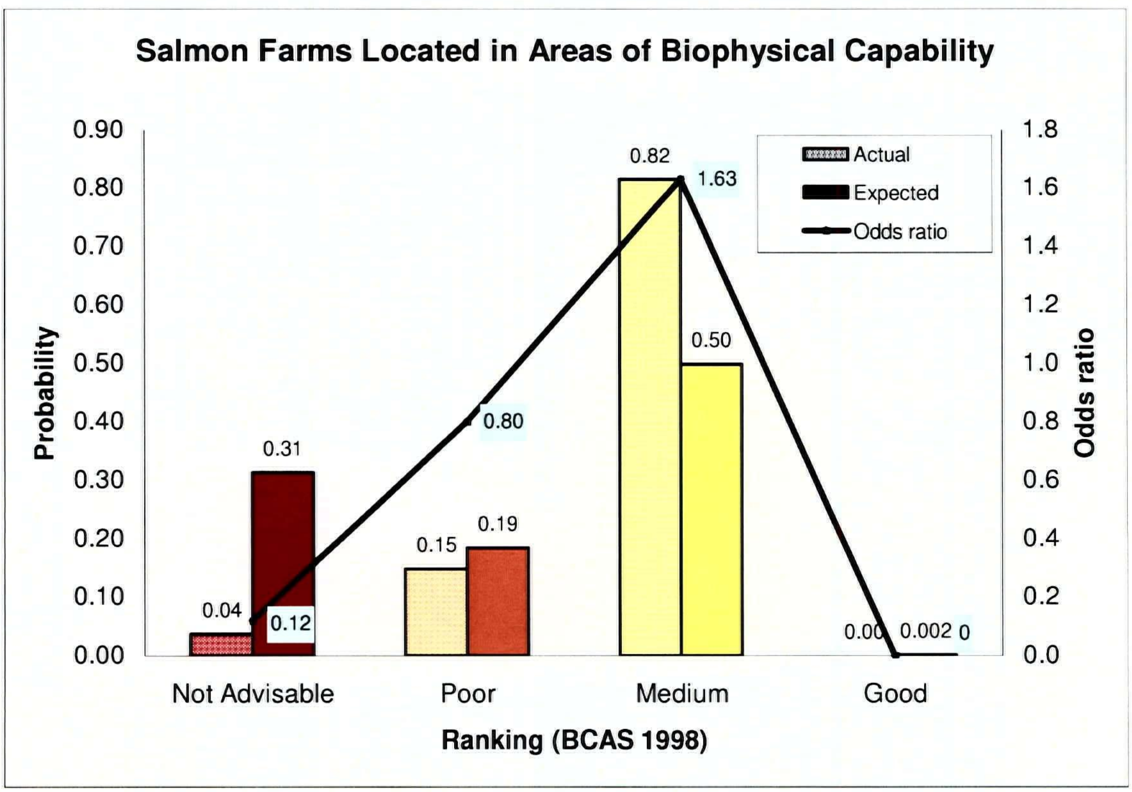
Figure 5.6. Salmon farms mapped onto biophysical capability zones of the British Columbia Aquaculture System (H2). Biophysical criteria were used to rate areas as Good (green), Medium (yellow), Poor (orange) or Not Advisable (red) for salmonid culture.



Created by Zosia Bornik, Nov. 09, 2004
Projection: BC Albers Equal Area Conic
Data Source: BC MAFF

Odds ratios were 0.12 for areas considered "not advisable" and 0.8 for areas considered to have "poor" biophysical capability for salmon aquaculture. This indicates that fewer farms were sited in these zones than would be expected given the zone's relative area. The odds ratio for "medium" biophysical capability areas, however, was >1 (1.63), indicating that significantly more farms were sited in yellow zones than would be expected. 0/27 farms were found to be located in the green zone, which was rated "good" for salmonid culture by the BCAS, but represented only 0.2% of the entire study region. The fact that no farms were sited in the green zone may reflect the small size of the area (capacity = maximum 2 farms for a given company) or access challenges, either of which could be significant enough deterrents as to outweigh the area's exceptional biophysical capability.

Figure 5.7 Summary of salmon farm location in areas ranked for biophysical capability in the British Columbia (H2).



Results indicate that salmon farms in the Broughton Archipelago tend to be preferentially located in coastal areas ranked in the BCAS with higher biophysical capability for aquaculture than in areas with little or no such properties. This is not to suggest that the British Columbia Aquaculture System was used explicitly to site salmon farms in the Broughton Archipelago - indeed, most of the salmon farms in the area were sited prior to the completion of the BCAS. However, assuming that the database represents a reasonably accurate measure of biophysical attributes important to salmonid culture, and assuming that qualities that make a site attractive for salmon aquaculture today were also considered attractive 20 years ago, we fail to reject H2 and conclude that salmon farms are preferentially located in areas of biophysical capability.

5.4 H3: Salmon farms are located to be close to processing plants? *Reject.*

This hypothesis was motivated by a perceived gap in the salmon aquaculture regulatory framework to address production-end factors related to siting, such as transportation networks, hatcheries, processing plants and labour. If it were revealed, for instance, that salmon farms were significantly clustered around processing plants, the siting of the plants themselves would clearly need to be prioritized in the regulatory framework. H3 seeks a spatial correlation between salmon farm point data and one such production-end factor: the location of plants that process farmed salmon.

In 2002, there were 129 seafood processing plants in British Columbia, of which 65 held licences to process salmon (BC MAFF, 2003b). Other licence categories include: salmon cannery, cold storage, invertebrates processing, row herring, fin fish processing, marine plant processing, sport-caught fish processing and trout processing (total categories = 22). It is not uncommon for a plant to be licensed to process more than one type of seafood, giving them the flexibility to shift processing loads according to market demand. For example, a plant may hold a licence to process salmon, in combination with licences for trout, and fin fish other than salmon or roe herring. (See Appendices 7 and 8 for complete list of salmon processing plants and licensing in British Columbia).

A salmon processing licence covers both wild and farmed salmon. While some processing plants will only deal with one type or the other, other plants will serve both industries, switching between wild and farmed on a yearly or even monthly basis (Williams, personal communication). Although the Ministry of Agriculture, Food and Fisheries surveys processors for their yearly production of all species, including farmed salmon, it is virtually impossible to know who is processing what at any given time.

Processing plants with salmon licences can be found in some 20 different towns and cities along the B.C. coast (Russell, personal communication). It may be possible to test for a spatial correlation between the location of towns with salmon processing capacity and salmon farm point data. However, Alpha Processing, a major salmon processing plant in Port Hardy, pointed out that the relationship between salmon farms and processors varies between companies. Their model is one of vertical integration: Pan Fish Canada owns every stage of production, from hatchery through to ocean net-pen sites, and processes all their fish at the company plant (Alpha Processing) in Port Hardy. Other scenarios would be better described as horizontal integration: a plant serves a number of different aquaculture companies, each shipping their fish in from various farm locations, at a range of distances from the plant. Hence, we reject H3 based on inventory data and interview results, and conclude that salmon farms are not sited to be close to processing plants. There are other factors driving the siting process.

Similar arguments could be put forth for other production-end factors, such as hatchery location and source of labour. Regarding hatcheries, it was discovered that while salmon processing may be horizontally integrated, most aquaculture companies own and operate their own local hatcheries (vertical integration). Although the number of hatcheries per company is much fewer than the number of salmon farms they serve, the transportation distance between hatchery and farm is much less of a concern than the ability of hatcheries to successfully raise smolt, and the ability of farms to successfully rear salmon to maturity (Williams, 2004). Therefore, hatcheries are sited in coastal areas that provide the necessary environmental conditions to ensure their own production viability, and their location is likely to have little influence on site selection for salmon farms.

Regarding labour, interviews revealed that while salmon processing plants may offer good employment opportunities for local communities, salmon farms themselves are now largely mechanized (eg. feeding, lighting) and only employ one or two on-site personnel. Employees are boated to the farm site by a company for one to two weeks at a time, and then replaced by fresh staff on a rotation basis (Morton, 2004). Different aquaculture companies are known to hire staff from the same towns, and Campbell River is a common source of employees for on-site monitoring. Hence, source of farm labour does not have a significant influence on the distribution of salmon aquaculture sites within the Broughton Archipelago. Along with hatchery location and other production-end factors, further exploration was deemed unnecessary.

5.50 H4: Salmon farms are located to protect coastal resource interests? *Reject.*

Coastal Resource Interest Studies (CRIS) were among the first attempts made in B.C. to compile information on coastal resources and uses, in order to provide guidance as to where to allow future development and where to prevent it. In particular, the Broughton Archipelago CRIS was intended to evolve an aquaculture opportunities map with appropriate review procedures for processing aquaculture applications. The premise for this hypothesis was the controversy that arose among interest groups following the completion of the CRIS in the Broughton Archipelago, over the use of local ecological knowledge in this study. Some participants observed that there were more salmon farms in the Red zones (no opportunity) than any other colour (Yellow = limited opportunity, or Green = conditional opportunity), and felt that their local knowledge had been used against them (see section 3.2).

H4 is concerned with testing whether there is a spatial correlation between salmon farm point data and locational attributes of areas designated in the CRIS as having no, limited or conditional opportunity for finfish aquaculture. Temporal aspects are important to consider here, as many of the site applications were accepted for review before the CRIS study was completed, and thus evaluated with respect to previously existing standards. A finer-grained analysis also allows for an examination of which coastal resources interests were best represented in the CRIS study, and the effect that this had, if any, on the siting of salmon farms.

A manual map overlay of salmon farm point data and CRIS finfish aquaculture opportunity areas was achieved using geographical coordinate data and feature matching. The overlay gave the initial impression that salmon farms were located predominantly in

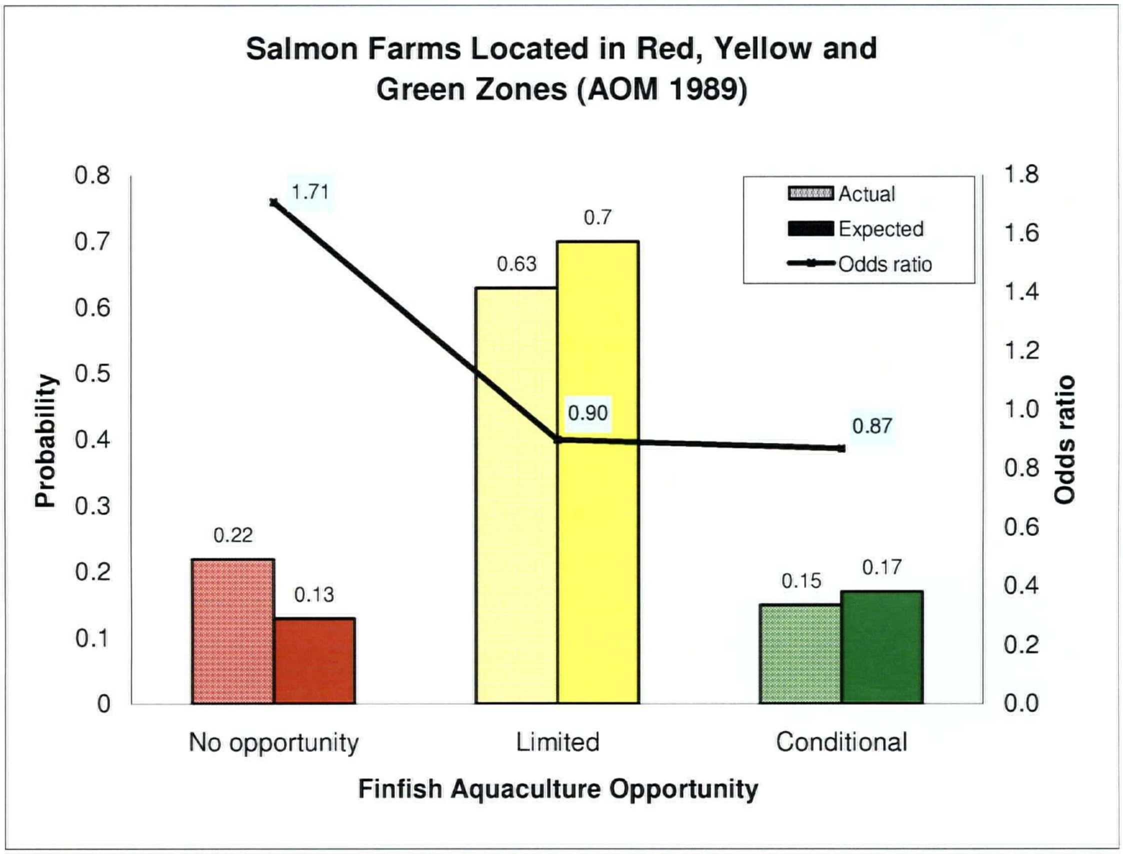
Yellow zones, with some falling into Red and Green zones. Salmon farm count data was normalized by probabilities of random point falling into each of the zones (this produced the same effect as normalizing by area, in H2).

Expected probabilities for each of the three zones were obtained by generating random geographical coordinates in Random.org and plotting points on the CRIS map. Land points were discarded and water points retained until 100 uniform random points had been plotted in the region of interest; 13% fell into Red zones, 70% in Yellow and 17% in Green. In other words, a randomly located point is far more likely to fall within a Yellow area than Red or Green, accounting in part for the initial observation that salmon farms were located predominantly in Yellow zones. Salmon farm count data was normalized to generate the actual probability of farms as located in each zone (Red = 0.22, Yellow = 0.63, Green = 0.15). Odds ratios were obtained by dividing actual by expected probabilities and results are presented in Figure 5.8.

The odds ratio for Red, or "No opportunity" zones was >1 (1.71), indicating that significantly more farms were sited in Red zones than would be expected given its relative area. The finding contradicts the original intent for designating these areas as "No opportunity", such that aquaculture applications would not be considered here. In contrast, odds ratios for areas considered to have "limited" and "conditional" finfish aquaculture opportunity were found to be <1 (0.9 and 0.87 respectively), indicating that fewer farms were sited in these zones than expected. It is important to recall that applications that were already initiated at the time of the study release were not subject to CRIS opportunity map requirements. Nevertheless, the results support the Salmon

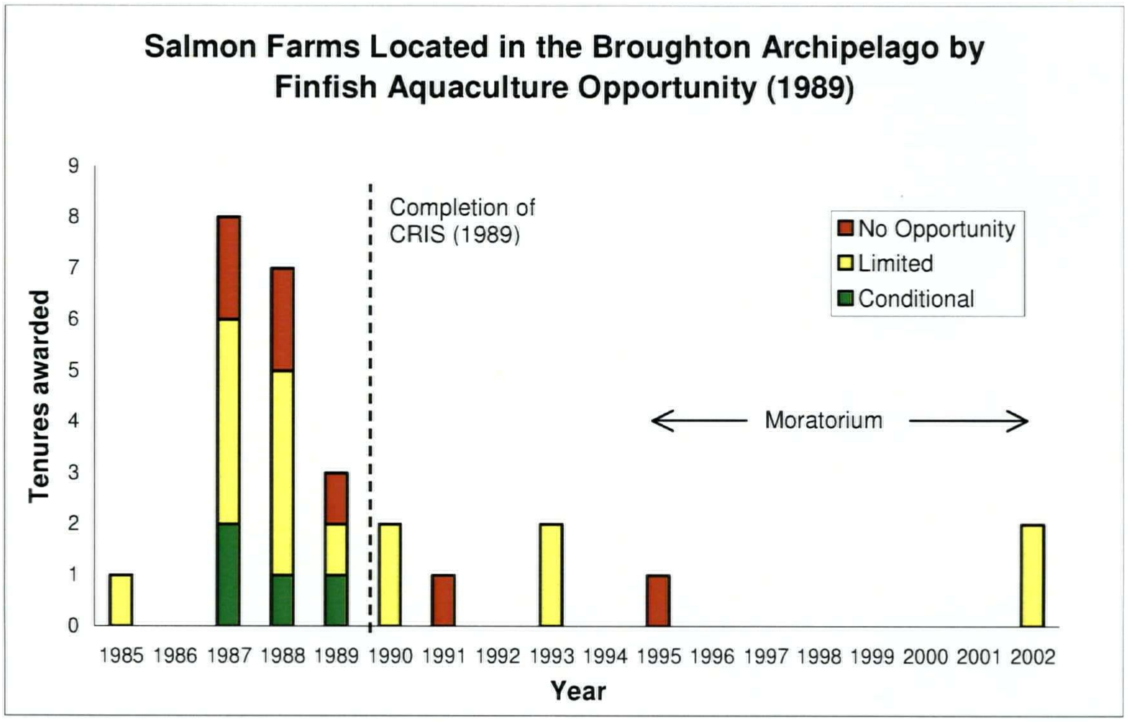
Aquaculture Review claim that the qualities that make an area suitable for coastal resource activities are similarly attractive for salmon farming.

Figure 5.8 Summary of salmon farm location in areas ranked for finfish aquaculture opportunity (suitability) in CRIS (H4).



In order to investigate the claim that local knowledge gathered for the CRIS was used to site salmon farms in the most productive areas, it is important to consider the temporal progression of salmon farm tenures awarded in the Broughton Archipelago. Figure 5.9 shows a timeline of salmon farms evaluated and approved prior to the completion of the Coastal Resource Interest Study, by aquaculture opportunity designation (Totals: 5=Red, 10=Yellow, 4=Green).

Figure 5.9 Salmon farms awarded tenure in the Broughton Archipelago from 1985-2002, sorted by finfish aquaculture opportunity (H4).



Two points are striking about this graph: (1) the bulk of salmon farms were sited prior the existence of any coordinated regulatory system, and (2) every application for tenure approved after the completion of CRIS went into Red and Yellow zones. This suggests that other factors driving the location salmon farms are perhaps being given priority over the protection of coastal resource interests. H4 is rejected.

5.51 Coastal resource valuation

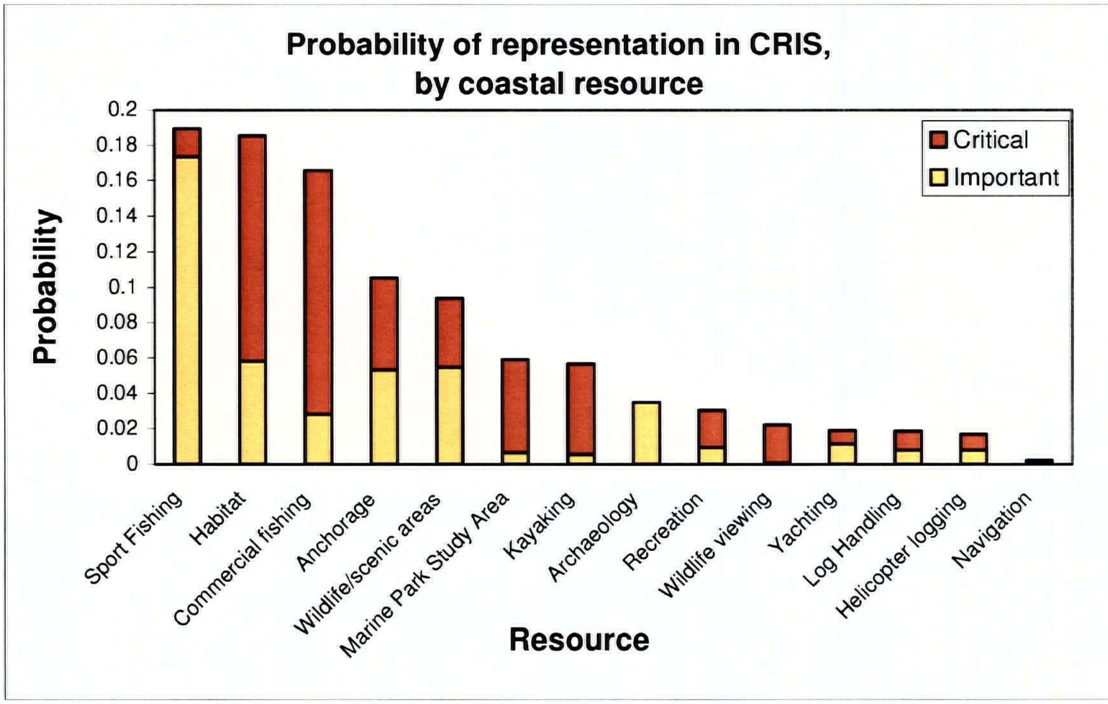
The designation of CRIS finfish aquaculture opportunity zones for the Broughton Archipelago was based on a detailed composite map, the product of several months of gathering information on "high value" coastal areas from local resource interest groups (see Section 3.2). The specific methodology used to build the composite map, as documented in the CRIS report, involved tracing the most detailed and group maps first while designations by other participants were adapted to these initial outlines, and involved "some degree of interpretation" in the mapping procedure (Catherine Berris Associates Inc, 1990). The wording of the report suggests that interest groups with the most experience in mapping (or with resources to hire a mapping expert), or participants who joined together to form a larger interest group, were perhaps better represented in the CRIS study. The sub-hypothesis was explored through a fine-grained analysis of the original composite map (see Appendix 9 for sample level of detail).

Figure 5.10 shows the relative probability of representation of fourteen coastal resources in the composite map. Probabilities were obtained by generating random geographical coordinates in Random.org until 100 uniform random points had been plotted in water regions of the Archipelago (land points were discarded). A buffer of 1km radius was drawn around each point, and an inventory taken of the number of Critical (C) and Important (I) resources found within each buffer area[2]. The best overall represented coastal resources were found to be sport fishing (19%), habitat (19%) and commercial fishing (17%), followed by anchorage (11%) and wildlife/scenic areas (9%). In other words, a randomly located point would be far more likely to be fall within an area considered critical or important for sport fishing than, for example, yachting. This may reflect differences in the level of detail in groups map submissions rather than actual

[2] 1 km was selected as an appropriate buffer distance based on current siting criteria (MAFF, 2000), which requires salmon farms to be located at least 1km away from ecological reserves, marine protected areas or proposed areas, herring spawning areas, salmonid-bearing streams and First Nations Reserves. Recommended buffer distances are <1km for some criteria not listed above, and >1km for others. For the purposes of the CRIS composite map analysis, an average radius of 1km was taken to represent the potential influence of salmon aquaculture sites on coastal resources.

differences in coastal resource use in the region. The average number of coastal resource activities or interests found within the 1km buffer of random points was 19.3 critical and 9.5 important.

Figure 5.10. Probability of coastal resource representation in CRIS composite map (in descending order, by summed critical and important designations) (H4).



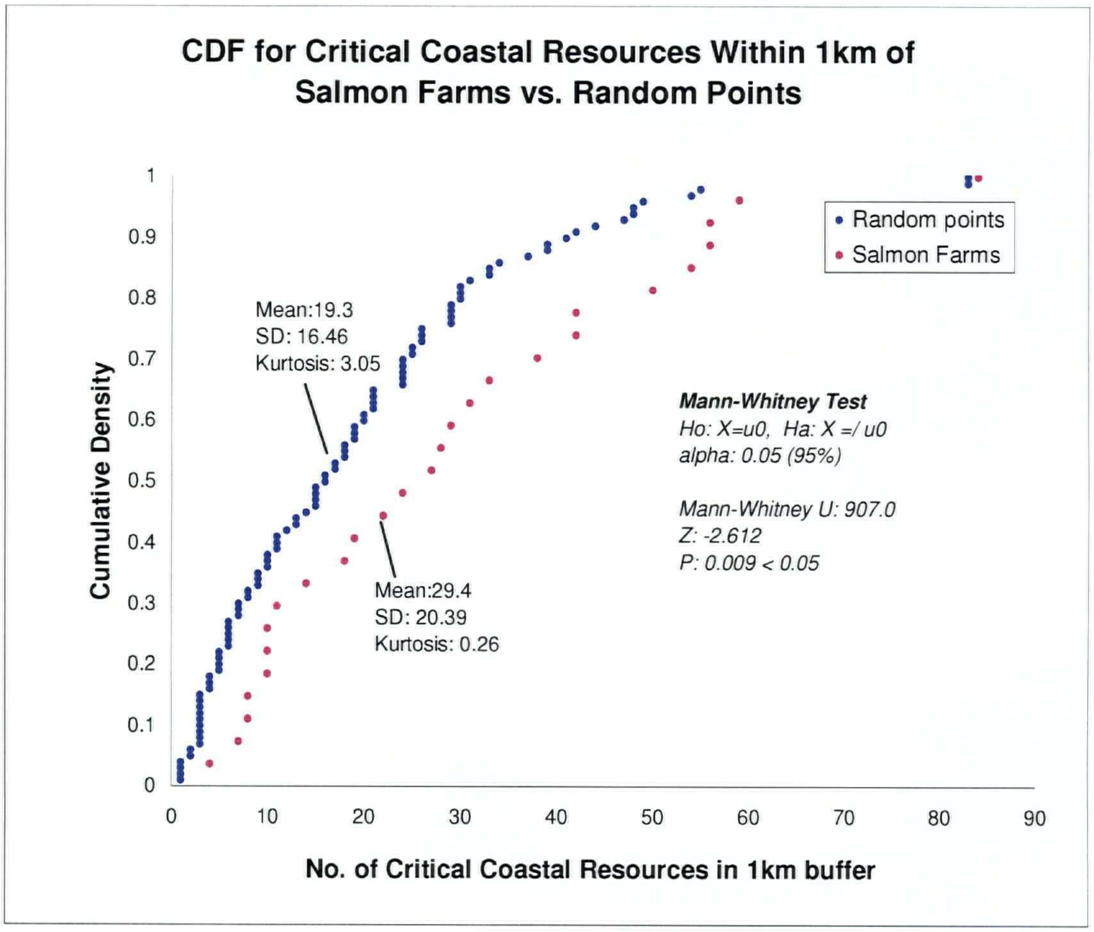
Salmon farm point data was overlaid with the CRIS composite map using geographical coordinate data and manual feature matching. A buffer of 1km radius was drawn around each point, and an inventory taken of the number of Critical (C) and Important (I) resources found within each buffer area. The average number of coastal resources found within the 1km buffer of salmon farms was 29.4 critical and 15.3

important resources, both higher than would be expected given the relative coverage of resource designations on the CRIS map (19.3 critical and 9.5 important, from above).

High value areas that participants submitted as "Important" were areas where, under certain management conditions, the activity/interest could co-exist with other activities. Areas classified as "Critical" were areas so essential that the activity/interest should take precedence over other activities, such as salmon aquaculture. Figure 5.11 compares cumulative density functions for the number of critical coastal resources found within a 1km buffer of salmon farms versus random points. When plotted, the CDF for salmon farms falls below and to the right of the CDF for random points, suggesting that on average, there are more critical resources found within the vicinity of salmon farms than random points.

The two distributions were tested for normality using the interactive histogram tool in SPSS. A non-parametric independent samples Mann Whitney U test was selected to determine whether there was a significant difference between the distributions. The Mann-Whitney U test is considered an alternative to the independent samples T-test (employed in H0). The test is appropriately used when the two samples in question differ in N and variance, and assumptions cannot be made about normality of the distributions. The results of the U test indicate that at the 95% confidence level there is a significant difference between the number of coastal resources in the vicinity of randomly distributed points versus salmon aquaculture sites. The results further support the rejection of H4. In contrast to the hypothesis, salmon farms as currently sited in the

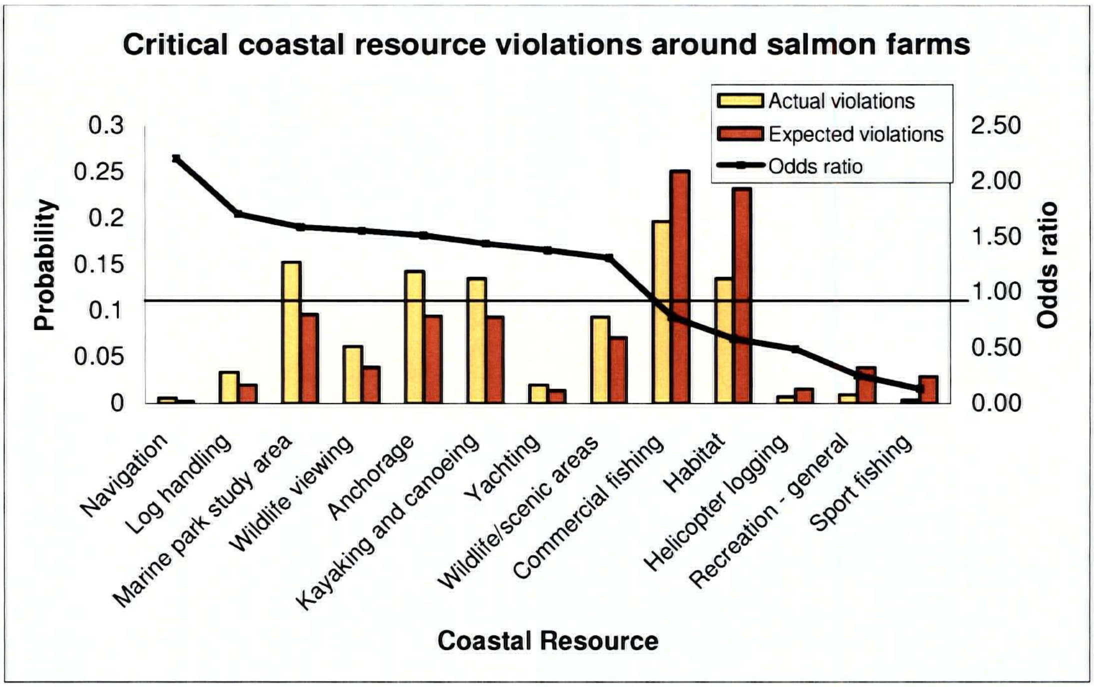
Figure 5.11. Cumulative density functions for critical coastal resources within 1km buffers of salmon farms and random points (H4).



Broughton Archipelago infringe on more critical coastal resources than if they had been sited in a random manner.

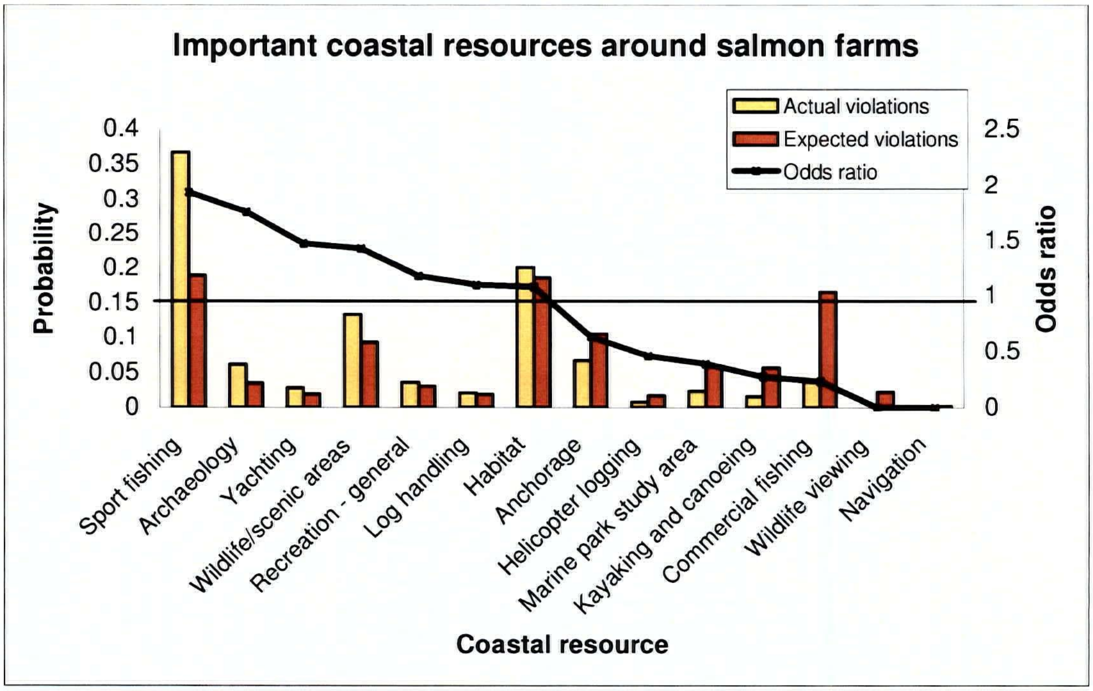
Figure 5.12a and 5.12b represent probabilities and odds-ratios for critical (a) and important (b) coastal resources found within the 1km vicinity of salmon farms in the CRIS composite map, in an attempt to draw out those coastal resources that were most affected by the siting of salmon farms. Given the definition of high value areas considered "Critical" by study participants, activities/interests in these areas are less likely to co-exist harmoniously with other activities (eg. salmon farming), than in areas classified as "Important". Hence, the greatest effect of salmon farm siting on coastal resources is in critical high value areas, shown in Figure 5.12a.

Figure 5.12a Summary of critical coastal resources around salmon farms. Odds ratios represent actual over expected probability



Results indicate that salmon farms were sited in areas considered by participating groups to be critical for navigation, log handling, marine park study areas, wildlife viewing, anchorage, kayaking/canoeing, yachting and wildlife/scenic areas (odds-ratios >1). Coastal resource interests that were "protected" over others in siting salmon farms included sport fishing, general recreation, habitat, and commercial fishing (odds ratios <1). As further evidence to the rejection of H4, salmon farms as located in the Broughton Archipelago were found to infringe on more critical coastal resources than were protected.

Figure 5.12b Summary of important coastal resources around salmon farms. Odds ratios represent actual over expected probability (H4).



5.6 H5: Salmon farms are located to meet current siting criteria? *Reject.*

Since the siting criteria for new aquaculture facilities were last updated in March 2000, two distinct efforts – one by a local NGO and a later attempt by the Ministry of Sustainable Resource Management – have been made to render the criteria more effective. In 2003, the Living Oceans Society produced a map summarizing the Salmon Aquaculture Review siting criteria for the Broughton Archipelago. The map ranked coastal areas on a graduated scale of zero to ten for salmon aquaculture suitability, based on how many of the 15 criteria were met in each area. Salmon farm point data was plotted over criteria layers, and many of the farms were found located in red, "poor suitability" zones (see Appendix 10).

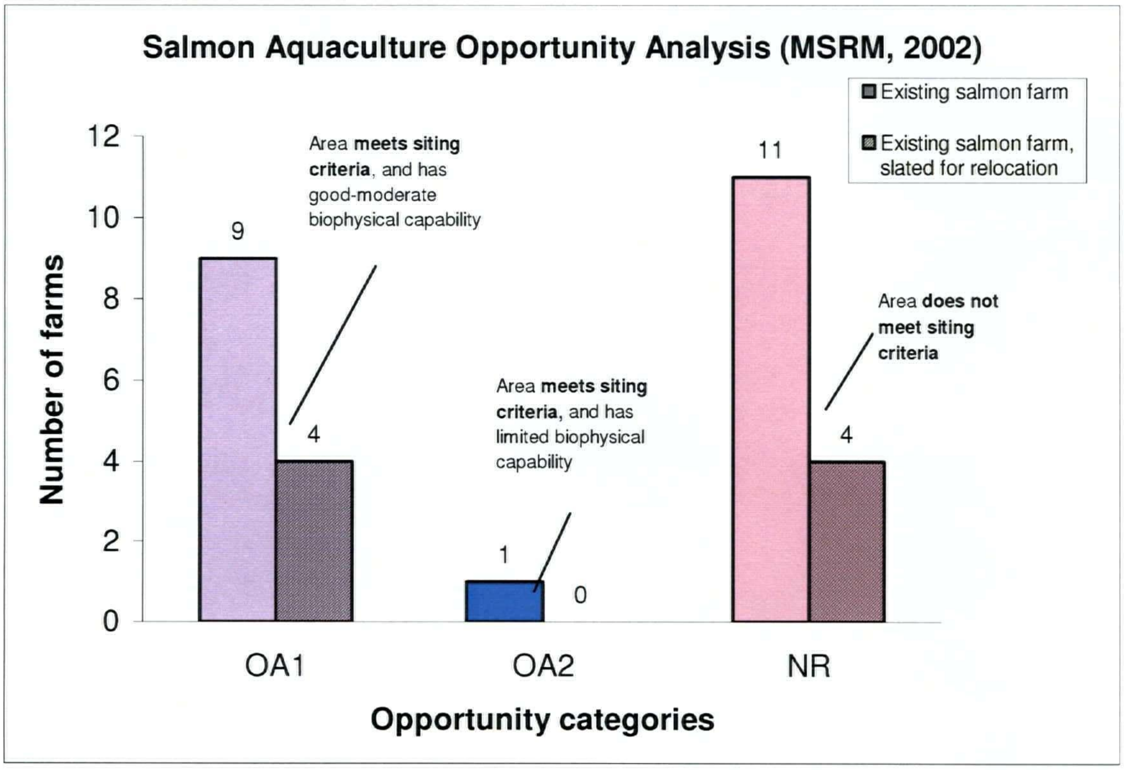
Concurrently, the Ministry of Sustainable Resource Management produced their own suitability maps, combining siting criteria and biophysical capability to produce opportunity areas (OA1, OA2 and Not Recommended) for salmon aquaculture. The North Island Straits, encompassing the Broughton Archipelago, was one of the first regions to be selected for this purpose (see Section 3.3 for methodology/intended use of the Aquaculture Opportunity Study). Of the two maps, the MSRM study offers the greater amount of detail on existing salmon farms, sorting sites by whether they have been slated for relocation or not. The information serves as an additional dimension of analysis in the testing of H5. Furthermore, the MSRM map organizes siting criteria areas by distinct suitability categories, whereas the Living Oceans Society map uses a graduated scale. Feasibility and depth of analysis led to the selection of the MSRM map for probing the validity of H5.

Hypothesis 5 is concerned with testing the effectiveness of current siting criteria in shaping the location of salmon farms in the Broughton Archipelago. Specifically, H5 asks whether there is a spatial relationship between the location of existing salmon farms and areas that meet the siting criteria (AO1 and AO2), and whether salmon farms that have been slated for relocation are currently located in areas where criteria are not being met. In Figure 5.13, salmon farms are sorted into histogram by opportunity area and MSRM selection for relocation.

At the time the Aquaculture Opportunity analysis was carried out, there were 29 existing salmon farms in the Broughton Archipelago, and 2 additional farms in the North Island Straits. Results indicated that 14/29 salmon farms are located in areas that meet the current siting criteria (Opportunity Area 1 and Opportunity Area 2), whereas 15/29 farms are located in areas that do not meet the siting criteria. Of the eight farms that were slated for relocation in 2002, only half are currently located in poor suitability areas (Not Recommended); the other half will be relocated from highly suitable areas that meet siting criteria and also have good-moderate biophysical capability.

The results suggest one of two things: either the current siting criteria for new aquaculture facilities plays a small to non-existent role in the salmon farm location/relocation process, or the Aquaculture Opportunity Study map fails to adequately represent coastal areas that accord or discord with siting criteria. The answer

Figure 5.13 Salmon farms in the Broughton Archipelago, by aquaculture opportunity category and relocation (H5). [3]



[3] Note: The colour scheme for this chart was selected to be consistent with colours used in the Aquaculture Opportunity Map for the North Islands Straits, and less for aesthetic reasons or effective communication.

may lie somewhere in between. However, the combination of scale issues, patchy spatial data, and definitional issues on the wording of certain criteria (eg. what constitutes a 'significant' salmonid-bearing stream? At what density to eelgrass and kelp become designated as 'beds'?) raises scepticism about the accuracy of any attempt to spatially represent this data. Nevertheless, both attempts to map salmon farm siting criteria over the last three years have shown farms to be located more frequently in poor suitability areas than moderate-high suitability. Hence we reject H5, based on the best available evidence, and conclude that salmon farms are not located to meet the current siting criteria.

References:

British Columbia Ministry of Agriculture Food and Fisheries, Aquaculture Development Branch (2003a). Guide to information requirements for marine finfish aquaculture applications. http://www.agf.gov.bc.ca/fisheries/Finfish/MFF_Guide_BW_single-sided.pdf. Accessed: January 27, 2004.

British Columbia Ministry of Agriculture, Food and Fisheries (1996). British Columbia Aquaculture System: Finfish Capability. http://srmwww.gov.bc.ca/rmd/lrmp/spatial/marine.htm#marine3. Accessed: March 21, 2004.

British Columbia Ministry of Agriculture, Food and Fisheries (2003b). Fisheries and Aquaculture Management: Aquaculture Wizard. http://www.fishwizard.com/aqua/index.asp Accessed: June 12, 2004.

Creative Salmon Company Ltd. http://www.creativesalmon.com/. Accessed: December 10, 2004.

Jenness, J. (2004a). Nearest Features (v.3.7). N. F. v.3.7. Flagstaff, AZ, Jenness Enterprises. http://www.jennessent.com/arcview/arcview_extensions.htm. Accessed April 07, 2004.

Jenness, J. (2004b). Random Point Generator (v.1.27). R. P. G. (v.1.27). Flagstaff, AZ, Jenness Enterprises. http://www.jennessent.com/arcview/arcview_extensions.htm. Accessed April 09, 2004.

Living Oceans Society (2003). Summary of the Salmon Aquaculture Review Siting Criteria: Broughton Archipelago. http://www.livingoceans.org/maps/pdfs/ff_brough_siting_3.pdf. Accessed: August 26th, 2003.

Mainstream Canada http://www.mainstream-group.com/contenido/canada/index2.html. Accessed: December 10, 2004.

Random.org. Random Number Generator. http://random.org/nform.html. Accessed: November 02, 2004.

Russell, H. Seafood Statistics Office, B.C. Ministry of Agriculture, Food and Fisheries, Seafood Development Branch. Personal communication: September 21, 2004.

Sawada, M. (2002). README: Instructinos to Use Nearest Neighbor Program (VBA Macro). ESRI ArcScripts. http://arcscripts.esri.com/details.asp?dbid=12227. Accessed October 22' 2004.

Williams, B. Scheduling and Human Resources, Pan Fish Canada. Personal communication: June 04, 2004.

CHAPTER VI Conclusion and recommendations

The findings of this research confirm that salmon aquaculture sites are not randomly located in the Broughton Archipelago, B.C., and provide a quantitative measure of the validity of five hypotheses on the determinants for their location. Salmon farms in this region were generally found to be clustered by company, some more than others, reflecting differences in both siting and acquisition strategies. Salmon farms were found to be located in areas of high biophysical capability where coastal resource interests and activities are also concentrated. Resources proportionally most affected by salmon farm siting include navigation, log handling, marine park study areas, wildlife viewing, anchorage, kayaking/canoeing, yachting and wildlife/scenic areas. Salmon farm sites in the Broughton are not selected for their proximity to processing plants, hatchery facilities, or labour. As currently distributed, salmon farms are equally likely to be found in areas that meet the existing siting criteria as in those that fail to do so. The same claim can be made for farms that have been slated for relocation.

The B.C. government's 1995 moratorium on the issuance of new salmon farm tenures was a response to an apparent need to review and address environmental issues and provincial policies regarding salmon aquaculture. When the moratorium was terminated five years later, the move was said to be justified by the completion of the Salmon Aquaculture Policy Framework, which successfully addressed outstanding concerns of the Environmental Assessment Office's Salmon Aquaculture Review of 1997 and developed one of the most comprehensive regulatory frameworks in the world. The framework included "science-based standards" for the siting and relocation of salmon farms that would protect the environment over the long term.

However, a close examination of the spatial distribution of salmon farms and other factors in the Broughton Archipelago reveals that there remain major gaps in our knowledge base of coastal resources. Such limitations prevent current siting guidelines from being met when locating or relocating farms, much less be incorporated into the regulatory framework. Out of the three spatial databases developed by the province over the last 20 years to guide the assessment of salmon aquaculture applications, only the biophysical capability rankings of the British Columbia Aquaculture System were found to correlate with the actual location of salmon farms in the Broughton Archipelago.

The Coastal Resource Interest Study conducted for the region did not serve its original purpose - to identify areas of high value to coastal resource users so that finfish aquaculture activities could be directed away from such areas. The claim that salmon farms were sited in areas identified by First Nations and other interest groups as critical to their activity was tested in this work, and verified. A significantly higher number of salmon farms were found to be located in "Red" zones than if they had been randomly sited. While the majority of salmon farm applications were evaluated prior to the completion of the Coastal Resource Interest Study, every farm approved since its publication has been sited in "Yellow" and "Red" Zones. The relationship suggests that the protection of coastal resource interests is not a priority under the existing development model for the salmon aquaculture industry.

Aquaculture Opportunity Maps, a more recent an initiative of the B.C. Ministry of Sustainable Resource Management, also failed to meet their original goal, to assist in the relocation of poorly sited salmon farms into areas where they would have a reasonable chance of success, and where habitat considerations, social conflicts or other related issues would not be barriers. Half of the farms designated by this study to be relocated were selected from highly suitable zones that met the siting criteria and had good-moderate biophysical capability. Furthermore, the study explicitly acknowledges its own data limitations, advising users not to use the zonation of areas for the purposes of limiting the scope of salmon aquaculture tenure applications.

The movement towards integrated coastal resource management, using geographic information systems to integrate ecological, social and economic data to support informed decision-making in coastal areas, is a step in the right direction. The North Island Straits Coastal Plan is an example of such a framework. Given that many of the salmon farm tenures in the Broughton will need to be renewed over the next 5 years (assuming a 20 year licence period), projects such as these could play an important role in shaping the industry to better reflect the limits of our knowledge, the interests of affected parties, and protect the long term sustainability of B.C.'s coastal ecology. While much will depend on the mandate of the current provincial government, the future of the salmon aquaculture industry in the Broughton Archipelago could look much brighter than it has in the past.

Appendix 1. List of recommendations on salmon farm siting in Salmon Aquaculture Review. (Source: EAO, 1997).

To identify potential impacts and conflicts in siting, the Ministry of Environment, Lands and Parks routinely refers applications to other agencies and interests. The effectiveness of the referral system is hampered by several factors: if comments are not returned in a timely manner, decisions may be made in the absence of full information; there is no obligation on the part of the Ministry of Environment, Lands and Parks to act on comments they receive; and there is no guidance for making tenuring decisions when conflicting advice is received. Even though the decision-makers have broad discretion, there are few effective avenues for consultations in advance of decisions. Recent initiatives to complement the referral process with face-to-face interagency communication, through the Vancouver Island Fish Farm Review Committee, have encouraged greater coordination and consensus, as well as enabling applications to be considered in groups. The committee approach to tenure review should be formalized, with provincial agency disagreements being referred to Interagency Management Committees for resolution. (Recommendation 1)

Another shortcoming of site-by-site referrals is that they restrict attention to a single site rather than considering the cumulative impact of multiple developments on a variety of values in a region or sub-region. Integrated coastal management plans, based on consensus among stakeholders and a thorough assessment of all biological resources, provide a fair and efficient mechanism for designating specific geographic areas suitable for different types and intensities of activities, including salmon farming. They should be prepared at both the sub-regional level (e.g., Central Coast) and the local level (e.g., Clayoquot Sound). As such plans may take considerable time to prepare, techniques should be developed on an interim basis to assess and allocate salmon farms in groups located within defined geographical areas and to provide for input of all those with an interest in such site allocations. (Recommendations 2 and 3)

To prevent or reduce negative impacts and conflicts, siting criteria should be established to define minimum distances for separation of farm sites from other uses and resource values, with greater than the minimum requirement being provided where detailed site-specific assessments show this to be necessary. (Recommendation 4) Where integrated coastal use plans provide clear direction, sites should be located in accordance with the plan.

Thorough inventories and mapping, though expensive, generate cost savings by facilitating precise and expeditious decisions that avoid the risk of conflict by their increased credibility. They are essential both for integrated coastal planning and for the assessment of salmon farm site applications. Government should continue to improve its inventories and mapping base, drawing on federal and provincial data, local and traditional knowledge, and private industry maps. Aquaculture suitability maps should continue to be developed from this information. In addition, to facilitate informed decisions, government should require applicants to provide detailed assessments of specified site characteristics, using resource inventories and mapping, site surveys and studies, and local consultation. (Recommendations 5 and 6)

Despite a keen public interest in the aquaculture industry, current opportunities for involvement in decision-making regarding salmon farming are sporadic and limited. Public input is essential not only to encourage well-informed decisions and reduce conflict, but as a matter of fairness. In addition to other avenues, government should establish local advisory working committees, comprising a balanced cross section of interests and using existing committees where appropriate, to provide advice on siting and management of farms. (Recommendation 7)

Where existing sites are poorly located and are causing significant problems, remediation plans should be developed, with measures to revise production levels, amend husbandry practices, incorporate different technology, or relocate farms to a different location. (Recommendation 8)

The early stages of the salmon-farming process take place in freshwater facilities, including land-based hatcheries and juvenile-rearing lake net-cages. Two Vancouver Island lakes (Lois and Georgie) currently have active aquaculture operations. Certain environmental impacts of salmon farming can be more significant in fresh water than in the ocean. There is an increased likelihood of escaped salmon competing with native fish populations and establishing colonies. In addition, low production or oligotrophic lakes are particularly susceptible to eutrophication resulting from absorption of waste nutrients. To reduce these risks, the government should prepare effective and consistent guidelines for approval of lake aquaculture facilities, and should develop and enforce water quality standards for dissolved waste discharges. (Recommendations 9 and 10)

Appendix 2. What Makes a Good Aquaculture Site. (Source: MAFF, 2003)

The following factors are considered desirable conditions for a salmon aquaculture site. Companies consider these factors (and others) in researching a site; however, siting decisions are ultimately made by government regulatory agencies, in conformance with all applicable laws and regulations. A suitable site for aquaculture will generally have:

- relatively uniform year-round temperatures and dissolved oxygen levels
- good oxygen exchange/flushing (e.g. not in an enclosed bay)
- no history of plankton blooms
- no nearby pollution sources
- adequate current speed for waste dispersion
- no extreme wave or current conditions
- low probability of severe storms or winter icing
- sufficient depth to allow clearance or at least 10m under cage structures
- no nearby seal/sea lion haulouts or populations of salmon predators
- minimal impact on sensitive marine habitat (e.g. shellfish beds, kelp beds, reefs, etc.)

This list is provided for general information only and is not intended to be exhaustive or to reflect all factors considered by a company or by government in selecting or approving a site for aquaculture use.

Appendix 3. Contact Summary for Broughton CRIS (Source: Catherine Berris Associates Inc., 1990)

Archaeology Society of B.C.
B.C. Oyster Growers Association
B.C. Federation of Naturalists
B.C. Speleological Federation
B.C. Wildlife Federation*[m]
Bill Mackay – Stubbs Island Charters*
Campbell River Museum
Canadian Coast Guard, Navigable Waters*[m]
Canadian Parks and Wilderness Society
Canadian Wildlife Service*[m]
Council of B.C. Yacht Clubs*[m]
Council of Marine Carriers*[m]
Council of Forest Industries*[m]
Chris Bennett – Sportfishing Guide*[m]
Department of Fisheries and Oceans, Aquaculture Division, Fisheries Branch*[m]
Don Watmough – Recreation Consultant/Writer*[m]
Fishing Vessel Owner's Association*[m]
Kwakiutl Territorial Fisheries Commission*
Larry Mangotitch – Oceaner Diving Charters, Divers World*[m]
Ministry of Agriculture and Fisheries, Aquaculture Operations*[m]
Ministry of Environment, Planning and Assessment Branch*[m]
Ministry of Forests, Port McNeill Forest District*[m]
Ministry of Municipal Affairs Recreation & Culture, Archaeology & Outdoor*
Ministry of Native Affairs, Natural Resource Management
Ministry of Parks, South Coast Region*[m]
Ministry of Regional Development, Tourism Development Branch
Ministry of State for Vancouver Island/Coast
Ministry of Tourism and Provincial Secretary, Product and Planning Branch*[m]
North Island & Mainland Salmonid Enhancement Alliance*[m]
North Island Mariculture Association*[m]
North Island Sportsman's Association*[m]
Outdoor Recreation Council of B.C.
Pacific Biological Station – Marine Mammals*[m]
Pacific Gillnetter's Association*
Pacific Troller's Association*[m]
Peter Barratt – Canadian Helicopters*[m]
Port McNeill Charterboat Association*[m]
Prawn Sub-Committee Shellfish Advisory Board*[m]
Raincoast Research*[m]
Recreational Canoeing Association of B.C.*[m]
Regional District of Mount Waddington*[m]
Sea Kayaking Association of B.C.*[m]
Underwater Archaeological Society of B.C.*
Underwater Harvester's Association

* indicates those who participated by submitting written comments
[m] indicates those who participated by submitting maps

Appendix 4. North Island Straits Aquaculture Opportunity Map Legend (Source: BC MSRM, 2002).

Opportunity Area 1:
Area meets siting criteria and has good to moderate potential for net cage salmon aquaculture

Opportunity Area 2:
Area meets siting criteria and has limited potential for net cage salmon aquaculture

Not Recommended:
Area does not meet siting criteria applied at this mapping scale

Existing salmon farm

Existing salmon farm slated for relocation

Finfish Tenure: 3km buffer

First Nations reserve: 1km buffer

Planning area boundary

Regional District boundary

Mount Waddington Regional District: conditional support confirmed
Comox Strathcona Regional District: support unconfirmed

Gwa'sala'Nakwaxda'xw First Nation: support confirmed for identified areas only

Kwiakah First Nation: support unconfirmed

Mamaleleqaia-Qwe'Qwa'Sot'Enox First Nation: support unconfirmed

Namgis First Nation: no support given

Cape Mudge (Weewiakay) First Nation: support unconfirmed

Tlowitsis-Mumtagila First Nation: support unconfirmed

Tsawataineuk First Nation: support unconfirmed

Kwikwasut'Inuxw First Nation: support unconfirmed

Kwagu'L First Nation: support given for identified areas only

Campbell River First Nation: support unconfirmed

Gwawa'enuxw First Nation: support unconfirmed

Appendix 5. North Island Straits Aquaculture Opportunity Map Notes (Source: BC MSRM, 2002).

NOTES

"Support" denotes that the identified First Nation and/or local government body has no objection to receiving an application for a finfish aquaculture operation in the opportunity areas identified within its geographic area of interest. Support does not eliminate requirements for referral of any site application to the First Nation and/or local government body or imply/assume approval of any site for salmon farming.

1. Salmon Aquaculture Siting Criteria used for this study are drawn from BC Assets and Lands Commercial Finfish Aquaculture Management Plan: SCHEDULE C - New Tenure Siting Criteria, (March 2000).

1 km in all directions from a First Nations reserve (may be relaxed with approval of affected First Nation);
1 km from the mouth of a salmonid-bearing stream determined as significant in consultation with DFO and the province;
1 km from herring spawning areas designated as vital, major or important by DFO and the province;
300 m from inter-tidal shellfish beds that are exposed to water flow from a salmon farm and which have regular or traditional use from First Nations, recreational, or commercial fisheries;
125 m from all other wild shellfish beds and commercial shellfish growing operations;
1 km from existing or approved proposals for ecological reserves <1000 ha.;
No salmon farms within the line of sight up to 1 km in all directions from existing federal, provincial or regional parks, and Marine Protected Areas (applications within study areas are subject to enhanced referrals)
Spacing between farm sites to be three kilometers or in accordance with a local area plan or Coastal Zone Management Plan (may be reduced to one kilometer in the case of farms operated by the same company).

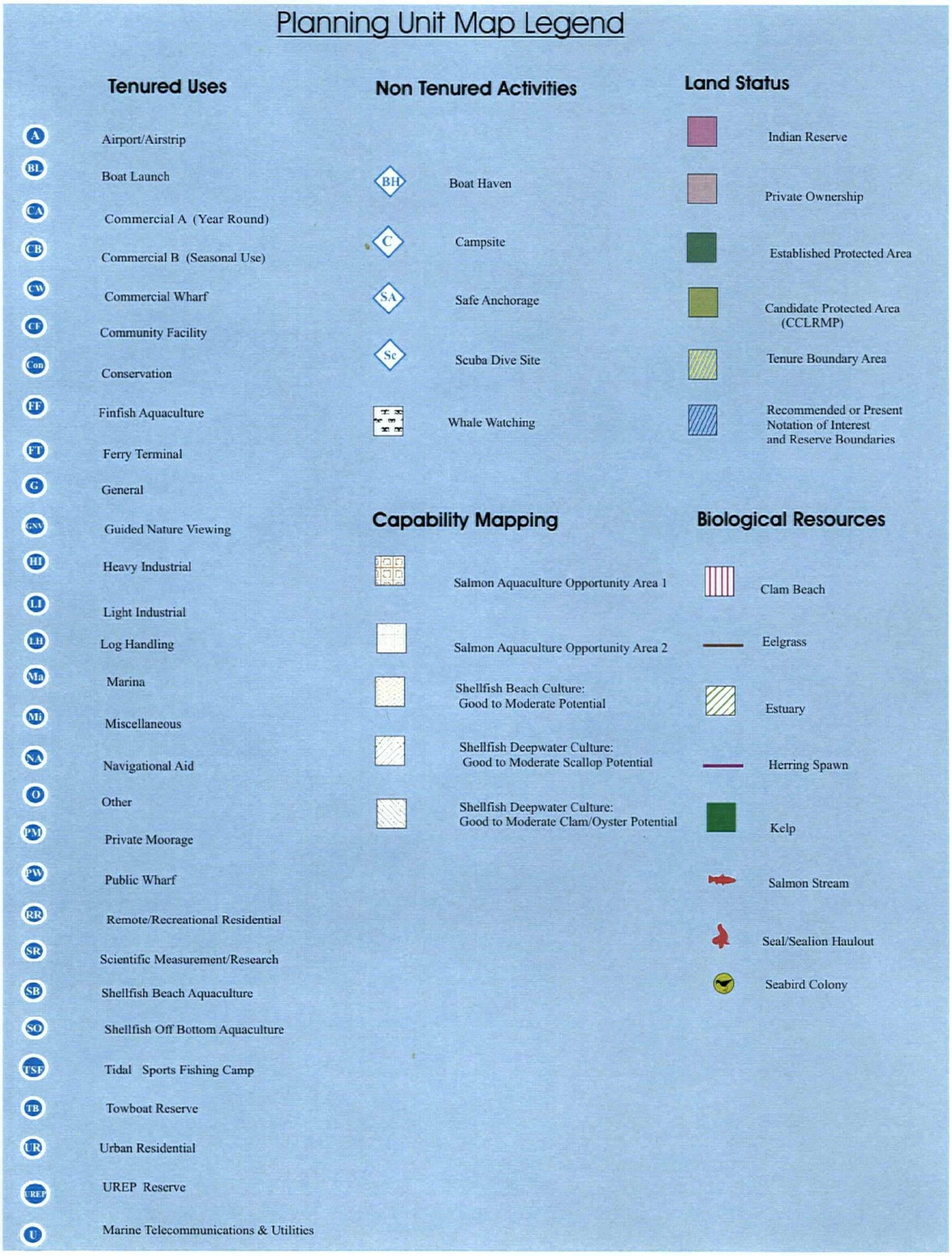
2. Aquaculture Biophysical Capability Capability is based primarily on assessments that were performed by Caine et al (1987) and Ricker (1987) using information available at that time. Modifications have been made on the basis of more recent evaluations in specific areas by industry and government staff. These assessments may not accurately reflect recent advances in net cage aquaculture technologies or specific requirements for different finfish species.

Data available for the 1987 biophysical studies were generalized to a 1:125,000 mapping scale and consequently, there may be specific areas within each "opportunity area" that are inconsistent with the general rating indicated on this map. The Opportunity Area 1 and 2 categories should therefore be used only as a general indication of capability. Some high potential localized opportunities can and do exist in areas generally classified as poor.

The categories good and poor are considered recommendations only and are not intended to limit the scope of tenure applications.

This map and associated material have not been subjected to a full assessment of resource values and interests and does not replace requirements for site specific reviews of any tenure application. It does not alleviate responsibility of an applicant to obtain necessary approvals from local government and federal agencies, including DFO.

Appendix 6. North Island Straits Coastal Plan Unit Map Legend (Source: MSRM, 2002).



Appendix 7. Processor Category Codes (Source: BC MAFF, 2004)

Processor Categories	
CSC	Commercial Salmon Cannery producing 1500+ Standard Cases
CSCS	Commercial Salmon Cannery producing <1500 Standard Cases
CSL	Cold Storage (Large - >80 cubic metres)
CSS	Cold Storage (Small - < 80 Cubic Metres)
F	Finfish Buyer (other than salmon or roe herring)
FP	Fin Fish Processing (not salmon or roe herring)
I	Invertebrates Buyer
IP	Invertebrates Processing
KF	Finfish Broker (other than salmon or roe herring)
KI	Invertebrates Broker
KR	Roe Herring Broker
KS	Salmon Broker
MPP	Marine Plant Processing
NHC	Fish Processing Not For Human Consumption
R	Roe Herring Buyer
RP	Roe Herring
S	Salmon Buyer
SFP	Sport-caught Fish Processing
SP	Salmon Processing
TP	Trout Processing
V	Vendor

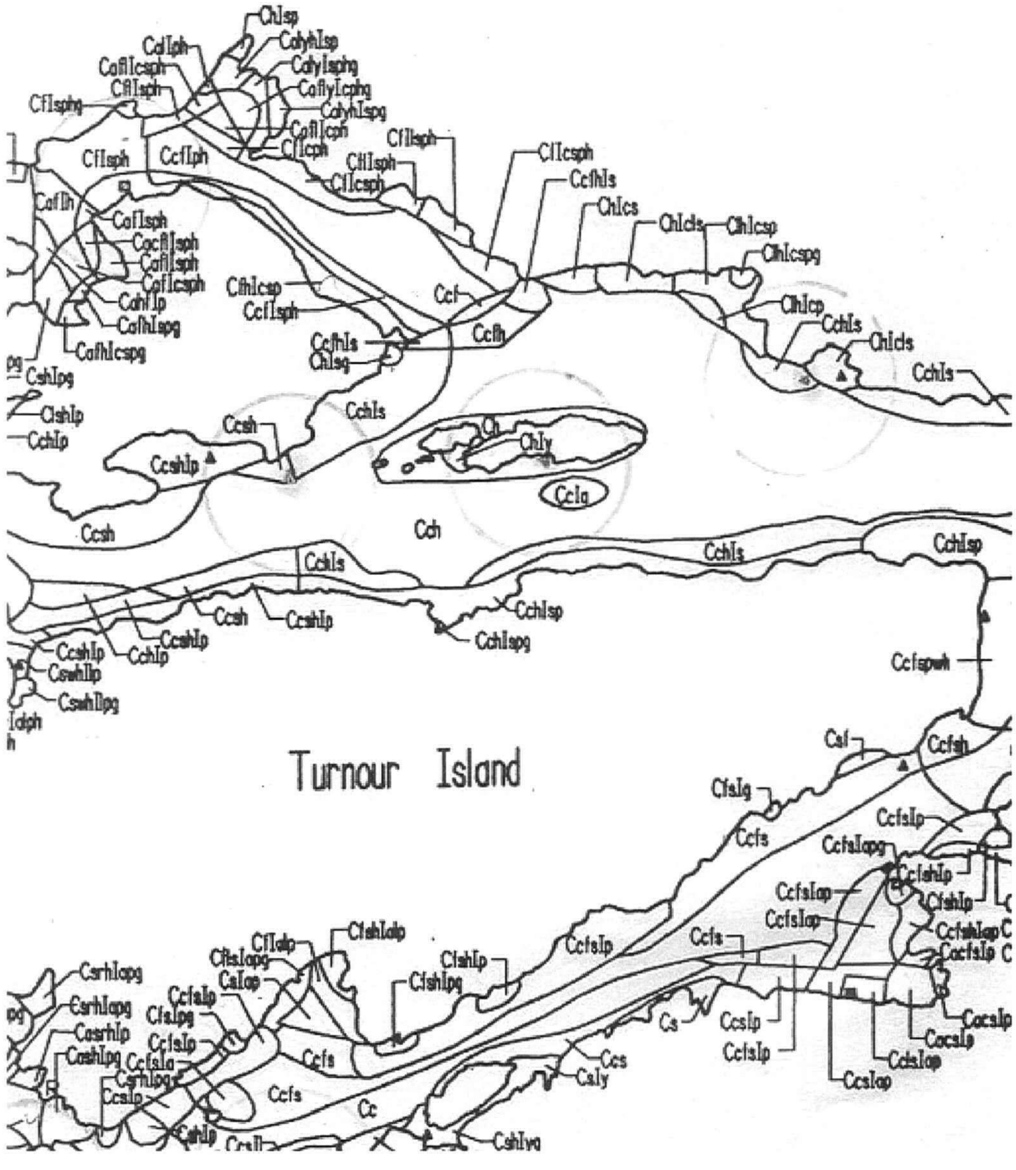
Appendix 8. Processing plants in B.C. with license to process salmon (Source: BC MAFF, 2003).

Company Name	Location	Licence Type
Agrimarine Processing Inc.	Campbel River	SP
Albion Fisheries Ltd.	Vancouver	CSL,FP,IP,SP,TP
Alpha Processing Ltd	Port Hardy	SP
Angel Seafoods Ltd.	Vancouver	FP,SP
Apsun Foods Inc.	Richmond	CSS,IP,SP
Aquatec Seafoods Ltd	Comox	IP,SP
Bella Bella Fisheries Ltd.	Waglisla	CSL,IP,RP,SP
Bella Coola Fisheries Ltd. - Delta	Delta	CSS,FP,RP,SP
Bella Coola Fisheries Ltd. - Tilbury	Delta	FP,NHC,SP
Brown's Bay Packing Co. Ltd	Campbel River	SP
Campbell River Fishing Co. Ltd	Campbel River	CSL,FP,IP,SP
Campbell River Seafoods & Locker Ltd.	Campbel River	CSS,FP,SP
Classic Smoke House	Vancouver	SP
Clear Pacific Trading Limited	Richmond	CSL,FP,RP,SP
Coast Select Smokehouse	Sointula	CSS,SP
Dave & Bernardita Holdings	Qualicum Bay	FP,SP
Dollar Food Mfg. Inc.	Vancouver	CSS,IP,SP
Eagleview Seafood Products Ltd.	Port Alberni	SP
Egmont Fish Plant Ltd.	Egmont	SP,SP,TP
Englewood Packing Co. Ltd	Telegraph Bay	SP
Finn Bay Sea Products Ltd.	Lund	IP
Fisher Bay Seafood Ltd.	Sidney	FP,SP
French Creek Seafoods	French Creek	IP,SP
Hardy Bouys Smoked Fish Inc	Port Hardy	FP,SP

Hi-To Fisheries Ltd.	Vancouver	CSL,FP,IP,MPP,RP,SP
Hi-To Fisheries Ltd.	Cowichan	CSS,FP,SP
Hooked on Seafood	Alert Bay	CSS,FP,IP,SP
Hornby Island Seafood Co.	Hornby Island	SP
Hub City Fishing Ltd.	Nanaimo	CSS,FP,IP,SP
Icicle Seafoods (BC) Inc.	Delta	CSCS,CSL,FP,RP,SP
Kawaki (Canada) Ltd.	Richmond	CSL,FP,RP,SP
Keltic Seafoods Limited	Port Hardy	FP,IP,MPP,SP
Kitasoo Seafoods Ltd	Klemtu	CSS,IP,RP,SP
Long Beach Shellfish	Tofino	SP
Luxury Smokers Ltd.	Richmond	SP
Maranatha Fishing & Packing	Gabriola Island	CSS,SP
Max Ryberg Catering/The Cod Father	Port Alberni	SP
Norden Food Ltd.	North Vancouver	CSL,SP,TP
North Delta Seafoods Ltd	Clearbrook	IP,RP,SP
North Douglas Distributors Ltd.	Saanich	CSS,IP,SP,TP
North Sea Products Ltd.	North Vancouver	CSL,FP,SP
Ocean Fisheries Ltd.	Vancouver	FP,RP,SP
Ocean Jewel Caviar Ltd.	Delta	CSL,RP,SP
Ocean Master Foods	Maple Ridge	SP
Orca Specialty Foods Ltd.	Surrey	CSL,SP
Pacific National Group Ent. Ltd.	Tofino	SP
Pacific Seafoods International	Sidney	CSL,SFP,SP
Portuguese Joe's Fish Market	Courtenay	CSL,FP,IP,SP
Redskin Fisheries	Pitt Meadows	SP
River Seafoods Ltd.	Delta	FP,SP

Robert Wholey & Co. (Canada)	Ucluelet	CSL,FP,SP
S.S.I. Sea Products	Salt Spring Island	CSS,FP,SP
Scanner Enterprises (1982) Inc.	Surrey	CSL,RP,SP
Scanner Enterprises (1982) Inc.	Surrey	CSL,FP,RP,SP
Scheves Mink & Feed Farm	Surrey	CSL,NHC,SP
Sea Fresh Fish Ltd.	Albion	SP
Seven Seas Fish Co. Ltd.	Delta	CSL,FP,SP
Shearer Fish Co. Ltd.	Delta	FP,SP
Soo Singapore Jerky Ltd.	Richmond	SP
Sung Fish Co. Ltd.	Vancouver	CSL,FP,IP,SP
VersaCold - Harbour Plant	Vancouver	CSL,FP,SP
Walcan Seafood Ltd.	Heriot Bay	CSL,FP,IP,RP,SP
Wescan Fisheries Ltd.	Vancouver	RP,SP
Wilderness Shellfish Co-op	Lund	IP
Yoshi's Salmon Smoke House Ltd.	North Vancouver	SP

Appendix 9. Sample from original CRIS composite map (Source: Morton, Personal communication).



Appendix 10. Summary of the Salmon Aquaculture Review Siting Criteria: Broughton Archipelago (Source: Living Oceans Society, 2003)