BIOECONOMIC MODELING OF A MULTICOHORT FISHERY: IMPLICATIONS FOR MANAGING THE ALASKAN KING CRAB INDUSTRY

By

Jeffrey E. Hanson
Scott C. Matulich
and
Ron C. Mittelhammer

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The authors are Assistant Professor, Department of Fisheries and Wildlife, Michigan State University, East Lansing; and Professors, Department of Agricultural Economics, Washington State University, Pullman, respectively. This research was funded, in part, by the Alaska Department of Fish and Game and the National Marine Fisheries Service. This research is reported under project number 0691, Agricultural Research Center, College of Agriculture and Home Economics, Washington State University.

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Abstract

The Alaskan king crab industry collapsed in the early 1980s due to stock declines and overexploitation. That collapse caused a transition within the industry and motivated analysis of the fishery. Bioeconomic modeling of the industry is presented, illustrating the importance of incorporating both biological and economic factors into the management process.

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Introduction

The Alaskan king crab industry is in a transition period, recovering from a dramatic boom-bust cycle. Statewide harvests began an unprecedented period of growth in 1969 that continued through 1980. Harvests more than tripled, culminating in record catches of 185.7 million pounds. Growth in the Bristol Bay fishery management area off the western coast of Alaska was largely responsible for the boom. Bristol Bay harvests rose from 8.6 million pounds in 1970 to the record catch of 130 million pounds in 1980. Within 3 years, however, the industry collapsed. King crab stocks were so scarce that the Alaska Board of Fisheries (ABF) instructed the Alaska Department of Fish and Game (ADFG) to close the Bristol Bay fishery.[1] Statewide harvests plummeted to 26.9 million pounds. A further reduction of 10 million pounds occurred by 1985 (U.S. Department of Interior 1947–1975; ADFG 1969–1983, 1970–1983).

The economic wake of this collapse has been extensive, involving virtually every participant in the fishery. Exvessel revenues to fishermen fell by more than 50 percent between 1980 and 1983, dropping by 93.2 million dollars. Processor sales dropped 178.0 million dollars (a 60 percent reduction), while sales from wholesalers declined by 304.2 million dollars (a 66 percent reduction). Multimillion dollar fishing vessels were idled, others shifted into different fisheries; processing plants closed and an industry-wide restructuring commenced.

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[1]The Alaska Board of Fisheries is responsible for policy formulation and regulation of all commercial and sport fisheries in Alaskan controlled waters. The Alaska Department of Fish and Game reports to the Board in an advisory capacity and administers all policies enacted by the Board.

The significance of the collapse may be placed in perspective by considering that the king crab fishery was the second most valuable Alaska seafood industry between 1968 and 1983. Only the combined value of all six salmonid species harvested in Alaska exceeded that of king crab (ADFG 1969–1983). Yet, the statewide king crab catch rarely exceeded one-third the total catch of salmon, by weight.

Total impact of the collapse extends well beyond the Alaskan economy. Butcher et al. (1981) identified direct linkages between the shellfish sector and the economy of the Puget Sound area in western Washington. Only 32 percent of total shellfish revenues were returned to the Alaskan economy in direct purchases of goods and services. Much of the remaining 68 percent were spent in the Seattle area for vessel maintenance/construction, gear and supplies, and general consumer goods. Moreover, most of the processing and cold storage firms are based in the Seattle area. The diminished flow of processed king crab products to domestic and foreign markets also caused a tripling of nominal wholesale and retail prices between 1980 and 1986 (National Marine Fisheries Service 1969–1984).

Short of blaming the open access milieu of this common property fishery, specific causes or contributing factors to the collapse must be identified if policymakers are to contribute to a recovery. Resolution of the underlying bioeconomics characterizing the Alaskan king crab industry is essential in this regard. Such a bioeconomic analysis of the industry is reported by Hanson (1987) and Matulich, Hanson and Mittelhammer (1987a, b, c).[2] This paper presents an overview of the bioeconomic model and the major results from historical and future simulation of alternative policy

[2]The first report by Matulich, Hanson and Mittelhammer (1987a) presents a recursive, age-structured biological model of Alaskan king crab. The second report (1987b) details the economic/market submodels, from initial harvest to final consumption. The biological and economic submodels are then integrated in the third report (1987c) to simulate industry responses/behavior under a variety of historical and potential future policy scenarios.

regimes. Simulation centers on industry response to various minimum size limit policies. Special attention is given to the Bristol Bay harvest area because of its dominant role in the recent industry "boom and bust".[3]

Overview of the Bioeconomic Model

The king crab industry can be viewed in a market equilibrium context involving supply and demand at two levels of the market: an input or raw crab market model and a final processed product market model. See Figure 1. The explicit interaction between management, biology, harvest and the market for king crab shown in this figure accounts for the feedback inherent in the overall bioeconomic system for a single year (July 1–June 30). A brief summary of each component is presented below as an overview of this complex commercial fishery model. Details pertaining to theoretical underpinnings and empirical estimation of all submodels are discussed in Matulich, Hanson and Mittelhammer (1987a, b, c).

Management provides an external control on industry behavior and allocation of the king crab resource. A variety of regulations are employed in the management of this fishery, including gear restrictions and exclusive registration in selected harvest areas. Sex, size and season length restrictions, however, are the principal regulations that are used actively to manage the Bristol Bay fishery. Annual decisions regarding these regulatory controls historically have been based on a combination of one–period–ahead stock forecasts and intraseasonal industry performance. Fishery policy has never explicitly recognized the dynamic market feedback effects among annual harvest policies, future harvestable stocks, current prices and future consumer behavior. In fact, economics has never played a prominent policy role in this once lucrative

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[3]The Bristol Bay harvest area contributed nearly 70 percent of total catch during the period from 1970–1980 (ADFG 1970–1983).

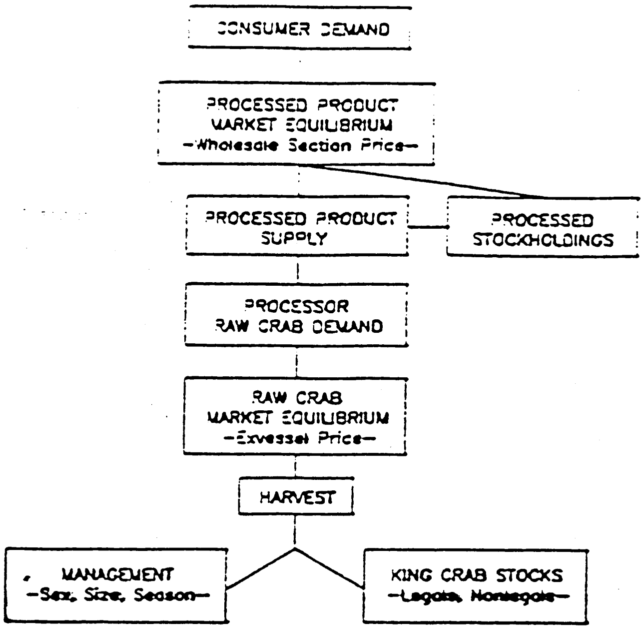

Figure 1. Components of market equilibrium in the Alaskan king crab industry.

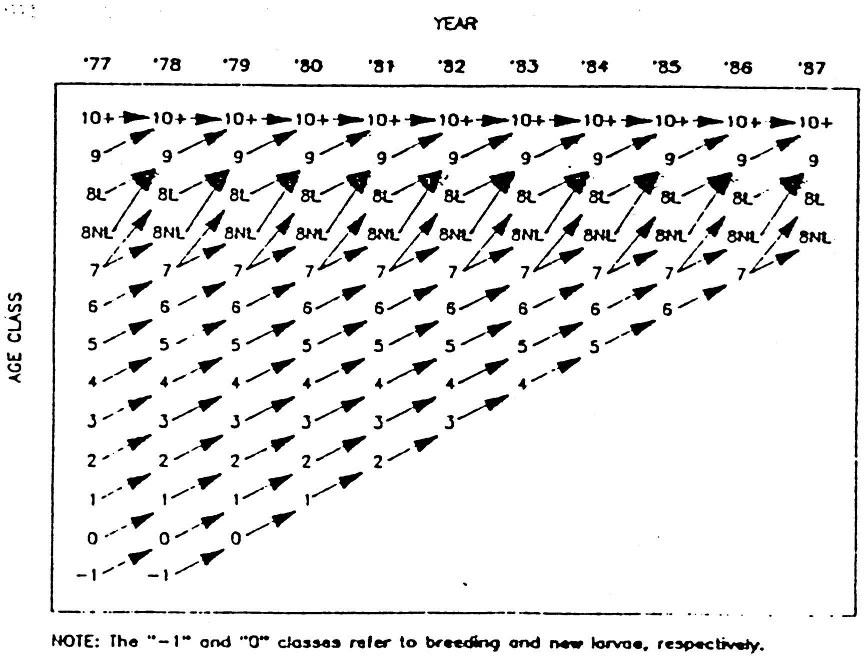

Figure 2. Recursive age-structured character of red king crab populations.

fishery.[4]

The importance of formulating policies that explicitly recognize the extremely long and complicated lags that characterize king crab population dynamics, and thus, the long range economic health of this industry, is illustrated in Figure 2. The beginning stock of legal (harvestable) crab in 1987 is shown to consist of three age classes of male crab: 8 year old legals (8L), 9 year olds (9) and 10 to 14 year olds (10–14). The recursion illustrated in this figure shows the pass-through or pipeline of unharvested legal (L) and nonlegal (NL) crab in the previous year that comprise the beginning stock of current year age classes. For example, both the current stock of $8L_t$ and of $8NL_t$ king crab were formed from surviving 7_{t-1} the previous period. Likewise, 9_t crab were formed from $8L_{t-1}$ and $8NL_{t-1}$; $10-14_t$ were formed from 9_{t-1} and $10-14_{t-1}$. Carrying this recursion back to parental stocks, 8 year old recruits in 1987 were created by sexually mature parent stocks 9 years earlier (1978). Nine year old recruits in 1987 are the progeny of adult crab stocks in 1977 (10 years earlier). The abundance of 10 year olds in 1987 is a function parental stock 11 years earlier, and so on.

Figure 2 clearly illustrates there are three dimensions to current period decisions concerning size limit policy that should determine the magnitude of 8L versus 8NL. Eight year old potential recruit class crab can have value as: (1) currently harvestable stocks, (2) future harvestable stocks (up to 6 years into the future), and (3) parent stocks of crab that can be harvested 9 to 15 or 16 years into the future. Evaluation of the implied biological and economic tradeoffs is precisely what is

[4]The general management objectives of the Alaska Board of Fisheries have been almost exclusively biological in nature, emphasizing conservation. The twofold objectives are: "(1) to establish a stable fishery, insofar as possible, eliminating the extreme fluctuations in catch that have characterized this fishery, and (2) to develop and maintain a broad based age structure of legal size male king crab, insuring both breeding success and the availability of a wide spectrum of year classes to the fishery" (ADFG 1985).

required by the Fishery Conservation and Management Act of 1976 (Public Law 94-265) and is the general objective of the composite bioeconomic analysis.

The biological response submodel for red king crab in Bristol Bay consists of seven estimated recruitment/growth functions and several definitional identities. The seven behavioral relationships combine to form a recursive, age-structured growth model for sexually mature male and female king crab biomass. The sexes are modeled separately to reflect the impact of males-only harvest regulations on population abundance. Primary research emphasis is given to the male equations because of this regulation.

Three classes of recruitment/growth relationships are formulated: Ricker (1954) spawner-recruit models, trajectory adjusted intrinsic recruitment (TAIR) models, and growth/mortality models similar to Deriso (1980). Individual single age-class equations are derived for beginning stocks of 5, 6, 7 and 8 year old males, and for 5 year old females. Aggregate cohort equations are estimated for 9 to 14 year old males and for 6 to 14 year old females. Statistical significance, overall goodness of fit and ability of these behavioral equations to predict history are good (see Matulich et al. 1987a). The beginning stock of legal king crab is defined as the sum of all 9 to 14 year old male crab and that portion of the 8 year old males allowed to be harvested by the ADFG size limit. Nonlegal crab are defined as all sublegal males and all females.

The biological submodel is linked to the market submodel through a lagged harvest relationship. Fishermen provide the primary supply of king crab by applying harvest effort to the beginning crab stock. Their behavior is captured by three behavioral relationships: total quantity harvested, effort, and fleet size. Total quantity harvested is formulated as a production function that depends upon total fishing effort and the beginning stocks of both legal and nonlegal crab. The abundance of legal crab at the start of the next season, in turn, is affected by current total harvest. Total effort, as measured by the number of potlifts during the season, is a function of fleet size, abundance of legal males, and the current price received, i.e., exvessel price. Season length and the harvest guideline control total harvest through the effort relationship.[5] Fleet size depends on existing capital stock, abundance of legal crab, and seasonal revenue expectations based on previous season's total harvest revenue.

An exvessel price offer function is used to incorporate processors' derived demand for raw crab into the market equilibrium model. Fishing commences when an initial exvessel price is negotiated between fishermen and processors; subsequent price changes reflect cumulative harvest and overall crab quality as the season progresses. The processors' bid or offer takes into account expected wholesale prices, processing costs and the costs of fishing. Accordingly, the seasonal average exvessel price offer relation is modeled as a bilateral monopoly price.

The wholesale market for king crab translates the processors' derived demand for raw crab into a supply of processed crab that confronts final demand for processed crab products. The supply of processed king crab is modeled as an inverse supply relationship linking total processed production to changes in inventory holdings. A minor quantity of imports are included as an exogenous injection to total supply. Production indirectly depends on holdover inventories, input prices, processing capacity, and market price expectations through the wholesale price relationship. Inventory holdings are modeled as a combination of transactional and speculative motives. Consequently, current production, future wholesale price expectations and the opportunity costs of holding inventories enter the holdings equation.

Domestic consumption behavior is a function of the wholesale crab price, the

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[5]The harvest guideline is a regulatory instrument used by the Alaska Board of Fisheries to control total harvest. The guideline is announced prior to the start of each season, placing an upper limit on total allowable catch.

price of a substitute good, and disposable per capita income; exports are treated as exogenous. Domestic consumption and export demand equilibrate with supply through the wholesale price.

Simulations

A variety of historical and future management scenarios were simulated using the estimated king crab bioeconomic model.[6] Industry response to actual management and policy conditions during the period from 1978 to 1983 was simulated to measure overall significance and predictive accuracy of the estimated model. Theil's forecast error statistics were used to evaluate predictive accuracy (Theil 1961, 1966). The inequality coefficient (Theil's U-statistic) ranged from 0.018 to 0.354 and averaged 0.113. The ex post forecasts of each endogenous variable deviated less than 10 percent, on average, from historically observed values. Based on these results, the estimated system of equations should produce fairly reliable and realistic simulations of alternative historical and future management scenarios so long as no major structural changes occur within the fishery.

Several historical simulations were conducted that focused on more restrictive harvest management preceding and during the period of rapid stock declines. These simulations provide insight into how different regulations would have affected crab resource availability and market conditions within the industry. It suffices to discuss the results of a single, alternative management scenario.

The minimum legal size limit was raised to prevent any harvest of 8 year old males. Actual size limit regulations permitted retaining approximately 12 percent of the 8 year old males. Each season was reduced to 80 percent of its historical length. All other predetermined variables remained at their historical values.

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[6]The simulations were solved using the SIMNLIN procedure in the SAS Institute's econometric software package (ETS).

Predicted harvest revenues under the more conservative (simulated) size limit strategy are illustrated in Figure 3. The simulated values are compared with actual harvest revenues observed during the same time period. Revenues to fishermen would have risen in all but one year despite the curtailed harvests imposed by more restrictive size limit regulations. This finding draws particular attention to the importance of market feedback effects of policy instruments designed primarily to manage the biological stocks. The more conservative harvest policy would have produced a larger present value revenue stream to fishermen over the simulation period. Fishermen would have earned 21.3 percent additional revenue under the conservative scenario in contrast to the actual revenue stream produced during the same period (410.6 million dollars versus 338.5 million dollars, 1978 dollars). The financial welfare of fishermen would have been enhanced even though fewer crab would have been harvested.

Results of this simulation suggest that the 1983 closure of the Bristol Bay fishery could have been prevented. The industry might have experienced some decline, but the destabilizing impacts resulting from complete closure may have been avoided. Agency managers and policymakers, however, could only know this in hindsight. There were inadequate time series data to develop a bioeconomic forecast model of the type used here.

These results should not be construed as the optimal policy regime. The long lags in this bioeconomic model prevented altering harvest policies that would have affected parent stocks that spawned the harvestable crab in 1978 to 1983. Accordingly, this simulation represents only the direct, short-term influence on exploitation. It does not assess whether the rapid decline of 1981–1983 could have been mitigated by alternative harvest policies affecting parent stocks 9 to 16 years earlier; different management during the early 1970s may have enhanced recruitment

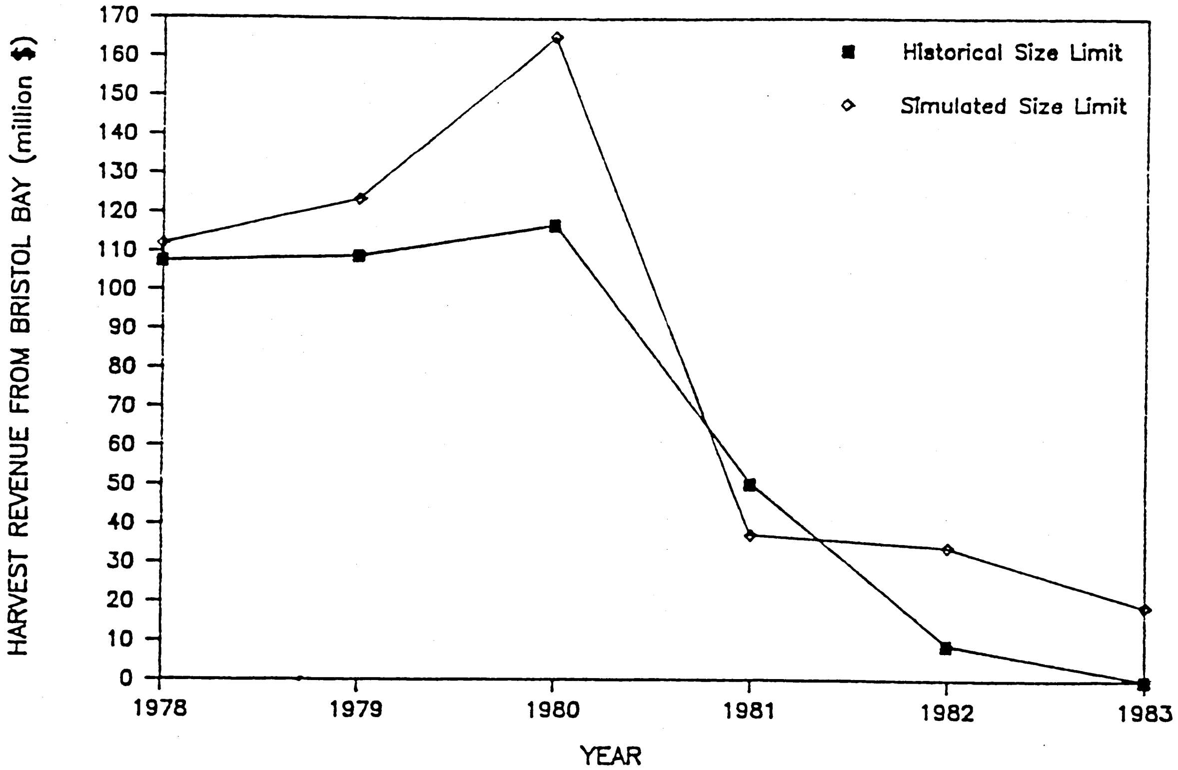

Figure 3. Comparison of the simulated conservative size limit (0%) management policy harvest revenues with the historical values, 1978–1983.

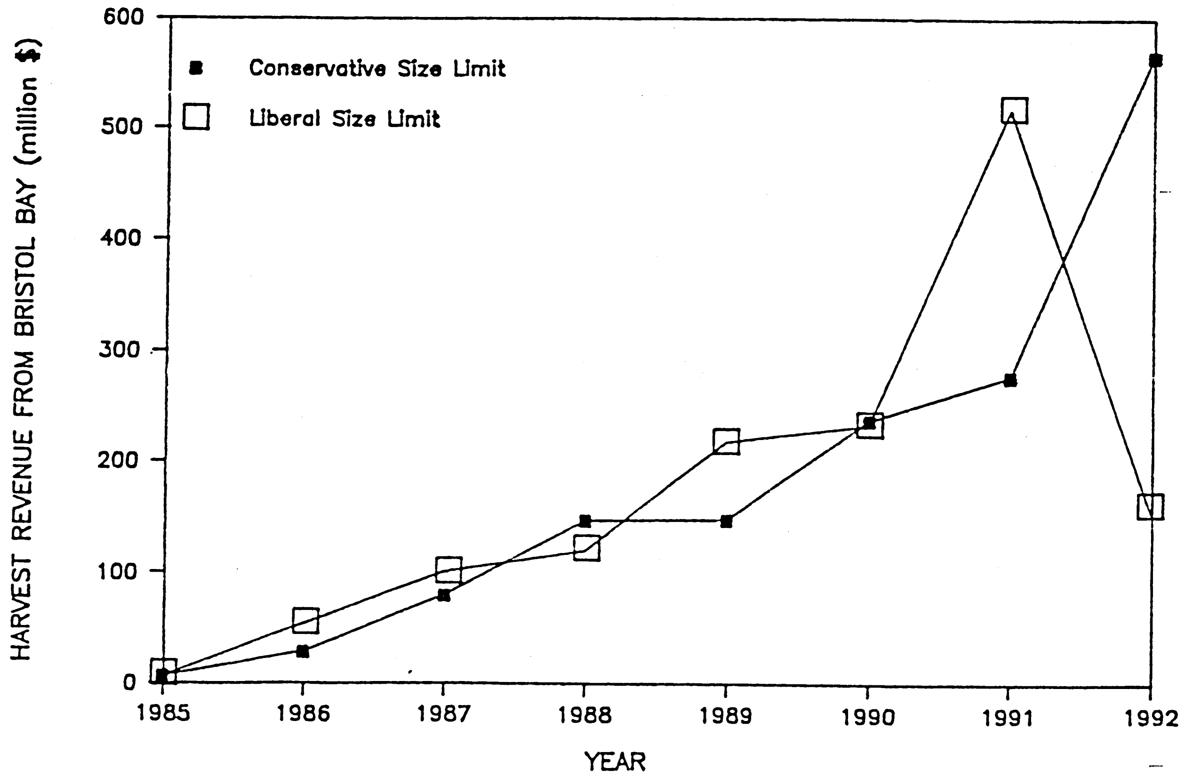

Figure 4. Comparison of simulated future harvest revenues using conservative (0%) and liberal (100%) size limit policies, 1985–1992.

in the early 1980s and produced more stable population levels. Future simulation, however, did provide insight into the long-term affects of conservative management on stock conditions.

An eight year period beginning in 1985 was simulated assuming two alternative, but constant, size limit policies. The same conservative size limit policy used in the historical simulation and a liberal policy allowing all 8 year old males to be harvested were simulated. Season length was fixed at seven days and the harvest guideline was set at 30 percent of the legal population in both scenarios.

Bristol Bay harvest revenue forecasts over the 8 year simulation period are presented in Figure 4 for each size limit scenario. Forecast changes in crab biomass, total harvest, effort and market supply follow the same general trends as harvest revenues.

Four general conclusions are suggested by the results illustrated in Figure 4. First, it is expected that the king crab industry will sustain relatively stable growth through 1990, regardless of size limit policy. Second, choice of size limit is forecast to cause radically divergent harvest and revenue outcomes in 1991 and 1992. Third, policy based on one-period-ahead forecasts that are driven by recruit class strength and ignore multiperiod, long-term consequences of management may precipitate another industry collapse in the early 1990s. Fourth, the present value of harvest revenue streams generated under each size limit policy reveal surprising stability despite divergent catch levels. The conservative policy produces the highest revenue stream ($997.7 million); the liberal policy is forecast to generate $976.9 million.

Total harvest revenue is expected to grow from 7.6 million dollars to as much as 238 million dollars during the first six years. This period of relatively stable growth is followed by two years of radically different harvest/revenue forecasts. The differences between the conservative and liberal policy scenarios result from a strong recruitment forecast in 1991. An estimated 87.7 million pounds of crab are predicted to recruit into the 8 year old cohort in 1991. This represents a three-fold increase above the prior year's recruitment. Accordingly, both 1991 revenue expectations exceed those of 1990. Only the conservative size limit policy, however, sustains that growth into 1992. The liberal policy immediately extracts all benefit of the strong recruitment. Weak recruitment in 1992 results in greatly diminished harvest revenues if all 8 year old males are legally harvestable. Conservative management, in contrast, supports greater pass through and continued revenue growth.

The shortcomings of myopic, one period ahead management are evident from the 1991–1992 seasonal forecasts. A liberal size limit policy would be prescribed based solely on current recruitment since it would generate the greatest revenue. The liberal policy, however, would trigger conditions similar to those observed in the early 1980s. Such liberal policy decisions fail to consider the dynamic forces influencing legal stock abundance. Although 1991 is predicted to have a strong recruit class,the 1992 class is forecast to be much smaller. Since the total stock of legal crab determines harvest potential, a multi-year time path of legal abundance rather than a single observation is a critical component to effective policy prescription.

In summary, the research underlying this paper demonstrates the essential role of supply in bioeconomic analysis. Failure to understand (model) the nexus between resource stocks and economic markets is, in part, responsible for the collapse of this $1 billion fishery. In a more generic context, such failure has perpetuated a broad spectrum of national fishery policies that artificially separate resource conservation from allocation, and focus on the former. Stated differently, failure to adequately model this complex supply problem as an inseparable part of the economic problem insures that policymakers will never recognize the dynamic feedback effects between the biological stocks and various aspects of the market.

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