Aquaculture Regulation: Economic and Legal Models for the US Exclusive Economic Zone

Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

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II. Abstract

This research project focuses on problems of "access" to ocean space in the US Exclusive Economic Zone (EEZ) as one of the principal impediments to realizing the nation's potential in aquaculture. The problem of access to sites for ocean aquaculture operations is fundamentally a problem of how a public resource (ocean space) should be allocated to its highest and best use. This project was designed to: (1) develop a framework for analyzing access system design; (2) characterize an economically "optimal" access system for ocean aquaculture operations; and (3) complement, using economic analysis, current efforts by academics, public interest groups, federal agencies, and the US Congress to develop laws and regulations governing ocean aquaculture in the US EEZ.

More generally, the project results demonstrate the utility of an approach to optimal allocation of ocean space from an economic point of view. Specifically, we have developed: (1) a model of market demand for sea scallops and blue mussels in New England and an economic analysis of their growout in open ocean aquaculture operations; (2) a bioeconomic model of finfish growout operations in New England waters; (3) a model of the optimal scale of an open-ocean aquaculture operation when it leads to adverse biological or economic impacts on a commercial fishery operating in the same region; and (4) a policy analysis that characterizes access systems in terms of certain generic features and that posits an economically efficient system as a baseline for clarifying the costs and benefits of systems designed to achieve alternative public policy objectives. Together, these four project components comprise a policy analysis framework that demonstrates the method by which decisions to site aquaculture facilities can be made on the basis of economic criteria.

III. Executive Summary

The key project findings and needs for future research can be summarized briefly as follows:

The open ocean growout of certain species of shellfish may be economically viable in southern New England. For sea scallops, the most promising approach appears to be seabed seeding. Blue mussels can be grown to market size in less than two years, and submerged longlines with hanging grow ropes are the preferred approach. Risks from the loss of crops are significant, but diversification across two or more crops may alleviate risk and help achieve full utilization of support vessels at relatively modest scales of operation.

Using the New England sea scallop market as an illustration, the project has demonstrated how simple simulations can be performed to model the impacts of changes in a given market on supply and demand. Useful refinements of the model can be pursued through simulations that use (i) alternative specifications (*e.g.*, the factors that determine demand); (ii) more detailed data (*e.g.*, the temporal distribution of product inventories, or the prices of an aquaculture operation's competing imports from different countries or into different US geographic markets); or (iii) alternative techniques to estimate parameters (*e.g.*, a three-stage least squares method to estimate market demand).

The open ocean growout of certain species of finfish (e.g., Atlantic cod, halibut, summer flounder) may be economically viable in New England, even for relatively low-value species such as cod. The most significant cost components by far are fingerlings and feed, but a variety of factors influence the economic viability of a growout operation. A bioeconomic model is therefore a valuable tool for analyzing the tradeoffs among specific design decisions and input costs.

Numerical simulations of our model for identifying the optimal scale of an aquaculture operation in the same geographic region as a wild harvest fishery identified one or more characteristics of each mode of seafood production that influence the scale and viability of the other in ways that are consistent with intuition. For example, when aquaculture exerts a significant negative impact on a wild-harvest fishery, the co-existence of the two types of operations often is suboptimal and the region should be used exclusively for either aquaculture or commercial fishing, Where the two uses must coexist, (i) the long-run equilibrium aquaculture acreage must decline as the operation's impact on the ecosystem carrying capacity for the wild stock is increased; and (ii) a faster growth rate and a greater ecosystem carrying capacity for the wild population can accommodate a larger scale of aquaculture.

The study also produced some results that are counterintuitive on the surface and raise important questions for future research, such as the finding that the steady-state scale of an aquaculture operation expands as the costs increase. A review of existing access systems for US onshore public natural resources and for aquaculture in US coastal states and foreign jurisdictions suggests certain generic attributes or design features that are useful for drawing lessons from disparate systems. We characterize a system comprised of economically efficient attributes that serve as a baseline against which alternative design features may be evaluated.

Recognizing that other public policy objectives may be regarded as on a par with or superior to economic efficiency, we develop the argument that positing an economically efficient system can help to clarify the benefits and costs of adopting a system that trades economic efficiency for other public policy goals. The method and argument are developed with reference to NOAA's proposed National Marine Aquaculture Act (NMAA) of 1999, in which the higher priority (relative to aquaculture) accorded to navigation, fishing, recreation, national defense, and other established activities, regardless of their economic value, is identified as the leading and most significant potential source of inefficiency.

The institutional environment as we have characterized it (*i.e.*, the NMAA of 1999) will be in need of updating to reflect changes in relevant legislation or executive policy and organization. In the near future, one of the more likely catalysts for such changes may be the deliberations of the recently appointed Presidential Ocean Commission.

While the project has successfully demonstrated the utility of an economic approach to optimal control of ocean space, it was beyond the scope of the project to specify and optimize a social welfare function. Actual implementation of the approach will require the collection of more specific data, which can be guided by this project's preliminary identification of the objectives upon which social welfare depends—in particular, economic efficiency, fairness, and environmental sustainability.

Continuing research along these lines is already under way with sponsorship from a separate research grant awarded to the Marine Policy Center in September 2000 through the NOAA National Marine Aquaculture Initiative (NMAI). Some of the key elements of MPC's NMAI project include the compilation of additional data on the uses and environmental characteristics of the New England marine environment; refinement of the operational aquaculture models to gain a clearer understanding of the effects of increased transportation costs on net benefits; and the incorporation of a spatial dimension and of additional end uses (besides wild harvest fish production) into the optimal allocation model to allow the estimation of the net benefits of alternative uses in specific "zones" and an examination of the tradeoffs among uses.

IV. Purpose

A. Problem or Impediment of Fishing Industry That Was Addressed

With many natural "wild capture" fish stocks exploited at or beyond capacity, the world has turned to aquaculture to supply the growing global demand for seafood. Aquaculture also holds the promise of as-yet inchoate opportunities for redeployment of labor and capital displaced from depleted wild fisheries (EOEA 1995). Nevertheless, the United States has yet to realize its potential in the growing aquaculture industry. Compared to aquaculture's 25% share of seafood production worldwide, in the United States it accounts for less than 5% of seafood production.

This research project has focused on problems of access to ocean space in the US Exclusive Economic Zone (EEZ) as a principal impediment to realizing the nation's potential in aquaculture. Ocean aquaculture operations are designed to constrain the stocks being raised to specific geographic areas using nets, pens, or other technologies. The site-specific nature of aquaculture requires "security of tenure" (limited property rights) to designated areas of ocean space, possibly including the underlying seabed and neritic and surface waters (Rieser 1997; Wildsmith 1982). Without security of tenure, other uses of the ocean may impinge on aquaculture operations (cf. Posner 1986) and investment capital is likely to be scarce (Cahill 1993; Kornfeld 1993).

The allocation of rights to ocean space is a contentious issue, particularly in the absence of a coordinated national policy governing the allocation of ocean space between aquaculture and competing uses. Currently the United States has only a rudimentary, *ad hoc* system for providing access to ocean space for aquaculture purposes. The most salient feature of the existing regime is that there is no institution in US law or policy providing for the establishment of property rights for open-ocean aquaculture, and no agency with responsibility for providing access to specific areas of the ocean for such purposes. Some proposals to establish an access system for ocean aquaculture have surfaced in the executive and legislative branches during the last few years, but so far none has been adopted.

B. Objectives of the Project

The problem of access to sites for ocean aquaculture operations is fundamentally a problem of how a public resource (ocean space) should be allocated to its highest and best use. This project has been designed to: (1) develop a framework for analyzing access system design; (2) characterize an economically "optimal" access system for ocean aquaculture operations; and (3) complement, using economic analysis, current efforts by academics, public interest groups, federal agencies, and the US Congress to develop laws and regulations governing ocean aquaculture in the US EEZ.

More generally, the project is intended to demonstrate the utility of an approach to optimal allocation of ocean space from an economic point of view. Recognizing that other public objectives may be favored over economic efficiency, the research reported here posits an economically efficient system in order to promote a clearer understanding of the benefits and costs of adopting a system that trades economic efficiency for other public policy goals.

The focus for data collection and application of the economic optimization models is the ocean environment off the coast of New England, but the research results are more broadly applicable. Thus, the project is intended to help the New England Region of NMFS achieve its strategic objective of stimulating an increase in gross revenues from aquaculture, and it also responds to NOAA's broader funding priority of promoting aquaculture development in the marine environment.

V. Approach

A. Work Performed

The research project consisted of the six steps[1] described in the following paragraphs. Figure 1 outlines the general methodological framework for the design of an optimal access system for ocean aquaculture.

Step 1: Literature Search, Review, and Analysis

The first step of the project entailed a thorough search and review of the literature on optimal access system design for natural resources. The primary focus for the review was lessons to be drawn, including economic models and comparative policy analyses, from the design of access systems for other public resources (e.g., offshore oil and gas, offshore hard minerals, federal timber and grazing lands. Also included in the literature search and review were analyses of the benefits and costs of ocean aquaculture operations.

The literature was reviewed and analyzed to identify (1) relevant theories, including recent advances in auction theory, and (2) sound empirical work that contributes information useful for the design of an optimal access system for ocean aquaculture operations.

Step 2: Examination of US Coastal State and Foreign Access Systems

The second step of the research project involved an examination of historical practice and current operation of access systems for freshwater and ocean aquaculture operations in the internal waters and territorial seas or on the submerged lands of US coastal states and foreign countries. In addition to a search of the substantial literature on comparative practice in nearshore coastal aquaculture operations, this aspect of the research project involved in-person and telephone interviews with coastal and marine resource managers in the New England states and with the Aquaculture Oversight Committee of the New England Fisheries Management Council (NEFMC).

Step 3: Characterization of the Resource and its Uses

In step three, the research team focused on coastal New England in developing a detailed description of the resource to be allocated (ocean space), its relevant attributes, and the potential economic side-effects (whether positive or negative) that are likely to occur if allocations to aquaculture are made. The researchers also examined the

[1] The original plan called for a seventh step, the convening of an experts meeting, which was ultimately deleted from the project plan of work for the reasons indicated in Section VII.A.

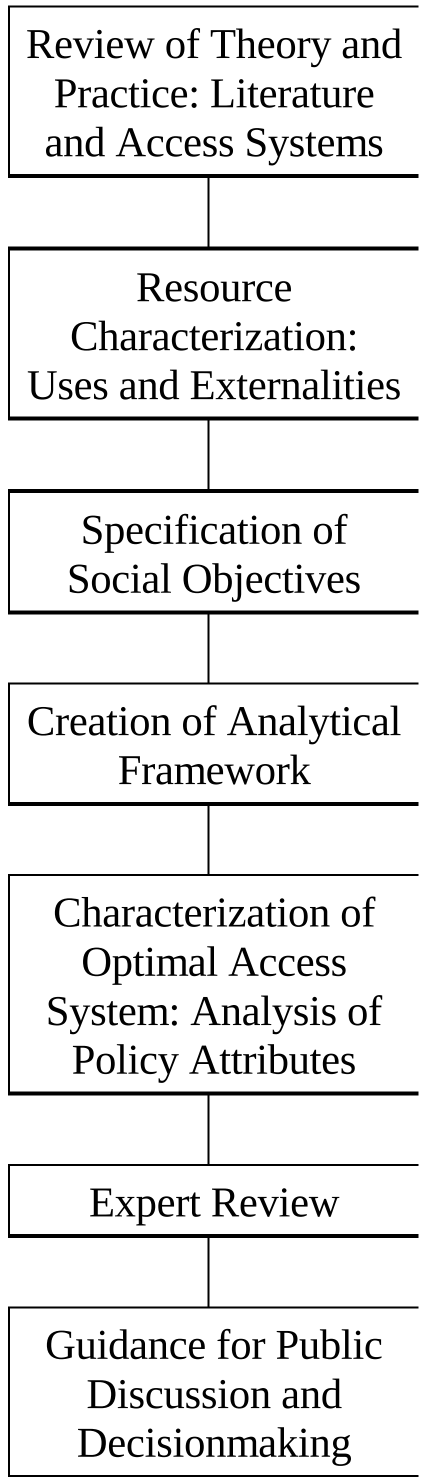

Figure 1. Policy analysis methodology

hypothesis that only limited areas of ocean space can be considered desirable sites for aquaculture (whether because of environmental conditions, the size of transportation costs, or institutional constraints such as public trust–type priorities) and therefore may be scarce and in demand.

Collecting the necessary information for this part of the project required searching the literature and public data sources and conducting interviews with relevant government officials, scientists and engineers, commercial fishermen and aquaculturists, and public interest groups.

Step 4: Identification of Social Objectives

This part of the project involved discussions with experts from government, industry, and academia to begin to identify the objectives for access to ocean space upon which social welfare depends. Some potential user groups and federal agencies have already specified certain objectives and identified specific legal requirements of ocean aquaculture operations. In step 4 of the project, the research team developed a broader list of interest groups and public objectives that may exist and would appear to require tradeoffs in order to optimize social welfare with respect to ocean access for aquaculture.

Step 5: Creation of a Policy Analysis Framework

Step 5 involved an application of relevant economic theory and empirical work to identify and clarify the issues that impinge on the design of an economically optimal access system for ocean aquaculture (cf. Hartwick 1989; Tiesberg 1980; Kalter, Tyner and Hughes 1975). Particular attention was paid to the characteristics of the resource and the potential side-effects of aquaculture operations.

The key activities in step 5 were the development of a method for estimating the net present values (NPVs) of several classes of aquaculture operations (e.g., finfish vs. shellfish; nets vs. pens vs. cages) in the US EEZ off New England; the definition of New England "iso-NPV" zones (*i.e.,* where the NPV of a given type of aquaculture operation does not vary); the comparison of NPVs for aquaculture vs. those associated with alternative uses of ocean space in the same area; and an examination of the interaction between an open-ocean aquaculture operation and a pre-existing wild harvest fishery when aquaculture adversely affects the fishery. The last of these activities involved the development and application of an optimal control model to determine the optimal scale of both the aquaculture operation and fishing effort so that the net benefit from fish production from the two combined is maximized.

In principle, the modeling and analysis carried out in step 5 can determine an economically *efficient* allocation of ocean space. However, in view of the likelihood that one or more pre-existing uses will be preferred over aquaculture, the research in this step also included an examination of the extent to which activities and institutions associated with alternative uses of ocean space should be treated as constraints--that is, given an arbitrarily high NPV--in the policy analysis framework. In such cases, the approach demonstrated in step 5 can be used to identify a *cost-effective* allocation of ocean space.

Step 6: Characterization of an Optimal Access System

In step 6, the research team drew upon their review of the literature, discussions with interested parties, and their identification of various social objectives to posit a set of policy attributes of an access system for open-ocean aquaculture. For each attribute, they first posited an economically efficient "baseline" arrangement and then considered possible modifications to the baseline that would permit the achievement of alternative social objectives. They also analyzed some of the positive or negative consequences of various deviations from the baseline case. To illustrate the use of this analytic framework, they also assessed the extent to which certain features of a NOAA-proposed system can be considered "optimal" from an economic standpoint. Finally, they identified the data requirements and relevant economic models or methodologies that will be needed to design and implement a comprehensive access system for open-ocean aquaculture.

B. Project Management

The project was managed and conducted by the Co-Principal Investigators, Drs. Porter Hoagland and Di Jin, who were involved in all aspects of the research and in each step of the project workplan. Dr. Hauke Kite-Powell of the Marine Policy Center was a collaborator in all phases of the project and made particularly significant contributions to the methodology for the estimation estimation of NPVs for shellfish and finfish aquaculture operations off New England. Dr. Ken Riaf, an attorney and currently the Co-Director of the Gloucester Aquaculture Project in Massachusetts, collaborated in the analysis of the legal aspects of regulatory constraints affecting the siting of offshore aquaculture operations. Research assistance was provided by Mary Schumacher and Kimberly Murray and secretarial assistance was provided by Gretchen McManamin.

VI. Findings

A. Accomplishments and Findings

1. Summary of Project Highlights

Key accomplishments and findings are reported in this section as part of detailed accounts of the modeling exercises and economic and policy analyses conducted in steps 5 and 6 of the research project. These exercises and analyses include (1) a model of market demand for sea scallops and blue mussels in New England and an economic analysis of their growout in open ocean aquaculture operations; (2) a bioeconomic model of finfish growout operations in New England waters; (3) a model of the optimal scale of an open-ocean aquaculture operation when it leads to adverse biological and/or economic impacts on a commercial fishery operating in the same region; and (4) a policy analysis that characterizes access systems in terms of certain generic features and that posits an economically efficient system as a baseline for clarifying the costs and benefits of systems designed to achieve alternative public policy objectives. Together, these four project components comprise a policy analysis framework that demonstrates the method by which decisions to site aquaculture facilities can be made on the basis of economic criteria.

In addition to the key accomplishments and findings reported in the remainder of this section, several significant work products developed in the course of steps 1 through 4 of the project are contained in an Appendix (Section IX of this report). These include a preliminary GIS presentation of data on the annual gross revenue associated with various ocean uses in the US Northeast region; a GIS display showing the geographic limits of an economically viable fluke (flounder) growout operation in New England; and detailed comparisons of access systems for US onshore natural resources, for aquaculture operations in the waters of selected New England states; and for aquaculture operations in the EEZs of Norway, Scotland, and Ireland.

The key findings developed in the four modeling and analytic components of the project can be briefly summarized as follows:

Market demand model and economic analysis of shellfish aquaculture operations in New England:
Open ocean growout of shellfish can be economically viable in southern New England. For sea scallops, the most promising approach appears to be seabed seeding. Blue mussels can be grown to market size in less than two years, and submerged longlines with hanging grow ropes are the preferred approach. Risks from the loss of crops are significant, but diversification across two or more crops may alleviate risk and help achieve full utilization of support vessels at relatively modest scales of operation.

Bioeconomic model of finfish aquaculture operations in New England:
Open ocean growout of finfish is economically viable in New England, even for

relatively low-value species such as cod. The most significant cost components by far are fingerlings and feed, but a variety of factors influence the economic viability of a growout operation. A bioeconomic model is therefore a valuable tool for analyzing the tradeoffs among specific design decisions and input costs.

Model of the optimal scale of open-ocean aquaculture:
When aquaculture exerts a significant negative impact on a wild-harvest fishery, the co-existence of the two types of operations often is suboptimal and the region should be used exclusively for either aquaculture or commercial fishing, Where the two uses must coexist, (i) the long-run equilibrium aquaculture acreage must decline as the operation's impact on the ecosystem carrying capacity for the wild stock is increased; and (ii) a faster growth rate and a greater ecosystem carrying capacity for the wild population can accommodate a larger scale of aquaculture.

Comparison of natural resource access systems and lessons drawn for the design of a system for allocating ocean space:
A review of existing access systems for US onshore public natural resources and for aquaculture in US coastal states and foreign jurisdictions suggests certain generic attributes or design features that are useful for drawing lessons from disparate systems. Here we posit a system comprised of economically efficient attributes that serve as a baseline against which alternative design features are evaluated. Recognizing that other public policy objectives may be regarded as superior to economic efficiency, we develop the argument that positing an economically efficient system can help to clarify the benefits and costs of adopting a system that trades economic efficiency for other public policy goals. The method and argument are developed with reference to NOAA's proposed National Marine Aquaculture Act of 1999, in which the higher priority (relative to aquaculture) accorded to navigation, fishing, recreation, national defense, and other established activities, regardless of their economic value, is identified as the leading and most significant potential source of inefficiency.

2. <u>Analysis of the Economics of Open Ocean Growout of Shellfish in New England (Sea Scallops and Blue Mussels)</u>

The viability of open ocean aquaculture depends on the technical and biological feasibility of growing aquatic species in the open water, on regulatory constraints, and on the economic viability of the operation. Focusing on the last of these constraints, in this component of the project we modeled the economics of open ocean growout of two species of shellfish: sea scallops (*Placopecten magellanicus*) and blue mussels (*Mytilus edulis*). The models were informed by the results of offshore growout experiments conducted in southern New England in the mid- and late 1990s, and they illustrate the conditions under which open ocean shellfish growout operations can be profitable.

We look first at scallops and then at mussels. For each species, we first consider the market demand, which determines the price the shellfish will command at the dock.

We describe demand modeling in some detail for scallops and present only the results for blue mussels. Then, we consider the economics of the growout operation to determine economic viability. We examine several possible growout technologies for sea scallops but confine the mussel analysis to a single technology (submerged longlines).

a. Sea Scallops

Whether offshore sea scallop aquaculture becomes commercially viable will depend upon both the costs of growing scallops relative to wild harvest operations and conditions in the relevant product market. Our analysis focused on these two aspects.

We have constructed a discounted cash flow model of the growout of sea scallops at a nearshore or offshore farm site. This analysis helps us to predict commercial feasibility. There are several sources of uncertainty in the cash flow model. An important source of uncertainty is the exvessel price for sea scallops. In order to help manage this uncertainty, we also developed and estimated a model of supply and demand for New England sea scallops.

There are other reasons for modeling price formation in the market for sea scallops. One reason is to gain a deeper understanding of the kinds of factors, such as scallop imports, substitute seafood products, inventories, consumer wealth, among others, that may influence demand. Other factors, including fishing effort, stock size, fishing costs, and technological change, may influence the supply of sea scallops. Aquaculture entrepreneurs will need to consider all of these factors in order to develop and run a successful operation.

i. New England Market Demand for Sea Scallops

In this section, we review briefly earlier studies from the published literature that have estimated demand for scallops. Next we present time series data that help us to gain an understanding of the market. Finally, we present our demand and supply estimation method, and we estimate demand for sea scallops in New England using monthly data during the period 1985-93. We show how simple simulations can be performed to model the impacts of changes in the market on supply and demand. We emphasize that the results of this analysis are preliminary. Clearly, the model can be refined with additional massaging of the data or alternative specifications. As we discuss the model, we point out areas in which improvements might fruitfully be made.

Previous Work

Table 1 compares studies from the published literature in which analysts have developed models of demand, supply, or price prediction. Models of supply and demand rely upon basic price and quantity data from the relevant market as well as other determinants. Price prediction models do not attempt to distinguish demand from supply[2]; they use quantity and other variables to estimate price directly.

Table 1
Economic models: scallops

Authors	Price Prediction	Demand	Supply	Data
Altobello, Storey and Conrad (1976)		X	X	1952-72 (annual)
Storey and Willis (1978)		X		1953-76 (annual)
Kellogg, Easley and Johnson (1988)†	X			1974-83 (weekly)
Kirkley and DuPaul (1994)				
Wang, Goodreau and Mueller (1986)		X	X	
Kahn and Rockel (1988)		X	X	
New England Fishery Management Council (1993)	X			1976-92 (annual)

†North Carolina bay scallops.
‡New York bay scallops.

Altobello *et al.* (1976) developed the first original study to model the New England sea scallop market. Our analysis closely follows the approach adopted by these authors. Our analysis differs in the use of monthly (instead of yearly) data and the use of more recent data. Like Altobello *et al.*, we employ a simple two-stage least squares technique to estimate supply and demand.

Data

We collected monthly data to estimate the models. The following figures illustrate some of these data.

Figure 2 displays monthly scallop landings in New Bedford from September 1985 through May 1996. New Bedford was picked as the largest and arguably the most important market for scallops in New England. The data are from the NMFS Northeast Fisheries Center's "weighout species landings summary" reports (Means, p.c., 1996). Landings are the combined landings of scallops of different meat counts (sizes). The plot in Figure 2 shows a very strong seasonality in the data with peak landings occurring in May to June and troughs occurring during December to February. This seasonality corresponds roughly to periods of peak fishing during the late spring and early summer. The series appears to have a long cycle demonstrating that 1988 through 1992 were the best years for landings in the series. This quantity enters into both the supply and demand models below.

[2] Typically, data on only prices and quantities do not permit the analyst to distinguish demand from supply.

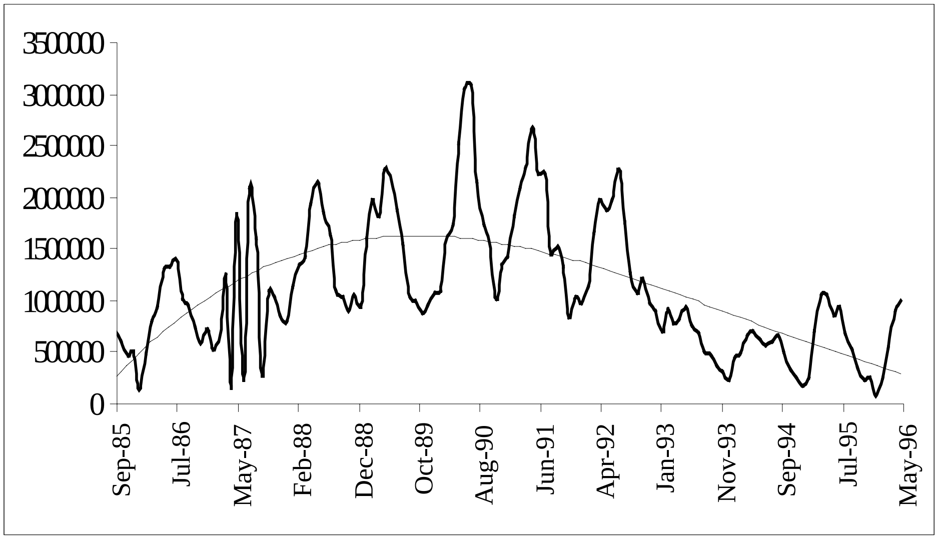

Figure 2. New Bedford monthly scallop landings (Sep 85-May 96) (pounds)

Figure 3 presents the monthly scallop "price" in New Bedford (Means, p.c., 1996). Price in this series is a reported value of landings across all grades of scallops divided by the total landings in that month. We can think of this price as a kind of weighted average across grades (sizes), with the grade quantities varying from month to month. The price series also shows a strong seasonality with peaks occurring during December. We note that this corresponds roughly with the drop-off in fishing in late fall as the weather begins to deteriorate. In addition, there is an increase in demand for sea scallops during the holidays. The long-term trend appears to show a general increase in price beginning in the late 1980s; this corresponds with the drop-off in landings shown in Figure 2. This price enters into both the supply and demand models below.

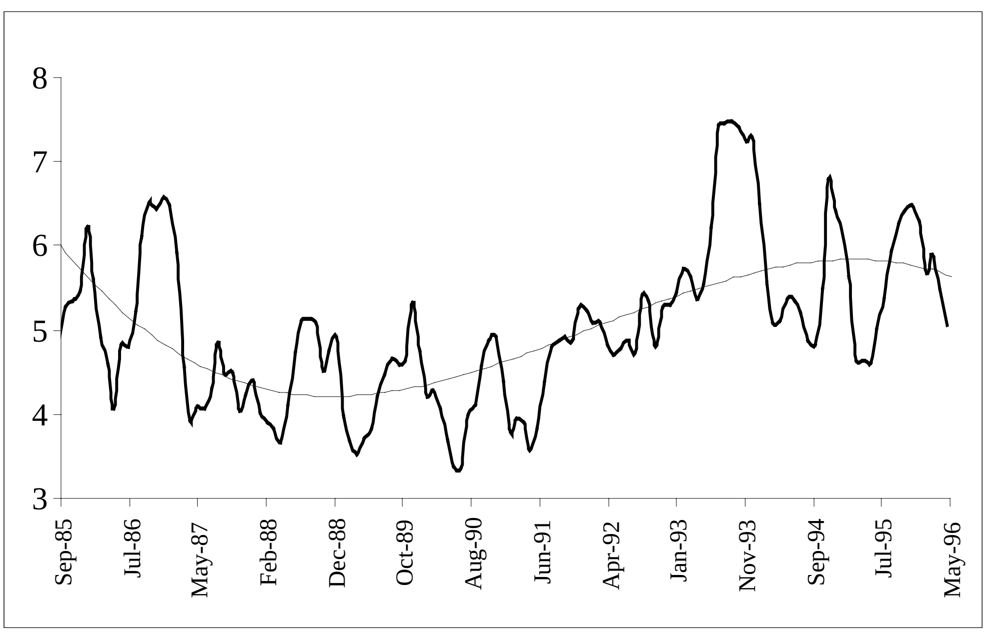

Figure 3. New Bedford monthly scallop price (Sep 85-May 96) ($/lb)

A complete analysis of the market for scallops should take into account the product differentiation according to scallop grade. Price per pound can vary considerably between grades or meat count levels (the number of shucked scallops making up one pound of meat). For example, in one data set covering two vessels' landings from March 1994 to December 1995, the premium attached to scallops in the 10 to 20 meats per pound category over scallops in the 20 to 30 meats per pound category was $0.55. Unfortunately, we do not have comparable data for the period for which we estimate demand and supply. We make an assumption that our market model is representative of scallops in the 30 to 40 meats per pound range; and we expect that a markup for scallops harvested from an aquaculture operation (expected to be 10 to 20 meats per pound) will be approximately $0.78. We note that the premium may vary considerably, depending upon the quantities of scallop grades that appear on the market from month to month. Hence, this markup should be regarded as only a rough approximation.

Figure 4 displays monthly aggregate scallop imports into the United States from January 1985 through June 1998 (NMFS 1998). These data include imports of different grades from several different source countries. The major scallop exporters include Canada, China, Chile, and Peru. Canadian scallops, in particular, are very close substitutes for New England scallops (Edwards, p.c., 1998). As seen in Figure 4, imports have been on an upward trend since the late 1980s. Lately, there appears to be some seasonality in the series as importers are tracking the late season price increases in the US market. The highest peaks correspond with significant exports from China: 2.5 million pounds during January-February 1994; 1.5 million pounds during May 1996; and 2.2 million pounds during December 1997. This series was not used to estimate supply and demand (import price was used instead), but it does contain useful information for understanding the market. It may be important in future work to disaggregate imports by country or by US customs district to see whether imports from particular countries or into particular districts are important determinants of supply and demand.

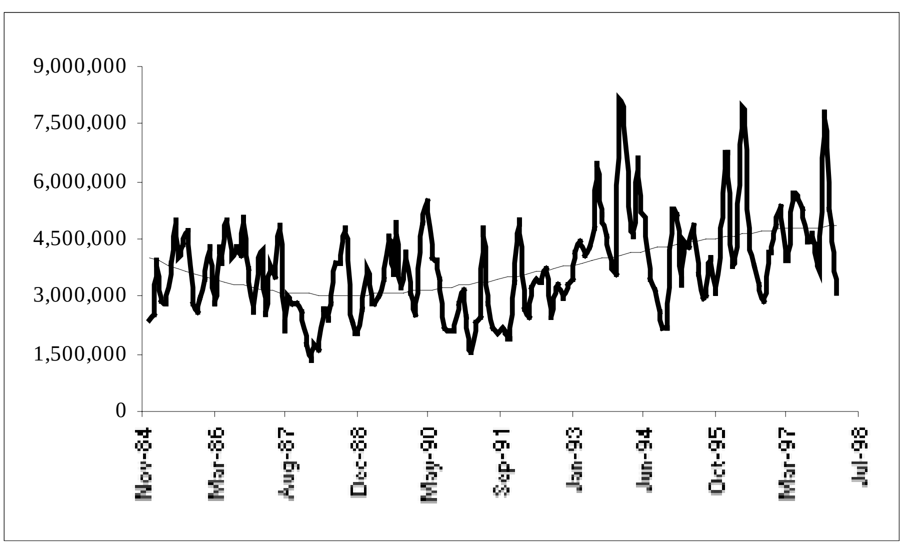

Figure 4. US monthly aggregate scallop imports (pounds)

Figure 5 displays the aggregate scallop import price in dollars per pound during January 1985 to June 1998 (NMFS 1998). The price series is very regular, showing distinct peaks in December. There does not appear to be much of a long-term trend in the series. Again, this series was constructed by dividing the value of imports by the quantity imported. It can be thought of as a weighted average import "price" across all sources and grades of imported scallops in the relevant month. This series was used as an instrument in the demand model.

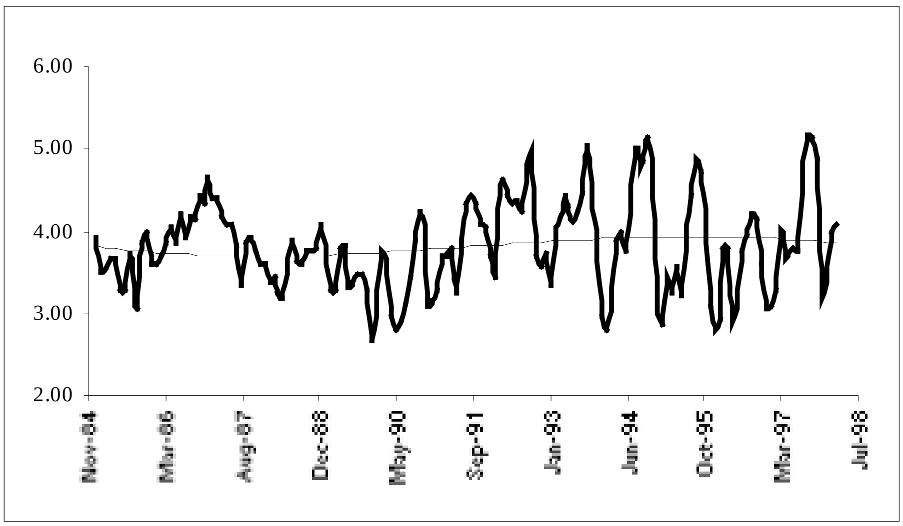

Figure 5. US monthly aggregate scallop import "price" ($/lb)

Figure 6 displays monthly scallop holdings (inventories) on thousands of pounds during September 1985 to May 1996 (NMFS 1985-1996). This series indicates that inventories tend to build in late summer and early fall. The series shows distinct peaks in the early fall. The series exhibits a slight long-term downward trend, possibly indicating that inventories are becoming less important in the scallop market. We employ this series as an instrument in the demand model. Scallop freezings are a subset of inventoried scallops. Freezings tend to peak during the summer, when most of the landings occur. These peaks are correlated with the largest landings, suggesting that freezings occur when the market is incapable of absorbing very large quantities of scallops. In reality, scallops could be sold fresh during any period, but, because the price is low, producers make a strategic decision to freeze scallops to be sold at a later date (at a price below fresh scallops). Scallop freezings have not been incorporated into our supply-demand model, but they may be a useful variable for future analyses.

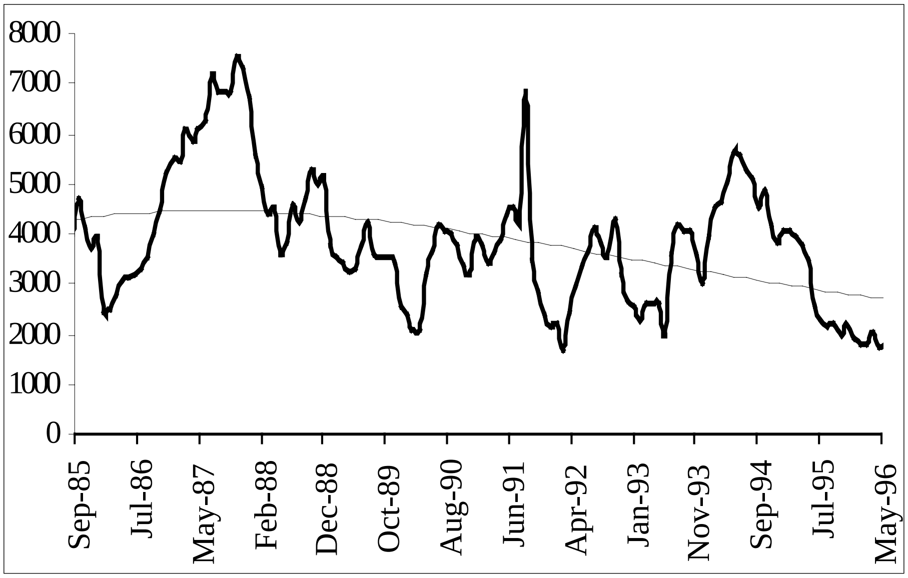

Figure 6. Scallop holdings: (Sep 85-May 96) (000 lbs)

Demand for Sea Scallops

A plot of New Bedford sea scallop prices against landings reveals an inverse relationship: as landings increase, prices decline (Figure 7). Without additional information, however, it is not possible to say whether this relationship is an accurate representation of the demand for sea scallops. For example, quantities of sea scallops demanded and supplied are both functions of sea scallop price. We can use economic theory to help differentiate demand from supply in the New England sea scallop market. Economic theory suggests that if we can identify other variables that are determinants of either demand or supply, then it may be possible to use this information to map out separate demand and supply schedules.

We expect that the demand for sea scallops may be a function of the exvessel price, p^l; a measure of disposable income, y; the size of inventories, I; and the price of imports, p^{imp}. In this model, we treat imports of scallops as close substitutes for New England sea scallops. (We use import price instead of quantity, but the latter is a potential variable to be explored in future work.) We expect that the supply of sea scallops may be a function of the exvessel price, p^l; the size of the wild stock, x; fishing effort, e; time, t; and the price of diesel fuel, f. Our stock size variable is an index available only on an annual basis, so that all values are constant during any particular year.[3] Fishing effort is measured in terms of the number of "days absent" for vessels in the New England sea scallop fleet. Time is a measure of factors that change during the length of the series, such as technological advances in harvesting. The price of diesel

[3] In future work, we may be able to create a monthly index of stock size by subtracting scallop harvest in each month from the annual value.

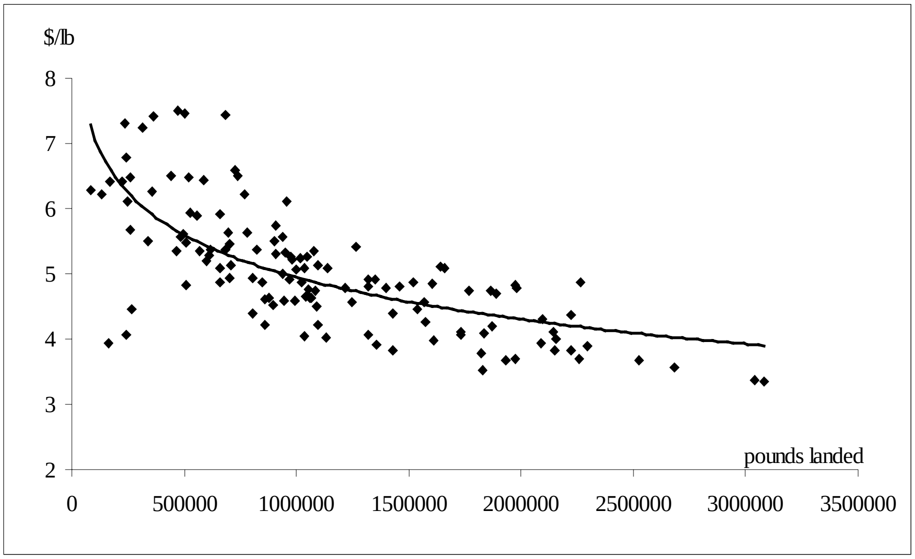

Figure 7. New Bedford sea scallop landings and prices (Sep 85-May 96)

fuel is a rough approximation of the cost of fishing. We write the quantities of sea scallops demanded, q^d, and supplied, q^s, as follows:

$$q_t^d = \beta_0 + \beta_1 p_t^l + \beta_2 y_t + \beta_3 i_t + \beta_4 p_t^{imp} + e_t^d$$
$$q_t^s = \alpha_0 + \alpha_1 p_t^l + \alpha_2 x_t + \alpha_3 e_t + \alpha_4 t + \alpha_5 f_t + e_t^s$$

This model is a set of linear simultaneous equations, and we use the two-stage least squares method to estimate it.[4]

Table 2 presents the results of the estimation using data from 1985 through 1993. All variables are significant except for disposable income. The results indicate that the current formulation explains about 57 percent of the variation in inverse demand and about 65 percent of the variation in quantity supplied.

[4] In future work, we may be able to improve the consistency of parameter estimates using a three-stage technique.

Table 2
Supply-demand regression results

Variable	Supply	Demand
Intercept	453.86 ***	10.19 ***
Estimated price	-66.84 ***	
Disposable income	-1.67	
Inventories	-0.76 *	
Import price	32.47 **	
Estimated landings		-0.02 **
Stock size		-0.12 ***
Days absent		0.03 *
Time		-0.02 ***
Price of Diesel Fuel		-0.02 **
R2	0.57	0.65
DW	1.29	0.66

Values significant at 10%(*), 5%(**), and 1%(***) confidence levels.

Figure 8 is a plot of supply (black) and demand (gray) in the market for New England sea scallops using mean values for the variables in dollars per pound. The horizontal axis represents landings of New Bedford sea scallops in 100,000 pound units. The model is a linear representation of both supply and demand, implying a choke price of about $7.36 per pound. The average market equilibrium over the 1985-93 period is about $5.42 per pound. The downward sloping supply curve is characteristic of an overexploited fishery, where it operates in the upper portion of a backward bending supply curve.

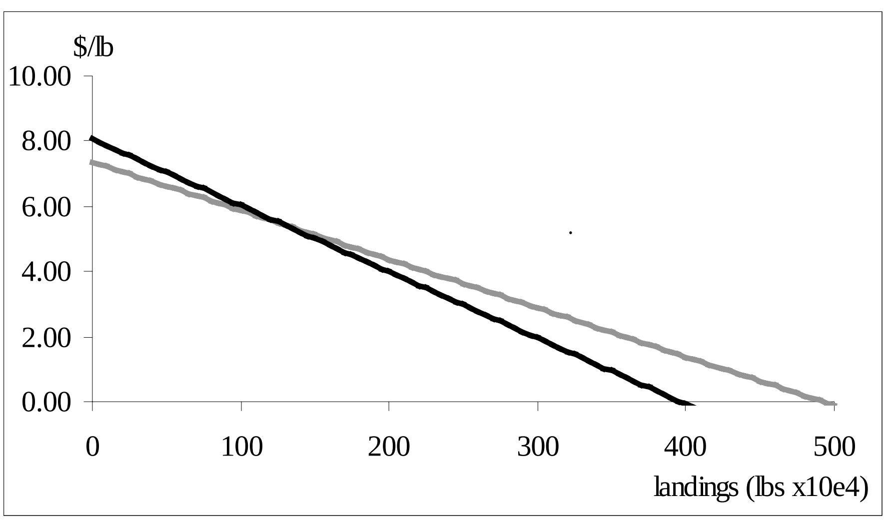

Figure 8. Average aggregate supply (black) and demand (gray) in the New England sea scallop fishery

Figure 9 is a plot of the demand curve. We show how changes in the variables other than landings act to act to shift demand up or down. For example, a decrease in the price of imports will lower the demand for New Bedford scallops and vice versa. Thus it will be important for aquaculture producers to keep a close eye on imports of scallops. Although we have not modeled demand for different grades of scallops, we can make the assumption that demand for the largest scallops can be represented by a demand curve that is shifted upward but parallel to average demand.

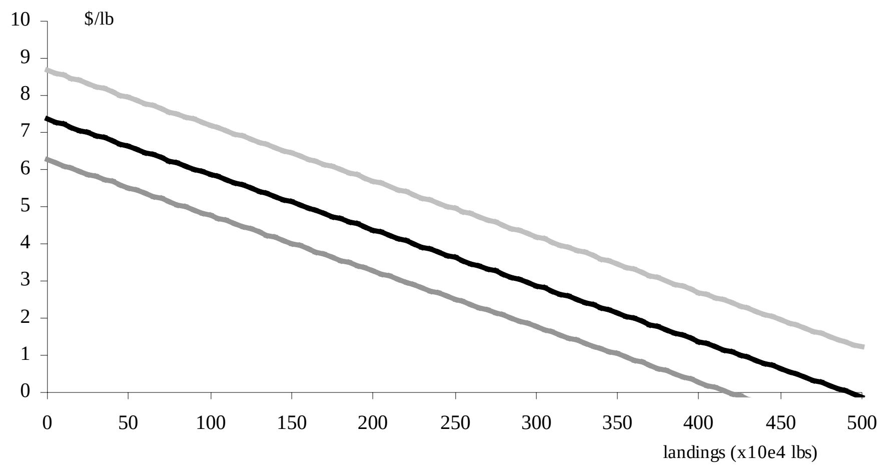

Figure 9. New England average aggregate sea scallop demand: shifts due to changes in the “price” of imports: $7.00/lb (light gray) and $2.00/lb (dark gray)

ii. <u>Open Ocean Growout of Sea Scallops</u>

We examine the economic viability of four alternative approaches to scallop farming: seabed seeding and three variations on cage culture:

- lantern cages
- bottom cage trawls
- bottom cage clusters

For each alternative, we estimate capital and operating costs and revenues over a 20-year period. We assume a two-year cycle from collection of juveniles to harvest, and we scale the farming operation in every case to produce 100,000 pounds of scallop meat per two-year cycle (that is, every other year).

Capital equipment includes guard buoys around the farming site and cages and cage moorings. Vessels are not treated as capital costs; rather, we model them as operational expenses and assume that appropriate vessels can be chartered or leased as needed for representative daily rates.

Baseline Assumptions

The following baseline assumptions are applied to all four farming modes:

- The farming site is 2 hours by boat from port.
- The farming site is surrounded by marker buoys spaced 200 meters apart. Marker buoys/moorings cost $3000 and have a life of 10 years with annual maintenance requirements of 3 hours of boat time and $150 per marker buoy.
- Cage moorings have a life of 10 years; the cages themselves have a life of 5 years.
- The growout cycle is 2 years, and the operation is scaled to bring to market 100,000 lbs of scallop meat per growout cycle. Scallops are sold at dockside for $7/lb of meat.
- A workday is 12 hours.
- Vessels are capable of capturing and bringing to the farming site an average of 40,000 juvenile scallops in one day.
- $20,000 per year is included for administrative/marketing/management expenses onshore.

In addition, we make specific baseline assumptions for each farming mode as outlined in Table 3. Cage and cage mooring cost estimates, deployment and harvesting efficiencies, maintenance requirements, and biological parameters are based on input provided by the engineering team for this project. The seabed seeding approach is expected to result in significantly greater loss and mortality and in lower growth (higher meat count at harvest) than the cage alternatives. The tradeoff is the greater cost associated with acquisition, deployment, maintenance, and harvesting of cages and moorings.

Results

The results of the economic model using the baseline assumptions for each farming approach are summarized in Table 4.

Under baseline assumptions, the only alternative that appears profitable is seabed seeding. A 100,000 lbs/cycle seabed seeding operation requires less than $400,000 in start-up capital and pays back the initial investment in four years. It requires a lease area of about 150 acres and requires the use of a large scallop vessel on average about 3 months out of the year.

The cage operations are not profitable because the higher survival rate and growth are not enough to justify the added cost of buying, maintaining, and deploying/harvesting the cages and associated moorings. Although they require smaller lease areas, the cage

Table 3
Baseline assumptions for economic model

	Seabed Seeding	**Lantern Cages**	**Bottom Cage Trawls**	**Bottom Cage Clusters**
Gear				
Cost of mooring gear	n/a	$2,000	$200	$2,000
Cost of cage	n/a	$5,000	$25	$25
# of cages/mooring	n/a	1	20	60
Mooring spacing	n/a	30 m	10 m	30 m
Operations				
Cage deployment	n/a	2 hours/cage	20 cages/hour	20cages/hour
Harvesting	5 acres/hour	1 cage/hour	40 cages/hour	40 cages/hour
Maint. visits to moorings	n/a	3 over 2 years	3 over 2 years	3 over 2 years
Maint. time per visit	n/a	1 hour/mooring	1 hour/mooring	2 hours/mooring
Mooring maint. cost	n/a	$100/year	$20/year	$100/year
Cage maintenance cost	n/a	$100/year	$5/year	$5/year
Boat cost	$2,000/day	$2,000/day	$500/day	$2,000/day
Biology				
Seeding density	40,000 juv/acre	10,000 juv/cage	100 juv/cage	100 juv/cage
Loss rate over 2 years	50%	20%	20%	20%
Average size at harvest	25 count	20 count	20 count	20 count
Other				
Shore facility lease	n/a	$10,000/year	$10,000/year	$10,000/year

Table 4
Baseline results of economic analysis

	Seabed Seeding	**Lantern Cages**	**Bottom Cage Trawls**	**Bottom Cage Clusters**
Performance				
NPV @ 10% real discount rate ($k)	1,354	*-3,723*	*-1,965*	*-7,324*
Avg. annual revenue ($k)	350	350	350	350
Avg. annual costs ($k)	171	533	393	693
Avg. net revenue/yr ($k)	179	*-183*	*-43*	*-343*
Scale				
Acreage	143 acres	62 acres	34 acres	104 acres
Gear	n/a	250 cages 250 moorings	25,000 cages 1250 moorings	25,000 cages 417 moorings
Number of marker buoys	14	9	7	12
Capital investment ($k)	42	1,777	896	1,494
Vessel time				
Collecting & deployment	142 days/cycle	126 days/cycle	220 days/cycle	220 days/cycle
Harvesting	3 days/cycle	32 days/cycle	79 days/cycle	79 days/cycle
Mooring & buoy maint.	5 days/year	50 days/year	237 days/year	160 days/year
Cost breakdown				
Gear acquisition ($k)	4 (2%)	303 (56%)	152 (39%)	212 (31%)
Gear maintenance ($k)	2 (1%)	46 (9%)	136 (35%)	152 (22%)
Collect/deploym't ($k)	142 (83%)	126 (23%)	55 (14%)	220 (32%)
Harvesting ($k)	3 (2%)	32 (6%)	20 (5%)	79 (11%)

operations demand between $1 million and $2 million in startup funding. Of the three alternatives, bottom cage trawls come closest to breakeven because gear costs are relatively modest. The bottom cage cluster approach appears to be economically hopeless.

We conducted sensitivity analysis on key parameters to test the robustness of the results produced by the baseline analysis. For the seabed seeding approach, we examined the effect of changes in dockside price and loss rate on profitability. For the cage alternatives, we estimated what changes in baseline parameters would be required to make the operations profitable.

Seabed Seeding: Figure 10 shows the net present value of a 100,000 lbs/cycle seabed seeding operation as a function of dockside price and mortality/loss rate. It is evident that the profitability of this approach to scallop farming is robust. Even at dockside prices as low as $4/lb, the operation is marginally profitable at loss rates as high as 50%; and at $6/lb, loss rates of nearly 70% could be tolerated. In a seabed seeding operation, the distance of the farming site from port is not as important as its location relative to likely juvenile catch areas.

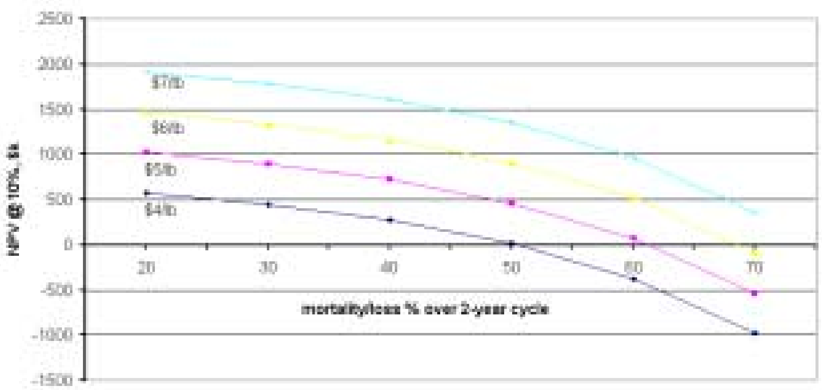

Figure 10. Net present value as a function of dockside price and cycle mortality/loss rate for scallop growout by seabed seeding

Lantern Cages: The expense of cage gear and filling/deploying cages is problematic. Even dramatic reductions in gear cost (down to 20% of baseline acquisition cost for moorings and cages) combined with a fourfold improvement in cage filling and deployment speed does not produce a profitable operation under baseline circumstances (NPV -$285k). NPV is just positive if, in addition to these efficiencies, the farming site is less than one hour from port.

A fourfold improvement in collecting/deploying/harvesting efficiency alone, without any reduction in gear cost below baseline assumptions, does not make the lantern cage operation viable, even if mortality/loss is reduced to zero. Gear cost is the driving factor here. It seems unlikely that a lantern cage operation of this kind can be profitable.

Bottom Cage Trawls: Gear acquisition and maintenance costs predominate. To produce a positive NPV, it is necessary to reduce mooring and cage acquisition/ maintenance costs by 50% and improve juvenile collection, cage deployment, and harvesting efficiencies by a factor of two over baseline assumptions, while also keeping the operation within one hour of port.

If gear acquisition costs cannot be reduced, it is possible to make the bottom cage trawl operation profitable if, in addition to the other improvements specified in the paragraph above, the mortality/loss rate can be cut to 10%. While this may represent a significant challenge, it seems the bottom cage trawl approach has a greater chance of being made profitable than either of the other cage operation modes.

Any weakness in dockside price below $7/lb makes profitability difficult even with the improvements outlined above.

Bottom Cage Clusters: As with the lantern cage approach, gear acquisition and collecting/deployment costs predominate. It seems virtually impossible to make the bottom cage cluster approach profitable even with across-the-board improvements by a factor of two and elimination of all mortality/loss.

Gear cost dominates the economics of all cage farming options. The economics of cage operations could be improved greatly if it is possible to increase the number of scallops per cage without significantly raising the cost of each cage.

iii. Optimal Farm Production of Sea Scallops

It is useful to think of the problem of production from an offshore farm as an inventory problem. The scallops grow over a period of about two years to a size that commands a premium over the average size scallop. If the potential production from an offshore farm is small relative to the market, then it is optimal for the farmer to act as a price taker. If it is possible to produce scallops during any month of the year, then the farmer should pick the month (usually January) with the highest price.

However, the market for scallops in New Bedford is not all that large. If significant quantities of scallops from an offshore farm are delivered to the market in New Bedford, they are likely to depress the price. Thus it makes sense to consider this effect when choosing the best time to harvest aquaculture product.

Figures 11 and 12 present the results of a simple optimization model that determines when and how many sea scallops should be harvested from the farm site (the two figures show the natural logarithm of thousands of pounds of aquaculture output). The demand for scallops has been incorporated specifically into the optimization routine. We first calculate average landings per month over a period of years. (The period can be selected by the farmer based upon experience with the market. For example, Figure 11 presents average landings per month over the period 1985-1996, and Figure 12 presents actual landings per month during 1995 only.) The model seeks to maximize total revenues over the year through the choice of production from the aquaculture site. In each month, production from the aquaculture site is added to average production for that month. This total production (wild harvest plus aquaculture) is inserted into the demand function to determine a market price. Next, aquaculture output is multiplied by the market price, and the costs of recovering aquacultured sea scallops is subtracted from this product. The result is a schedule of monthly harvest over the year.

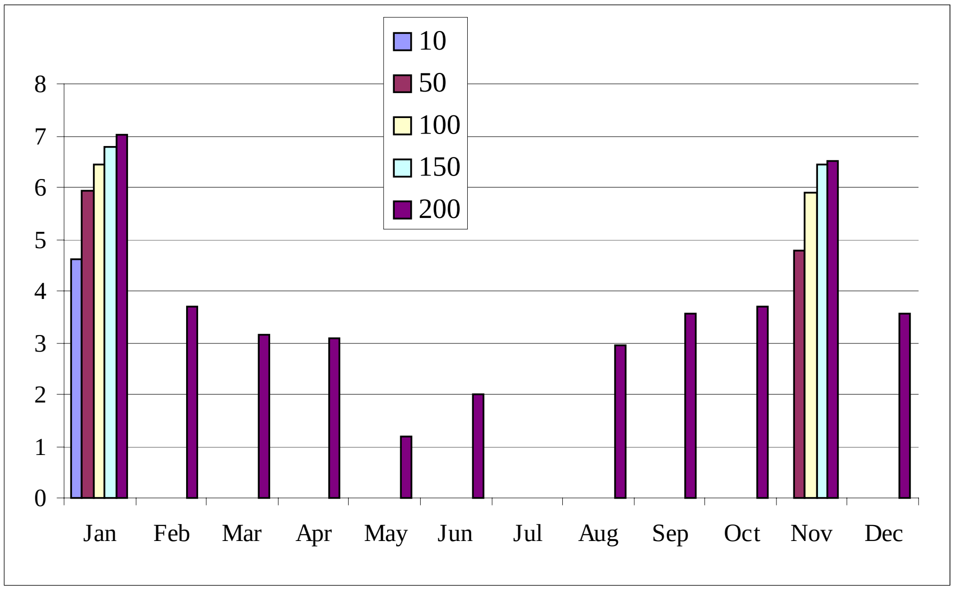

Figure 11. Optimal annual production profile (1985-96 basis)

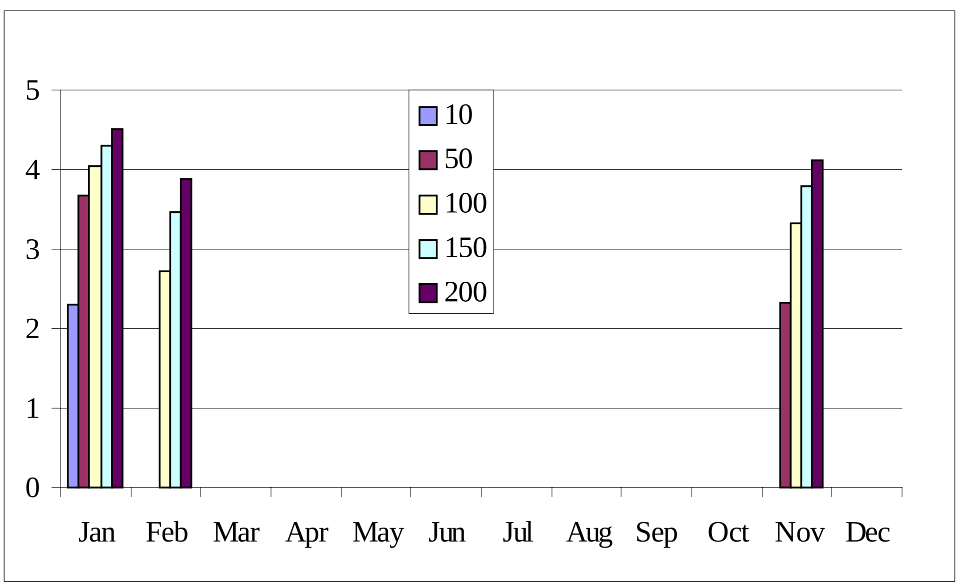

Figure 12. Optimal annual production profile (1995 basis)

In each case, we examine the pattern of harvests for four different levels of production. These levels are 10, 50, 100, and 200 thousand pounds (recall that the cash flow model described above was run with 100,000 pounds as the relevant output). Both cases demonstrate that when aquaculture output is small, the farmer should act as a price taker, harvesting and marketing his product only in January. As potential output increases, however, the time profile of output shifts. Using the long-term monthly average represented in Figure 11, output of up to 150 thousand pounds should be allocated in January and November. When output reaches 200 thousand pounds, there should be some level of production in every month except July.

When using wild harvest output from 1995 only, the time profile changes. Output in 1995 is well below the 12-year average in every month, but it tends to be less uniformly distributed so that the late fall and early winter outputs are much lower, relative to outputs in the other months, than the same output for the 12-year average. As a result, price tends to be relatively higher during the late fall and early winter of 1995, and therefore it pays to place aquaculture output on the market in November and January even at very high levels of production.

Because we are uncertain about mortality on the farm, the time profile of production is suggestive of a strategy for harvesting the aquaculture product. Referring back to Figure 11, it may be sensible to "sample" the product through partial harvesting, say, in October. This sample will give the farmer an estimate of mortality. If mortality is low, then a production profile that places product on the market in every month might be followed. If mortality is high, then production should be adjusted accordingly, and product would be placed on the market in November and January. Note also that the production profile can be readjusted during the year as market conditions become revealed and as uncertainty about the quality of the farmed product is reduced. In essence, the optimization routine should be used as a real-time production and marketing tool.

b. Blue Mussels

Consumption of blue mussels is relatively low in the United States, but it is increasing strongly. Like sea scallops, blue mussels are native to New England waters and grow rapidly in the warmer waters of southern New England. We discuss both market and growout economics for blue mussels in less detail than for scallops. Many of the conceptual issues are the same.

i. New England Market Demand for Blue Mussels

Figure 13 displays monthly data from 1992 through 2001 on the exvessel value of US landings (wild harvest) of blue mussels and the value of imports (mainly cultured product) from Canada. The data include both wild harvest landings and coastal aquaculture production. The Canadian aquaculture product commands a significant premium over the wild harvest product. US production now includes significant production (not shown) of mussels broadcast for seabed growout from coastal Maine.

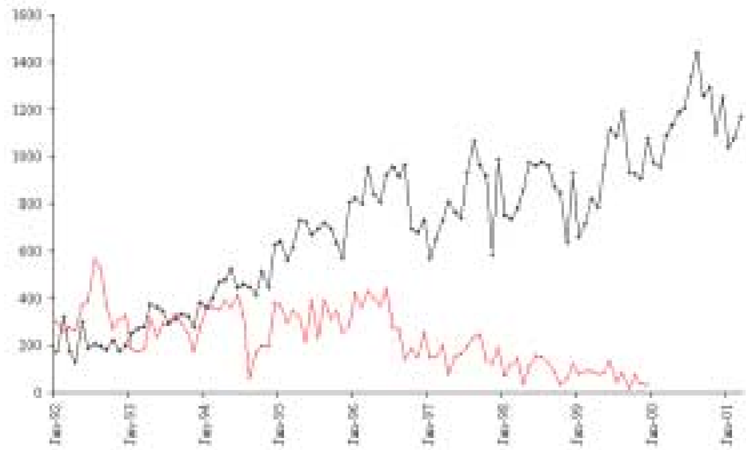

Figure 13. Value of US production (red line) and Canadian imports (black line) of blue mussels:1992-2001, $US 2001 (000s)

We estimate a model of blue mussel market price from the monthly distribution of the value per pound of imported Canadian cultured blue mussels during 1990-97 (averaging 91¢ per pound). We assume that price is distributed lognormally with a mean of 64¢ per pound and a standard deviation of 11¢ per pound. The mean has been adjusted downward to account for the effect of domestic production on market price.

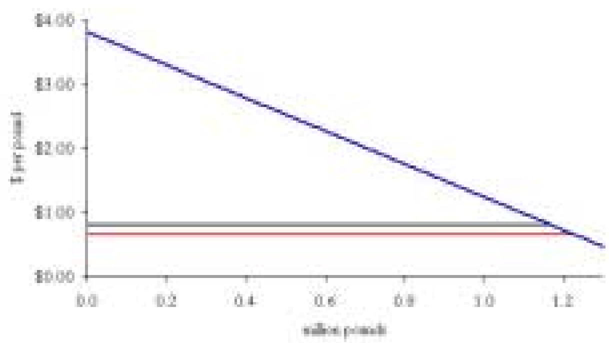

Figure 14. Monthly demand for cultured Canadian blue mussels, 1997-98

Figure 14 depicts the demand for cultured blue mussels imported from Canada during 1997-98. The horizontal lines represent the price of mussels without (black) and with (red) production from a hypothetical US coastal-ocean farm. Our models predict that a full-scale open-ocean aquaculture farm is likely to supply enough mussels to the market to drive price down. Note that price is variable, as there are a number of influential factors, including the supply of substitute shellfish and the effects of competitive strategies. As an example of the latter, the US International Trade

Commission currently is investigating an antidumping complaint issued by a US producer against Canadian growers.

ii. Open Ocean Growout of Blue Mussels

Our model of blue mussel growout is informed by a longline growout experiment conducted by the Woods Hole Oceanographic Institution in Rhode Island Sound in the late 1990s (Hoagland *et al.* 1998).

We model an offshore mussel longline operation that fully utilizes the annual capacity of one service vessel (*e.g.*, a small scalloper of approximately 20 GRT). Such a vessel requires fixed cost payments on the order of $80,000 per year. Daily variable costs (fuel and supplies) are $1400, including $800 in crewmember wages. We estimate that one vessel is capable of servicing a field of 300 longlines. We assume that 150 longlines are harvested once every two years. Each year, about 225 days are spent maintaining the longlines and 38 days are required for harvesting. During years when the longlines are being deployed, an additional 38 days are required to deploy one-half the field (150 longlines).

Each longline is designed to support 25 mussel socks or growout ropes. Each grow rope produces, on average, 350 pounds of mussels over a two-year growout period. A longline assembly costs $7,500 to purchase, $400 to deploy, and $250/year to maintain, not including the costs of running the service vessel. Each longline is designed to last ten years, at which time it must be replaced. Additional costs include those associated with processing (sorting, debearding, and cleaning), transport to the market, and management costs.

Developing a model of production risk is problematic in the absence of a history of offshore production activity. This parameter can be affected by storm events, predation, parasitism, disease, temperature, and availability of food, among other things. We assume that production takes an extreme value distribution with a mode of 380 pounds per grow rope and a scale of 50 pounds. The majority of possible values for production from a sock thus range between 80 and 480 pounds per grow rope.

The model predicts that this operation becomes profitable at dockside prices between $0.65 and $0.80/pound. This result suggests that mussel farming at an offshore location is commercially feasible if the product can be sold at a premium reflecting high quality.

c. Conclusions

Our analysis suggests that open ocean growout of shellfish such as scallops and blue mussels can be economically viable in southern New England.

For sea scallops, the most promising approach appears to be seabed seeding. A 100,000 lbs/cycle seabed seeding operation requires less than $400,000 in start-up capital and pays back the initial investment in four years. It requires a lease area of about 150 acres and requires the use of a large scallop vessel about 3 months out of the year, on average. The cage operations are not profitable offshore because the higher survival rate and growth are not enough to justify the added cost of buying, maintaining, deploying, and harvesting the cages and associated moorings. Although they require smaller lease areas, the cage operations demand between $1 million and $2 million in startup funding. Of the three alternatives, bottom cage trawls come closest to breakeven because gear costs are relatively modest.

Blue mussels can be grown to market size in southern New England in less than two years. Submerged longlines with hanging grow ropes are the preferred approach and have been proven in offshore conditions. The growout operation becomes profitable at dockside prices between $0.65 and $0.80/pound, which probably can be attained with proper product positioning.

While these results are encouraging for the future of shellfish aquaculture in the open waters of New England, risks from loss of crops remain significant. Diversification across two or more aquaculture crops (for example, combining a scallop and mussel operation) can alleviate this risk and help achieve full utilization of support vessels at relatively modest scales of operation.

3. A Bioeconomic Model of Open Ocean Growout of Finfish in New England

Like most new ventures, offshore aquaculture entails uncertainties that to date have held back its development. Which species of fish are best suited to open ocean aquaculture? Which locations make the most sense? What level of investment is needed? What are the likely financial returns and risks of such projects? These questions can be answered in part using bioeconomic models of open ocean growout operations.

Here we describe such a model and then apply it to examine the open ocean growout in New England waters of three general types of finfish: salmon, cod, and flounder.

a. The Model

The model optimizes stocking and harvesting schedules, and it projects financial flows for an open ocean finfish growout operation. It allows for comparison of alternate growout sites based on their physical characteristics (distance from shore, water temperature, water depth, etc.). 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.

The model's optimization procedure assumes that the growout operation is to produce a fixed amount of fish (v_h, by weight) each month (or in specified months only). The model determines the optimal stocking time and number of fish for each harvest month. It also calculates expected financial flows and summary values such as project NPV and the amount of up-front investment required.

For each harvest month h (h=1,2,3,…,12), the model uses a species-specific growth function to calculate the weight at harvest of an individual fish ($f_h(m)$) stocked as a fingerling in month m (m=h-23,h-22,h-21,…). (Feasible stocking months can be specified where fingerlings are not available year-round.) The model then calculates the number of fish at harvest $n_h(m)=v_h/f_h(m)$ and works backward, using the mortality function, to calculate the number of fingerlings to be stocked.

For each harvest month h, the model then identifies the stocking month m that results in the maximum net revenue (discounted difference between revenue and variable cost). Revenue is the product of harvest weight and price, which varies with fish size and time of year: $v_h*p(h,f_h(m))$. (Stocking months that result in sub-market-size fish result in zero revenue and are not considered.) Variable costs include the cost of fingerlings, feed and medication, and harvesting, including associated vessel costs. The maximum net revenue determines the optimal stocking month (and length of growout), as well as the number of fingerlings.

Once stocking decisions have been optimized, the model calculates the financial performance of the growout operation month-by-month over 15 years to determine projected cash flows, project NPV, and investment capital needed, as well as operational parameters such as vessel utilization and feed volume.

The model uses several input parameters to describe the growout operation. Principal parameters include the amount to be harvested each month and the characteristics of the growout site (water temperature, wave profile, water depth, and distance from shore). Biological factors are captured by a growth function (monthly growth as a function of fish weight and water temperature), a mortality rate, and a feed conversion ratio (the latter two are specified as a function of fish size), as well as the maximum feasible culture density (fish weight per cubic meter of water). Other inputs include cage system and support vessel capacities and costs, fingerling size and cost, and feed and medication costs. Dockside price is specified as a function of fish size and time of year.

b. <u>Application of the Model</u>

We apply the model to three species of finfish: cod, salmon, and flounder. Each species has its own growout regime. Cod can be stocked and harvested year-round. Salmon is harvested year-round but stocked only when the water temperature is above 6 deg. C. Flounder are stocked at larger size (500 grams) only in April and May, and harvested six months later. The cod and flounder growout takes place in southern New England waters, while salmon are grown in northern New England.

i. Input Parameters

The growout sites used in the baseline analysis are located 6 km from the shore station or dock used by the support vessel. The water depth is 50 m. Water temperature profiles are shown in Figure 15.

The cage system input parameters are summarized in Table 5.

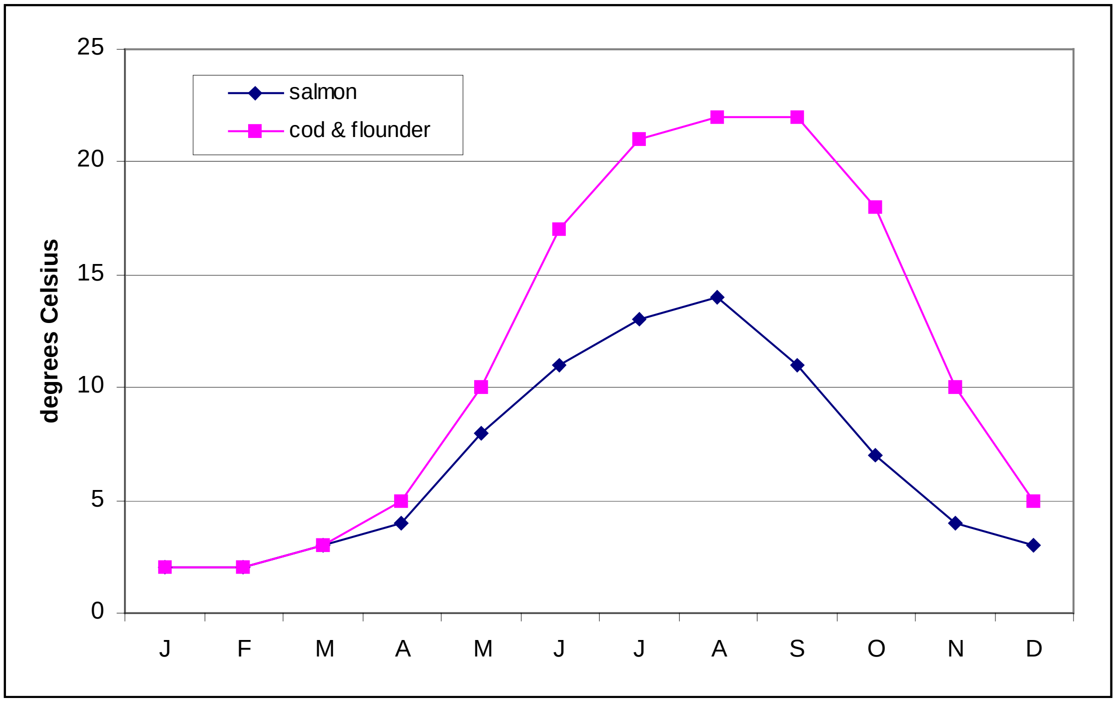

Figure 15. Water temperature at growout sites

Table 5
Cage system parameters
(d = water depth in meters)

	Cod	Salmon	Flounder
Purchase cost, $\$/m^3$	15.00	15.00	15.00
Mooring and installation cost, $\$/m^3$	2 + 0.02d	2 + 0.02d	2 + 0.02d
Maintenance cost, $\$/m^3$/year	1.00	1.00	1.00
Operating cost, $/cage/day	10.00	10.00	10.00
Maximum cage size, m^3/cage	2,000	2,000	2,000
Maximum fish density, kg/m^3	35	30	20 kg/m^2
Useful life, years	15	15	15

Because the flounder growout operation is limited to two harvest months, we give it a different allocation for fixed vessel and onshore costs. The fixed cost allocation for the growout support vessel, which stocks the cages, carries feed to the cages, supports maintenance, and carries out harvesting, is $100,000/year for cod and salmon and $20,000/year for flounder ($100,000 is the total annual fixed cost for a vessel of this size). 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.

Additional onshore costs for the cod and salmon operations are $35,000/year for dock use and other onshore facilities, $75,000/year for management and administrative costs, and $50,000/year for marketing and distribution. For flounder, these costs are $5,000, $20,000, and $15,000, respectively. Insurance costs are 0.25% of the installed cage value and 1% of expected fish revenue. Permitting costs are $10,000/year except $25,000 in year 0 and $20,000 in years 5, 10, and 15.

Biological input parameters describing growth, mortality, feed conversion, feed cost, etc. are summarized in Table 6. Sources include Best (1995) for cod, Bjørndal (1990) for salmon, and Link (1995) for flounder.

Table 6
Biological parameters
(w = fish weight in grams)

	Cod	**Salmon**	**Flounder**
Monthly growth, g	(see equation 1)	141 + 0.024w	75
Mortality, %/month	1 – 0.0001w	1 – 0.0001w	1 – 0.0001w
FCR	3 – 0.0008w	4 – 0.0006w	4 – 0.0006w
Medication, g/kg fish/month	1	1	1
Water weight for stocking, per g fish	5	5	5
Feed cost, $/kg	0.55	0.90	0.65
Med cost, $/kg	10.00	10.00	10.00
Stocking weight, g/fish	50	150	500
Fingerling cost, $/fish	0.85	1.75	2.00

The growth equation used for cod is derived from Jobling (1988):

$$g = 0.37223 w^{0.559} e^{0.297t - 0.000538t^3} \qquad (1)$$

Figure 16 illustrates how the effect of fish size and water temperature on growth as predicted by equation (1).

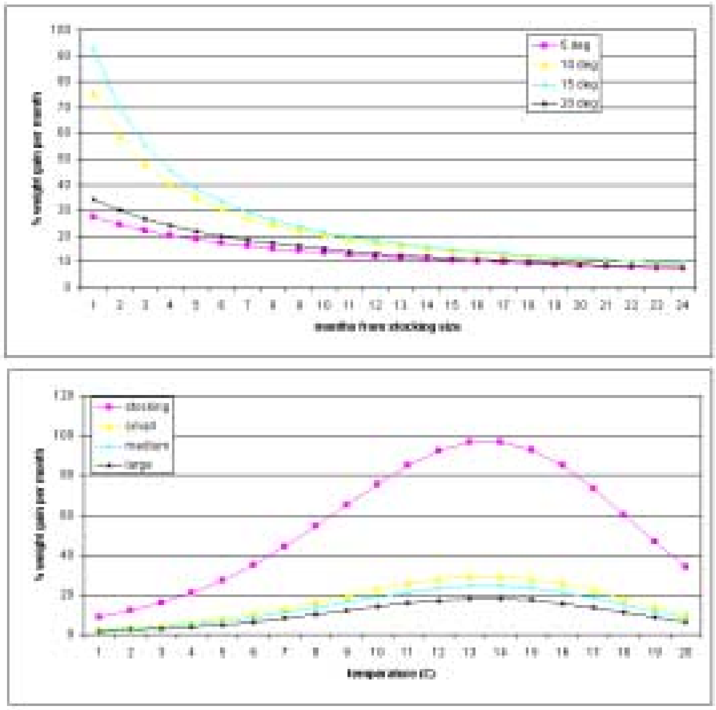

Figure 16. Cod growth model illustrated

The markets for finfish produced by the growout operations are characterized by monthly average dockside prices, as shown in Figure 17. These prices are based primarily on landed value reported by the National Marine Fisheries Service. The prices shown in Figure 17 are for medium or “market” size fish. The model assumes a premium for fish larger and a discount for fish smaller than the size range described in the caption to Figure 17. The average premium is 10% for cod, 30% for flounder, and 23% for flounder; the average discounts are 15%, 18%, and 8%, respectively.

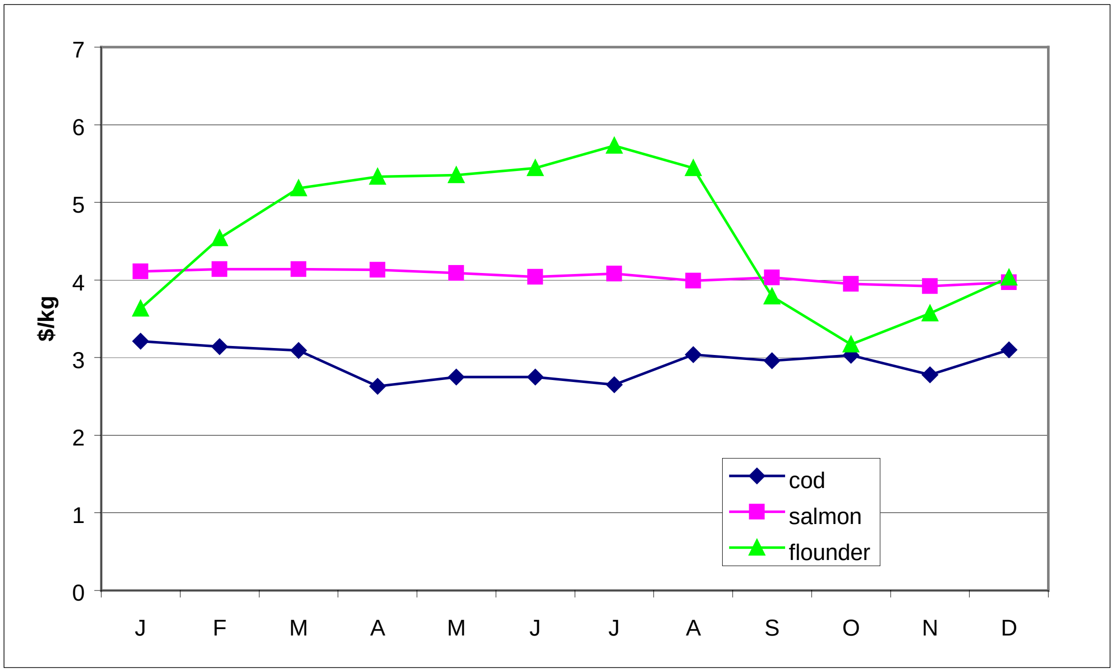

Figure 17. Dockside price for medium size cod (1.13 – 2.27 kg), salmon (2.00 – 3.00 kg), and flounder (0.91 – 1.80 kg)

ii. Results

Each operation is based on 5000 m^3 of cage capacity per harvest (month), with growout located 6 km from the shore facility. Optimized stocking and harvesting schedules are illustrated in Figures 18, 19, and 20.

Key model output parameters for the baseline farm operations are summarized in Table 7.

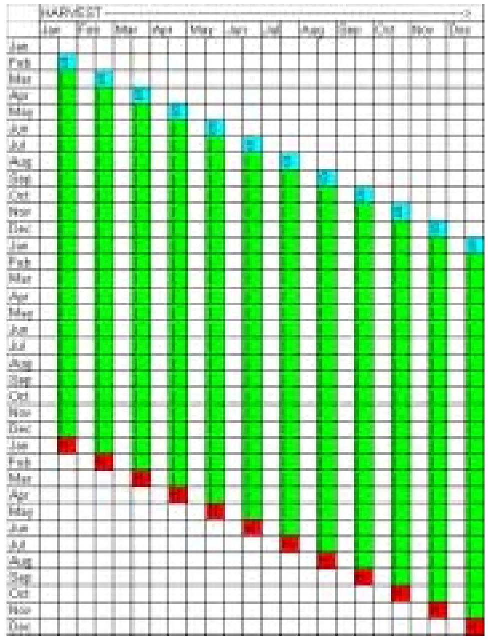

Figure 18. Stocking and harvest schedule for cod. Two sets of cages are needed for each harvest month due to the two-year growout cycle.

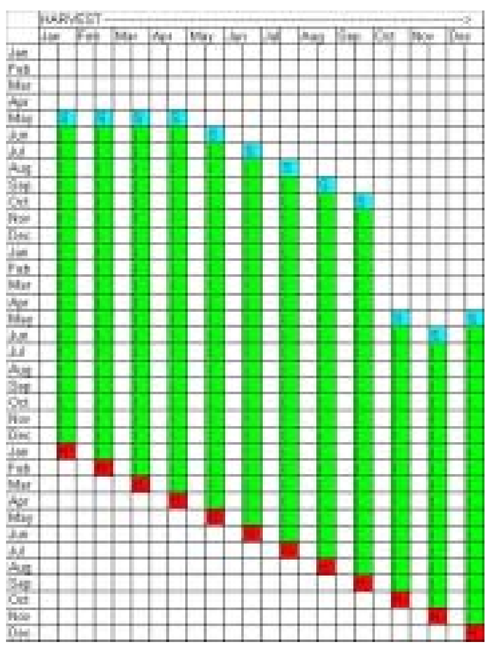

Figure 19. Stocking and harvest schedule for salmon, showing effect of water temperature limiting stocking times

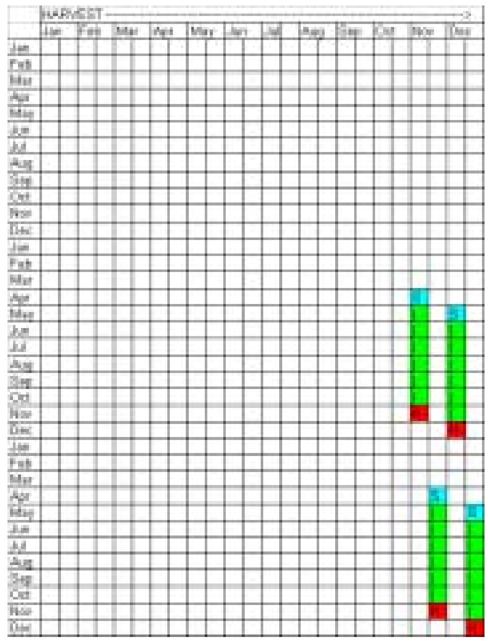

Figure 20. Stocking and harvest schedule for flounder

Table 7
Baseline growout operation results

	Cod	**Salmon**	**Flounder**
Number of cages	72	72	6
Fingerlings stocked/year	1,788,000	532,000	261,000
Tons of feed/year	5,416	5,281	474
Boat days/year	81	77	14
Average harvest weight, g	1,466	4,093	1,025
Harvest, tons/month	175	151	125
NPV at 5% discount rate, $m	1.50	14.16	1.07
Investment capital required, $m	8.61	9.24	1.17

Figure 21 illustrates the main components of total annual expenses for the three growout operations.

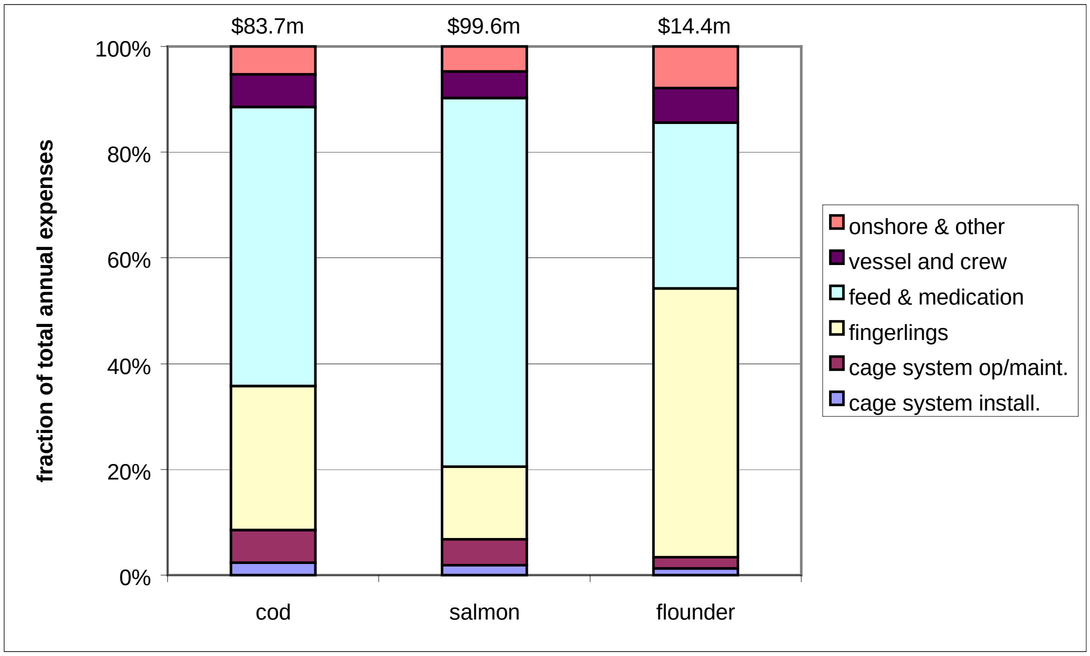

Figure 21. Baseline growout cost components

In keeping with aquaculture experience, feed cost is the most significant cost component (the high "fingerling" cost component for the flounder operation reflects the lengthy onshore growout prior to cage stocking, and the relatively short offshore growout period). Figure 22 shows how the NPV of each growout operation is affected by feed cost. It suggests that salmon growout remains profitable at feed costs in excess of $1.10/kg, but that flounder can be grown economically only below $0.80/kg, and cod only below $0.60/kg.

Figure 23 shows the effect on NPV of distance from shore of the growout site. For cod and flounder, economically viable growout requires a location that allows the support vessel to make at least two round trips per day. (See Figure A.1 in the Appendix for a preliminary GIS display of the geographic limits of economic viability for fluke growout in waters off New England.)

The higher value of salmon permits profitable growout further offshore. In general, it makes economic sense to locate growout sites as close to shore as possible given other constraints.

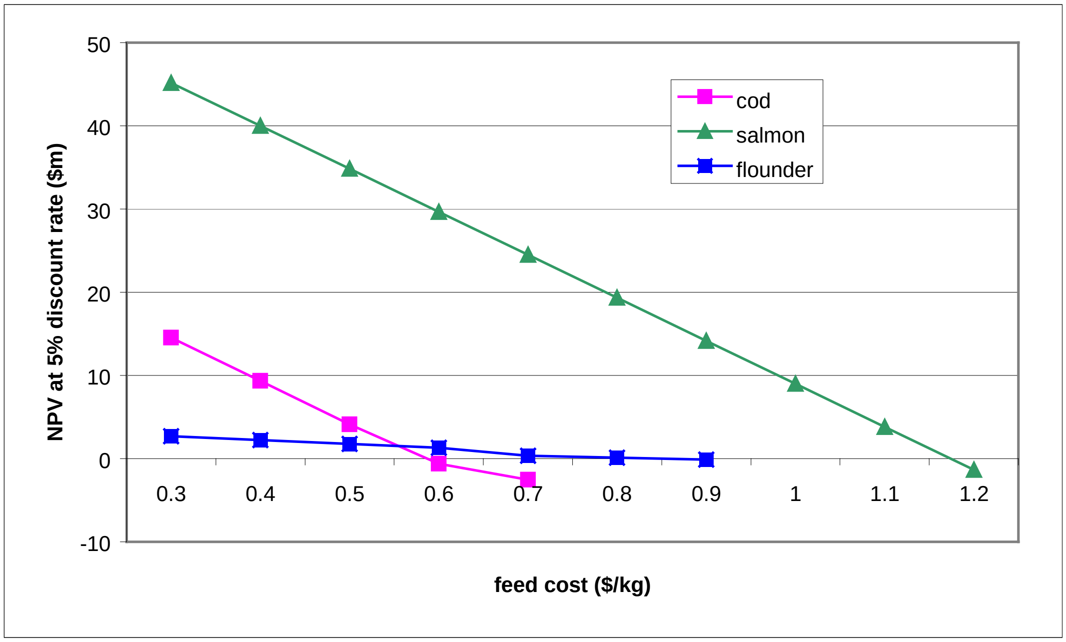

Figure 22. NPV of 5000 m^3/harvest growout operations at 5% real discount rate at varying levels of feed cost.

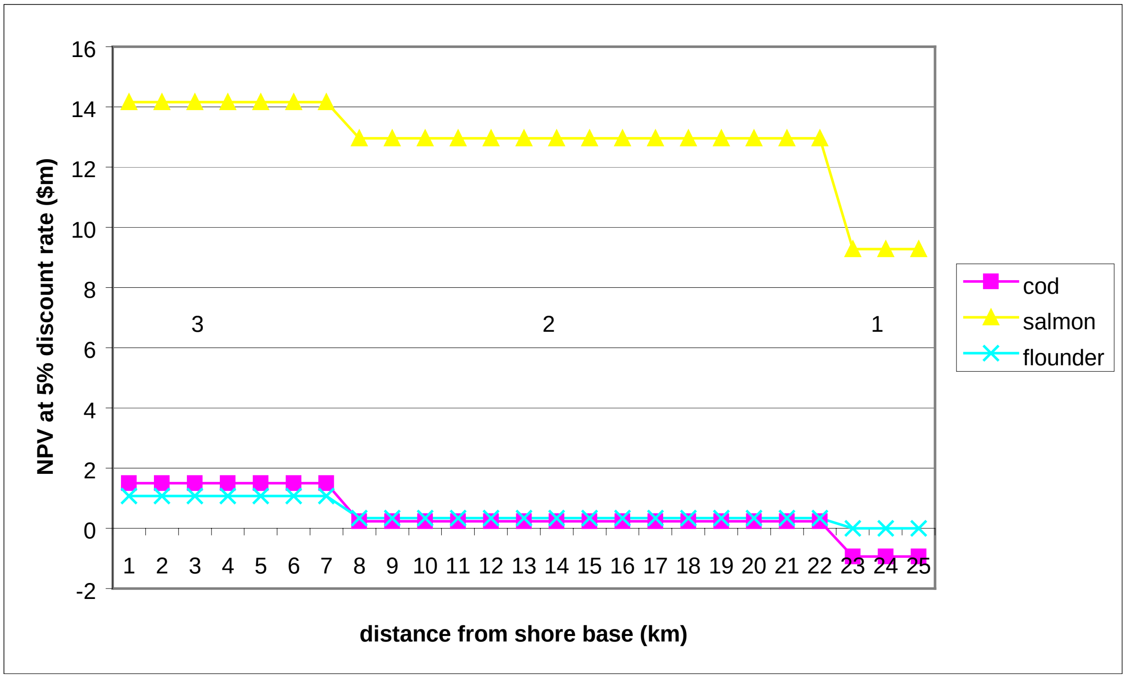

Figure 23. NPV of 5000 m^3/harvest growout operations at 5% real discount rate at varying distances from the shore facility. NPV here depends directly on how many round trips the supply vessel can make in one day.

Figure 24 illustrates the effect of maximum culture density on NPV. The higher densities necessary to make cod growout profitable result in part from its lower market value.

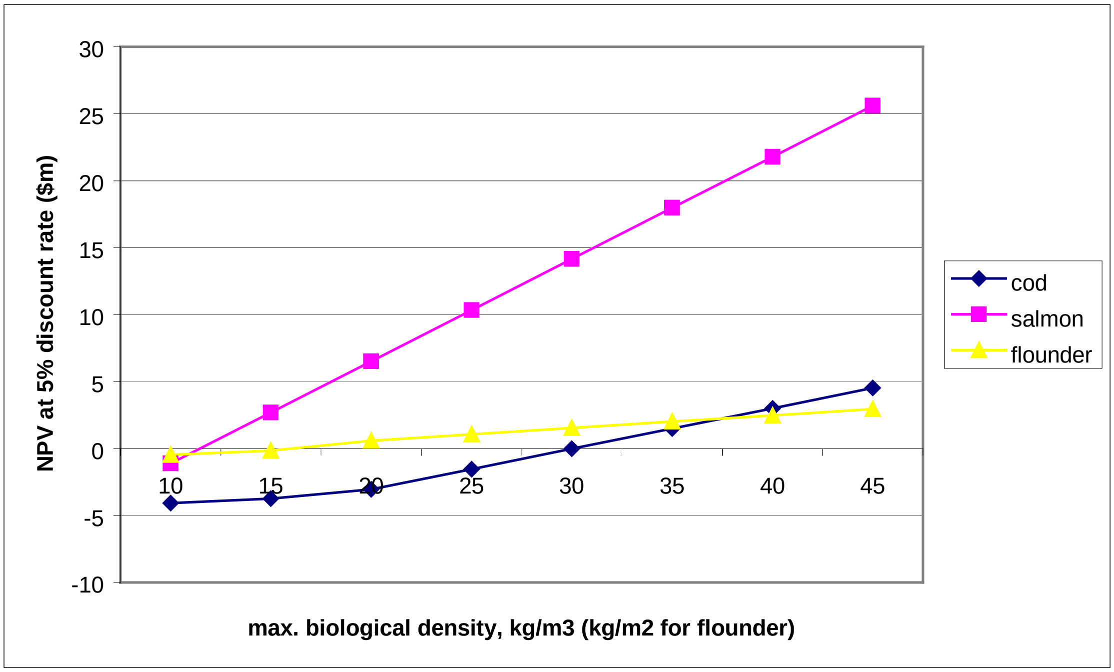

Figure 24. NPV of 5000 m^3/harvest growout operations at 5% real discount rate at varying maximum culturing densities (biomass per unit cage space)

c. <u>Conclusions</u>

Our application of a bioeconomic model to the growout of three types of finfish off the coast of New England suggests that open ocean growout is economically viable in this region, even for relatively low-value species such as cod. Fingerlings and feed are by far the most significant cost components. Cage system operation and maintenance, vessel operations, and crew expenses are also substantial, and point to the importance of automation in making open ocean growout competitive. Other parameters that have a significant effect on growout economics include the maximum sustainable growout density and market conditions.

We emphasize that the numerical results generated in this application of the bioeconomic model are less important than the general conclusions suggested by the analysis and the utility of this approach to specific examination of future open ocean growout proposals. Many factors influence the economic viability of a growout operation, and the main value of a general bioeconomic model is in the ability to analyze the tradeoffs among specific design decisions and input costs.

4. A Model of the Optimal Scale of Open Ocean Aquaculture

The literature on the economics of aquaculture is small but growing rapidly. Existing studies in this area may be categorized into two groups. The first group focuses on aquaculture itself, including the analyses of production processes (Karp *et al.* 1986; Arnason 1992; Kazmierczak and Caffey 1995) and product markets (Kouka 1995; Engle and Kouka 1995). The second group examines the interaction between aquaculture and other factors, including the impacts of aquaculture on commercial fisheries (Anderson 1985a,b; Anderson and Wilen 1986) and on the marine environment (Sylvia *et al.* 1996).

Anderson (1985a) presents a single-species model in which private salmon ranching has no direct impacts on the biology of a wild harvest fishery, and the ranch product is a perfect substitute for the wild product. The growth of the salmon stock is characterized by a surplus production model. The model suggests that the entry of a competitive rancher increases the wild harvest fish stock, reduces price, and increases the total supply of fish to the market.

In a separate study, Anderson (1985b) models the growth of a ranched stock and a natural stock using distinct Beverton-Holt recruitment functions. The author shows that there exists a range of prices where both fish stocks can coexist. However, there is a limit price above which the wild harvest stock could be driven to extinction through overfishing stimulated by the expansion of the ranched stock. The range of prices under which both species can coexist can be increased either through restrictions on fishery effort or by reducing the catchability of the ranched stock. Cooperative management results in profits from both activities.

Anderson and Wilen (1986) examine the implications of private salmon ranching in the Pacific Northwest on market structure, salmon prices, ocean and aquaculture production, and salmon fishing regulation. They model the behavior of a dominant salmon rancher facing a competitive open-access fishery using dynamic nonlinear programming. Primary attention is given to production and regulation influencing strategies of an optimally managed salmon ranch under selected institutional and biological constraints. The effect of such behavior is evaluated with regard to salmon prices, natural salmon stocks, ocean fishing effort, and ocean fishery productivity.

Our study extends this literature by examining the interaction between open-ocean aquaculture and a wild harvest fishery when aquaculture impacts the fishery adversely. We examined the interaction using an optimal control model. The model is designed to answer a basic question about the economically optimal scale of aquaculture in a region given that commercial fisheries are prosecuted there already. In the model, a hypothetical "regional manager" chooses the optimal scale of aquaculture as well as fishing effort so that the net benefit of fish production from both the commercial fishery and aquaculture is maximized.

In the model, we examined two types of impacts on the fishery. First, the cost of fishing rises as aquaculture expands (*e.g.*, due to interference with fishing operations).

Second, expansion of the aquaculture area affects the carrying capacity of the ecosystem for the wild fish stock. These two impacts are modeled as constraints that affect, respectively, the dynamics of the growth of the wild fish stock and the acreage allocated to aquaculture.

The model extends the classical bioeconomic model of a fishery. It can be used to assess a number of important policy variables. For example, it can be used to examine the steady-state (long-run equilibrium) level of aquaculture with respect to different levels of impacts on the wild stock. We developed numerical examples to illustrate the interactions between aquaculture and the commercial fishery and the optimal scale under various economic and biological conditions.

a. <u>The Model</u>

Take a linear demand function:

$$P = P_0 - \xi h \qquad \textbf{1}$$

where P_0 is the choke price, ξ is the slope, and h is the landings of fish or production from aquaculture supplied to the market. With this demand, we can compute the social benefit (B) at a given level of supply, h, to be:

$$B(h) = \int_0^h (P_0 - \xi\eta)d\eta = P_0 h - \xi h^2 / 2 \qquad \textbf{2}$$

The production function for the wild harvest fishery is:

$$h_f = qXE \qquad \textbf{3}$$

where h_f is the level of landings from the wild harvest stock, q is a catchability coefficient, X is the size of the natural fish stock, and E is an aggregate variable that represents fishing effort.

The production function for aquaculture is:

$$h_a = wS \qquad \textbf{4}$$

where h_a is farmgate output, w is a positive coefficient, and S is the total acreage for aquaculture. According to this model, a larger area is needed if aquaculture is to increase its supply to the market.[5]

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[6] We assume that a certain aquaculture technology is used. Thus, capital and labor are proportional to acreage. For discussion of aquaculture production see Shang (1981). Allen *et al.* (1984) describes modeling techniques for the biological (*e.g.*, growth and reproduction) and physical (*e.g.*, pumping and feeding) aspects of an aquaculture system. See also Hatch and Kinnucan (1993).

The total benefit is the sum of the revenues from the harvest of fish from the wild stock and the production of fish through aquaculture operations. From equations (**3**) and (**4**), benefits are a function of E, X and S:

$$B(E, X, S) = B_f(h_f) + B_a(h_a) \qquad \textbf{5}$$

The cost of fishing, C_f, is modeled as a function of both fishing effort, E, and the total geographical area, S, allocated for aquaculture operations:

$$\frac{\partial C_f}{\partial E} > 0, \qquad \frac{\partial C_f}{\partial S} > 0 \qquad \textbf{6}$$

The second inequality implies that the cost of fishing increases as aquaculture operations expand, assuming that aquaculture operations interfere with fishing.

The cost of aquaculture, C_a, also is a function of the total area S; and the annual cost of investment in new acreage (I) is a function of the annual increment, z, to the total acreage S.

$$\frac{\partial C_a}{\partial S} > 0, \qquad \frac{\partial I}{\partial z} > 0 \qquad \textbf{7}$$

A hypothetical regional manager chooses the scale of aquaculture, S, and the level of fishing effort, E, to maximize the net benefits of fish production from both the wild harvest fishery and aquaculture production:

$$\max \int \{B(E, X, S) - C_f(E, S) - C_a(S) - I(z)\} e^{-\delta t} dt \qquad \textbf{8}$$

subject to

$$\dot{X} = F(X, S) - qEX \qquad \textbf{9}$$

$$\dot{S} = z \qquad \textbf{10}$$

The two constraints describe the growth of the wild stock and changes in aquaculture acreage. We employ a surplus production model to describe the growth, F, of the wild stock:

$$F(X, S) = rX - \frac{rX^2}{K - \varphi S} \qquad \textbf{11}$$

where r is an intrinsic growth rate, and K represents the ecosystem's carrying capacity. The denominator of the second term on the right hand side of equation (**11**) implies that, as the total acreage devoted to aquaculture expands, the wild fish stock experiences a decline in ecosystem carrying capacity at rate φ.

The current-value Hamiltonian is:

$$H = B(E,X,S) - C_f(E,S) - C_a(S) - I(z) + \lambda[F(X,S) - qEX] + \beta z \quad \textbf{12}$$

The marginal conditions for an interior solution include:

$$\frac{\partial H}{\partial E} = \frac{\partial B}{\partial E} - \frac{\partial C_f}{\partial E} - \lambda qX = 0 \quad \textbf{13}$$

$$\frac{\partial H}{\partial z} = -\frac{\partial I}{\partial z} + \beta = 0 \quad \textbf{14}$$

$$\dot{\lambda} - \delta\lambda = -\frac{\partial H}{\partial X} = -\frac{\partial B}{\partial X} - \lambda\frac{\partial F}{\partial X} + \lambda qE \quad \textbf{15}$$

$$\dot{\beta} - \delta\beta = -\frac{\partial H}{\partial S} = -\frac{\partial B}{\partial S} + \frac{\partial C_f}{\partial S} + \frac{\partial C_a}{\partial S} - \lambda\frac{\partial F}{\partial S} \quad \textbf{16}$$

i. <u>Same Species</u>

As a first example, we assume that aquaculture will produce the same species as the commercial fishery and that the product is undifferentiated in the market. As a consequence, the benefit function (**5**) becomes:

$$B = P_0(qXE + wS) - \xi(qXE + wS)^2/2 \quad \textbf{17}$$

We specify the cost and investment functions as

$$C_f = cE + gS \quad \textbf{18}$$

$$C_a = vS \quad \textbf{19}$$

$$I = bz \quad \textbf{20}$$

Equations (13) through (16) become

$$\lambda = P_0 - \xi(qXE + wS) - c/(qX) \quad \textbf{21}$$

$$\beta = b \quad \textbf{22}$$

$$\dot{\lambda} - \lambda[\delta - r + qE + 2rX/(K - \varphi S)] + qE[P_0 - \xi(qXE + wS)] = 0 \qquad \textbf{23}$$

$$\dot{\beta} - \delta\beta + w[P_0 - \xi(qXE + wS)] - g - v - \lambda r\varphi X^2/(K - \varphi S)^2 = 0 \qquad \textbf{24}$$

Assuming that a steady-state equilibrium is feasible, equations (**9**) through (**11**) and (**21**) through (**24**) can be used to solve X as a function of E. S is a function of E and X.

$$X = \frac{\varphi c(r - qE)^2}{rq(\delta b + g + v)} - \frac{c(\delta + r - qE)[wr - \varphi(r - qE)^2]}{rq(2qE - \delta - r)(\delta b + g + v)} \qquad \textbf{25}$$

$$S = \frac{K}{\varphi} - \frac{rX}{\varphi(r - qE)} \qquad \textbf{26}$$

The solution at steady-state can be determined as follows. First, for any E, calculate X using equation (**25**). Then calculate S using equation (**26**). Next, calculate λ using equation (**21**). Finally, substitute E, X, S and λ into equation (**24**). Now, equation (**24**) is a function of E only. We can solve for the optimal E^* using a numerical technique such as bisection. Once E^* is known, S^* and X^* can be determined.

ii. <u>Two Different Species</u>

Suppose the natural fishery and aquaculture produce different species which are sold in different markets.

$$B = P_f qXE - \xi_f (qXE)^2/2 + P_a wS - \xi_f (wS)^2/2 \qquad \textbf{27}$$

where P_f and P_a are the choke prices, and ξ_f and ξ_f the slopes of two linear demand functions for the two species from natural fishery and aquaculture, respectively.

Substituting the values for B, C_f, C_a, and I found in equations (**27**) and (**18**) through (**20**) into the marginal conditions represented by equations (**13**) through (**16**), yields:

$$\lambda = P_f - \xi_f qXE - c/qX \qquad \textbf{28}$$

$$\beta = b \qquad \textbf{29}$$

$$\dot{\lambda} - \lambda[\delta - r + qE + 2rX/(K - \varphi S)] + qE(P_f - \xi_f qXE) = 0 \qquad \textbf{30}$$

$$\dot{\beta} - \delta\beta + w(P_a - \xi_a wS) - g - v - \lambda r\varphi X^2/(K - \varphi S)^2 = 0 \quad \textbf{31}$$

At steady-state, equations (**28**) and (**30**) can be used to solve for E as a function of X:

$$E = \frac{(P_f qX - c)(\delta + r)}{\xi_f (qX)^2 (q + r) + cq} \quad \textbf{32}$$

Substituting equations (**26**), (**29**), and (**32**) into equation (**31**) yields an equation in X only. As in the first case, equation (**31**) can then be solved by the bisection technique.

b. Data and Selected Simulation Results

For a preliminary simulation of the model, we consider the case in which aquaculture produces the same species as the commercial fishery. We look at a hypothetical summer flounder (fluke) fishery in Rhode Island Sound, and we abstract from the commercial harvest of other species, the important recreational fishery for fluke, the effects of existing conservation and management measures, among other complications.

i. Data

We conducted a literature survey to find relevant parameters for the summer flounder fishery. A surplus production model has been developed by the US National Marine Fisheries Service, but it is not believed to be very reliable, and it is not used for fisheries management purposes. The model suggests an intrinsic growth rate ranging from $0.49 \leq r \leq 1.08$ (SARC 2000).[6] We use an estimate of carrying capacity of 35 million pounds, which is 15 percent of the current estimate of biomass capable of producing maximum sustainable yield (SARC 2000). The selection of this biomass level is not completely arbitrary, as it represents the proportion of annual harvest share for Rhode Island during 1980-92 (MAFMC & ASMFC 1998).[7] We use the Edwards and Murawski (1993) estimate of catchability for yellowtail flounder: $q = 0.000011$.

We calculate an average price of $1.81/lb ($3,620/ton) for summer flounder from the national value of landings divided by national landings for 1999. The use of this price abstracts from regional and seasonal variations in price as well as premiums known to be paid in the market for different grades of fluke. We use the level of RI state landings during 1999 as a proxy for the Rhode Island Sound harvest level h_f = 1,636,528 lbs. We were unable to find a published demand model for fluke, so we borrow the demand slope

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[6] In their study of the New England groundfish fishery, Edwards and Murawski (1993) employ an intrinsic growth rate of 0.23 for yellowtail flounder, a related species.

[7] Because we consider the Rhode Island Sound region, we might want to include the proportional share of Massachusetts landings as well. Adding an additional 9 million pounds to represent the average Massachusetts harvest share gives us a range of carrying capacity of 35 to 54 million pounds to be used as a variable in a simulation exercise.

parameter for yellowtail: $\xi = 0.017$ (Edwards and Murawski 1993). Using the point represented by price and harvest and the slope parameter, we calculate the choke price, P_0, for a linear demand curve. Estimates of fishing costs for trawler classes II and III were obtained from the New England Fisheries Science Center in Woods Hole.[8]

For the culturing of summer flounder, the following parameter estimates were obtained from a model developed at the WHOI Marine Policy Center (Kite-Powell *et al*. 2001b): yield (w) = 120 tons/acre/year; production cost (v) = \$470,000/acre/year; and initial investment (b) = \$90,000/acre. The capital investment is assumed to have a life of 15 years. Maintenance costs have been included in production costs.

All parameters for summer flounder, after unit conversions, are summarized in Table 8.

Table 8
Input parameters for summer flounder

Variable	**Description**	**Value (PH)**	**Unit**
r	intrinsic growth rate	0.49	$time^{-1}$
K	carrying capacity	17.5	10^3 ST
φ	aquaculture impact on the carrying capacity	vary	10^3 ST/acre
q	catchability coefficient	0.000011	day^{-1}
w	coefficient in aquaculture production function	0.12	10^3 ST/acre
c	unit cost of fishing effort (E)	3.3	10^3\$/day
g	aquaculture impact on fishing cost	vary	10^3 \$/acre
v	unit cost aquaculture production	470	10^3 \$/acre
b	unit investment cost	90	10^3 \$/acre
δ	discount rate	0.07	
P_0	intercept of fish demand function	3640	\$/ST
ξ	slope of fish demand function	34	$\$10^{-3}/ST^2$

ii. <u>Simulations</u>

Take first the simplest case in which ocean aquaculture has no effect on the biology and harvesting operations of the wild harvest fishery, the farmed product is a perfect substitute for the wild product in the market, and demand is perfectly elastic (the slope parameter equals zero).

From the model, when we analyze aquaculture operations independent of the fishery, we have:

$$S = \frac{wP_0 - v - \delta b}{\xi w^2}$$

[8] The Mid-Atlantic Council's management plan for fluke identifies trawlers of all four size classes catching fluke, but most landings are made by trawler classes II and III.

The acreage increases if either the revenue ($w \cdot P_0$) rises or the cost (v) declines. We see also that the slope (ξ) is an important factor. In the model, the cost of aquaculture is linear with respect to acreage. When demand is perfectly elastic ($\xi = 0$) and revenues exceed costs, we conclude that $S = \infty$. In other words, using the simple structure for modeling aquaculture production, with these assumptions, aquaculture production should be expanded until it takes up the entire region.

Analogously, we can solve for maximum economic yield (MEY) in a commercial fishery when there is no aquaculture production and when demand is perfectly elastic (Conrad and Clark 1987). The optimal stock and fishing effort from the canonical bioeconomic approach are:

$$X = \frac{1}{4}\left[\frac{c}{P_0 q} + K\left(1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{P_0 q} + K\left(1 - \frac{\delta}{r}\right)\right)^2 + 8K\frac{c\delta}{P_0 q r}}\right]$$

$$E = \frac{r}{q}\left(1 - \frac{X}{K}\right)$$

Using the parameter values described in the last section, we can compare the net benefits of aquaculture versus those that result from commercial fishing when each is considered independently. Our results suggest that the economic benefit associated with aquaculture exceeds that of the commercial fishery, implying that, if decisions are based solely upon economic criteria, then the region should be devoted completely to aquaculture. This result would not be surprising if we were modeling a regulated open-access fishery in which resource rents are dissipated at the steady state. It is moderately surprising given that we are comparing a fishery being managed to achieve MEY. Note that the result in this case does depend upon the value of the model parameters.

We also simulate the benefit associated with the simultaneous coexistence of a commercial fishery and aquaculture. We find that the net benefits of the coexistence of both uses is less than the net benefits of either use taken independently. Moreover, we find that whenever aquaculture exerts a *significant* negative impact on the commercial fishery, the coexistence of both uses usually is suboptimal. Thus, if the net benefits from aquaculture exceed those from the commercial fishery, then a regional manager would want to allocate all of the available space to aquaculture. Alternatively, if the net benefits from the commercial fishery exceed those from aquaculture, say, by using a different parameterization of the model, then the entire region should be devoted to the wild harvest fishery.

In order to understand the influence of ocean aquaculture on the commercial fishery, we examined simulations of internal solutions of the steady-state (*i.e.*, long-run equilibrium) that involve the coexistence case. Recall that the input parameters in Table 8 resulted in a corner solution (*i.e.*, aquaculture only) for most of the simulations when g and φ were varied. In order to achieve internal solutions, we modified some of the parameters in Table 8. In effect, we are constraining the model to produce the coexistence of both uses as the economically optimal outcome. As shown in Table 9, several parameters were adjusted upward: carrying capacity, K, was increased from 17.5 to 175; aquaculture yield, w, was increased from 0.12 to 0.2; and the aquaculture production cost, v, was increased from 470 to 710. Also, a flatter demand (ξ = 0.034) was used. (For a fixed choke price, this represents an expansion of demand.)

Figure 25 depicts a decline in steady-state aquaculture acreage S as φ, the parameter affecting the impact of aquaculture on carrying capacity, increases. From equation (26), it is clear that S is inversely related to φ. This result is intuitive when both uses must coexist, as we might expect a smaller scale of aquaculture in the region if it causes greater damage to the carrying capacity.

Table 9
Parameters used in simulations

	Fig. 25	Fig. 26	Fig. 27	Fig. 28	Fig. 30	Fig. 31
Variable	**φ**	**G**	**B**	**B**	**K**	**K**
R	0.49	0.49	0.9	0.4	0.49	0.9
K	175	175	175	175	**90 – 620**	**90-620**
φ	**0 – 0.6**	0.1	0.1	0.1	0.1	0.1
Q	0.000011	0.000011	0.000011	0.0013	0.000011	0.0013
W	0.2	0.2	0.2	3	0.2	3
C	3.3	3.3	3.3	3.3	3.3	3.3
G	0.001	**0 - 9**	0.001	0.001	0.001	0.001
V	710	710	710	710	710	710
B	90	90	**0 - 90**	**0 – 200**	90	90
δ	0.07	0.07	0.07	0.5	0.07	0.5
P_0	3640	3640	3640	3640	3640	3640
ξ	0.034	0.034	0.034	0.034	0.034	0.034

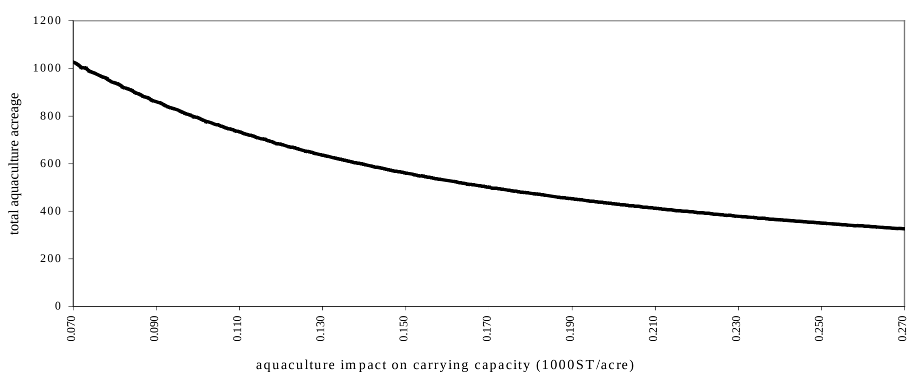

Figure 25. Optimal total aquaculture acreage as a function of the impact of aquaculture on ecosystem carrying capacity for the commercial stock

When the impact of aquaculture on fishing costs, g, is increased, landings from the commercial fishery h_f decline. This makes sense as evidence of a direct effect of aquaculture on fishing costs. Note, however, that aquaculture output h_a grows with increases in g (Figure 26). This positive relationship may be counterintuitive, but it may be explained by examination of equation (**25**). Note that g and stock size, X, are inversely correlated. As g is increased, the stock size diminishes, and the total space S allocated to aquaculture can therefore expand [equation (**26**)]. As S expands, aquaculture production can grow concomitantly.

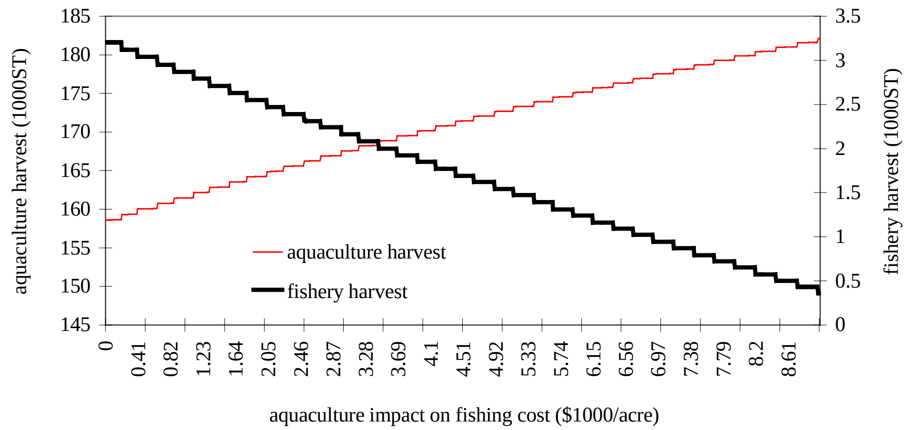

Figure 26. Impact of aquaculture on the cost of commercial fishing

According to our current model specification, the impact g on fishing costs, the unit cost b of investment, and the production cost ν of aquaculture have similar effects on the steady-state results. This can be seen clearly in equation (**25**), in which the term ($\delta b + g + \nu$) is in the denominator of both terms on the right hand side, and so it can be factored out. Note first that all three variables are negatively correlated with X, and thus, they are likely to be positively correlated with S. In Figure 27 we show the relationship between aquaculture investment cost b and aquaculture yield h_a and net benefit. As b rises, h_a increases, and the net benefit rises after a period of initial decline. In our model, h_a is linear with respect to S [equation (4)]. Thus, the same relationship between g and h_a applies here: when the unit cost of investment b increases, the stock size X will decline [equation (**25**)], and as X drops, S goes up [equation (**26**)].

As discussed above, the influence of g on h_f and h_a is more transparent than the similar influence of b and ν. As components of the variable costs of aquaculture, ostensibly, increases in b and ν should make aquaculture less competitive with commercial fishing. One possible intuition is as follows: other things being equal, when the costs of aquaculture are low, a corner solution (*i.e.*, aquaculture only) prevails; in order to have both uses continue to coexist for higher aquaculture acreage levels necessitates that the costs of aquaculture be relatively high. This may be true only within specific ranges of the parameter values.

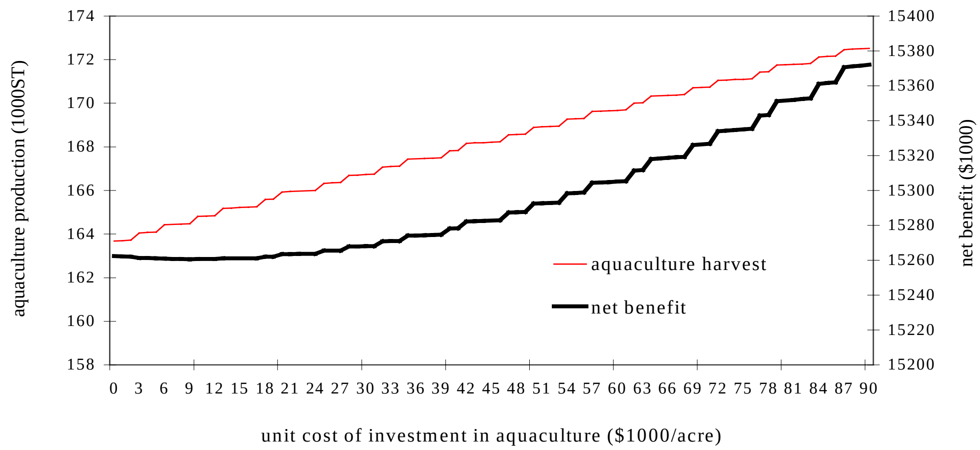

Figure 27. Aquaculture production and net benefits as functions of the unit cost of investment in aquaculture

To illustrate the effects of parameters on model results, we reexamine the relationship between b and S with a different set of parameters (Table 9), which include a lower intrinsic growth rate (r = 0.4); a higher catchability (q = 0.0013); a higher aquaculture yield (w = 3); and an (unrealistically) high discount rate (δ = 0.5). The results appear in Figure 28. In this case, the scale of aquaculture operation S declines as the unit cost of investment b increases. From Equation (**26**), we see that when r < qE, S and X are positively correlated. Thus, when b rises, the stock size X falls [equation (**25**)], and as a result, S will decline as well.

Our simulations on the coexistence of commercial fisheries and aquaculture reveal that the population dynamics of the fishery is a key factor affecting the long-run equilibrium scale of aquaculture. From equations (**9**) and (**11**), we can derive the relationships among X, E, K, S, and φ at the steady-state (when dX/dt = 0). As shown in Figure 29, a greater K provides a greater range of X. An increase in S or φ reduces the range for X. The range for E is always the same. Figure 30 presents how the acreage S and net benefits increase as carrying capacity K becomes larger. The effect of higher intrinsic growth rate on S is plotted in Figure 31. Generally, both a higher carrying capacity and a faster growth rate can accommodate larger scales of aquaculture.

c. <u>Conclusions</u>

In this project component, we examined the interactions between a wild harvest fishery and ocean aquaculture using an optimal control model. The model is designed to examine the economically optimal scale of aquaculture in a region when aquaculture exerts negative impacts on commercial fisheries. In the theory section, we developed models for two cases. In the first case, aquaculture will use a certain offshore area to

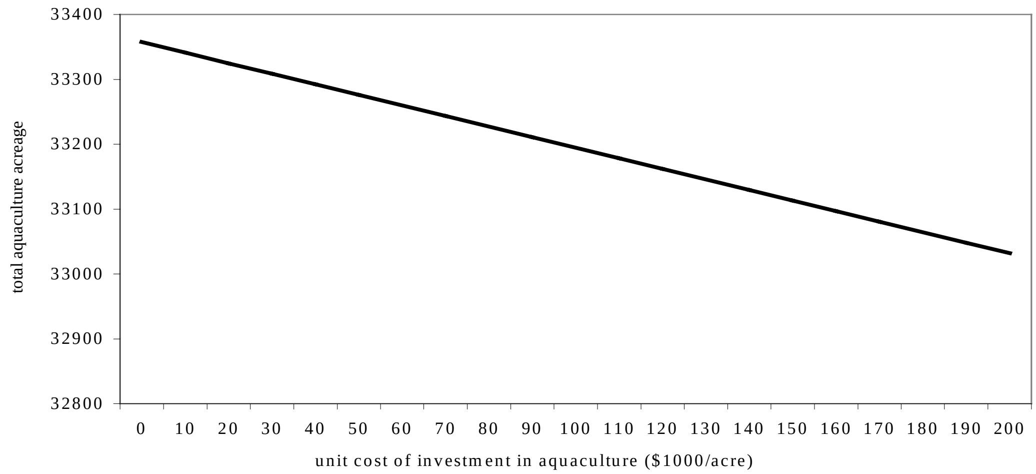

Figure 28. Optimal total aquaculture acreage as a function of unit cost of investment in aquaculture

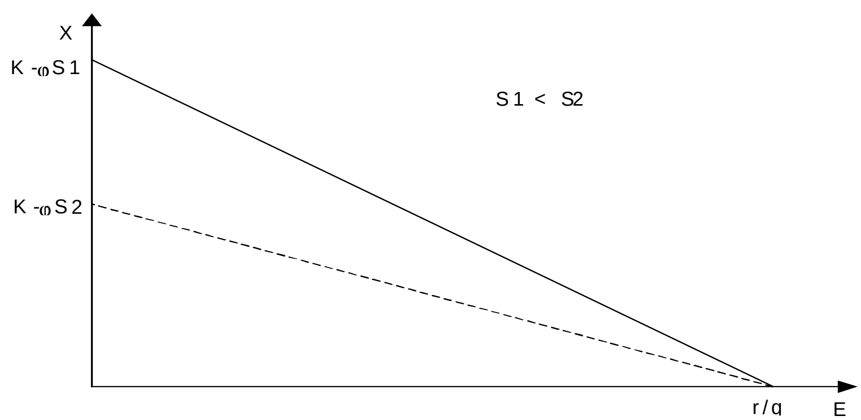

Figure 29. Steady state equilibrium dX/dt = 0

produce the same species as the commercial fishery. In the second case, the commercial fishery and aquaculture produce different species, which are sold in different markets.

We developed numerical simulations to illustrate the first case where aquaculture that produces the same species as the commercial fishery is under consideration for development in the same geographic region. Results of the study suggest that when aquaculture exerts a significant negative impact on the fishery, the economic optimum often is associated with a corner solution of the model (*i.e.*, the region should be used

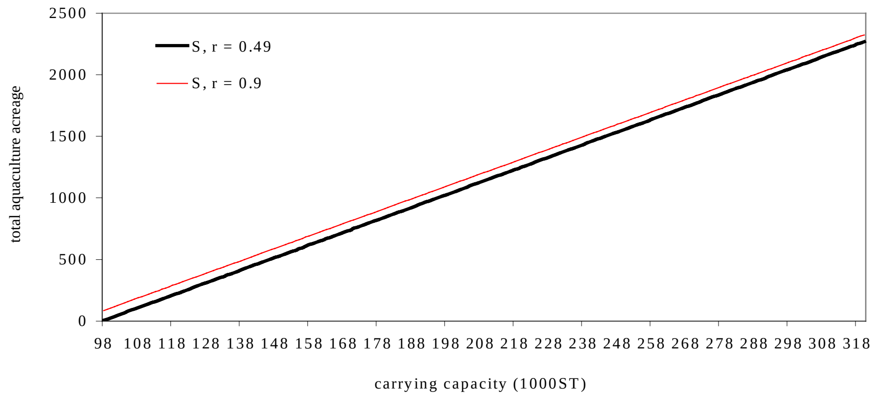

Figure 30. Optimal total aquaculture acreage as a function of carrying capacity (r = 0.49 and r = 0.9)

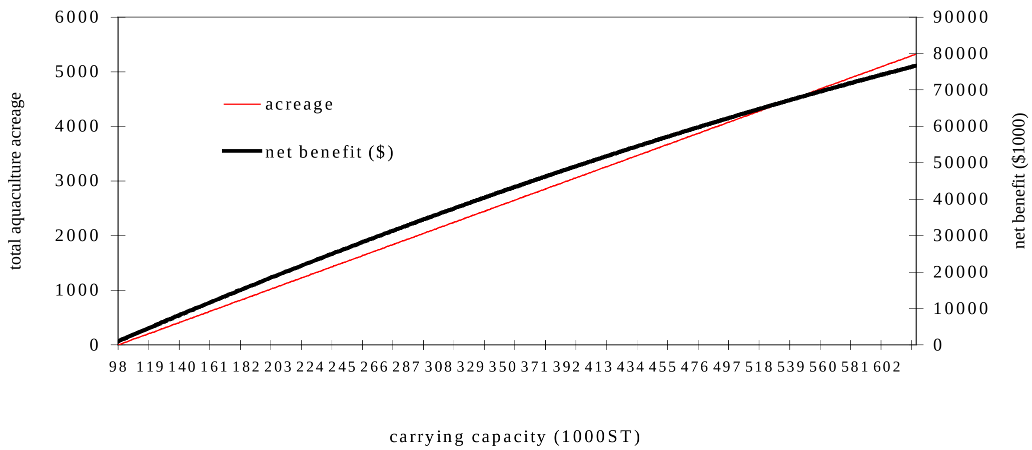

Figure 31. Total aquaculture area and net benefits as functions of carrying capacity

exclusively for either aquaculture or commercial fishing), and co-existence is suboptimal. In fact, using parameters for our hypothetical case involving the summer flounder fishery in Rhode Island Sound, we could not find a superior solution involving the coexistence of both uses. In general, if the net benefits from aquaculture exceed those from commercial fishing, then it is economically optimal to replace the fishery with aquaculture (and vice versa). This finding may be due in part to the linear specification of the aquaculture production and cost functions.

Using modified parameter values, we also examined internal solutions of the steady-state (*i.e.*, long-run equilibria) to model the feasibility of the coexistence of both uses. In this mode, we can simulate different levels of the negative impacts of aquaculture on the fishery. For example, when both uses are constrained to coexist, the long-run equilibrium aquaculture acreage must decline as its impact on the carrying capacity of the wild stock is increased. In addition, we have shown that the population dynamics of the fishery is a key factor affecting the long-run equilibrium geographic scale of aquaculture. Thus, a greater carrying capacity and a faster growth rate can accommodate a larger scale of aquaculture when both uses must coexist. Finally, the study has led to several results that are counterintuitive on the surface (*e.g*., the steady-state aquaculture scale expands when aquaculture costs increase). Thus, the application of the model has raised important questions for future research.

5. A Comparison of Natural Resources Access Systems and Lessons for Ocean Aquaculture in the US Exclusive Economic Zone

This component of the research project focused on the design of a system for allocating a natural marine resource. The resource is "ocean space" with all of its attendant characteristics, including geographic location, nutrient fluxes, plankton densities, temperature ranges, current flows, flushing rates, predators, parasites, contaminants, among other features. We consider allocating ocean space specifically for the purpose of culturing marine species of fish, shellfish, or plants. As such, the allocation of ocean space is directly analogous to the allocation of land for growing crops or raising livestock. Like land, ocean space is not homogeneous; its geographic location relative to natural phenomena, such as nutrient upwelling, and its proximity to markets and to human uses on the land and in the ocean, such as wharf facilities or commercial fishing grounds, may give rise to differences in quality.

The existence of quality differences implies that, like good cropland, high-quality ocean space is a scarce natural resource. As a consequence, ocean space useful for open-ocean aquaculture has economic value. This value is known in the terminology of economics as a "resource rent."[9] Further, there may be a gradient of quality from high to low, implying a corresponding gradient in resource rent.[10] The disposition of resource rent plays a central role in the design of a system of access to any natural resource, including ocean space for aquaculture. If rent is ignored, then a natural resource is likely to be allocated inefficiently, resulting in the wasteful use of not only the resource but of human and capital resources as well. The clear over-exploitation and depletion of many wild harvest marine fishery resources is a classic example of what happens when we ignore the disposition of resource rents.

In the discussion that follows, we consider a baseline access system for which the primary policy objective is to allocate ocean space in order to maximize the realization of

[9] The concept of resource rent can be traced back to the writings of the English political economist David Ricardo in 1817. In the case of the use of ocean space for aquaculture, resource rents are equivalent to the revenues from an aquaculture operation, net of all relevant costs including payments to capital and labor and negative externalities, or the opportunity costs of displacing or diminishing other human activities that generate rents.

[10] This is analogous to the "bid-rent" concept first put forward by von Thunen in 1836. See Ledyard and Moses (1976) for a modern development of the bid-rent theory with respect to the case of forest resources.

resource rents. We argue that the creation of strong and legally transferable property rights is critical to achieving this goal. Further, we show that it is important that there be legal institutions (laws and agencies) to establish these rights and to provide means for enforcement against any infringement of rights.[11] Thus, we conclude that a system of access to ocean space is necessary for the development of ocean aquaculture as a productive sector in the US economy.

We recognize that there may be significant obstacles impeding the achievement of such a simple policy objective. First, substantial uncertainty may surround the estimation of resource rent in any specific case. The presence of uncertainty implies that we may be unable to measure resource rent with a high degree of precision until after the resource has been allocated and utilized. However, it may be possible to incorporate simple principles that reduce the costs associated with making decisions to allocate ocean space that turn out, *ex post*, to be inefficient.

Second, there may be other human uses of ocean space, such as commercial and recreational fishing, shipping, mineral extraction, boating, fish and wildlife conservation, or others, that take precedence in law or in historical practice. In principle, we would like to compare the resource rents that are generated by these uses to those that result from aquaculture to determine the highest and best use of ocean space. (See Figure A.2 in the Appendix for a preliminary GIS presentation of ocean uses and associated economic values in the waters off New England.) In practice, legal or political barriers are already in place that require the treatment of these other uses—at least in the short term—as constraints on the amount of high-quality ocean space available for aquaculture. If ocean uses are not mutually exclusive, then multiple uses may occur in the same area simultaneously.

A third consideration is that a single policy objective to maximize resource rent is unlikely to be adopted as an overriding goal. Other social objectives are likely to be put forward in the policy debate over the allocation of ocean space. Table 10 summarizes a number of such objectives, which have been extracted from policy statements emerging from the Department of Commerce, other agencies, and from inchoate legislative

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[11] It may be useful to consider the US public as the "owner" of ocean space. In this case, a federal agency would enabled to act on the public's behalf to "dispose" of the resource in a way that recieves the highest economic return. Outer Continental Shelf oil and natural gas resources are allocated according to this model. Note, however, that such a system is in itself a distribution of resource rents that is unnecessary for achieving a goal of economic efficiency. All that is required for efficiency is that the rights be established, enforceable, and freely transferable.

Table 10
Comparison of broad aquaculture policy objectives

General	**Department of Commerce**	**NOAA**	**NEFMC***	**NMAA 1999**[**]	**FAO Code of Conduct**
Overall	DoC mission to "create sustainable economic opportunities in aquaculture in a manner that is environmentally sound . . . ." Mission complements and is an integral part of DoC's effort "to restore and maintain sustainable wild stock fisheries in order to maximize the benefits of US coastal resources for its citizens."	NOAA is "best suited to oversee aquaculture activities that affect marine ecosystems and occur in public waters"; "A successful NOAA program to meet public needs for aquaculture development and environmental protection will focus on: (1) research, development, and technology transfer; (2) financial assistance to businesses; (3) environmental safeguards including regulatory and permit procedures; and (4) coordination."	Aquaculture is encompassed within the MSFCMA as a "harvesting" activity; NEFMC policy to encourage biologically and environmentally sound aquaculture projects and to develop management strategies that maximize opportunities for the aquaculture industry's "productive co-existence" with the traditional commercial fisheries . . ." Encourage projects that maximize biological, social, and economic values	"It is the policy of the United States to—restore the Nation's marine fisheries and sustain the economic base of coastal communities by reducing overfishing, protecting essential fish habitat, enforcing conservation laws, and expanding research and public-private partnerships for the development of environmentally sound marine aquaculture. . . "	Code establishes "principles" for "responsible fishing and fisheries activities" (aquaculture is defined as a fishery) taking into account all relevant biological, technological, economic, social, environmental, and commercial aspects The code is directed to members and non-members of FAO, but it is voluntary
Use Conflicts	Hold national and regional meetings with aquaculture constituents to inventory resources and issues and set priorities for the future	"traditional users" (fishermen) must be incorporated into the regulatory process; develop innovative coastal management tools; NOAA will identify geographic areas that reduce conflicts	The proposed activity should not "unreasonably interfere" with other uses of the area [i.e., commercial fishing]; encourage projects requiring less exclusivity	US policy to ensure that the placement and operation of and new marine aquaculture facility within the US or the EEZ "does not pose unreasonable economic constraints on the recognized legitimate use of marine waters for navigation, fishing, recreation, national defense, and other activities."	States should produce and regularly update aquaculture development strategies and plans to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other activities
Regulation	Develop a code of conduct for responsible aquaculture by the year 2000 Develop a set of aquaculture guidelines for DoC aquaculture activities Develop an efficient and transparent permitting process for aquaculture	Develop more efficient permit procedures; one federal agency should be responsible for coordinating federal permitting; pre-approve areas for aquaculture	NEFMC will position itself as the "point of contact" for aquaculture developers' first-come, first-serve review policy; a single entity should not receive excessive "benefits"; discourage projects that are "large in size" and lack justification; developer must demonstrate "likelihood" that project can receive all necessary and relevant permits		States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of "responsible aquaculture"
Environmental protection	Aquaculture technologies are to emphasize, where possible, "pollution prevention rather than pollution control techniques"	Establish national criteria for "environmentally safe" aquaculture operations	Project should present acceptable biological impacts; should be compatible with the long term ability of the area to support ecologically significant flora and fauna	US policy to ensure placement and operation of any new marine aquaculture facility is "environmentally sound"	States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and

General	Department of Commerce	NOAA	NEFMC*	NMAA 1999**	FAO Code of Conduct
	Minimize adverse impacts on protected species through the proper design and siting of facilities and the application of appropriate deterrent technology				ecosystem integrity, based upon the best available scientific information
Production	Increase annual value of domestic production from $0.9 to 5.0 billion Double the value of non-food products and services to increase industry diversification		Project should present acceptable economic impacts	US policy to encourage private investment in marine aquaculture facilities locat4ed in coastal waters or the EEZ US policy to achieve a 20 percent increase in the contribution of marine aquaculture to the gross domestic product by the year 2004	States should promote responsible aquaculture practices in support of rural communities, producer organizations, and fish farmers
Financial assistance	Provide financial, marketing, and trade assistance	Advocates continued use of the Fisheries Finance Assistance program and authorization of the CCF program to include aquaculture		US policy to restructure existing financial assistance programs to encourage private investment	
Employment	Increase employment from 180 to 600k		Encourage projects that propose to enhance harvesting opportunities for displaced fishermen	US policy to encourage private enterprise to develop new employment opportunities in marine aquaculture facilities	
Consumption	Increase per capita consumption of seafood from 15 to 18 lbs				States should ensure food safety of aquaculture products
Research	Conduct basic and applied research to domesticate high-valued species and those that are least likely to create environmental problems	R&D on environmental impacts and standards; systems development; growth and production of marine species; biotechnology;	Encourage pilot or demonstration projects	US policy to promote R&D in marine biology, marine ecology, genetics, ocean engineering, economics, law, public policy and other disciplines	
Technology	Develop to improve production systems and safeguard the environment	Development of DNA technology; transfer of technology to industry		US policy to promote R&D in marine aquaculture technology	
Exports	Increase annual value of exports from $0.5 to 2.5 billion			Act is designed, in part, to "reduce the trade deficit in fish products."	
Wild Stocks	Enhance depleted stocks through aquaculture; develop effective enhancement strategies	Enhancement is a potential purpose	Projects that remove pressure from or enhance wild stocks should receive preferential treatment		Promote R&D of culture techniques to protect, rehabilitate, and enhance endangered species

*Draft (13 August 1997).
**Draft (September 1998).

proposals. Some of these objectives relate to the economic goal, albeit implicitly, such as those that recognize the social costs associated with pollution. Others focus on fairness to existing users or the distribution of rents across so-called “stakeholder” groups. We recognize the legitimacy of many of these objectives. However, we take note that the achievement of some of these other objectives is likely to compromise the achievement of the resource rent objective. We clarify this point in the discussion that follows. Another way of conceptualizing this issue is that, in order to accommodate some types of social objectives, it may be necessary to "pay" for them by foregoing the collection of resource rents.[12] This tradeoff should be acceptable to society if the costs of alternative social objectives are transparent; if they are not, then the likelihood of incurring economic waste through the allocation of ocean space is increased.

a. Methodology

In this subsection, we report on the results of research on the design of an optimal access system for open-ocean aquaculture. The research is based mainly on the results of a review of the literature on access systems that have been established for a wide variety of public natural resources. We have initiated the development of a database of access systems for these other resources and for aquaculture in other jurisdictions. Where relevant, we draw examples from these systems to illustrate useful features for a system of access for open-ocean aquaculture.

Several commentators have conducted comparisons of access systems specifically for aquaculture. At the level of national governments, Bye (1990) finds a body of confused and contradictory laws and the lack of a serious political commitment to aquaculture in many countries. (See Table A.1 in the Appendix for a table comparing aquaculture access systems in three European countries.) The author calls for the establishment of a lead US agency with responsibility for aquaculture, the development of a national aquaculture plan, and the implementation of an “appropriate” legal framework to encourage industrial development. Cullinan and van Houtte (2000) note that there is now a growing interest in the development of a “comprehensive” regulatory framework in many countries; this trend is abetted by Article 9 of the United Nations Food and Agriculture Organization’s Code of Conduct for Responsible Fisheries (CCRF). Although nonbinding, the CCRF includes, as a principle, the statement that nations should establish an appropriate legal framework to facilitate the development of “responsible” aquaculture. A recent special issue of the *Journal of Applied Icthyology* (2000) presents a comparison of the regulation of marine aquaculture in several western European nations, focusing on rules related to environmental impacts and monitoring.

At the US federal level, a rudimentary access system is now in place for open-ocean aquaculture (Brennan 1995; Eichenberg and Vestal 1992). This system is outlined in Table 11, which includes in the last column several unanswered policy questions. At

[12] Alternatively, one might conceptualize rent payments as compensation for lost opportunities to use the ocean in other ways. Schantz (1994) describes this perspective with respect to a proposed royalty structure for locatable minerals on the US public lands.

present, the US Army Corps of Engineers serves as the de facto “lead agency,” on account of its jurisdiction under section 10 of the Rivers and Harbors Act of 1899. Significantly, there is no authority at present for the allocation of ocean space for the exclusive purpose of conducting open-ocean aquaculture. A wide range of broad institutional frameworks have been proposed, but, to date, no framework has been adopted. Because of the potential for conflicts with existing commercial wild harvest fisheries, Brennan (1995) suggests that regional fishery management councils may be the most appropriate locus of management authority. In the interest of promoting environmental protection and minimizing regulatory uncertainties, Hopkins *et al*. (1997) argue for a cooperative approach involving the many federal agencies with jurisdiction over one or more aspects of marine aquaculture. As a third possibility, Reiser (1997) recommends that coastal states extend their jurisdiction to manage open-ocean aquaculture, following the oversight and guidance of federal agencies.

At the US state level, DeVoe and Mount (1989) compare the institutional structures for aquaculture in ten coastal states, concluding that few structures meet the needs of the aquaculture industry. The authors identify five criteria, including scope, size and duration, exclusivity, costs, and residency, that must be addressed in order for a state to attract industrial interest in the aquaculture sector. On the other hand, Rychlak and Peel (1993) are much more sanguine about the future growth of aquaculture, even after a review of the “myriad” of federal, state, and local regulations faced by the industry. Other compilations of state policies can be found in Wypyszinski (1994) and MCZM (1995). (And see Table A.2 in the Appendix for a comparison of systems in three New England states.)

The research presented here differs from these earlier treatments by focusing on the generic features of a system of access, by drawing examples from a range of resource management cases (see Table A.3 in the Appendix), and by considering what may be the most economically efficient features.

b. Generic Policy-Relevant Features of an Access System

We divide the discussion of the basic features of an access system for ocean aquaculture into eleven sections. These features include: (i) nature of the resource; (ii) management structure; (iii) research programs; (iv) method of allocation; (v) tenure; (vi) size; (vii) transferability; (viii) financial terms of allocation; (ix) performance requirements; (x) resolution of multiple use conflicts; and (xi) enforcement aspects. Many of these features overlap. In the discussion that follows, we consider first a baseline (economically efficient) feature. Next, we consider modifications to the baseline that permit the achievement of alternative social objectives, and we discuss some of the positive or negative consequences of such modifications.

Table 11

Existing US ocean aquaculture "access system"

Action	**Legal Requirement(s)**	**Authorities**	**Agency**	**Open Questions**
Quasi-permanent occupation of ocean space (seabed or water column)	None	None	None	There is no mechanism to allocate exclusive property rights. There is no lead agency with responsibility for allocating ocean space or integrating the many legal authorities. Is there a federal "public trust doctrine"?
Obstruct navigation	§10 permit	Rivers and Harbors Act, 33 USC §403; Outer Continental Shelf Lands Act, 43 USC §1333(e)	ACoE	Beyond the federal TS are structures that are "attached" (vs. "erected upon") the OCS subject to the permit requirement? Should a "general" §10 permit be established?
Establish private aids to navigation (*i.e.*, "stake claim"); lights on netpens	Authorization (typically an annual permit)	14 USC §83, 84, 85	USCG	
Construct and operate an aquaculture facility	None; aquaculture exemption for managed species (Atlantic salmon); aquaculture "special management areas" (sea scallops); fishery management plan (hard rock corals); prohibition of aquaculture	Magnuson-Stevens Act, 16 USC §1801 *et seq.* [presumption based upon an opinion issued by NOAA General Counsel]	NMFS; FMCs	Is ocean aquaculture a form of "fishing" as defined under the MSFCMA? Can an "Aquaculture FMP" be developed if aquaculture is not considered to be a "fishery" as defined in the Act?
Support aquaculture facility with vessels or barges ≥ 5 GRT	Vessel documentation		USCG	
Discharge pollutants (including feed)	§402 point source discharge permits* (within TS) (for netpens only)	Clean Water Act, 33 USC §1342	EPA	Is EPA administrative determination that netpens are "concentrated aquatic animal production facilities" valid? Unclear whether NPDES permit is required? Is "fish feces" a pollutant? Is there a "vessel exemption"? Should a "general" NPDES permit be established?
Discharge of pollutants into the TS, CZ, or oceans	§403 disposal effects review	Clean Water Act, 33 USC §1343	EPA	

Action	Legal Requirement(s)	Authorities	Agency	Open Questions
Dump material (matter of any kind, including biological matter or animal waste) into ocean waters (or transport for ocean dumping)	§102 permit	Ocean Dumping Act, 33 USC §1412	EPA	Exemption for "developing, maintaining, or harvesting fisheries resources"? What is the definition of "fish" wastes?
Dump dredged or fill material (or transport for ocean dumping)	§404 permit; §103 permit	Clean Water Act, 33 USC §1344; Ocean Dumping Act, 33 USC §1413(a)	ACoE	Should a "general" permit be established?
Affect essential fish habitat (EFH) adversely	EFH conservation recommendations (advisory only)	Magnuson-Stevens Act, 16 USC §1801 *et seq.*	NMFS	
Affect the quality of the human environment significantly	Assess environmental impacts	National Environmental Policy Act, 42 USC §4332(2)(C); E.O. 12114	Relevant lead agency	At what scale is an EIS required? Does NEPA apply beyond the TS?
Affect any threatened or endangered species adversely (including adverse modification of designated critical habitat)	§7 consultation (formal or informal)	Endangered Species Act, 16 USC §1531 *et seq.*	NMFS	When is a Biological Assessment required? What is considered to be an adverse modification of critical habitat? When is the continued existence of a listed species deemed to be "jeopardized" by an aquaculture facility? What are "reasonable and prudent" alternatives to avoid harm (including technological solutions)?
Release cultured species accidentally				When are species considered genetically different?
"Take" marine mammals		Marine Mammal Protection Act, 16 USC §1383(a)(1) or §1381 (a)(5)(A) or §1381 (a)(5)(D)	NMFS	Is aquaculture entitled to an exemption as a type of commercial fishery? Are permits for incidental take or incidental harassment authorizations necessary? How are nuisance marine mammals to be controlled? What nonlethal technological "solutions" are permissable?
"Take" protected birds	Depredation permit	Migratory Bird Treaty Act, 16 USC §703 *et seq.*	FWS	What nonlethal technological "solutions" are permissable?
Grow "federally managed" species		Magnuson-Stevens Act, 16 USC §1801 *et seq.*	NMFS; FMCs	Is production from aquaculture facilities subject to the same kinds of management measures as wild harvest fisheries (*e.g.*, minimum size restrictions)?

Action	Legal Requirement(s)	Authorities	Agency	Open Questions
Grow "organic" fish	USDA certification	Organic Food Production Act, 7 USC §6501 *et seq.*	USDA	National Organic Program does not yet include "aquatic animals." What are the growing practices under which aquacultured fish are likely to be certified as "organic"?
Grow threatened or endangered, exotic, or state "game fish" species	Prohibition	Endangered Species Act, 16 USC §1531 *et seq.;* Lacey Act, 16 USC §3371 *et seq.*; state laws	FWS; relevant state(s)	Possible exception for enhancement of marine threatened or endangered species?
Grow "genetically modified organisms"	Possible prohibitions on consumption	Food, Drug and Cosmetic Act, 21 USC §301 *et seq.* and state FDCA-type laws	FDA	Is FDA the appropriate agency?
Impact coastal zone	Consistency review(s)	Coastal Zone Management Act, 16 USC §1451 *et seq.*; state CZMPs and laws	Relevant state(s)	At what scale or scope does an aquaculture project trigger a consistency determination?
Apply pharmaceuticals	Can use "registered" drugs only	Food, Drug and Cosmetic Act, 21 USC §301 *et seq.* and state FDCA-type laws	FDA; relevant state(s)	What fish vaccines are permitted?
Apply pesticides	Regulation of use; prohibition on "contaminated" or "adulterated" food from travelling in interstate commerce	Federal Insecticide, Fungicide, and Rodenticide Act, 7 USC §136 *et seq.*; Food, Drug and Cosmetic Act, 21 USC §1 *et seq.* and state FDCA-type laws	EPA	Can pesticide applications in the marine environment be "registered" under the Act? What is the likelihood of chemical trespass or private nuisance actions?
Impinge upon cultural properties	§106 "taking into account" the effects of the issuance of federal licenses on resources that are listed or deemed eligible for listing as National Register properties	National Historic Preservation Act, 16 USC §470f	Relevant lead agency	What about the effects on underwater cultural resources that are not deemed eligible for listing as National Register properties?

* Effluent guidelines for the regulation of "aquatic animal production facilities" are currently under development by EPA pursuant to a consent decree issued in *NRDC* v. *EPA*, (D.D.C. Civ. No. 89-2980, January 31, 1992, as modified). The focus of the guidelines will be on excess nutrients and hypoxia. Regulations are expected to be finalized by 2004.

i. Nature of the Resource

It is critical to the success of an aquaculture operation for the culturist to understand the physical and environmental characteristics of the site. There are many dimensions to a full characterization of an open-ocean site, all of which may affect the economics of the operation and therefore the realization of resource rents. What is critical is the development of an understanding of how the variability of these characteristics affects growth and survival over the growout cycle for the species of interest. Some of the more important dimensions[13] include the temperature regime, which can affect the growth rate of individuals; nutrient levels, which may enhance primary productivity, thereby providing a source of food for shellfish; the dissolved oxygen content of the water, which can affect respiration in aquatic animals; the proximity of the site to sources of chemical contamination; the potential for the cultured animals to pick up viruses or other pathogens; and the presence of predators and parasites, among other things (Landau 1992).

Ocean space for use in aquaculture is an example of a renewable resource. Depending upon stocking densities, feed requirements, and current flows, the local area surrounding an aquaculture site may undergo environmental change in the short term. These changes imply a build-up of nutrients from food and animal waste products, potential changes in the productivity of the system, leading on occasion to eutrophic and hypoxic conditions. There exists also the potential for the displacement of endemic organisms, movement of macro-nutrients, biochemical oxygen demand, algal blooms, and disease downcurrent from a site. In most cases, such effects are thought to be less prevalent in the open-ocean than in protected embayments or estuaries. If such effects occur, typically, these conditions may be reversed if the ocean space is allowed to lie fallow for a period of time. In order to rejuvenate ocean space for aquaculture and to minimize downstream effects, the fallowing of ocean space has been written in as a requirement for European finfish culture sites in ocean and fjord environments.

In certain circumstances, open-ocean aquaculture may become a nonrenewable resource. This might happen if the use of the ocean for aquaculture results in an irreversible change in the nature of the ecosystem through, say, the release of exotic species, genomic modifications of wild animals, or hysteresis associated with changes in the dominance of certain phytoplankton or species at higher trophic levels.

A strong argument can be made that the lack of understanding about site characteristics may preclude incipient commercial interest and investment in ocean aquaculture. It is generally believed that the open ocean is a clean environment for which the likelihood of conflicts with other human uses is small. However, depending upon the species to be cultured, much more information must be known about environmental characteristics at specific locations. The collection and display of environmental information useful for selecting ocean space of high quality for aquaculture is one of the

[13] We do not list all of the dimensions here. We assume that salinity in the open-ocean environment is relatively constant, averaging about 35 parts per thousand, and the minor variability of salinity in the open-ocean does not constrain aquaculture development.

main objectives of a number of public demonstration projects, including the Massachusetts Ocean Resource Information System (MORIS), which is a geographic information system useful for aquaculture siting now under development by the Massachusetts Office of Coastal Zone Management (Myre *et al.* 2001).

The survey and classification of ocean space into areas that are potentially of a quality suitable for aquaculture is analogous to the conduct of mineral surveys for outer Continental Shelf (OCS) hydrocarbons and hard minerals (Table 3).[14] Because of the ownership structure established under the Outer Continental Shelf Lands Act (OCSLA), it has been important for US government agencies to survey and estimate the resource potential of OCS lands. Such estimates provide a basis for identifying areas to be offered for lease and for calculating the size of the resource rent. At the same time, private firms may conduct seismic surveys to develop their own estimates of resource potential and value. Another provision of OCSLA is that, in certain circumstances, firms may cooperate on drilling exploratory wells and sharing the resulting information, thereby reducing the costs of duplicative prospecting activities. The industry may recommend that the US Minerals Management Service make available for lease areas that have been surveyed by industry.

Ideally, a survey program for open-ocean aquaculture would take into account only those physical and environmental characteristics determined to be important for aquaculture. Ocean areas might then be classified by species appropriate for growing in each area. Using models of operational economics for the culturing of these species, it would be possible to estimate the size of resource rents. It may then be feasible to compare these rents with the potential rents available for other uses of the ocean, such as commercial fishing, merchant shipping, waste disposal, or recreational uses.

In some circumstances, a survey cannot reveal all of the information needed to estimate the productivity of an area of ocean space for aquaculture. Some existing access systems allow for experimental or prototype aquaculture operations to take place. For example, under Irish policy, a one- to three-year "trial license" may be obtained for farmers to engage in experimental aquaculture. Similarly, in the state of Maine, special aquaculture research licenses are available.

ii. <u>Management Structure</u>

Table 11 presents the existing management structure or regime for allocating ocean space for aquaculture in the United States. The existing regime is clearly fragmented, representing the policies, programs, and activities of a wide range of federal agencies that arguably have some responsibility for the external effects resulting from a wide range of ocean uses, including open-ocean aquaculture. As listed in the last column, there are a number of unanswered questions that pertain to the application of each of these policies. The most salient feature of the existing regime is that there is no agency with responsibility for providing access to specific areas of the ocean for aquaculture.[15]

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[14] An analogous survey process is in place for timber resources on US national forest lands.

[15] Johnson and Hayes (1993) argue that the Magnuson-Stevens Act provides authority for NMFS as the

In particular, there is no institution in US ocean law and policy that provides for the establishment of property rights for open-ocean aquaculture operations.

There are two critical economic issues that arise with respect to the design of a management structure. The first pertains to the nature of management. We can conceptualize a spectrum of management ranging from a hierarchical regime, characterized by a central agency that allocates the resource, to a decentralized regime, where a number of ocean users or stakeholders have a voice in a political allocation process. A credible hypothesis is that economic efficiency is an increasing function of management centralization. For example, we might expect that a centralized management could focus more easily on the objective of capturing resource rents. One model for this is the MMS five-year leasing program for OCS lands. Conversely, attention to fairness, in terms of meeting the actual or potential needs of a group of stakeholders, should be an increasing function of decentralization. As a consequence, we might expect something like the structure that appears in recent proposed legislation,[16] where aquaculture may be shunted to ocean space of potentially marginal quality so that established ocean uses continue to occur in their traditional areas.

Political negotiations over the design of the management structure may lead to opportunities for "rent seeking." Rent seeking is an economically wasteful activity that results from the political activities of interest groups or individual firms to gain special privileges or advantages over competitors or other interests. Not only is the act of rent seeking wasteful, but the resulting allocation of resources may be wasteful as well. Evidence of rent seeking appears in proposed legislation that assigns a priority to other uses of the ocean over the siting of aquaculture. It is possible that these other uses are more highly valued than aquaculture, but that result is unlikely in all situations. Ironically, advisory boards, such as those constituted by industry representatives for making recommendations on grazing lands or for managing fisheries, may contribute to the problem of rent seeking. In these circumstances, there may be a question of balancing the costs of rent seeking with the benefits of establishing a board with industry representatives who have both technical expertise and practical experience.

In practice, an access system will need to be designed to consider many, if not all, of the issues identified in Table 11. Thus, it will be necessary for a decision process to be designed that permits agencies with particular expertise and legal responsibilities to weigh in on ocean space allocation decisions.

iii. <u>Research Programs</u>

Research into open-ocean aquaculture has been initiated even in the absence of a well-defined system of access. In New England, test-bed projects have been initiated by the Gloucester Aquaculture Project (sea scallops); Coonamessett Farm, Westport Scalloping Corporation, and the Massachusetts Institute of Technology Sea Grant

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lead agency.

[16] Marine Aquaculture Act of 1995, S. 1192, 104th Cong., 1st Sess., August 11, 1995.

Program (sea scallops); the Woods Hole Oceanographic Institution (blue mussels); and the University of New Hampshire (blue mussels; sea scallops; eastern oyster; winter flounder). Funding in the amount of several million dollars has been obtained through federal sources, including the various Sea Grant Programs and line items in NOAA budgets, the NMFS Saltonstall-Kennedy Program, the NOAA National Marine Aquaculture Initiative, state programs, and private industry. These projects have begun to demonstrate the technical, biological, and economic feasibility of operating open-ocean aquaculture facilities.

Many existing natural resource access systems incorporate features that encourage aquaculture research and development (R&D) activities. Connecticut has established a "State Shellfish Fund" that can be used to support research. Maine has established the Maine Aquaculture Innovation Center to combine public and private funding to focus on aquaculture R&D. In some cases, such as Ireland or Maine, a separate category of licenses exists to allow research aquaculture to take place. As evidenced by the Irish "trial license," which lasts from one to three years, these licenses may be limited in duration. (Other resource systems incorporate policies for rights holders to credit research [or exploration] expenditures against up-front payments or royalties as an element of their allocation methods. These systems are described in more detail below.) Research licenses may be important means for characterizing those physical and chemical features of the ocean environment that are critical to the eventual success of an aquaculture operation. Further, they may help to identify the potential for conflicts with other uses or the nature and scope of impacts on fish and wildlife habitat. Such programs complement an array of existing policies, focused on agricultural development as well as technological innovation, that are already in place in most developed countries (Jarvinen and Magnusson 2000).

iv. Method of Allocation

The method of allocation refers both to the nature of the legal rights that are established and to the means for distributing those rights to users. Beyond the submerged lands of the US coastal states, there is no clear territorial jurisdiction that would permit the outright sale of areas of the ocean as private property. The reasons for the absence of territorial rights are historical as well as practical. Transient uses of the ocean, such as for navigation or commercial fishing, often are accorded a priority (a "public trust") over other uses on the basis of the economic benefits that historically have been associated with such uses. Further, until the advent of recent technological advances, it has been excessively costly to monitor and enforce private property rights in the ocean. US domestic and international law now recognize the sovereign rights of a coastal nation over the exploitation of the natural resources of an "exclusive economic zone" (EEZ), which extends 200 nautical miles from the territorial sea baseline.

Rights to "exploit" areas of the EEZ for the purposes of aquaculture might be conveyed in the form of a lease, as in OCS oil and gas development, or a license (or permit), as for commercial fishing. The form of the conveyance of rights is not as important as the nature of the rights that are conveyed. In general, the weaker the rights--in terms of shortness of tenure, geographic limits, difficulty of transfer to other parties, potential for revocation, work or performance requirements, or requirements to accommodate alternative uses--the more risky it becomes for the aquaculture entrepreneur. The reason for the increased risk is that such restrictions decrease the flexibility of the entrepreneur to respond to the inevitable, but difficult to foresee, environmental and market fluctuations. The costs associated with these risks will reduce the size of the resource rent, making it less likely that the access system can be characterized as efficient (cf. McDonald 1979).

In theory, the nature of the legal rights need not be linked to the means for allocating the rights, but in practice it often is. Rights, such as licenses, might be given away (or charged a minor administrative fee) on a first-come, first-served (FCFS) basis. Some prominent historical examples of such "discretionary" systems include claims staked under the 1872 Mining Law to help settle the American West or the issuance of commercial fishing licenses for federally managed species. Many modern access systems for aquaculture operate the same way, including those in northern Europe and in New England. Often such allocations are predicated on the classification of areas as suitable for aquaculture by a responsible government agency, such as is the practice in Massachusetts.

An FCFS system may work smoothly where the natural resource is in abundant supply relative to the demand for access. In such a case, there is little potential for conflict among developers of the resource or between resource developers and users of other overlapping resources. If rights are freely transferable, then a FCFS system may be seen as economically efficient, particularly where users with potential conflicts also have access to the market for aquaculture rights.[17] Further, the administrative costs of a FCFS system potentially are low relative to alternative rights allocation mechanisms. The present system for providing access to the EEZ for aquaculture can be characterized as a FCFS system.

Where there is significant industrial interest, and where the supply of high-quality ocean space is scarce, the need arises for a method of allocating the resource among multiple interested parties. In an attempt to allocate ocean space "fairly," some access systems recognize a priority among types of applicants. For example, under the Maine aquaculture policy, the Maine Department of Marine Resources has the authority to use its discretion in the allocation of licenses among multiple applicants. However, riparian owners must be preferred to historical fishermen, who in turn are preferred to riparian owners located within 100 feet of leased coastal waters. While such a system may appear to be fair on the surface, it provides no guarantee that those who obtain the rights are likely to be the most economically efficient aquaculturists.

An alternative method for allocating the resource, involving the competitive sale of rights, is theoretically capable of allocating ocean space in an efficient manner. Examples of resources sold by competitive sale include timber on the national forest

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[17] If other "stakeholders" have access to the market, then they may be willing to purchase aquaculture rights in order to preclude aquaculture development. Farrow (1989) presents a discussion of a hypothetical market for "lease delay rights" in the context of OCS oil and natural gas development.

lands (Coggins and Wilkinson 1987), oil and natural gas on OCS lands, and portions of the electromagnetic spectrum. The Connecticut Department of Agriculture has the authority to auction harvesting licenses for access to state oyster cultch beds to the highest responsible bidder. Van Ginkel (1988) describes the operation of a competitive auction system for underwater oyster grounds that was operational in the Oosterschelde estuary of the Dutch province of Zeeland in the late 19th century. In comparison with the open-access oyster fishery that the auction system replaced, tremendous gains in industry capitalization, employment, and production occurred, lasting for nearly 60 years.[18]

Competitive sales often involve the conveyance of "leases," although there is no reason why "licenses" (or permits) could not be sold similarly. Competitive sales may occur through the use of an auction.[19] In the case of OCS lands, potential developers bid "bonuses" or upfront payments for the rights to explore, develop, and produce oil and gas.[20] The bonus is a portion of the expected resource rent. Additional rents are captured by the US federal government through the payment of royalties upon production. Bids may be affected (usually downward) by existing institutions, such as those that impose liabilities or other requirements for reducing potential environmental impacts.[21] The competitive sale mechanism is potentially capable of being an efficient means for allocating access to a natural resource, but it may be administratively costly. It works well in cases in which there is a significant demand for a scarce resource (i.e., rents are likely to be large). From a political perspective, if the US public is perceived as the "owner" of the resource, then the collection of rents in this manner provides a source of income to be used for other public purposes.

v. <u>Tenure</u>

The length of time during which the rights may be held by an entrepreneur is another important feature of an access system. In general, the longer the tenure, the stronger the rights, because this allows entrepreneurs to plan for a longer development period. In this sense, tenure is analogous to the investment horizon for holding securities. A longer horizon permits an investor to reduce risk costs by riding out short-term market fluctuations.

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[18] A number of events, including overproduction, disease, predators, and war, led to the decline of the Zeeland oyster industry, followed by the introduction of new institutions. In particular, overproduction led to the depletion of phytoplankton stocks, implying that the Dutch government had not designed the leasing program to optimize the exploitation of the most important feature of "estuarine space," namely the limited phytoplankton stock. A similar problem exists now off the coast of China (Guo 1998).

[19] A very extensive literature on bidding behavior exists, analyzing optimal bidding strategies (Reece 1978; Wilson 1977; Rothkopf 1969).

[20] There are a number of variations on bidding with upfront bonuses. Among these are bids on the royalty, the combination of a royalty and a bonus, a share of profits, or work commitments (Mead et al. 1984; Mead 1976). These variations may involve different levels of fixed or "sliding scale" royalties (Jones *et al*. 1979). Some of these alternatives have been tested in actual sales of OCS lease tracts .

[21] For example, Opaluch and Grigalunas (1984) find that the total value of high bids placed in a 1979 lease sale for oil and natural gas on Georges Bank declined by 20 percent because of their perceptions of the risks associated with a policy of strict liability for oil spills.

There is no consistency as to length of tenure across access systems for different types of natural resources. US federal timber contracts run for five years, but most terms are met within 1 to 3 years. US federal grazing permits run for ten years, and they include a priority for reissuance to the existing permittee. Norwegian aquaculture permits run 20 years with a five-year renewal option; this is the same length of time incorporated into the proposed US Marine Aquaculture Act of 1995. Of the access systems we examined, Massachusetts may have the most confused tenure authority. In Massachusetts, a section 57 "shellfish growing license" has a ten-year term with renewals not to exceed 15 years each; a section 18 "waterways license" for the removal, filling, dredging, or altering of submerged lands has a 30-year term with a possible 35-year renewal; a section 10A "harbormaster approval" for temporary structures under 2,000 ft^2 lasts one year with possible renewals; and a local conservation commission "order of conditions" for altering wetlands lasts three years with possible annual renewals. Apparently, there is no clear tenure requirement for a section 17B "aquaculture permit" in Massachusetts.

The usefulness of a long tenure is tied closely to two features: the transferability of rights and performance requirements. If rights are not transferable or if there exist requirements to utilize the resource regardless of market conditions, then the culturing rights may be weakened, thereby reducing realizable resource rents. The potential costs of a limited tenure may be reduced through policies that grant rights holders a priority to renew their rights after an administrative review.

vi. Tract Size

A model of operational economics also can be useful in determining the optimal minimum efficient scale (MES_{ij}) for some species i in region j if the size of the basic culturing unit (longline, netpen, growout space) is known (Kite-Powell et al. 2001a,b; see also sections VI.A.2 and VI.A.3 of this report). However, tract size may need to account for the likelihood of external effects, such as the depletion of the plankton stock in shellfish culturing, increases in nutrient levels in finfish culturing, or the transfer of disease. The damages resulting from these effects must be balanced against the benefits of a higher density of culturing operations. Where these effects are highly uncertain, developing estimates of the marginal values will be problematic.

Alternatively, an economic model that determines MES could be complemented with models of regional impacts. For example, using examples of regulatory rules of thumb from Norway and Maine, Silvert (1992) suggests a basic "regional impacts" model for determining the minimum size of the area (O_{ij}) of ocean for culturing species i in region j:

$$O_{ij} \geq \frac{T_j \cdot F_i}{\lambda_i \cdot D_j}$$

where T_j is a regional average flushing time; F_i is the production (biomass) of fish; λ_i is a parameter that describes the loading rate of nitrogen or another pollutant of interest; and

D_j is an average regional water depth. The larger of either O_{ij} or MES_{ij} can be used to estimate the number of feasible culturing operations in an ocean region.[22] Ideally, this kind of information should be compared to estimates of the opportunity costs of displacing other valued uses, such as commercial fishing (e.g., Jin et al. 2001; also section VI.A.4 of this report).

vii. Transferability

In terms of designing an access system that is economically efficient, the transferability of access rights is one of the most critical features of the system. Transferability refers to the ease with which rights may be bought or sold in a market setting. In the absence of any legal restrictions, transferability can be affected by typical market characteristics, such as the number of buyers and sellers, information asymmetries across market participants, the quality of the ocean area, as well as exogenous economic and environmental conditions. In Louisiana, private oyster leases are issued through a FCFS discretionary process. The leases convey the right to the exclusive use of the seabed for oyster growing, and they are freely transferable and may be inherited. Lessees have a priority for renewal of the lease after the statutory 15-year tenure expires. Keithly *et al.* (1992) argue that these provisions provide lessees with incentives for long-run profit-maximizing investments and lease improvements.

In the case of public access systems for natural resources, proposed rights transfers typically must be vetted by the relevant administrative authority prior to the actual transfer. Vetting may be imposed for various reasons, the most common being the purported need to ensure that rights holders meet some level of technical and economic competence, so that the resource is not wasted or misused and so that external costs, such as pollution or the spread of disease, are not incurred. Access systems for which the public is designated as the owner of the resource typically require that the rights revert back to the public so that resource rents are not captured by some other party. Notwithstanding the purported need for administrative oversight of rights transfers, vetting imposes costs that limit transferability and reduce economic efficiency.

viii. Financial Terms of Allocation

Public systems that allocate access to natural resources often start with a goal of recovering some or all of the resource rent for the public as "owner" of the resource. There are a number of methods of capturing rent, including annual fixed payments (or "rentals"), severance taxes, royalties, resource rent taxes, and bonus bids (Neher 1990). From a theoretical perspective, only bonus bids and royalties tied to net profits (pre-tax revenues net of costs) are economically efficient means of capturing rents. At a competitive auction, bonus bids approximate the entire expected resource rent, because competitors are willing to bid all of their forecasted excess "profits" in order to obtain the rights to develop the resource.[23] Practically speaking, the choice is often between a

[22] Normally, we might expect that $O_{ij} \geq MES_{ij}$.

[23] Hansen (1985) suggests that there may be a tendency in bonus bid auctions for the winning bid to approach the second highest bid and therefore to be less than the full rent. The author suggexsts that

bonus bidding system and a gross royalty (severance tax) set on the value of production; the advantages and disadvantages of both systems are summarized in Table 12.

A royalty or "profit tax" also captures rent, but, because a royalty usually is set as a fixed percentage of net profits, only a specified proportion of the rent is collected. A royalty also creates an incentive to "gold plate" or overestimate factor costs in order to reduce the size of the royalty payment. Fixed annual payments (rentals) also may capture rents, but they are not based upon variations in production revenues or costs, so they may be less or greater than the true rent, or equal to it merely by chance. However, rentals are sometimes used to provide an incentive for firms to remain diligent in the performance of their planned work. When treated by firms as accounting costs, both royalties and rentals can lead to premature and economically inefficient termination of a lease or license.[24]

A severance tax or "gross royalty" is based upon the gross value of production, leading directly to a reduction in gross revenues and to either the forestalling of a commercially feasible project or its premature termination. A "resource rent tax" creates an additional incentive for exploration or innovation by subsidizing a project in its early phases when cash flows are negative. Once cash flows turn positive, a royalty is paid on net profits. Again, this kind of financial term creates an incentive to gold plate. Further, governments often may be reluctant to subsidize operations directly.

The US federal system for granting "privileges" to livestock owners for access to grazing lands collects a portion of the resource rent through fees. By regulation, grazing fees are set on an "animal unit month" (AUM) basis. An AUM is approximately 775 pounds of grass or the amount of forage needed to sustain one steer (or five sheep or goats) for one month. A complex formula based upon price indices is used to adjust the fee on an annual basis, which is currently fixed at $1.35 per month. The fee may be adjusted up or down by so-called "ability to pay factors," including private grazing land lease rates, cattle prices, and livestock production costs. These factors may help the government to estimate the size of the resource rent. However, it is clear that the fee is only a fraction of the market price for private grazing rights, and it has been criticized as a subsidy. As a consequence, a surcharge may be applied where the permittee allows

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auctions set up so that bids are made as a function of profit shares may yield more of the rent. However, profit share auctions select the firm that bids the highest share,which is not necessarily the most efficient firm.

[24] Rothkopf and Engelbrecht-Wiggans (1992) recommend the use of royalties that decline with cumulative production or over time as a method for reducing this inefficiency.

Table 12

Advantages and disadvantages of bonus and royalty bidding schemes

	Bonus Bidding	**Royalty Bidding**
	Bonus is paid in a lump sum before assignment of property rights.	Royalty is paid as production occurs
Advantages	• Use of the property rights is timed so that present value of the economic rent inherent in the resource is maximized • Payment is a sunk cost to the bidder and it does not affect subsequent marginal operating decisions. The optimal development and production profile will be followed by the lessee. • The system identifies the most efficient producer who values the property most highly. • The system minimizes administrative and compliance costs. No expensive monitoring and policing is required. • The system facilitates collection of economic rent by the owner (government). • The system induces expeditious development of properties. When a large up-front payment has been made, the bidder loses interest, thus the rate of return is reduced for any delay in developing the property.	• Payments to the government correspond with production, in both amount and time. Under this system, the possible political embarrassment of a small fee being paid to the government for a productive area is avoided. • No "front-end" payment is required. This may stimulate additional bidding competition, particularly from small firms. • The system shifts some of the uncertainty of development to the lessor from the lessee. As a result, a risk-averse lessee will require a smaller risk premium and will bid more for the property.
Disadvantages	• Participation in bidding requires more initial capital than it does in other systems. This may restrict competition, particularly by small firms just entering the industry. • The system maximizes risk and uncertainty borne by the lessee and minimizes the sharing of risk by the lessor.	• The system may not identify the most efficient firm. • If bidding is on severance taxes, the system leads to premature abandonment of properties. This is because this type of royalty payment is treated as a marginal production cost by the firm. • The system adversely affects production timing. Because royalty payments are treated by firms as marginal production costs, the firm is induced to defer the start of production beyond the date that would have been chosen in the absence of the royalty payment. • The system may encourage speculation in property rights. • The system causes less capacity to be installed as the royalty payments to the government correspond with production quantities.

other ranchers to use federally permitted grazing lands. Due to the geographic characteristics of the resource, usually located adjacent to a base ranch, the federal government may be forced to use a fixed fee to collect rents. This proximity may limit the number of feasible users, making it difficult to administer a fully competitive auction for grazing privileges that would capture the rent.

It is important to reiterate the distinction between the efficiency consequences of the distribution and collection of rents. The question of who captures or collects the rents is purely a distributional one that is not addressed by economic efficiency. For example, the potential exists for an access system that allows the entrepreneur to retain any rents to be economically efficient. However, if entry is unlimited, the potential exists for rents to be dissipated, which is an economically inefficient outcome. Consequently, there is a need for an institutional framework that seeks to maximize the aggregate economic rents from ocean space through limits on access.

Where significant uncertainty exists *ex ante* about the existence or size of resource rents, bonus bids may be close to zero. If an ocean area is found to be productive for aquaculture *ex post*, then rents will accrue to the successful bidder. If a public goal is to capture some of the resource rents, then a combination of financial terms, such as a bonus-royalty system, may be established. In this case, firms bid bonuses taking into account the payment of royalties upon production. This calculation will reduce the size of the bids. However, once the operation demonstrates net profits, the public receives a portion of the rents through the royalty.

Financial terms also may be structured so that other public goals are achieved. For example, the size of a royalty could be reduced concomitant with requirements for firms to control nutrient releases, to develop innovative feeding methods that reduce the loss of fishmeal, to minimize escapement, etc. In this way, aquaculture firms may be encouraged to internalize costs that they have ignored in the past.

ix. <u>Performance Requirements</u>

Most access systems include requirements for rights holders to perform a certain level of work on an ongoing basis or according to a schedule. These so-called performance (or "due diligence" or assessment) requirements are put in place mainly because of concerns for the opportunity costs of displacing other potentially productive uses. Economic incentives may be tied to performance requirements; for example, the payment of annual rentals on OCS leases prior to the production of oil or natural gas provides an incentive to explore and develop a hydrocarbon deposit.[25]

On occasion, concerns are expressed about the potential for private "speculation" with public resources. The term speculation has a pejorative connotation, but it is not necessarily inefficient. [26] Where rights are freely transferable, and there is no concern

[25] Consistent with the resource rent tax discussd above, proposals have surfaced over the years to permit exploration and development expenditures to be credited against annual rentals (*cf.* PLLRC 1970).

[26] Compare the analysis of Ronald Coase (1974) with respect to potential performance requirements for the

about the distribution of rents, then speculation can be productive, representing an economically efficient waiting period to improve the likelihood of profitability. Where other uses of the area or resource are displaced, however, and where rights over alternative uses and resources are not fungible or tradable, then speculation might result in a situation in which other potentially beneficial uses are foregone.[27] In these situations, it may be efficient to include performance requirements in the bundle of rights established for aquaculture in the ocean. However, it is important to note that the need for performance requirements in this situation is a result of the absence of a market for rights to undertake the other uses of the ocean. The stringency of the performance requirements should depend upon the value of other uses; stringency should be an increasing function of value.

Termination conditions are one type of performance requirement. These conditions identify the reasons for revoking rights if certain conditions are not met. These conditions may include performance requirements, financial payments, environmental monitoring, reporting requirements, and encroachment on other proximate uses, among other things.

x. Resolution of Multiple-Use Conflicts

Any system devised to provide access to ocean space for aquaculture will be asked to perform many complex functions and to balance many competing interests. Although the question of whether a "public trust doctrine" applies in the EEZ remains unanswered, access policy may need to be consistent with generally recognized public uses in order to gain legislative support and public approval. Policymakers will be pressed to confront the critical and sensitive issues of compensation, exclusivity, and displacement of other uses.

The need for methods of resolving multiple use conflicts arises from the recognition that allocation decisions may lead to opportunity costs in terms of displaced uses (including such "nonuses" as habitat protection or ecosystem sustainability). It is also a reflection of the absence or incompleteness of property rights for alternative uses of ocean space as a public resource. The policy debate about how to deal with allocating a scarce resource among multiple and potentially mutually exclusive uses comes under the rubric of "policy integration" or "comprehensive management" (Underdal 1980). An important conclusion of the limited research on this topic is that the establishment of a regime for managing multiple uses may lead to a more complex political dynamic among

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exploitation of deep seabed minerals. A quarter of a century ago, these requirements were the subject of debate for inclusion into the United Nations Convention on the Law of the Sea. Coase argued that "such [provisions are] completely unnecessary and, if [they have] any effect at all, it will be to cause wasteful expenditures to be incurred."

[27] Importantly, the extent to which other uses and resources are managed in an efficient way will affect the size of opportunity costs. For example, the opportunity costs of displacing an open-access fishery for which rents have been dissipated may be very small. If this fishery is the only alternative use, then there may be no economic reason for instituting performance requirements.

interest groups. This dynamic, *per se*, may threaten entrenched stakeholders or special interests who have become comfortable with the status quo (Juda and Burroughs 1990).

Notwithstanding institutional inertia favoring single-use resource management, most modern access systems already incorporate methods of resolving existing or potential conflicts among alternative uses. These methods include the fundamental rules relating to public notice and comment; opportunities for government agencies to review and recommend changes; and the establishment of management councils and advisory boards, among others. The requirements under the National Environmental Policy Act (NEPA) to assess and state the environmental consequences of federal agency actions that might have an adverse impact on the quality of the human environment is another form of multiple use conflict resolution. Judicial review of certain types of agency allocation decisions may be available, although, in the United States, allocation decisions typically are accorded substantial discretion.

For aquaculture, exclusivity need only pertain to the sole right of the cultivator to the proceeds from the product being farmed and to the rights necessary to maintain, free from interference, the integrity of grow-out structures in designated waters. Allowing compatible multiple uses to take place in essentially the same space at the same time is analogous to split estates created on federal property in many western states. There timber harvest, grazing and subsurface mining (*i.e.*, the utility values in the land) have, in many instances, been conveyed to separate entities. This split in legal and equitable title, where federal ownership is retained but the beneficial use is conveyed to private holders for development purposes, has resulted in high productivity for land that might otherwise be tied to a single use.

xi. Enforcement Aspects

It should be obvious that the value of a property right that is established under an access system is directly related to its enforceability. If infringements are not easily redressed, then other users may undertake activities that preclude or diminish aquaculture. There are at least two important dimensions to enforceability: legal and economic. The legal dimension refers to the extent to and ways in which rights holders have access to the legal system. The economic dimension refers to the costs of both monitoring a property and accessing the legal system. Some existing access systems, such as those in North and South Carolina, include provisions for damage to permitted aquaculture operations (Hess 1994).

c. Discussion: NOAA's Proposed National Marine Aquaculture Act

In this section we assess the extent to which the features of an access system for marine aquaculture in the United States can be considered “optimal” from an economic standpoint. The system we examine, called the National Marine Aquaculture Act (NMAA), was proposed internally within NOAA in 1999. It has not yet been adopted or submitted as proposed legislation to Congress, and, if an updated version exists, the features of the new version may differ from those that are analyzed here.

Through the use of the term "marine waters" in section 2(a)(7), the proposed access system appears to recognize ocean space as the relevant resource to be allocated. However, the proposed system has a decidedly fisheries management cast as evinced in its twin goals to restore the Nation's marine fisheries and to sustain the economic base of coastal communities. Moreover, according to section 2(b)(4), the development of "environmentally sound" marine aquaculture may not "pose unreasonable constraints on the recognized legitimate use of marine waters for navigation, fishing, recreation, national defense and other activities." Thus, regardless of the economic value of these pre-existing uses, they are to be accorded a priority relative to marine aquaculture. This provision is the leading and most significant potential source of inefficiency in the proposed NMAA.

The management structure is centralized, assigning lead responsibility to the Secretary of Commerce for allocating access. Under section 4(c), other federal agencies are to coordinate their programs to ensure the success of the Secretary's program. The Secretary, in consultation with EPA, is to develop environmental standards to minimize damages from fish escapement, genetic releases, disease transmission to wild fish stocks, and other threats. Potentially affected states may develop their own environmental standards, which must be incorporated into their coastal zone management programs and approved by the Commerce Secretary. States are also afforded a review of license applications. Again reflecting the political sway of the fishing industry, regional fishery management councils are given *four months* to "review" license applications. The NMAA is noticeably silent with respect to the treatment of coastal state and FMC reviews.

Section 5 of the NMAA establishes a national R&D program in marine aquaculture. The proposed bill does not include an appropriation to sponsor R&D, but it does list specific research focuses. These focuses include R&D on the species selection, spawning, regulation, technological controls, and materials and structures. The bill authorizes the application of fisheries financial assistance programs to the marine aquaculture industry. The history of the overexploitation and economic waste generated by such programs in the commercial fisheries sector should be evidence enough to convince policymakers that their application to marine aquaculture would be costly and inappropriate.

Section 7(a) of the NMAA discusses allocation methods. The proposed bill would establish a discretionary FCFS system of issuing licenses. There is no mention of a planning process through which areas suitable for licensing might be identified by industry or other interests. The FCFS method may make sense in the early phases of industry development, where there is minimal demand for ocean space for aquaculture purposes. However, if the industry begins to take off, no provision has been made to permit the Secretary to switch to a competitive allocation method. This is not necessarily economically inefficient, if licenses are available over long periods and if they are freely transferable. Nevertheless, the option to use a competitive allocation is important, as high-quality ocean space for aquaculture may well be in limited supply when other pre-existing ocean uses are given a priority.

The Secretary has the discretion to establish license terms and conditions. Presumably, such provisions will characterize the license as an exclusive right to occupy ocean space, but this aspect is not specifically mentioned in the NMAA. Other than fixed annual rentals (discussed below), and a general requirement to comply with the discretionary terms and conditions, there are no specific performance requirements. From the standpoint of economic efficiency, the absence of performance requirements is beneficial. However, a provision in section 7(h) allowing the Secretary to modify, suspend, or revoke a license in whole or in part "where circumstances have changed" severely reduces the value of the license as an economic asset. Clearly, this provision gives great flexibility to the Secretary to modify allocation decisions. One would hope that any such modifications would be made to allocate ocean space to the highest and best use, but undoubtedly reasons will be put forth to change allocations for political ends. In order to encourage efficient development of the industry, it will be necessary to articulate in much greater detail the conditions under which such modifications, suspensions, or revocations may occur.

NMAA section 7(d) limits the license tenure to 20 years with the possibility of 5-year renewals at the option of the Secretary. The period of initial tenure appears long enough to allow for an adequate planning horizon and strengthens the property right dimension of a license. There is no provision for determining the tract size of a license. It is possible that size issues might be addressed in the environmental standards called for by the proposal. Other agencies, including the US Coast Guard, are to be utilized to carry out the purposes of the Secretary's program, but the NMAA is otherwise silent with respect to the enforceablity of a license.

The Secretary is authorized, under section 7(d), to establish procedures for transferring licenses from the licensee to another person. This discretion is appropriate, and any procedures should be designed to facilitate such transfers and to permit licensees to utilize efficient methods of transfer, such as through competitive sales.

NMAA Section 7(e) would establish financial terms, including administrative fees, rentals, and royalties. There is a need to think more carefully about the effects of these proposed financial terms on the emergence, development, and efficiency of the ocean aquaculture industry. Annual rental payments are to be based upon the areal coverage of the license. Application and administrative fees are to be charged on an annual basis at the discretion of the Secretary. If economic rents are minimal, this provision is likely to discourage the emergence of the industry. Moreover, it would appear difficult to constrain the activities of the administrating body with an open-ended fee structure. In line with other access systems, it may make more sense to waive the fees until they might be covered through the collection of economic rents.

Fixed annual rentals are not an efficient means for the collection of economic rent, and there appears to be no rational basis for tying them to the size of the area occupied by an aquaculture operation. The NMAA would establish a royalty at one percent of the value of production. This appears to be a gross royalty, which is an inefficient means for collecting rents because it acts like a severance tax. Further, there is no rationale for selecting the one percent level of the royalty. In the early days of ocean aquaculture, it may be more sensible to ignore the collection of what are likely to be minor economic rents. Once the industry proves to be profitable, a system of allocating the resource competitively might be put in place, thereby permitting the collection of rents.

d. Conclusion

Posner (1986) has observed that: "[i]t is . . .not surprising that property rights are less extensive in primitive than in advanced societies and that the pattern by which property rights emerge and grow in a society is related to increases in the ratio of the benefits of property rights to their costs." As open-ocean aquaculture emerges as a valuable use of the ocean, entrepreneurs will require a system of access that permits exclusive and legally enforceable rights to conduct their activities. There is now an opportunity in the United States to think carefully about the important features of such a system.

When considering the design of the features of an access system for open-ocean aquaculture, economic efficiency is enhanced through the establishment of property rights that are long term, of adequate size, easily transferable, and for which performance requirements are minimized. Certainly, ways to call aquaculture entrepreneurs to account for the external effects of their activities, including nutrient loading, disease transmission, and escapement of genetically modified organisms, among other things, should be considered in access system design. Notwithstanding these effects, open-ocean aquaculture should be regarded as a legitimate use of the ocean and put on an equal footing with other uses (and with non-uses). One of the clearest ways to do this is to compare the net economic value of aquaculture with other uses. One might easily predict the result when a potentially profitable aquaculture operation is compared to a regulated open-access fishery in which economic rents have been fully dissipated or the resource has been overexploited.

It is obvious to any observer or participant in the process of marine policymaking that there will be other public objectives regarded as superior to economic efficiency. In large part, the selection of less than fully efficient policies may be a consequence of the political process by which policies are put forward, debated, amended, adopted, and implemented. We have argued here that it makes sense to posit an economically efficient system in order to understand more clearly the benefits and costs of adopting a system that trades economic efficiency for other public policy goals.

B. Problems Encountered and Their Consequences for Results

The research team encountered no problems that had significant consequences for the project results. As expected, data limitations in some cases dictated the use of assumptions and estimates whose precision is uncertain (e.g., the average scallop meat grade supplied to the New Bedford market and the markup for scallops harvested from an aquaculture operation). In such cases, the numerical results in question must be treated as a rough approximation only. Seeing, however, that the general objective of the research project was to provide preliminary analyses that demonstrate the utility of an economic approach to policymaking about the allocation of ocean space, such less-than-ideal circumstances should not be considered to have compromised the project results.

In the same vein, we consider the points covered in the next section to be promising avenues for refining and extending the modeling and other analytic approaches whose utility for policymaking has been successfully demonstrated in this project.

C. Need for Additional Work

The analyses reported in Section VI.A point to several areas where additional research can be fruitfully undertaken to update or otherwise enhance relevant datasets, refine models and estimation techniques, and explore some counterintuitive preliminary results. We note in particular the following instances:

- Using the New England sea scallop market as an illustration, the project has demonstrated how simple simulations can be performed to model the impacts of changes in a given market on supply and demand. Useful refinements of the model can be pursued through simulations that use (i) alternative specifications (*e.g.*, the factors that determine demand); (ii) more detailed data (*e.g.*, the temporal distribution of product inventories, or the prices of an aquaculture operation's competing imports from different countries or into different US geographic markets); or (iii) alternative techniques to estimate parameters (*e.g.*, a three-stage least squares method to estimate market demand).

- The institutional environment as characterized in Section VI.A.5 will be in need of updating to reflect changes in relevant legislation or executive policy and organization. In the near future, one of the more likely catalysts for such changes may be the deliberations of the recently appointed Presidential Ocean Commission.

- Numerical simulations of our model for identifying the optimal scale of an aquaculture operation that coexists with a wild harvest fishery identified one or more characteristics of each mode of seafood production that influence the scale and viability of the other in ways that are consistent with intuition (*i.e.,* the acreage allocated to aquaculture, and the growth rate of and ecosystem carrying capacity for the wild population). At the same time, the study also produced some results that are counterintuitive on the surface and raise important questions for future research, such as the finding that the steady-state scale of an aquaculture operation expands as the costs increase.

- While the project has successfully demonstrated the utility of an economic approach to optimal control of ocean space, it was beyond the scope of the project to specify and optimize a social welfare function. Actual implementation of the approach will require the collection of more specific data, which can be guided by this project's preliminary identification of the objectives upon which social welfare depends—in particular, economic efficiency, fairness, and environmental sustainability.

A number of the activities suggested above, along with some others, are already under way under a separate research grant awarded to the Marine Policy Center in September 2000 through the NOAA National Marine Aquaculture Initiative (NMAI). Some of the key elements of MPC's NMAI project include the compilation of additional data on the uses and environmental characteristics of the New England marine environment; refinement of the operational aquaculture models to gain a clearer understanding of the effects of increased transportation costs on net benefits; and the incorporation of a spatial dimension and of additional end uses (besides wild harvest fish production) into the optimal allocation model to allow the estimation of the net benefits of alternative uses in specific "zones" and an examination of the tradeoffs among uses.

VII Evaluation

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

All of the research project's four main objectives (discussed in the subsequent paragraphs) and all but one of its discrete goals (*i.e.*, the specific "steps" for conducting the research, Section V.A) were attained. The missing element was a one-day meeting of experts that was initially proposed to be held as Step 7 of the project. Although the workshop itself was cancelled, its purposes were largely accomplished in a more ongoing and decentralized fashion, inasmuch as the principal investigators remained in touch with a wide range of experts by email and telephone throughout the course of the project.[28]

To recap the discussion in Section IV.B, the main objectives of the research project were the following:

- to develop a framework for analyzing access system design;
- to characterize an economically "optimal" access system for ocean aquaculture operations;
- to complement, using economic analysis, current efforts to develop laws and regulations governing ocean aquaculture in the US EEZ; and
- to demonstrate the utility of an approach to optimal allocation of ocean space from the standpoint of economic efficiency.

Our framework for analyzing access system design consists of the components depicted in Figure 32. Expressed in terms of research activities, we have characterized

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[28] Other factors that weighed in the decision to cancel the workshop included the roughly equivalent opportunity to present the results of the research and to meet with aquaculture experts at the Open Ocean Aquaculture Conference in New Brunswick, Canada, in June 2001; the alternative use of travel funds to send project consultant Ken Riaf to Washinton for the 1999 Department of Commerce Summer Aquaculture Workshop; and the alternative use of the remaining workshop budget to cover the costs of research.

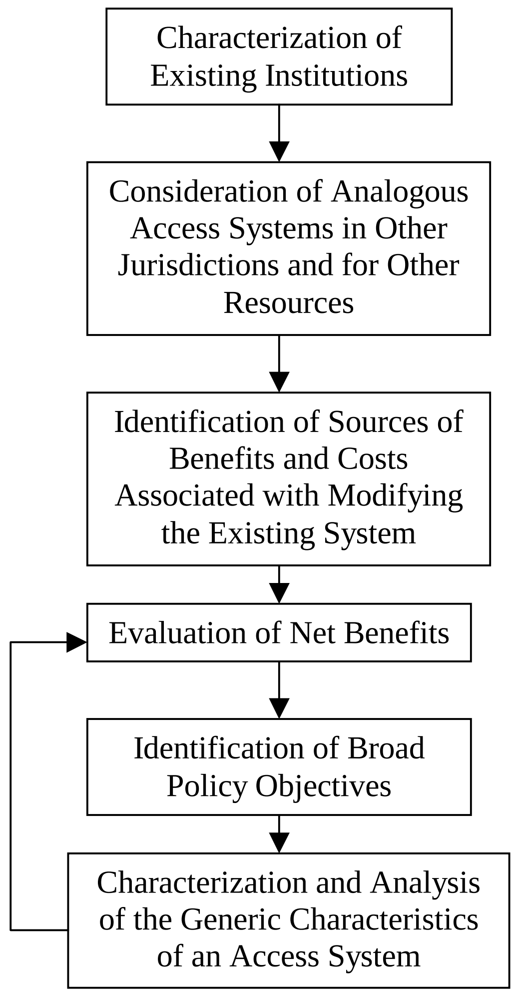

Figure 32. Project analytical framework

the evolving institutional environment, based initially on a set of generic, policy-relevant attributes suggested by a comparison of access systems for onshore public natural resources in the United States and for ocean aquaculture in US coastal states and in other nations. Further, we have commented on the benefits and costs of some of the alternative attributes or design features in terms of such social welfare objectives as economic efficiency, fairness, and environmental sustainability. Seeing that any of these objectives (or possibly others) may be given priority over economic efficiency in actual practice, we have posited an economically efficient system as a baseline for clarifying the benefits and costs of a system that trades economic efficiency for some other public policy goal.

The intended application and the utility of our analytic framework have been demonstrated by means of a combination of (i) illustrative applications to actual or proposed policy objectives and institutional arrangements; and (ii) the development and application of theoretical and operational models of the economics of aquaculture operations and alternative uses of ocean space. Specifically, we have provided:

- a general review of the objectives and practices of relevant agencies and legislative proposals and of their respective social benefits and costs, including a detailed critiqued of NOAA's proposed National Marine Aquaculture Act of 1995;

- economic models and analyses of market demand and the factors that determine the viability of ocean aquaculture operations for several species of shellfish and finfish in New England; and

- a theoretical model of ocean space allocation to help decisionmakers think more clearly about economic choices among uses of the EEZ, including a framework that allows the explicit analysis of the tradeoffs between aquaculture operations and commercial wild harvest fisheries.

Our characterization of an economically optimal access system is based upon all facets of the project, including the literature review, the application of relevant economic theory, the analysis of lessons learned from other natural resources access systems, a preliminary characterization of resource use (using GIS mapping technology), the identification of broad social objectives, and the development of the analytical framework. We anticipate that the dissemination of the project results, together with our continuing work to refine the models and extend the analyses to incorporate additional economic, spatial, and environmental factors, will complement and enhance the ongoing efforts of academics, public interest groups, federal agencies, and the US Congress to develop laws and regulations that help the nation realize the potential of ocean mariculture in the US EEZ.

B. Dissemination of Project Results

The methodologies and results of the four major modeling exercises and economic and policy analyses were presented at the Open Ocean Aquaculture IV conference held in St. Andrews, New Brunswick, Canada, in June 2001, where copies of the respective papers were distributed (Hoagland *et al*. 2001; Jin *et al*. 2001; Kite-Powell *et al*. 2001a,b). In addition, this final project report will be made available as a downloadable PDF file on the website of the Marine Policy Center (http://www.whoi.edu/science/MPC/dept/). Finally, selected aspects of the research results will be submitted for publication in peer-reviewed and topical journals.

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IX. Appendix: Additional Work Products

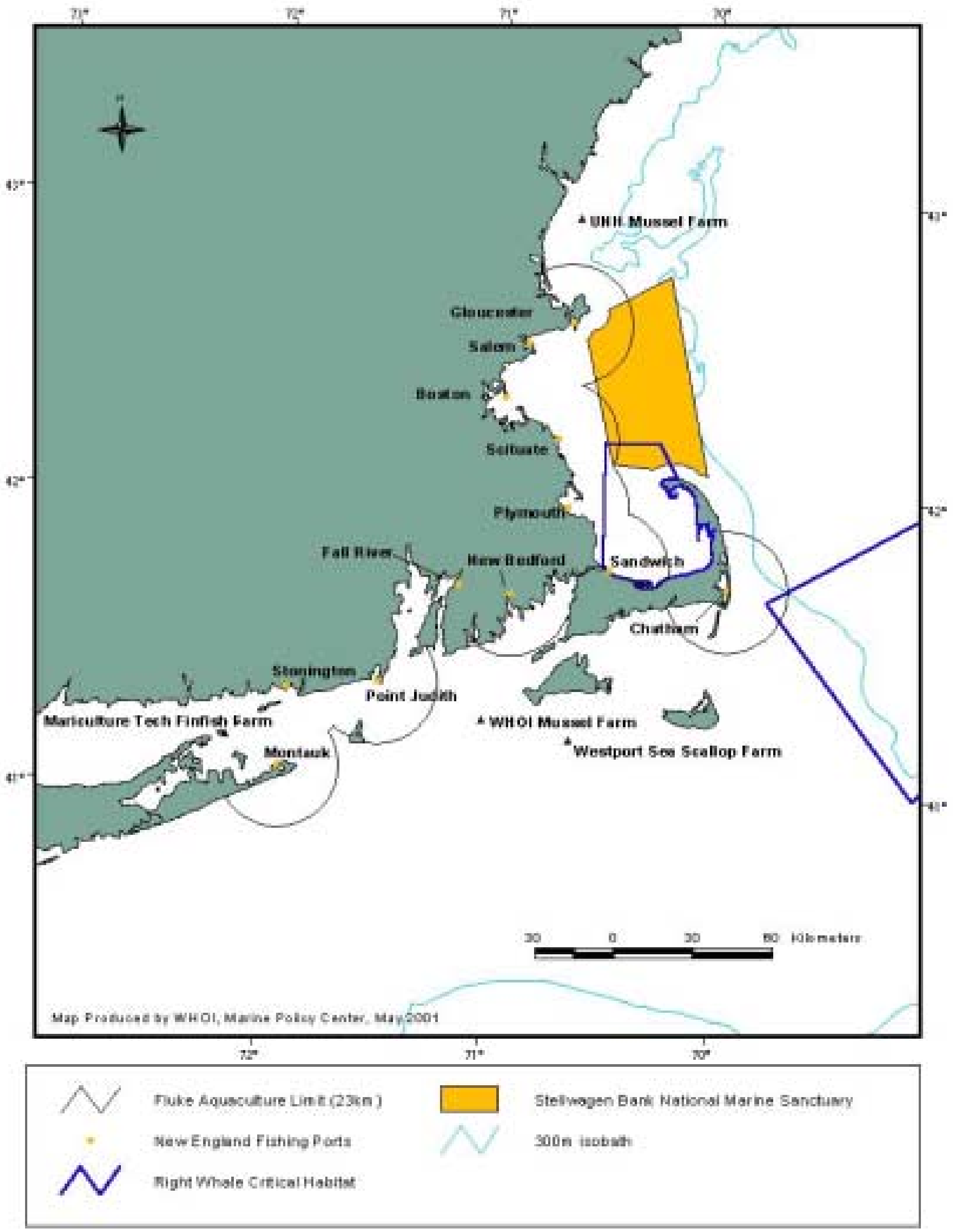

Figure A.1. Geographic limits of economic viability for fluke growout in waters off New England

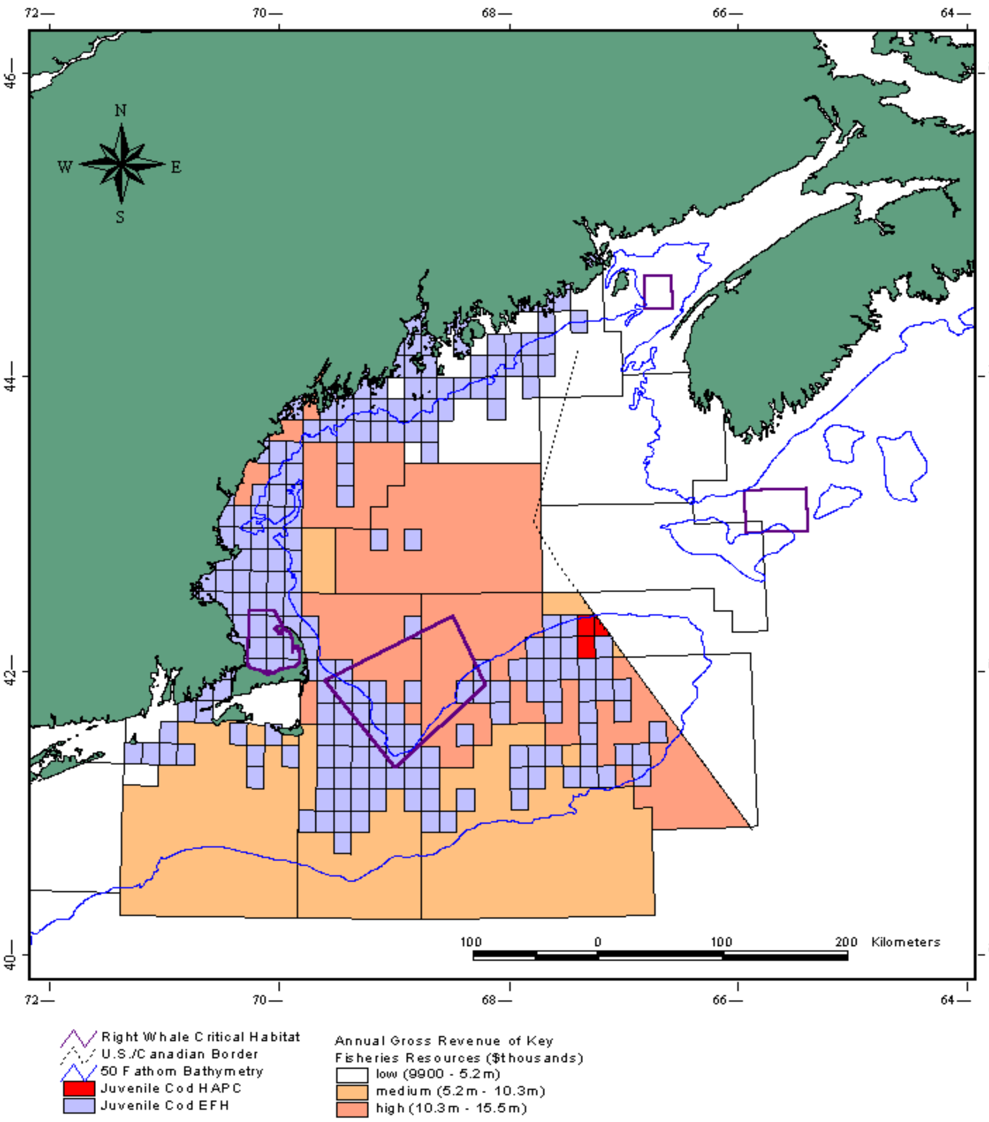

Figure A.2. Preliminary GIS presentation of some data on ocean uses for the US Northeast. Data shown include the 1990-93 average annual gross revenue for key commercial wild harvest fisheries, critical habitat areas, and essential fish habitat for juvenile cod.

Sources: New England Fisheries Management Council, Center for Marine Conservation, and NMFS Northeast Fisheries Science Center.

Table A.1
Comparison of European aquaculture access systems

	Norway	**Scotland**	**Ireland**
Geographic area	>2 million square meters	400-500 cage farms	
Species Produced * = primary species; (_) = R&D scale	Atlantic salmon*; rainbow trout*; cod; halibut; turbot; eels; blue mussels; scallops; oysters	Atlantic salmon*; rainbow trout; turbot; (halibut); Pacific oysters; European oysters; scallops; queens; blue mussels	Atlantic salmon*; blue mussels*; Japanese oysters*; rainbow trout; flat oysters; scallops; clams
Production	460,000 mt of salmonids; 600 mt of shellfish	112,000 mt of salmonids; 1,350 mt of mussels	14,000 mt of salmonids; 7,000 mt of mussels
Property instrument	License	Lease; consent to discharge (license)	Aquaculture license and a "foreshore" license (which is contingent upon the granting of an aquaculture license)
Spatial rights	Right to occupy an area of the marine environment for growing fish	Right to use territorial sea bed and foreshore (intertidal zone) for aquaculture; right to discharge "trade effluent" into an "allowable zone of effect" (AZE)	Right to engage in a clearly defined type of aquaculture and to use and occupy a particular area of the "foreshore"
Managing agency	Ministry of Fisheries	Crown Estate Commissioners; Scottish Environmental Protection Agency	Ministry of Marine and Natural Resources
Research program	Unknown		A 1 to 3 year 'trial license' may be obtained to engage in experimental aquaculture
Selection process	Unspecified; submission of application by prospective licensee triggers licensing; the total number of licenses are controlled as a form of production limitation	Unspecified; submission of application by prospective lessee triggers leasing	Unspecified; submission of application by prospective licensee triggers licensing
Multiple use conflict resolution	License is conditioned on requirements of the Ministry of Environment under the Pollution Control Act of 1981 and the Ministry of Agriculture under the Fish Diseases Act of 1997	SEPA identifies existing and potential uses to establish "environmental quality objectives"; AZE volume is calculated based upon water quality standards designed to achieve these objectives; Lease applicant is encouraged (but not always required) to carry out an environmental impact assessment (EIA); together with CEC, Scottish producer organizations have developed a manual for conducting an EIA to facilitate this process; an EIA may be mandated if the proposed operation exceeds certain thresholds; Environment Act requires safeguarding of socioeconomic concerns in rural areas	All applications for salmonid breeding operations (or other aquaculture operations likely to affect the environment) must be accompanied by an environmental impact statement; salmon cages may not prevent the passage of migratory fish; public notice is required; comments may be submitted to MNR by the public; aggrieved parties may appeal to the Aquaculture licenses Appeals Board
Method of allocation	Discretionary		Discretionary
Size	< 12,000 cubic meters	Discharge consent specifies a	Salmon stocking density is

	Norway	Scotland	Ireland
		limit on the maximum biomass to be held at any one time	limited to <20 kg m^{-3}; salmon smolt inputs and production may be limited
Tenure	20 years with 5 year renewal		Aquaculture license (<20 yrs); foreshore license (10 yrs); an uninterrupted 2 month fallowing period is required each year
Transferability			
Fees		Applicant bears the costs of statutory requirements for public monitoring and for required public notices	
Royalties			
Rentals		Unspecified "annual rent"	
Subsidies			
Documentation requirements			Type, quantity, and frequency of application of all chemicals and antibiotics must be recorded
Performance requirements		Medicines cannot be used; only registered antifouling treatments can be applied; EC Directive on Dangerous Substances may limit the use of chemicals;	Licensee must take all necessary measures to prevent the escape of salmon from cages; notification of MNR of any appearance of disease or escaped fish within 24 hours; prior MNR approval for towing of cages to/from licensed area or for growing other kinds of fish
Termination conditions			
Inspections and reports	Records required at the license, site, and unit/sea cage levels	Operations are monitored by CEC to ensure compliance with lease terms and conditions; SEPA monitors to ensure compliance with discharge consent	Periodic environmental monitoring for sea lice and benthic conditions may be required

Table A.2
Comparison of coastal state access systems (New England)

	Maine	**Massachusetts**	**Connecticut**
Geographic area	Submerged lands (mean *low* water to 3 nmi)	Submerged lands (mean *low* water to 3 nmi)	Submerged lands (mean *high* water to 3 nmi)
Dominant Species/~ Sales	Atlantic salmon and steelhead ~ $55m	Northern quahog ~ $9m	Eastern oyster ~`$62m
Property instrument	Lease	§57 shellfish growing license; §17B aquaculture permit; §18 waterways license; §10A harbormaster "approval"; DMF "propagation permit" required for possession of seed shellfish	Lease (shellfish); "designation" of shellfish culture grounds in town waters; application process for marine finfish culture; discharge permits may be required for releases from some "marine based aquacultural systems"
Spatial rights	Exclusive use of water column and seabed; lease must be 2,000 ft away from other aquaculture sites or fish weirs, 10 ft above the bottom (for net pens), and in currents ≥0.1 knots	Exclusive use of lands and waters within 100 ft of structure	Exclusive
Managing agency	Maine Department of Marine Resources (DMR) in coordination with Maine Department of Environmental Protection (DEP), EPA, and ACoE	Municipality for §57 license; Massachusetts Division of Marine Fisheries (DMF) for §17B permit; Massachusetts Department of Environmental protection (DEP) for §18 license; Local harbormaster for §10A approval	Connecticut Department of Agriculture (CDA) in state waters; shellfish commission in town waters
Research program	Special aquaculture research licenses available. Maine Aquaculture Innovation Center links private and public resources for R&D		State Shellfish Fund can be used to support research
Selection process	Applicants recommend site, conduct environmental evaluation, describe existing uses, characterize physical and ecological impacts	Applicants recommend site and include detailed plans describing the project and the proposed area	Applicants recommend site
Multiple use conflict resolution	DMR must find that lease does not unreasonably interfere with in/egress of riparian owners; navigation, fishing and other uses; public use and enjoyment within 1,000 feet of beaches, parks, and docking facilities; the ability of the area to support ecologically significant flora and fauna; DEP issues a water quality certification (in lieu of a waste discharge license)	Culturing activity must not "materially obstruct" navigation; it cannot impair the private rights of any person; it is precluded by the existence of commercial or recreational shellfisheries; removal, fill, dredging, or altering of submerged lands requires an "order of conditions" (OOC) from the local Conservation Commission (ConCom) and a license from DEP under §18 (or harbormaster approval if temporary structure <2,000 sqft under §10A); ACoE and EPA permits may be required; DEP water quality certification and EPA point source permits may be required; DMF surveys project area to certify that no adverse impacts to shellfish or other natural resources will occur for §57 license	Leases cannot be issued if they interfere with established rights of fishing; CDA must classify coastal waters prior to the issuance of a license; CDA also is authorized to purchase shell and deposit as cultch to form state shellfish beds; access to harvest from these beds are by license; town waters cannot be designated for culturing if they are natural shellfish beds
Method of allocation	Discretionary; if multiple applicants, then priority is: DMR $\succ$ Riparian owner $\succ$ Historical fishermen $\succ$	Discretionary; shellfish licensing may occur only in areas classified as "approved" by DMF	Auction: highest responsible bidder

	Maine	Massachusetts	Connecticut
	Riparian Owners within 100 feet of leased coastal waters		
Size	5 acre tracts; <100 acres per site; <150 acres per applicant	No restriction; may be subject to terms and conditions established by municipality for shellfish growing	>10 acres
Tenure	10 years	§57 license: 10 years with renewals not to exceed 15 years each; §18 license: 30 years with renewal to 65 years; §10A approval: 1 year with renewal; ConCom OOC is issued for 3 years only with annual extensions possible; DMF propagation permit must be obtained annually	3 to 10 years with renewal option
Transferability		§57 license: approval of municipality required; transfer must go to an eligible person; some municipalities allow subleasing, others prohibit it; license may transfer to a relative upon death of the licensee	Must be recorded by CDA
Fees	Application fee of $100 to $1,000, depending upon acreage	$25 filing fee if Wetlands Protection Act order required; $1 recording fee and $4 license fee to town clerk	Lease application fee of $70; minimum bid is $2 per acre; lease must be surveyed by CDA at a cost of $35 per corner; administrative fee to cover the costs of designation by the shellfish commission; aquaculture exempt from obstruction to navigation fee ($350), if no ACoE permit required; $50 fish hatchery application fee for finfish culture
Royalties			2 percent annually of the value of a lease or franchise (referred to as a tax) for state waters; real estate tax for town waters
Rentals	≥$50 per acre per year	$5 to $25 per acre per year at the discretion of the municipality	
Subsidies	Loan guarantees available from the Finance Authority of Maine; a capital investment fund provides direct loans, security as collateral or for equity investments, and general assistance	Marine seafood processing revolving loan fund	
Documentation requirements	Record lease in registry of Deeds; publish lease in newspaper; submit annual harvesting reports	Record lease	Record lease
Performance requirements	$500 to $5,000 performance bonds; area must be marked	§68A license can be revoked due to lack of use of licensed area	$50 fine for speculating in lease rights
Termination conditions	Lease is revoked if activities determined to be conducted in a manner "substantially injurious to marine organisms"	§68A license can be revoked due to failure to comply with license conditions; §57 license can be forfeited if gross revenues <$100 per acre for first 2 years or <$250 per acre for any 3 consecutive years	Loss of lease rights due to nonpayment of lease or franchise tax for a period of 5 years
Inspections and reports	Annual DMR lease review; monthly DMR water profiles; annual DMR macro benthic surveys; DEP checks the size and number of fish monthly; DEP requires biannual benthic surveys	§57 licensees required to report annually on shellfish production	Annual report of existence of lease or franchise; a fine of 10 percent of the value of the lease or franchise; shellfish sanitation program inspection

Table A.3

Comparison of marine aquaculture and US onshore natural resource access systems

	Marine Aquaculture (NMAA 1999)	**Marine Fisheries**	**Outer Continental Shelf Lands**	**Federal Timber**	**Federal Grazing Lands**
Valued resource attributes	Location, quality, and quantity of ocean space	Species, quality, and quantity of fish	Location, quality, and quantity of oil and natural gas	Species, quality, and quantity of timber	Size of area, quality of forage, water access, and proximity of base ranch
Resource use	Occupation; local biota	Fish harvest	Hydrocarbon extraction	Timber harvest	Livestock feed
Renewability	Renewable	Renewable	Nonrenewable	Renewable	Renewable
Geographic area	6 billion acres of exclusive economic zone	6 billion acres of exclusive economic zone	Area of the US continental shelf (not yet officially delimited); in practice, leasing has been limited to the EEZ in the Gulf of Mexico, Southern California, and Alaska	67 million acres of the national forests are available for regularly scheduled timber harvests; between 0.5 to 1 percent are harvested in any year; federal softwood timber harvests supply only about 6 percent of the US market	259 million acres of public rangelands (63 percent are BLM rangelands; 37 percent are FS rangelands)
Property instrument	License	License	Lease	Timber sale contract	Grazing district permit; forage lease outside grazing district
Spatial rights	Unspecified rights for *operation* of a marine aquaculture facility	Regulated open-access; spatial or seasonal closures or exemptions in some fisheries; two marine fisheries have tradeable quota systems	Exclusive use of lease tract for exploration, development, and production of hydrocarbons in 9 m^2 lease tract	Rights to fell, yard, load, haul, mill, and resell prescribed timber on specified sites in national forests; right to access sites on FS roads or by cutting roads under FS authority	"Privilege" (not a property right) to graze private livestock on federal lands (limited to nearby private "base property" owners)
Managing agency	DoC/NMFS	Regional FMC; DoC/NMFS	DoI/MMS	USDA/FS; DoI/BLM	DoI/BLM; USDA/FS
Research program	National marine aquaculture research and development program focused on: selection of appropriate species; spawning and growout techniques; regulatory and physical controls to protect the marine ecosystem; engineering of materials and structures	Saltonstall-Kennedy program funds research on fishing technologies and markets; regional MARFIN programs; Natioanl Sea Grant program	Development of 5-year schedule of lease sales involves collection and analysis of environmental, economic, and social data; research has been funded on oil spill modeling and clean-up	FS conducts research on ecologically sound forest managment; FS forest products laboratory conducts research on forest conservation; Knutson-Vandenberg Fund, funded with timber sale receipts, is used for reforestation, timber stand improvements, resource mitigation, and enhancement activities	
Selection process	Unspecified; submission of application by prospective licensee	Regulated open-access; some areas closed to fishing on an *ad hoc* basis;	5-year lease planning (FYLP) process for the identification and sale of	Each national forest must develop and periodically revise a comprehensive	BLM determines grazing land in accordance with a "land use planning

	Marine Aquaculture (NMAA 1999)	Marine Fisheries	Outer Continental Shelf Lands	Federal Timber	Federal Grazing Lands
	triggers licensing	two ITQ fisheries	leases; formal process for industry to rank areas that may be offered and for State Governors to comment on proposed areas; EIS prepared on FYLP	forest management plan, which includes the location and timing of timber sales; FS identifies a sale site, plans roads, cuts prescriptions, appraises the timber, conducts an environmental assessment, and advertises the sale in a local paper	process," which considers both forage availability and historical grazing; grazing rights are always linked to a base ranch
Multiple use conflict resolution	Consultation required with Secretaries of Defense, Transportation, and EPA; public notice requirements; NMFS to promulgate rules on environmental standards in consultation with EPA; states may adopt federal rules or their own more stringent rules	FMCs attempt to resolve gear and space conflicts among fisheries; FMP amendment process must consider other uses of the ocean including habitat protection and protected species interactions; FMP amendments are subject to NEPA requirements; FMCs make recommendations that are implemented by NMFS; public notice requirements apply	The Secretary of the Interior must select the timing and location of leasing " . . . to obtain a proper balance between the potential for environmental damage, the potential for the discovery of oil and gas, and the potential for adverse impact on the coastal zone."	Under formal "multiple use" concept, uses of timber, forage, and water in the national forests are placed on an "equal footing" with wildlife conservation and recreation; public input is considered during the development and revision of national forest comprehensive plans to decide on the disposition of timber at certain sale sites; 25 percent of FS receipts must go to counties where national forests are located to be used on roads and schools; FS receipts go to a large number of special trust funds, only about 10 percent is deposited in the US Treasury's general account	BLM is supposed to manage public rangelands for "multiple uses," but its planning process has been criticized as lacking in cohesiveness and direction; permits can be obtained free of charge to cross land, conduct research, or for recreational use; allotment management plans describe how land will be used and monitored for carrying capacity; periodic NEPA reviews; riparian needs, clean water compliance, and threatened-endangered species compliance are monitored; 50 percent of grazing revenues are directed toward range improvement, habitat enhancement, and watershed protection
Method of allocation	First-come, first-served	Licensing and harvest restrictions are set by the NMFS and Regional Fisheries Council using "National Standards" principles in combination with the FMP developed for that region. (9)	Competitive "bonus" closed bidding auction system; minimum bid of $25 per acre (~$144,000 per tract)	Competitive oral auction among bidders who have submitted a bond (sealed bidding is sometimes used);FS establishes "base rates" or minimum prices for each species in each region; FS appraises timber at specific sale sites using a "transaction evidence appraisal system," which is based upon recent sales with adjustments; FS can make "stumpage rate adjustments" (changes up or down in the contract price due to changes in	BLM: applicants reviewed, but preference right based on historical use for permits in grazing districts FS: noncompetitive for existing permits; competitive bidding for new or discontinued existing permits; local lease rates used to decide value; bids require range improvements; if qualified sealed bids are not received, oral auction is used

	Marine Aquaculture (NMAA 1999)	**Marine Fisheries**	**Outer Continental Shelf Lands**	**Federal Timber**	**Federal Grazing Lands**
				lumber market prices); all timber is purchased prior to being cut	
Tenure	20 years with 5 year renewal	1 year (3)	5 to 10 years for exploration; production can continue as long as the resource is producing in “paying quantities”	5 years, but most contracts are completed within 1-3 years	10 years with priority for reissuance at end of term; temporary permits available with no priority for reissuance
Transferability	Transferable; conditions yet to be determined	Not transferable (3)	Transferable upon approval of the Secretary of the Interior	Transferable for good reason; original contractee still responsible, unless assigned to another	BLM: leases remain attached to the base ranch (preference for permit reapplication) FS*:* grazing waiver reverts to NFS
Fees	License application fees; annual fees to cover administrative costs	License fee: $50 for the first target fishery and $20 for each additional fishery			Grazing Fee of $1.35 per “animal unit month” (the amount of forage needed to sustain one animal unit for one month or about 775 pounds of grass; 1 beef steer = 5 goats or sheep) adjusted by “ability to pay factors” (private grazing land lease rates, cattle prices, and livestock production costs); surcharge for allowing cattle owned by others to graze on leased or permitted land; $10 paperwork fee for all transfers and new leases
Royalties	One percent of the annual value of production	No royalties or rentals are required, only licence fees 3), taxes on equipment, and export fees. Fees are limited under the Magnuson Act to only recover administrative costs. (8)	At least 12.5 percent of the value of production; can range up to 33.3 percent; some experimental bidding systems involve bidding on the royalty rate; rate can be renegotiated		
Rentals	Rental payment proportional to the area covered by the license		$3 “minimum royalty” per acre, which can be credited to royalty (~$17,280 per lease tract)		
Subsidies	Fishing vessel CCF monies may be withdrawn tax free to make investments in marine aquaculture; DoC financial assistance programs to	Significant subsidies historically; capital construction fund and fishing vessel loan guarantees still exist; most subsidies have been removed	General depletion allowance for mineral extraction	Credits to timber purchasers to compensate them for required road construction; FS covers the cost of “slash” disposal	Critics have argued that grazing fees are too low, effectively subsidizing grazing on federal rangelands; value of access to federal rangelands for

	Marine Aquaculture (NMAA 1999)	**Marine Fisheries**	**Outer Continental Shelf Lands**	**Federal Timber**	**Federal Grazing Lands**
	be made fully available to qualified applicants				grazing is often capitalized into the net worth of ranch properties; one-half of federal grazing revenues are used for improvements, such as water developments, to benefit ranchers
Documentation requirements		Vessel must have state registry or USCG registry; some fisheries are limited to historical participants, requiring documentation of past participation	Exploration and development-production plans must be produced prior to each activity	Contractee must prove financial capability and clean record of compliance with conservation laws	
Performance requirements		Continued future participation in some fisheries may require evidence of past participation; this may be especially true in move toward property right systems (ITQs)	Operator must exhibit “due diligence” in performing activities to explore for or develop-produce hydrocarbons; a bond of $50,000 per lease or $300,000 per “area” is required	Must abide by stipulation set in contract; must comply with relevant national forest comprehensive management plan	Must comply with land use plans-range improvement plans
Termination conditions	Licenses can be modified, suspended, or revoked in whole or in part due to noncompliance with terms and conditions	Must renew license yearly; some fisheries have a 60-100 day grace period to renew the license	Leases can be modified, suspended, or revoked in whole or in part due to noncompliance with terms and conditions		Grazing permit or lease can be suspended or cancelled if permittee or lessee is convicted of violating environmental laws
Inspections and reports		Depending on the fishery, a log book detailing catch by species, bycatch and discards, and landings must be kept	Reports on monthly operations, including amount produced	Periodic inspections for compliance with contract	Periodic inspections for needs to maintain natural vegetation and clean water; compliance with permitted use level allotment-carrying capacity monitored