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Open-Ocean Aquaculture:
Economic Measures for Mitigating Risk and Encouraging Development

Marine Policy Center
Woods Hole Oceanographic Institution
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FINAL REPORT

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Table of Contents

List of Tables

List of Figures

I. Report Title, Author, Organization, Grant Number, Date

Title: Open-Ocean Aquaculture: Economic Measures for Mitigating Risk and Encouraging Development

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II. Abstract

Open-ocean aquaculture is an emerging industry in which potentially significant opportunities exist for the fishing community and other businesses to profit from the production and processing of seafood grown in the ocean. The economic costs of risk and uncertainty, however, represent significant barriers to economic growth in this industry. In the face of these costs, entrepreneurs are unlikely to make investments, and industrial growth will not take place. This project was focused on identifying and characterizing sources of risk and uncertainty associated with open-ocean aquaculture; estimating the levels of those risks that are measurable; describing uncertainties for which risks cannot be estimated; estimating the expected net economic benefits from aquaculture operations under risk and uncertainty and developing estimates of potential industry investment levels; and identifying institutions or policy instruments for managing risk and uncertainty. These objectives were pursued through four major study components: (1) a review and analysis of aquaculture policy and regulation; (2) development of a firm-level investment-production model and risk assessment framework with a simulation of the production of Atlantic cod (*Gadus morhua*); (3) an in-depth profile of the US industry and market for blue mussels (*Mytilus edulis*) as a prospective open-ocean aquaculture product; and (4) the identification of institutional mechanisms for mitigating risk and uncertainty. This final report provides detailed accounts of the four study components and the resulting findings and conclusions.

III. Executive Summary

Open-ocean aquaculture is a nascent industry in which potentially significant opportunities exist for the fishing community and other businesses to profit from the production and processing of seafood. A historical lack of economic development in this sector may be due to an incomplete understanding among both aquaculture entrepreneurs and potential financial backers of the economic dimensions of open-ocean aquaculture operations.

The economic costs of risk and uncertainty, in particular, represent significant barriers to economic growth in open-ocean aquaculture. In the face of these costs, entrepreneurs are unlikely to invest in the industry, and industrial growth will not take place. Further, without a sound understanding of the ways in which risks and uncertainties can be managed to mitigate their costs, natural resource management agencies will be unable to develop appropriate policies both to enhance industrial development and to protect the environment.

This project involves the development of a framework for assessing risk in open-ocean aquaculture. The framework consists of three components: a firm-level investment-production model that simulates a specific growout project and estimates the project's benefit-cost values; a model that calculates the risk premium for a risk-averse investor; and a model that quantifies the option value for a risk-neutral investor.

Using these models, we describe investment rules under different conditions and show that, under uncertainty, the traditional NPV rule of making an investment should be modified. Generally, under the modified rules, a larger project value is needed to justify an augmented total cost of investment. We conduct simulations of the models, focusing on the growing of Atlantic cod (*Gadus morhua*), a prospective open-ocean aquaculture species. The results of the simulations suggest that investment level is inversely related to both the risk level and the degree of risk aversion.

Throughout the United States, aquaculture firms face a wide variety of laws and regulations that govern the manner in which they plan, site, and operate aquaculture facilities. Although a legal framework is necessary for aquaculture to exist as an industry, there are many instances where development of the industry is impeded by uninformed, outdated, or inappropriate regulatory regimes, or, in some cases, by the *absence* of basic laws and policies to establish and protect property interests. The absence of policy or the lack of policy coordination are major sources of risk and uncertainty affecting the costs of both near-shore and open-ocean aquaculture.

Based on a review of the literature and a survey of industry participants and state aquaculture coordinators and regulators, we identify eleven policy and legal issues that likely constrain the growth of the industry. In rough order of importance, these issues are: administrative and jurisdictional overlaps; lease and tenure processes; control of disease; interstate transport of product; competition with foreign imports and international trade barriers; policies governing interactions with protected species or impacts on habitats; rules concerning the culture of commercially harvest species; federal and state effluent regulations; culturing of genetically modified organisms; culturing of non-indigenous species; and permitting in the US exclusive economic zone.

We take a close look at the market structure of the blue mussel (*Mytilus edulis*), a species that is relatively far along the path toward commercialization as an open-ocean aquaculture product. The relevant market can be defined as trade in a processed (cleaned) blue mussel in eastern

North America. Processors add value to the raw product and ensure a consistent and steady supply to downstream customers or distributors. Some branding is present for the wholesale trade, but final consumers do not appear to distinguish mussels by source. This feature of the market could change as the market grows and consumers become more sophisticated. Changes in the quantity of processed mussels supplied and purchased in the market are associated with general market conditions, such as restaurant sales and disposable income, and also fluctuations in the price of substitute shellfish.

Mussel production has been increasing worldwide. The market for mussels in eastern North America, supplied primarily by producers on Prince Edward Island and in Maine, has been among the leaders in this growth. Production is burgeoning in all of the other Canadian maritime provinces, and R&D projects are well advanced in the New England states. The industry experience in Newfoundland indicates the importance of husbandry and the potential for geographic clustering economies that may exist when farms are linked to a regional processor or distributor.

Prospective aquaculture entrepreneurs must assess the financial and administrative benefits and costs of alternative organizational forms, including individually owned businesses, partnerships, general business corporations, limited liability companies, or cooperatives. For a small-scale grower, the choice may be effectively limited to either going it alone as an individually owned business or joining with others in a cooperative. Where the industry is building up from small-scale or part-time growers who require technological expertise, processing facilities, and a market for their product, cooperatives may contribute to the reduction of risks for these firms.

Other forms of cooperation that may help to mitigate risk and uncertainty include market orders, which do not yet exist for the aquaculture industry, and trade associations. Trade associations in aquaculture serve important roles by acting as a "voice" for the industry in legislative deliberations and by commenting on proposed rules; in the adoption of best management practices or codes of conduct; in the development of product quality standards; in the establishment and protection of intellectual property, including brand names or trademarks; and in advertising and market promotions. A trade association is now emerging for the shellfish industry on the US east coast.

Our work has been sponsored primarily through a grant from the US Department of Commerce. Complementary support has been provided by the US Department of Agriculture, the University of New Hampshire, and the Johnson Endowment of the WHOI Marine Policy Center.

IV. Purpose

A. Problem or Impediment of Fishing Industry That Was Addressed

Open-ocean aquaculture has been described as an area in which potentially significant opportunities exist for the fishing community to profit from the production and processing of seafood protein. The historical lack of economic development in this sector is due, in part, to an incomplete understanding among both aquaculture entrepreneurs and potential financial backers of the economics of open-ocean aquaculture operations.

The economic costs of risk and uncertainty, in particular, represent significant barriers to economic growth in this sector. In the face of these costs, entrepreneurs from the fishing communities are unlikely to invest in the industry, and industrial growth will not take place.

Further, without a sound understanding of the ways in which risks and uncertainties can be managed to mitigate their costs, natural resource management agencies will be unable to develop appropriate policies to enhance industrial development.

By enhancing understanding of the sources of risk and uncertainty and how they can best be managed, this project may help to pave the way for industrial development and economic growth in open-ocean aquaculture.

B. Objectives of the Project

The main goal of the project has been to identify and characterize institutions and public policies appropriate for reducing the costs of risk and uncertainty that have precluded the emergence and development of an open-ocean aquaculture industry. In order to achieve this goal, six specific objectives were pursued:

- identify and characterize sources of risk and uncertainty associated with open-ocean aquaculture;
- estimate the levels of those risks that are measurable;
- describe uncertainties for which risks cannot be estimated;
- estimate the expected net economic benefits from aquaculture operations under risk and uncertainty to firms and market sectors and develop estimates of potential industry investment levels;
- identify institutions or policy instruments for managing risk and uncertainty; and
- present findings to industry, natural resource management agencies, and the public.

The project extends the results of recently completed and ongoing research projects conducted by the Principal Investigators and sponsored by NOAA and other institutions. As a consequence, many of the analyses rely at least in part on data for New England or the broader northeast region,[1] where much of this research has been focused.

V. Approach

A. Work Performed

The project involved research, analysis, and modeling efforts that were organized according to the six tasks described below.

1. Analysis of the sources of risk and uncertainty

This task began with a literature review that covered risk and uncertainty arising in the areas of regulation, economic returns, international competition, environmental effects, and user conflicts. Regulation emerged as a key topic for in-depth analysis, in part because it has a

[1] Following the structure of the US Department of Agriculture's Cooperative State, Research, Education, and Extension Service, the Northeast region is defined to include Connecticut, Delaware, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and the District of Columbia.

significant bearing on most other sources of risk and uncertainty. Aquaculture is one of the most heavily regulated industries in the United States, and the relevant laws, regulations, and administrative programs entail a complex mix of constraints on investment and development as well some clear benefits for the industry. Section VI.A.2 provides an in-depth review and analysis of federal and northeastern states' aquaculture policy and regulation, including discussion of policies with a bearing on environmental effects, user conflicts, international competition, and various categories of operating costs, among other topics.

In addition to their treatment in the regulatory analysis, the other sources of risk and uncertainty were incorporated in a risk assessment framework developed as part of the project (Section VI.A.3 and Task 2 below).

2. <u>Development of models of industry investment under risk</u>

This task involved the development of an extension to operational models previously constructed by the Principal Investigators that characterize the economic operation of marine aquaculture ventures for growing different species (Kite-Powell *et al.* 2003a, b; Kite-Powell and Hoagland 2001; Kite-Powell *et al.* 2001; Hoagland and Kite-Powell 2000; Hoagland *et al.* 1999). These models estimate the cash flow of hypothetical ocean mariculture farms based on inputs such as the scale of the operation, its location, growout technologies, other input costs, and product markets (*cf.* Zucker and Anderson 1999; Forsberg 1999; Bjørndal 1990). The operational models optimize stocking and harvesting schedules and project financial flows, and they allow for comparison of alternate growout sites based on physical characteristics (distance from shore, water temperature, water depth. etc.). They take into account seasonal variability in the price of landings as well as the effect of water temperature on growth rates. The models also can be used to estimate negative or positive external effects, such as pollution or the removal of nutrients from the water.

For this project, the research team developed a framework for assessing risk in open-ocean aquaculture by extending their existing operational models to analyze firm-level operational revenues and costs, associated risk levels (i.e., the variance in revenues and costs), and investor risk preferences. The framework consists of three components: a firm-level investment-production model that simulates a specific growout project and estimates the project's benefit-cost values; a second model that calculates the risk premium for a risk-averse investor; and a third model that quantifies the option value for a risk-neutral investor. The models are described in Section VI.A.3, with an illustration using a case study of open-ocean culturing of Atlantic cod (*Gadus morhua*) in New England.

3. <u>Analysis of industrial organization and market structure</u>

As discussed in the regulatory analysis (Section VI.A.2), the US aquaculture industry as a whole is in reality a set of markets that may or may not be closely linked or even share technological approaches. Firms may or may not be vertically integrated from production through retail. Separate markets exist for individual species of fish or shellfish. Some markets may be closely related, as for different species that are close economic substitutes (such as blue mussels and hard clams), while other markets may be very distinct from one another (such as those for bait fish and farm-raised trout). Production technologies may be similar across markets while differing within the same market.

Given this complexity and diversity, our approach to analyzing industrial organization and market structure was to focus on one or more species-specific markets that have not been addressed by previous research.[2] Section VI.A.4 presents an in-depth review of the northeastern US market for blue mussels, including a summary of the world market, an historical review of US market development, and descriptions of production processes and technology evolution, the current US market structure, and consumer characteristics and market demand.[3]

In a complementary effort, the research team has also developed a preliminary projection of the future size of an open-ocean aquaculture industry in New England producing farmed Atlantic cod. In forecasting the future expansion of aquaculture in coastal-ocean environments, most studies focus only on the constraint posed by the local environmental assimilative capacity. We are developing an alternative market-oriented approach for projecting the growth of the industry. We evaluate equilibria in the market for seafood, where the product may be supplied either by a wild-harvest fishery or open-ocean aquaculture or both.

In our framework, the net demand for farmed fish determines the size of the aquaculture industry and, in turn, the levels of pollution discharges. Analogous to studies of assimilative capacity, the socially optimal industry size may be constrained by environmental damages resulting from pollution. In open-ocean environments where the assimilative capacity is unlikely to be a serious constraint, however, the market-oriented approach is a much better method for projecting industry growth.

4. Evaluation of the effects of management policy changes on private investment

This task called for an examination of the behavior of the risk investment model (Task 2) using sensitivity analyses to characterize the effects of regulatory changes and alternative levels of public financial support on investment in the industry. Publicly subsidized crop insurance was the policy instrument selected for examination as a potential tool to mitigate risk in aquaculture markets.

Work proceeded on developing a numerical example using parameter estimates obtained from a model of a netpen operation for the culturing of summer flounder. Effort on this task was redirected to the model simulation and industry analysis tasks when we became aware of two circumstances that caused us to question the fruitfulness of proceeding with an examination of the effects of crop insurance at this time. First, the situation in all of the relevant markets is currently one of very constrained availability of insurance coverage, owing to very poor underwriting results across the aquaculture industry as a result of severe losses in almost all areas of the industry that are insured (Secretan, n.d.). Second, our planned study would likely duplicate the considerable research efforts on this subject that are proceeding under the sponsorship of the

[2] Species-specific market and organizational analyses have been undertaken by other researchers for farmed salmon (Forster 2003), baitfish (Engle and Stone, n.d.), catfish (Tucker *et al.* 2004), and trout (Hinshaw *et al.* 2004).

[3] The blue mussel has been the species of focus for at least two test-bed open-ocean R&D projects, located at the Woods Hole Oceanographic Institution (WHOI) and at the University of New Hampshire (UNH). The UNH effort is now proceeding toward commercialization. Because of UNH's interest in the blue mussel, we focused our description of market structure on this species, and we received complementary sponsorship from their program for this analysis.

National Risk Management Feasibility Program for Aquaculture (NRMFPA), a joint program of the US Department of Agriculture's Risk Management Agency and Mississippi State University.[4]

5. Identification and characterization of appropriate policy instruments

This task uses the results of the previously discussed tasks to identify courses of action that may prove useful for managing regulatory uncertainties. Potentially useful policy instruments are identified and discussed mainly in the results of the regulatory analysis (Section VI.A.2), which highlights specific opportunities for improvement in three general areas: laws and policies whose *absence* is constraining industry growth and development; existing regulatory regimes that produce similar results by virtue of being uninformed, outdated, or otherwise inappropriate; and instruments whose application should be further developed and expanded, such as the use of best management practices (BMPs) developed on the basis of industry consensus with guidance from government agencies.

In addition to public policy instruments, we have also considered measures that can be taken independently by industry to mitigate the costs of risk and uncertainty. In Section VI.A.6, we discuss the potential advantages of three such institutional mechanisms—cooperatives, marketing orders, and trade associations—as they apply to operators in the blue mussel market.

6. Final report and public outreach

In addition to producing this final report, the research team has presented the results at appropriate conferences and other fora and has submitted several papers based on the project results for publication in peer-reviewed and topical journals. Section VII.B of this report provides a complete listing of these presentations and forthcoming publications, as well as information about how to access these and other materials that will be made available on a project website to be hosted by the Marine Policy Center of the Woods Hole Oceanographic Institution.

B. Project Management

The project was managed jointly by the Co-Principal Investigators, Drs. Porter Hoagland, Di Jin, and Hauke Kite-Powell. The Co-Principal Investigators also collaborated on the research and analysis, with each taking the lead in different areas according to their respective interests and expertise. Dr. Hoagland had primary responsibility for analyzing the regulatory constraints and benefits to aquaculture[5] and identifying appropriate policy instruments to mitigate the costs of risk and uncertainty. He also shared the lead in analyzing the potential value of industry cooperatives with Dr. Kite-Powell, who led the review of industry organization and market structure for the blue mussel market. Dr. Jin had primary responsibility for developing the three

[4] To date, these efforts have produced a detailed survey of the availability of aquaculture crop insurance at the US market and farm levels (Secretan, n.d.); annual workshops (see, e.g., NRMFPA 2002, 2003); and NRMFPA White Papers on issues, policy designs, and research (e.g., NRMFPA, n.d.). These reports, as well as a series of species-specific industry analyses (Forster 2003; Engle and Stone, n.d., Tucker *et al.* 2004; Hinshaw *et al.* 2004), can be accessed at the NRMFPA website at http://www.agecon.msstate.edu/Aquaculture/pubs.php.

[5] We collaborated in the regulatory analysis with Mr. John Duff, Professor at the University of Massachusetts Boston, and Ms. Tessa Getchis of the Connecticut Sea Grant Extension Program. Their effort was supported in part by funding from the Northeastern Regional Aquaculture Center (NRAC) through a grant from the U.S. Department of Agriculture's Cooperative State, Research, Education, and Extension Service (USDA-CSREES).

models that comprise the risk assessment framework and for producing the simulation using Atlantic cod.

VI. Findings

A. Actual Accomplishments and Findings

1. Summary of Project Highlights

Key accomplishments and findings are reported in this section in the form of four major research products resulting from the modeling exercises and analyses conducted for this project. These major research products are: (1) a review of aquaculture policy and regulation at the federal and state levels and an analysis of their effects on industry growth and development; (2) a firm-level investment-production model for assessing risk to an open-ocean aquaculture operation; (3) an in-depth profile of the US industry and market for blue mussels; and (4) an analysis and recommendations concerning institutional mechanisms for mitigating risk in the ocean culturing of blue mussels. The key findings that have emerged from these efforts can be briefly summarized as follows:

- ***Review and analysis of aquaculture policy and regulation:*** Throughout the United States, aquaculture firms face a wide variety of laws and regulations that govern the manner in which they plan, site, and operate aquaculture facilities. Although a legal framework is necessary for aquaculture to exist as an industry, there are many instances where development of the industry is impeded by uninformed, outdated, or inappropriate regulatory regimes, or, in some cases, by the *absence* of basic laws and policies to establish and protect property interests. Based on a review of the literature and a survey of industry participants and state aquaculture coordinators and regulators, we identify eleven policy and legal issues that likely constraint the growth of the industry. These issues represent significant legal and policy risks that increase the costs to aquaculture entrepreneurs. To a large extent, the costs of these policy risks remain undetermined. In rough order of importance, these issues are: administrative and jurisdictional overlaps; lease and tenure processes; control of disease; interstate transport of product; competition with foreign imports and international trade barriers; policies governing interactions with protected species or impacts on habitats; rules concerning the culture of commercially harvested species; federal and state effluent regulations; culturing of genetically modified organisms; culturing of non-indigenous species; and permitting in the US exclusive economic zone.

- ***Firm-level investment-production model and risk assessment framework:*** The risk assessment framework consists of three components: a firm-level investment-production model that simulates a specific growout project and estimates the project's investment and expected net present value (NPV); a second model that uses expected value-variance analysis to calculate the risk premium for a risk-averse investor; and a third model that quantifies the option value for a risk-neutral investor. Through the three models, we describe investment rules under different conditions. We show that under uncertainty the traditional NPV rule of making an investment should be modified. Generally, under the modified rules, a larger project value is needed to justify an augmented total cost of investment. The results of a simulation using Atlantic cod in New England suggest that investment level is inversely related to the risk level and the risk aversion parameter. The scale of operations under uncertainty is smaller than the scale under certainty, and investment time is affected by the dynamics of project value. Both growth in project payoff and uncertainty in the payoff can create a value to waiting (i.e., option value).

- ***Profile of the US industry and market for blue mussels***: Mussel production has been increasing worldwide, and the market for mussels in eastern North America has been among the leaders in this growth. Producers on Prince Edward Island and in Maine are the main suppliers, but production is growing significantly in all the other Canadian maritime provinces, and R&D projects are well advanced in the New England states. The market can be defined as trade in a processed (cleaned) blue mussel. Some branding is present for the wholesale trade, but final consumers do not appear to distinguish mussels by source. This situation may change as the market continues to grow and as consumers become more sophisticated. Changes in the quantity of processed mussels supplied and purchased are associated with general market conditions, such as restaurant sales and disposable income, as well as with fluctuations in the price of substitute shellfish. The industry experience in Newfoundland indicates the importance of husbandry and the potential for geographic clustering economies that may exist when farms are linked to a regional processor or distributor.

- ***Institutional mechanisms for mitigating risk in the blue mussel market***: Growers must assess the financial and administrative benefits and costs of alternative organizational forms, including individually owned businesses, partnerships, general business corporations, limited liability companies, and cooperatives. Where the industry is building up from small-scale or part-time growers who require technological expertise, processing facilities, and a market for their product, cooperatives may contribute to the reduction of risks for individual firms. Unlike the case with other agricultural products, however, few cooperatives exist in aquaculture. Other forms of cooperation include market orders, which do not yet exist for the aquaculture industry, and trade associations. Trade associations serve the important roles of acting as a voice for the industry in legislative deliberations and by commenting on proposed rules; in the adoption of best management practices or codes of conduct; in the development of product quality standards and the establishment and protection of intellectual property; and in advertising and market promotions.

2. Review and Analysis of Aquaculture Policy and Regulation

a. Introduction

Throughout the United States, aquaculture operators face a wide variety of laws and regulations that govern the manner in which they plan, site, and operate aquaculture facilities. Many local, state, and federal laws and regulations have been designed to enable aquaculture to exist as a viable industry and to flourish. It is obvious that aquaculture cannot be conducted in the absence of a legal system that establishes property rights, provides a means for the enforcement of these rights, and ensures the safety of the product for consumers.

Although a legal framework is necessary for aquaculture to exist as an industry, there are many instances where uninformed, outdated, or inappropriate regulatory regimes impede aquaculture development (DoC 1999; MCZM 1995; Ewart *et al.* 1995; Rychlak and Peel 1993; Bye 1990; DeVoe and Mount 1989; Kennedy and Breisch 1983; NRC 1978). Inconsistencies in the law can lead to an uncertain legal environment for aquaculturists.[6] Regulators are put in the conflicting position of promoting the development of the industry and regulating its effect on other uses of the land and sea (DeVoe 1999; NRC 1992). Operators are sometimes forced to undertake activities while lacking adequate information or a complete understanding of laws and regulations. Conflicts and concerns often may be left unresolved until an issue is brought before an adjudicatory body. Legal constraints such as these detract from the stability and certainty that otherwise would facilitate sustainable aquaculture development, slowing or halting the growth of the industry, or perhaps even leading to its decline.

Policies that both facilitate and constrain aquaculture have been reviewed by a number of commentators (McCoy 2000; Brennan 1999; Barr 1997; Rieser and Bunsick 1999; Rieser 1997; Hopkins *et al.* 1997; Rychlak and Peel 1993; Eichenberg and Vestal 1992; Wildsmith 1982; Kane 1970). In 1981, the US Fish and Wildlife Service sponsored a comprehensive review of aquaculture regulation across the nation (the "Aspen Report"). The report's authors identified at least 120 federal laws that, at that time, either directly (50 laws) or indirectly (70 laws) affected aquaculture. Further, the authors found more than 1,200 statutes regulating aquaculture in 32 states (ASC 1981). An important finding of the Aspen Report was that aquaculture businesses must obtain at least 30 permits, on average, in order to site and operate their businesses. McCoy (2000) concludes from his review of the Aspen Report and other studies that aquaculture may be the most highly regulated industry in America.[7] In its responses to periodic surveys of constraining factors, the industry seems to agree with McCoy by consistently ranking legal and regulatory constraints near the top of the list of factors.

Wypyszinszki *et al.* (1994) began to assemble the body of law relating to marine aquaculture in the US Northeast, but their work remains unfinished due to insufficient resources. A number of excellent analyses emerged from that effort, including a study of the public trust doctrine by Eichenberg and Vestal (1992) and a study of "reverse regulation" of the oyster industry in Long Island Sound.[8]

Here we examine a range of aquaculture policies in an effort to identify those laws and regulations that may impede development unnecessarily within the United States. Through a survey of industry and government officials and a review of the literature, we find that specific laws and policies or the *absence* of laws and policies can be argued to impose constraints on growth in certain segments of the industry.

b. Methods and Some Comments on Industry Context

This analysis incorporates information obtained from three main sources. First, we distributed two survey instruments to gather information from both the industry and from state aquaculture

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[6] For example, Ewart *et al.* (1995) observe that inconsistencies among state effluent discharge policies often are cited as a legal constraint to the development of aquaculture.

[7] Such conclusions are common in published commentary about the aquaculture industry in the United States. We are unaware of any analytical study, however, comparing regulation across industries to assess the extent to which one industry may be more regulated than another.

[8] The term "reverse regulation" refers to the situation where one industry or activity must curtail or terminate its operations because of the external effects of another industry or activity. In the case of shellfish culturing, public safety regulations limit production when pathogen levels, which result from non-aquaculture activities, exceed a specified health standard.

coordinators (or from the relevant state regulators). Second, we reviewed the published peer-reviewed and topical literatures to identify research on legal constraints to aquaculture development and to find discussions or news reports about more recent issues.[9] Third, we conducted a limited number of telephone interviews with experts from both industry and government.[10]

Our main objective has been to identify the universe of laws and regulations pertaining to aquaculture, including policies that both promote and constrain the industry. We have also developed a database of state statutes and case law. Here we discuss briefly some of the promotional efforts that have been undertaken at the state level in recent years before focusing our attention in greater detail on the legal constraints.

We consider the identification and brief description of specific legal constraints to be the most important part of the analysis. In Table 1, we present an organizing framework that extends the work of Wypyszinski *et al.* (1994). General categories of legal issues are listed in the leftmost column. Broad geographical/technological categories are listed as headings for each row. The numbers in the table correspond to the ranking (from 1 to 11) of legal constraints that we discuss in greater detail below.

We note that our survey cannot be considered to be an unbiased sampling of industry opinion. The responses to surveys are presented in Table 2. We are unable to report a response rate, because many of the surveys were distributed by state aquaculture extension agents to their own confidential list of industry participants. To a large extent, the survey responses are "validated" with our review of the literature, some limited telephone interviews, and our own personal knowledge of the issues. As a consequence of the limited, self-selected nature of the survey responses, the ranking of legal constraints that is derived from the survey responses and that we present below should be regarded as somewhat subjective. Nevertheless, we consider the identification and ranking of the issues to be an important first step for organizing industry efforts to reduce or remove the constraints.

We use the industry survey results to help establish a ranking of legal constraints to aquaculture development. We assume that the purpose of such a ranking is to establish priorities for efforts to modify the relevant policies so that these constraints can be mitigated or removed. The development of strategies to modify constraining policies is the logical next step, and we note that the most effective approach may depend upon the ease with which specific policies can be changed. Thus, a policy that is highly ranked as a legal constraint (*e.g.*, the public trust doctrine in certain states) might be extremely difficult to change. As a consequence, such a policy might be ranked lower than one that is more easily modified.

A caveat relates to the organization of the aquaculture "industry," which in reality is a set of markets that may or may not be closely linked or even share technological approaches. Typically, we conceptualize the structure of a market as a "vertical" flow of product from hatchery to growout to the downstream activities of processing, distribution, and final retail sale to the consumer. Firms may or may not be vertically integrated from production through retail.

[9]The published literature is included in the reference list (section VIII) of this final report. The topical literature we reviewed included *Fish Farming News*, *Aquaculture Magazine*, and *World Aquaculture*. We reviewed issues of these journals dating back to 2000.

[10]We treat all survey responses and personal communications with the industry as proprietary and confidential.

Table 1. Classification of Legal and Regulatory Issues

	Onshore Pond/Raceway	Onshore Recirculating	Coastal Shellfish	Coastal Netpens	Open-Ocean
SITING					
Lease, Tenure, and Permitting Process	2	2	2	2	2, 11
Public trust			2	2	
Riparian rights			2	2	
Wetland alteration					
Coastal zone management					
Navigation					
Environmental impact assessment					
WATER USE					
Supply					
Effluents	8	8		8	
STOCKING					
Spat collection					
Breeding (incl. GMOs)	9	9	9	9	9
Imports					
Transport					
CULTIVATION					
Feeding					
Disease Control	3	3	3	3	3
Predator control					
Non-native species	10		10	10	10
Protected species interactions				6	6
HARVESTING					
Closed seasons					
Depuration					
PRODUCT MARKETING					
Dealer license					
Labeling (origin, organic)					
Inspection of plant/product					
Barriers to trade	4, 5, 7	4, 5, 7	4, 5, 7	4, 5, 7	4, 5, 7
GOVERNMENT ASSISTANCE	1	1	1	1	1

Table 2: Rankings of Growth-Constraining Policy Issues from Survey Responses*

Policy Issue	Industry	Govt	CT	DE	MA	MD	ME	NJ	NY	RI	WV
Administrative and jurisdictional overlap (regulatory agencies)	1	1	all		all	all	finfish	all		shellfish	
Lease and tenure process	2		all	all	all	all	all	all			
Control of disease	3		all				finfish	shellfish	all	shellfish	finfish (fw)
Interstate transport of product	4		all		all			shellfish	shellfish	shellfish	finfish (fw)
Competition with foreign imports and international trade barriers	5		shellfish	shellfish	shellfish		all	shellfish	shellfish	shellfish	
Policies governing interactions with protected species or impacts on habitats	6	2	shellfish		shellfish	shellfish	marine finfish	shellfish		shellfish	
Rules concerning the culture of commercially harvested species	7	3	shellfish		all			shellfish	all		
Federal and state effluent regulations	8		finfish, shellfish		all		finfish		all		finfish (fw)
Use of genetically engineered species	9					all	marine finfish	all			finfish (fw)
Introduction of exotic (non-indigenous species for purpose of aquaculture)	10					shellfish	marine finfish		all		finfish (fw)
Permitting in the US Exclusive Economic Zone	11				shellfish						

*Respondents (aquaculture industry members and government regulators) were asked to identify key law and policy issues within their states that constrain growth in the aquaculture industry. Entries in the table indicate which general segment of the industry (e.g., shellfish or finfish farmers) identified the relevant policy issue as a constraint. No responses were received from Pennsylvania, Vermont, New Hampshire, or the District of Columbia. Policy issues are discussed in greater depth in the text.

A number of separate markets exist for individual species of fish or shellfish. Some of these markets may be closely related; for example, blue mussels and hard clams are economic substitutes. Others may be very distinct, as baitfish are not close substitutes for farm-raised trout. Another cross-cutting issue concerns production technologies, which might be similar across markets but could differ within the same market.

All of these factors could influence the extent to which a particular law or policy is perceived as a constraint. As a hypothetical example, a firm that processes cultured shellfish might like to see more farm production, which would reduce the price that it pays for raw product. Thus, this firm, situated downstream in the processing sector of the industry, might argue that riparian rights limiting the number of tideland leases are a clear constraint to industry development.[11] On the other hand, firms with existing leaseholds might prefer that it be difficult for competitors to obtain access to additional areas because more production could reduce their own revenues. The extent to which these considerations are valid depends upon competition in the market, *i.e.*, are producers price-takers who are selling their product at marginal cost? These are the kinds of issues that should be kept in mind when thinking about the extent to which laws and regulations are truly constraints in a broadly defined US aquaculture industry.

c. Policies that Facilitate Aquaculture Growth and Expansion

It is obvious that aquaculture cannot take place in a policy vacuum. For example, some analysts have pointed to the *absence* of a federal policy for open-ocean aquaculture in the US exclusive economic zone (EEZ) as a significant constraint on the development of an offshore industry (Brennan 1999; DoC 1999). Clearly, legal rules that establish and enforce private property rights are critical to the development of the industry both onshore and offshore (Hoagland *et al.* 2003). Other policies, including those that encourage R&D, curb degradation of water quality, and promote public health also must be seen as contributing to the development of the industry.

While some laws and regulations may be deemed as constraining factors, others work to foster a natural environment in which aquaculture operations can grow. Salient examples at the state level include interagency coordination, technical assistance, sponsorship of R&D efforts, marketing assistance, and other forms of industry promotion (Jarvinen and Magnusson 2000). For example, Jarvinen (2000) finds that public sector financing has promoted the development of aquaculture technology and leads to the sharing and diversification of aquaculture investment risks.

i. Lead Agencies and Formal Guidance

In light of the fact that aquaculture operations, because of their nature, fall under the legal and regulatory jurisdiction of multiple agencies (agriculture, environmental protection, public land management, coastal or marine resources, etc.), states ordinarily designate one state agency as the "lead" agency. Such designation directs existing and prospective operators to a "liaison" or starting point agency that will then direct the operators toward or through the relevant regulatory regime governing the particular type of aquaculture operation. Most states also have created inter-agency coordinating committees or task forces to facilitate multi-agency jurisdictional issues.

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[11] This example is drawn from personal communications with market participants in the northeastern oyster-growing industry.

In Connecticut, lawmakers have established an Interagency Aquaculture Coordinating Committee comprised of the departments of agriculture, environmental protection, consumer protection, and economic development to provide for the development and enhancement of aquaculture in that state.[12] The Commissioner of Agriculture serves as chairperson of the coordinating committee. Similarly, Delaware established an Aquaculture Council to examine the legal and regulatory structure governing aquaculture activities and to make recommendations to "simplify regulatory processes or otherwise enhance the regulatory climate with respect to the efficient siting and operation of aquaculture" activities.[13] The legal framework governing aquaculture operations in Maryland includes the authorization of a lead 'aquaculture' agency (the state department of agriculture), the designation of the University of Maryland as the state's lead agency for research in aquaculture production, and the establishment of an aquaculture advisory committee charged with the responsibility of "formulat[ing] and mak[ing] proposals for advancing Maryland aquaculture."[14]

In an effort to assist prospective aquaculture operators, Massachusetts state authorities constructed a guidance document designed to answer the question: "What permits will my aquaculture operation require?"[15] Massachusetts has also created a three-center network to assist the aquaculture industry. This network carries out programs to assist industry members with cultivation, business, and marketing skills.

Pennsylvania's Aquaculture Advisory Committee[16] was established to encourage, *inter alia*, long-term investment by reducing the number of agencies involved (by transferring most authority to the Department of Agriculture) and including aquaculture in promotional and economic developmental programs that are available to other industry sectors.[17] As the lead agency, Pennsylvania's agriculture department was also directed to "develop a plan to promote and develop aquacultural industry."[18] In an effort to monitor the health of the industry, Pennsylvania also calls for a biennial survey of the industry itself.[19]

In 1988, lawmakers in Maine established an Aquaculture Innovation Center (MAIC) designed to promote the development of a variety of aquaculture operations in the state.[20] The aquaculture "industry" in Maine comprises salmon, trout, mussels, softshell clams, and oyster operations. The center has also identified other species as potentially viable (halibut, clams, groundfish, urchins, and scallops). The center supports aquaculture by bringing experts in business and science together with the state's Commissioner of Economic and Community Development, the Maine International Trade Center, and the Maine Technology Institute. MAIC also funds

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[12] CT Gen. Stat. Ch. 422 § 22-11e.

[13] 3 De. C. § 405.

[14] MD AGRIC § 10-1301 to 10-1302.

[15] Massachusetts Aquaculture Permit Guidance Document (Massachusetts Department of Food and Agriculture--Aquaculture Coordinators Office - Massachusetts Aquaculture Advisory Group 1998).

[16] PA ST 3 Pa.C.S.A. § 4216.

[17] PA ST 3 Pa.C.S.A. § 4202.

[18] PA ST 3 Pa.C.S.A. § 4215.

[19] PA ST 3 Pa.C.S.A. § 4217.

[20] 5 M.R.S.A. § 13141.

technological development projects.[21] Delaware calls on the state's Department of Agriculture to "develop and implement a technical assistance and marketing program to assist owners and operators of aquacultural facilities and to promote Delaware aquaculture products."[22] The Maryland Industrial Partnership (MIPS) program was developed to fund innovation in aquaculture, among other industries. MIPS teams scientists with businessmen to solve targeted industry problems. These state-funded partnerships have greatly assisted Maryland's aquaculture industry.

Like many other states, New Jersey established an advisory body in the form of an Aquaculture Advisory Council within the state department of agriculture.[23] The state also created a distinct Aquaculture Task Force to "define the roles of the various concerned state agencies in carrying out a permanent program to promote the development of an aquaculture program."[24] Similar efforts to designate coordinating agencies and establish aquaculture development efforts exist in other NRAC states.

ii. Water Quality

Most states have revised their water quality protection laws expressly to take into account the environmental effects that state-run or state-permitted projects may have on areas that support aquaculture operations (Ewart *et al.* 1995). As a consequence, proponents of a wide range of development projects must demonstrate that such projects will not significantly impact water quality for aquaculture operations.

iii. Information and Technology Transfer

In Rhode Island, the recent development of a state aquaculture extension program has provided opportunities for technology transfer and problem solving for the industry. All northeastern states employ the time and resources of agricultural or marine resource extension services personnel to address questions and concerns on aquaculture issues. In Connecticut, the Bureau of Aquaculture, located in the Department of Agriculture, promotes the aquaculture industry. Industry members have benefited from strong shellfish pathology and water quality monitoring programs.

Of benefit to aquaculture operators throughout the northeastern region, the Northeastern Regional Aquaculture Center (NRAC) of the US Department of Agriculture has a strong aquaculture extension network in the northeastern United States. Extension personnel develop educational programs on priority topics identified by industry and facilitate technology transfer between NRAC-funded researchers and the aquaculture industry.

iv. Tax Treatment, Property Protection, and Land Use Policies

A number of states grant favorable tax treatment to aquaculture operations in the form of exemptions from sales or use taxes.[25] Some states have instituted specific civil or criminal

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[21] See http://www.maineaquaculture.org/

[22] 3 De. C. § 404.

[23] NJ ST 4:27-5(a).

[24] NJ ST NJ ST 23:2B-10.

[25] See e.g., RI ST § 20-10-3.1 Sales and use tax exemption. Any person engaging in aquaculture shall be eligible for the tax exemption in § 44-18-30(33) provided that the requirements set forth in that section are met. Id.; NJ ST

penalties for trespass on aquaculture areas or damage to aquaculture operations.[26] States also may promote aquaculture production specifically via zoning designation regulations or waterfront revitalization programs.[27]

d. Policies that Constrain Aquaculture Growth and Expansion

Recent research findings in the legal and social sciences literature indicate that the regulatory and policy constraints on freshwater and marine aquaculture development relate directly to the socio-economic concerns of coastal and traditional fishing community members, as well as the physical, chemical, and biological capacities of prospective development sites. Some of the recurring barriers identified by legal and policy analysts (Rieser 1997; NRC 1978) over the course of the last twenty-five years include:

- the limited availability of property rights or other interests that can secure a producer's investment;
- poorly defined or enforced standards (*e.g.*, water quality) that fail to reduce conflicts among competing resource users;
- poorly defined agency jurisdictions and responsibilities, leading to delays in defining applicable standards or regulations or in taking actions, such as permit issuance;
- the existence of redundant regulations due to overlapping agency responsibilities; and
- inappropriate application of restrictions designed to protect wild stocks (*e.g.*, size limits).[28]

Aquaculture operators seek clearly defined property interests. A reasonable contention is that effective aquaculture development depends on the ability of individuals to secure financing, which in turn is related directly to the ability of prospective developers to identify their legal

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54:32B-8.16(a): Receipts from sales of tangible personal property and production and conservation services to a farmer for use and consumption directly and primarily in the production, handling and preservation for sale of agricultural [including aquacultural] or horticultural commodities at the farming enterprise of that farmer are exempt from the tax imposed under the "Sales and Use Tax Act." Id. See also, 36 M.R.S.A. § 2013. Refund of sales tax on depreciable machinery and equipment purchases [including aquacultural equipment]; MD TAX GENERAL § 10-724(b) (individual may claim a credit against the State income tax in an amount equal to 100% of the purchase price of aquaculture oyster floats).

[26] RI ST § 20-10-16 Penalties. (b) Any person damaging, disturbing, or interfering with any area subject to an aquaculture permit or any person damaging, disturbing, interfering, or taking by any means whatsoever, or possessing the cultivated species in an area subject to an aquaculture permit, without the permission of the permittee, is guilty of a misdemeanor and subject to imprisonment not exceeding one year or a fine of not more than one thousand dollars ($1,000), or both. In addition to that fine and/or imprisonment, all vessels, dredges, tongs, rakes, and other implements used to damage, disturb, interfere, or take cultivated species in those areas may be forfeited to the state. Id.

[27] See e.g., RI ST § 45-24-30 (6).General purposes of zoning ordinances. Zoning regulations shall be developed and maintained in accordance with a comprehensive plan prepared, adopted, and as may be amended, in accordance with chapter 22.2 of this title and shall be designed to address the following purposes . . . Providing for the preservation and promotion of agricultural production, forest, silviculture, aquaculture, timber resources, and open space. Id. See also, NY EXEC § 915 (5) (re: waterfront revitalization programs) local government waterfront revitalization program [may be eligible for program benefits where the local program supports] . . . waterborne transportation facilities and services, and support facilities for commercial fishing and aquaculture. Id.

[28] Rieser (1977, p. 211), citing National Research Council (NRC 1978) at pp. 85-90.

interests in areas and resources that may serve as collateral. Public concerns include a general wariness of government-led efforts that are perceived as creating or reallocating property rights or interests in public water areas or resources. Particular concerns are raised by historical users of public waterways and tidelands.

Vestal (1999) points out the direct contrast between the agricultural concepts of exclusive use (sought by aquaculture operators) and the open access/multiple use policies that have applied to public waterways historically and that invariably invite conflict. Yet little work has been conducted on the means by which marine and land-based aquaculture developers might gain the requisite financing by pledging legally valid aquaculture-related property interests as security. Some commentators have indicated that even the legal interest in profits resulting from aquaculture development are insufficiently acknowledged (DoC 1999).

While there has been no talk by state or federal governments of conveying away complete and exclusive rights in the ocean to aquaculture development, certain legal interests (leasehold terms of limited duration, etc.) could be utilized to establish identifiable interests and serve to address the requirements of financing institutions. Corollary to those rights, legal responsibilities should be clearly identified to address the concerns of other stakeholders.

Efforts to establish regulatory operating environments within which aquaculture might take place have led to the creation of Hydra-like legal regimes. Some researchers are working on the development of technologies and the design of institutions to streamline siting and regulatory processes. Yet, jurisdictional overlap, redundancy, and buck-passing continue to be cited as factors frustrating aquaculture development.

Federal, state, and local laws and policies that constrain or fail to mitigate impediments to aquaculture operations may in fact prevent future growth and expansion of the industry. Wypyszinski *et al.* (1994) note that: "[s]tate statutory and case law is generally very state- and situation-specific, and a range of use conflicts may arise between non-aquaculturists and aquaculturists, including: visual impact; economic (diminution in value) impact to proximate property owners; and alienation of public trust lands." In addition to those conflicts, new disputes have arisen over the course of the last twelve years that indicate the current legal and regulatory framework constrains aquaculture development.

In what follows, we use the results of our surveys to rank the leading policy and regulatory constraints to aquaculture in the Northeast. Brief descriptions of these issues follow. A number of other issues with some potential to cause constraint were identified by the aquaculture industry, including fallowing requirements (*e.g.*, salmon net pens in Maine); the management of natural hazards and risk assessments (*e.g.*, the bonding of leases on which structures have been installed in most coastal states); and organic certification requirements (*e.g.*, Connecticut shellfish growers are unable to obtain USDA organic certification under current guidelines).

i. Administrative and Jurisdictional Overlaps

In areas of nearshore marine aquaculture, regulatory jurisdiction falls under the aegis of multiple local, state, and federal agencies. Because many states recognize aquaculture as a form of agriculture, regulatory control falls within the state agriculture department; however, these departments may not have jurisdiction over the public lands where much aquaculture takes place. Public lands management typically falls under the authority of the state department of environmental protection (or management or conservation, etc.). The regulatory picture becomes even cloudier when towns or counties are accorded jurisdiction over local waters. Confusion over administrative policies can lead to delays in permit granting and subsequent loss of revenue to the grower.

It is important to recognize that criticisms of administrative overlaps sometimes are inapt in that there may be no explicit "overlap" in the strict sense of two agencies regulating the same activity. In discussions with both industry participants and government officials, we have found that the term "overlap" often is used in a general sense to connote the complexity of regulation and the confusion that is the predictable consequence of the complexity.

A review of state statutes governing the designation of aquaculture "lead agencies" suggests that states have made substantial efforts in recent years to respond to concerns about jurisdictional overlap. The recurring identification of administrative overlap as an industry impediment may now be one of perception as much as effect. Nonetheless, perceptions may have real impacts and, as such, states might consider efforts that would characterize aquaculture-related laws and regulations as residing in one "place."

ii. Leasing, Tenure, and Permitting Policies — Private and Public Rights

Coastal and marine-based aquaculture operations must deal with the complexity of utilizing what are considered the "public trust" resources, *i.e.*, state intertidal and sub-tidal lands, "great ponds" (in the case of Massachusetts and Maine), and state water columns. The doctrine itself dates back to the Roman Code of Justinian and was adopted as a legal principle by English sovereigns. As a doctrine of English common law, the rule was retained by the United States upon gaining independence. Simply put, certain public lands (tidelands and coastal waters) are deemed so important to the general public that they are held in trust by the sovereign (currently each state) for the benefit of the citizens of the state for purposes including fishing, navigation, and commerce. In some cases, public trust purposes have "evolved" to include ecological functions, public recreation, or other recognized uses (Eichenberg and Vestal 1992).

The public trust doctrine operates much like a private trust at the elemental level. There are three components to the trust: property, trustee(s), and a defined set of beneficiaries. Unlike a private trust, however, all three elements of the public trust are uniquely public in nature. The unique nature of public trust lands and the common law terms of the trust relationship generally prohibit the state as trustee from divesting the property through permanent alienation (*i.e.*, fee simple sale). Limited exceptions may apply where a state can show that a section of land being conveyed is limited so as not to disrupt the purpose of the trust while at the same time such conveyance is deemed to be in the public interest. It is important to remember that courts have not hesitated to overturn state legislative and/or executive branch actions deemed to impair substantially the public's interest in these uniquely situated trust lands.[29]

Leasing, tenure, and permitting have become overwhelming tasks for operations involved in marine-based aquaculture in the United States. The public trust doctrine applies to state-owned

[29] Secure Heritage, Inc. v. City of Cape May, 825 A.2d 534 N.J.Super.A.D.,2003 (public trust doctrine dictates that trust lands must be held, protected, and regulated for the common use and benefit); McQueen v. South Carolina Coastal Council, 580 S.E.2d 116 (So. Carolina 2003) (state cannot permit activity that substantially impairs the public interest in marine life, water quality, or public access); State v. Central Vermont Ry., Inc., 571 A.2d 1128 (Vt. 1990) (title to lands submerged beneath navigable waters is held by people as sovereign, in trust for public uses).

submerged lands out to three nautical miles, but its application varies by state. In five Atlantic states—Massachusetts, Maine, Pennsylvania, Rhode Island and Virginia—the intertidal lands (between mean high and mean low water) may be held as private property (Underwood 1997). Those private ownership rights, however, remain encumbered by the public's right to "fish, fowl and navigate" in or over them.[30] In Massachusetts, aquaculture is not considered one of the public trust purposes that must be accommodated.

Because of the public trust, the very spaces that are valuable for marine aquaculture operations cannot ordinarily be transferred from the state to private entities or individuals. Faced with this restriction, states are limited in the type of access they may grant to prospective aquaculturists. In most cases, marine aquaculturists may gain access and use only to sub-tidal lands and water column space in the form of permits or leases. Even where multi-year leases are granted, aquaculture activities can be restricted or revised if they interfere with other uses of the coastal zone, such as recreational and commercial fishing, shipping, boating, and other types of recreation.

In the case of marine aquaculture, public rights of use and access may restrict businesses. Those most significantly affected are shellfish and finfish operations, which utilize gear (cages, net-pens, longlines, etc.) in the water column that interferes with other uses of the coastal zone such as recreational and commercial fishing, shipping, and boating. In several states, aquaculture is given lower priority than navigation, fishing, and most other uses of the coastal zone. The subordination of aquaculture and other "non-traditional" uses of coastal areas is evident in a number of state constitutions.[31] This low priority has constrained some operations.

Some states accord a preference for certain uses of submerged lands to owners of upland property adjacent to navigable waters (riparian rights). The most important preference is a right of access by dredging, filling, or wharfing. Aquaculture may be constrained by riparian rights to the extent that these activities displace aquaculture or put aquaculturists who are non-riparian owners at a competitive disadvantage. The application of riparian rights varies by state. Geographic location may provide an advantage to riparian owners over the public in enjoying public trust rights. Riparian rights may not substantially interfere with public trust rights, however.

In coastal areas, the industry also may be subject to the "federal consistency" requirements of the federal Coastal Zone Management Act. The CZMA may prompt a determination of the extent to which federally permitted aquaculture operations in state waters or in the US exclusive economic zone are consistent with a state's coastal management plan. One such federal permit is that issued by the US Army Corps of Engineers (ACoE) under section 10 of the Rivers and Harbors Act (RHA). The section 10 permit is required for the installation of aquaculture gear in navigable waters. This permit relates to potential obstructions to navigation and is not an aquaculture permit *per se*. Further, it is not a legal right to the exclusive use of navigable waters. Application for a permit may trigger the ACoE's "public interest review process," which could

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[30] Opinion of the Justices, 424 N.E.2d 1092 (Mass.1981) ; Bell v. Town of Wells, 557 A.2d 168 (Maine 1989).

[31] See e.g. RI CONST Art. 1, § 17 Fishery rights -- Shore privileges –The people shall continue to enjoy and freely exercise all the rights of fishery, and the privileges of the shore, to which they have been heretofore entitled under the charter and usages of this state, including but not limited to fishing from the shore, the gathering of seaweed, leaving the shore to swim in the sea and passage along the shore; and they shall be secure in their rights to the use and enjoyment of the natural resources of the state with due regard for the preservation of their values. Id.

involve the assessment of environmental impacts and the development of an environmental impact statement (EIS). In the course of evaluating a section 10 permit application, ACoE seeks comments from the National Marine Fisheries Service's (NMFS) Protected Resources Division, which determines the likelihood of any impacts from a project on endangered or threatened species or marine mammals, and from other federal (US Environmental Protection Agency, US Coast Guard, US Fish and Wildlife Service) and relevant state agencies.

iii. Control of Disease

Disease control is a problem prominent in most segments of the aquaculture industry of the United States. Each type of disease may require particular control methods and rules. The control of disease is important to the viability of aquaculture operations, but implementing controls may be costly. Not surprisingly, government and industry officials may disagree over the nature and scope of disease control.

A national aquatic animal health plan now is being developed under the auspices of the Joint Subcommittee on Aquaculture (JSA). One component of this national plan is an aquatic animal health plan for salmonids in the EEZ, which is being put together by NMFS. A New England Salmonid Health Committee, made up of fish and wildlife experts from the six New England states, has adopted guidelines for the uniform handling among the interested states of disease issues for salmon and trout (NESHC 2001).

The management of an outbreak of infectious salmon anemia (ISA) in Maine in 2001 is a recent example of disease control in practice. Control of the disease required the slaughter of 2 million fish, requirements for the fallowing of net pen sites, and disinfection of the surfaces of vessels and equipment below the waterline. Net pens now may be restocked only at lower densities and with only one year class, and movements of fish are to be restricted and subject to monitoring for the disease. An integrated pest management (IPM) system must be implemented to control sea lice, a fish parasite that may harbor the ISA virus. Control of disease, although vital to operational success, can be a costly constraint to the industry.

In New York, as is the case in some other states, the lack of diagnostic support to handle disease pathology and testing for importation has caused considerable problems for the industry; this is changing, however, as funding has been allocated to begin a state laboratory there. In other states, such as Massachusetts and Connecticut, designated shellfish pathologists have been a major asset to those industries; and Vermont requires all of its hatcheries to be certified on a regular basis.

Until recently, restrictive policies on the use of pharmaceuticals has limited the options that the aquaculture industry has to prevent or control disease in cultured fish. For example, shellfish growers in Massachusetts have noted that they are restricted by these policies because even a minute amount of chemical treatment to induce triploidy in oysters makes the product unmarketable. Industry participants now recognize, however, that triploidy may be more easily induced by employing traditional cross-breeding methods that utilize tetraploid and diploid strains.

The lack of drugs to treat disease is a significant problem faced by aquaculture producers. It is thought that the small size of the markets relative to the costs of development for drugs to treat so-called "minor species" (defined to include all aquaculture species) is the primary reason that few drugs exist. In 1996, Congress asked the US Food and Drug Administration (FDA) to develop proposals to increase the legal availability of animal drugs for minor uses and minor species (MUMS). In 1998, with input from industry and other stakeholders, FDA published a set of proposals, including monetary grants for clinical studies, tax credits, protocol assistance, and prolonged periods of marketing exclusivity (FDA 1998). FDA's proposals, which follow the lead of the successful "orphan drug" program for humans, have been incorporated into legislative proposals during the last two congresses, but none has been enacted to date.[32]

iv. Interstate Transport of Product

State rules concerning the imports of fish eggs, fingerlings, and shellfish seed from other states are non-uniform. Confusion, misinformation, or non-compliance has contributed to the introduction of non-indigenous species and an increased incidence of disease, devastating some aquaculture businesses and changing the nature of local or regional ecosystems. While many states have restricted transport to a few trusted companies, other states do not follow a strict protocol or possess testing facilities for the transport of live fish, eggs, or seed. The existence of inconsistent policies for interstate shipment of these aquaculture products has hampered the ability to develop a comprehensive interstate transport program. When only limited supplies of eggs, fingerlings, or shellfish seed are available, market prices are usually driven up by the lack of competition.

While a comprehensive analysis of individual state laws restricting the importation or trans-shipment of aquaculture products was not conducted as part of this research, it is important to note that some states may run afoul of the commerce clause of the US Constitution. The commerce clause, designed to maintain and protect interstate commerce, may pre-empt state aquaculture importation restrictions. Through its police power, a state may retain authority to regulate matters of legitimate local concern even though interstate commerce may be affected.

In determining whether a state has overstepped its role in regulating interstate commerce, the courts will distinguish between state laws that burden interstate transactions only incidentally and those that affirmatively discriminate against such transactions. Laws in the former category violate the commerce clause only if the burdens they impose on interstate trade are clearly excessive in relation to local benefits. Laws in the latter category are subject to more demanding scrutiny, and the state must demonstrate that the statute serves a legitimate local purpose *and* that such purpose could not be served as well by available nondiscriminatory means.[33]

v. Foreign Competition

Competition with low-cost seafood imports can reduce sales of native products. Increasing imports of foreign products (*e.g.*, Vietnamese "catfish") affects native markets and further reduces the expansion of US products into the worldwide markets. Northeast producers are now seeking niche markets in which to sell high-priced or value-added products.

US trade law provides US aquaculture producers with the opportunity to initiate complaints in antidumping cases, triggering investigations into aquaculture imports that are sold in the US

[32] In 2004, Congress amended the federal Food, Drug, and Cosmetic Act to provide grants or contracts for the development of designated new animal drugs, expedited approval for use, and exclusive marketing rights (P.L. 108-282).

[33] Maine v. Taylor, 106 S.Ct. 2440 (1986) (upholding a Maine statute restricting the importation of live bait fish where the state could show that importation could introduce a parasitic health threat to local species).

market at below production cost. Both southeastern US catfish farmers and Maine mussel farmers have been successful in obtaining redress in recent antidumping actions. Collected countervailing duties are distributed to aggrieved US firms through the provisions of the so-called Byrd Amendment, which was enacted in 2001. The direct distribution of these duties to firms runs counter to the provisions of international trade law, according to a recent ruling by the World Trade Organization. It is likely that legislative action will modify the Byrd Amendment's system of distribution, resulting in the wider distribution of countervailing duties to affected communities or possibly the deposit of collected duties into US Treasury accounts. Consequently, the benefits to US aquaculture firms of initiating trade investigations will be reduced.

Shellfish industry members have been particularly jeopardized by the mislabeling of brand name shellfish. Cultured clams grown originally outside the Northeast have been labeled improperly as local product. The inability of the government to mandate and verify the origin of aquaculture products has not only reduced sales of local product; it has tarnished the industry's reputation.

Recently, Congress enacted a "Country of Origin" provision requiring the labeling of both farm-raised and wild fish as to country of origin and to distinguish between wild and farm-raised fish. Regulations to implement this language were required as of 30 September 2003.[34]

vi. <u>Policies Governing Interactions with Protected Species or Impacts on Habitat</u>

Federal action that has been determined to have a "significant effect on the quality of the human environment" may require the drafting of an environmental impact statement (EIS) under provisions of the US National Environmental Policy Act. Federal actions include the issuance of permits, licenses, or leases. An example of the relevance of this policy to aquaculture in the EEZ was the opposition expressed by the Boston-based Conservation Law Foundation to the proposed Norwegian American Fish Farm salmon pen operation on grounds that a federal EIS was required. The drafting of an EIS is a substantial undertaking involving months or years of time and significant expenditures.

Similarly, some states have state environmental protection acts (SEPAs) that would trigger environmental reviews where a state action (including permit grant) could have adverse environmental impacts. Several states are requiring aquaculture businesses to conduct pre-permit environmental assessments and to conduct continuous environmental monitoring once a permit is issued. Expensive monitoring equipment, the utilization of paid consultants, the loss of wages, among other things, add significant expenses to the cost of growing aquaculture products.

Where cultured species are farmed in the vicinity of stocks of endangered species, the aquaculture industry may face additional restrictions. The best example concerns the Atlantic salmon farming industry in Maine. In 2000, eight salmon runs in Maine were listed as endangered. The industry is involved with several stakeholder groups in crafting a salmon recovery plan under the federal Endangered Species Act (ESA), which may impose additional burdens on the industry related to containment, fish marking, the use of non-North American strains, and disease control. The industry has voluntarily implemented a code of practice for fish containment. The industry has argued that the ESA salmon recovery plan provisions should match the requirements to be set forth in national pollution discharge elimination system (NPDES) permits under the US Clean Water Act.

[34] P.L. 107-171.

Other protected species issues relate to potential interactions with marine mammals or turtles through entanglements in gear or adverse effects on habitat and the loss of eelgrass beds in estuarine environments. In particular, these concerns are most heightened where the proposed installation is within a transit, feeding, or nursery area. This issue can be very contentious, one in which perceptions of problems may be as important as actual impacts. In particular, there are significant concerns about the potential for the entanglement of individuals of the western North Atlantic stock of the northern right whale (*Eubalaena glacialis*), which is a highly endangered species. These concerns have the potential to halt activity on any proposed project. In some cases, the development of a biological assessment under section 7 of ESA may be required. Biological assessments are to be conducted by the relevant lead federal agency, but, in order to expedite the process, industry applicants for federal permits often end up doing much if not all of the work.

A noted example of rules concerning protected species that restrict cultivation practices has occurred in West Virginia. Aquaculture of paddlefish has become popular and necessary for stock restoration. Commercial or scientific culture for research is prohibited, however, because the species is still considered "protected."

vii. Rules Concerning the Culture of Commercially Harvested Species

A small number of states have regulations that prevent the culture of species that are commercially or recreationally harvested by fishermen. Recently in Maine, an aquaculturist engaged in the production of sea worms has prompted a "worm digger protest" by traditional harvesters seeking protection from "unnatural" production efforts.[35]

A more difficult problem faced by aquaculturists concerns the export of their product to states that have commercial fishery rules that define the characteristics of the product. For example, a three-inch size restriction on the commercial harvest of oysters in Massachusetts prevents the sale or even the transport through the state of smaller oysters grown in Connecticut or Rhode Island. Resolution of this problem may require the development of technologies that enable state inspectors to distinguish between cultured and wild-harvest product. Such technologies might also provide a resolution to some of the mislabeling and brand poaching that goes on.

In some cases, regulations have been promulgated for the specific purpose of preventing competition between fishermen and aquaculturists. New Jersey and Massachusetts, for example, limit shellfish cultivation to bottom areas that do not naturally produce shellfish. These regulations have caused problems in New Jersey, where aquaculture industry participants have pointed out that lease areas suitable for shellfish growout are unavailable.

viii. Federal and State Effluent Regulations

The US Environmental Protection Agency (EPA) recently promulgated federal rules to regulate the discharge of pollutants from three types of aquatic animal production facilities: recirculating systems, flow-through systems, and net pens.[36] The rules apply to aquaculture operations producing more than 100,000 pounds of fish annually. They include a numerical standard for the discharge of total suspended solids (TSS) for recirculating and flow-through systems.

[35] For example, see the editorial that appeared on 24 August 2003 in the *Boston Globe* (p. D10) entitled "Bait and Switch."

[36] 40 CFR Part 451 (*Federal Register* 69:162 at 51892, August 23, 2004).

Achievement of the TSS standard is expected to lead to reductions in discharges of nutrients and biochemical oxygen demand (BOD). The rules also establish feed monitoring requirements for marine net pen operations. Drugs, pesticides, non-native species, and pathogens are controlled through proposed best management practices (BMPs). Molluscan shellfish culturing, closed pond systems, and lobster pounds are exempt from the rules. Enforcement is carried out by EPA or an authorized state agency.

In the area of freshwater aquaculture, federal regulations concerning effluent management hinder growth in some businesses due to the expense of converting growout systems. Compliance with these guidelines, however, may promote aquaculture as a more "environmentally friendly" method of food production. In marine aquaculture, and specifically in net pen culture, the industry will be less likely to experience major operation conversion costs. Although feed monitoring requirements will require an additional expense, reduced feed waste may offset these expenses to some extent.

The Federal Water Pollution Control Act (also known as the Clean Water Act, or CWA) prohibits the discharge of any pollutant into the waters of the United States without a permit. EPA administers a national pollutant discharge elimination system (NPDES) pursuant to section 1342 of the CWA. Pursuant to section 1328, EPA has been given specific authority to grant discharge permits to aquaculture operators. EPA, in turn, may delegate this permit-granting authority to states, as has been the case in Maine.

In Maine, operators of salmon aquaculture operations began applying for NPDES permits in the early 1990s. EPA indicated that the applications were under consideration for a lengthy period, prompting environmental organizations to sue the aquaculture operators for discharging without a permit. While the operators claimed that the permit applications should have held any such suit in abeyance, a federal court decided otherwise.[37] The operators were deemed in violation of the CWA and the court imposed conditions on the continuing operations. At the same time, the court rebuked EPA for its failure to establish effluent standards for aquaculture operations. With the recent delegation of CWA authority to the state, on 19 June 2003, the Maine Department of Environmental Protection issued a Maine Pollutant Discharge Elimination System General Permit for Atlantic Salmon Aquaculture.[38] Other states have also fashioned discharge permit standards for aquaculture operations.[39]

ix. Culture of Genetically Modified Organisms

The utilization of genetically modified organisms (GMOs) for aquaculture is a modern issue in which the absence of regulation or the inappropriate nature of regulation is perceived as a constraint by some segments of the aquaculture industry. Some entrepreneurs who are at the vanguard of research in the bioengineering of fish and shellfish may not yet be in the business of growing fish. As a consequence, it is unclear that they are regarded by some as actual participants in the aquaculture industry. These individuals or firms are potential entrants into the industry, and the absence of policy or the existence of an inchoate regulatory regime could constrain the growth of the industry in this area.

[37] U.S. Public Interest Research Group v. Atlantic Salmon, 215 F.Supp.2d 239 (D. Me. 2002).

[38] See http://www.maine.gov/dep/blwq/docstand/aquaculture/MEG130000.pdf (last accessed 1 Sept. 2003).

[39] See PA ST 3 Pa. C.S.A. § 4213.

Traditional selective breeding techniques have been practiced ever since the emergence of aquaculture as a form of food production. More recent technological advances now permit the manipulation of the actions of specific genes, allowing the rapid growth of fish that exhibit certain desired properties, such as color, texture, disease resistance, temperature tolerance, or taste.

Where the effects of the human consumption of genetically engineered fish are unknown, the protection of public health remains a leading concern. Preliminary marketing studies have revealed reluctance on the part of some consumers about purchasing GMO fish, and, consequently, some aquaculture operators have chosen to advertise the fact that they are *not* producing GMO fish. Public education remains a priority for acceptance of these cultured products. Environmental implications are at issue as well, including escapement from net pens resulting in the loss of habitat for wild stocks or the degradation of natural gene pools (Kapuscinski and Hallerman 1991). The latter issues have attracted considerable negative attention from environmental organizations (Goldburg and Tripplett 1997).

Because the genetic modification of fish or shellfish for aquaculture is a biotechnology that is still in its infancy, the regulation of such modifications is undeveloped (Gorski 1993). At the federal level, both the National Environmental Policy Act and the Endangered Species Act are likely to be invoked as relevant laws. The utility of both laws may be limited, however, in cases where it is impossible to know or difficult to predict the impacts of releases of GMOs until after the fact. Other laws, including the Food, Drug, and Cosmetic Act, the Toxic Substances Control Act, and the Clean Water Act (CWA), appear to be poor fits to serve as the basis for regulating the production of GMO fish, but they are sure to be called upon by opponents to control this form of aquaculture. Indeed, in a recent case, the CWA was relied upon to justify the exclusion of the growing of non-native strains of salmon in netpens off the coast of Maine (*n.b.*, these strains are not GMOs, however). In a settlement agreement in a related case, another Maine salmon producer agreed not to stock its netpens with GMO salmon.

Guidelines for GMO research and development have been developed by both the National Institutes of Health (NIH) and USDA. These guidelines are used to regulate releases of GMO fish from research facilities, but they are applicable only to federally funded research activities. Privately funded research is beyond the reach of these guidelines. While the lack of regulation would seem to be beneficial to the industry in this instance, the absence of government oversight over R&D in such a frontier area could actually inhibit consumption.

x. Introduction of Exotic or Non-indigenous Species for Purpose of Culture

The Lacey Act is used to regulate the import and interstate transport of non-native species. Some non-native species have found beneficial use in the control of pests in aquaculture operations. Regulation of these species as "non-native" would therefore adversely affect those aquaculture operations. An example is the black carp, which is used to control levels of ram's horn snails in pond culture. The ram's horn snail is an intermediate host of yellow grubs, which can infest hybrid striped bass, making them unfit for sale. Black carp are now produced as a triploid variety, which cannot reproduce and invade non-culture habitats, but this variety has also been prohibited for interstate sale.

Although some exotic or introduced species have proven beneficial to aquaculture operations initially, the environmental effects of exotics that do not remain within the culture area has proved devastating. Development of effective regulations to stop the introduction and establishment of harmful exotic species is being examined. The introduction of the non-native oyster, *Crassostrea ariakensis*, into the Chesapeake Bay for aquaculture purposes has created major concerns not only within the shellfishing industries of Maryland and Virginia, but in the eyes of the public. Non-native species have the potential to introduce disease and to compete with native organisms for food supplies. Further, non-native species such as *C. ariakensis* can change habitat structure, and they have no natural predators.

xi. Permitting in the US Exclusive Economic Zone

The regulation of offshore aquaculture in the United States is problematic and unsettled. At present, there is no federal policy pertaining specifically to the permitting of aquaculture in the area from three to 200 nautical miles offshore known as the exclusive economic zone (EEZ). Public debate over the establishment of any such policy is still only in its early stages (Rieser and Bunsick 1999; Rieser 1997). At a minimum, a section 10 permit is required from the US Army Corps of Engineers.

The responsibility for aquaculture policy is not yet clearly defined and a permitting system is not in place for offshore marine aquaculture in the US Exclusive Economic Zone. In the absence of a regulatory framework, not only is expansion of the existing industry impossible, but potential future growth and research in this area is discouraged (Barr 1997).

In 1993, the General Counsel of the National Oceanic and Atmospheric Administration determined that aquaculture facilities in the EEZ are subject to the federal Magnuson-Stevens Act at the discretion of the regional fisheries management councils. In order to formalize their authority, these councils must prepare fisheries management plans (FMPs). FMP preparation is a public process requiring approval of the relevant council's membership (a group historically dominated by commercial wild harvest fishery interests), followed by approval from NMFS. The New England Council has not prepared an FMP specifically for aquaculture, but in December 1996 it issued a "Draft Aquaculture Policy." This draft statement makes it clear that the New England Council intends to develop an "aquaculture management strategy" at some point in the future (Brennan 1997). The details have yet to be worked out, but it is clear that the New England Council will be concerned about any potential impacts on existing commercial fisheries, including both biological impacts and loss of access to specific areas.

e. Conclusions and Research Recommendations

Participants in the aquaculture industry are faced with a wide variety of laws and regulations that govern the manner in which they plan, site, and operate aquaculture facilities. Aquaculture may be one of the most heavily regulated industries in the United States, but many of the relevant regulations and administrative programs clearly benefit the industry. Given the diverse characteristics of the industry, in terms of the multiplicity of markets, political jurisdictions, and technologies, it is inevitable that some policies will be perceived as constraints on industry growth. Indeed, because of the large number of distinct markets comprised by the aquaculture industry, it is likely that any specific regulation or policy might be perceived by some segment of the industry as constraining. In many cases, the same regulation or policy might be regarded as facilitating by some other segment of the industry.

Using surveys and a literature review, we have identified a range of policy and legal issues that likely constrain the growth of the industry. We have ranked these issues on a scale of 1-11. The most important issue concerns administrative complexity, where confusion about the relevant rules may lead to excessive financial and time costs.

Based upon feedback from participants at an industry workshop in 2003, issues relating to interstate trade are perceived by many in the industry to be among the most constraining. In the future, research might usefully be directed at characterizing the laws and policies among states that relate to animal health, including disease inspections and certifications. Also, state laws and regulations that restrain trade on the basis of conserving and managing wild harvest fisheries ought to be characterized. Increasing the transparency of these rules and highlighting non-uniformities among disparate state approaches to the control of movements of diseases and invasive species, as well as to conservation of fishery resources, is likely to lead ultimately to a more homogeneous and less confusing regional legal regime.

The industry has voiced interest in the development of so-called best management practices (BMPs). There are a number of precedents in other regions or internationally, such as the aquaculture industry in Europe, where BMPs have been adopted and implemented by participants in specific markets. A perceived advantage of the BMP approach is that it emerges as the product of consensus among industry participants, sometimes guided by government agencies. As such, BMPs are a form of soft law, a set of normative principles that does not involve explicit regulation. It would be productive to direct legal and policy research toward understanding the implications of BMPs for market structure, their effectiveness in achieving stated objectives, their costs in comparison with government regulation, and their resiliency over time.

3. Risk Assessment in Open-Ocean Aquaculture: A Firm-Level Investment-Production Model

a. Introduction

Open-ocean aquaculture is considered a potentially significant growth area for the future economy of New England and for the United States generally.[40] One of the most important issues in open-ocean aquaculture development is the management of risk and uncertainty. The industry is in an early stage of development. Compared with more mature industries, the marine aquaculture industry faces high levels of risk and uncertainty in areas such as procedures and regulations governing access, entry and operation (Hoagland *et al.* 2003); economic returns; and production technologies. The economic costs of risk and uncertainty represent significant barriers to economic growth in open-ocean aquaculture. In the face of these costs, entrepreneurs are unlikely to invest in the industry, and industrial growth will not take place. Further, without a sound understanding of the ways in which risks and uncertainties can be managed to mitigate their costs, natural resource management agencies will be unable to develop appropriate policies to enhance industrial development.

In this study, we develop a framework for risk assessment in open-ocean aquaculture. The framework consists of three components. At the center of the framework is a firm-level

[40] Because most of the United States' nearshore waters are heavily used for fishing and recreation, the most promising directions for US aquaculture are on shore (growing fish in tanks) and far offshore, in open water relatively free of use conflicts and environmental contamination. New England is well positioned to build an open ocean aquaculture industry: it has suitable waters and long-established fishing communities with the requisite expertise to deploy and maintain gear offshore.

investment-production model that simulates a specific growout project (Kite-Powell *et al.* 2003a). In the model, several key economic and biological variables may be specified as stochastic. As a result, the model may be used to calculate both the expected return from an investment and the variance associated with that return. Using the outputs from the firm-level model, the second model in our analytical framework examines the investment rule for a risk-averse investor facing uncertain payoffs and calculates a risk premium for the project. The last model in our framework presents the investment rule for a risk neutral investor facing both uncertainty in future project return and irreversibility in investment and computes the option value of the project. We illustrate our models using a case study of open-ocean aquaculture of Atlantic cod (*Gadus morhua*) in New England.

The remainder of this paper is organized as follows. Section b describes the investment-production model. Investment under uncertainty is discussed in Section c. Section d outlines the data used for simulation. Results of the simulations are summarized in Section e. Section f presents the conclusions.

b. A Model of Firm-Level Investment and Production

To examine a firm's investment in open-ocean aquaculture, we first need to model the interactions among various economic and biological factors in a specific production process (e.g., species, technology, and location). Typically, a firm-level investment-production model includes revenue from fish sales, different cost components, and a biological growth function.[41] Suppose revenue and cost projections for an open-ocean aquaculture project are accurate and there are no risks. In this special but unrealistic case, investment decisions can be made according to a basic investment rule: invest when the value of the project is at least as large as the investment costs.

In this study, we focus on risk assessment and investment decisions. Our model assumes that the growout operation is to produce a fixed amount of fish each month, following pre-determined stocking and harvesting schedules.[42] The model simulates fish growth and projects financial flows for each month in a 15-year period. It calculates project value, the amount of up-front investment required, and net-present value (NPV).

The model takes into account seasonal variability in the price of fish landings as well as the effect of water temperature on fish growth rates. It allows for comparison of different species at alternate growout sites based on their biological and physical characteristics (Kite-Powell *et al.* 2003a). Several economic, biological, and environmental variables (e.g., price, mortality, and water temperature) may be specified as stochastic to capture random effects in fish growth and revenue from sales. For a given set of stochastic variables, the model calculates both the mean and the variance of the project value.

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[41] The total cost of a specific technology consists of fixed and variable components. Fixed cost (e.g., construction cost) is sunk cost once an investment has been made. Variable cost (e.g., feed, energy and labor) may be controlled in future operations. Production may be optimized to improve the economic efficiency of a specific system. For example, the biomass growth rate may be controlled through feeding rate and changes in density (e.g., stocking rate, survival/culling) (see Allen *et al.* 1984; Arnason 1992).

[42] A different version of the model allows the optimization over stocking time and number of fish for each harvest month (see Kite-Powell *et al.* 2003a).

i. Fish Growth

To ensure year-round fish yield, a certain number of fingerlings are stocked each month. For a particular cohort, the fish growth may be modeled using the Beverton-Holt approach (Ricker 1975), as follows:

$$x(\tau) = n(\tau)w(\tau) \tag{1}$$

where n is the number of fish in thousand and w is the weight of a fish in grams. In discrete time (τ = month) and without intervention,

$$n(\tau) = n(\tau - 1)(1 - m) \tag{2}$$

where m as the mortality rate (Allen *et al.* 1984), the number of fish will decrease while the weight grows.

The growth rate of individual fish weight (w) in discrete time is:

$$w(\tau) = w(\tau - 1) + g(\tau - 1) \tag{3}$$

where $g(\bullet)$ is the weight growth function of an individual fish. The feed conversion ratio (FCR) is defined as:

$$s(\tau) = \frac{f_0(\tau)}{g(\tau)} \tag{4}$$

where s is the FCR and f_0 is the quantity of feed per fish. Thus, the total feed quantity in kg at τ is

$$f(\tau) = f_0(\tau)n(\tau) = s(\tau)g(\tau)n(\tau) \tag{5}$$

ii. Revenue from Fish Sales

For specific stocking and harvesting schedules, the model calculates the financial performance of the growout operation month-by-month over 15 years to determine projected cash flows. For an individual aquaculture farm, price is exogenous. We model dockside price as a function of fish size and time of year. With total fish biomass at harvest time $x(T)$ in kg and market price (p) in \$/kg, the gross revenue from the sale of a cohort is

$$R(t) = p[w(T),t]x(T) \tag{6}$$

where t is time over the study period [t = 1, 2, …, 180 (month)].[43]

iii. Costs of Investment and Production

The total cost includes expenditures on cages, a boat, fingerlings, feed, and shore-based operations (e.g., administration and marketing). In the model, we assume a sequential cage installation schedule. For cod, the growout period is two years. There are 24 cohorts. Thus, for

[43] In the model, we specify stocking and harvesting schedules within this time frame. For example, Cohort 1 is initially stocked at t = 1 (τ = 0), harvested at t = 24 ($\tau = T$), and restocked at t = 25 (τ = 0). Note that $R(t) = 0$ for t = 1 – 23.

each of the first 24 months, there is one new cage added to the farm. The investment cost of each cage is

$$c_k(t) = v(acq + inst) \qquad t = 1,2,...,24 \tag{7}$$

where c_k is the cost of each cage in \$, v is the cage volume in m^3, *acq* is the cage acquisition cost in \$/m^3, and *inst* is the cage mooring and installation cost[44] in \$/m^3. For cage maintenance in subsequent months, the maintenance cost is

$$c_m(t) = v \cdot cn(t) \cdot cm(t) \qquad t = 25,26,...,180 \tag{8}$$

where *cn* is the number of cages in the farm, and *cm* is the cage operating and maintenance cost in \$/m^3/year.

Each month, feed and fingerlings are transported to the farm and harvest is transported back to shore by boat. Aggregating cage-level feed quantity [$f(\tau)$ from (5)], we have the farm-level monthly feed quantity (*fq*) in kg:

$$fq(t) = f(t) \cdot cn(t) \tag{9}$$

For each month, the quantity of fingerling and water transported for stocking (*sq*) in kg is

$$sq(t) = stock \cdot sg \cdot \varphi \tag{10}$$

where *stock* [= $n(0)$] is the number of fingerlings in thousands, *sg* is the fingerling weight in gram/fish, and φ is ratio of water weight to fingerling weight during transport to farm. For each month, the number of boat days (*bd*) is calculated as either the number of days necessary for transporting harvest from the farm or the number of days needed for transporting feed and fingerlings to the farm, whichever is greater.

$$bd(t) = max\{x(T)/ld, [fq(t) + sq(t)]/ld\}/trip \tag{11}$$

where $x(T)$ is the fish harvest in kg, *ld* is the boat payload in kg, *fq* is the feed quantity in kg, *sq* is the quantity of fingerlings in kg, and *trip* is the number of round-trips per day.[45]

For each month, boat cost (c_b) is

$$c_b(t) = bfix/12 + bvar * bd(t) \tag{12}$$

where *bfix* is the vessel fixed cost in \$/year, and *bvar* is the variable and crew cost in \$/day. Fingerling cost (c_r) is

$$c_r(t) = 1000 \cdot stock \cdot sp \tag{13}$$

where *sp* is the fingerling cost in \$/fish. Feed cost (c_f) is

$$c_f(t) = fq(t) \cdot fp \tag{14}$$

where *fp* is the feed cost in \$/kg. Shore cost (c_s) is

$$c_s(t) = (sh + ins)/12 \tag{15}$$

[44] This may be modeled as a function of water depth.

[45] This may be modeled as a function of distance to shore.

where *sh* is the on shore cost (e.g., dock, facilities, management administration, marketing and distribution) in \$/year and *ins* is the insurance cost in \$/year.

From Equations (7), (8), and (12) through (15), we can calculate the total cost (C) in each month

$$C(t) = \sum_i c_i(t) \tag{16}$$

Note that $i = [k, m, b, r, f, s]$.

iv. Net Revenue

As noted, our model simulates monthly cash-flow for a 15-year period and $t = 1, 2, \ldots, 180$ (month). The cages are installed sequentially in the first 24 months. From (7), we define the total investment as:

$$I = \sum_{t=1}^{24} \frac{C_k(t)}{(1+\delta/12)^t} \tag{17}$$

where δ is the annual discount rate (monthly discount rate is $\delta/12$). The project's net present value may be computed using (6) and (16) as:

$$NPV = \sum_{t=1}^{180} \frac{R(t)-C(t)}{(1+\delta/12)^t} \tag{18}$$

c. Investment under Uncertainty

i. Risk Aversion and Risk Premium

Open-ocean aquaculture firms operate in coastal and offshore waters and are subject to different levels of risk from changes in input and output markets and biological growth. To assess the impacts of these risks on investment and production decisions, we may specify several variables in the above model [e.g., price (p) and mortality rate (m)] as stochastic and generate associated distribution of NPV. Typically, firms are risk averse (Kumbhakar 2002). In this section, we examine the effect of risk attitude and risk level on investment and risk premium. As an example, we assess the impacts of various risk and uncertainty factors on the investment decision by a firm with respect to production scale (i.e., number of cage farms).[46]

Let $V = E(NPV) + I$ be the expected return on investment from one cage farm and ε be a random variable distributed $\varepsilon \sim (0, \sigma_\varepsilon^2)$. We model the single farm return as $V+\varepsilon$ and specify the firm's net return from multi-farm operation as:

$$\Pi = [(V+\varepsilon) - I]N \tag{19}$$

[46] Here we focus on investment decision regarding a specific production technology. Generally, risk and uncertainty may also affect the selection of technology and output level. The EV framework can also be used to examine firm-level production under various uncertainties related to output price, output quantity, and input prices (see Robison and Barry 1987).

where N is the number of cage farms developed by the firm. We apply expected value-variance (EV) analysis to this problem (Robison and Barry 1987).[47] The firm's certainty equivalent net revenue can be expressed as:

$$\Pi_{ce} = [V - I]N - \frac{\lambda}{2}N^2\sigma_\varepsilon^2 \tag{20}$$

where λ is the Pratt-Arrow risk aversion function (a measure of firm's risk attitude). The certainty equivalent net revenue equals the expected risky return minus the "risk premium" (i.e., cost of risk-bearing).

The firm seeks to choose N that maximizes its certainty equivalent revenue (20), the first order condition yields:

$$N = \frac{V - I}{\lambda\sigma_\varepsilon^2}. \tag{21}$$

The above result suggests that firm will invest in open-ocean aquaculture if the expected marginal return is greater than marginal cost ($V > I$). However, the number of cage farms (N) is inversely related to the risk level (σ_ε^2) and the risk aversion parameter. If the risk level rises or the firm becomes more risk averse (greater λ), the investment level will decline. The scale of open-ocean aquaculture operations is smaller with higher risk level.

When risk and uncertainty are present, the basic investment rule should be modified. Generally, a greater revenue stream will be required to justify the same level of investment. Although individuals have different attitudes toward risk, most are either risk neutral or slightly risk averse (see Kumbhakar 2002; Eggert and Martinsson 2004). For risk-averse investors, the investment rule is to invest if the value of the project is at least as large as the investment cost plus a risk premium. As shown in (20), the risk premium is positively related to an investor's level of risk aversion and the variance of project value, which is a measure of risk. Although the risk premium may not always be straightforward to calculate, one can think of it as analogous to the insurance premium that an investor pays to mitigate potential losses.

ii. Uncertainty, Irreversibility, and Investment Timing

In addition to uncertainty, a choice of whether to invest in open-ocean aquaculture can be characterized as irreversible (or reversible only at considerable cost) in the sense that equipment and materials used for aquaculture production are industry-specific and not easily used for other purposes. A substantial portion of the investment expenditures therefore comprise sunk costs. In the face of uncertainty and irreversibility, there may be value to an investor from delaying investment. This value is called an option value (see Dixit and Pindyck 1994). Typically, option value is defined as the difference in uncertain net benefits between two development strategies: invest immediately or wait until new information becomes available (Arrow and Fisher 1974). Option value can exist even for risk neutral investors who would ordinarily not consider accounting for a risk premium.

[47] The EV analysis can be used to optimize an investment decision involving a tradeoff between an investment with a certain payoff and a risky investment, which can be characterized by its variance.

The issue of investment timing and option value may be examined using a framework described by Dixit and Pindyck (1994). In their model, the value of an investment project (V) evolves according to the following geometric Brownian motion with drift:

$$dV = \alpha V dt + \sigma V dz \tag{22}$$

where α is the drift coefficient, and σ the variance coefficient. Both α and σ are constants. dz is the increment of a Wiener process. Equation (22) implies that the current value of the project is known, but the future values are lognormally distributed with a variance that grows linearly with the time horizon. Although information arrives over time (the firm observes changes in V), the future value of the project is always uncertain.

If the value of the project (V) is rising, $\alpha > 0$. The value of σ (> 0) captures the risk level. To maximize the expected present value, the firm's problem is

$$F(V) = max\, E\{[V(T_0) - I]e^{-\delta T_0}\} \tag{23}$$

where T_0 is the unknown future time when the investment is made, δ is the discount rate in continuous time, I is the irreversible investment, and $F(V)$ is the option value. The maximization is subject to Equation (22). Because of the presence of uncertainty, it is usually not possible to calculate the exact time (T_0). Instead, once an option value is estimated, it is optimal to invest as soon as the project value (V) exceeds the sum of investment costs plus option value [$V^* = I + F(V)$].[48]

Dixit and Pindyck (1994) have shown that the critical value above which investment should be made immediately (V^*) is greater than or equal to I. The wedge between V^* and I is driven by uncertainty and irreversibility. For example, a higher risk level (the value of σ) results in higher $F(V)$ and V^*.

A key feature here is that the project value may change over time. An investor can maximize a project's net present value (NPV) by choosing the optimal time at which to invest. Importantly, one needs to consider option value only when the project's benefits are appreciating ($\alpha > 0$),[49] for example, due to a rising price or declining costs. Note that even if the current benefits are less than costs, implying that NPV would be negative, because benefits (V) are growing, the option value [$F(V)$] will be positive and investment should be made in the future when V reaches V^*.

d. Data

i. Input Parameters for the Investment-Production Model

We apply the models described above to Atlantic cod. Cod can be stocked and harvested year-round in southern New England waters. The growout site is located 6 km from the shore station or dock used by the support vessel. The water depth is 50 m. Monthly water temperatures are shown in Table 3. Also included in Table 3 are the monthly average dockside prices for cod.

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[48] For detailed discussions on the subject and specific equations for estimating $F(V)$ and V^*, see Dixit and Pindyck (1994), pp.136-155.

[49] If the project value will remain constant or fall over time ($\alpha \leq 0$), it is clearly optimal to invest immediately.

These prices are based primarily on landed value reported by the National Marine Fisheries Service. Biological data for the analysis are from Jobling (1988), Best (1995), and Bjørndal (1990). For specific functional forms, we model mortality in (2) as a function of fish weight (w):

$$m(\tau) = 0.01 - 0.000001w(\tau) \tag{24}$$

The above specification is based on experience with salmon farms as reported in Bjørndal (1990). According to Jobling (1988), the monthly growth in (3) is as a function of fish weight and water temperature:

$$g(\tau) = 0.37223w(\tau)^{0.559}e^{0.297\gamma - 0.000538\gamma^3} \tag{25}$$

where g is in grams per month, w is weight in grams, and γ is the temperature in degree Celsius.

Table 3. Monthly Average Temperatures and Cod Price by Size

Month	**Water Temperature**	**Cod Price** ($/kg)		
	C^0	Small	Medium	Large
Jan	2	2.70	3.14	3.57
Feb	2	2.64	3.14	3.48
Mar	3	2.59	3.09	3.43
Apr	5	2.21	2.63	2.91
May	10	2.31	2.75	3.05
Jun	17	2.31	2.75	3.05
Jul	21	2.23	2.65	2.94
Aug	22	2.55	3.04	3.37
Sept	22	2.49	2.96	3.29
Oct	18	2.54	3.03	3.36
Nov	10	2.33	2.78	3.08
Dec	5	2.60	3.10	3.44

Note: Cod size categories are: small (750 grams $\leq w <$ 1,130 grams); medium (1,130 grams $\leq w <$ 2,270 grams); and large ($w \geq$ 2270 grams). For $w <$ 750 grams, the assumed price is zero.

Following Jobling (1988) and Best (1995), we specify FCR as a function of fish weight:

$$s(\tau) = 1.5 - 0.0038w(\tau) \tag{26}$$

Table 4 summarizes other model input parameters describing the cage system, stocking, feed cost, boat, etc. These data are based on personal communications with cage manufacturers, industry experts, and Bjørndal (1990). As shown in the table, the cage capacity per cohort is 5,000 m^3. The fixed cost for the growout support vessel, which stocks the cages, carries feed to the cages, supports maintenance, and carries out harvesting, is $100,000/year. Operating costs are $1,500/day for fuel and other consumables, and personnel costs are another $1,500/day. The vessel has an operating speed of 15 km/h and a payload capacity of 30 metric tons. On a typical round trip carrying feed, it spends 3 hours on site. The maximum length of a work day is 12 hours; and due to weather constraints and maintenance requirements, the vessel is at sea a maximum of 25 days per month. Onshore costs include $30,000/year for dock use and other onshore facilities, $70,000/year for management and administrative costs, and $50,000/year for marketing and distribution.

Table 4. Firm Model Input Parameters

Parameter	**Description**	**Unit**	**Value**
V	cage volume per cohort	m^3	5,000
Acq	cage purchase cost	$/$m^3$	15.00
Inst	cage mooring and installation cost	$/$m^3$	3.00
Cm	cage operating and maintenance cost	$/$m^3$/year	1.00
Stock	number of fingerlings stocked per cohort	1,000 fish	150
Sg	stocking weight	gram/fish	50
φ	ratio of water weight to fingerling weight during transport to farm		5
Sp	fingerling cost	$/fish	0.85
Fp	feed cost	$/kg	0.60
Bfix	vessel fixed cost	$/year	100,000
Bvar	vessel variable and crew cost	$day	3,000
Ld	vessel payload	metric ton	30
Trip	round trips per day		3
Sh	on shore cost	$/year	150,000
Ins	insurance cost	$/year	50,000
δ	annual discount rate		0.07

ii. Risk Preferences

Although a precise measure of individual or firm risk perception is not an easy task (Anderson *et al.* 1977), there have been a number of empirical studies estimating risk aversion parameters (Binswanger 1980; Eggert and Martinsson 2004) or factors affecting risk perceptions (Moses and Savage 1989). Binswanger (1980) shows that at high payoff levels, virtually all individuals are moderately risk-averse with little variation according to personal characteristics. Wealth tends to reduce risk aversion slightly, but its effect is not statistically significant. Using panel data on salmon farming from Norway, Kumbhakar (2002) reveals that all salmon farmers are risk averse and that the farmers' risk preferences exhibit decreasing absolute risk aversion.

Although the absolute risk-aversion parameter (λ), which measures subjective risk preference, can be any value, the results of a study by King and Robison (1981) indicate that the absolute risk-aversion coefficient should be concentrated in the range from -10^{-4} to 10^{-3}. For a risk-averse decision maker, λ is a positive number. Decisions involving risks are affected by the value of λ. However, when λ is greater than 0.1 or very small (close to zero), the decisions are usually not sensitive to changes in λ. In this study, sensitivity analysis with respect to λ is performed between 10^{-1} and 10^{-6}.[50]

e. Simulations and Results

Using the input parameters in Tables 3 and 4, we use the firm model[51] to calculate the baseline (deterministic) results summarized in Table 5. For the set of input parameters, an open-ocean cod farm requires an investment of $2.01 million to construct and generates $12.63 million in return. The project's net present value (NPV) is $10.62 million. Once fully installed, the farm produces cod year round with an average production rate of 177 metric tons per month.

Table 5. Firm Model Baseline Results (One Cod Farm)

Output Variable	**Description**	**Unit**	**Value**
NPV	net present value	$ million	10.620
V	project value	$ million	12.630
I	investment	$ million	2.010
x(T)	average fish harvest	metric ton/month	177
n(T)	average number of fish harvested	fish/month	120,535
w(T)	average harvest fish size	kg	1.47
$12 \cdot E[fq(t)]$	average feed quantity	metric ton/year	2,765

[50] This range covers most λ values examined by researchers. For examples, See Peck (1975), Hanson and Ladd (1991), Martinez and Zering (1992), Vukina and Anderson (1993).
[51] All computer programs for the study are written in MATLAB.

To examine how different input values affect the project payoff, sensitivity analyses are conducted with respect to key parameters. For example, since feed cost accounts for a significant portion of the operating cost in aquaculture operations, we illustrate the impact of rising feed cost on NPV in Figure 1. Also shown in the figure is the effect of discount rate on NPV. As the feed cost approaches $1/kg, NPVs drops into the neighborhood of zero. As expected, for a fixed feed cost NPV declines with a higher discount rate.

As noted, several key economic and biological variables in the model may be specified as stochastic. In this example, we attach a normally distributed random element, $\xi_j \sim N(0, \sigma_j^2)$, to each of the five variables: mortality rate (*m*), water temperature (γ), fish weight growth (*g*), fish price (*p*), and feed cost (*fp*). We run the stochastic version of the firm model for two sets of variances, as Cases 1 and 2 shown in Table 6. The resulting expected NPVs and the variances of project NPVs are shown in Table 7. For Case 1, the expected NPV is $10.81 million and the variance of project NPV is 6.37. For Case 2, the expected NPV is $11.83 million with a much

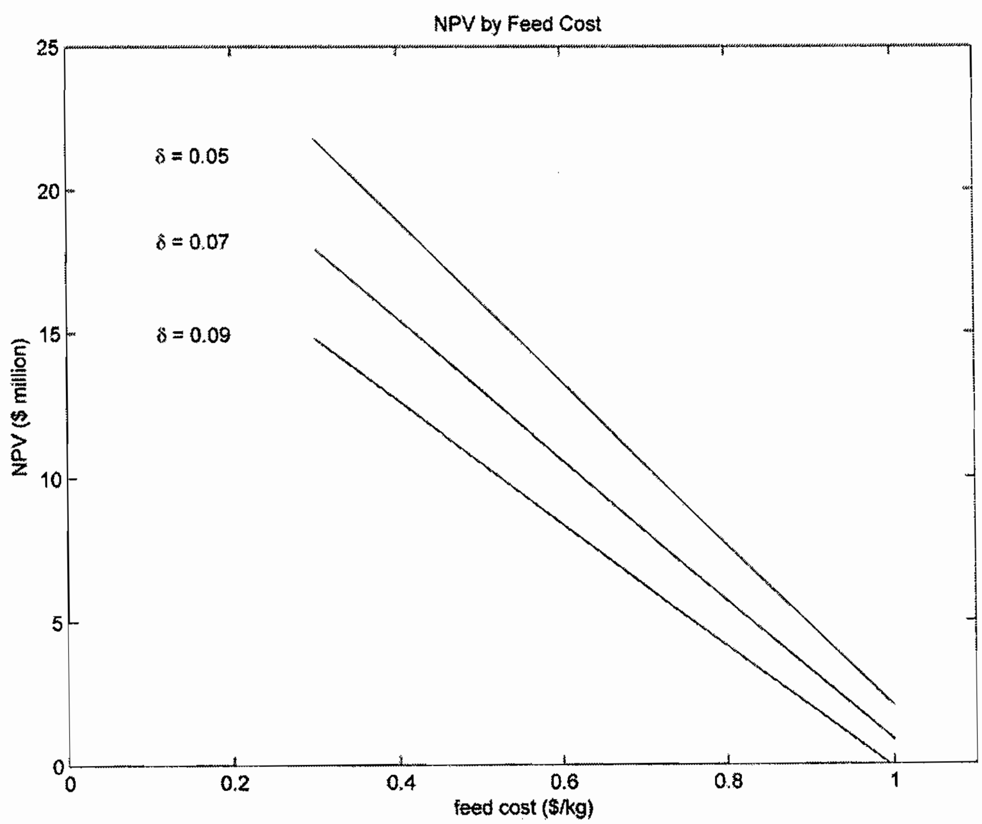

Figure 1. NPV by feed cost and discount rate.

larger variance of 33.88. The histograms of the random error terms attached to each of the five variables and resulting NPVs for Cases 1 and 2 are depicted in Figures 2 and 3, respectively. The figures show that for the set of smaller variances (Case 1), the NPV is always positive, while for the set of larger variances (Case 2), the left side tail of the distribution clearly suggests the possibility of negative net returns.

Table 6. Stochastic Variable Specifications

Variables	Stochastic Variables	Error Distributions	Case 1	Case 2
mortality rate (m)	$m\ exp(\xi_m)$	$\xi_m \sim N(0,\sigma_m^2)$	$\sigma_m^2=0.01$	$\sigma_m^2=0.051$
temperature (γ)	$\gamma + \xi_\gamma$	$\xi_\gamma \sim N(0,\sigma_\gamma^2)$	$\sigma_\gamma^2=0.1$	$\sigma_\gamma^2=0.5$
fish growth (g)	$g\ exp(\xi_g)$	$\xi_g \sim N(0,\sigma_g^2)$	$\sigma_g^2=0.01$	$\sigma_g^2=0.05$
fish price (p)	$p + \xi_p$	$\xi_p \sim N(0,\sigma_p^2)$	$\sigma_p^2=0.1$	$\sigma_p^2=0.5$
feed cost (fp)	$fp + \xi_{fp}$	$\xi_{fp} \sim N(0,\sigma_{fp}^2)$	$\sigma_{fp}^2=0.01$	$\sigma_{fp}^2=0.05$

Table 7. Risk Aversion and Risk Premium (One Cod Farm)

	Risk Level					
	Case 1: Var(NPV) = 6.368			Case 2: Var(NPV) = 33.879		
Risk Attitude	Expected NPV ($\$10^6$)	Risk Premium ($\$10^6$)	Certainty Equivalent NPV ($\$10^6$)	Expected NPV ($\$10^6$)	Risk Premium ($\$10^6$)	Certainty Equivalent NPV ($\$10^6$)
$\lambda = 0.001$	10.809	0.003	10.806	11.829	0.017	11.812
$\lambda = 0.01$	10.809	0.032	10.777	11.829	0.169	11.660
$\lambda = 0.1$	10.809	0.318	10.490	11.829	1.694	10.135

The effects of changing risk attitude and risk level on risk premium are also depicted in Table 7. These results are computed using Equation (20) with $N = 1$. In the first case (Var(NPV) = 6.368), when an investor is moderately risk averse ($\lambda = 0.001$), the risk premium is \$3 thousand (see the third column in Table 6). The risk premium will increase to \$318 thousand if the investor becomes highly risk-averse ($\lambda = 0.1$). The certainty equivalent NPV reduces from \$10.81 million to \$10.49 million as the investor becomes more risk averse. Similarly, risk premium grows as the risk level (i.e., the variance of NPV) increases (Case 2).

Next, we examine the impacts of changing risk attitude and risk level on investment level (i.e., production scale), assuming that the firm may set up multiple cod farms. Using the farm-level NPV and investment (I) in Table 5, we calculate the number of farms (N) using Equation (21).

The results are plotted in Figure 4. In panel (a), we fix the variance of project NPV. Given the large positive project NPV, a risk-neutral firm ($\lambda = 0$) will set up as many farms as its budget allows. This will be true when the firm is moderately risk averse (e.g., $\lambda = 0.001$). The firm will seriously restrict its production scale only when it is highly risk averse (e.g., $\lambda = 0.1$). Similarly, the production scale declines as the risk level rises [see panel (b)]. Figure 4 also shows how the firm's risk premium rises with respect to production scale [panel (c)], and the changes in certainty equivalent NPV (20) by production scale [panel (d)]. The peak in panel (d) depicts the optimal value and the corresponding number of farms that represent the firm's optimal production scale.

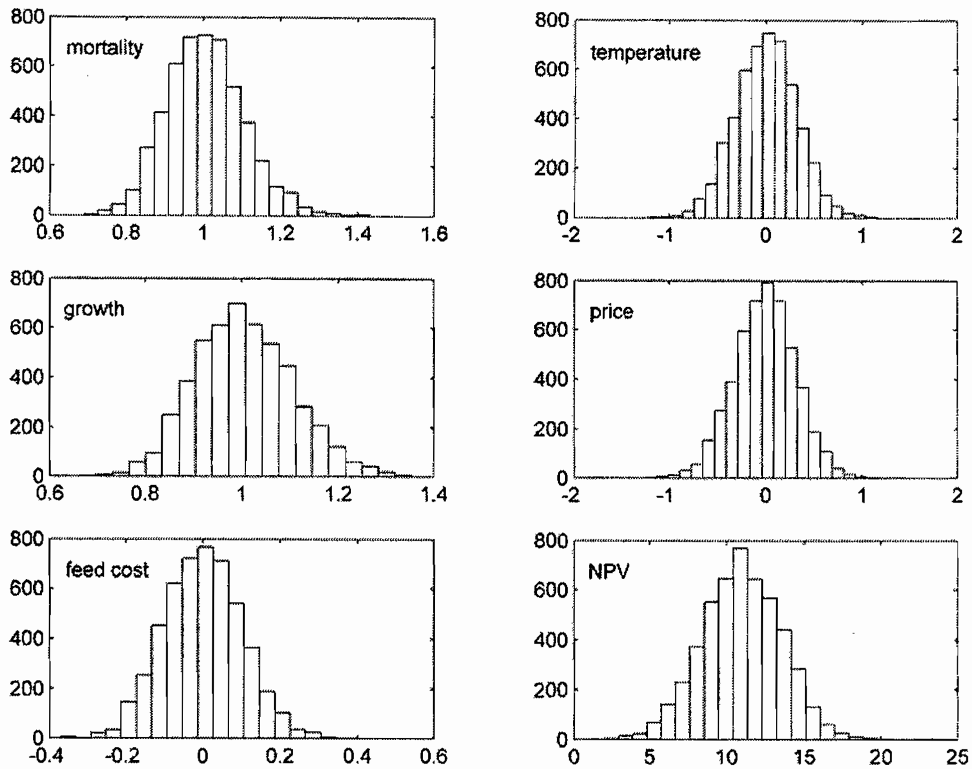

Figure 2. Histograms of NPV and errors associated with key parameters (Case 1).

Notes: As specified in Table 4, the error distributions shown above are $exp(\xi_m)$ for mortality, ξ_y for temperature, $exp(\xi_g)$ for fish weight growth, ξ_p for fish price, and ξ_{fp} for feed cost. Number of iterations = 5,000.

Finally, we examine option value at the farm-level. Following Dixit and Pindyck (1994), we calculate the critical value V^* at which it is optimal for the firm to invest in a farm. The option value of the investment project is the difference between V^* and investment (I). The results are included in Table 8. As shown in the table, the option value becomes larger if the risk level increases or the project value appreciates at a higher rate. For example, if the project value appreciates at 2% per year, the discount rate is 7% per year, and the investment cost is \$2.01 million, option value rises from \$1.31 million to \$18.83 million as σ grows from 0.1 to 0.9. Our baseline project value is \$12.63 million (see Table 5) which is greater than the V^*s of most cases in Table 7, except for five cases close to the lower right corner in the table [($\alpha = 0.01$, $\sigma = 0.9$); ($\alpha = 0.02$, $\sigma = 0.7$ and 0.9); ($\alpha = 0.03$, $\sigma = 0.7$ and 0.9)]. Thus, it is optimal to invest immediately except in these five cases.

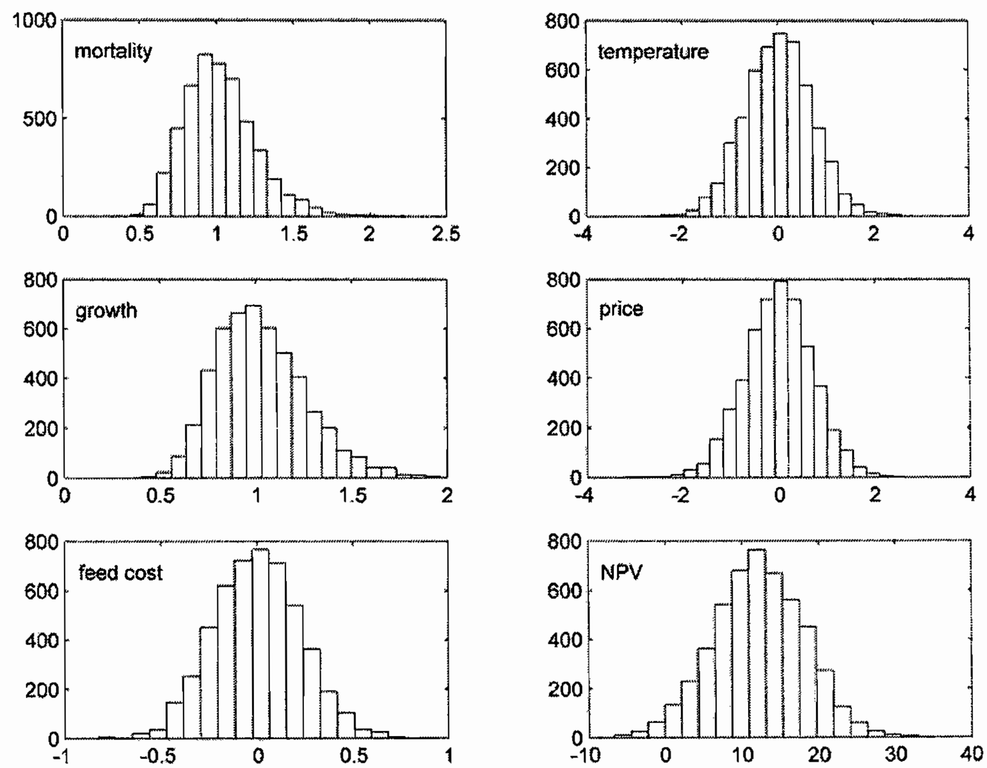

Figure 3. Histograms of NPV and errors associated with key parameters (Case 2).

Notes: As specified in Table 4, the error distributions shown above are $exp(\xi_m)$ for mortality, ξ_y for temperature, $exp(\xi_g)$ for fish weight growth, ξ_p for fish price, and ξ_{fp} for feed cost. Number of iterations = 5,000.

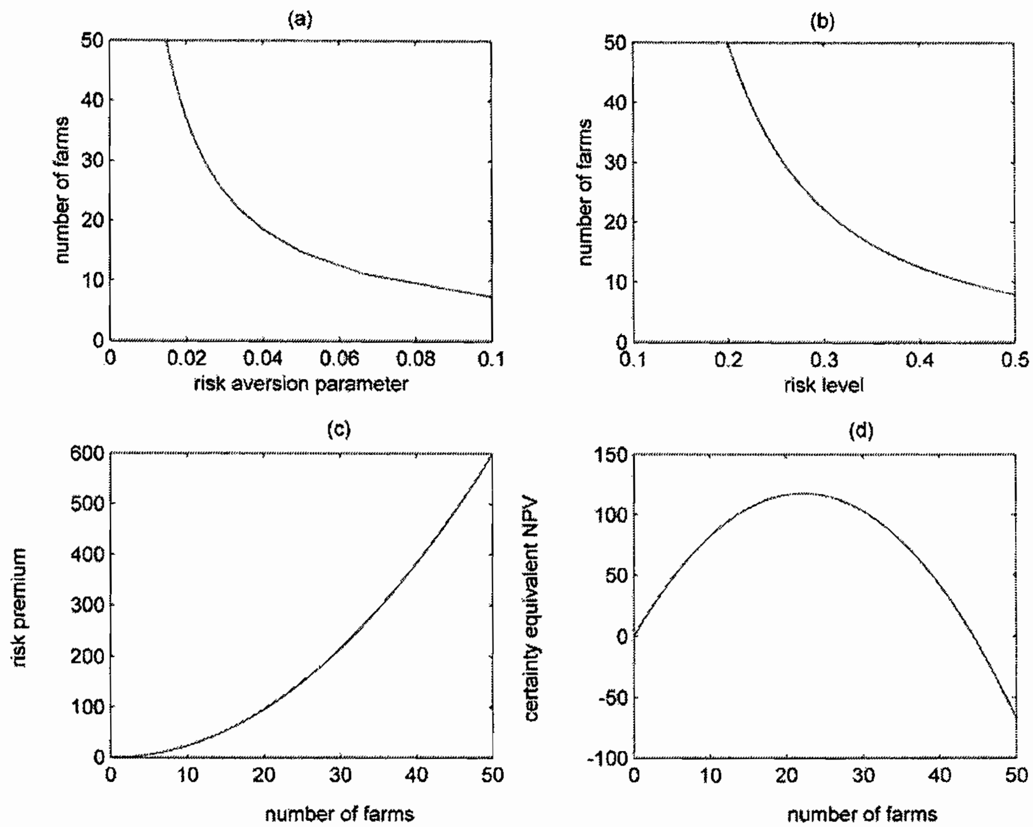

Figure 4. Impacts of risk attitude and risk level on investment and production scale.

Notes:

(a) Investment level by risk attitude with risk level fixed at $\sigma = 0.3E(V)$ with $E(V) = 12.63$.

(b) Investment level by risk level [percent = $\sigma/E(V)$] with risk attitude fixed at $\lambda = 0.033$.

(c) Increasing risk premium by investment level with risk attitude fixed at $\lambda = 0.033$.

(d) Certainty equivalent NPV by investment level with risk attitude fixed at $\lambda = 0.033$.

f. Conclusions

Open-ocean aquaculture operations must take into account the significant risk and uncertainty of working in an exposed, deepwater environment. Sources of uncertainty also include future market demands, biological factors, and unexpected shifts in regulatory policies. In this study, we develop a framework for risk assessment in open-ocean aquaculture. The analytical framework is based on a firm-level investment-production model that simulates a specific growout project and estimates the project's investment and expected NPV. Using expected value-variance (EV) analysis and outputs from the firm-level model, a second model calculates the risk premium (i.e., cost of risk-bearing) for a risk-averse investor. Finally, a third model quantifies the option value for a risk-neutral investor.

Table 8. Option Value (One Cod Farm)

Uncertainty	Investment ($\$10^6$)	Project Value Appreciation					
		$\alpha = 0.01$		$\alpha = 0.02$		$\alpha = 0.03$	
		Option Value ($\$10^6$)	V^* ($\$10^6$)	Option Value ($\$10^6$)	V^* ($\$10^6$)	Option Value ($\$10^6$)	V^* ($\$10^6$)
$\sigma = 0.1$	2.010	0.884	2.894	1.313	3.323	2.010	4.020
$\sigma = 0.3$	2.010	2.891	4.901	3.618	5.628	4.730	6.740
$\sigma = 0.5$	2.010	5.940	7.950	7.227	9.237	9.167	11.177
$\sigma = 0.7$	2.010	10.166	12.176	12.268	14.278	15.424	17.435
$\sigma = 0.9$	2.010	15.647	17.657	18.825	20.835	23.594	25.605

Note: For specific equations for estimating V^*, see Dixit and Pindyck (1994), Equations (13), (14) and (15) on page 142 and Equation (24) on page 152.

Through the three models, we describe investment rules under different conditions. We show that under uncertainty, the traditional NPV rule of making an investment should be modified. Generally, under the modified rules, a larger project value is needed to justify an augmented total cost of investment. For example, the investment rule for risk-averse investors is to invest if the value of the project is at least as large as the investment cost plus a risk premium. The investment rule under irreversibility and uncertainty suggests that an investor should invest if the value of the project is at least as large as the investment costs plus an option value.

We illustrate our models using a case study of open-ocean aquaculture of Atlantic cod (*Gadus morhua*) in New England. The results suggest that investment level is inversely related to the risk level and the risk aversion parameter. The scale of aquaculture operations under uncertainty is smaller than that under certainty. Investment time is affected by the dynamics of project value. Both growth in project payoff and uncertainty in the payoff can create a value to waiting (i.e., option value). The option value is positively related to project value appreciation and risk level.

Open-ocean aquaculture is an emerging industry. Some technical, biological, and regulatory uncertainties surrounding open-ocean growout systems are now being resolved through publicly sponsored demonstration projects. However, it has become clear that entrepreneurs in this industry may need to utilize institutional innovations and to consider policies that further reduce the economic costs associated with risk and uncertainty in order for the industry to become viable and to expand in the future. Our risk assessment framework is designed to contribute to policy analysis related to the open-ocean aquaculture industry by providing a set of useful analytical tools and baseline model parameters.

4. A Profile of the US Industry and Market for Blue Mussels

a. World Market Trends

Worldwide, the production of mussels of all types has been increasing at an average of about 5 percent per year during 1950-2000, reaching nearly 1.7 million metric tons in 1999. The United Nations Food and Agricultural Organization (FAO) estimates that the worldwide combined total landed and farmgate value of mussels in 2000 was roughly $645 million.

In the last several decades, the nature of the market has changed significantly, as producers have been switching away from wild harvests toward a variety of culturing techniques. Hickman (1997) refers to marine mussels as having those characteristics that make them an "ideal candidate for aquaculture," including their rapid rates of growth, high productivity on almost any substrate, relatively straightforward husbandry, ability to filter plankton and take up nutrients, and resilience to disease. About 85 percent of world mussel production now comes from ocean aquaculture. Denmark is the only country that still produces very large quantities of wild harvest mussels, but producers there are now investing seriously in the capacity to culture mussels.

China is the world's largest producer of mussels today, growing more than 400,000 metric tons of a wide variety of species each year. Especially attractive to suppliers is a $500 million European market for blue mussels, where Spain, Italy, the Netherlands, Denmark, and France are firmly entrenched as the region's leading producers. New Zealand has become one of the world's leading producers, focusing on growing the native green-lipped mussel (*Perna canaliculus*). The green-lipped mussel is processed and frozen for export to Asian, American, and European markets. An expansion of demand on the world market, particularly for blue mussels (*Mytilus spp.*), is calling forth increased production in many parts of the world, including Scandinavia (especially Norway and Sweden), Ireland, South Africa, and North America.

Although most of the world's production of mussels is canned (nearly 65 percent) or frozen (nearly 35 percent), most international trade in the residual (<1 percent) is in the high-valued premium fresh or chilled product (Vannuccini 1999). Spain and Denmark lead the world in the production of canned product. Unlike the preferences for local types of some shellfish species, however, such as those for oysters in France, the international trade for mussels is very active, as sophisticated European consumers appear to enjoy mussels from both local and international sources (Holmyard 1997). European Union shellfish sanitation regulations limit imports of fresh product from extra-EU sources, however, so much of the international trade in fresh mussels occurs among EU countries. The Netherlands leads among producers of fresh or chilled product for the European market.

b. Northeast American Market Trends

The Northeast American market for fresh processed blue mussels has been expanding even more rapidly than the world market, particularly during the last decade. Farms located in the Canadian Maritimes supply most of the market in the United States and Canada, and Canadian farm production increased more than 10 percent per year in the last decade (Couturier 2001). Mussels are produced on the west coast of both Canada and the United States, from Alaska through British Columbia and Puget Sound, and on down to San Diego. Production on the west coast tends to be restricted to *Mytilus trossulus* and *Mytilus galloprovincialis*, both of which are close relatives of *Mytilus edulis*.

The most impressive development in the Northeast American blue mussel industry has occurred during the last two decades on Prince Edward Island (PEI). PEI mussel production grew from about 100,000 pounds per year in 1981 to nearly 40 million pounds in 2001. Although mussel production occurs in all of the Canadian maritime provinces, PEI producers do not encounter impediments to the same degree as producers in other provinces (Muise 1990). Among these impediments are conflicts with other nearshore uses (New Brunswick and Nova Scotia), remoteness (Newfoundland and Quebec), slowed growth due to cold temperatures (Newfoundland), and permitting delays and litigation (Nova Scotia). PEI production also occurs in waters with enough temperature diversity to allow almost a year-round supply of high-quality, pre-spawning stock to the market.

In 1987, a catastrophic harmful algal bloom, which resulted in 129 amnesiac shellfish poisonings and two deaths, stopped the PEI industry cold for a year, and rippled through producers and processors in the entire northeastern American market. PEI producers responded to this event with an organized program of environmental monitoring and a public relations campaign to reassure consumers.

The PEI experience can be contrasted strongly with recent attempts to develop the industry in Newfoundland (KPS 2002). In response to the unemployment resulting from the severe depletion of groundfish stocks, significant levels of government support have encouraged development of capacity in blue mussel culturing, following the PEI model. This support continues to date, as about $C20 million in federal and provincial funding has been budgeted for aquaculture development in Newfoundland during 2001-2006.

While still young, the Newfoundland industry has struggled to provide consistent quality at a competitive price. Upon careful inspection, farms were found to have low yields, to be utilizing inefficient husbandry practices, and to be operating at high costs. One critical issue is distance from the fresh market. A second problem, and one that clearly provides lessons for an industry developing in US waters, was the inability of farmers to realize economies from the geographic clustering of farms in the proximity of processing facilities. There may be at least two sources of clustering economies. First, there may be scale economies in processing and distribution because of fixed capital investments. Second, there may be transportation cost savings for farmers. These market structure characteristics are clearly recognized by the successful value-added players in the market, including processor/distributors in PEI and Great Eastern Mussels in Maine.

c. Historical US Market Developments

Interest in the development of a mussel industry has a long history in the United States. Field (1921) reports on pre-World War I efforts by the US Bureau of Fisheries to create a market through publicity campaigns; the provision of free mussels to first-class hotels, restaurants, and clubs; the free distribution of mussels to members of the Boston police force; and the utilization of YMCA educational programs to increase consumer awareness. At the time, these efforts were expected to create a "permanent and growing demand" for mussels, but such was not to be the case.

Until recently, very high levels of production in New England occurred only during World War II, at which time the natural stocks were cropped off and exported (Lutz 1977), and in the late 1960s and early 1970s, during a resurgence of demand in the important New York City market (Clifton 1980).

In the mid-1970s, the US National Marine Fisheries Service (NMFS) identified a number of economic issues constraining further development of the market for mussels, including sporadic supply, inconsistent quality, and a limited demand (Lutz 1977). A survey of 300 west coast restaurants by researchers at the University of Washington identified similar constraints (Waterstrat 1978). In particular, dealers found it difficult to cover the costs of distributing mussels other than seasonally and then only in bulk to wholesalers in large established markets, thereby bypassing local retailers.

As a complement to the 1977 NMFS study, students at the University of New Hampshire's Whittemore School of Business analyzed the factors constraining the development of the blue mussel industry in New England (Broadhurst *et al.* 1976). This study recommended several courses of action to remedy market constraints, including: educating consumers about mussels to erase negative preconceptions; product differentiation through branding, slogans, and packaging; demonstrating quality to support a higher price; and maintaining a reliable supply. By the 1990s, several of these recommendations had been implemented.

US production exceeded supply from Canadian farms and processors until the mid-1990s. Since the mid-1990s, most of the eastern US market has been supplied by imports from Canada. These imports, which are a mixture of partially processed farmgate product and some wholesale product, command a premium over wild product prices, averaging more than 80 cents per pound during the last five years.

In March 2001, an investigation was initiated by the US International Trade Commission to consider a complaint that mussels exported from Canada to the United States had been sold at less than fair value (dumping). Although the investigation was terminated prior to any final decision on dumping, the initial determination and views of the Commission helped to define the relevant market as processed blue mussels, specifically *Mytilus edulis*. Further, the Commission distinguished between the farming and processing activities, while recognizing a "commonality of economic interest" between the industry processing mussels and the industry cultivating mussels.

This market definition might be interpreted, in retrospect, as helping to blur a distinction between alternative production technologies (bottom culture and longline culture) by redirecting the focus of the market onto the processed product. Where historically the Canadian cultured (and processed) product commanded a premium over bottom culture or wild harvest mussels, now the market is more likely to be perceived as a relatively homogeneous processed product, regardless of the culturing technology. Nowhere is this interpretation more obvious than in the value data compiled by the State of Maine for NMFS, which demonstrates a significant increase in the US price per pound of blue mussels, starting in January 2001.

d. <u>Production Processes and Evolution of Technology</u>

Mussels for sale in the Northeastern American market are produced by three different methods. The oldest method, still practiced today, is the wild harvest of mussels by dredging from natural beds. The geographic distribution of mussel beds is patchy, and their existence in any particular location may be fleeting. Thus fishing targets may shift from time to time. Historical wild harvest production has occurred off the coasts of all of the Canadian Maritimes, the New England states, and sporadically in the mid-Atlantic states down to North Carolina.

There are as many as a dozen areas where the commercial fishery for mussels is actively prosecuted off the coast of Maine. These areas are pulse-fished, to crop down the local stock, and then left alone for two to three years in order to allow recruitment. Access to the fishery is by license only from the Maine Division of Marine Resources. There are three main markets for this fishery: (1) juveniles may be used for grow-out on nearshore leases in Maine; (2) some larger mussels are sold to processor/distributors for resale into wholesale and retail markets; and (3) others are crudely processed and sold as a product directly to retailers and restaurants.

By the mid-1980s, mussel producers had begun experimenting with transplanted bottom culturing, surface longline rope culturing, and raft culturing, and they set quality standards for a washed and graded fresh mussel product (Brooks 1994). Processors purge, declump, grade, debyss, package, and distribute mussels. Processors add value to the raw product, but a crucial role is an inventory function, to ensure a consistent and steady supply to downstream customers or distributors ("fish houses"). The fish houses purchase mussels from processors with a very small margin; they truck the mussels to retailers, restaurants, and consumers; and they typically handle a wide range of other seafood products in addition to mussels.

The raft technology has been adapted from culturing techniques in Spain and Scotland and is now being established in nearshore areas (especially in Maine and Washington State) where there are few competing uses (Newell 2000). The longline technology is related to that used for culturing the green-lipped mussel in New Zealand, and is being examined for both nearshore and open-ocean settings. In the open-ocean, the longline technology must be submerged, and the distance from shore and need to employ more durable gear may increase the costs of the operation. Nevertheless, there are even fewer potential conflicts with other ocean uses offshore than in nearshore areas (Langan 2000). Although the longline technology is more costly than either rafts or bottom culturing, the relatively warmer temperatures found in New England waters may accelerate growth (*cf.* Karayuecel and Karayuecel 1999; Mason 1976), thereby increasing productivity and revenue.

Within the last decade, interest has grown in investigating the potential for larger-scale operations in the open ocean. Two pilot projects (one organized and run by UNH scientists off the Isles of Shoals in the western Gulf of Maine and one by WHOI scientists off Martha's Vineyard in Rhode Island Sound) have demonstrated the biological and engineering feasibilities of this new kind of technology. It has always been assumed that estuarine environments are optimal with respect to the important temperature and food availability (phytoplankton concentration) parameters. These projects have revealed that this assumption holds in the coastal ocean as well.

Researchers at the WHOI Marine Policy Center have developed a business planning model of the operations of an open-ocean aquaculture longline system for blue mussels (Kite-Powell *et al.* 2003a). This model is based upon a set of assumptions about an operational open-ocean blue mussel farming operation.

The expanding market now is leading to the research and development of new biotechnologies, including investigations into the production of triploid mussels (Brake *et al.* 1999). The production of these non-spawning varieties may reduce the pre- and post-spawning variability in meat yields. If successful, this technology could permit the culturing of a premium product with consistently high meat yields.

e. Current Market Structure

The structure of the US market for blue mussels extends from the producers upstream to consumers downstream. The market involves a flow of mainly fresh product from growers to processors/distributors (who are commonly one entity) to retailers, restaurants, and individual consumers. The majority, sometimes as much as 95 percent, of the product is imported from Canada, primarily from Prince Edward Island (PEI). The market for mussels is somewhat regionalized, because the product needs to be kept in seawater or packed in ice, and transportation costs can contribute significantly to the delivered price.

Smaller markets exist for frozen (vacuum packed) and canned mussels. One US processor in the vacuum-packed market, BlueGold Ltd., operated out of New Bedford, Massachusetts, in the 1990s but now has relocated to Nova Scotia.

Other shellfish are partial substitutes for blue mussels, including soft-shell clams (*Mya arenaria*), quahogs (*Mercenaria mercenaria*), mahogany clams (*Arctica islandica*), oysters (*Crassostrea virginica* and other species), and bay scallops (*Argopecten irradians*). We provide more detail on substitutes in the description of market demand below. The green-lipped mussel (*Perna canaliculus*) from New Zealand also is a substitute, but it is typically marketed as a frozen, half-shell product, and it does not compete as a fresh product.

As the market has been expanding in the last two decades, vertically integrated processor/distributors have emerged, differentiating their product and adding value (Scarratt 2000). This vertical integration is very much in the European tradition of both fresh and canned production. On Prince Edward Island, a large number of growers (well over 200) sell to a small number (fewer than a dozen) processors. Some of these processors also are integrated back into growing. The processors truck fresh product to fish houses in eastern metropolitan markets, focusing on Montreal, Toronto, Quebec City, Boston, New York, and Philadelphia. Increasingly, fresh PEI mussels are now being trucked as far west as upstate New York, Cleveland, and Chicago, and down the east coast to Florida. There is some very limited movement of PEI mussels to the west coast of the United States and, on occasion, to Europe. Exports to Europe are costly, as they are air-freighted, and they depend crucially upon favorable exchange rates.

Mussels are produced in the other maritime provinces, including Newfoundland, Nova Scotia, and New Brunswick, but not nearly on the same scale as on PEI. Newfoundland arguably is too far from the major markets for effective delivery of fresh product, and so with government support a vacuum-packed frozen processing capacity has been under development there. The market for this product has not materialized completely, however, and Newfoundland processors currently may be sitting on as much as two years of frozen inventory, and farmers are operating at well below full capacity. There is some active culturing near Halifax, Nova Scotia, to supply that market, but local opposition to aquaculture has slowed potential development of culturing operations along the Nova Scotian coast. Minor production also occurs in New Brunswick and Quebec, and at least some of this product may be trucked to PEI processors, where it enters PEI distribution channels.

In the United States, the market is divided roughly into the eastern and western halves of the country, with the dividing line at Chicago. The western market is supplied by producers in Washington State and California, including Taylor Seafood, an integrated multiproduct firm that cultures the Mediterranean blue mussel (*Mytilus galloprovincialis*, referred to colloquially as a "gallo"). Interestingly, retail prices in the western US market have been known to be as much as a $1.00 more per pound than those in the east. In fact, the ITC (2001) found that *Mytilus trossulus* was selling on the west coast at three times the price of *Mytilus edulis* on the east coast. Moreover, NMFS data on California production, which is compiled only annually, suggests, somewhat incredibly, a rough market price of more than $5.00 per pound for gallos. The eastern US market is very competitive, and it is served by the PEI processors, Great Eastern Mussels (GEM) of Tenants Harbor, Maine, and American Mussel Harvesters (AMH) of North Kingstown, Rhode Island.

All of these participants tend to be vertically integrated, broadly defined, with either contracts or informal buying arrangements from suppliers, significant investment in processing capacity, and the means to distribute the product to metropolitan fish houses, supermarket chains, or restaurants. The PEI processors obtain product from surface longline culture (the Japanese or New Zealand method) operations. GEM contracts with independent growers who lease nearshore areas for bottom growout (the so-called Dutch method) or raft culture (the Spanish method). AMH has long standing relationships with independent harvesters who supply bottom grown mussels from the coast of Maine, and it purchases mussels from some of the PEI surface longline operators.

Product differentiation has been achieved mainly by growing a higher quality mussel in comparison with wild harvest product. In general, the differentiated cultured product commands a higher price. The price premium is due almost solely to product quality (Clifton 1980), although there may be significant variability in price for the cultured product over a year. Price differences in processed mussels, regardless of their provenance, now tend to be fleeting, if they exist at all. Nevertheless, mussels of lower quality, such as crude-processed, wild-harvest product, will sell at a discount.

Brooks (1994) found that the mussel processors actively developed innovative marketing campaigns, employing brand names, designing creative packaging, conducting supermarket demonstrations, and developing value-added products. Brand names include Great Eastern, Restaurant Ready® Whitewater, Island Blues (PEI), and Scotian Pride (Nova Scotia). Both farmers and processor/distributors seem to be convinced that branding differentiates their product in the market, but it is likely that this is important only for retailers and restaurant buyers. There is as yet little evidence that consumers are able to distinguish between varieties that originate from different locations or that are produced with different technologies. The absence of a branding premium may be evidence of the immaturity of the industry, as well as the lack of a credible means for certifying brands.

f. Consumer Characteristics and Market Demand

The average price of processed mussels in the United States has been relatively stable over the last decade. In the eastern US market, the demand for most shellfish, and especially mussels, increases in the late summer (August) and in the early winter (December through February). Figure 5 depicts the monthly variability in a market price index for blue mussels that combines imports and domestic production during 1992-2001. The index has been created by weighting price per pound from each source by the relative share of supply from each source. The index does not vary much around the average of $0.85 per pound. Variablity in the price, shown by the thin lines that depict the range of +/- one standard deviation, appears greater in August than in the other months.

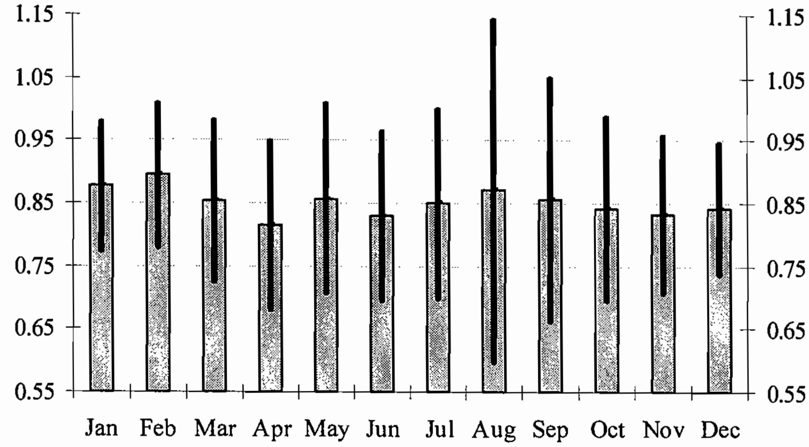

Figure 5. Supply-weighted monthly price of blue mussels during 1992-2001.

Notes: Value per pound of imports and domestic production is weighted by the proportion of US sales from each source. Units are 2003 US dollars per pound of processed blue mussels.

Few studies exist that discuss consumer characteristics and other factors affecting the demand for shellfish, particularly mussels. What studies exist typically are dated or tailored to specific local markets. Consequently, it is difficult to generalize the results of these studies to regional or national markets or to draw lessons for the blue mussel market.

We summarize some general results here:

- Household expenditures on shellfish increase with price reductions (and vice versa) (Cheng and Capps 1988).
- Household expenditures on shellfish increase with coupon value (Cheng and Capps 1988).
- There may be significant variability in purchases of shellfish by season (Capps and Lambregts 1991).
- Household expenditures for shellfish apparently are unaffected by changes in the prices of meats and poultry (Capps and Lambregts 1991).
- In a local market, the effects of advertising on purchases of shellfish are minimal (Capps and Lambregts 1991).
- Shellfish consumption may be significantly affected by socioeconomic factors. Those more likely to consume shellfish include minorities (especially Asians), older consumers, higher income consumers, employed individuals living in small households, and urban dwellers (Nayga and Capps 1995).
- Studies of blue mussel consumption in the Netherlands show that price increases with increases in quality (Gibbs *et al.* 1994).

- Pre-spawning blue mussels, which have a relatively high meat to shell ratio, command a premium over post-spawning stock.
- The demand for mussels can be affected adversely by natural hazards, including harmful algal blooms, causing price to decline significantly (Wessells *et al.* 1995).
- The risk of eating mussels has an adverse effect on the likelihood that consumers will purchase blue mussels (Brooks and Anderson 1994).

We have developed a model of the market for processed mussels imported from Canada using monthly data from 1997 to 2001 on per capita disposable income, fish and shellfish sales, restaurant sales, and prices of substitutes, including the price of domestic mussels (historically a wild harvest or rough processed product), oysters, hard clams, softshell clams, and bay scallops. This model cannot be considered a true demand model, because we have not attempted to distinguish between demand and supply effects. Nevertheless, the model appears to describe the market well, and it could be used to help understand how changes in many of the variables might affect the US market for processed mussels.

We present the elasticities for three versions of the model in Table 9. These numbers represent percentage changes (positive or negative) in the quantity of processed mussels from Canada supplied to the US market that result from percentage changes in the relevant variable. A one percent change in the quantity of imported mussels averages almost 12,000 lbs during this period. Thus, according to Model A, we could predict that a one percent change in restaurant sales, for example, would lead to an increase in imports (which can be interpreted also as an opportunity for domestic supply) of about 20,000 pounds of processed mussels (1.70*12,000).

Table 9. Elasticities from a Model of the Market for Imported Processed Blue Mussels from Canada into the United States*

Variable	Units (1 percent change)	Model A	Model B	Model C
Price of imported mussels	$0.008/lb	-0.47	-0.45	-0.49
US per capita disposable income	$260	1.82	1.71	1.43
US restaurant sales	$104 million	1.70	1.81	2.08
US mussel price	$0.005/lb	0.08	0.09	0.07
Softshell clam price	$0.050/lb	-0.09	-0.08	
Oyster price	$0.028/lb	0.17	0.17	0.15
Hard clam price	$0.065/lb	0.13		
Bay scallop price	$0.021/lb	-0.03	-0.02	
Sea scallop price	$0.062/lb	-0.09		

*Imports from Canada are used as a proxy for the market for processed blue mussels in the eastern United States. More detail on the model specifications and the model data are available upon request from the authors.

g. Summary

Mussel production has been increasing worldwide. The market for mussels in eastern North America, supplied primarily by producers on Prince Edward Island and in Maine, has been among the leaders in this growth. Production is ramping up in all of the other Canadian maritime provinces, and R&D projects are well advanced in the New England states.

The market can be defined as trade in a processed (cleaned) blue mussel in eastern North America. Processors purge, declump, grade, debyss, package, and distribute mussels. Processors add value to the raw product and ensure a consistent and steady supply to downstream customers or distributors. Some branding is present for the wholesale trade, but final consumers do not appear to distinguish mussels by source. This feature of the market could change as the market grows and consumers become more sophisticated.

There may be lessons for prospective growers to draw from experience in the development of the industry in Newfoundland. These lessons relate to the importance of husbandry and the potential for geographic clustering economies that may exist when farms are linked, formally or informally, to a processor/distributor.

Changes in the quantity of processed mussels supplied and purchased in the market are associated with general market conditions, such as restaurant sales and disposable income, and also fluctuations in the price of substitute shellfish.

5. Institutional Mechanisms for Mitigating Risk in the Ocean Culturing of Blue Mussels

a. Introduction

Mussel growers must assess the financial and administrative benefits and costs of alternative organizational forms, including individually owned businesses, partnerships, general business corporations, limited liability companies, or cooperatives (Frederick 1997). For the prospective small-scale mussel farmer, the choice may be effectively limited to either going it alone as an individually owned business or joining with others in a cooperative. Here we present an overview of some issues relating to the cooperative choice. We also identify and describe two other forms of cooperation that could lead to future payoffs: marketing orders and trade associations.

b. Cooperatives

In 1995, more than 4,000 agricultural cooperatives were operating in the United States, comprising almost 4 million members and generating over $2 billion in net earnings on more than $100 billion in sales (Frederick 1997). One of the primary reasons for the establishment of a cooperative is to raise profits by increasing market power. One way to increase market power is through greater horizontal concentration. Recent mergers and acquisitions in agricultural cooperatives have been primarily horizontal, which suggests that cooperatives are seeking to increase their market power (Hudson and Herndon 2000).

Cooperatives must be organized according to specific rules, which typically are embodied in state law. These rules include requirements that the cooperative be operated for the mutual benefit of its members, voting rights are not tied to capital investments, and limits exist on the payment of dividends to shareholders, among others.

In 1980, over 100 commercial fishing cooperatives existed in the United States, comprising more than 10,000 fishermen (Garland and Brown 1988). Fishing cooperatives may be established under the 1934 federal Fishery Cooperative Marketing Act. Since 1934, several judicial decisions have made clear the limits on the ability of fishing cooperatives to exert market power by anti-competitive means, such as by fixing prices or restricting production, even where such practices might lead to the beneficial conservation of fish stocks. More recent federal legislation now permits the establishment of fishing cooperatives in specific fisheries, such as those for groundfish off the west coast (Adler 2002).

In the case of aquaculture, examples of cooperative functions might include the operation of fish hatcheries, feedstock supply, value-added processing, insurance, market intelligence, and the marketing and distribution of cultured seafood. Where the industry is building up from small-scale or part-time growers who require technological expertise, processing facilities, and a market for their product, cooperatives may contribute to the reduction of risks for individual firms. Thus, small agricultural-type cooperatives have begun to be established for growing catfish, shrimp, and hybrid striped bass. Examples include the Southern Kentucky Aquaculture Cooperative and the Illinois Fish Farmers Cooperative.

Cooperatives can serve one or more of the following general functions:

- enhance bargaining power relative to downstream consumers (who may be processor/ distributors);
- reduce the costs of inputs through volume purchasing, including the costs of purchasing insurance on various aspects of grower operations;
- provide growers with access to a market;
- broaden market opportunities;
- add value through processing;
- exploit economies of scale and reduce duplication in processing; and
- improve the consistency of product quality.

Where market volatility increases uncertainty about the returns to investment in aquaculture, downstream processors might have opportunities to take advantage of producers. This is known as a "holdup" problem. Even the signing of contracts may not preclude holdups, because contracts may be incomplete. The possibility of opportunism may force prospective aquaculture entrepreneurs to make investments at lower levels or more slowly than they might in the absence of uncertainty. Schrader (1989) explains that this is one of the classic reasons for the establishment of processing or marketing cooperatives.

Downstream of fishermen and seafood farmers, there appears to be little concentration in the seafood processing industry, which is capable of handling a wide variety of raw products and for which there are few serious barriers to entry. The blue mussel processor/distributors, however, have made significant capital investments in grading, cleaning, and debyssing equipment and separate holding tanks for blue mussels (needed because mussels will byss-up if placed in a tank with clams). In theory, the potential geographic clustering economies referred to earlier could lead to incentives for the formation of mussel grower cooperatives to balance the market power of downstream processor/distributors or for growers to establish their own processing capability. The evidence for this is thin, however. For example, there has been some establishment of grower marketing cooperatives for blue mussels on PEI, but these tend to be unstable, in part because of competition from other growers.

Some market participants hypothesize that in the early stages of industry development, cooperatives may serve as a catalyst for the growth of the industry by reducing market risks. In New Zealand, for example, green-lipped mussel growers formed cooperatives in the early years of that industry, where mussels were first farmed to supply a market for a nutraceutical end-use. The cooperatives failed as the market for a frozen product was developed and matured, and large, fully-integrated commercial fishing companies entered the business. A competitive fringe of small producers still exists in the New Zealand industry, and small and large growers are members of the Mussel Industry Council, a trade association that develops quality standards and codes of practice, protects intellectual property rights, conducts market promotions, and serves as the voice of the mussel industry.

Although cooperatives do exist in the aquaculture industry, the cooperative business model appears to have been utilized to a lesser extent in this industry than in agriculture generally. Although it has encountered some legal problems in its historical attempts to control the market for cultured catfish, the Delta Pride cooperative in Mississippi may be a leading example of a successful cooperative in the freshwater aquaculture business. Delta Pride is fully vertically integrated from hatcheries through distribution. The growth of the catfish aquaculture business during the last 20 years has been impressive, attracting foreign entry, such as the export of basa, masquerading as "catfish," from Vietnam into the US market.

For small-scale, part-time freshwater growers who participate in cooperatives, a source of risk reduction comes in the form of farm product diversification, where farms produce other non-seafood agricultural or dairy products. Analogously, in the open-ocean case, aquaculture can be seen as a way for commercial wild-harvest fishermen to diversify their seafood production businesses.

Importantly, to the extent that supply can be maintained, the risks of supply disruptions to downstream consumers can be reduced through a cooperative. PEI mussel production provides an example, although it is not strictly limited to the cooperative concept. Thus, in the PEI situation, growers that are hit by harmful algal blooms may have to halt harvests for a period of time until their product detoxifies *in situ*. Yet there are enough growers to ensure that product continues to be supplied to the market; this geographic diversification reduces the risk of supply disruptions. One possible result is that downstream consumers may be willing to pay a premium for a consistent source of supply from a geographically diversified cooperative.

c. Marketing Orders

Another form of collective action is permitted under federal authority to establish "marketing orders" for agricultural commodities. Marketing orders authorize the establishment of a committee of growers and handlers (processors and distributors) to stabilize the markets for fruit, nut, or vegetable products. Successful stabilization may reduce the market risks faced by farmers. Although marketing orders are an interesting concept, we are unaware of an authority for the implementation of marketing orders in seafood commodities.

A marketing order allows the establishment of product and marketing standards that differentiate a product from substitutes. Standards may include those for minimum grade, size, quality, and maturity of product and those relating to the size, capacity, weight, and dimensions of containers. Container standards are designed to eliminate deceptive distribution practices and pricing. Other purposes of marketing orders include the compilation and publishing of market information; the establishment of volume controls (quotas) or pooled reserves to ensure production; the sponsorship of research on production and marketing; and market promotion, including advertising.

A good recent example of the application of a federal marketing order concerns the Vidalia onion, a variety of sweet, mild, hybrid yellow Granex onion grown in a specific geographic area in Georgia (Clemens 2002). Vidalia onions command a significant premium in the market for onions. The existence of this premium attracts entry into the market, including the rebagging and mislabeling of non-Vidalia onions as Vidalias. (Mislabeling has been an issue also in the market for shellfish.) The issuance of a federal marketing order permitted growers and handlers to jointly fund market promotion, set a quality standard, and sponsor research on technology to extend the shelf life of fresh onions. The latter activity led to a capacity to lengthen the duration of the fresh market and control supply more effectively. While some market risks are controlled, the production of Vidalia onions is still subject to environmental risks, however, including weather, insects, and disease.

d. Trade Associations

There does not appear to be historical precedent for the use of either horizontal or vertical coordination explicitly to reduce the costs of risk in the blue mussel industry. A possible exception is the wide use of trade associations, which may reduce market risks through the supply of information. Trade associations in aquaculture also serve important roles by acting as a "voice" for the industry in legislative deliberations and commenting on proposed rules; in the adoption of best management practices or codes of conduct; in the development of product quality standards; in the establishment and protection of intellectual property, including brand names or trademarks; and in advertising and market promotions. An East Coast Shellfish Growers Association, modeled after the successful Pacific Coast Shellfish Growers Association, is now under development for a variety of cultured shellfish products grown in the eastern United States.

e. Summary

We have reviewed some of the benefits of cooperation among aquaculture operators. Where the industry is building up from small-scale or part-time growers who require technological expertise, processing facilities, and a market for their product, cooperatives may contribute to the reduction of risks for individual firms. Unlike other agricultural products, few cooperatives exist in aquaculture.

Other forms of cooperation include marketing orders, which do not yet exist for the aquaculture industry, and trade associations. Trade associations in aquaculture serve important roles by acting as a "voice" for the industry in legislative deliberations and by commenting on proposed rules; in the adoption of best management practices or codes of conduct; in the development of product quality standards; in the establishment and protection of intellectual property, including brand names or trademarks; and in advertising and market promotions. A trade association is now emerging for the shellfish industry on the US east coast.

B. Problems Encountered and Their Consequences for Results

No problems were encountered that significantly affected the project results, although some research effort was reallocated from Task 4 to Tasks 2 and 3 during the second year of the project. As explained below, this reallocation of effort also entailed a one-year extension of the project schedule.

Task 4 called for an examination of the behavior of the risk investment model (Task 2) using sensitivity analyses to characterize the effects of regulatory changes and alternative levels of public financial support on investment in the industry. Publicly subsidized crop insurance was the policy instrument selected for examination as a potential tool to mitigate risk in aquaculture markets. Considerable progress was made on the development of a numerical example using parameter estimates obtained from a model of a netpen operation for the culturing of summer flounder. As this work proceeded, however, the research team became aware of two circumstances suggesting that further work on this task might not be the most fruitful line of effort at this time. First, they reviewed a new study which reported that the availability of crop insurance was severely constrained in all the relevant markets as a result of poor underwriting results stemming from severe losses in almost all areas of the industry that were insured (Secretan, n.d.). Second, the recently established National Risk Management Feasibility Program for Aquaculture (NRMFPA) had made crop insurance an important focus of its own research agenda, so the potential existed for a substantial duplication of effort between the two projects.

The research team decided to redirect its effort from Task 4 to two other activities: developing the simulations of the risk assessment framework using the case of Atlantic cod, and extending its series of interviews with participants in the aquaculture industry. The interview responses were used for two main purposes: to help validate the models of industry investment under risk (Task 2); and to confirm the research team's understanding of the structure of the blue mussel market (Task 3). The research team requested and was granted a one-year, no-cost extension to the original project schedule in order to complete the additional interviews.

C. Need for Additional Work

The analyses reported in Section VI.A point to several areas where additional research can be fruitfully undertaken to enhance understanding and improve the management of risk and uncertainty in aquaculture operations. We briefly discuss several such topics below.

- Our regulatory analysis identified and rank-ordered 11 areas where policy and legal issues appear to constrain the growth of the aquaculture industry. A logical next step is to develop an industry strategy for surmounting existing regulatory constraints. We suggest a research approach that focuses on the economic feasibility of open-ocean aquaculture and assesses its business requirements and constraints as a way to identify specific policy changes that would favor industry growth and development.

- Issues relating to restraint of interstate trade ranked fairly high in importance on our list of regulatory constraints. Future research might usefully be directed at characterizing laws and policies at the state level that relate to animal health, including disease inspections and certifications, and those that restrain trade on the basis of conserving and managing wild harvest fisheries.

- Another topic that received much comment from those interviewed for the regulatory analysis was the development of best management practices (BMPs), a set of normative principles that does not involve explicit regulation but rather is the product of industry consensus, sometimes guided by government agencies. It would be useful to conduct legal and policy research toward understanding the implications of BMPs for market structure, their effectiveness in achieving stated objectives, their costs in comparison to government regulation, and their resiliency over time.

- In light of the complexity and diversity of the US aquaculture industry, it would be useful to conduct additional in-depth analyses of industrial organization and market structure for additional species of finfish and shellfish, as was done in this study for the blue mussel industry and market.

- The economic modeling component of this project investigated how risk and uncertainty in open-ocean aquaculture affect firm-level investment decisions. An important follow-on to these modeling efforts would be to develop market-oriented projections of the future expansion of an open-ocean aquaculture industry as a whole. Most efforts to project industry growth have focused on coastal ocean operations and on local environmental assimilative capacity as the main constraint determining the socially optimal level of an aquaculture operation. Since assimilative capacity is not likely to present a serious constraint to aquaculture in the open ocean, however, a more realistic projection of industry size would be one based on the net demand for farmed fish in a market where the product may be supplied by a wild harvest fishery, by an open-ocean aquaculture industry, or by both.

Researchers at the WHOI Marine Policy Center have already begun work on some of the research activities mentioned above. For example, with support from the STAR Grant Program of the EPA, they have begun development of a market-based projection of the future expansion of an ocean aquaculture industry for farmed Atlantic cod.

VII. Evaluation

A. Extent to Which the Project Goals and Objectives Were Attained

The main goal of the project has been to identify and characterize institutions and public policies appropriate for reducing the costs of risk and uncertainty that have precluded the emergence and development of an open-ocean aquaculture industry. This goal was attained through a series of tasks involving legal research, reviews of the relevant social science and industrial organization literature, data collection on the blue mussel industry and market, surveys and interviews of industry participants and state resource managers, and economic modeling and simulation of industry investment under risk. These tasks were conducted to support analysis organized into four main topics: industry organization and market structure, regulatory and other sources of risk and uncertainty to the industry, industry investment under risk, and appropriate industry-based institutions and public policy instruments for managing risk.

Based on a comprehensive review of the literature, legal research, and a series of industry surveys and interviews, our regulatory analysis identified 11 legal and policy issues that appear to constrain growth in the aquaculture industry. These 11 issues were rank-ordered in terms of how significant a constraint they represent. In addition, the analysis of industrial organization and market structure in the blue mussel industry identified specific risks associated with foreign competition, disease and predation, environmental effects, and economic returns. The regulatory and industrial analyses also identified institutions from the public policy and the industrial arenas that show promise for mitigating risk and uncertainty.

In terms of more quantitative analysis, we developed economic models of firm-level investment under risk and used data for farmed Atlantic cod to quantify the impacts of changing risk attitude and risk level on investment level. We also used the model and the cod dataset to calculate the critical value at which it is optimal for a firm to invest in a cod farm.

Activities undertaken by the project team to present their findings to industry, natural resource management agencies, and the public are described in the next section.

B. Dissemination of Project Results

The methodologies and results of the regulatory and industrial analyses were presented at major national and international conferences that were attended by natural resource managers and industry participants and regulators. Along with the modeling exercises, the regulatory and industrial analyses are also the subject of papers that have been published or submitted for publication in the peer-reviewed and/or topical literatures. More specifics on these various presentations and publications are provided in the list below.

Presentations and publications based on the regulatory analysis:

- Presentation entitled "A Review of Legal and Policy Constraints to Aquaculture in the US Northeast" at the 24th Milford Aquaculture Seminar, hosted by the National Marine Fisheries Service in Milford, CT, February 23-25, 2004.
- Abstract of the Milford presentation published in Volume 23, No. 2 of the *Journal of Shellfish Research* (Duff et al. 2004).
- "A Review of Facilitating and Constraining Aquaculture Policy and Regulation," published as Aquaculture White Paper No. 5 of the Northeastern Regional Aquaculture Center (Duff et al. 2003).

Presentations and publications based on the analysis of the blue mussel industry:

- Presentation and Abstract entitled "Economics of Offshore Culture of Blue Mussels in Southern New England" at the annual meeting of the World Aquaculture Society, Honolulu, Hawaii (March).
- "Business Planning Handbook for the Ocean Aquaculture of Blue Mussels" (Hoagland, Kite-Powell, and Jin 2004).

Publication based on the firm-level investment-production model:

- A complete account of the risk assessment framework and the illustration using Atlantic cod has been submitted for publication to *Aquacultural Economics and Management* (Jin, Kite-Powell, and Hoagland 2004).

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