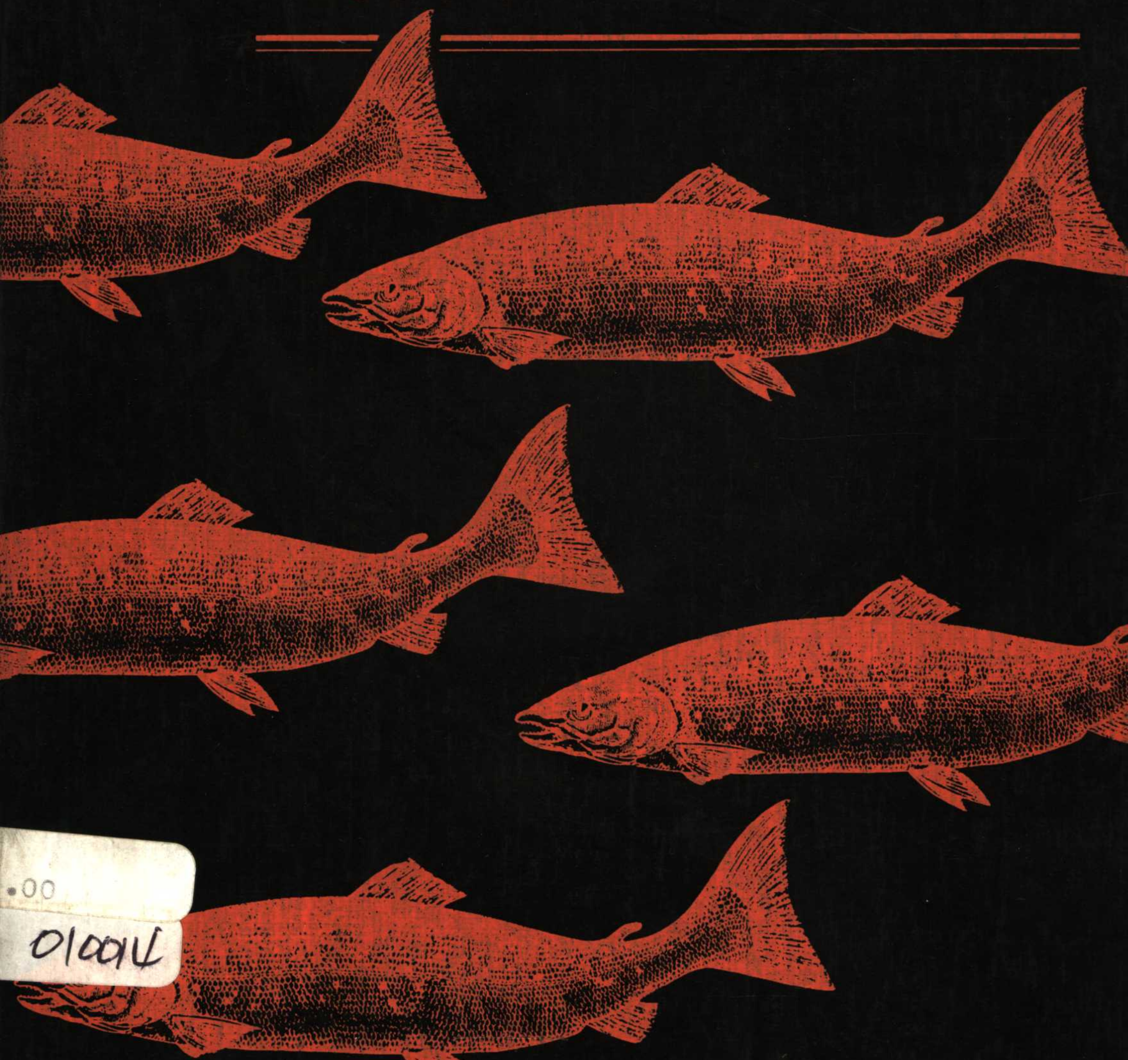
Aquaculture

Models and Economics



edited by
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Preface

The production and marketing of aquaculture products has grown dramatically in recent years. The economics of aquaculture is a rather new academic area for pursuit of state-of-the art economic research. Economic analyses of the production and marketing of aquaculture products have been, in the past, quite limited; however, recently, with the growth in aquaculture enterprises worldwide, economic researchers have begun to address this topic with the theoretical and methodological rigor used in other sectors.

In this book we attempt to accomplish two objectives. First, we present interdisciplinary research on aquaculture that will contribute to a broadening audience interested in the growth and profitability of this dynamic growth area. Aquaculture is very diverse with a multitude of species that have proven profitability—catfish, shrimp, salmon, crawfish, tilapia, carp, and trout. In addition, many species are beginning to be analyzed in terms of both production and marketing feasibility. Thus, the economics of aquaculture spans a broad array of industries with differing problems and opportunities.

The second objective is to demonstrate the impact that economic research can have in supporting the evolution of new industries. Demand analyses provide estimates of the responsiveness of consumers to changing prices of fish and other food products. Supply analyses permit forecasting of future supplies and evaluation of government policies and regulation. Supply/demand analyses assist in anticipating price movements resulting from exogenous economic forces (inflation, income price of competitive products, and minimum wage charges). Effects of industry pricing and promotion strategies can also be evaluated.

Marketing studies on aquaculture products indicate important consumer and product characteristics that influence market demand. Analysis of market segments can help in targeting product characteristics to market niches. Socioeconomic characteristics of consumers profile existing and potential markets. Consumer attitudes toward the aquaculture product and its competitors are important information for targeting marketing and promotion efforts to address perceived or actual inadequacies of the product in the eyes of the final consumer.

Production economics is largely dependent on an interdisciplinary understanding of biology, engineering, and economics. Bioeconomic modeling is useful in characterizing the interaction of considerations that are involved in production decisions. Simulation of the decision-making process can indicate areas for research with high payoff.

Farm management analysis is closely related to production economics. Such analyses are more involved in the daily operation of the farm business and include financial and marketing factors. The impact of changing production practices on farm operations, profitability, and cash flow are useful in planning management decisions.

We are indebted to John Hershberger, president, and Louis D'Abramo, program coordinator, of the World Aquaculture Society for assisting the authors. Papers were submitted for review by the editors and two anonymous referees. Reviewers included: Trond Borndahl, Wade Griffin, Carole Engle, Gilbert Sylvia, Richard Bacon, Sam Logan, Walter Keithly, PingSun Leung, Johannes Lambregts, Priscilla Brooks, Ron Mittelhammer, Oral Capps, Terry Hanson, Oscar Cacho, David Harvey, Conrado Gempesaw, Mark Herrmann, Ken Roberts, James Anderson, David Egan, and Robert Nelson.

We are especially grateful to Trudy Barnes, who served as word processor and copy editor for the book. Her contribution added greatly to the quality of the text, tables, and figures. Without her efforts the volume would not have been produced in a high-quality, timely fashion.

Appreciation should also be expressed to Carol Lee and Terry Hanson for proofreading and editing assistance.

We would also like to express our appreciation to Walt Armbruster of the Farm Foundation for financial support to defray publication cost.

Upton Hatch
Henry Kinnucan

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Introduction

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Introduction

Aquaculture has experienced dramatic growth in recent years. Demand has increased as a result of nutritional concerns and rising income. Supply from capture fisheries has increased slowly, largely reflecting constant gross catch with improved utilization efficiency. Much of the growth of aquaculture has been driven largely by the deficit from capture fisheries. An estimated 25% of shrimp, 27% of salmon, and 98% of catfish consumption in the U.S. is farm-raised, not captured from the wild (Miller).

Table 1.1 indicates the growing diversity of aquaculture products. Aquaculture involves a multitude of species that have proven profitability under certain circumstances—catfish, shrimp, salmon, crawfish, tilapia, carp, oysters, mollusks, clams, and trout. In addition, many species are beginning to be analyzed in terms of both production and marketing feasibility. New opportunities are not only in grow-out and food production but also in baitfish (Pounds, Engle and Durman), sport fish (Nash), tropical ornamental species for aquarium hobbyists (Harvey) and in the hatchery and nursery operations that are needed to provide "seed" to supply other production phases (Hatch et al.).

Aquacultural production is a major challenge for economic modeling. Although similarities with the grow-out of other confined animals have been an important starting point for many models of aquacultural production (Leung and Shang; Talpaz and Tsur; Talpaz et al.; Chavas, Kliebenstein, and Crenshaw), crucial differences—particularly in pond ecology, monitoring, and feed utilization—require additional quantitative sophistication that is not

TABLE 1.1 Worldwide Aquaculture Production: Volume by Selected Species Groups and Total Value by Geographic Region[a]

	Years			
	1986	1987	1988	1989
Selected Species Group	thousands of metric tons			
Carps and other Cyprinids	3,555	4,156	4,610	4,577
Tilapias and other Cichlids	213	254	266	326
Salmons, Trouts, Smelts	333	401	464	562
Shrimp, Prawns	299	483	544	509
Oysters	929	975	1,009	940
Channel Catfish	149	170	165	184
Mussels	798	940	1,047	1,050
Clams, Cockles, and Arkshells	439	444	456	466
Geographic Regions	millions of U.S. dollars			
Africa	49	74	107	144
North America	614	715	837	796
South America	317	680	779	800
Asia	12,996	15,801	18,361	18,016
Europe	1,919	2,270	2,626	2,962
Oceania	43	49	104	129
USSR	437	517	602	655
Total Worldwide	16,375	20,106	23,416	23,502

[a]*Source:* Food and Agriculture Organization of the United Nations, 1991.

essential for other animal production systems. Because of the sensitivity of aquatic species to temperature and other environmental conditions (e.g., dissolved oxygen, ammonia, salinity, and pH), the complex interaction of ecological factors can have a significant impact on the growth (Cacho; Cuenco, Stickney and Grant) and the profitability of aquaculture (Cacho, Kinnucan, and Hatch). The monitoring problems associated with the grow-out of a population that cannot be seen or handled is probably the most crucial management problem. The producer cannot determine the number of animals and their health at any given time. Aquaculture models may often need a stochastic element to represent this inability to monitor the progress of the animal population during the growing season (Karp, Sadeh, and Griffin; Hatch and Atwood). Land animals can be checked on a regular basis to monitor health and, in fact, actually are often identified and monitored as individuals. These monitoring problems are more problematic for open pond culture, the dominant technology in much of aquaculture, than for closed systems or cage culture; however, the ecological problems for the latter are worse. The density of the fish that is necessary to make closed systems profitable has tended to lead to a myriad of problems related to removing waste. Waste accumulation in cage systems can be addressed by the nature of the body of water in which the cage is placed. Salmon culture has been quite successful in cages placed in bays (Bjorndal; McFeeters); however, even this success has been mitigated by problems with disease and waste disposal. Cages in ponds may need aeration and are limited by the total area of the pond (Boyd).

Feed utilization is another source of uncertainty for the manager of an aquacultural production facility because the amount of feed actually consumed by the fish can be observed in a qualitative way as they come to the surface to feed, but can not be known with much precision (Lovell). Loss of nutrients occurs quickly after feed is in the water. Feed not consumed within a few hours decomposes, decreasing available dissolved oxygen and other water quality factors. Low dissolved oxygen levels decrease fish appetite and growth and increase risk of fish mortality. One of the most important decisions is how much to feed each day. Land animals are frequently fed *ad libitum*, where the animal can consume as much as it desires throughout the day. In contrast, fish are often fed to satiation, which involves determining fish appetite by observing quantity of feed that is consumed in a period of 15 to 30 minutes. The producer can then decide to feed at some reduced level to maximize returns.

As technical feasibility of an increasing number of species in various environmental conditions and locations has been established, economic feasibility has become increasingly important. Fine-tuning of farm management practices to provide an alternative enterprise for both commercial and subsistence production has received attention from both domestic extension programs and international donors. The focus of much of this effort has been centered around the selection of the most appropriate species, scale and intensity of operation, and market and infrastructure development. Worldwide, commercial efforts have focused primarily on shrimp, salmon and catfish and subsistence programs have been dominated by tilapia and carps (National Research Council; Hatch and Engle). There is a broad range of potential new species for culture that are being investigated for technical feasibility, but have yet to be proven under commercial conditions. Undoubtedly, some of these species may become important fish products in the near future.

Aquaculture's ability to provide a consistent high quality standardized product for large commercial markets has made it attractive for institutional markets. Restaurants and retail supermarkets have had problems with the inconsistent quality and quantity of fish and seafood from capture sources (Olowolayemo, Hatch and Zidack; Pomeroy, Nyankori, and Israel). As a competitor with other sources of protein (principally beef, pork, and chicken) fish has a higher feed conversion ratio and contains less fat, Table 1.2 (Lovell).

The marketing of aquacultural products has tended to be dominated by processors. Due to economies of size and the expense of transporting live fish, many aquaculturists are served by few processors (Kinnucan and Sullivan; Nyankori). Alternative marketing channels have been profitable for small numbers of producers; however, the limited market represented (restaurants, live-haul, and fish-out) creates a dependence on the processor for moving large quantities of product (Engle et al. 1989).

Price is an especially important aspect of marketing (Lin et al.). Because of the large number of fish species available in the market, the demand for any particular aquacultural product is likely to be price elastic (Kinnucan et al.). This means that price increases will be resisted by the consumer. Looked at another way, increases in production or marketing efficiency that lower price offer an important avenue for accelerating the rate of growth of aquaculture.

Information dissemination and consumer education programs can play a vital role in expanding the demand for aquacultural products. The unique advantages of aquaculture in terms of the ability to control environmental factors that may affect the safety and nutritional quality of fish may not be perceived by the consumer unless the information is communicated. The negative product image associated with some fish species may be overcome with appropriately designed generic advertising campaigns (Kinnucan and Venkateswaran 1990). In other cases, product differentiation and market segmentation can be facilitated through the development of consumer information programs tailored to specific target groups.

TABLE 1.2 Comparison of Feed Utilization and Carcass Characteristics of Selected Food Animals[a]

Source of flesh	Weight gain per g of food consumed	Characteristics of dressed carcass		
		Refuse	Lean	Fat
	-- g --	percentage		
Channel catfish	0.84	14	81	5
Beef	0.13	15	60	25
Pork	----	21	54	25
Chicken	0.48	30	65	9

[a]*Source:* Adapted from Lovell, 1989.

Aquacultural products are similar to other new products in that they are subject to the same S-shaped diffusion paths (Zidack and Hatch). Whether the diffusion proceeds slowly or rapidly is determined to a significant degree by the marketing effort that the industry can put behind its product. Although industry advertising offers an efficient mechanism for stepping up the rate of consumer acceptance of aquacultural products, the collective action required to obtain the funding and the attendant free-rider problems pose a challenge for the diverse and fragmented aquacultural industry (Kinnucan and Venkateswaran 1991).

Econometric modeling of aquaculture has tended to follow the traditional path of such efforts in other sectors of the economy (Anderson and Wilen; Crutchfield; Doll; Herrmann and Lin). Modeling of supply is complicated greatly by the monitoring problem mentioned earlier. At any given time there is a large "floating inventory" of fish in ponds that often can not be measured with much precision (Zidack, Kinnucan, and Hatch 1989). The lags that are prevalent with the grow-out of land animals are also important in modeling aquaculture supply. In addition, the rapid growth of an "infant industry" can result in misallocation of resources and price instability. Inadequate information related to potential growth has been a major contributor to cyclical periods of excess supply or demand in catfish aquaculture (Zidack and Hatch). Knowledge of supply response is especially important in determining the potential effectiveness of industry-sponsored advertising campaigns (Kinnucan, Zidack, and Hatch; Zidack, Kinnucan and Hatch 1992).

Demand analysis faces the difficulty of determining appropriate selection of competitor products with the large number of fish species and the potential competition with other meat and protein sources (Cheng and Capps; Hatch; Engle et al. 1990; Bird; DeVoretz; Kabir and Ridler; Tsoa, Schrank, and Roy; Wirth, Halbrendt and Vaughn). Although the controlled environment in which aquaculturally produced species are raised should be an advantage for these products relative to wild-caught species, especially during periods of heightened consumer awareness of specific or general problems with safety in wild-caught populations, a close relationship between demand for raised and wild fish has been empirically documented. In many cases, the consumer does not seem to make the distinction between farmed and wild supply and tends to react to a "scare" associated with one particular species at one particular time as an indictment of fish and seafood supply generally. Thus, farm-raised species as yet have not benefitted from safety concerns related to wild fish (Sylvia). Returns to promotion and advertising (Kinnucan, Venkateswaran, and Hatch 1990; Capps and Lambregts; Brooks and Anderson) may be particularly high for fish species, especially farm-raised, in a market environment in which the consumer is deluged by reports of seafood safety problems (Anderson and Morrissey; U.S. Department of Commerce). Economist have been innovative in their research approaches to studying consumer demand for fish and seafood (Wessells and Anderson), but much more needs to be done if we are to have an adequate research base upon which to make informed decisions about resource allocation and public policy affecting aquaculture.

An Overview of the Book

This book is organized in four parts. In part I (chapters 2 - 4), optimization models are presented for the three most important aquacultural species in North America - shrimp, catfish and salmon. In part II (chapters 5 - 7), farm management applications are discussed and recommendations suggested. In part III (chapters 8 - 10), econometric models of shrimp, catfish and salmon are presented. In part IV (chapters 11 - 13), marketing applications provide practical recommendations for continued market development of aquaculturally-produced species. The book concludes with some remarks related to future directions in economic research on aquaculture.

In chapter 2, Gilbert Sylvia and James Anderson present a dynamic multi-level policy model for optimizing private and public net-pen salmon aquaculture strategies. Using non-linear programming and regression analysis, the aquacultural sector's problem is solved for alternative public policies and environmental conditions. The dynamic response function is then estimated and the multi-objective policy problem parameterized. Policy information is summarized in the form of tradeoff curves and capitalized policy frontiers. The model is intended to provide quantitative measures of the environmental tradeoffs associated with industry development to allow for a more objective policy discussion concerning firm-level production strategies, regional industry development and environmental protection.

In chapter 3, PingSun Leung, Donna Lee and Eithan Hochman present and compare the methodologies used in modeling shrimp and prawn operations. Because of the close to homogeneous growth of shrimps and the heterogeneous growth of prawns, different cultural practices are used by producers rearing these two animals. Shrimp operations are generally of a single stocking and harvesting nature, while prawn producers practice continuous stocking and selective harvesting. This chapter reviews and compares past modeling efforts of these two animals. For shrimp operations, the authors extend the classical growing inventory model, which was originally developed for broiler production. In modelling prawn operations, the authors use two sub-models: a stochastic population sub-model and an economic optimization sub-model.

In chapter 4, Oscar Cacho develops a differential-equation simulation model for fish growth. A bioenergetics approach is taken in which the balance between energy intake and energy expenditures determines growth. The effects of fish weight, diet composition, feeding rates, and temperature on fish growth and body composition are incorporated. The model simulates results from research ponds. The dynamic optimization effort is useful in illustrating a complex set of interactions and can be used to identify biological research opportunities with high potential payoffs.

In chapter 5, Carole Engle and Gayle Pounds develop and present results from multi-period and risk programming models that are designed to select optimal production management strategies for catfish production. Single-batch strategies stocked with 18-20 centimeter fingerlings at 14,800 per hectare maximized returns above variable cost. Off-flavor problems force catfish farmers to hold fish for longer periods and incur additional inventory cost.

The risk of off-flavor, cash flow restrictions and limited availability of operating capital resulted in replacement of single-batch with multiple-batch production strategies. The higher stocking rate with larger fingerlings generally was selected for multiple-batch strategies. This study partially explains why catfish farmers utilize multiple-batch production strategies even though potential net returns are highest with single-batch production systems.

In chapter 6, Conrado Gempesaw, Ferdinand Wirth, Richard Bacon and Levsiri Munasinghe analyze the economics of vertical integration in hybrid striped bass aquaculture. Production of hybrid striped bass can be classified into four stages. Stage 1 is the hatchery spawning, egg and fry production. Stage 2 is the growth of fry to phase I fingerlings (1-2 inches). Stage 3 is the production of phase II fingerlings (6-8 inches). Stage 4 is the grow-out of phase II fingerlings to 1.5-pound market size. The aquaculture producer has the following production options: (1) specialize in a specific phase, (2) partially integrate several phases, and (3) fully integrate the four production phases. A dynamic, stochastic, whole farm, capital-budgeting simulation model is used to examine the financial returns associated with the economics of specialization, partial integration, and full vertical integration in hybrid striped bass production. Results indicate high returns but considerable risk in hybrid striped bass production. In addition, interregional competition in hybrid striped bass production is evaluated. The Delmarva farm was found to earn lower internal rates of return in comparison with North Carolina and Mississippi farms but had similar net cash farm incomes.

In chapter 7, Samuel Logan and Warren Johnston analyze the optimum replacement of broodstock for rainbow trout. The economics of retaining rainbow trout broodstock for multiple spawns is affected by changes in growth, mortality, and egg production (number, size, quality) as the broodstock ages. Contributions to the firm's net income are analyzed for operating policies of retaining broodstock for one through four spawns. The initial spawn occurs naturally in December. Subsequent spawns, administered under photoperiod control, follow at 10-month intervals. Retaining broodstock for two-spawns doubles the number of spawns for any cohort of fish relative to the single-spawn program because of the photoperiod acceleration. The two-spawn strategy provides a present value to a 50-year stream of net contributions of $546,006. Higher mortality levels, lower feed efficiency, and reduced egg production per pound of biomass for the larger fish result in lower net contributions for the three- and four-spawn policies.

In chapter 8, Walter Keithly, Kenneth Roberts, and John Ward quantify the impacts of shrimp aquaculture on U.S. imports and domestic warm-water dockside shrimp prices using a simultaneous-equations model. It includes the U.S. and Japan shrimp import markets and U.S. dockside demand. The model was developed to investigate the impacts of imports on domestic shrimp fishermen. The research focuses on the role of farm-raised supply in the proliferation of U.S. imports during the 1980's, and the subsequent impact on prices.

In chapter 9, Walter Zidack, Henry Kinnucan, and Upton Hatch present a dynamic monthly econometric model of the U. S. processed catfish industry that incorporates industry characteristics such as rapid sales growth, industry sponsored advertising, and imperfect competition at the processor level. Parameter estimates indicate an inelastic farm supply and an elastic demand at the processor level. The purpose of the research was to quantify key economic relationships in the catfish industry for policy analysis and industry planning. The structural model estimated could be used for policy simulation or as a component of a larger modeling effort to provide a more comprehensive analysis of industry growth and other issues.

In chapter 10, Mark Herrmann, Ron Mittelhammer, and Biing-Hwan Lin present an econometric model of world trade in wild and farmed salmon. Interrelationships between the demands for Pacific and Atlantic salmon in major international markets and an analysis of the profitability of Atlantic salmon farming are the focuses of the study. The model is used to estimate the effects of exogenous market forces on farmed salmon price in Washington's Puget Sound and the ex-vessel prices received by fishermen in North America. The system of equations was estimated using a Bayesian bootstrapping two-stage least-squares program that was constructed in the GAUSS programming language.

In chapter 11, David Egan reports the results of recent seafood consumption surveys in the United States and Canada conducted by a consultant team for the Canadian Department of Fisheries and Oceans. The U.S. survey identifies a "salmon consumer" group (43%) and a "non-salmon consumer" group (47%). The majority of consumers did not perceive a difference between farmed and wild salmon. Canada ranks highest of all producing regions in consumer identification with salmon. Using a contingent valuation approach, price elasticities of -3.5 and -2.4 in the U.S. retail and restaurant sectors, respectively, were calculated. A U.S. salmon consumption model is used to analyze the relationship between salmon consumption and income, age, education level and place of residence. The regression models, although statistically significant, have relatively poor explanatory power. The majority of salmon consumption is presently concentrated to a small segment of the population. Salmon consumption would increase the most from year-round availability of fresh salmon with occasional, at-home consumers of salmon. All five areas (San Francisco, Los Angeles, Chicago, New York and Dallas) surveyed showed good potential for increased consumption based on year-round availability of fresh salmon. In each area, gains in the retail sector are potentially higher than in the restaurant sector. San Francisco, which has the highest per capita consumption of salmon, shows the lowest potential for growth in the restaurant sector. Consumption patterns in the Canadian survey are similar to the U.S. survey except for a higher overall salmon consumption rate (66%). The Canadian survey indicates that at-home salmon consumption would increase when in-store recipes are made available.

In chapter 12, Johannes Lambregts, Oral Capps and Wade Griffin estimate seasonal demand for catfish from 1987 to 1988 in a Houston, Texas retail market using a polynomial approximation method. Fillets appear to have less seasonality than whole dressed catfish. Small seasonal differences exist in the intercept estimates. For dressed catfish, the own-price and cross-product price elasticities and autonomous demand parameters show seasonal differences. Beef is a gross substitute for catfish products. Shellfish appear to be a strong complement to whole dressed catfish. The relationship between catfish products is somewhat asymmetrical in this market; fillets are a gross substitute for whole dressed, but not vise versa.

In chapter 13, Priscilla Brooks investigates consumer perceptions of seafood safety and the implications for aquaculture as it relates to blue mussels in the Northeast. The blue mussel (*Mytilus edulis*) industry has developed rapidly in the past fifteen years. Once considered as bait or "trash" fish and targeted primarily to ethnic markets, blue mussels have attained gourmet status and are now found in white tablecloth restaurants, gourmet shops and supermarkets throughout the United States. Despite the recent expansion of the U.S. market, real wholesale prices have declined substantially, suggesting that supply is growing faster than demand. Further development of the industry and the seemingly underdeveloped U.S. market is threatened by: (1) a lack of market information on consumer preferences for, and attitudes towards, wild and cultivated mussels with which to design an effective marketing campaign; and (2) a perceived health risk from eating mussels, exacerbated by recent incidents of shellfish poisoning and adverse media publicity about seafood safety.

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