2004

An Economic Analysis of the Pacific Halibut Commercial Fishery

Keith R. Criddle
Utah State University

Mark Herrmann

Economic Research Institute Study Paper

ERI # 2004-20

AN ECONOMIC ANALYSIS OF THE PACIFIC HALIBUT COMMERCIAL FISHERY

by

KEITH CRIDDLE

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

and

MARK HERRMANN

Department of Economics
University of Alaska Fairbanks
Fairbanks, AK 99775

December 2004

AN ECONOMIC ANALYSIS OF THE PACIFIC HALIBUT COMMERCIAL FISHERY

Keith Criddle, Professor

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

Mark Herrmann

Department of Economics
University of Alaska Fairbanks
Fairbanks, AK 99775

Information on other titles in this series may be obtained from: Department of Economics, Utah State University, 3530 Old Main Hill, Logan, UT 84322-3530.

AN ECONOMIC ANALYSIS OF THE PACIFIC HALIBUT COMMERCIAL FISHERY

Keith Criddle and Mark Herrmann

EXECUTIVE SUMMARY

While many of the world's fish stocks are in decline, biomass and harvest levels remain high in the Alaskan and British Columbian halibut fishery. The fishery has undergone substantial restructuring over the last decade from a regulated open-access no-holds-barred derby that relied on large frozen inventories to satisfy wholesale demands to a slow-paced individual quota-based fishery that has reorganized supply chains to deliver high-quality fresh product throughout a protracted season. In addition, there have been substantial fluctuations in estimates of halibut stock abundance and the halibut quotas derived from those estimates. Other issues that have also presented challenges to halibut management include halibut bycatch in other commercial hook-and-line and trawl fisheries and growth of halibut sport fisheries. On the horizon looms the potential that increasing production of farmed halibut will penetrate North American halibut markets and depress wholesale and exvessel prices much as salmon aquaculture did. To explore the economic consequences of these changes, we have developed an empirically-based stochastic bioeconomic simulation-optimization model of the Pacific halibut fishery. The model includes a simultaneous equation system model of halibut exvessel price formation, wholesale price formation, export price determination, inventory demand, and a mixed structural-time series model of halibut population dynamics.

Model Results

We found that the supply of Alaskan halibut sold on the domestic wholesale market is relatively inelastic and is principally affected by an exogenously determined (by the IPHC) supply with minor adjustments for changes in end-of-year inventories and very minor amounts of exports. We estimate that the own-price flexibility for domestic consumption of halibut is -0.29 and that the cross-price flexibility with imports from British Columbian is -0.17, all else equal. In addition, we found that increases (decreases) in season length, the U.S. price of meat, and disposable income will increase (decrease) wholesale price and that an increase (decrease) in fuel costs will decrease (increase) the purchase price of halibut. Inventories serve to smooth supply within and between seasons. We estimate that increases (decreases) in landings and the current wholesale price will lead to an increase (decrease) in ending inventory levels whereas increases (decreases) in the expected future wholesale price and season length will decrease (increase) inventory levels.

British Columbian exports are the principal alternative supply of halibut into the U.S. market. We estimate that a one-percent increase in British Columbian landings will increase exports to the U.S. by 0.70 percent and that a one-percent increase in the real export price will increase exports by 0.92 percent, all else equal. We also found that an increase in the U.S. real wholesale domestic price of Pacific halibut will lead to a 1.12 percent increase in the price of imported

British Columbia halibut, all else equal. In addition, an increase (decrease) in the length of the British Columbia halibut season will increase (decrease) the U.S. import price while an increase (decrease) in the length of the Alaska halibut season will decrease (increase) the import price.

The exvessel price for Alaskan landings of Pacific halibut was modeled as a function of the U.S. real wholesale price of Pacific halibut, Alaskan landings, and the real price index of fuel. We estimate that a one-percent increase in the real wholesale price will increase the Alaskan exvessel price by 1.23 percent, all else equal. In addition, we found that an increase (decrease) in the real price of fuel (a proxy for processing costs) will decrease (increase) the Alaska exvessel price. The exvessel price for British Columbian landings was modeled as a function of the real export price, the real price index of energy, and the Alaskan season length. We estimate that a one-percent increase in the real export price of British Columbian halibut will result in a 1.15 percent increase in British Columbian exvessel prices, all else equal. As in the Alaska exvessel price equation, we found that an increase (decrease) in the real price of energy will lead to a decrease (increase) in British Columbian exvessel prices and that an increase (decrease) in season length in Alaska will decrease the British Columbian exvessel price.

The dynamics of coastwide halibut populations were modeled as a structural-time series equation system. We estimate that steady-state sustainable yields reach a maximum of 91 million pounds at a coastwide population biomass level of 280 million pounds. Although steady-state sustainable revenues are maximized at a steady-state sustainable harvest of 91 million pounds, there is less than a 5% difference in the estimated magnitude of steady state sustainable revenues for landings from 79 to 91 million pounds and coastwide population biomass levels of 170 to 400 million pounds. Our estimates were robust for changes in environmental conditions that affect the productivity, recruitment success, or growth rate of halibut.

Model Implications

We used our model to explore four issues: the effect of variations in total allowable catch on the magnitude of commercial fishing revenues in Alaska; the effect of transition from derby to individual quota management on the magnitude and distribution of commercial fishing and processing revenues in Alaska; the potential effect of the emergence of halibut aquaculture outside the U.S. and Canada on the magnitude of commercial fishing revenues in Alaska; and, the potential effect of season elongation on the magnitude of commercial fishing revenues in Alaska.

In the 2002 base year, 58.1 million pounds of halibut were landed in Alaska. As landings increase from this level so does total revenue. As landings continue to increase, price becomes increasingly sensitive to equal percentage increases in landings. Simulated exvessel revenues peak when landings reach 104.2 million pounds. However, the productivity of North Pacific halibut stocks limits the magnitude of sustainable removals to no more that 91 million pounds in steady state equilibrium. Because catch-per-unit effort is higher at higher population levels, the marginal cost of harvesting the sustainable yield is lower at population levels above the biomass level associated with the maximum sustainable yield, thus it is more profitable for the harvesting sector to harvest from a population that is above the biomass level associated with the maximum sustainable yield.

The introduction of IFQs in the Alaskan halibut fishery resulted in substantial increases in exvessel and wholesale prices while leaving exvessel-wholesale margins largely unchanged. After accounting for changes in IPHC, we estimate that implementation of IFQs in Alaska caused average wholesale prices (for 1995 to 2002) to increase by $0.24 per pound and caused average Alaskan exvessel prices (for 1995 to 2002) to increase by $0.22 per pound. Before 1990 the spread between British Columbian and Alaskan exvessel prices for Pacific halibut was approximately $0.32 per pound. From 1991-1994 (following implementation of IVQs in British Columbia and prior to the implementation of IFQs in Alaska) the average spread increased to $0.95 per pound. In the immediate aftermath of IFQ implementation in Alaska (1995-1997), the average spread decreased to $0.10 per pound. Since 1997, exvessel prices in British Columbia and Alaska have been virtually undifferentiated. We estimate that implementation of the Alaska IFQ program decreased average (1995-2002) exvessel prices in British Columbia by $0.32 per pound.

Our results suggest that 90% of the wholesale price gains attributable to implementation of Alaska IFQ program accrued to the fishermen. This is what would be expected if the processors are largely competing for the raw product. In a competitive market, as wholesale prices rise, processors can be expected to bid up the price of the product to cover their costs of production. If the cost structure is not significantly changed from the pre-IFQ period then you would not expect the margin to change substantially. Matulich (2002) and Matulich and Clark (2003), indicate that of the 104 halibut processing firms operating before IFQ implementation, only 31 continue to process halibut. Fifty-one new firms have entered the market since 1995 and have captured 34 percent of the market share. Several of these new firms are custom processors or broker/reprocessors that are also the buyer of record. As exvessel prices were bid-up, pre-existing processors lost money. Therefore, although the halibut industry is healthy and vibrant, processors who invested in nonmalleable capital that was unsuitable for profitable operation under the longer, slower IFQ fishery, believe that the value of their investment in capital was unfairly diminished as a consequence of the *de gratis* allocation of IFQs to fishing vessel owners. Concern about protecting the market share of existing crab processors has led to the adoption of a two-pie quota system (with community protection) in the Bering Sea crab fisheries.

Our simulations suggest that if farmed halibut were to be sold in the same markets that wild halibut is currently sold in, the resulting exvessel revenue losses to Alaskan fishermen would be substantial, all else equal. Under current demand conditions and at projected aquaculture production cost levels, the sale of farmed halibut into the same markets as wild halibut would cease to be profitable as farmed production levels approached 50 percent of Alaskan landings. A more likely scenario would be that before exports of farmed halibut to the U.S. drove farmed prices towards the cost of production, aquaculture producers would seek to develop export markets in other countries. Although there are important differences between salmon and halibut markets, it would not take unthinkable amounts of farmed halibut being sold on the domestic markets to substantially affect the wild halibut industry.

Under the demand conditions characteristic of 2002, environmental and biological limits to the productivity of wild halibut stocks lessens the likely magnitude of adverse impacts to Alaska halibut fishermen of the growth of farmed halibut production. If the wild fishery were to harvest the maximum sustainable yield of about 91 million pounds, total revenues from wild and farmed production would continue to increase as farmed production increased to about 14 million pounds. Although farmed production above 14 million pounds would lead to decreased total revenues to farmed and wild production, farmed production could increase to about 30 million pounds without reducing the combined revenues from wild and farmed production to below revenues that would be available to a wild-harvest-only scenario with harvesting at the maximum sustainable yield

Since 1995 the Pacific halibut fisheries in British Columbia and Alaska have been running the exact same 245-day seasons from March to November. Farmed halibut is likely to first be sold during the months of November through March, when the wild halibut fishery is currently closed much as farmed salmon first infiltrated new markets by selling product primarily during the off-season. Consequently, fishermen and processors have already suggested that the IPHC consider the possibility of lengthening the Pacific halibut season to preempt or at least slow the establishment of farmed halibut in seasonal niche markets. Our model suggests that lengthening the Pacific halibut season will increase revenues by spreading the supply of "fresh" halibut over an additional four months each year. We estimate that lengthening the season to year-round will raise exvessel prices and revenue by 4.1 to 4.9 percent, an exvessel revenue increase of approximately $6 million. Even if the revenue increase associated with lengthening the season are less than the incremental costs of season elongation, the benefits of denying a seasonal niche market to farmed halibut may justify moving to a 365 day season.

Table of Contents

List of Tables

List of Figures

List of Equations

AN ECONOMIC ANALYSIS OF THE PACIFIC

HALIBUT COMMERCIAL FISHERY[1]

Introduction

While many of the world's fish stocks are in decline, biomass, harvest levels, exvessel prices, and revenues remain high in the Alaskan and British Columbian fisheries for Pacific halibut (*Hippoglossus stenolepis*).

> Halibut continues its enviable climb towards this season's combination of record high harvests and record high prices, putting an all-time record $233 million into fishermen's pockets in 2003. That was up 35 percent from 2002, a year that had looked good to most observers. The gain was shared by participants in every one of the 10 IPHC management areas. Halibut Individual Fisherman Quota (IFQ) share prices have surged right along with the general leap in the value of the fishery. Shares that were priced at $7 to $8 per pound for various Gulf of Alaska areas a little over a year ago are now receiving offers ranging as high as twice that (Meloy 2004).
>
> Seeing the market hunger for fresh halibut, commercial fishing professionals from Dutch Harbor to Sitka sang the praises of a fishery that provides a reliable revenue stream for fishermen, processors, and coastal communities during tough economic times. Said Cora Crome of the Petersburg Vessel Owners Association, "As we've had the economic downturns in salmon, halibut has become a very core fishery" (Melow and Drouin 2003).

The economic importance of this fishery to Alaska provides motivation for research to better understand the links between the biological factors leading to healthy halibut stocks and the economic characteristics of a healthy halibut industry.

Pacific halibut are managed under the Halibut Convention of 1923, a bilateral agreement between the United States and Canada. The treaty established the International Fisheries Commission now the International Pacific Halibut Commission (IPHC), a scientific body with responsibility for conducting stock assessments and recommending conservation measures for halibut in the Pacific Northwest, Gulf of Alaska, Aleutian Islands, and Eastern Bering Sea. In 1976, the Commission's jurisdiction was extended to the 200-mile fisheries conservation zones established pursuant to the Fishery Conservation and Management Act (FCMA) in the United States and corresponding legislation in Canada. Canadian and U.S. halibut fishers were excluded from each other's territorial and extended jurisdiction waters in 1978. Although the IPHC retains authority to establish area specific harvest limits, each nation is responsible for allocating catches among its various user groups ensuring that the sum of commercial, sport, and other removals within its jurisdictional waters does not exceed the regional specific IPHC quotas.

The organization and management of the commercial fishery for halibut has undergone two significant changes over the last decade. First, beginning with the 1991 season, the Canadian

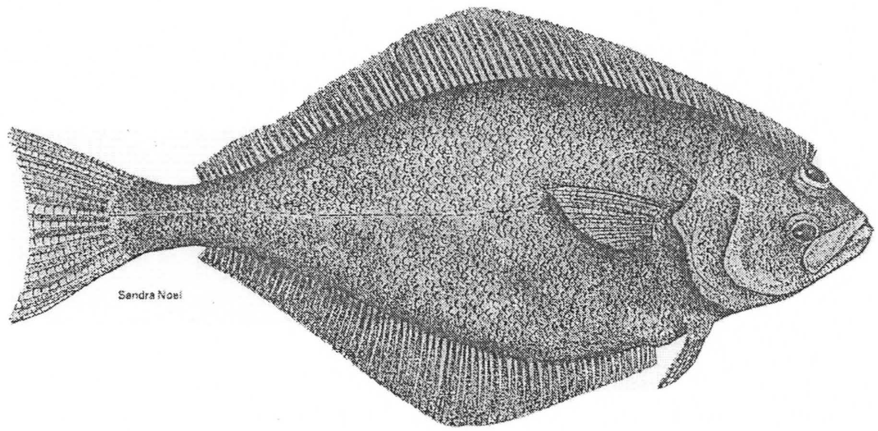
---

[1] This publication is prepared for the Alaska Sea Grant College Program as a final report on a project funded from the National Oceanic and Atmospheric Administration Office of Sea Grant, Department of Commerce, under grant no. NA 16RG2321 project no. RR/32-02, and from the University of Alaska with funds appropriated by the state. All opinions are the authors and do not necessarily represent the Alaska Sea Grant College Program.

Department of Fisheries and Oceans (DFO) transformed management of the British Columbia halibut fishery from regulated open access to an individual vessel quota (IVQ) program. Next, beginning with the 1995 season, the North Pacific Fisheries Management Council (NPFMC) implemented an individual fishery quota (IFQ) program for halibut fisheries in Alaskan waters. In addition, there have been substantial fluctuations in estimates of halibut stock abundance and the halibut quotas derived from those estimates. The IPHC substantially reduced the quotas in the 1995 and 1996 seasons, and then greatly increased the quotas starting in 1997 and continuing to the present. Because the supply of halibut is largely determined by the IPHC quotas, the economic effects of the implementation of IVQs and ITQs cannot be clearly understood without simultaneously accounting for the effects of policy induced changes in the supply of halibut.

Other issues that have also presented challenges to halibut management include halibut bycatch in other commercial hook-and-line and trawl fisheries and growth of halibut sport fisheries. Efforts to manage growth in the sport fishery include the halibut charter Guideline Harvest Limit (GHL) program to be implemented in 2005 and proposed implementation of IFQs in the U.S. halibut charter-based sportfishing sector (NPFMC 1997, 2000). On the horizon looms the potential that increasing production of farmed halibut will disrupt North American halibut markets and wild capture fisheries in much the same way that the rapid growth of salmon farming devastated the North American salmon industry. In response to possible increases in farmed halibut, and because of the advantages of marketing fresh halibut, there have been proposals to increase the length of the halibut season to year-round (IPHC 2003).

The lack of a rigorous model of Pacific halibut supply and demand relationships and the lack of an empirically-based bioeconomic model of the commercial sector, has limited the ability of fishery managers to quantify the economic consequences of changes in the quantity of halibut available to the commercial fishery. This report is intended to remedy, in part, this lack and to model the Pacific halibut markets and to establish the link between Pacific halibut harvest levels and revenues in order to gauge the economic effects of past management actions and to aid in planning for the future. This report summarizes the structure of and findings based on an empirical stochastic bioeconomic simulation-optimization model of the Pacific halibut fishery. The model includes a mixed structural-time series model of halibut population dynamics and a simultaneous equation system model of halibut exvessel price formation, wholesale price formation, export price determination, and inventory demand. The model is used to analyze the linkages between harvest and revenues, to derive a total revenue curve, to examine the revenue effects from implementation of the Alaska halibut IFQ program, to anticipate the potential economic consequences of the inevitable expansion of farmed halibut production, and to explore the potential economic consequences of season elongation.



Pacific Halibut
Line drawing by Sandra Noel. Source (Seafood Leader 1991).

The Pacific Halibut Fishery: Four Issues

In this report we will discuss four issues: the effect of total allowable catch on the level of industry revenues; the effect of individual transferable quotas on the level of industry revenues; the potential economic consequences to industry revenues of the development of a halibut aquaculture industry outside of the U.S. and Canada; and, the potential effects on industry revenue of elongating the commercial fishery season.

Total Allowable Catch and Associated Industry Revenues

The IPHC sets and monitors commercial halibut catch in ten statistical regions. The current boundaries of the IPHC statistical regions are represented in Figure 1.

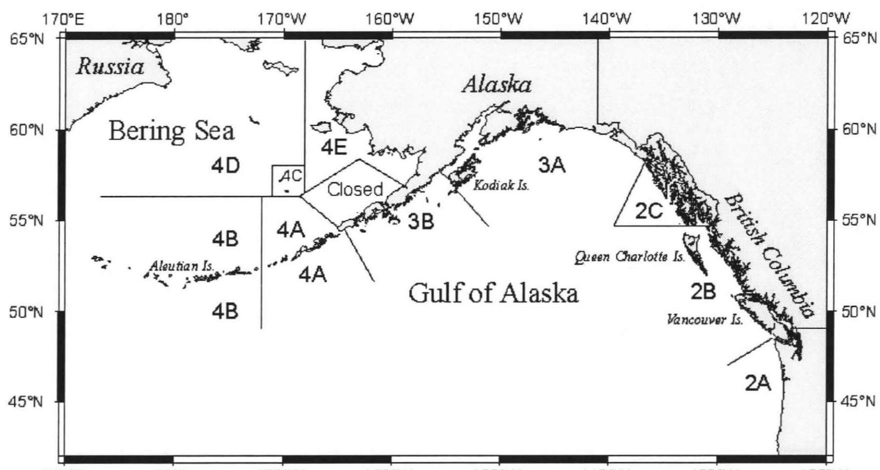


Figure 1. IPHC regulatory areas.
Source: (http://www.iphc.washington.edu/halcom/images/RegAreasbig.gif).

While the halibut stocks are widely regarded as healthy and well managed, following a period of relatively constant or steadily increasing quotas, there have been substantial fluctuations in halibut quota over the last fifteen years. From 1988, when the North Pacific halibut coastwide commercial catch quota peaked at over 74 million pounds, there was a steady decline in quota that bottomed out at 48.7 million pounds in 1995. The 1995 coastwide quota was 8.3 million pounds less than the 1994 quota. In 1996, the IPHC used a new method of estimating halibut biomass, and concluded that halibut was more abundant than had been previously thought (IPHC 1996) and recommended a 36 percent increase in the coastwide quota from 1996 to 1997. The increase resulted in a rapid increase in cold storage holdings in 1997 followed by a substantial decrease in exvessel prices in 1998. In 1999, IPHC biologists recommended a coastwide quota of 86 million pounds and suggested that the quota could have been set as high as 100 million pounds. However, due in part to fears that even an 86 million pound quota would glut the market, the commission set the coastwide quota at 74.1 million pounds (Spiess 1998).

The coastwide quota for 2000 was reduced to account for changes in the catch efficiency of gear used in the annual IPHC setline survey and to account for a general decline in biomass in areas 2B and 3A (IPHC 2000).

> Amid controversy over its assessment model, the International Pacific Halibut Commission reduced the total halibut quota for 2000 by almost 10% from 1999's near-record quota. The 2000 quota is 67.5 million pounds. Though that's still well above the fishery's 25-year average of some 47 million pounds, many fishermen were concerned by a striking 26% decrease in Area 3As quota. At 18.3 million pounds, 3A's quota is one of its lowest in the last 15 years.
>
> With these quotas stemming from the IPHC's controversial stock assessment model, the commission found itself defending its figures; some fishermen say their quota is too low and others charge that too much halibut is being taken (Wyman 2000).

Recent quotas are again near record high levels and expected to remain strong.

> Don't expect a halibut shortage this year. In fact, there will be more halibut on the market than anytime in recent history. Meeting in Seattle, Jan. 22-25, the International Pacific Halibut Commission set an overall catch limit of 74.92 million pounds. Though the halibut biomass is expected to decrease due to long term natural fluctuations in ocean temperature and recruitment, the adult population remains strong. Consequently the commission bumped the 2002 catch limits by nearly a million pounds (Amerongen 2002).

Indeed, the 2004 coastwide quota of 76.5 million pounds is the largest ever set by the IPHC. Catch quotas for 1982-2004 are represented in Figure 2 and reported in Table 14.

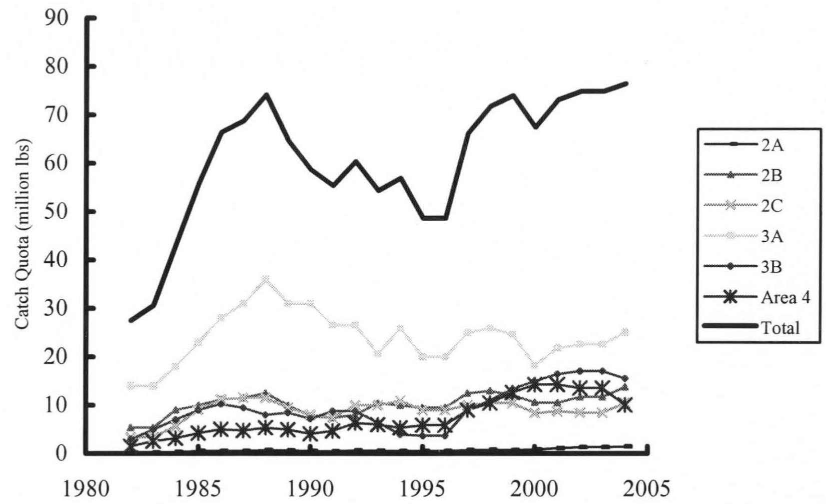


Figure 2. Catch quotas by IPHC regulatory area and coastwide (1982-2004).

Alaska and British Columbia landings of Pacific halibut are shown in Figure 3 and reported in Table 11.

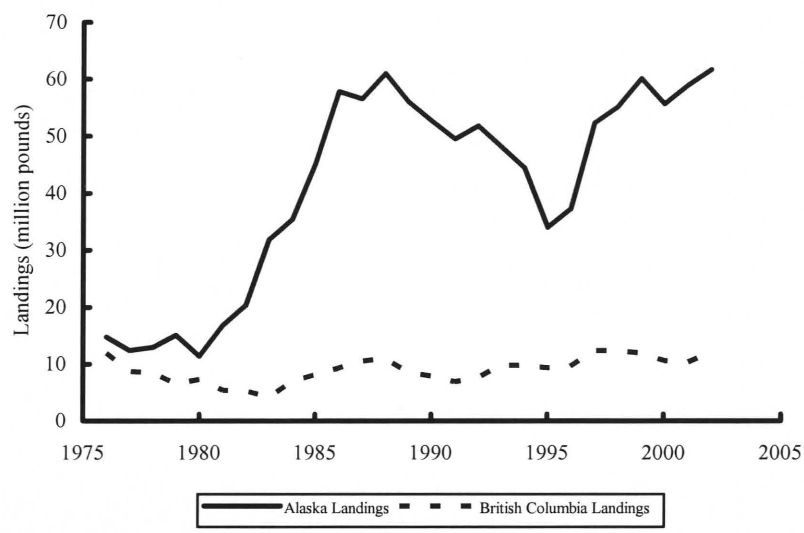


Figure 3. Alaska and Canadian landings of Pacific halibut (1976 to 2002).

The majority of Pacific halibut landings occur in British Columbia (regulatory area 2B) and the Gulf of Alaska (regulatory areas 2C, 3A, and 3B). In 2002 (the last year included in our model), landings from these four regions were 12.1, 8.6, 23.1, and 17.3 million pounds, respectively, and comprised 82 percent of the total landings (74.7 million pounds) of Pacific halibut (IPHC 2003).

However, high landings do not necessarily mean that the halibut industry is economically healthy; profits can be reduced by high costs and low product quality occasioned by the race-for-fish or by low exvessel prices that arise from a saturated market. The halibut market has been a classic case of the race-for-fish problem (NRC 1999). Prior to rationalization, increases in fleet size and harvest power resulted in dramatic reductions in season length (Figure 4).

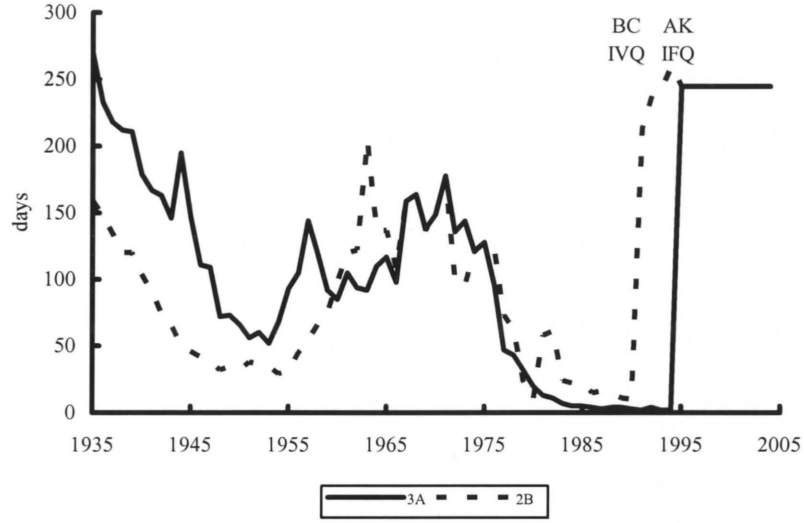


Figure 4. Commercial fishing season length in Pacific halibut management areas 2B and 3A (1935-2004).

From 1976 (the first year of the modeling period) to 1990 (the last year before British Columbia IVQs were imposed), the season length in British Columbia declined from 123 to 10 days. With implementation of IVQs, the 1991 season length increased to 213 days in British Columbia. In area 3A (Alaska), where derby-style fishing continued through 1994, the season decreased from 96 days in 1976 to just 2 days in 1994. From 1991 to 1994, when the British Columbia season averaged 239 days, area 3A of the Alaska fishery averaged just 2.5 days. When Alaska adopted IFQs the season was elongated to 245 days in Alaska and British Columbia.

Changes in the spread between exvessel prices in Alaska and British Columbia during the transition from open-access to ITQs provide important insights into the effects of fishery rationalization. Before 1990 the spread between British Columbian and Alaskan exvessel prices for Pacific halibut was approximately $0.32 per pound. From 1991-1994 (following implementation of IVQs in British Columbia and prior to the implementation of IFQs in Alaska) the average spread increased to $0.95 per pound. In the immediate aftermath of IFQ implementation in Alaska (1995-1997), the average spread decreased to $0.10 per pound. Since 1997, exvessel prices in British Columbia and Alaska have been virtually indistinguishable (Figure 5).

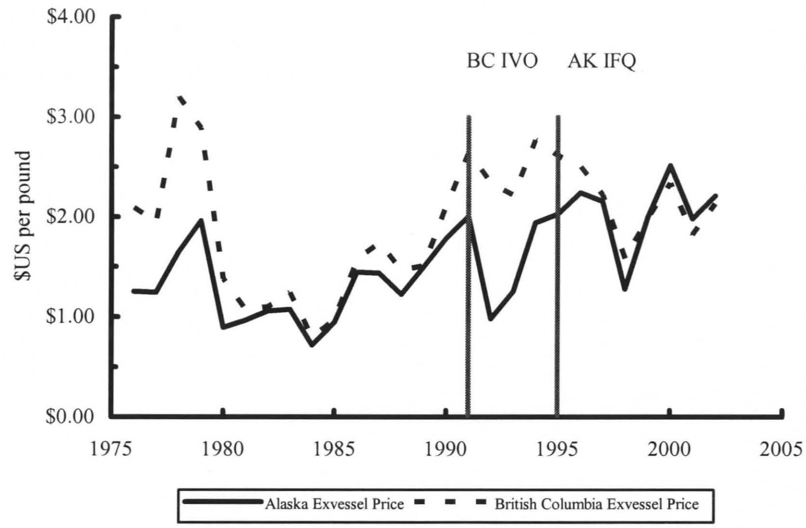


Figure 5. Exvessel price ($/lb) of Pacific halibut in Alaska and British Columbia from 1976 to 2002.

Changes in exvessel revenues couple the effects of variations in exvessel prices and variations in total allowed catches and have been more volatile in Alaska than in British Columbia.

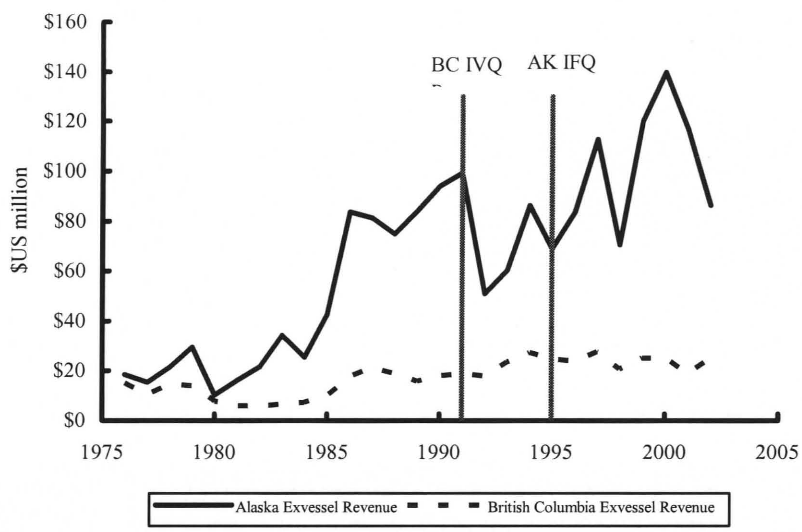


Figure 6. Exvessel revenues ($ million) from Pacific halibut landings in Alaska and British Columbia (1976 to 2002).

Halibut markets are currently strong and annual revenues are rising with increased harvests.

> Halibut continued its enviable climb towards this season's combination of record high harvests and record high prices, putting an all-time record $233 million into fishermen's pockets in 2003. That was up 35 percent from 2002, a year that had looked good to most observers. The gain was shared by participants in every one of the 10 IPHC management areas (Meloy, 2004).

Although halibut harvest quotas have been set to support biological objectives, examination of the relationship between harvest, prices and revenues provides important insights into the economic consequences of changes in harvest quotas. Increased harvests do not necessarily mean increased revenues; at some point, increases in harvests begin to saturate markets and cause revenues to decrease (as they have with salmon). The pertinent questions are: how close is the market to saturation and how sensitive will revenues be to increases in halibut supply occasioned by the eventual expansion of halibut aquaculture.

Individual Transferable Quotas and Associated Industry Revenues

Immediately following implementation of the FCMA in 1976, the NPFMC proposed a limited entry program. The proposal was shelved in late 1978 during negotiations over the U.S.-Canada Halibut Convention. The council next approved a one-year moratorium on allowing new participants in the Alaskan commercial halibut fishery for 1982, but because the action was conditional on passage of an amended North Pacific Halibut Act and because the amended Act was not passed until after the start of the 1982 fishing season, no action was taken. In early 1983, the council approved a three-year moratorium. But the National Oceanic and Atmospheric Administration's administrator disapproved the action and suggested that the council instead investigate a permanent limited entry system. The council went even further with consideration of IFQs for the commercial fishery in 1988. In December 1991, the NPFMC approved an IFQ program for halibut as well as sablefish. The final rule creating halibut and sablefish IFQs was published in the Federal Register in 1993 and implemented in 1995 (Pautzke and Oliver, 1997).

> Three years ago, Dave Whitmire, a Bristol Bay gillnetter, pondered his fishing fortune. The days in the bay when he could net $100,000 in a four-week salmon season were over, he concluded, and they weren't coming back. When Whitmire looked around for a fishery with a future, the answer was obvious: halibut. It was a fishery worth investing in. An individual fishing quota system (IFQ), introduced to the fishery in 1995, had given fishermen control over when and where they could fish. No more 24-hour derbies, which meant fish had to be frozen or sold in a glutted fresh market. Whitmire bought some longline gear and headed west, down the Alaska Peninsula to Dutch Harbor, where stocks of the biggest flatfish in the sea were increasing and quota was still relatively cheap. He also started making phone calls to line up markets for his fish.
>
> Getting fresh fish out of Dutch was expensive, so he had to find some markets which would pay a premium for the highest-quality halibut. He eventually found the kind of customer he was looking for: a high-end foodservice distributor in Chicago. These days, Whitmire makes more money than he ever did in the bay, and the price of halibut just keeps going up. Now that markets throughout the Lower 48 have gotten a taste of this fish at peak quality, they're willing to pay the price.
>
> The value of the halibut fishery is at record levels. The stocks are well managed, and catches are at near- record highs. The overall quality of the fish being landed has improved considerably. And Americans around the country can get a great tasting fish fresh eight months a year. It's a case study of how an individual quota system can transform a fishery for the better (Seafood Business 2000).

In their review of international experience with IFQ systems, Squires et al. (1995) conclude that:

> ITQs are expected to generate a number of economic benefits. Some of the most important come through cost reduction and increases in economic efficiency due to more efficient input choices, optimum fleet size and structure, and eliminating wasteful competition in the race to fish.

In fisheries, such as the halibut fishery in which the fishing season had been reduced to just a few days, IFQs have the great advantage of being able to extend the fishing and marketing season. This allows for increases in fresh fish sales, better product quality, and a wider choice of processing options for fishermen, including the option of directly marketing their catches to wholesalers, retailers, institutional purchasers, and restaurants.

Wilen and Homans (1994) provide a theoretical discussion of the marketing losses that occur in absence of an individual quota system (open access fisheries):

> Marketing losses occur in open access or regulated open access fisheries for several reasons. Foremost among these is poor quality raw product associated with the race to catch fish (gear damaged fish, undersized fish, lack of on-board handling). Additional factors include reduced quality wholesale product associated with capacity bottlenecks, freezing deterioration, and inability to market when fewer substitutes are available. All of these translate into lower ex-vessel prices, which in turn affect the process of rent dissipation.

Under IFQ-based management, safety has also improved because harvesters have more flexibility of where and when to fish and can avoid more dangerous situations. "The number of Coast Guard search and rescue operations involving halibut and sablefish longliners fell dramatically the first year the program was implemented, dropping from 33 cases in 1994 to 14 cases in 1995" (Alaska's Fisherman's Journal 1998).

A distinct advantage in the halibut fishery was changing the end-product form from predominately frozen to predominantly fresh (Herrmann 1996). This is especially true in British Columbia: where approximately 40 percent of British Columbia halibut was marketed fresh in the pre-IVQ period while approximately 94 percent has been marketed fresh in the post-IVQ period (Casey et al. 1995).

> Quota shares have put the halibut fisherman in the driver's seat, where he never was during the days of the "derby" fishery. If prices slump unacceptably, he doesn't go out. When demand or market conditions bring them back up, he goes back out. When the weather turns nasty, he waits until it improves. Then neither he nor his fish take a beating.
>
> He fishes at his own pace, allowing sufficient time for careful dressing and chilling, no longer having to pack many fish into whatever space he can. Knowing his total allowable catch pre-season, he can hook and pack the number appropriate for his vessel's hold and chilling capacity, and can catch the rest later when he is ready to do so. Taking time handling his catch means higher quality, and consistently high quality provides access to better prices.
>
> Since the IFQ-holding halibut fishermen can, in effect, set his own season, he can also fit halibut fishing in with other activities. Many small boat, small quota-holding fishermen choose their halibut days to fit into lulls in their salmon season, for example. Switching

> back and forth between fisheries whenever the other one offers more opportunity maximizes the values of both.
>
> Fresh halibut have always demanded higher prices at retail, and the IFQ fishery has made it possible to sell the great majority of them fresh for 8-1/2 months each year, rather than just for the few weeks surrounding the several annual "derbies."

Other than Herrmann's (1996, 2000) analyses of the British Columbia halibut fisheries, there has been very little empirical analysis of the price and revenue effects of IFQs, yet these effects are extremely important to fishermen and processors. Indeed, perceptions about the division of IFQ-induced rents between the harvesting and processing sectors in the halibut fishery were influential in the decision to adopt a two-pie system (harvester and processor quotas with community protections) in the Bering Sea crab fisheries. The Alaskan IFQ and British Columbian IVQ programs have given the harvesters increased temporal and spatial control and resulted in increased exvessel prices and reduced harvesting costs. However, while some of the increased exvessel price and revenue has resulted from changes in the halibut quota and some has resulted from changes in product form, some has arisen from redistribution of rents from the *preexisting* processors to harvesters who were initial *de gratis* recipients of quota share.

> When Canada implemented IVQs, the market had trouble absorbing all the fresh halibut mainly because many buyer and processors weren't able to adapt. But that's changed dramatically. Many of the big players in frozen fish got out of halibut. New, smaller buyers who could buy more halibut and move fast to meet the needs of more diverse customers stepped in (Seafood Leader 1995).
>
> Prices varied from port to port. Without derby pressure, fishermen were able to shop around for buyers. One Kodiak long-liner, for example, reported he took his fish to Homer, where the price was 35 cents higher (Alaska's Fisherman's Journal 1997).

Most *preexisting* processors in the halibut and sablefish industry were not pleased with the harvester only IFQs.

> Certainly, not all traditional processors were thrilled with the new system, as the quantity of halibut handled by the large, mainstream processors dropped considerably. As expected, fishermen were able to shop their catch around and find the best deal. IFQs opened the door much wider for smaller, independent buyers who supply specialized retail or food-service markets (Pacific Fishing 1996).
>
> "The IFQ system has definitely caused a redistribution of fish," says John Sevier, manager of Sitka Seafoods. "We don't have guarantees any more of how much fish we'll have, so it's harder to make deals. During the derby days, we'd have a million pounds or more on our hands, and it was easier to predict the market (Welch 1997).
>
> The loudest chorus of complaints is coming from processors. With so many new buyers now buying halibut directly from fishermen, the competition is driving traditional halibut buyers crazy. "With IFQs, fishermen can schedule their deliveries and sell to anybody they want to. There are too many people buying fish right off the boat," complains one processor in Southeast Alaska. "That's driving boat prices up to where it's impossible to make money" (Seafood Business 2000).

In testimony before the U.S. House of Representatives Subcommittee on Fisheries Conservation, Wildlife, and Oceans, Committee on Resources, Matulich (2002) stated that:

> Halibut processors, on average, lost more than half of their pre-IFQ gross operating margin. This policy-induced loss is even more remarkable because the gross value of the halibut fishery nearly doubled due to the IFQ policy.

He further testified that:

> A harvester-only IFQ allocation (in any manifestation) does not recognize the prior economic interests of both harvesting and processing sectors. It does not allow both sectors to benefit from rationalization

Matulich and Clark (2003) conclude that *preexisting* halibut processors were made worse off under the harvester-only IFQ program. They estimate that the *preexisting* halibut processing industry lost 56 percent of its prior quasi-rents and that 82 percent of the *preexisting* halibut processors were made worse off.

Farmed Halibut and Potential Revenue Effects

Until recently, discussions about the impacts of aquaculture on the profitability of Alaska's wild fisheries have been dominated by concerns about salmon. Recent advances in aquaculture production systems for cod and halibut have awakened concerns for the potential impact of aquaculture on the profitability of capture fisheries for those species. These concerns are reflected in recent press articles. For example,

> Nobody can dispute the negative effect that farmed salmon has had on the wild-fish industry in Alaska. Now fish farmers are taking a hard look at what else there is to grow that could mimic wild caught salmon in the marketplace (Welch 2003).

> After years of research [in 1994], a Norwegian company has put the first farmed halibut on the market. The fish range in size from six to 25 pounds and are grown in Norway, Portugal, Spain and France. They are raised in the dark in 500,000-liter rectangular tanks and take about 40 months to reach market size (Seafood Leader 1994).

> Kate Troll, a Fisheries Specialist with the Alaska Department of Commerce and Economic Development Division of Trade and Development asks "With farmed halibut on the horizon, it is only prudent to ask the question if farmed halibut will be round two for Alaska's fishing industry" (Forster 1999).

The good news for the Alaska capture-based fishing industry is that halibut farming has not grown as quickly as expected. Although the grow-out phase has been very successful, the hatching technology has been slow and some of the effort initially focused on halibut farming has switched to cod farming. The bad news is that there still remains tremendous amount of interest in farming halibut. The economic effects of competition from farmed salmon has put the Alaskan wild salmon fishery into an economic tailspin from which it has not yet recovered; it is not unreasonable to speculate that development of halibut aquaculture could have similarly profound effects on the capture fishery for halibut.

Concern and confusion over the possible effects of farmed halibut is mirrored in the headlines in the popular fish press.

> "Halibut farms could someday eclipse fishery, study says" (Arenson 1999).

> "Halibut farms no "threat," says Forster" (Arenson 1998).

> "A new threat: Will fish farmed decimate Alaska's booming halibut fishery the way they did the salmon fishery?" (Loy 2002a)
>
> "Fish farmers switch from halibut to cod as flatfish pose problems" (Welch 2002).
>
> "Here come the halibut farmers" (Loy 2002b).

Add the fact that Norwegians are largely credited with fomenting and driving the farmed salmon revolution, and that they are now farming cod, halibut, and even experimenting with king crab (Jystad 2003), and it makes the Alaska halibut industry very nervous. Bruce Leaman, executive director of the IPHC, stated that the IPHC is very concerned about the potential impact of farmed halibut (IPHC 2003).

The most quoted piece of work on farmed halibut is authored by John Forster who has 33 years of international experience in commercial aquaculture and is the president of Stolt Sea Farm Washington Inc. Forster (1999) notes that most countries that are seriously interested in farming halibut are farming Atlantic halibut (*Hippoglossus hippoglossus*). He also notes that although there are difficulties with survival and growth at the hatchery stage, halibut are easy to grow once they become juveniles. "Once through the hatchery stage, halibut juveniles are robust and do well under farm conditions" (Forster 1999).

Although Forster (1999) concludes that "farmed halibut will not be a serious competitor for wild Pacific halibut in the near future…", he cautions that

> In the longer term, 15 to 20 years, it is probable that the supply of farmed halibut will exceed landings from the wild fishery. The farmed product will then become the supermarket staple in the same way farmed salmon has become today. Though this may appear to threaten the market for wild, Pacific halibut: there is time to prepare and it could, in fact, present another opportunity. Alaska's salmon industry has shown what can be done with the high quality salmon products by marketing labels of origin, such as Copper River salmon. Pacific halibut is one of the world's highest quality wild fish and it is harvested from a fishery which is predictable and well managed. It would seem that it could enjoy similar success if and when the time comes that farmed halibut becomes the principle commodity.

As with salmon, the most limiting factor to halibut aquaculture is cost of production and whether there are cost reductions that can be achieved through technological advances. Forster estimates that current production costs are between $2.43 to $2.79 per pound (1999 dollars), but that future (15-20 years from now) costs may be expected to be more in the range of $1.45 to $1.89 per pound (in 1999 dollars). Forster emphasizes that these costs are "highly speculative". However, his estimates mirror the cost reductions that occurred in salmon aquaculture and suggest that 15-20 years from now, halibut farmers will need $1.45 to $1.89 per pound (in 1999 dollars) live weight to break even. Prices for wild halibut can be expected to drop to near the breakeven price for farmed product.

> The development of a new species for aquaculture always seems to take longer and cost more than any of its proponents expect. Halibut is no exception. As the salmon farming industry has shown, however, production can increase quickly once key technical hurdles have been overcome and if the species in question has what it takes to be a good farm fish. Halibut appears to have what it takes and both the main hurdles, namely juvenile production and on growing in net pens, would seem to be susceptible to technical

> innovation. At some point in future, therefore, it is possible, even probable, that the halibut farming industry will take off. Whether this will be in 5, 10, 15 or 20 years is hard to say, but enough of the key elements are in place to suggest it will happen. When it does, the cost of producing farmed halibut will come down and so, most likely, will the price for which it is sold. Farmed, rather than wild, halibut could then become the grocery store staple, in the same way as farmed salmon is today (Forster 1999).
>
> At some point in this evolution, volumes of farmed halibut will exceed landings of wild Pacific halibut. Since seventy three million pounds is not a huge amount of fish, compared, for example, with 1.5 billion pounds of farmed salmon which is now produced worldwide, this point could be reached quite quickly, perhaps by 2010 (Forster 1999).

The British Columbia Ministry of Agriculture, Food and Fisheries also contracted out for a study of the economic potential for farmed halibut (Gislason 2001). The report was written after an extensive literature review and interviews with thirty-four individuals familiar with various farmed halibut issues. The study concluded that farmed halibut will be a better quality than wild fish and that the potential negative impact from farmed halibut production is a 20 percent reduction in the wholesale price for the wild product.

Since issuing his report to the Alaska Department of Commerce, Forster has stated that the progress on halibut farming is going somewhat slower that he estimated in his report.

> John Forster, an aquaculture consultant in Port Angeles, Wash, who predicted in a 1999 report for the state of Alaska that farmed halibut production could outstrip the Pacific catch by 2010, says the halibut juggernaut has slowed a little as aquaculture giants like Norway have shifted their focus to cod.
>
> But halibut still is very much in the mix as farmers search for the perfect white fish: one that tastes good, can be raised quickly and easily, and has a high fillet yield, Forster says. So far, that perfect fish hasn't been found, but farmers believe they have a "salmon- size opportunity" in white fish, he says (Loy 2002b).

Nevertheless, farmed halibut is coming and when it arrives, it is likely to have substantial impacts on markets for wild harvests.

Season Elongation and Potential Revenue Effects

Since 1995 the Pacific halibut fisheries in British Columbia and Alaska have been running the exact same 245-day seasons from March to November. In part because of the threat of farmed halibut, there have been suggestions that the Pacific halibut season be lengthened.

> The halibut industry continues to be concerned about the threat posed by aquaculture of halibut. The primary focus of this concern is the loss of market share for wild fish, particularly during the period when the commercial halibut fishery is closed. Industry wishes to address this concern by having wild, fresh halibut on the market for as much of the season as possible. One mechanism to achieve this end is to extend the commercial halibut season beyond its present period March 15th – November 15th (IPHC 2003).

Lengthening the season would mean a longer period of time that halibut could be sold fresh and close the opportunity for farmed halibut to exploit the 120 day window that wild halibut is not fished.

> Long term, halibut producers are keeping an eye on the new halibut farming industry. But with Individual Fishing Quotas, halibut fishermen are better prepared to compete with farmers than salmon fishermen, notes the buyer. A seven-month supply of fresh, high-quality halibut from fleets means farmers can't compete by offering better visual quality and shelf life. The niche they'll have to exploit is, 'we can give you fresh halibut in December and January,' he [a major buyer] says (Warren 1998).

Gislason (2001) concludes that there will be strong demand for farmed halibut and "it would be sold at a premium price in the four month off season for the wild fishery". By lengthening the season, the wild fishery could potentially increase current revenues and prevent the farmed halibut industry from serving as the sole supplier of fresh halibut during these months. As Gislason notes "The impact of the farmed product on the wild fishery depends on the role (quality, season, product form) the wild product serves in the marketplace".

However, lengthening the season is not without problems. The IPHC reports that

> … winter fisheries would intercept fish migrating to and from its spawning grounds, resulting in a long-term redistribution of biomass. While conservation for the stock as a whole can be guaranteed, the traditional summer distribution of fish might be altered.

Safety concerns are also a consideration:

> "The Coast Guard is real nervous about putting a small-boat fleet out in the middle of the Gulf in the winter," says Ralph Hoard, IPHC commissioner. A season extension would also strain Coast Guard resources for enforcement and tax the IPHC's ability to incorporate catch data into its quota recommendation for the following year (Wyman 2000).

A decision to lengthen the season should take account of biological and economic considerations. Later in this report we will examine how a longer season might affect total revenues to the fishery. Finally, other proposals have been put forth such as letting fishermen in British Columbia catch live halibut and store them in net pens to sell during the winter much as tuna are held in Mexico and Australia (Forster 1999). "Canada has no law prohibiting landing live halibut; the U.S. has. Were U.S. policy to change, however, halibut pens still wouldn't be legal in Alaska because of the state's anti-aquaculture law" (Wyman 2000).

Literature Review

The following is a summary of prior work that has, to at least some extent, attempted to quantify the relationship between Pacific halibut harvests and exvessel prices and revenues. Estimation of a demand curve was the central focus in some of these works. In others, it was a necessary component of a model intended to explore other aspects of halibut management. With few exceptions, previous studies of the demand for Pacific halibut have been formulated as single-equation reduced form exvessel inverse demand functions. In some cases, the model is a simple linear regression of exvessel price as a function of landings. In other cases, demand shifters were specified. The use of a single-equation approach is often justified on the grounds that supply is predetermined by factors outside of the market, i.e. set by the IPHC's biology-driven quotas. If landings are invariant to market conditions, then a demand curve can be identified by regressing landings on price as long as demand is stable over the period of analysis. Primary demand and cost shifters can be added to the equation to account for variations in demand though time.

However, problems remain with these techniques because changes in cold-storage inventories affect the actual supply reaching the marketplace and the level of inventories may be endogenously determined. Moreover, the relationships governing wholesale-exvessel price formation may change over time.

In a study examining the socially optimal rate of capitalization of halibut vessels, Schellberg (1993) estimated a derived exvessel demand equation for halibut landed in the Seattle port from 1946 to 1977. Schellberg used a logarithmic formulation and estimated real exvessel price as a function of harvest and a linear time trend (in his final estimation, the time trend was dropped because it was not statistically significant). Schellberg found a constant price flexibility of –0.60 for the time period of 1946-1977. Criddle (1994) used a linear exvessel price equation where the North American exvessel price was modeled as a function of landings (using data from 1935 to 1992). His results indicated that a one million pound increase in landings would lower the exvessel price by $0.018 per pound. In a model of the British Columbia halibut fishery, Cook and Copes (1987) modeled the British Columbia exvessel price as a function of British Columbian harvests, season length (in area 2B), and the price of salmon. Unfortunately, little detail is given about this demand equation. The same general market model was used by Conklin and Kolberg (1994) in their application of a generalized method for analyzing stability potential in discrete renewable resource models subject to open access market based harvest activity.

Lin et al. (1988) estimated a more sophisticated reduced-form exvessel demand equation for North American Pacific halibut using IPHC annual data from 1955 through 1984. They modeled real exvessel price (combined Canadian and U.S.) as a function of North American landings, the length of the halibut season (area 3A), U.S. cold storage holdings (head-off dressed halibut), and the U.S. real wholesale price of all finfish. Although real expenditure for food was initially included in the model, it was not statistically significant and was omitted from the final model. Lin et al. found a mean-level exvessel price flexibility of –0.18 suggesting that, revenues would increase in concert with increases in halibut landings even for substantial increases in landings relative to the 1955-1984 mean level, all else equal. Their equation also indicated that a one-percent increase in the number of fishing days would increase exvessel price by 0.15 percent, the first study to quantify a price-induced benefit of an individual transferable quota program that would lengthen the fishing season. Lin et al. also found that a one-percent increase in cold storage holdings would depress price by 0.27 percent, and that a one-percent increase in the wholesale price of finfish would induce a 1.16 percent increase in the price of halibut.

As part of a larger work on regulated open access resource exploitation, Homans (1993) estimated separate exvessel and wholesale price equations for Pacific halibut. The wholesale price equation was estimated with two-stage least squares, where wholesale price was modeled as a function of harvest, marketing period length, and lagged wholesale price. The exvessel price equation was estimated using ordinary least squares and modeled as a function of current and lagged wholesale price, current and lagged harvest, and the marketing period. This formulation is based on the assumption that the market adjusts at the wholesale price level and that exvessel price is formed, in part, as a markdown of wholesale price. Using data from 1959 through 1978, Homans estimated a long-run wholesale own-price elasticity of -1.16 and exvessel price flexibilities that, depending on marketing period, ranged between –1.12 and –1.59, indicating that the market was saturated at the exvessel level.

Knapp (1997) attempted to measure the effects of the Alaska halibut IFQ program by quantifying exvessel price-quantity relationships. At the wholesale level Knapp differentiated between frozen halibut, non-IFQ fresh halibut (fresh halibut prior to 1995 for Alaska and prior to 1991 for British Columbia), 1991-1994 IVQ fresh halibut (British Columbia only), and post-1995 IFQ fresh halibut (British Columbia and Alaska). Using price and quantity data, he attempted to estimate three inverse demand equations over the period 1987-1995. However, results were only reported for one of the estimated equations ($R^2 = 0.37$); parameters for the other two equations were not estimated statistically, but were instead drawn by hand to give a "visual best fit". The slopes in Knapp's estimated, and hand-drawn equations suggest that the price of frozen halibut will decline by $0.0255 for each one million pound increase in frozen halibut and that the price of fresh halibut will decline by $0.02 for each one million pound increase in fresh halibut. Knapp estimates that the 1995 exvessel price increased by between $0.11 and $0.20 per pound, depending on region, and that the lower quota increased exvessel prices by another $0.07 per pound.

Herrmann (1996) used three equations to model exvessel price formation in the British Columbian market for Pacific halibut. (Because the current study expands on Herrmann 1996 and 2000, a detailed discussion of these models will be left to later). The equation system was estimated using three-stage least-squares on data from 1974-1994. Among other findings, Herrmann estimated a British Columbia halibut import own-price elasticity of –1.68 and an income elasticity of 1.84. He estimated that a one-percent increase in season length would lead to a 0.13 percent increase in exvessel prices in British Columbia. He concluded that between 1991 and 1995, implementation of IVQs in British Columbia increased exvessel prices between $CDN 0.55 and $CDN 0.77 per pound. Revenue increases due to the price increases were estimated to be 3.98, 4.98, 7.71, and 6.55 million $CDN in 1991, 1992, 1993, and 1994, respectively, for a total four-year revenue increase of $CDN 23.2 million. Herrmann (2000) expanded on this model, adding a reduced-form Alaska exvessel price equation and estimating the remaining price advantage in British Columbia after the introduction of Alaska IFQs in 1995. He concluded that British Columbian prices remained elevated after the introduction of Alaska IFQs but that the increase was reduced to approximately $CDN 0.40 per pound relative to pre-IVQ prices. That is, he estimated that approximately one-half of the price advantage of the British Columbia IVQ system was lost after 1995 when Alaska adopted IFQs. However, increased landings dampened some of the revenue losses as the British Columbia IVQ induced exvessel revenue four-year total for 1995-1999 to $CDN 16.1 million, down from the $CDN 23.2 million for 1991-1994. Still, this brought the estimated eight-year British Columbia halibut revenue increase, due to IVQs to $CDN 39.5 million.

There has not been a comprehensive bioeconomic analysis of the commercial Pacific halibut fishery since the introduction of IVQs in British Columbia (1991) and IFQs in Alaska (1995). While earlier studies by Crutchfield and Zellner (1962), Lin et al. (1988), NPFMC (1991), Homans (1993), Schellberg (1993), Criddle (1994), and Love et al. (1995) offer some helpful insights, they are not useful descriptions of the post-IFQ implementation fishery and offer, at best, rudimentary models of the exvessel market structure. Post-implementation analyses of the Canadian (Casey et al. 1995; Cook and Copes 1987) and Alaskan (NRC 1999, Dinneford et al. 1999) fisheries ignore or offer similarly naïve models of the economic behavior of markets for Pacific halibut.

The International Supply and Demand Equilibrium Model

The Market Model

In constructing an international supply and demand model for Pacific halibut, it is imperative to include the essential features of the commodity's supply and demand while avoiding the introduction of so much detail that the model cannot be estimated. Modeling is an art of striking a balance between realism and simplicity. Ultimately, the overall effectiveness of a model is determined by how it adds to an understanding of market dynamics.

Alaska and British Columbia harvest virtually all the world's supply of Pacific halibut[2]. Because the overwhelmingly main market for halibut is the U.S. (other smaller markets do exist) the world's price of Pacific halibut will be assumed to be set in the U.S. market. Although the upper bounds on harvests are exogenously set according to biological criteria, and the decision to harvest up to the upper bound is not mandated, and the allocation of these harvests (to immediate consumption or inventory) is an endogenous choice.

The main model that contains the equilibrium supply and demand model is presented in the flow chart below (Figure 7).

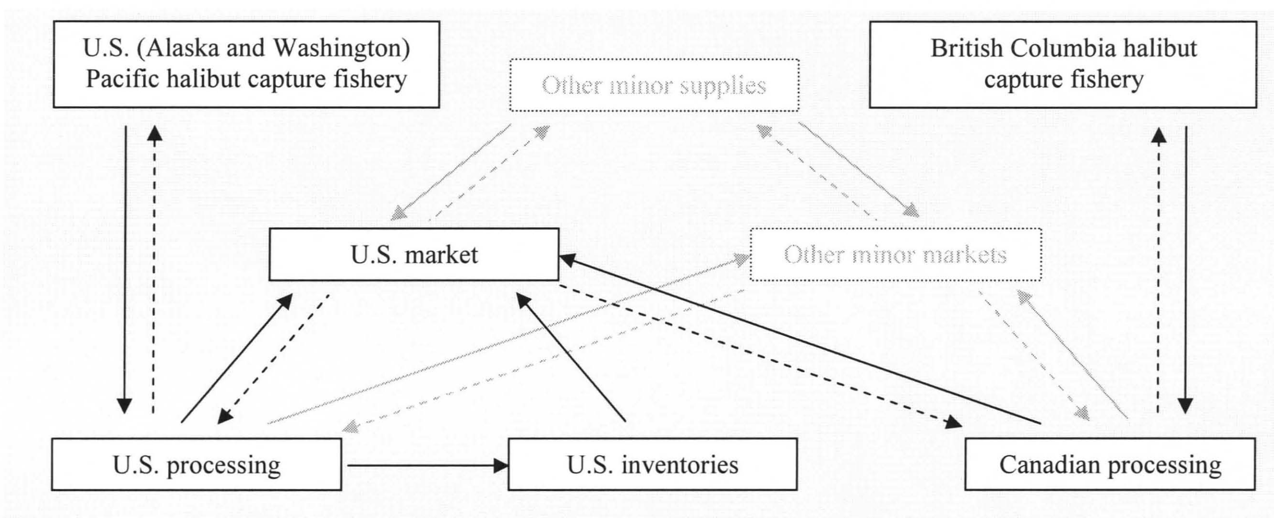


Figure 7. Product and financial flows in the Alaska and British Columbia halibut fisheries. Solid arrows represent product flows and dashed arrows represent financial flows. Light gray flows not modeled.

The entire modeled equilibrium system for the supply and demand for halibut from Alaska and British Columbia, can be represented by six behavioral equations and five market clearing identities. The equation system consists of eleven endogenous variables and eleven equations. The behavioral equations included in the model are: (1) the U.S. derived wholesale demand for

---

[2] During the modeling period, over 99% of the U.S. landings of Pacific halibut originated in Alaska. For ease, we will refer to U.S. landings of Pacific halibut as "Alaska halibut". Pacific halibut is also landed in the Russian Far East, but flows into the international market have been limited and sporadic.

Pacific halibut; (2) the demand for U.S. inventories of Pacific halibut; (3) the export of Pacific halibut from British Columbia to the U.S.; (4) the price linkage between British Columbia exports to the U.S. and the U.S. wholesale price of Pacific halibut; (5) the derived exvessel demand equation for Pacific halibut from Alaska; and, (6) the derived exvessel demand for Pacific halibut from British Columbia

Simultaneous Demand and Supply Equations

1) U.S. derived wholesale demand $P_t^{US\,R\,W} = f_1(QC_t^{US}, QC_t^{BC}, SEAS_t^{AK}, PPI_t^{US\,Meat\,R}, PPI_t^{US\,Fuel\,R}, INC_t^{US\,R})$

2) U.S. inventory demand $INV_t^{US} = f_2(LAN_t^{US}, P_t^{US\,W}, P_{t-1}^{US\,W}, SEAS_t^{AK})$

3) British Columbian exports to U.S. $QS_t^{BC} = f_3(LAN_t^{BC}, P_t^{Import\,R})$

4) British Columbian export price linkage $P_t^{Import\,R} = f_4(P_t^{US\,W}, SEAS_t^{BC}, SEAS_t^{AK})$

5) Alaska derived exvessel demand $P_t^{AK\,Exv\,R} = f_5(P_t^{US\,R\,W}, LAN_t^{AK}, PPI_t^{US\,Fuel\,R})$

6) British Columbia derived exvessel demand $P_t^{BC\,Exv\,R} = f_6(P_t^{Import\,R}, CPI_t^{Can\,Fuel\,R}, SEAS_t^{AK})$

Market Clearing Identities

7) $$QC_t^{US} = \frac{LAN_t^{AK} + LAN_t^{WA} + (INV_{t-1}^{US} - INV_t^{US})}{POP_t^{US}}$$

8) $$QC_t^{BC} = \frac{QS_t^{BC}}{POP_t^{US}}$$

9) $$P_t^{US\,R\,W} = \frac{P_t^{US\,W}}{PPI_t^{US\,IFF}}$$

10) $$P_t^{AK\,Exv\,R} = \frac{P_t^{AK\,Exv}}{PPI_t^{US\,IFF}}$$

11) $$P_t^{Import\,R} = \frac{P_t^{Import}}{CPI_t^{Can\,Food}} EXCH_t$$

(Variable definitions and sources are listed in Table 1 and Table 2).

Table 1. Market model variable definitions

$CPI_t^{Can\ Food}$	Canadian consumer price index food [h]
$CPI_t^{Can\ Fuel}$	Canadian consumer price index for fuel (energy)[h]
$CPI_t^{Can\ Fuel\ R}$	Canadian consumer price index (real) for fuel (energy) ($P_t^{Can\ Fuel\ R} = P_t^{Can\ Fuel} / PPI_t^{Can\ Fuel}$)
$EXCH_t$	Canadian-U.S. exchange rate (\$CDN/\$U.S.)[b]
INC_t^{US}	U.S. personal disposable income (billion \$U.S.)[b]
$INC_t^{US\ R}$	U.S. real per-capita personal disposable income ($INC_t^{US\ R} = INC_t^{US} / (PPI_t^{US\ IFF} \times POP_t^{US})$)
INV_t^{US}	U.S. beginning inventories of frozen halibut (blocks, fillets and steaks) (lbs) [d]
INV_{t-1}^{US}	U.S. ending inventories of frozen halibut (blocks, fillets and steaks) (lbs) [d]
LAN_t^{AK}	Landings of halibut in Alaska (lbs) [f]
LAN_t^{WA}	Landings of halibut in Washington (lbs) [f]
LAN_t^{US}	U.S. landings of Pacific halibut ($LAN_t^{AK} + LAN_t^{WA}$) (lbs) [f]
LAN_t^{BC}	Landings of halibut in British Columbia (lbs) [g]
$P_t^{AK\ Exv}$	Exvessel price of halibut landed in Alaska (\$/lb) [a]
$P_t^{AK\ Exv\ R}$	Exvessel price (real) of halibut landed in Alaska (\$/lb) [i]
$P_t^{BC\ Exv}$	Exvessel price of halibut landed in British Columbia (\$CDN/lb) [g]
$P_t^{BC\ Exv\ R}$	Exvessel price (real) of halibut landed in British Columbia ($P_t^{BC\ Exv\ R} = P_t^{BC\ Exv} / PPI_t^{CF}$)
$P_t^{BC\ Exp\ R}$	Price (real) of halibut exported to the U.S. from British Columbia [i]
P_t^{Import}	Import price of Canadian halibut in the U.S. (\$/lb) [e]
$P_t^{Import\ R}$	Import price (real) of Canadian halibut in the U.S. (\$/lb) [i]
$P_t^{US\ W}$	U.S. wholesale price of halibut (\$/lb) [c]
$P_{t-1}^{US\ W}$	U.S. lagged wholesale price of halibut (\$/lb) [c]
$P_t^{US\ R\ W}$	U.S. wholesale price (real) of halibut (\$/lb) [i]
POP_t^{US}	U.S. population (millions) [b]
$PPI_t^{US\ Meat}$	U.S. producer price index for meats, poultry, and fish [b]
$PPI_t^{US\ Meat\ R}$	U.S. producer price index (real) for meats, poultry, and fish ($PPI_t^{US\ Meat\ R} = PPI_t^{US\ Meat} / PPI_t^{US\ IFF}$)
$PPI_t^{US\ IFF}$	U.S. producer price index for intermediate food and feed [b]
$PPI_t^{US\ Fuel}$	U.S. producer price index for fuel products and power [b]
$PPI_t^{US\ Fuel\ R}$	U.S. producer price index (real) for fuel products and power ($PPI_t^{US\ Fuel\ R} = PPI_t^{US\ Fuel} / PPI_t^{US\ IFF}$)
QC_t^{US}	U.S. per-capita consumption of halibut from Alaska (lbs) [i].
QC_t^{BC}	U.S. per capita consumption of halibut imported from Canada (lbs) [i]
QS_t^{BC}	Canadian exports of Pacific halibut to the U.S. (lbs)[e]
$SEAS_t^{AK}$	Pacific halibut season length in area 3A (days) [f]
$SEAS_t^{BC}$	Pacific halibut season length in area 2B (days) [f]

Table 2. Market model variable sources

(a)	Alaska Commercial Entry Commission, computer printouts. Juneau, Alaska, 2003.
(b)	Economagic. http://www.economagic.com, 2003.
(c)	Alaska Department of Fish and Game. Division of Commercial Fisheries. Commercial Operators Annual Reports (COAR). Computer Printouts, 2003.
(d)	U.S. Department of Commerce. Various Issues. Frozen Fishery Statistics, various issues: U.S. cold storage holdings of fishery products. National Marine Fisheries Service, Silver Springs Maryland various issues and NOAA website http://www.st.nmfs.gov/st1/market_news/index.html.
(e)	National Marine Fisheries Service. Foreign Trade Division. Collected by the U.S. Department of Commerce. Various computer printouts and Web Site, http://www.st.nmfs.gov/st1/trade/index.html.
(f)	International Pacific Halibut Commission, various annual reports annual and web site, http://www.iphc.washington.edu/halcom/about.htm.
(g)	Canada Department of Fisheries and Oceans. Commercial Catch Statistics. Vancouver, British Columbia, various issues and website, http://www.dfo-mpo.gc.ca/communic/statistics/Historic/main_e.htm.
(h)	Government of Canada, Statistics Canada, CANSIM$, http://cansim2.statcan.ca/.
(i)	See market clearing identities.

Equations

The theoretical underpinnings of each of the six behavioral supply and demand equations follow. We present each equation with an explanation of why the equations were modeled in the way that they were. Expected parameter signs are indicated beneath each right-hand-side variable. Additional equation motivation will appear in the estimation section where appropriate.

Simultaneous Demand and Supply Equations

1) U.S. derived wholesale demand:

$$P_t^{US\,R\,W} = f_1\left(\underset{-}{QC_t^{US}}, \underset{-}{QC_t^{BC}}, \underset{+}{SEAS_t^{AK}}, \underset{+}{PPI_t^{US\,Meat\,R}}, \underset{-}{PPI_t^{US\,Fuel\,R}}, \underset{+}{INC_t^{US\,R}} \right)$$

The U.S. wholesale price is modeled as a derived inverse demand function for halibut consumed in the U.S. As the landings of Pacific halibut in the U.S. and British Columbia are set by the IPHC, based on biological sustainability considerations, the disappearance of Pacific halibut in the U.S. is largely a function of conditions external to the market. Virtually all of the Alaska landings of Pacific halibut are consumed in the U.S. (some annual differences are due to changes in inventory) as is a vast majority of the British Columbia landings. Therefore, it is largely the price of Pacific halibut that adjusts to landings to clear the U.S. market. The U.S. derived wholesale demand equation is hypothesized to be a function of both demand and supply factors that affect both the consumer demand and also the margins between retail and wholesale price.

The U.S. derived demand wholesale real price ($P_t^{US\,R\,W}$) is hypothesized to be a function of the estimated U.S. per-capita consumption of Alaska (and Washington) halibut (QC_t^{US}) the per-capita consumption imported British Columbia halibut (QC_t^{BC}) and the season length ($SEAS_t^{AK}$) as a proxy for increased fresh halibut supplied to the market and also other timing and quality advantages of longer halibut seasons. The Pacific halibut landed in British Columbia and Alaska are drawn from a single undifferentiated stock of fish. Because the vast majority of British Columbian landings are exported to the U.S., the British Columbia halibut per-capita import quantity into the U.S. is included as an endogenous variable in the same way as is Alaska halibut.

To capture the marketing advantages of elongated seasons associated with individual fishery quotas the season length (proxied by the season length of area 3A) was used in the derived wholesale demand equation. One of the largest revenue advantages of an individual fishery quota is that the season is slowed down allowing an increased amount of halibut to be sold throughout much of the year on the higher-priced fresh market. Another marketing advantage of a more relaxed fishery is that both the fishers and processors can more carefully handle the fish leading to a higher-quality product. Additionally, there is more time to search out the most lucrative markets. The empirical use of the season length as a demand shifter has been motivated theoretically and included in empirical studies (Lin et al., 1988; Cook and Copes, 1987; Homans, 1993; Casey et al., 1995; Herrmann, 1996 and 2000; and Knapp, 1997).

From 1984 to 1994 (pre-Alaska Halibut IFQ management) the percentage of Alaska halibut processed fresh was just 14.3 percent. During the first three years after the IFQ was in place the fresh halibut production was 33.9 percent and has risen to nearly 50 percent in the last four years (Figure 8).

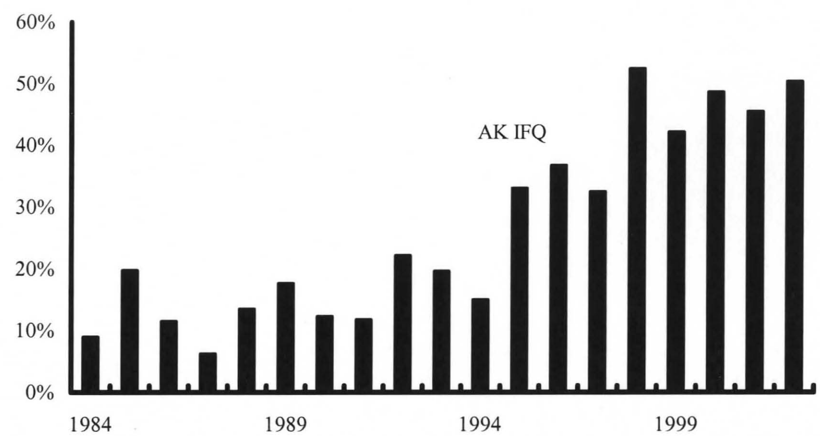


Figure 8. Percent of Alaska harvested Pacific halibut sold as fresh processed product (1984 to 2002).

The real producer price index for meat was included as a substitute for halibut ($PPI_t^{US\,Meat\,R}$). Meat was theorized to be a good aggregate substitute product as "there is no overwhelming statistical evidence in the literature that any particular fish species or class of fish species might substitute for halibut. As halibut is one of the least 'fish'-tasting fish, it is likely that possible market substitutes for it range well outside the normal fish products" (Herrmann 2000). The income effect is proxied by $INC_t^{US\,R}$. The deflated price index for fuel ($PPI_t^{US\,Fuel\,R}$) is included as a general proxy for the real cost transporting the processed halibut to the consumer. As retailers anticipate higher (lower) transportation costs, the quantity they demand from wholesalers will decrease (increase). Thus a decrease (increase) in quantity demanded at the retail level will decrease (increase) price at the wholesale level..

2) U.S. inventory demand

$$INV_t^{US} = f_2\left(\underset{+}{LAN_t^{US}}, \underset{-}{P_t^{US\,W}}, \underset{+}{P_{t-1}^{US\,W}}, \underset{-}{SEAS_t^{AK}} \right)$$

The demand for U.S. inventory of Pacific halibut (INV_t^{US}) is hypothesized to be a function of the current landings (LAN_t^{US}), current and expected prices ($P_t^{US\,W}$ and $P_{t-1}^{US\,W}$) and season length ($SEAS_t^{AK}$). This equation was specified to incorporate both holding inventories for a buffer against running out of supplies as well as for speculative reasons (for a more detailed discussion of the theory see Herrmann 1990). Modeling current inventories as a function of current landings captures the fact that inventories are held because of the timing of transactions and as a buffer against running short of supply as halibut is moved through the "pipeline". Prices reflect the speculative component of inventory demand; inventory will be held if it is expected that future prices will rise faster than inflation and the cost of storage. It can be shown that using either a geometric mean or adaptive price expectations, that the sign on the lagged price will be positive and the sign on the current price will almost certainly be negative. The lagged price (under either price expectation formations) is a portion of price expectation. If prices are expected to increase (decrease), more (less) inventory will be held. The current price has two effects on ending inventories. The first is that as current price rises the motivation is to sell at the higher price, and vice versa. The mitigating motivation is that a current price increase is also a factor in increasing price expectations for the future which would have the opposite affect on inventory demand. However, it is almost certain that the motivation to sell at the certain high current price outweighs the desire to increase inventory holdings for future sales (see Herrmann 1990) and this variable is theorized to be negatively signed.

Finally, as discussed in the last section, the longer the season length the more fresh halibut will be processed in relation to frozen halibut. This will mean that there will be less halibut to hold in inventory as fresh halibut cannot be held more than a couple of weeks. Additionally, as the largest portion of the season length increases are from the IFQ, after the IFQ program was implemented, the harvest and marketing of halibut could be chosen to coincide more favorably to better market conditions lessening the need to hold inventory (Figure 9).

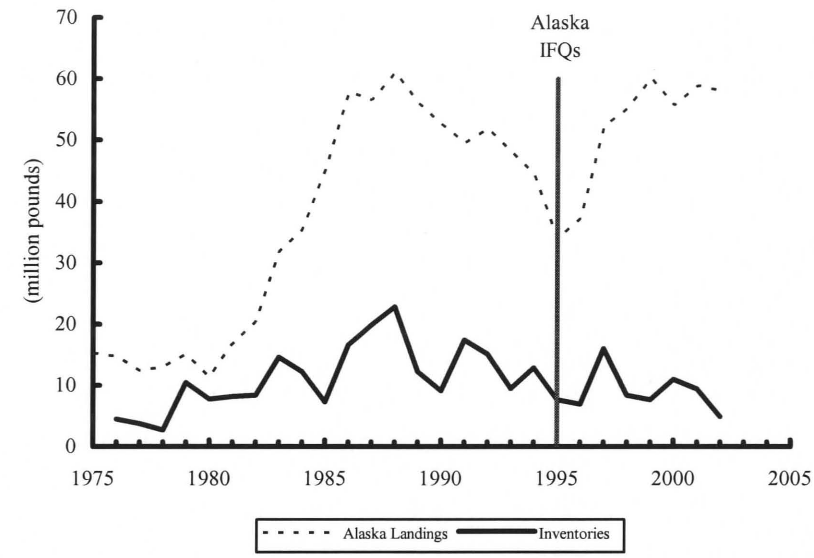


Figure 9. Alaska landings and U.S. inventory levels of Pacific halibut (1976 to 2002).

Figure 9 shows the relationship between landings and inventory levels. The relationship tracks closely until approximately three years after Alaska went to the IFQ program and the fishing industry was able to alter its production and marketing strategies.

3) British Columbia export allocation:

$$QS_t^{BC} = f_3\left(\underset{+}{LAN_t^{BC}}, \underset{+}{P_t^{Import\,R}}\right)$$

The bulk of British Columbian landings of Pacific halibut are exported to the U.S. (QS_t^{BC}). The U.S. is the world's largest consumer of Pacific halibut; the U.S. imported 50 to 80 percent of British Columbia's annual landings of halibut in the pre-IVQ period and has imported close to 90 percent in the post-IVQ period. Thus, a major factor in allocation to the U.S. market is the exogenously determined (by the IPHC) landings (LAN_t^{BC}). A small amount of supply is consumed domestically (virtually no other exports) so the allocation to the U.S. is partly determined by the real export price ($P_t^{Import\,R}$).

Ideally, there could be other variables included in this equation such as cost variables and a domestic market price, but a reliable domestic market price series could not be constructed and energy cost proxies were not significant. The fact that energy cost variables were not statistically significant is not surprising since major export markets in the U.S. are closer to British Columbia than are many Canadian markets.

4) British Columbia Export price linkage:

$$P_t^{Import\,R} = f_4\left(\underset{+}{P_t^{US\,W}}, \underset{+}{SEAS_t^{BC}}, \underset{-}{SEAS_t^{AK}}\right)$$

The U.S. market for Pacific halibut is virtually the world market for Pacific halibut; it is the market where the Pacific halibut price is established. In the U.S. derived wholesale demand equation the U.S. wholesale price of Pacific halibut was modeled as the function of own quantity, the quantities from British Columbia and other demand shifters. The consumer price of Pacific halibut will largely be the result of an equilibrium price needed to clear the domestic market of the Alaska and British Columbia harvests. The reduced form equation for the U.S. wholesale price is then modeled as being derived from the consumer price. Likewise, the import price for British Columbia halibut ($P_t^{Import\,R}$) is linked to the U.S. wholesale price ($P_t^{US\,W}$) which is largely established by market forces to clear the Alaskan halibut harvest. With the products essentially identical, with only one significant market, clearly the influence of the "law of one price" is evident (see Figure 10).

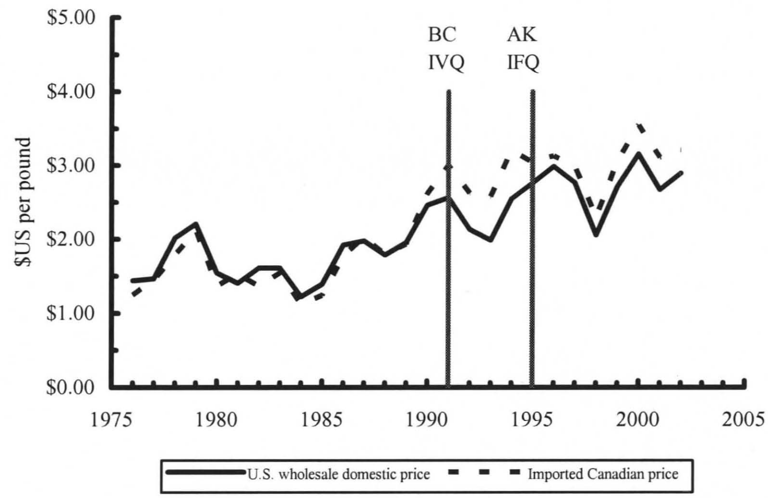


Figure 10. The U.S. wholesale price of Alaskan production of Pacific halibut and the U.S. import price of Pacific halibut from British Columbia for 1976 through 2002 ($/lb).

From 1976 to 1990 the correlation between the U.S. wholesale price for Alaskan halibut and the imported price of British Columbian halibut is nearly perfect ($r = 0.96$). Starting in 1991, when the Canadian IVQ program for Pacific halibut went into effect, the imported price of British Columbia halibut increased in relation to the wholesale price of domestic halibut ($SEAS_t^{BC}$). This separation lessened a bit beginning in 1995 when the Alaska IFQ program was implemented ($SEAS_t^{AK}$). Nevertheless, it is clear that the British Columbia price is linked to the dominant domestic U.S. wholesale price (which is simultaneously influenced by the import of Canadian Pacific halibut) with differences being due to periods that the season lengths were altered because of the two individual transferable quota programs. In other words, importers were willing to pay for imports of British Columbia halibut the amount that they would need to pay the Alaska processors with differences arising after the British Columbia first went to the IVQ program and improved the export product in relation to the Alaska product. These differences diminished after the Alaska IFQ program went into effect.

5) Alaska derived exvessel demand

$$P_t^{AK\,Exv\,R} = f_5\left(\underset{+}{P_t^{US\,R\,W}}, \underset{-}{LAN_t^{AK}}, \underset{-}{PPI_t^{US\,Fuel\,R}}\right)$$

The derived exvessel inverse demand curve was formulated with the real exvessel price of Pacific halibut landed in Alaska ($P_t^{AK\,Exv\,R}$) being determined by the real wholesale price ($P_t^{US\,R\,W}$), the landings of Pacific halibut in Alaska (LAN_t^{AK}), and the real producers price index for fuel ($PPI_t^{US\,Fuel\,R}$). The exvessel price of Alaskan halibut can be characterized as a mark-down of the wholesale price (see for example, Homans 1993). The correlation coefficient between these two prices, for the modeled time period, is 0.94 (Figure 11).

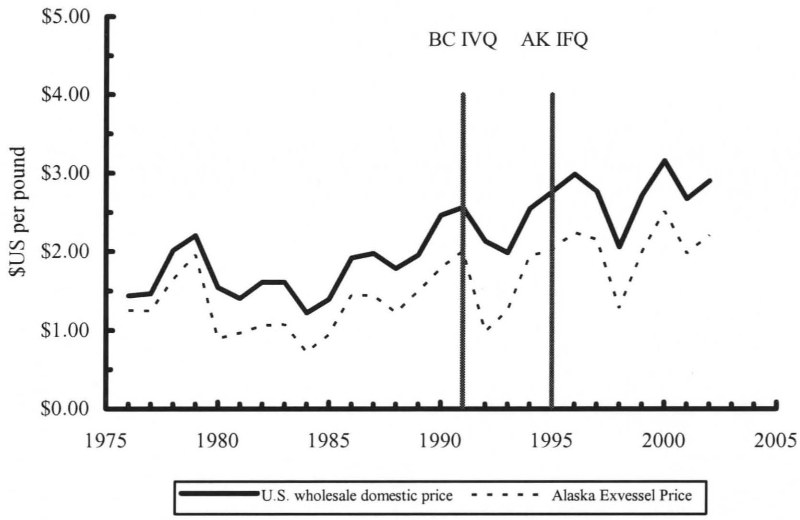


Figure 11. The U.S. wholesale price of Alaskan production of Pacific halibut and Alaskan exvessel price for Pacific halibut landings from 1976 to 2002 ($/lb.).

A basic question is whether the exvessel-wholesale price relationship was altered after the Alaska halibut fishery was converted to IFQ-based management. Several variables were used to test whether the relationship between exvessel and wholesale price was altered after 1995. Matulich and Clark (2003) suggest that pre-existing processors were harmed when IFQs were allocated free of charge to harvesters because the IFQs provided fishermen with increased market power that enabled them to search for the best deal over an elongated season. This matter will be explored in the section simulating IFQs and price effects (page 43). For the moment, it is sufficient to examine whether the relationship between reported exvessel and wholesale prices changed subsequent to the implementation of IFQs. The correlation between the wholesale and exvessel price from 1976 to 2002 is 0.94. Alaskan season length ($SEAS_t^{AK}$) was included in the initial specification of equation 5 to account for a possible structural break between wholesale and exvessel price (see the estimated equation on page 31), however, the evidence for a structural break was not statistically significant.

Alaskan landings were also included as an explanatory variable. Although exvessel price may be principally determined by the wholesale price, the bargaining position of the fishermen and processors can be expected to vary depending on the volume of the harvest. The bargaining position of the processors will weaken in years with low harvests and strengthen in years with large harvests. The real price of fuel was included to proxy the increased processor costs. As processor's costs rise the exvessel prices that they are willing to pay decrease.

6) British Columbia derived exvessel demand

$$P_t^{BC\ Exv\ R} = f_6\left(\underset{+}{P_t^{Import\ R}}, \underset{-}{CPI_t^{Can\ Fuel\ R}}, \underset{-}{SEAS_t^{AK}} \right)$$

The derived exvessel inverse demand curve for British Columbia halibut was formulated in the same way as the derived demand for Alaskan halibut. The real exvessel price of British Columbian halibut ($P_t^{BC\ Exv\ R}$) is modeled as a derivative of the real export price ($P_t^{Import\ R}$), the real consumers price index for fuel ($CPI_t^{Can\ Fuel\ R}$) and the length of the Alaska halibut fishery ($SEAS_t^{AK}$). British Columbian landings were also included in the initial model specification, but were dropped from the final model because their effect was not statistically significant.

In the same way that the exvessel price of Pacific halibut landed in Alaska is thought to be marked down from the U.S. wholesale price, the exvessel price of halibut landed in British Columbia is thought to be marked down from the U.S. export price. Although we would not expect the correlation between British Columbian exvessel and export prices to be as strong as the correlation between the Alaskan exvessel and wholesale prices, the correlation coefficient between British Columbian exvessel prices and export prices has been strong over the last twenty years (*r* = *0.80*) (see Figure 12).

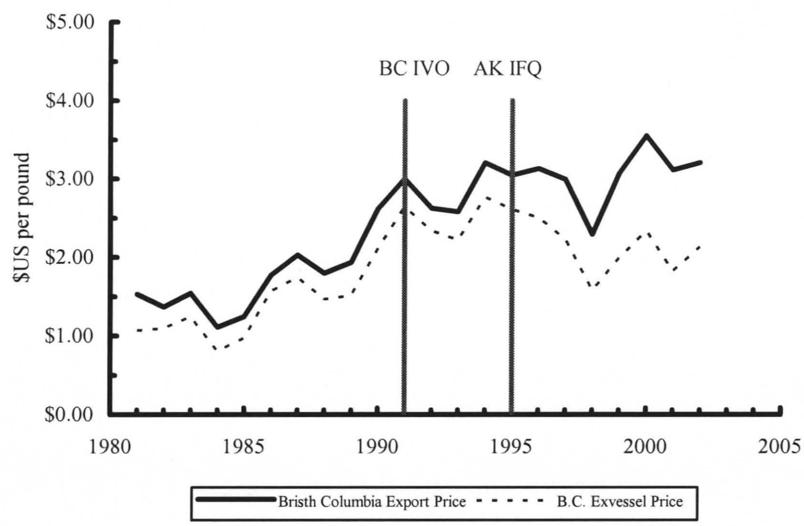


Figure 12. The British Columbia export price of Pacific halibut to the U.S. and the British Columbia exvessel price of Pacific halibut from 1981 to 2002 ($/lb.).

The length of the Alaskan season was included to test whether British Columbian fishermen lost some of their bargaining power once the Alaskan fishery converted to IFQs and the Alaskan season lengthened. The length of the British Columbian season was also included in the initial model specification but deleted from the final model because the estimated influence of the season length in British Columbia was not statistically significant. The real price of fuel was included to reflect the cost of transportation from British Columbian fishing grounds to U.S. Markets. The recorded U.S. import price is the price paid at U.S. ports. Therefore, it would be expected that as the cost of transportation increases (decreases) the wedge between the U.S. import price and the British Columbian exvessel price will increase (decrease).

Market Model Estimation

The aggregate model used annual data over the sample period of 1976 to 2002[3]. The equations were estimated using the three-stage least squares (3SLS), a full-information systems method in that uses a variance-covariance matrix to adjust coefficient estimates across all of the structural equations. Coefficient estimates derived using 3SLS are asymptotically more efficient than coefficient estimates derived using two-stage least squares (2SLS). The one drawback of the 3SLS approach is that if an equation is mispecified (yielding biased estimates of the parameters), the misspecification will affect the entire system of equations, not just the mispecified equation.

The estimated coefficients and goodness of fit statistics for each equation are reported in the following sections. Asymptotic t-values and corresponding one-tailed p-values are reported along with the parameter estimates. The p-values are estimates of the probability of a type I error on a one-sided null hypothesis that the estimated parameter is zero.

All reported mean-level elasticities are of the generic form $(\partial y/\partial x)(\bar{x}/\bar{y})$. Sometimes these are interpreted, or referred to, as "elasticities" and sometimes they are referred to as "flexibilities" such as the own-price flexibility of demand for inverse (price dependent) demand equations. The Durbin-Watson statistic (DW) was used to detect first-order serial correlation, a frequent indicator of model mispecification. In no case was the magnitude of the DW statistic sufficient to lead to rejection of the null hypothesis of no first-order serial correlation can be rejected ($\alpha = 0.05$) (Greene 1993).

---

[3] The only exception to the time series being carried out to 2002 was for the quantity of Pacific halibut imported to the U.S. from British Columbia The 2002 estimate of these exports was not considered reliable and therefore was not used. Estimation and forecasting are carried out in the presence of missing values by forecasting the missing values with the current set of parameter estimates (SAS 2004).

Bloc 1: Simultaneous Demand and Supply Equations

Equation 1. U.S. derived wholesale demand.
Dependent variable: U.S. real wholesale price of Pacific halibut.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
U.S. per-capita consumption	-0.036	-4.24	0.0002	-0.29
U.S. per-capita Canada imports	-0.121	-2.09	0.0253	-0.17
Alaska season length	$8.11x10^{-6}$	1.52	0.0726	0.03
Real U.S. price meat	0.036	5.08	<.0001	1.81
Real U.S. price fuel	-0.014	-6.31	<.0001	-0.53
Real U.S. per-capita income	87,716.1	3.87	0.0050	0.65
Constant	-0.009	-1.56		

$R^2 = 0.83$, $DW = 2.18$

As discussed previously, the supply of halibut sold on the domestic market is relatively inelastic and is principally affected by an exogenously determined (by the IPHC) supply with minor adjustments for changes in end-of-year inventories and very minor amounts of exports. Because of this, we have modeled the U.S. Pacific halibut wholesale price formation to include those explanatory factors that affect the price level at which the wholesale market clears. All variables were found to be a statistically significant at a significance level of 3 percent or less, with the exception of the Alaskan season length variable which was statistically significant at the $\alpha = 0.08$ level using a one-sided hypothesis test. The estimated DW statistic is not significantly different from 2.0 indicating an absence of first-order serial correlation, a condition that can be caused by model misspecification. The squared correlation coefficient, between the actual and predicted wholesale price, was 0.83 indicating that 83 percent of the observed variation in wholesale prices can be explained by the observed variation in the explanatory variables. Using Alaskan and Washington landings (adjusted for changes in inventory) as an approximation for domestic consumption, the mean level own-price flexibility (1976-2002) is -0.29, all else equal. Changes are smaller for the U.S. real wholesale price in regard to the mean-level imports from the smaller British Columbian landings of Pacific halibut with the cross-price flexibility being -0.17. A one-percent increase in season length, on average, increased wholesale price by 0.03 percent.

Our decision to include the real producer price index of meat (meat, poultry, and fish) as a substitute good for halibut is supported by the strong statistical relationship. It is not surprising that the U.S. consumer, in choosing to buy or not buy halibut, will make a decision partly based on the price of other meat products (both fish and non-fish). The price flexibility indicates that over this time period a one-percent increase in the U.S. price of meat was associated with a 1.81 percent increase in the wholesale price of halibut. The fact that this is a rather large number is not surprising because the relative consumption of other meat sold in the U.S. far surpasses the consumption of halibut and small changes in the price of meat can lead to relatively large changes in meat consumption relative to the total available amount of halibut on the U.S. market. The income level in the U.S., as measured by U.S. disposable personal income, is also a significant explanatory variable. At the mean-level, a one-percent increase (decrease) in disposable personal income is expected to increase (decrease) the wholesale price by 0.65 percent.

The variable used as a proxy for the cost (real price) of transporting processed halibut to the consumer was the deflated price index for fuel. As the cost of transporting the processed halibut from the processor to the consumer increases the amount that retailers are willing to pay for halibut decreases, decreasing the wholesale price (FOB). This decrease in wholesale price is exacerbated if the wholesaler, with little other options than the domestic market, seeks to retain the original exported quantity of halibut. At the mean-level, a one-percent increase in fuel costs leads to a 0.53 percent decrease in the purchase price of halibut. If retailers anticipate higher transportation costs, the quantity they demand from wholesalers will decrease. Thus a decrease in quantity demanded at the retail level will decrease price at the wholesale level. This will be even more pronounced if the wholesalers, with few other options, needed to dispose of most of their current production in the domestic market. Thus, they would need to lower the wholesale price even more to sell all their halibut at a reduced retail derived demand.

Equation 2. U.S. inventory equation.
Dependent variable: U.S. Pacific halibut ending inventories.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
U.S. landings	0.223	6.82	<.0001	0.83
U.S. wholesale price	-7.78×10^8	-3.27	0.0018	-1.40
U.S. lagged wholesale price	6.6×10^8	3.03	0.0031	1.17
Alaska season length	-22031.9	-3.12	0.0025	-0.16
Constant	5,515,641	1.35		

$R^2 = 0.45$, $DW = 2.13$

All of the estimated slope coefficients in the inventory equation were statistically significant at the one-percent significance level. However, the model fit (R^2) is rather low, indicating that only 45 percent of the variation in ending inventory levels can be explained by observed variations in the explanatory variables. This is not unexpected as the ending inventory levels are somewhat arbitrary, being measured at the end of the calendar year. For much of the modeled time period, the halibut season was limited to just a few days in the middle of the summer. If the model had been based monthly data it may have been easier to estimate a model with a better fit. Additionally, other variables, such as interest rates and fuel costs, were initially included in the model as proxies for the cost of holding inventory, but were not found to be statistically significant.

The mean-level elasticity on the U.S. inventory equation indicates that a one-percent increase (decrease) in landings will lead to a 0.83 percent increase (decrease) in ending inventory levels, all else constant. An increase (decrease) in the current wholesale price will decrease (increase) inventories by an estimated 1.40 percent at the mean. Increases (decreases) in the lagged prices reflect changes in price expectations and were found to increase (decrease) inventory levels by

1.17 percent at the mean. A one-percent increase in season length decreases inventory levels by 0.16 percent all else equal.

Equation 3. British Columbia export supply equation.
Dependent variable: British Columbia halibut exports to the U.S.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
British Columbia landings	0.587	3.56	0.0009	0.70
British Columbia real export price	$2.21x10^8$	6.44	<.0001	0.92
Constant	-4,613,948	-3.43		

$R^2 = 0.80$, $DW = 1.67$

The British Columbia export supply is modeled as a function of British Columbian landings of Pacific halibut and the real export price of Pacific halibut. Cost variables, such as fuel, were included in the initial model specification but omitted from the final model because they were not statistically significant. This is most likely due to the fact that both end-export and Canadian domestic markets are of similar distances from the landed halibut with U.S. export markets sometimes being closer and sometimes farther away than Canadian domestic markets. The equation has a very good fit ($R^2 = 0.80$) considering it only has two explanatory variables. The coefficients of both explanatory variables are statistically significant at the one-percent significance level.

The mean-level elasticities indicate that on average (all else equal) a one-percent increase (decrease) in landings would increase (decrease) exports to the U.S. by 0.70 percent. A one-percent increase (decrease) in real price would increase (decrease) exports by 0.92 percent.

Equation 4. Import price linkage for British Columbia halibut.
Dependent variable: British Columbia real export price to the U.S.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
U.S. real wholesale price	1.174	14.37	<.0001	1.12
British Columbia season length	0.000024	8.48	<.0001	0.14
Alaska season length	-0.00001	-4.08	0.0003	-0.04
Constant	-0.004	-2.99		

$R^2=0.95$, $DW = 1.69$

The British Columbia real price for halibut exported to the U.S. is modeled as a function of the U.S. real wholesale price for domestic halibut, and the lengths of the British Columbian and Alaskan halibut seasons. The equation has an excellent fit ($R^2 = 0.95$). The estimated coefficients on the explanatory variables are all statistically significant at the one-percent level. The mean-level elasticities indicate that on average, a one-percent increase in the U.S. real wholesale domestic price of Pacific halibut will lead to a 1.12 percent increase in the price of imported British Columbia halibut. That is, the British Columbian price is correlated with the U.S. wholesale price, with differences being attributable to differences in season lengths. The largest differences in season lengths occurred between 1991 and 1994 when British Columbia prosecuted their Pacific halibut fishery under IVQs and Alaska remained derby-style regulated open-access fishery. During this time, importers were willing to pay a premium for halibut from British Columbia. In general, the differences in season length capture the relative differences in prices due to the differences in the fresh frozen market, quality and marketing opportunities. A one-percent increase in the length of the British Columbia halibut season was estimated to increase the U.S. import price by 0.14 percent, all else equal. Likewise, an increase in the length of the Alaska halibut season was estimated to decrease the import price by 0.04 percent.

It is clear that longer seasons benefit both Canadian and Alaskan fisheries. Therefore, we would expect that the elasticity of import price to season length would be relatively higher for the British Columbia season length than the Alaska season length. If both season lengths increase, prices should rise due to a more desired product being place on the market. However, a portion of the price advantage that British Columbia enjoyed as a result of the substantial difference in season lengths between introduction of the Canadian IVQ program and implementation of the Alaska IFQ program evaporated when Alaska adopted IFQs (see Herrmann 2000).

Equation 5. Alaska derived exvessel demand.
Dependent variable: Alaska real exvessel price for Pacific halibut.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
U.S. real wholesale price	0.901	12.29	<.0001	1.23
Alaska landings	$-3.09\text{x}10^{-13}$	-2.03	0.0273	-0.09
Real U.S. price fuel	-0.003	-1.42	0.0842	-0.15
Constant	0.00008	0.04		

$R^2 = 0.90$, $DW = 2.01$

The exvessel price for Alaskan landings of Pacific halibut was modeled as a function of the U.S. real wholesale price of Pacific halibut, Alaskan landings, and the real price index of fuel. The equation fits well with an R^2 equal to *0.90*. All variables are statistically significant at $\alpha = 0.09$ or less. The mean-level elasticities indicate that, on average, a one-percent increase (decrease) in the real wholesale price will increase (decrease) the Alaskan exvessel price by 1.23 percent, all else equal. The direct movements are somewhat tempered by changes in Pacific halibut landings. A one-percent increase (decrease) in landings will decrease (increase) the exvessel price by 0.09 percent, all else equal.

Recall that the real price of fuel was included to proxy the increased processor costs. As processor's costs rise, the price that they are willing-to-pay for halibut deliveries decreases. A one-percent increase (decrease) in the real price of fuel will decrease (increase) the exvessel price by 0.15 percent.

Equation 6. British Columbia derived exvessel demand.
Dependent variable: British Columbia real exvessel price for Pacific halibut.

Variable	Estimated coefficient	T-ratio	One-sided p-value	Mean-level elasticity
Natural logarithm of British Columbia real export price	0.030	12.31	<.0001	1.15
Natural logarithm of Canadian real energy prices	-0.017	-8.40	<.0001	-0.65
Alaska season length	-0.00002	-2.19	0.019	-0.06
Constant	0.133	14.77		

$R^2 = 0.88$, $DW = 1.73$

The exvessel price for Pacific halibut landed in British Columbia was modeled as a function of the British Columbian real export price of Pacific halibut to the U.S., the real price index of energy, and the Alaskan season length. The equation was estimated in the linear-log form because the equation estimated in the linear form exhibited some serial correlation indicating that the functional form may have been incorrectly specified. As with the Alaskan exvessel price equation the British Columbian exvessel price equation has a good fit ($R^2 = 0.88$). All of the estimated slope coefficients are statistically significant at the 2 percent significance level. The mean-level elasticities indicate that, on average, a one-percent increase (decrease) in the real export price of British Columbian halibut will result in a 1.15 percent increase (decrease) in British Columbian exvessel prices.

The real price of fuel was included to represent the cost of transportation from British Columbian fishing grounds to U.S. markets. The estimated coefficients indicate that a one-percent increase (decrease) in the real price of energy will lead to a 0.65 percent decrease (increase) in British Columbian exvessel prices. As the Alaskan season lengthens a one-percent increase in season length decreases the British Columbian exvessel price by 0.06 percent, holding all other variables including the export price constant. This indicates that British Columbian fishermen lost some of their advantage in export prices when Alaska implemented IFQs.

Market Model Historical Simulations

Historical simulation goodness-of-fit statistics often provide a better test of the predictive accuracy of an equation system than is provided by the residuals for individual equations because separately evaluating the individual equations does not provide information on how they interact as a system. Individual equation goodness-of-fit statistics are used to incorporate inter- and intra-temporal linkages, which exist within the market response model. These interdependencies are explicitly incorporated into the dynamic model simulation, where each of the equations in the market response model is solved for its reduced form. Thus, model simulation provides a more robust measure of actual model performance (Herrmann 1996). Model simulations were conducted using the Newton algorithm in SAS (SAS 2004). The historic dynamic simulation was performed on the system over the period from 1976 to 2002. The goodness-of-fit statistics are reported in Table 3.

Table 3. Historical simulations.

Variable	R	MA%E	RMS%E	Theil-U Decomposition UM	UR	UD	U1
U.S. wholesale price ($P_t^{US\,W}$)	0.93	8.1	10.4	0.00	0.00	1.00	0.094
U.S. inventory (INV_t^{US})	0.76	28.3	38.4	0.00	0.02	0.98	0.272
British Columbian exports to the U.S.(QS_t^{BC})	0.93	25.5	44.9	0.00	0.01	0.99	0.180
British Columbian export price to the U.S. (P_t^{Import})	0.96	8.3	10.6	0.00	0.01	0.99	0.092
Alaskan exvessel price ($P_t^{AK\,Exv}$)	0.82	15.7	23.2	0.00	0.00	1.00	0.173
British Columbian exvessel price ($P_t^{BC\,Exv}$)	0.90	12.6	17.1	0.01	0.02	0.97	0.135

Where *r* is the estimated correlation between the observed and predicted values; *MA%E* is the mean percent error; *RMS%E* is the root mean percentage error; *UM* is the bias component of the Thiel U decomposition, an indication of systematic error, *UR* is the variance component of the Thiel U decomposition, an indication of unsystematic error; *UD* is the covariance component of the Theil-U decomposition; and *U1* measures the predictive ability of a forecast. By construction, $UM+UR+UD=1$ and it is desirable for *UD* to be close to 1. The Theil inequality statistic *U1* is equal to 0 for a perfect forecast, 1 if the model forecast is no better than a naïve forecast (a forecast based on the previous time period's value), and greater than 1 if the model forecasts are worse than the naïve forecast. These forecast measures are further described in Appendix A.

The goodness-of-fit statistics indicate that the model generally performed well in estimating actual conditions. The correlation coefficients ranged between 0.76 and 0.96. The mean absolute errors ranged between 8.1 percent and 28.3 percent, and the root-mean-squared errors ranged between, and 10.4 percent and 44.9 percent. The Theil-U statistics indicate that the errors are not systematic. The Theil inequality coefficient (*U1*) indicates that the predictive accuracy of the model far exceeds the predictive accuracy of a "no change" forecast.

Figures 13 to 18 provide a representation of the actual and predicted values of each of the endogenous variables within the system. In most cases, the predicted quantities and prices closely track the historically observed prices and quantities. The one exception is, not surprisingly, the inventory equation.

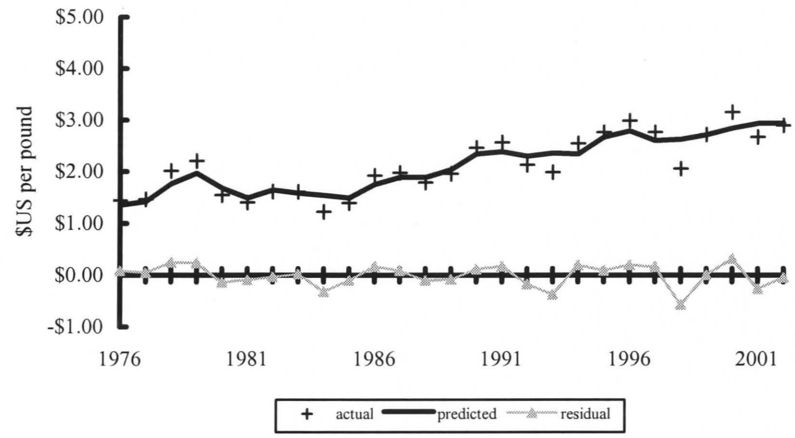


Figure 13. Actual and predicted U.S. wholesale price ($/lb) for Pacific halibut, 1976 to 2002.

The large residual in 1998 may reflect a drawdown of inventories accumulated in 1997 during a period of volatility in the determination of IPHC quotas.

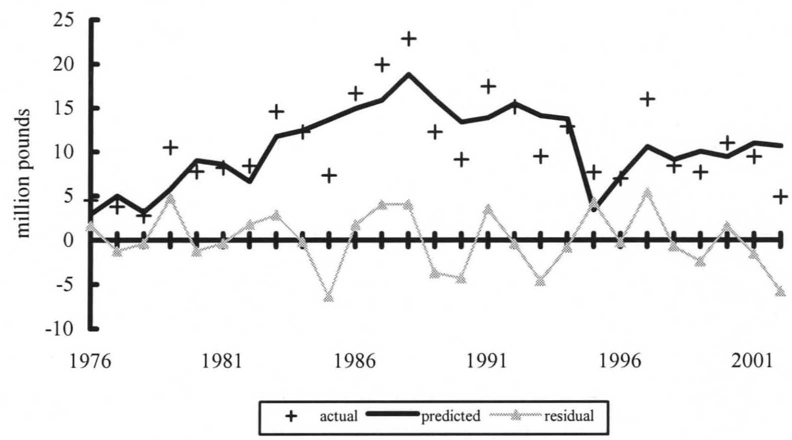


Figure 14. Actual and predicted U.S. inventories (million pounds) of Pacific halibut, 1976 to 2002.

Again, the large residual in 1997 may reflect an accumulation of inventories in response to the marked increase in the 1997 IPHC quota relative to the 1995 and 1996 quotas.

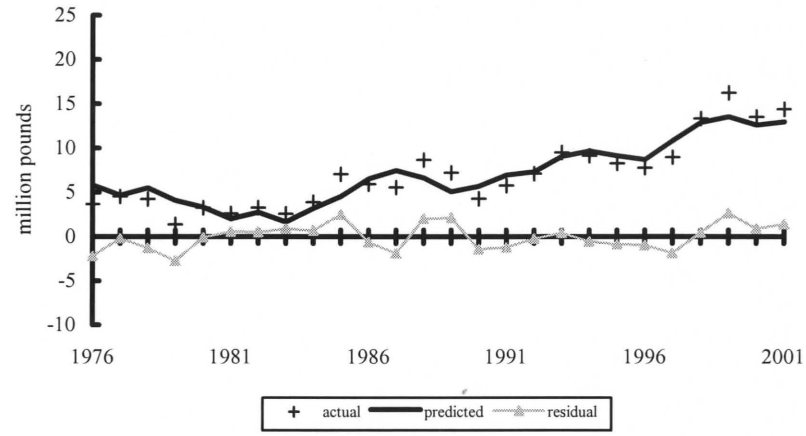


Figure 15. Actual and predicted U.S. imports (million pounds) of Pacific halibut from British Columbia, 1976 to 2001.

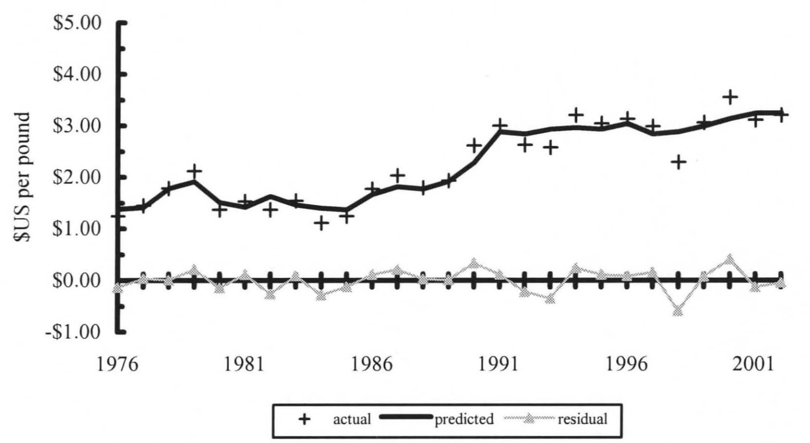


Figure 16. Actual and predicted U.S. import prices ($/lb) for Pacific halibut from British Columbia, 1976 to 2002.

Again, the large residual in 1998 could be attributed to a market correction for the accumulation of inventories in 1997 that resulted from the rapid increase in IPHC quotas between 1996 and 1997.

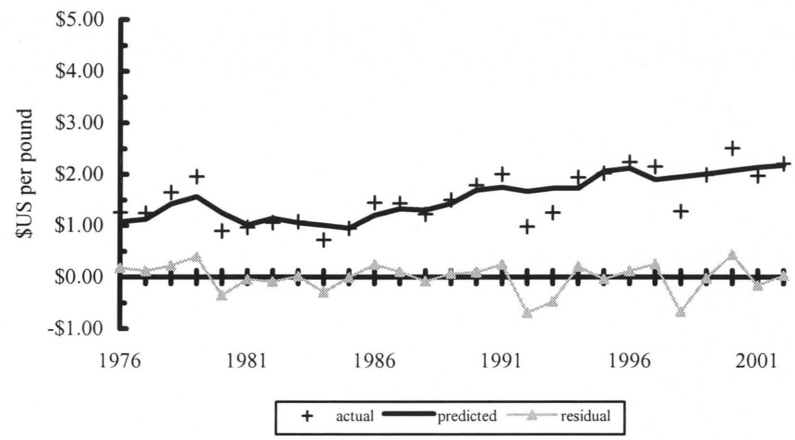


Figure 17. Actual and predicted exvessel price ($/lb) of Pacific halibut landed in Alaska, 1976 to 2002.

Here, the large residual in 1992 could reflect uncertainties in the market for Alaskan halibut as the market adjusted to changes in the supply of halibut from British Columbia under the newly implemented IVQ program. The large residual in 1998 can be attributed to a market correction for the accumulation of inventories in 1997 that resulted from the rapid increase in IPHC quotas between 1996 and 1997.

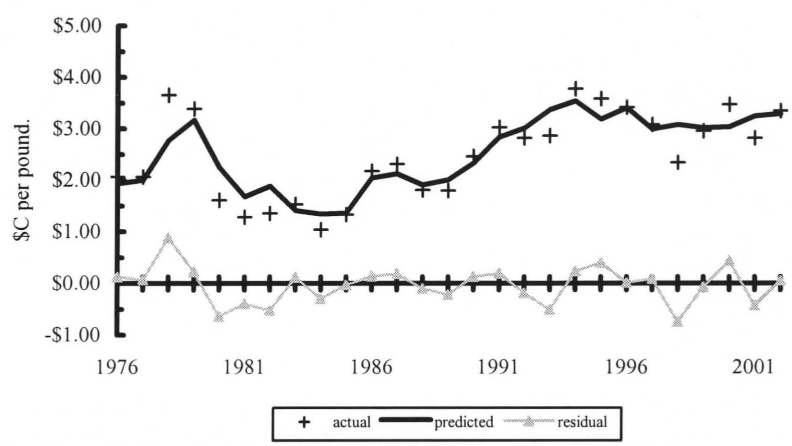


Figure 18. Actual and predicted exvessel price ($CDN/lb) of Pacific halibut landed in British Columbia, 1976 to 2002.

The dissipation of inventories accumulated in 1997 also depressed British Columbian exvessel prices in 1998 to a greater degree than the model was able to predict.

Confidence Intervals

The simulations reported above are point estimates. While point estimates are informative, it is useful to examine the confidence intervals surrounding these estimates. A Monte Carlo simulation method (SAS 2004) was used to estimate the confidence intervals for this system of equations.

Monte Carlo Simulations

Draws from a multivariate normal distribution are made on the estimated covariance matrix of the error terms (the residuals computed from the parameter estimates). These are then used to perturb the covariance matrix of the parameter estimates. The new parameter estimates are then used in dynamic simulations using the same Newton Algorithm used in the historical simulations. The means of the estimated endogenous variables from 1000 draws as well as the associated 5th and 95th percentiles are calculated to give a 90% confidence interval. The means and 5th and 95th percentiles for Pacific halibut prices are presented in Figure 19 through Figure 22.

The means and 5th and 95th percentiles for the U.S. wholesale price of Pacific halibut are shown in Figure 19:

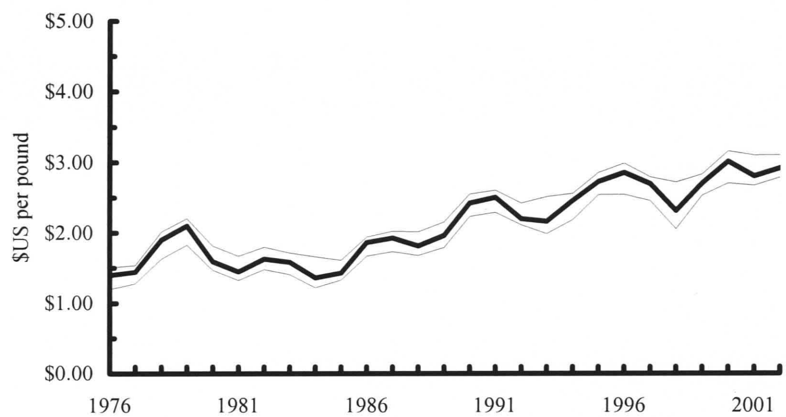


Figure 19. Simulated U.S. wholesale price ($/lb) for Pacific halibut with 90% confidence intervals, 1976-2002.

The actual U.S. wholesale mean price of Pacific halibut from 1976-2002 was $2.12 per pound with the simulated mean of $2.12 per pound. The 90% mean confidence interval is ($1.93 to $2.29).

The means and 5th and 95th percentiles for the U.S. import price of British Columbian halibut are shown in Figure 20.

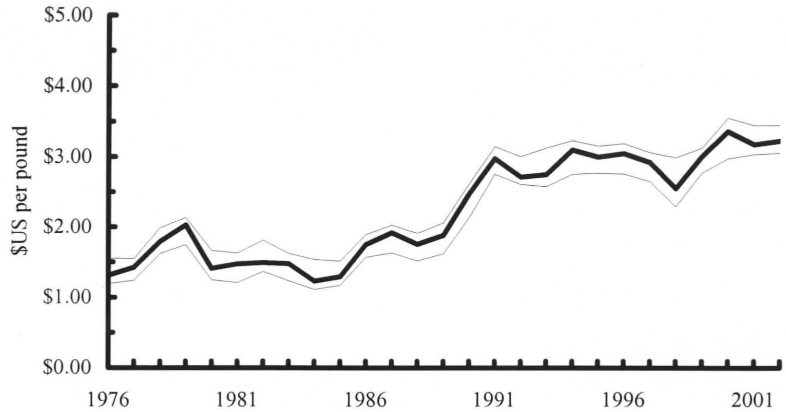


Figure 20. Simulated U.S. import price ($/lb) of Pacific halibut from British Columbia with 90% confidence intervals, 1976 to 2002.

The actual U.S. import price of British Columbian halibut from 1976-2002 was $2.24 per pound with the simulated mean of $2.25 per pound. The 90% mean confidence interval is ($2.02 to $2.46).

The means and 5^{th} and 95^{th} percentiles for the Alaskan exvessel price of Pacific halibut are shown in Figure 21.

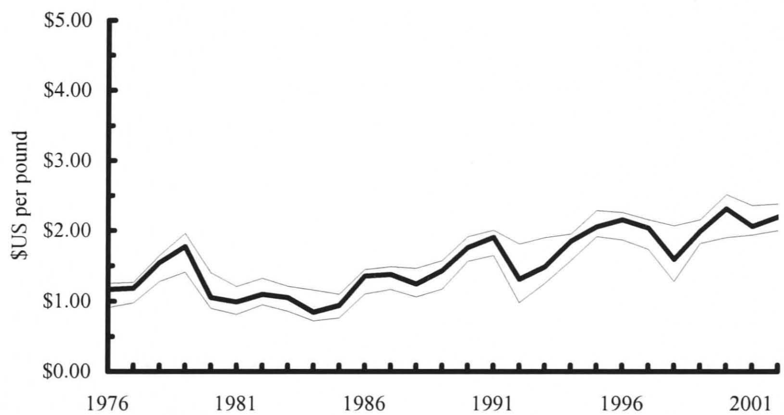


Figure 21. Simulated exvessel price ($/lb) and 90% confidence intervals for Pacific halibut landed in Alaska, 1976-2002.

The average exvessel price of Pacific halibut landed in Alaska from 1976-2002 was $1.55 per pound with the simulated mean of $1.55 per pound. The 90% mean confidence interval is ($1.31 to $1.76).

The means and 5^{th} and 95^{th} percentiles for the British Columbian exvessel price of Pacific halibut are shown in Figure 22.

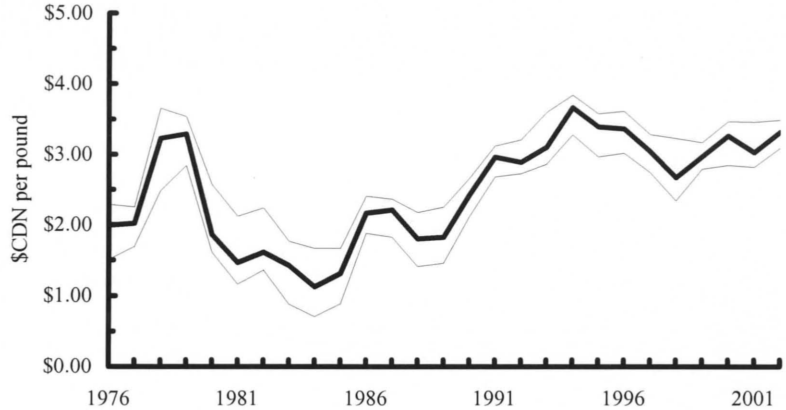


Figure 22. Simulated exvessel price ($CDN/lb) and 90% confidence intervals for Pacific halibut landed in British Columbia, 1976 to 2001.

The average exvessel price of Pacific halibut landed in British Columbia from 1976-2002 was $CDN2.50 per pound with a simulated mean of $CDN2.50 per pound. The 90% mean confidence interval is ($CDN2.14 per pound to $CDN2.84 per pound).

Results and Discussion

Sensitivity Analysis

Sensitivity analyses were conducted varying Alaskan halibut landings, British Columbian halibut landings, and the Canadian-U.S. exchange rate, holding all else constant. For the results reported for the entire period the changes to the exogenous variable was made in every period[4]. This allows inventory changes to be mostly realized. The results of the sensitivity analyses are reported for the changes in simulated U.S. wholesale and Alaskan exvessel prices for Pacific halibut for both the 1976 to 2002 interval and for the most recently modeled 2002 year. These are reported in Table 4 through Table 10.

Table 4. Effects of changes in Alaska and British Columbia halibut harvests and exchange rates on simulated U.S. wholesale prices (mean level 1976-2002).

	-30%	-20%	-10%	0%	+10%	+20%	+30%
Alaskan landings	6.8%	4.5%	2.3%	0.0%	-2.3%	-4.5%	-6.8%
British Columbian landings	3.0%	2.0%	1.0%	0.0%	-1.0%	-2.0%	-3.0%
Canadian-U.S. exchange rate	3.8%	2.5%	1.2%	0.0%	-1.2%	-2.3%	-3.4%

[4] When the changes are reported for 2002 the changes to the exogenous variable are made for both 2001 and 2002. Changing the 2001 landings (or other exogenous variable) allows inventory changes to be reflected in the 2002 simulated revenue and prices. This was done for each of the sensitivity analysis as well as all 2002 simulations following in this report.

Table 5. Effects of changes in Alaskan and British Columbian halibut harvests and exchange rates on simulated Alaskan exvessel prices (mean level 1976-2002).

	-30%	-20%	-10%	0%	+10%	+20%	+30%
Alaskan landings	10.7%	7.1%	3.6%	0.0%	-3.6%	-7.1%	-10.7%
British Columbian landings	3.7%	2.5%	1.2%	0.0%	-1.2%	-2.5%	-3.7%
Canadian-U.S. exchange rate	4.6%	3.1%	1.5%	0.0%	-1.5%	-2.9%	-4.2%

Table 6. Effects of changes in Alaskan and British Columbian halibut harvests and exchange rates on simulated U.S. wholesale prices (2002).

	-30%	-20%	-10%	0%	+10%	+20%	+30%
Alaskan landings	7.2%	4.8%	2.4%	0.0%	-2.4%	-4.8%	-7.2%
British Columbian landings	2.8%	1.9%	0.9%	0.0%	-0.9%	-1.9%	-2.8%
Canadian-U.S. exchange rate	5.4%	3.5%	1.7%	0.0%	-1.7%	-3.3%	-4.9%

Table 7. Effects of changes in Alaskan and British Columbian halibut harvests and exchange rates on simulated Alaskan exvessel prices (2002).

	-30%	-20%	-10%	0%	+10%	+20%	+30%
Alaskan landings	11.6%	7.7%	3.9%	0.0%	-3.9%	-7.7%	-11.6%
British Columbian landings	3.4%	2.3%	1.1%	0.0%	-1.1%	-2.3%	-3.4%
Canadian exchange rate	6.6%	4.3%	2.1%	0.0%	-2.0%	-4.0%	-5.9%

Increases (decreases) in landings decrease (increase) wholesale and exvessel prices. The ultimate effect on revenue, of changes in landings, depends on the relationship between landings and prices and the magnitude of landings. At least through a 30 percent increase in Alaskan landings, the simulated prices decline at a lower rate than the increases in landings and therefore, simulated revenues increase. However, when British Columbian landings are increased, simulated Alaskan exvessel prices and revenues fall.

A strengthening U.S. dollar relative to the Canadian dollar encourages increased imports of British Columbian halibut and exerts a downward pressure on prices for Alaskan halibut. Simulations show, that over the entire modeling period, a 10 percent strengthening (weakening) of the U.S. dollar would have decreased (increased) U.S. wholesale prices by 1.2 percent and decreased (increased) Alaskan exvessel prices by 1.5 percent. When isolated to 2002, a 10 percent strengthening (weakening) of the U.S. dollar would have decreased (increased) U.S. wholesale prices by 1.7 percent and Alaskan exvessel prices by 2 percent.

Total Revenues and Optimal Static Harvest Levels

The relationship between the production of raw goods and the revenues generated to the primary producer is a much discussed economic relationship. In the case of Pacific halibut, this fishery-wide relationship is between policy-regulated IPHC catch quotas and the resulting exvessel revenues generated to the halibut fleet. The exvessel revenues that fishermen receive depend on many factors such as relative bargaining strength with buyers (normally processors), the cost of processing and getting the fish to the end-markets, and the strength of the market for the final product.

A static total revenue curve can be estimated by simulating changes in Pacific halibut prices given changes in Pacific halibut landings. The Pacific halibut total revenue curve was simulated for changes in the Pacific halibut harvests from Alaskan waters for 2002. In the baseline simulations the simulated 2002 exvessel revenue ($126,696,365) closely approximated actual exvessel revenues ($128,450,371). Because actual and simulated revenues are very similar we will work with the simulated revenues without adjusting them to actual revenues. Therefore, in the following discussion, it should be kept in mind that actual 2002 revenues were slightly higher than the simulated figures that we discuss.

As landings vary, revenues are affected in two ways: revenues vary as a direct consequence of changes in harvest levels and as a consequence of changes in exvessel prices as simulated from all the interactions reflected in the entire system of equations. The total revenue curve was estimated by varying both the 2001 and 2002 Alaskan halibut landings away from their 2001 and 2002 levels of 58.9 and 58.1 million pounds, respectively, while holding all other variables at their actual 2002 levels (see Figure 23).

Again, both the 2001 and 2002 landings were changed to allow changes to inventory to be captured in 2002. Since any changes to landings will effect future years because of inventory changes, it was seemed more accurate to investigate changes to the 2002 season from simulated changes in landings for not only 2002 (in which inventory effects will show up in 2003) but also for 2001.

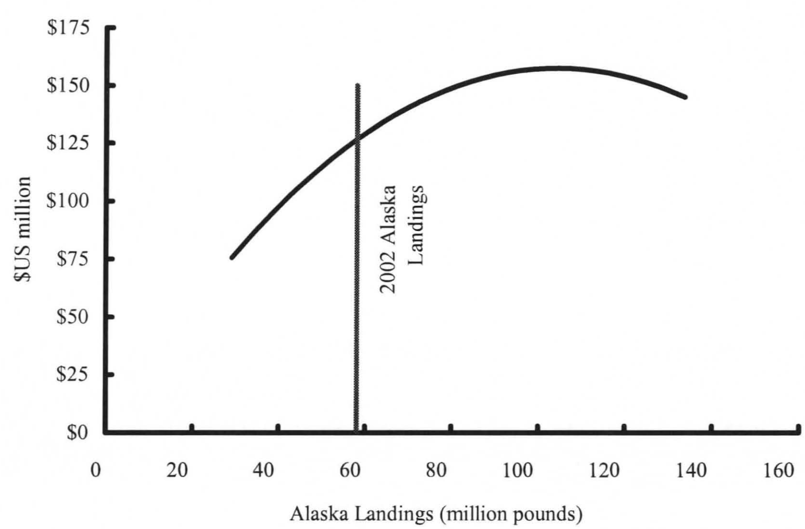


Figure 23. Simulated exvessel revenues ($ million) as a function of Alaskan landings of Pacific halibut.

In the 2002 base year, 58.1 million pounds of halibut were landed in Alaska and sold at an exvessel price of $2.21. As landings increase from this level so does total revenue. As landings continue to increase, price becomes increasingly sensitive to equal percentage increases in landings. Simulated exvessel revenues peak when landings reach 104.2 million pounds. At this point the simulated exvessel price is \$1.52 and simulated exvessel revenues are \$157.5 million dollars.[5] The relationship between the changes in landings and the simulated changes in prices are shown in Figure 24).

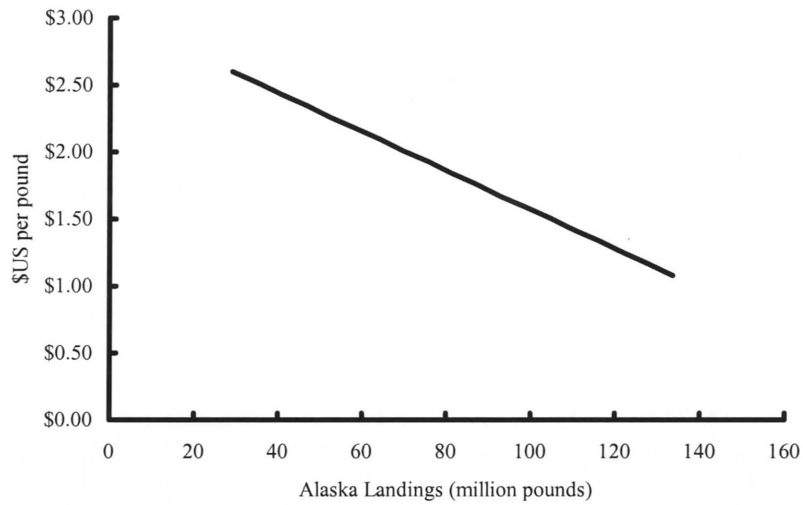


Figure 24. Simulated 2002 exvessel price changes for increased (decreased) Alaska catch levels of Pacific halibut (million pounds).

In Figure 23, we see that Alaskan exvessel revenues would increase as Alaskan halibut landings increase to 104.2 million pounds. However, biological (or regulatory) factors, which may lead to changes in Alaskan landings, are likely to affect all 10 IPHC regulatory areas (although not equally). The next set of simulations simulates what would happen if the combined landings from all halibut producing regions changed simultaneously. In the 2002 base year, a total of 70.1 million pounds of halibut was landed in Alaska, British Columbia and Washington. The Alaskan total revenue exvessel curve was estimated by varying the total Pacific halibut landings away from their 2001 and 2002 level of 69.8 and 70.1 million pounds, respectively, while holding all other variables at their actual 2001 and 2002 levels (see Figure 25).

[5] The exvessel revenue equation for halibut landings in Alaska was fitted to a quadratic function to estimate the maximum exvessel revenue. The equation was $TR_t^{AK} = -0.00076 + 3.022408 LAN_t^{AK} - 0.014497\left(LAN_t^{AK}\right)^2$ where TR_t^{AK} is the estimated Alaska exvessel revenue and LAN_t^{AK} is the magnitude of Alaska landings of Pacific halibut.

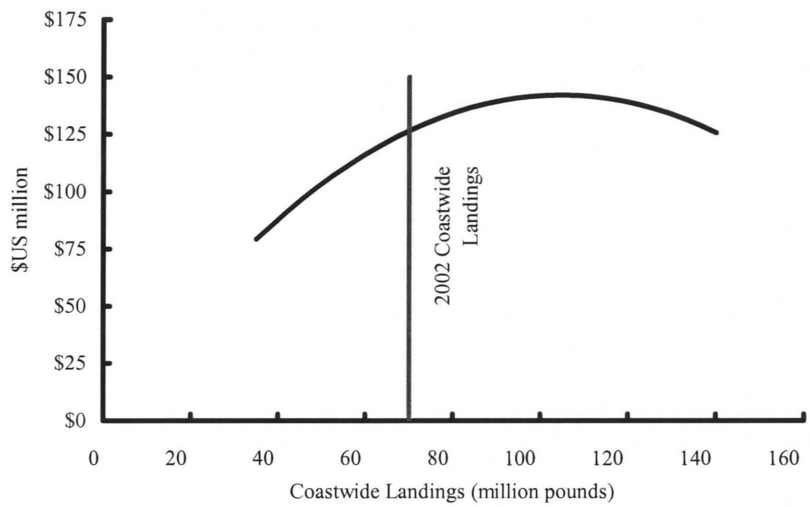


Figure 25. Simulated Alaskan 2002 exvessel revenue changes for increased (decreased) combined catch levels of Alaska, British Columbia and Washington landings of Pacific halibut (million pounds).

Simulated Alaskan exvessel revenues peak when coastwide landings equal 104.6 million pounds. If the increase in Alaskan landings is a proportionate share of the increase in coastwide landings, Alaskan landings would be approximately 86.7 million pounds when coastwide landings are 104.6 million pounds, and Alaskan revenues would peak at $142.2 million dollars.[6] Exvessel revenues are lower under this set of simulations than in the previous simulations because Alaska landings are less at the exvessel revenue peak when landings increase proportionately across all producing regions.

Effects of IFQs

To simulate the effect of the Alaska IFQ program on wholesale and exvessel prices, as well as exvessel revenues, the model was first simulated to estimate the Pacific halibut weighted average prices and revenues for 1995 through 2002. The model then was simulated to reflect what the market conditions would have been if the Alaska IFQ program had not been put into place. That is, in these simulations, the Alaska season length was set to 2 days (the length of the 1993 and 1994 season) for 1995 to 2002. The prices and revenues under the simulated current fishery, and that of the simulated continuance of the race-for-fish fishery are compared in Table 8.

---

[6] The equation was $TR_t^{AK} = -0.012 + 2.7189 LAN_t^{All} - 0.012997\left(LAN_t^{All}\right)^2$ where TR_t^{AK} is the estimated Alaska exvessel revenue and LAN_t^{All} is the combined Pacific halibut landings from Alaska, British Columbia and Washington State.

Table 8. Simulated exvessel and wholesale prices and exvessel revenues without implementation of the Alaska IFQ program (1995-2002).

	Wholesale price ($/lb)	Alaska exvessel price ($/lb)	Exvessel revenue ($ U.S. million)	BC exvessel price ($ U.S./lb)
Actual	2.74	2.01	101,694,344	2.13
Predicted without IFQ programs	2.50	1.80	90,825,073	2.45
Predicted increases due to Alaska IFQ program	0.24	0.22	10,869,271	(0.32)
Predicted increases due to Alaska IFQ program (%)	8.7%	10.7%	10.7%	(15.1%)

The Alaska IFQ program is estimated to have increased average wholesale prices (for 1995 to 2002) by $0.24 per pound and is estimated to have increased average exvessel prices by $0.22 per pound. An exvessel increase of $0.22 per pound over this time period translates to an average annual exvessel revenue gain of just under $11 million (an annual gain of approximately 10.7 percent).

Our estimates of the increase in wholesale and Alaskan exvessel prices is quite a bit lower than was estimated by Matulich and Clark (2003). Using the 1992-1993 and 1999-2000 seasons as benchmark periods, Matulich and Clark estimated that the Alaska IFQ program led to a $1.19 increase in wholesale prices and a $1.15 increase in exvessel prices. However, the difference between these two periods is the largest spread in any 7 year period over the last thirty-years (the time period for which accurate exvessel price data has been gathered). For example, if you look at the difference between the 1994-1995 and 2001-2002 average exvessel price difference is just $0.11 per pound. Just using a year earlier, between 1991-1992 and 1998-1999 the spread is just $0.14 per pound.

Our model suggests that implementation of the Alaska IFQ program decreased exvessel prices in British Columbia by an average of $0.32 per pound over 1995 to 2002. This is close to Herrmann's (2000) estimate, based on a different model and over a shorter time period (1995-1998). Herrmann estimated that the British Columbia exvessel price decreased by $0.27 per pound as a consequence of the implementation of Alaska's IFQ program. Herrmann (2000) predicted that, from 1991 to 1994, the British Columbia IVQ program increased British Columbia exvessel prices by $0.53 per pound. This was in line with a prediction of a price increase of $0.40 to $0.80 per pound by Canada Department of Fisheries and Oceans economist Bruce Turris before implementation of the Alaska IFQ program (Doherty 1990).

Our results indicate that nearly all of the wholesale price gains from the Alaska IFQ program, 90 percent, accrue to the fishermen. This is what would be expected if the processors are largely competing for the raw product. In a competitive market, as wholesale prices rise, processors can be expected to bid up the price of the product to cover their costs of production. If the cost structure is not significantly changed from the pre-IFQ period then you would not expect the margin to change substantially. In this regard, our results are similar to those reported in Matulich and Clark (2003), who estimated that 96 percent of increase in wholesale exvessel prices accrued to fishermen.

These relatively stable margins can be seen in Figure 26 and Figure 27.

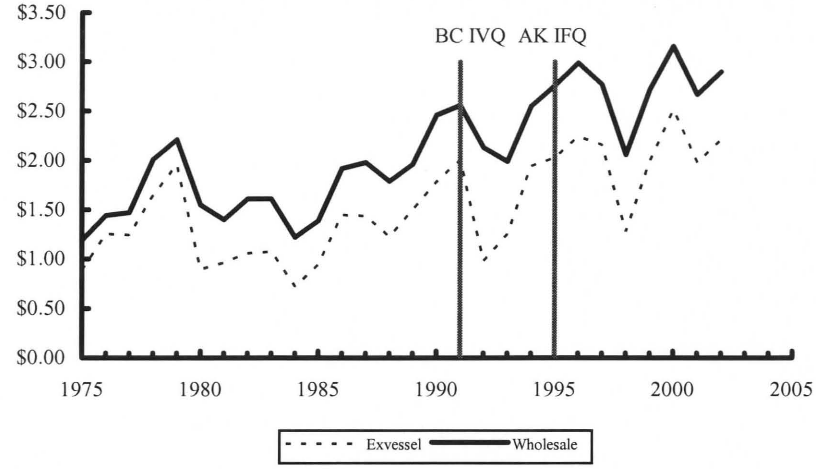


Figure 26. Nominal exvessel and wholesale prices for Pacific halibut in Alaska from 1975-2002 ($/lb).

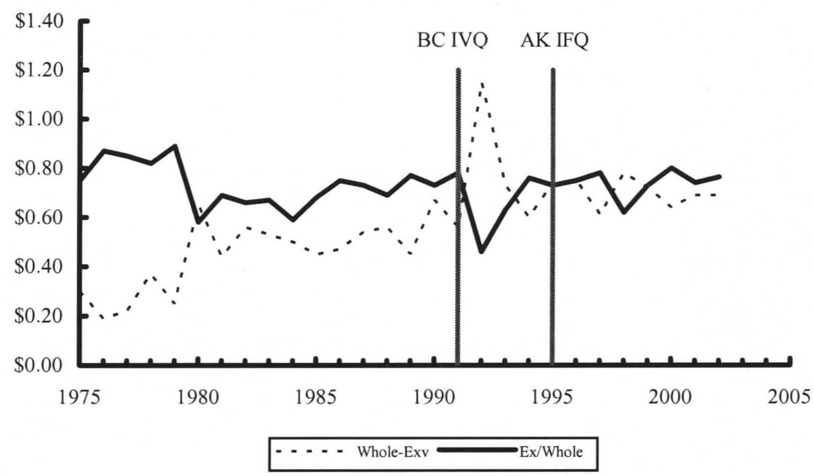


Figure 27. Alaska halibut margins (nominal wholesale less nominal exvessel) and percent exvessel of wholesale 1975-2002.

Not only have the margins not changed but neither has the average number of firms (Figure 28).

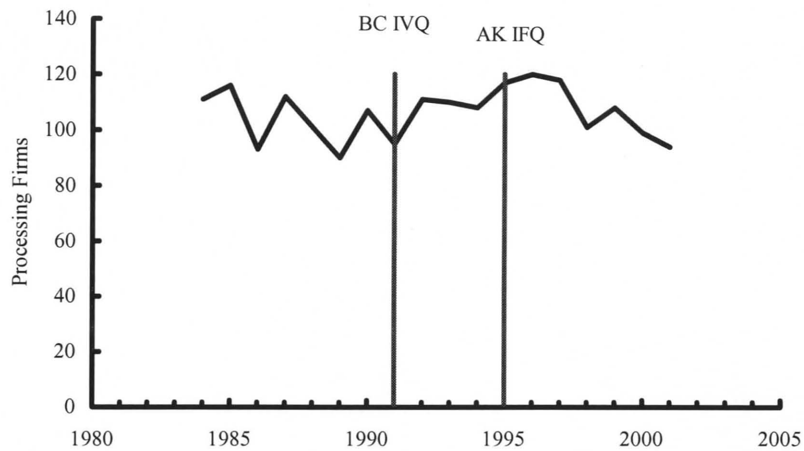


Figure 28. Number of U.S. processing firms producing halibut 1984-2000.

The introduction of IFQs in the Alaskan halibut fishery resulted in substantial increases in exvessel and wholesale prices while leaving exvessel-wholesale margins largely unchanged. This has resulted in substantial gains to first generation IFQ recipients with modest gains to processors.

This portion of the study has focused on the change in revenues to the halibut industry as a result of the introduction of IFQs. In addition to the changes in revenues, there has been a substantial redistribution of revenues among halibut processors. Many of the processors that were active in buyers in the derby fishery lost market share to new processors.

> "I'd have to say that in Canada the fisherman have benefited quite a bit" said John Nordmann, president of Delta, British Columbia's S.M. Products.
>
> Small companies like his own also have benefited. Nordmann said that before IVQs he bought hardly any halibut. "Now we have a big chunk. The big companies don't like to keep the shop open and running when a lot of fish isn't coming in. The mom and pop operations can do that, though-they're more cost efficient." He thinks the same thing will happen to a lesser degree in Alaska. "Some leaner players will establish themselves."
>
> When British Columbia switched to an IVQ system a few years ago, smaller buyers took over and he halibut price paid to fishermen went up. Because much more fish started going fresh to the market, buyers didn't need to be big companies with massive resources and freezing operations. In fact, those companies found themselves at a disadvantage. Big buyers now have a much smaller role in the Canadian halibut business as a result (Shaw 1994).

Matulich and Clark (2003) estimate that the *pre-existing* halibut IFQ processing sector "lost 56% of its 1992-1993 average annual quasi-rents following the introduction of IFQs". So, if the wholesale margin increased slightly after IFQs were implemented and the number of processing firms did not alter significantly, why did Matulich and Clark conclude that the processing sector lost such a large share of it's prior quasi-rents? The answer seems to be that as the character of the fishery changed from a derby to a protracted season with consistent supplies of fresh fish, processing needs also changed and processors that were unable to adapt lost market share to new processors with more flexible infrastructure and lower operating costs. The new processors have substantially smaller investments in physical infrastructure and lower processing costs than many of the processors that were active prior to IFQ implementation. Matulich and Clark report that of the 104 halibut processing firms operating before IFQ implementation, only 31 continue to process halibut. Fifty-one new firms have entered the market since 1995 and have captured 34 percent of the market share. Several of these new firms are custom processors or broker/reprocessors that are also the buyer of record. As exvessel prices were bid-up, pre-existing processors lost money. Those that survived saw their market share decline from 62 percent to 28 percent (Matulich and Clark 2003). Therefore, although the halibut industry is healthy and vibrant, processors who invested in nonmalleable capital that was unsuitable for profitable operation under the longer, slower IFQ fishery, believe that the value of their investment in capital was unfairly diminished as a consequence of the *de gratis* allocation of IFQs to fishing vessel owners. Concern about protecting the market share of existing crab processors has led to the adoption of a two-pie quota system (with community protection) in the Bering Sea crab fisheries.

Season Elongation and Potential Revenue Effects

As we have previously stated, one issue pertaining to the market for farmed halibut is that farmed halibut is likely to be first sold during the months of November through March when the wild halibut fishery is currently closed (see page 13). Farmed salmon first infiltrated new markets by selling product primarily during the off-season (October to May). In this way, the product reached new consumers and did not face direct competition from fresh supplies of wild salmon; after a period of time, farmed salmon became readily acceptable as a substitute for wild salmon throughout the year. Industry groups have suggested that the IPHC consider the possibility of lengthening the Pacific halibut season to preempt or at least slow the establishment of farmed halibut in seasonal niche markets.

Regardless of the state of farmed halibut production, lengthening the Pacific halibut season should increase revenues by spreading the supply of "fresh" halibut over an additional four months each year. To explore the likely effects of season elongation, we used our model to run simulations with the Alaskan and British Columbian season lengths increased to 365 days. The results of our simulation are reported in Table 9.

Table 9. Simulated 2002 Alaska halibut exvessel price and revenue with and without extending the Alaska and British Columbia commercial fishing season length to 365 days.

	Wholesale price ($/lb.)	Exvessel price ($/lb)	Exvessel revenue ($)
Actual season	2.90	2.21	128,450,371
Simulated increases under a 365-day season	0.12	0.11	6,289,614
Predicted with 365 day season	3.02	2.32	134,739,985
% Increase due to the season extension	4.1%	4.9%	4.9%

The projected increases in exvessel prices and revenues are a result of the increased availability of fresh halibut during the winter months. It is predicted that the increase in season length will raise prices and revenue by 4.1 to 4.9 percent; an increase in exvessel revenues of approximately $6 million. These gains are relatively modest compared to the gains attributed to IFQs but it is important to remember that with IFQs, the season length increased from little more than 2 days to 245 days, a much larger change than going from 245 to 365 days.

Whether lengthening the season would be advantageous to the industry depends on several factors, including changes in revenues, changes in fishing, processing, and management costs, and long-term biological impacts to this and other fisheries. Finally, even if the revenue increases are modest, if farmed halibut becomes increasingly more prevalent, the largest advantage of moving to a 365 days season may be to delay the penetration of farmed halibut into seasonal niche markets.

Farmed Halibut and Potential Revenue Effects

The State of Alaska is concerned about the possibility that farmed halibut could devastate the Alaskan halibut fishery much as farmed salmon devastated the Alaskan salmon fishery. In fiscal year 2003, the Alaska Governor's budget echoed these concerns in a list of "key department issues": "The Alaska fishing industry faces many serious challenges in the years ahead due to the increasing worldwide production of low-priced, high-quality farmed salmon and the imminent mass production of farmed halibut" (DCED 2001).

As previously discussed, the Forster report speculates that the intense competition from farmed halibut may be some time down the road.

> It does not present an immediate competitive threat to wild halibut, nor is it certain that farmed halibut will, necessarily, have a negative impact on the market for wild fish, especially in the short and medium term. What is certain, in this author's opinion; is that marine finfish aquaculture will continue its worldwide expansion and that halibut will succeed as a farm fish because it has attributes that make it well suited for this purpose (Forster 1999).

Much of the discussion about halibut, even among the leading authorities, such as John Forster, is educated speculation but given the economic disaster that salmon aquaculture precipitated on the race-for-fish salmon fishery, educated speculation about potential impacts of halibut aquaculture can at least bring the issues to the forefront for discussion.

We used our model to explore the potential effects of farmed halibut on prices and revenues in the Alaskan wild halibut fishery. The simulations were run conditioned on the assumptions that: 1) the market for halibut 15-20 years down the line will be similar to what it was in 2002; 2) farmed halibut will enter the existing U.S. markets through the same import channels as wild halibut from British Columbia, 3) the market will perceive farmed Atlantic halibut and wild Pacific halibut as perfect substitutes; and, 4) the wild halibut season will be elongated to 365 days to compete with farmed halibut.

The first assumption is necessary because this is the model that was specified and estimated using information about market conditions through 2002. While it is likely that many factors will change in 15 to 20 years, it is difficult to know how they will change, whether they will resemble conditions observed in the past or whether they will represent entirely new conditions. Therefore, these simulations really ask what would have been the market effect in 2002 if farmed halibut production had instantly, and dramatically, increased. The second assumption also represents an assumption that the future will resemble the past and present. The U.S. has been and is the primary market for halibut and we assume that the U.S. will remain the primary market for halibut through the near future and therefore, that most farmed halibut, wherever produced, will be channeled into the U.S. market. Because the most mature import channel is that from British Columbia, we assumed that farmed halibut will follow a similar channel. The third assumption, that farmed halibut is a perfect substitute for halibut landed in the wild capture fishery, is necessary to simulate the effects in this model. However, this assumption is not that unreasonable as Forster and others report that, to date, farmed Atlantic and wild Pacific halibut (on the market place) have been "interchangeable". The simulations are for 25 percent increments of farmed halibut as a percent of Alaskan landings of wild halibut (up to 100 percent) (Table 10).

Table 10. Simulated 2002 Alaska halibut price and revenue with hypothetical farmed salmon production (as a percent of wild Alaska halibut production) assuming an elongated 365 day capture fishery season.

Famed halibut production as a percent of Alaska harvest	Simulated farmed halibut production (million pounds)	Wholesale price ($/lb.)	Exvessel Price ($/lb.)	Exvessel revenue ($ U.S. million)
0%	0	3.02	2.32	134,450,371
25%	14.5	2.66	1.99	115,701,606
50%	29.1	2.30	1.66	96,444,254
75%	43.6	1.95	1.33	77,318,801
100%	58.1	1.59	1.00	58,193,348

These simulations suggest that if farmed halibut were to be sold in the same markets that wild halibut is currently sold in, the resulting loss in exvessel revenue to the Alaskan fishery would be substantial. Of course, this scenario should be considered a worst case scenario, a warning that intense pressure on price and revenues are likely to occur if halibut farming continues to be developed as projected. If wild Pacific halibut prices decreased by as much as indicated in Table 10, it would also mean that farmed halibut prices would decrease similarly. Forster estimates that current costs to produce farmed halibut are between $2.43 and $2.79 per pound and that future (15-20 years) costs can be expected to be in the range of $1.45 to $1.89 per pound. Even with minimal transportation costs, the sale of farmed halibut into the same markets as wild British Columbian halibut would cease to be profitable as farmed production levels approached 50 percent of Alaskan landings. For an expansion of more than 50 percent of farmed production into the U.S. to occur, demand would need to expand or farmed halibut production costs would need to fall below projected cost levels.

A more likely scenario would be that before exports of farmed halibut to the U.S. drove farmed prices down towards costs of production, that halibut farming countries would need to develop export markets in other countries. As Forster writes:

In many ways the situation is analogous to Atlantic salmon farming in the late 70's and early 80's. The wild harvest of Atlantic salmon at that time was only about 20 million pounds and was soon exceeded by the supply of farmed salmon, as this new aquaculture industry developed. This might have been expected to lead to an immediate price collapse, but this did not happen for several years, by which time annual production of farmed salmon was more than 200 million pounds. There was, in fact, a latent unrecognized demand for fresh salmon, much larger than would have been predicted, based on then current consumption of wild Atlantic salmon. The new farmed product filled a market void and farmers were able to keep increasing their production for several years before any sign of market weakness became apparent.

A presumption in the development, of halibut farming is that a similar situation applies. A major market evaluation conducted for multiple Norwegian clients in 1992 notes: "Fresh salmon expanded all major European markets considerably-in the early eighties. There are good reasons to believe the same will happen with halibut". How far this analogy extends is open to question, but in the next five years, at least, it does not seem likely that supplies of farmed halibut will unsettle markets for wild halibut of either Atlantic or Pacific origin. During this period, halibut farmers will focus their marketing effort on upscale restaurants and retail outlets, mostly in N. Europe, where halibut is highly regarded. They will promote it as Atlantic halibut and will emphasize its consistent quality, size and year round availability, though they are likely to get their best prices during late fall, winter and spring, when wild Atlantic halibut are most scarce. Their promotional efforts may, actually, increase, or re-awaken, interest in fresh halibut as a category, much as promotion by salmon farmers stimulated new demand for fresh salmon in the early 80's. In turn, this could open up new opportunities for fresh Pacific halibut, now that it is available for a substantial part of the year (Forster 1999).

However, there are also some differences between salmon and halibut. At the time that farmed salmon was being developed, salmon was consumed in more world markets than halibut is currently consumed in. The salmon season was significantly shorter than the current halibut season, limiting fresh salmon to the summer months whereas fresh halibut is now already available for two-thirds of the year. It seems unlikely that there is as much room for market expansion in the case of farmed halibut as there was for farmed salmon. In any case, it will be the cost of producing farmed halibut that will be the limiting factor and without significant new markets or market expansion; it would not take unthinkable amounts of farmed halibut being sold on the domestic markets to substantially affect the wild halibut industry.

The Population Model

Pacific halibut is managed as a single stock throughout its range. Consequently, the biomass of halibut can be represented as:

$$X_t = \sum_{i=1}^{n} x_{it} ,$$

where X_t is the coastwide biomass, x_{it} is the biomass of halibut in area i in time t, and n represents the number of IPHC management areas: 2A, 2B, 2C, 3A, 3B, and 4A-E (see Figure 1).

Because of data limitations, IPHC stock assessments have been based on models of the dynamics of the stock in the center of its distribution (areas 2B, 2C, and 3A) expanded to the full range based on survey catch rates (Sullivan, Parma and Clark 1999). Thus the modeled biomass can be represented as

$$X_t = \tilde{X}_t + u_t$$

where

$$\tilde{X}_t = \sum_{i=2}^{4} x_{it}$$

and

$$u_t = X_t - \tilde{X}_t = x_{1t} + x_{5t} + x_{6t} + x_{7t} + x_{8t} + x_{9t} + x_{10t}$$

The biomass of fish populations changes over time as a result of growth, recruitment, predation, other natural mortality, and intentional and incidental harvesting. Unfortunately, while harvesting is observable and current biomass can be sampled, natural mortality, predation, and recruitment are latent variables. Following Criddle and Havenner (1991) we adopt a hybrid structural-time series approach that relates the latent variables to present and past observables. The model is comprised of four equations: a stock dynamics equation, a recruitment equation, and two matrix equations that serve as an error correction process.

Stock dynamics are modeled as a delay-difference process described by

12) $$X_t = \beta_1 X_{t-1} + \beta_2 X_{t-1}^2 + \beta_3 r_t - h_{t-1} + \upsilon_t$$

Where r_t is the number of age-8 recruits in millions, h_{t-1} is the sum of commercial, sport, and personal use removals, and υ_t is a normal random variable. Equation (12) can be re-expressed in terms of the explicitly and implicitly modeled components of the population:

$$\tilde{X}_t + u_t = \beta_1\left(\tilde{X}_{t-1} + u_{t-1}\right) + \beta_2\left(\tilde{X}_{t-1} + u_{t-1}\right)^2 + \beta_3 r_t - h_{t-1} + \upsilon_t$$

or

12’) $$\begin{aligned}\tilde{X}_t &= \beta_1 \tilde{X}_{t-1} + \beta_2 \tilde{X}_{t-1}^2 + \beta_3 r_t - h_{t-1} + \upsilon_t - u_t + \beta_1 u_{t-1} + \beta_2\left(2\tilde{X}_{t-1} u_{t-1} + u_{t-1}^2\right) \\ &= \beta_1 \tilde{X}_{t-1} + \beta_2 \tilde{X}_{t-1}^2 + \beta_3 r_t - h_{t-1} + \varepsilon_t\end{aligned}$$

Where ε_t includes sample and observation error processes.

Clark and Hare (2002), model halibut recruitment is a function of lagged values of biomass and latent processes that are correlated with lagged values of the Pacific Decadal Oscillation (PDO), a proxy for changes in the suitability of oceanographic conditions. Rather than impose a particular functional form or dynamic structure on the linkage between recruitment and the Pacific Decadal Oscillation, we have chosen to model recruitment using a Ricker function

13) $$r_t = \tilde{X}_{t-8} \exp\left(\gamma_0 + \gamma_1 \tilde{X}_{t-8} + \eta_t\right)$$

and to include the Pacific Decadal Oscillation as a covariate in a multivariate time series error-correction model. While the residuals to equations (1’) and (2) are characterized by complex serial correlations, they can be regarded as draws from stationary stochastic processes. Because even nonlinear stationary time series have linear state space representations (Aoki 1990), the dynamic factors that are important in the residuals of equations (12') and (13) can be modeled using innovation form equations (14) and (15).

14) $$\omega_t = \begin{pmatrix} \eta_t \\ \varepsilon_t \\ PDO_t \end{pmatrix} = \mathbf{C}z_t + e_t$$

15) $$z_{t+1} = \mathbf{A}z_t + \mathbf{B}e_t$$

Equations (14) and (15) represent a system of matrix equations that can be solved for latent state variables, z_t, that represent dynamic factors present in the covariates, ω_t. The state variables are unobservable but can be determined after the model parameters have been estimated and are constructed to be minimum sufficient statistics for the past realizations of the ω_t. The number of states can be less than, equal to, or greater than the number of series modeled depending on the degree to which the series are correlated and on the complexity of the underlying dynamics. Equation (14) projects the residuals of equations (12'), (13), and the PDO onto the latent state variables. Equation (15) describes the dynamics of the state variables and is written as a first-order difference equation because it is possible to augment equations (14) and (15) to first-order by defining states equal to the lag of other states. The matrices **A** and **B** represent the intertemporal dynamic linkages between state variables. The deterministic component of system dynamics are embodied in **A** while **B** is analogous to the Kalman filter update matrix. Because the states extract all of the information in the past, only serially uncorrelated innovations (ε_t) orthogonal to the states remain. The solution to equations (14) and (15) is developed in Aoki (1990) and Havenner and Aoki (1991).

Because the coefficients in equations (12') and (13) are correlated with the residuals, efficient estimation requires that the model be iterated to convergence in a manner analogous to the coefficient-covariance iteration typical of seemingly unrelated regression methods. With estimates of the elements in β_i, γ_i, $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{C}$, and a set of initial conditions z_0, equations (12'), (13), (14), and (15) can be solved for estimates of biomass, recruitment, and the PDO.

Results and Discussion

The data used for estimating the parameters of the population model are included in Tables 11, 12, and 13, in the appendix. The results we report are based on 75 iterations with convergence to eight decimals. The coefficient estimates for equation (12') are

$$\tilde{X}_t = 1.336\left(\tilde{X}_{t-1}\right) - 6.488\times 10^{-4}\left(\tilde{X}^2_{t-1}\right) + 8.964\left(r_t\right) - h_{t-1} + \hat{\varepsilon}_t \qquad R^2 = 0.995$$

All of the coefficients have p-values less than 0.01. The value of R^2 represents the fit to equation (12') conditioned on the fit to equations (13), (14) and (15).

The fit of equation (12') can be represented graphically as:

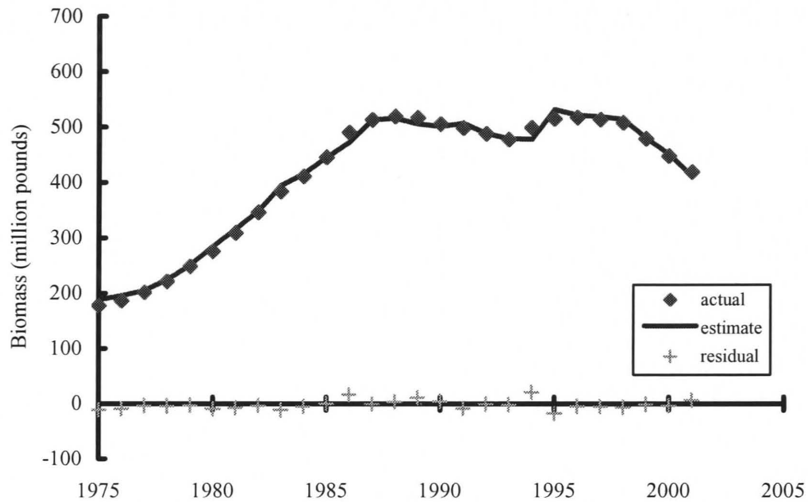


Figure 29. Coastwide biomass of Pacific halibut 1975-2001. IPHC estimates are represented by diamond symbols, model estimates by a thick solid line, and residuals by + symbols.

The coefficient estimates for equation (13) are

$$r_t = \tilde{X}_{t-8}\exp\left(-3.117 - 3.009\times 10^{-3}\tilde{X}_{t-8} + \hat{\eta}_t\right)\exp(\upsilon_t) \qquad R^2 = 0.519$$

where

$$\upsilon_t = \left(\tfrac{1}{2}\right)\hat{\sigma}^2 - \left(\tfrac{1}{2}\right)\hat{\sigma}^2\begin{pmatrix}1 & \tilde{X}_{t-8}\end{pmatrix}\begin{pmatrix}n & \tilde{\mathbf{X}} \\ \tilde{\mathbf{X}}' & \tilde{\mathbf{X}}'\tilde{\mathbf{X}}\end{pmatrix}\begin{pmatrix}1 \\ \tilde{X}_{t-8}\end{pmatrix}$$

and $\hat{\sigma} = 0.141$, and $\mathbf{X}$ is the matrix of observed values of biomass. The value υ_t is a transformation necessary to eliminate bias in the model forecasts (Kennedy 1983).

The fit of the recruitment equation (13) can be represented graphically as:

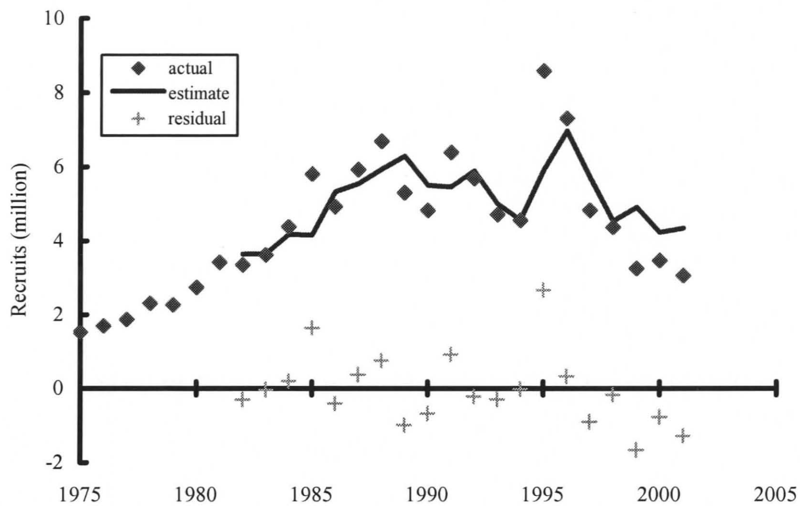


Figure 30. Coastwide recruitment of Pacific halibut 1975-2001. IPHC estimates are represented by diamond symbols, model estimates by a thick solid line, and residuals by + symbols.

The fit to the PDO time series can be represented graphically as:

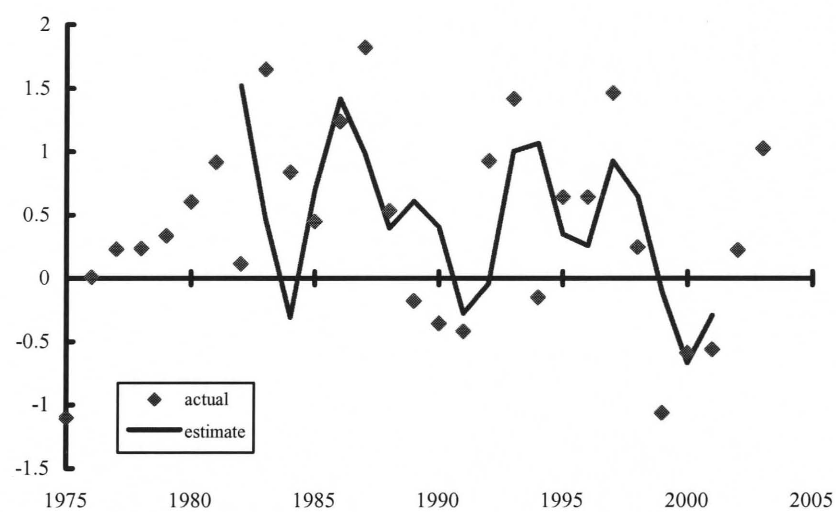


Figure 31. Pacific Decadal Oscillation 1975-2001. The PDO values are represented by diamond symbols, model estimates by a thick solid line.

The associated coefficient of determination is: $R^2 = 0.162$.

The state space time series equation system was specified with a system lag length of four years, allowing lags of up to twelve years on the individual time series. The coefficient estimates for equations (14) and (15) are

$$\omega_t = \begin{pmatrix} \eta_t \\ \varepsilon_t \\ PDO_t \end{pmatrix} = \begin{pmatrix} -0.3969 & 0.0423 & 0.8187 \\ -3.4244 & -5.2755 & -2.1925 \\ -0.5778 & 0.0342 & -0.0984 \end{pmatrix} z_t + e_t$$

$$z_{t+1} = \begin{pmatrix} 0.3387 & -0.6356 & -0.1551 \\ 0.7526 & 0.1342 & 0.0334 \\ -0.1170 & -0.6265 & 0.2623 \end{pmatrix} z_t + \begin{pmatrix} -0.4406 & -0.0356 & -0.4734 \\ 0.2788 & 0.0089 & 0.6137 \\ 0.5775 & 0.0227 & -0.3676 \end{pmatrix} e_t$$

The **A** matrix describes the dynamic linkages among the state variables. The three eigenvalues of **A** are:

Eigenvalues of **A**	Moduli
$0.1576 \pm 0.7024i$	0.7199
0.4200	0.4200

Because the roots of **A** lie within the unit circle, the dynamics of the error-correction and PDO reflect a dampened oscillation. The persistence of the latent dynamics can be represented by allowing the final values of the estimated states to decay following the impact of a one-time shock.

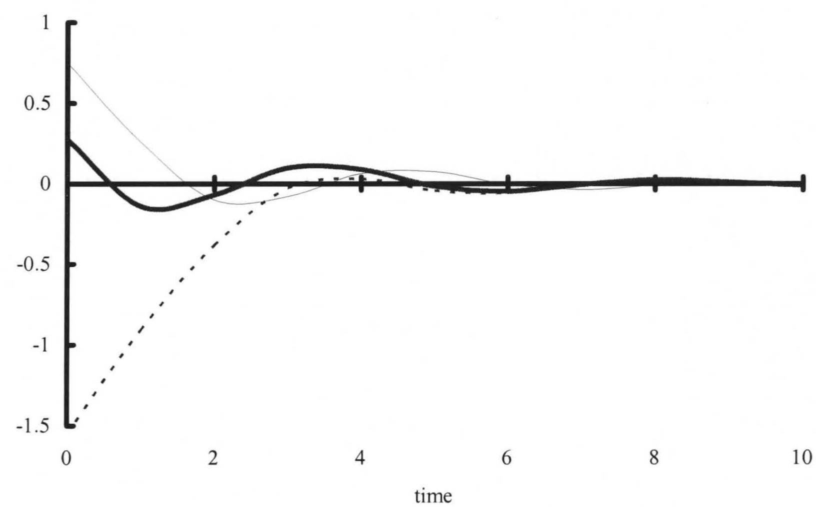


Figure 32. Decay path of latent state variables in response to an initial shock.

The historical time path of the state variables shows the influence of multiple shocks

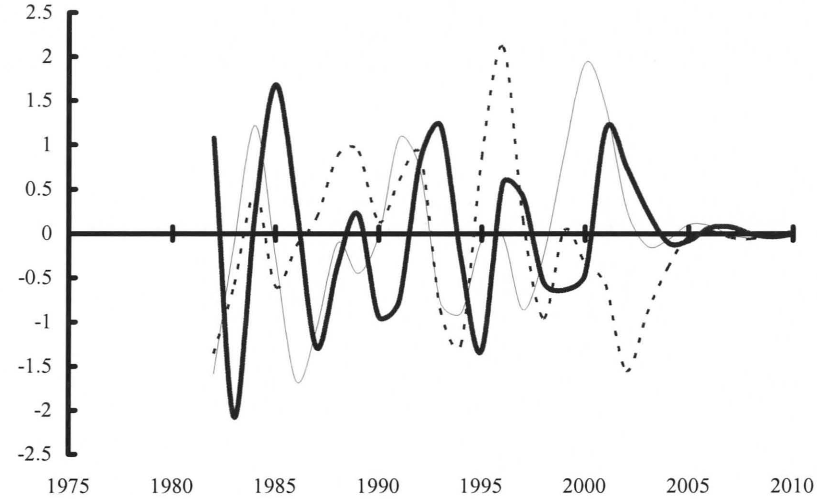


Figure 33. Value of latent state variables 1975-2001 and projected decay path 2002-2010.

The expected value of steady state biologically sustainable yields can be derived from equations (12') and (13) and represented by Figure 34:

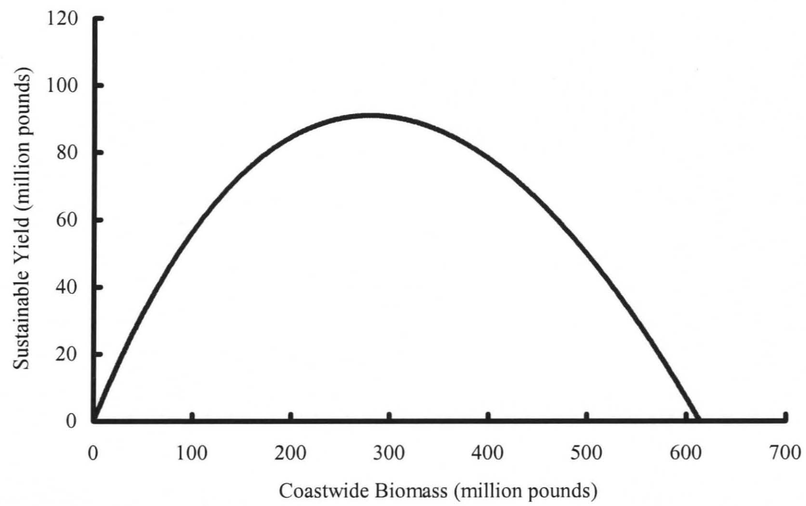


Figure 34. Coastwide sustainable yields of Pacific halibut.

The coastwide expected steady state sustainable yield reaches a maximum of 91 million pounds at population biomass of about 280 million pounds. Comparing the sustainable yields in Figure 34 with the exvessel revenues in Figure 25 (and Figure 35, below), it is evident that the expected steady state maximum sustainable yield of the fishery (91 million pounds) is less that the level of harvests at which exvessel revenues are maximized (104.6 million pounds). That is, the limits of natural production present a binding constraint to the revenues that can be realized from the wild harvest.

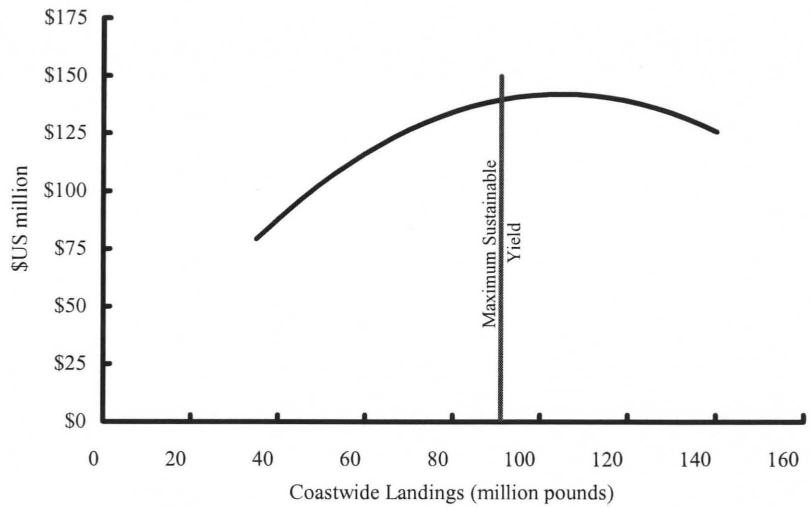


Figure 35. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds).

Under the demand conditions characteristic of 2002, the inherent biological limits to natural production lessen the likely magnitude of adverse impacts to Alaska halibut fishermen of the growth of farmed halibut production. If the wild fishery were to harvest the maximum sustainable yield of about 91 million pounds, total revenues from wild and farmed production would continue to increase as farmed production increased to about 14 million pounds. Although farmed production above 14 million pounds would lead to decreased total revenues to farmed and wild production, farmed production could increase to about 30 million pounds without reducing the combined revenues from wild and farmed production to below revenues that would be available to a wild-harvest-only scenario with harvesting at the maximum sustainable yield.

Expected recruitments (equation 13) associated with steady state biomass levels can be represented by Figure 36:

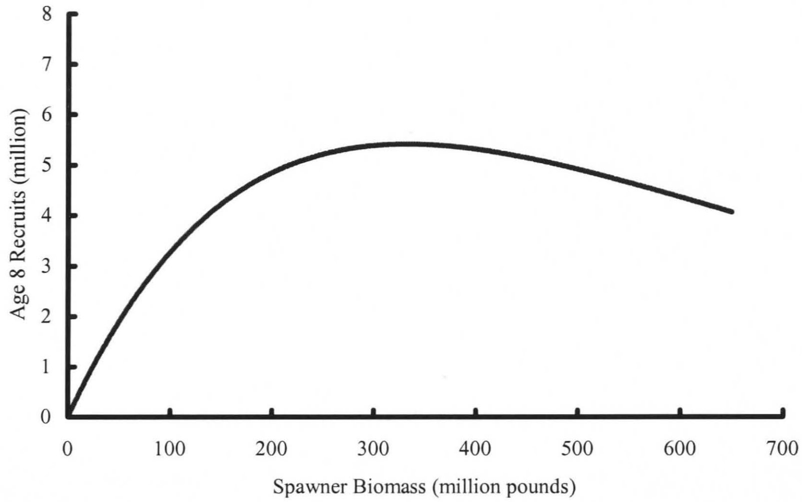


Figure 36. Coastwide recruitment of Pacific halibut.

The ocean environment is dynamic and the productivity of natural species is subject to interannual and decadal scale variation. Changes in the productivity of the ocean environment affect the magnitude of sustainable harvests and associated revenues. Figure 37 represents a 10 percent increase and a 10 percent decrease in the carrying capacity for halibut in the North Pacific.

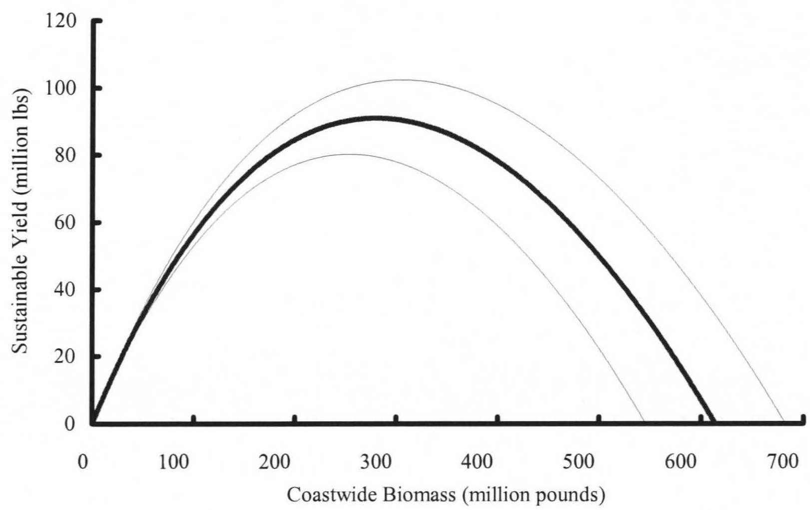


Figure 37. Coastwide sustainable yields of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in ocean productivity for Pacific halibut.

The magnitude of recruitments is dependent on the population of halibut. Consequently, the expected recruitments associated with steady state biomass levels will also change as ocean productivity changes. The expected recruitments associated with baseline and plus or minus 10 percent changes in the carrying capacity for halibut in the North Pacific are represented in Figure 38.

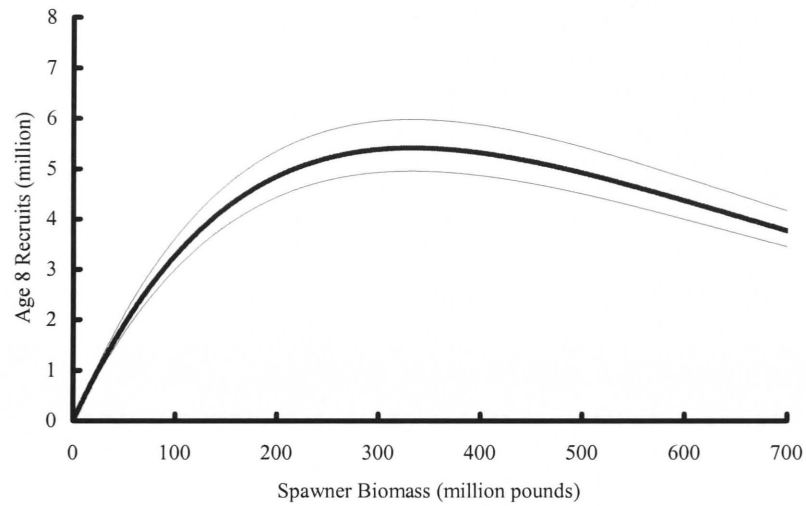


Figure 38. Coastwide recruitment of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in ocean productivity for Pacific halibut.

Instead of affecting the overall carrying capacity for halibut, changes in the ocean environment could affect recruitment success. The expected recruitments associated with baseline and plus or minus 10 percent changes in recruitment success are represented in Figure 39.

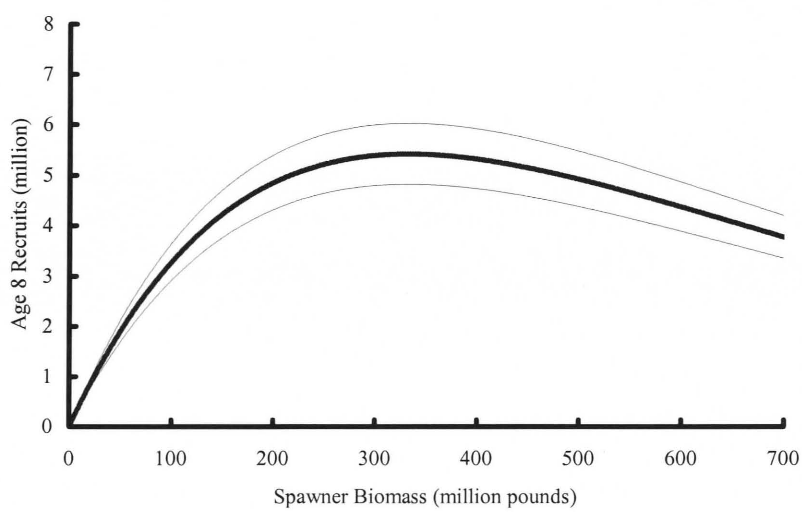


Figure 39. Coastwide recruitment of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in recruitment success.

The steady-state sustainable yields associated with plus or minus 10 percent changes in recruitment success are represented in Figure 40.

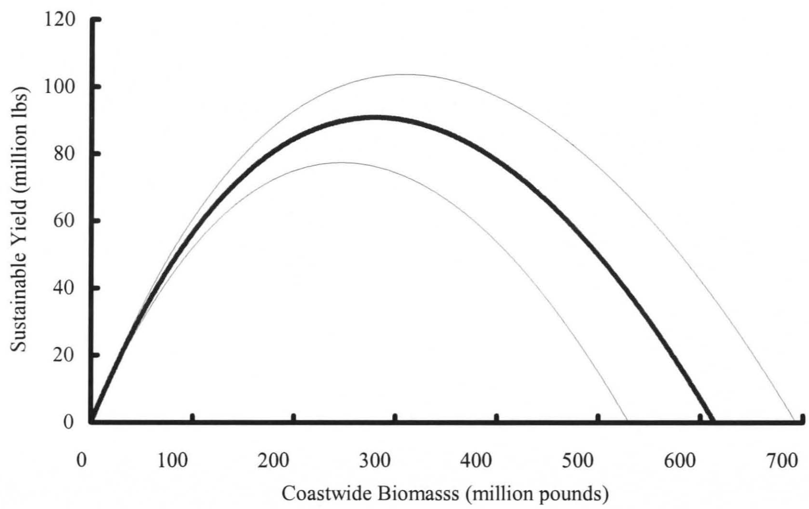


Figure 40. Coastwide sustainable yields of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in recruitment success.

Yet another way that halibut could be affected by changes in the ocean environment is for the environmental changes to lead to changes in the growth rate of halibut. Figure 41 represents the steady-state baseline sustainable yields and the sustainable yields predicted for 5 percent increases and decreases in the growth rate of halibut.

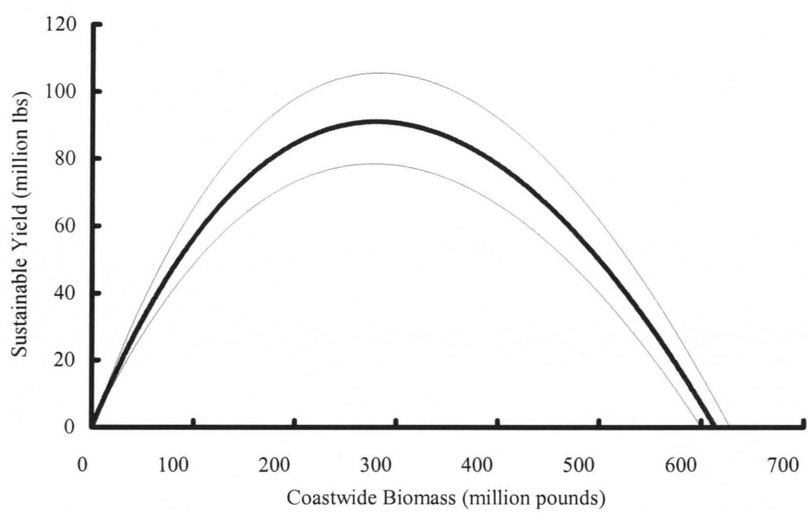


Figure 41. Coastwide sustainable yields of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 5 percent increase or 5 percent decrease in the growth rate of Pacific halibut.

The expected recruitments associated with steady state biomass levels will also change as the growth rate changes. Figure 42 represents steady-state baseline recruitments and recruitments predicted under a 5 percent increase or 5 percent decrease in the growth rate of halibut.

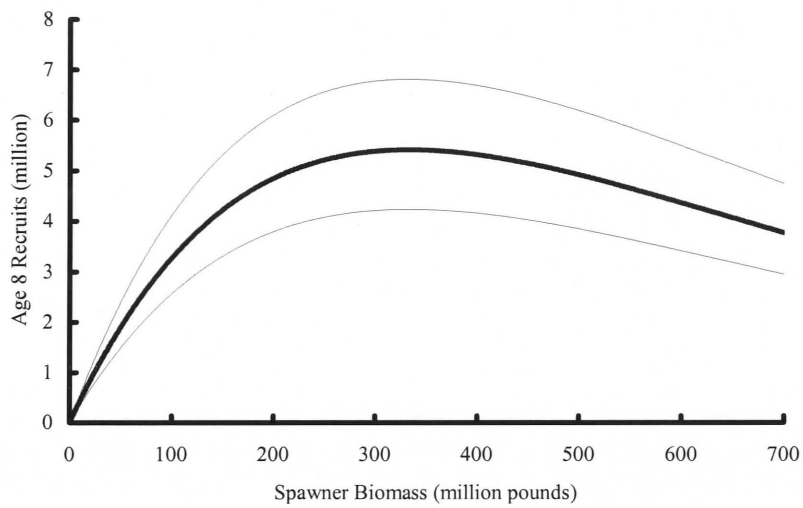


Figure 42. Coastwide recruitment of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 5 percent increase or 5 percent decrease in the growth rate of Pacific halibut.

The Bioeconomic Model

The bioeconomic model is formed as a combination of the international supply and demand model and the population model and represents the economic attributes of the set of biologically sustainable harvest levels and associated population levels. Figure 43 represents sustainable revenues to Alaska associated with different levels of coastwide biomass.

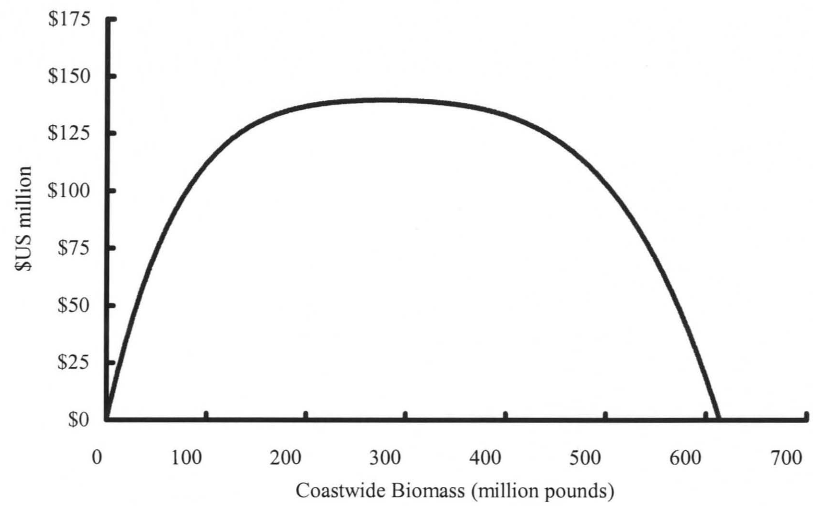


Figure 43. Simulated sustainable levels of Alaska 2002 exvessel revenue for increased (decreased) combined catch levels of Alaska, British Columbia and Washington State landings of Pacific halibut (million pounds).

Figure 43 suggests that similar levels of sustainable revenues can be achieved over a wide range of populations. This occurs because of the inverse relationship between price and quantity that helps maintain high revenues over a broad range of population levels. Indeed, there is little difference in the magnitude of sustainable revenues associated with halibut populations in the 150 to 500 million pound range. Because catch-per-unit effort is higher at higher population levels, the marginal cost of harvesting the sustainable yield is lower at population levels above the biomass level associated with the maximum sustainable yield, thus it is more profitable for the harvesting sector to harvest from a population that is above the biomass level associated with the maximum sustainable yield.

The steady state bioeconomic model can also be used to examine the economic implications of changes in the ocean environment that lead to changes in the carrying capacity for Pacific halibut. Figure 44 includes baseline steady state sustainable revenues and sustainable revenues under conditions that result in a 10 percent increase or 10 percent decrease in the carrying capacity of halibut stocks in the North Pacific.

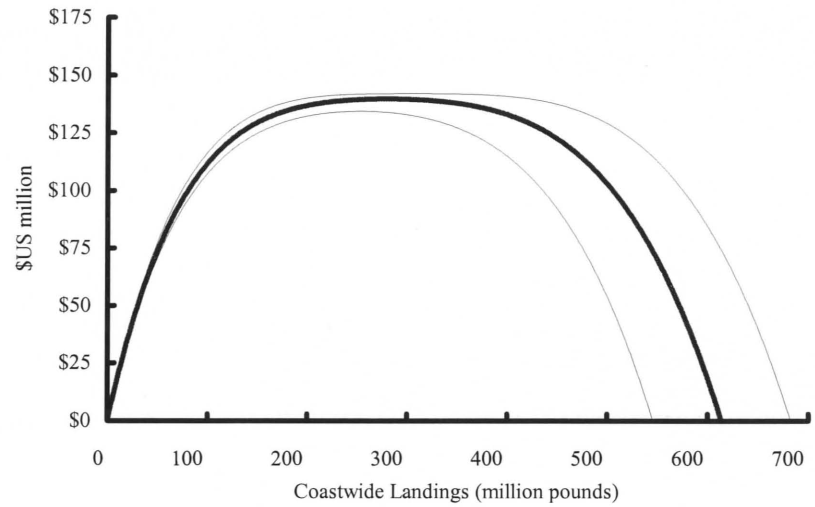


Figure 44. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in the carrying capacity of halibut in the North Pacific.

Although increases in carrying capacity lead to increased levels of sustainable harvests, the inverse relationship between exvessel price and the poundage of halibut landings means that there is little difference in total sustainable revenues over a broad range of population biomass levels and associated sustainable yields even over a plus or minus 10 percent range of variation in the overall productivity of halibut in the North Pacific (see Figure 45).

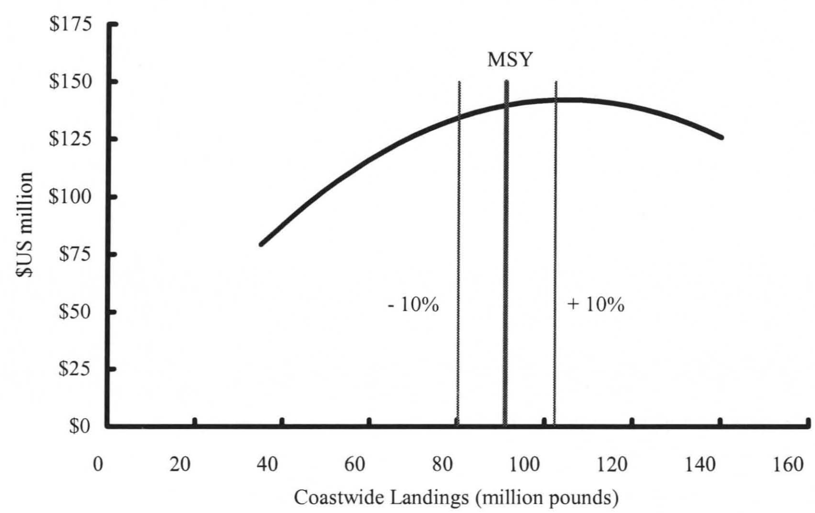


Figure 45. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in ocean productivity for Pacific halibut.

Similarly, the steady state bioeconomic model can be used to examine the economic implications of changes in the ocean environment that lead to changes in recruitment success. Figure 46 includes baseline steady state sustainable revenues and sustainable revenues under conditions that result in a 10 percent increase or 10 percent decrease in recruitment success.

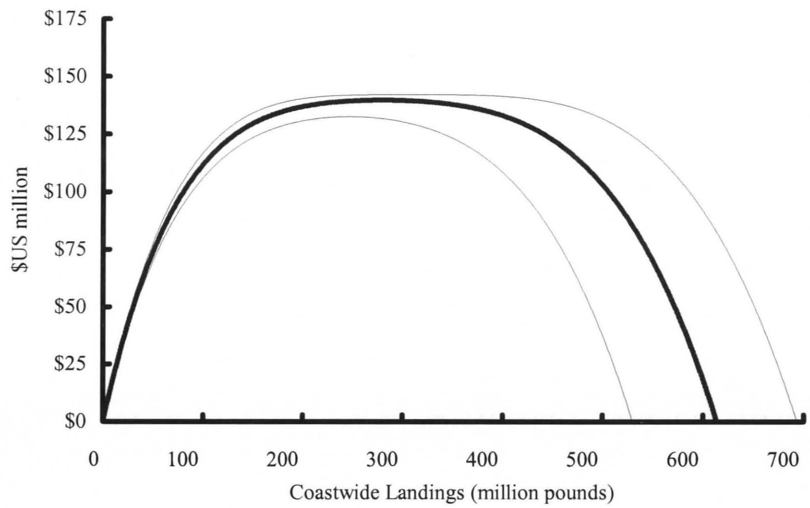


Figure 46. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in recruitment success.

Again, even though increases in recruitment success lead to increased levels of sustainable harvests, the inverse relationship between exvessel price and the poundage of halibut landings means that there is little difference in total sustainable revenues over a broad range of population biomass levels and associated sustainable yields even over a plus or minus 10 percent range of variation in recruitment success (see Figure 47).

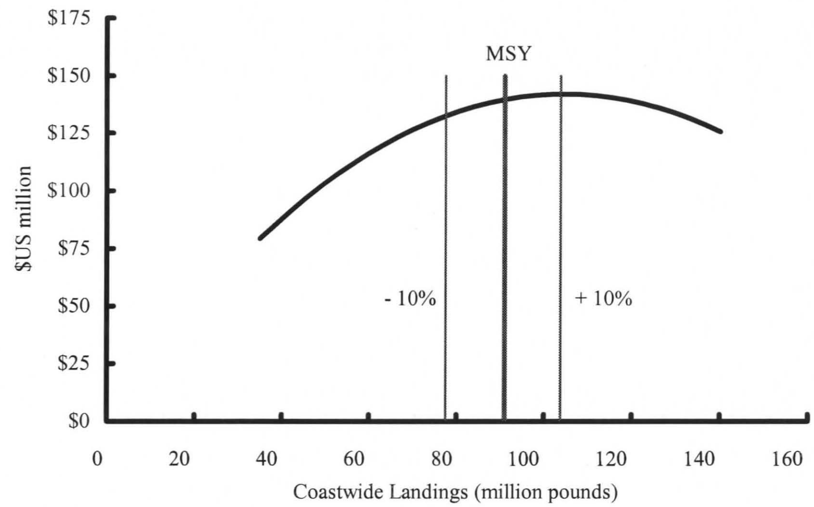


Figure 47. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 10 percent increase or 10 percent decrease in ocean productivity for Pacific halibut.

Figure 48 includes baseline steady state sustainable revenues and sustainable revenues under conditions that result in a 5 percent increase or 5 percent decrease in the growth rate of halibut.

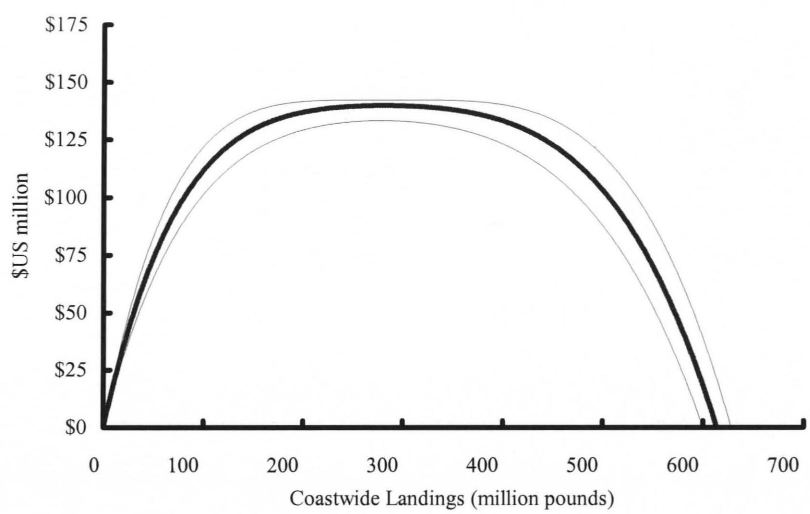


Figure 48. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 5 percent increase or 5 percent decrease in halibut growth rates.

Again, even though increases in recruitment success lead to increased levels of sustainable harvests, the inverse relationship between exvessel price and the poundage of halibut landings means that there is little difference in total sustainable revenues over a broad range of population biomass levels and associated sustainable yields even over a plus or minus 5 percent range of variation in growth rates for halibut.

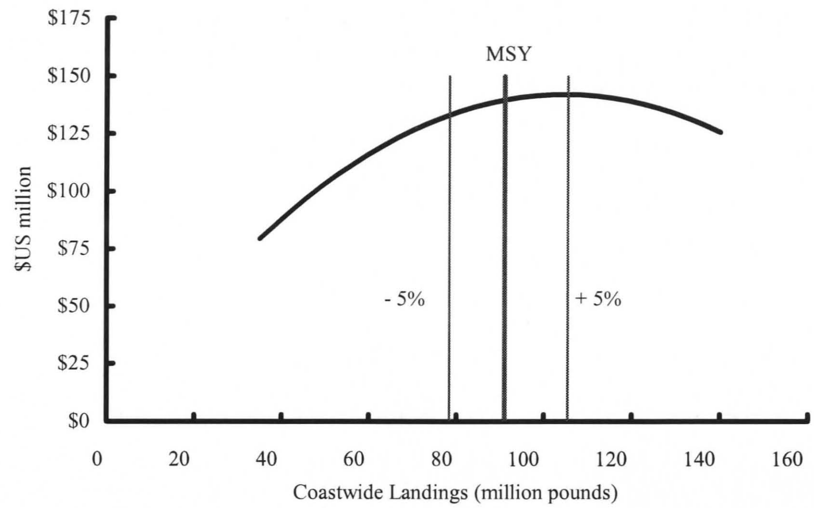


Figure 49. Simulated Alaska 2002 exvessel revenues at biologically feasible steady state sustainable coastwide landings of Pacific halibut (million pounds) under baseline conditions and conditions that result in a 5 percent increase or 5 percent decrease in halibut growth rates.

Discussion

While many of the world's fish stocks are in decline, biomass and harvest levels remain high in the Alaskan and British Columbian halibut fishery. The prices and revenues generated by the halibut industry are among all-time highs. The economic importance of this fishery to Alaska provides motivation for research to better understand the links between the biological factors leading to healthy halibut stocks and the economic characteristics of a healthy halibut industry. This report summarizes the structure of and findings based on an empirical stochastic bioeconomic simulation-optimization model of the Pacific halibut fishery.

The Alaskan and British Columbian halibut fishery is often discussed as a type case of the changes that arise following the transition from an open access derby style fishery to a slow-paced individual quota based fishery. However, there have been conflicting interpretations of these changes. Conflicting interpretations have arisen in part because of the lack of baseline analyses before the implementation of IVQs in British Columbia or IFQs in Alaska, in part because of the lack of a rigorous market model to account for simultaneous changes in market conditions and catch quotas, and because of the lack of public access to verifiable information about harvesting, processing, and storage costs before or after IVQ/IFQ implementation. Because our model accounts for simultaneous changes in demand, supply, inventories, and important market factors, such as exchange rates, that affect price and revenue formation, we are better able to differentiate between changes that are a result the implementation of IVQs/IFQs and changes that are a consequence of other sources of variations.

The introduction of IFQs in the Alaskan halibut fishery resulted in substantial increases in exvessel and wholesale prices while leaving exvessel-wholesale margins largely unchanged. Our results suggest that 90% of the wholesale price gains attributable to implementation of Alaska IFQ program accrued to fishermen. As exvessel prices were bid-up, processors who had invested in nonmalleable capital that was unsuitable for profitable operation under the longer, slower IFQ fishery, lost market share to newer and more flexible processors. The timing of IVQ/IFQ implementation particularly onerous for traditional processors because it came on the heals of the aquaculture-induced collapse of salmon prices, leaving processors increasingly reliant on revenues from processing halibut, sablefish, and other species that had been relatively inconsequential in the pre-farming heyday of salmon processing.

Alaska and British Columbia are again on the verge of watching a transformation in fisheries markets, this time driven by the growing levels of marine whitefish aquaculture. Our simulations suggest that if farmed halibut were to be sold in the same markets that wild halibut is currently sold in, the resulting exvessel revenue losses to Alaskan fishermen would be substantial. Although there are important differences between salmon and halibut markets, it would not take unthinkable amounts of farmed halibut being sold on the domestic markets to substantially affect the wild halibut industry. Will British Columbia permit halibut farming as it has permitted salmon farming? Will Alaska stand on the sidelines in halibut aquaculture as it has in salmon aquaculture? The answer to these questions will affect the degree to which Alaska and British Columbia will be benefited or harmed by halibut farming. Regardless of whether Alaska and British Columbia permit halibut aquaculture within state or territorial waters, a substantial growth of halibut aquaculture will exert downward pressure on wholesale and exvessel prices for wild halibut. Extending the wild-harvest season will slow, but not prevent, the successful penetration of farmed halibut. Nevertheless, under the restructuring that has occurred following the implementation of IVQs and IFQs, the halibut industry is in a much better position to weather competition from farmed halibut. However, it can be anticipated that the value of IVQ/IFQ shares will decline if wholesale and exvessel prices weaken due to increased halibut aquaculture. Those quota shareholders and processors who have invested under the assumption of continued elevated wholesale and exvessel prices will face financial difficulties when the value of their assets declines to reflect softer prices.

While the regional catch quotas set by the IPHC are ostensibly based on purely biological considerations, the quotas have occasionally been reduced to mitigate concerns about over-saturating halibut markets. Our market model and the bioeconomic model that incorporates our population model suggest that under current demand conditions, revenues are constrained by the sustainable yield of halibut, not by consumer demand. That is, although increases in the quantity of halibut released into the exvessel and wholesale markets will result in decreased prices, the increased quantity more than offsets the decreased price, thus revenues will increase as landings increase up to the maximum sustainable level of landings under current environmental conditions. However, because the sustainable revenue curve is relatively constant over a broad range of stock biomass levels and associated sustainable yields, the revenue losses associated with harvesting less than the maximum sustainable yield are relatively small for reductions of up to 5% of the maximum sustainable yield.. Because catch-per-unit effort is higher at higher population levels, the marginal cost of harvesting the sustainable yield is lower at population levels above the biomass level associated with the maximum sustainable yield, thus it is more profitable for the harvesting sector to harvest from a population that is above the biomass level associated with the maximum sustainable yield. This suggests that a sustainable harvest management strategy that holds halibut population biomass above the biomass that maximizes the sustainable yield will provide revenues that closely approximate the maximum sustainable revenue, while at the same time reducing harvesting costs and reducing the likelihood of unanticipated negative shocks to the magnitude of halibut populations. We intend to explore these aspects of risk in stochastic simulations we will run from the models reported in this paper.

References

Alaska's Fisherman's Journal. 1997. Halibut fleet cuts quota closer. January: 30-31.

Alaska's Fisherman's Journal. 1998. Academy gets earful on IFQs. January: 28-29.

Amerongen, J. 2002. Halibut quota bumps up. *Alaska Fisherman's Journal.* March 10 - 12.

Aoki, M. 1990. *State Space Modeling of Time Series*. Springer-Verlag, NY.

Arenson, B. 1998. Halibut farms no "threat", says Forster. *Pacific Fishing*, November: 24.

Arenson, B. 1999. Halibut farms could eclipse fishery someday, study says. *Pacific Fishing.* May: 15.

Casey, K, C. Dewees, B. Turis, and J.E. Wilen. 1995. The effects of individual transferable quotas in the British Columbia halibut fishery. *Marine Resource Economics* 10: 211-230.

Clark, W.G., and S.R. Hare. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. *North American Journal of Fisheries Management* 22: 852–862.

Conklin, J., and W. Kolberg. 1994. Chaos for halibut? *Marine Resource Economics* 9: 159-182.

Cook B.A. and P. Copes. 1987. Optimal levels for Canada's Pacific halibut catch. *Marine Resource Economics* 4: 45-61.

Criddle, K.R. 1994. Economics of resource use: a bioeconomic analysis of the Pacific halibut fishery. Pages 37-52 in D. Shaw (Editor). *Proceedings of the Fourth International Symposium of the Conference of Asian and Pan-Pacific University Presidents*. Alaska Sea Grant, Fairbanks AK.

Criddle, K.R., and A.M. Havenner. 1989. Forecasting halibut biomass using system theoretic time series methods. *American Journal of Agricultural Economics* 71: 422-431.

Criddle, K.R., and A.M. Havenner. 1991. An encompassing approach to modeling fishery dynamics: modeling dynamic nonlinear systems. *Natural Resource Modeling* 5: 55-90.

Crutchfield, J.A., and A. Zellner. 1962. Economic aspects of the Pacific halibut fishery. *Fishery Industrial Research* 1: 1-73. (reprinted in 2003 by University of Chicago Press).

Department of Community and Economic Development (DCED). 2001. State of Alaska FY2003 Governor's operating budget. Commissioner's Office, Component Budget Summary. Juneau, AK.

Dinneford, E, K. Iverson, B. Muse, and K. Schelle. 1999. Changes under Alaska's IFQ program 1995 to 1998. Commercial Fisheries Entry Commission, Juneau, AK.

Doherty, T.J. 1990. ITQs for British Columbia's halibut fishery? *Pacific Fishing.* August: 26-28.

Forster 1999. Halibut farming: its development and likely impact on the market for wild Alaska halibut. Report to the Alaska Department of Commerce.

Gilason, G.S., and Associates. 2001. *Halibut and Sablefish Aquaculture in BC.* Prepared for the BC Ministry of Agriculture, Food and Fisheries, Victoria, BC, December.

Greene, W.H. *Econometric Analysis 2^{ed}*. Macmillian Publishing Co. New York. 791p.

Havenner, A.M., and M. Aoki. 1991. State space modeling of multiple time series. *Econometric Reviews* 10: 1-59.

Herrmann, M. 1990. *An Economic Analysis of World Salmon Markets: Effects of Salmon Farming*. Ph.D. Dissertation. Washington State University. 789p.

Herrmann, M. 1996. Estimating the induced price increase for Canadian Pacific halibut with the introduction of the individual vessel quota program. *Canadian Journal of Agricultural Economics* 44: 151-164.

Herrmann, M. 2000. The individual vessel quota price induced effects for Canadian Pacific halibut: before and after Alaska IFQs. *Canadian Journal of Agricultural Economics* 48: 195-210.

Homans, F.R. 1993. *Modeling Regulated Open Access Resource Use*. Ph.D. Dissertation, Department of Agricultural Economics, University of California, Davis.

IPHC. (International Pacific Halibut Commission). 1996. Annual Report 1995. IPHC, Seattle, WA.

IPHC. (International Pacific Halibut Commission). 2000. Annual Report 1999. IPHC, Seattle, WA.

IPHC. (International Pacific Halibut Commission). 2003. Annual Report 2002. IPHC, Seattle, WA.

Jystad, P.T. 2003. Norwegians invest in crab farming. *Intrafish*. August: 23.

Kennedy, P. 1983. Logarithmic dependent variables and prediction bias. *Oxford Bulletin of Economics and Statistics* 45: 389-392.

Knapp, G. 1997. Alaska halibut markets and the Alaska halibut IFQ program. Final report for Saltonstall-Kennedy Program (grant # NA37Fdo184), Anchorage, AK.

Lin, B.-H, H.S. Richards, and J.M. Terry. 1988. An analysis of the exvessel demand for Pacific halibut. *Marine Resource Economics* 4: 305-314

Love, A.H, D.M. Burton, G. Sylvia, and S. Lei. 1995. Regulatory controls and market power exertion: a study of the Pacific halibut industry. *Natural Resource Modeling* 9: 229-254.

Loy, W. 2002b. Here come the fish farmers. *Pacific* Fishing. October: 36-37.

Loy, W. 2002a. A new threat: Will fish farms decimate Alaska's booming halibut fishery the way they did the salmon fishery? *Anchorage Daily News*. August 18.

Matulich, S.C. 2002. Testimony of Scott C. Matulich before the Subcommittee on Fisheries Conservation, Wildlife, and Oceans. U.S. House of Representatives. February 13.

Matulich, S.C., and M. Clark. 2003. North Pacific halibut and sablefish IFQ policy design: quantifying the impacts on processors. *Marine Resource Economics* 18: 149-167.

Meloy, B., and M. Drouin. 2003. Stats pack: halibut. *Pacific Fishing Magazine.* March: p.45-46.

Meloy, B. Stats pack 2004: Stats pack: halibut. *Pacific Fishing Magazine.* March: p.34-35.

NPFMC (North Pacific Fishery Management Council). 1991. Sablefish and halibut fixed gear fisheries individual fishery quota system draft implementation plan. North Pacific Fishery Management Council, Anchorage, AK.

NPFMC (North Pacific Fishery Management Council). 1997. Draft environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed regulatory amendments to implement management alternatives for the guided sport fishery for halibut off Alaska, North Pacific Fishery Management Council, Anchorage, AK.

NPFMC (North Pacific Fishery Management Council). 2000. Draft environmental assessment/regulatory impact review/initial regulatory flexibility analysis for a regulatory amendment to implement management measures under a guideline harvest level and/or moratorium for halibut in areas 2C and 3A. North Pacific Fishery Management Council, Anchorage, AK.

NRC (National Research Council Committee to Review Individual Fishing Quotas). 1999. *Sharing the Fish: Toward a National Policy on Individual Fishing Quotas*. National Research Council, National Academy Press.

Pacific Fishing. 1996. Stats Pack: halibut. March: 90-91.

Pautzke, C.G., and C.W. Oliver. 1997. Development of the individual fishing quota program for sablefish and halibut longline fisheries off Alaska. North Pacific Fisheries Management Council, Anchorage, AK

Sackton, J. 2003. 2003 will be 'defining year' for Alaska Fisheries. Seafoood.COM News. www.seafood.com/news/current/86535.html.

SAS Institute. 2004. *The SAS System for Windows.* V. 8.02.

Schellberg, T. 1993. The problem of nonmalleable capital revisited: a study of the Pacific halibut fishery. *Natural Resource Modeling* 7: 245-277.

Seafood Business. 2000. Buyer's guide: Pacific halibut. October: 42-49.

Seafood Leader. 1991. Halibut. March/April. 37-48.

Seafood Leader. 1994. Halibut. September/October. 51-52.

Seafood Leader. 1995. Finfish: halibut. 75-81.

Shaw, D. 1994. Derby days are done, but are ITQs the answer?. *Seafood Leader.* November/December: 107-113.

Spiess, B. 1998. Halibut stock is up – quota rises to 72 million pounds. *Pacific Fishing.* March: 32-33.

Squires, D, J. Kirkley, and C.A. Tisdell. 1995. Individual transferable quotas as a fisheries management tool. *Reviews in Fisheries Science* 3: 141-169.

Sullivan, P.J, A.M. Parma, and W.G. Clark. 1999. The Pacific halibut stock assessment of 1997. Scientific Report No. 79, International Pacific Halibut Commission. Seattle, WA.

Warren, B. 1998. Seafood report. *Pacific Fishing*. December p9.

Welch, L. 1997. It's a halibut heyday: fishermen are reaping the benefits of an IFQ system. *National Fisherman.* June: 16-18.

Welch, L. 2002. Fish farmers switch from halibut to cod as flatfish pose problems. *Alaska Journal of Commerce.* October. www.alaskajournal.com/stories/102102/fis_102102.shtml.

Welch, L. 2003. The farm report: halibut down, cod up. *Alaska Fisherman's Journal.* February: 34, 71.

Wilen J.E., and F.R. Homans. 1994. Marketing losses in regulated open access fisheries. *Proceedings of the Sixth Conference of the International Institute of Fisheries Economics and Trade.* Ed. M. Antona, J. Catanzano, and J.G. Sutinen. Paris, France.

Wyman, J. 2000. Less halibut, more controversy: commission weighs live halibut plan. *Pacific Fishing.* March: 32-33, p135.

Appendix A: Goodness-of-Fit Statistical Equations

A_t are the actual values at time t and F_t are the forecasted values at time t.

Correlation Coefficient

$$r = \left(\frac{1}{(n-1)}\right)\sum\left(\frac{F_t - \bar{F}}{s_F}\right)\left(\frac{A_t - \bar{A}}{s_A}\right)$$

where s_F and s_A are the standard deviations of the actual and forecasted values

Mean Absolute Percent Error

$$MA\%E = \left(\frac{100}{n}\right)\sum\left(\frac{|F_t - A_t|}{A_t}\right)$$

Root Mean Squared Percent Error

$$RMS\%E = 100\sqrt{\left(\frac{1}{n}\right)\sum((F_t - A_t)/A_t)^2}$$

Theil U Decomposition:

Bias Proportion $$UM = \frac{(\bar{F} - \bar{A})^2}{\sum(F_t - A_t)^2 / n}$$

Variance Proportion $$UR = \frac{(s_F - s_A)^2}{\sum(F_t - A_t)^2 / n}$$

Covariance Proportion $$UD = \frac{2*(1-r)s_F s_A}{\sum(F_t - A_t)^2 / n}$$

Theil U1 $$U1 = \frac{\sum(F_t - A_t)^2 / n}{\sqrt{1/n\sum_{t=2}^{n}[(A_t)^2}}$$

Appendix B: Population Model Data

Table 11. Landings of Pacific halibut (million pounds).

	WA	CA	AK	Total
1974	0.515	4.624	16.167	21.306
1975	0.460	7.127	15.278	22.865
1976	0.238	7.283	14.797	22.318
1977	0.207	5.427	12.430	18.064
1978	0.097	4.607	13.034	17.738
1979	0.046	4.857	15.069	19.972
1980	0.022	5.650	11.432	17.104
1981	0.202	5.654	16.789	22.645
1982	0.211	5.236	20.423	25.870
1983	0.265	5.436	31.911	37.612
1984	0.431	9.054	35.420	44.905
1985	0.493	10.389	45.211	56.093
1986	0.581	11.225	57.819	69.625
1987	0.592	12.246	56.511	69.349
1988	0.486	12.858	61.044	74.388
1989	0.472	10.431	56.017	66.920
1990	0.203	8.574	52.590	61.367
1991	0.233	7.191	49.520	56.944
1992	0.282	7.626	51.813	59.721
1993	0.366	10.573	48.104	59.044
1994	0.380	9.916	44.404	54.700
1995	0.270	9.524	33.978	43.772
1996	0.290	9.557	37.272	47.119
1997	0.760	12.420	52.293	65.473
1998	0.460	13.150	55.126	68.736
1999	0.454	12.704	60.099	73.257
2000	0.483	10.811	55.629	66.923
2001	0.680	10.288	58.897	69.865

Table 12. Coastwide (Alaska, British Columbia, Washington) removals of Pacific halibut (million pounds).

	Commercial	Sport	Personal Use	Wastage	Bycatch	Total Removals
1974	21.310	0.000	0.000	0.000	10.708	32.018
1975	27.620	0.000	0.000	0.000	6.973	34.593
1976	27.540	0.000	0.000	0.000	7.562	35.102
1977	21.880	0.289	0.000	0.000	8.272	30.441
1978	22.000	0.378	0.000	0.000	8.166	30.544
1979	22.540	0.563	0.000	0.000	10.207	33.310
1980	21.870	0.845	0.000	0.000	12.695	35.410
1981	25.720	1.112	0.000	0.000	10.642	37.474
1982	29.010	1.299	0.000	0.000	8.574	38.883
1983	38.380	1.616	0.000	0.000	6.517	46.513
1984	44.960	1.840	0.000	0.000	5.697	52.497
1985	56.110	2.355	0.000	1.600	4.385	64.450
1986	69.620	3.177	0.000	3.200	4.501	80.498
1987	69.480	3.509	0.000	2.722	5.906	81.617
1988	74.350	4.877	0.000	1.953	6.669	87.849
1989	66.930	5.233	0.000	2.025	5.361	79.549
1990	61.590	5.586	0.000	1.655	9.149	77.980
1991	57.081	6.509	2.000	2.227	9.385	77.202
1992	59.891	6.179	1.100	1.255	8.943	77.368
1993	59.268	7.725	0.920	0.814	5.671	74.398
1994	54.731	7.065	0.920	1.289	7.996	72.001
1995	43.882	7.447	0.528	0.257	6.942	59.056
1996	47.343	8.083	0.528	0.347	7.279	63.580
1997	65.197	9.025	0.528	0.290	7.106	82.146
1998	69.757	8.586	0.528	0.359	7.636	86.866
1999	74.305	7.379	0.730	0.395	7.011	89.820
2000	68.305	9.016	0.730	0.222	6.615	84.888
2001	70.715	8.106	0.730	0.238	7.088	86.877

Table 13. Data used for biological modeling

	Coastwide Total Removals	Area 2B, 2C, 3A Age 8 recruits (million)	Area 2B, 2C, 3A Age 8+ biomass (million lb net)	Pacific Decadal Oscillation
1974	32.018	1.290	140.400	-0.34
1975	34.593	1.520	145.590	-1.10
1976	35.102	1.690	152.180	0.01
1977	30.441	1.870	166.520	0.23
1978	30.544	2.310	190.800	0.24
1979	33.310	2.270	218.100	0.34
1980	35.410	2.740	242.570	0.60
1981	37.474	3.420	273.560	0.92
1982	38.883	3.350	308.480	0.11
1983	46.513	3.620	345.130	1.65
1984	52.497	4.380	364.530	0.84
1985	64.450	5.810	393.120	0.45
1986	80.498	4.930	425.470	1.24
1987	81.617	5.930	432.510	1.82
1988	87.849	6.700	438.030	0.53
1989	79.549	5.310	429.460	-0.18
1990	77.980	4.830	426.060	-0.36
1991	77.202	6.390	420.790	-0.42
1992	77.368	5.690	411.350	0.93
1993	74.398	4.720	400.560	1.42
1994	72.001	4.560	425.150	-0.15
1995	59.056	8.590	443.530	0.64
1996	63.580	7.310	458.810	0.64
1997	82.146	4.830	450.710	1.46
1998	86.866	4.380	426.670	0.25
1999	89.820	3.260	392.710	-1.06
2000	84.888	3.480	358.570	-0.59
2001	86.877	3.070	334.560	-0.56

Table 14. IPHC commercial catch limits (million pounds) by regulatory area

	Regulatory Areas									
	2A	2B	2C	3A	3B	4A	4B	4CDE	Area 4	Total
1982	0.200	5.400	3.400	14.000	3.000				1.500	27.500
1983	0.200	5.400	3.400	14.000	5.000	1.200	0.800	0.600	2.600	30.600
1984	0.300	9.000	5.700	18.000	7.000	1.200	1.100	0.850	3.150	43.150
1985	0.500	10.000	9.000	23.000	9.000	1.700	1.300	1.250	4.250	55.750
1986	0.550	11.200	11.200	28.100	10.300	2.000	1.700	1.350	5.050	66.400
1987	0.550	11.500	11.500	31.000	9.500	1.750	1.750	1.275	4.775	68.825
1988	0.750	12.500	11.500	36.000	8.000	1.900	2.000	1.500	5.400	74.150
1989	0.650	10.000	9.500	31.000	8.500	1.800	1.900	1.300	5.000	64.650
1990	0.520	7.800	8.000	31.000	7.200	1.500	1.500	1.100	4.100	58.620
1991	0.450	7.400	7.400	26.600	8.800	1.700	1.700	1.300	4.700	55.350
1992	0.650	8.000	10.000	26.600	8.800	2.300	2.300	1.730	6.330	60.380
1993	0.600	10.500	10.000	20.700	6.500	2.020	2.300	1.720	6.040	54.340
1994	0.550	10.000	11.000	26.000	4.000	1.800	2.100	1.500	5.400	56.950
1995	0.520	9.520	9.000	20.000	3.700	1.950	2.310	1.660	5.920	48.660
1996	0.520	9.520	9.000	20.000	3.700	1.950	2.310	1.660	5.920	48.660
1997	0.700	12.500	10.000	25.000	9.000	2.940	3.480	2.580	9.000	66.200
1998	0.820	13.000	10.500	26.000	11.000	3.500	3.500	3.500	10.500	71.820
1999	0.760	12.100	10.490	24.670	13.370	4.240	3.980	4.450	12.670	74.060
2000	0.830	10.600	8.400	18.310	15.030	4.970	4.910	4.450	14.330	67.500
2001	1.140	10.510	8.780	21.890	16.530	4.970	4.910	4.450	14.330	73.180
2002	1.310	11.750	8.500	22.630	17.130	4.970	4.180	4.450	13.600	74.920
2003	1.310	11.750	8.500	22.630	17.130	4.970	4.180	4.450	13.600	74.920
2004	1.480	13.800	10.500	25.060	15.600	3.470	2.810	3.785	10.065	76.505