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A Bioeconomic Simulation of the Alaskan King Crab Industry

by
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A BIOECONOMIC SIMULATION
OF THE ALASKAN KING CRAB INDUSTRY,

by

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ABSTRACT

The report presents a bioeconomic simulation model of the Alaskan red king crab industry for the period 1970-92. A biological stock submodel is joined. with. an economic-market submodel to predict behavioral responses of the industry and of crab stocks to a variety of management controls. Initially, the simulations are hindcast between 1970 and 1983 to indicate the potential role of- regulatory policy in this tumultuous fishery. Future simulations are then conducted to anticipate the role of management policy on future industry conditions from 1985 to 1992.

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INTRODUCTION

The- Alaskan king crab industry[3/] 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 in 1980. Increased fishing effort in the Bristol Bay fishery management area 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 Department of Fish and Game (ADF&G) ordered complete- closure of. the Bristol Bay fishery. Statewide harvests plummeted to 26.9 million pounds. An additional 10 million pounds were lost by 1985 (U.S. Department of Interior 1947-75; Alaska Department of Fish and Game 1969-83, 1970-85).

The economic wake of this collapse has been extensive, involving virtually every participant in the fishery. Between 1980 and 1983, ex-vessel revenues to fishermen fell by more than 50% dropping by $93.2 million. Processor sales- dropped $178.0 million (a 60% reduction), while sales from wholesalers declined by $304.2 million (a 66% reduction).

[3/] "King crab" is the common name given to three crustaceans in the family of stone crabs, Lithodidae. The three species are the red king crab (*Paralithodes camtschatica*), the blue king crab (*Paralithodes platypus*), and the brown or golden king crab (*Lithodes aequispina*), All three species inhabit waters of the north Pacific Ocean. They are similar in appearance though noticeably varied in shell color. The red king crab has been the cornerstone of the Alaskan king crab industry because of its large size; shallow, inshore distribution; and historically greater abundance. The other two king crab species, though harvested commercially, have been much less abundant and restricted to more localized and remote habitats. Harvest pressure and commercial importance of these two species has increased during the past 6 years principally because red king crab stocks have declined; only limited (primarily incidental) catches were made prior to 1981.

Multimillion dollar fishing, vessels were. idled,. others shifted into different fisheries, processing plants closed and an industry-wide restructuring commenced.

The significance of the collapse may be placed in perspective by considering the fact 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 (Alaska Department of Fish and Game 1969-83). Yet, the statewide king crab catch rarely exceeded one-third the total catch of salmon, by weight.

The 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% of total shellfish revenues were returned to the Alaskan economy in direct purchases of goods and services. Much of the remaining 68% were spent in the Seattle area for vessel maintenance and construction, gear and supplies, and general consumer goods. Moreover, most of the processing and cold. storage- firms- were- 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 1969-84).

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 is essential in this regard. This report is one in a series of three that collectively comprise a bioeconomic analysis of the Alaskan king crab industry; it simulates industry responses and behavior under a variety of historical and future policy scenarios. The second report (Matulich, Hanson and Mittelhammer 1988b) examines the population dynamics of this fishery and establishes the age-structured biological response submodels. The third report (Matulich, Hanson and Mittelhammer 1988a) details the economic/market submodels, from initial harvest to final consumption. The research findings contained in theses three reports are intended to provide insight into future management of the fishery.

Initially, an overview of the composite bioeconomic model is presented as backdrop to subsequent simulations and policy analysis. The composite model describes how the Alaskan king crab industry has operated for nearly 2 decades. Four general scenarios. then are simulated to evaluate the response of crab stocks, fishermen, processors, wholesalers, and consumers to past and potential future ADF&G management policies. Two of the scenarios focus on historical information, predicting industry behavior for the period 1977 to 1983. The first historical scenario is designed to establish the overall goodness of fit of the bioeconomic model; industry response to actual management and policy conditions are simulated and compared to actual behavior. The second historical scenario explores whether the 1983 closure of the Bristol Bay fishery might have been prevented had more restrictive size limit and season length policies been implemented. The remaining two general scenarios forecast the consequences of: 1) six alternative size limits, and 2) two alternative season length policies for the 9-year period 1984-92.[4/] None of the future simulation results should be regarded as optimal management prescriptions. Rather, they illustrate likely outcomes

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[4/] The 1984 simulation serves to recalibrate the system after the structural break caused by season closure in the Bristol Bay fishery. Thus, 1984 does not represent a true ex ante forecast and is not reported here. Simulation results are reported only for the 1985-92 period.

to plausible management policies, assuming that the behavior of the industry and the behavior of the biological stocks do not change in some fundamental way.

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 (Fig. 1). The explicit interaction between management, biology, harvest and the market for king crab shown in Figure 1 accounts- for the feedback inherent in the overall bioeconomic system for a single year (1 July-30 June). A brief summary of each component is presented below as an overview of this complex fishery model. Details pertaining to theoretical underpinnings and empirical estimation of all submodels are discussed in Matulich, Hanson and Mittelhammer (1988a,b).

Management provides an external control on industry behavior. The general management objectives of the Alaska Board of Fisheries are twofold "(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" (Alaska Department of Fish and Game 1985). A variety of management regulations are employed to achieve these general objectives, including gear restrictions and exclusive registration in selected fishing areas. However, sex, size, and season length are the principal regulations that are actively used to manage the Bristol Bay fishery. Annual decisions regarding these regulatory controls historically

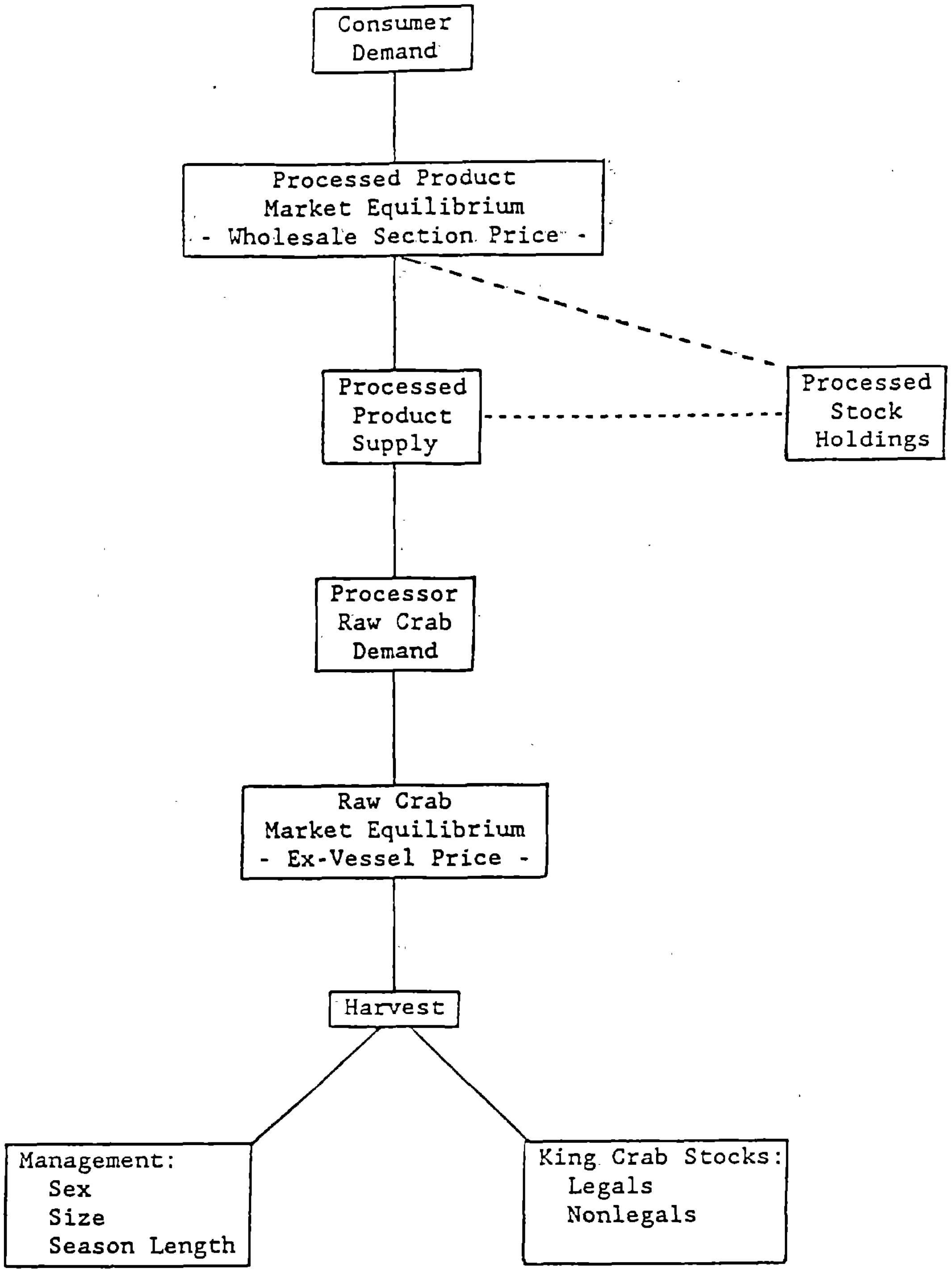
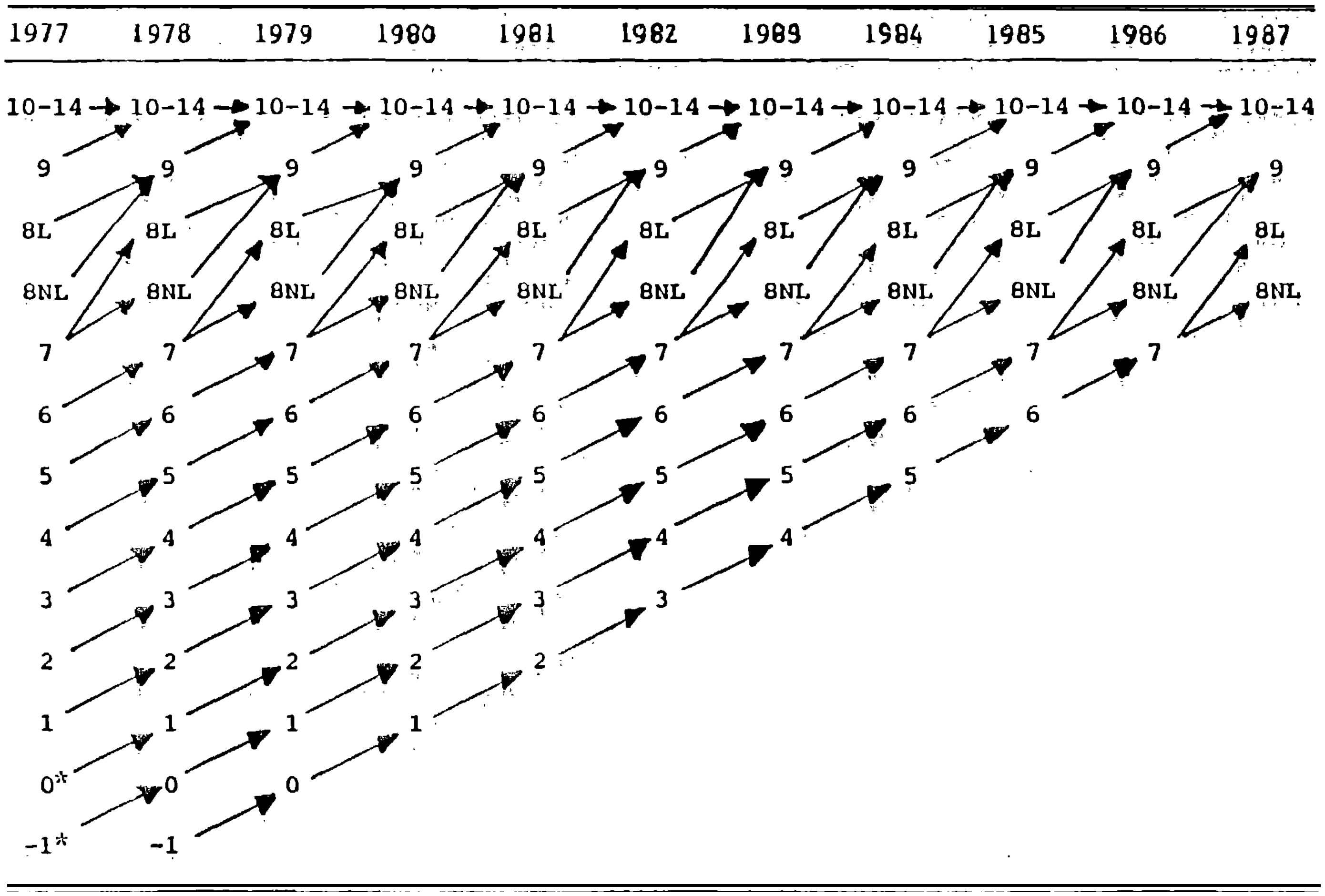


Figure 1. --Components of market equilibrium in the Alaskan king crab

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 policy, future harvestable stocks, current prices, and future prices.

Figure 2 illustrates the long and complicated lags that are important considerations when formulating policies to help assure the long-run economic health of this fishery. 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 class. For example, both the current stock of $8L_t$ and of $8NL_t$ were formed from surviving $7_{t\ 1}$ the previous period. Likewise, 9_t was formed from $8L_{t\ 1}$ and $8NL_{t\ 1}$; $10\text{-}14_t$ was formed from 9_{t-1} and $10\text{-}14_{t-1}$ Carrying this recursion back to parental stocks, 8-year-old recruits in 1987 were created by sexually mature parent stock 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 are a function of parental stock 11 years earlier, and so on.

This figure clearly illustrates that 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) current harvestable stocks, 2) future harvestable stocks (up to 7 years into the future), and 3) parent stocks of progeny that can be harvested 9 to 15 or 16 years into the future. Evaluation of the



*The term 0 and -1 refer to newly hatched larvae and breeding, respectively.

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

implied biological and economic tradeoffs is precisely what is required by the Magnuson Fishery Conservation and Management Act (1976).

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 very good. The beginning stock of legal king crab then 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 ADF&G size limit. Nonlegal crab are defined as all sublegal males and all females. The complete biological submodel is given in Appendix A along with variable definitions and data sources.

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 represented by three behavioral relationships: total quantity of king crab harvested, fishing 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., ex-vessel price). Season length and harvest guideline control total harvest through the effort relationship. Fleet size depends on existing capital stock, abundance of legal crab, and seasonal revenue expectations based on the previous season's total harvest revenue.

An ex-vessel price offer function is used to incorporate processors derived demand for raw crab into the market equilibrium model. Fishing commences when an initial ex-vessel price is negotiated; subsequent price changes reflect cumulative harvest and overall crab quality as the season progresses. The processors' bids or offers take into account expected wholesale prices, processing costs, and the costs of fishing. Accordingly, the seasonal average ex-vessel 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 cost of holding inventories enter the holdings equation.

Domestic consumption behavior is a function of the wholesale crab price, the 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. The complete market submodel also is presented in Appendix A.

The system of behavioral relationships and structural identities given in Appendix A provide the econometric basis to simulate both historical and future scenarios of the industry. The simulations not only help establish the overall accuracy of the econometric model as a system, but also reveal important insights into past and future management of the fishery.

INDUSTRY SIMULATIONS

Simulation results are reported in three parts. The results begin with the historical simulation of actual management policies. The second set of results addresses the question of whether a different management strategy might have prevented closure of the Bristol Bay fishery in 1983. The presentation of results concludes with the future scenarios.

Each of the simulations are solved using the SIMNLIN procedure in the SAS Institute's econometric software package (ETS). The SIMNLIN procedure is designed to solve simultaneous systems of nonlinear equations and to simulate the dynamic behavior of the solution over time (SAS Institute 1984). The Newton gradient search algorithm was selected from those available in the SIMNLIN procedure-to solve the equation system (Judge et al., 1985, p. 955-958).

Historical Simulation of Actual Management Policies

Testing overall significance and predictive accuracy of a multiequation model system requires simulating actual history using an ex post forecast (based on actual or observed values of the predetermined model variables) to predict endogenous variable values (Pindyck and Rubinfeld 1981). Solved rather than observed values of the lagged endogenous variables were used in all historical and future simulations. Information generated from the ex post forecast analytically is more complicated, but provides a more robust evaluation criteria than statistical analysis of individual equations using R^2 and t tests, and even accuracy of individual predictions. The complete bioeconomic model is evaluated on the basis of three general criteria: 1) a comparison of observed and predicted values of all endogenous variables in the simulated system, 2) several fit statistics generated from the ex post forecast, and 3) Theil's (1961, 1966) forecast error statistics.

Table 1 is a listing of historical simulation results based on the actual management regime between 1978 and 1983. The ex post forecast of each endogenous variable is reported along with the corresponding observed value, which is listed below in parentheses. On average, the forecasts. deviate less than 10% from their historically observed values and accurately predict turning points in the data.

Five commonly used goodness-of-fit statistics are reported in Table 2, together with the observed mean value for each endogenous variable in the model. The observed mean values provide a reference for evaluating each of the five reported statistical measures. These five goodness of fit measures include: mean simulation error (ME), mean percent error (ME%), mean absolute simulation error (MAE), root mean square percent error (RMSE%), and simple correlation coefficient (R). Each statistic is discussed in Appendix

Table 1.--Ex post forecast results, predicted/ actual), 1978-83.

Variables	1978	1979	1980
PSECT	4.183 (4.045)	4.057 (3.401)	3.508 (3.982)
PMEAT	8.532 (9.398)	8.352 (6.861)	7.541 (8.412)
WTAVP	4.677 (4.673)	4.672 (3.884)	4.082 (4.575)
SECTHOLD	19.842 (15.148)	21.035 (13.212)	22.850 (20.330)
SECTPROD	114.086 (96.395)	135.567 (136.411)	157.032 (173.926)
SECTSUP	108.821 (104.910)	134.374 (138.348)	155.217 (166.808)
SECTCONS	57.014 (53.103)	70.298 (74.272)	106.023 (117.614)
QHARVUS	140.189 (122.498)	152.911 (153.755)	174.952 (191.847)
QHARVW	45.154 (34.880)	60.005 (45.927)	30.888 (61.899)
QHARVT	95.034 (87.618)	92.907 (107.828)	144.064 (129.948)
POTLIFTS	0.427 (0.406)	0.371 (0.315)	0.675 (0.567)
WPUE	222.551 (215.721)	250.638 (342.066)	213.371 (229.068)
VESSELS	170.036 (162.000)	240.109 (236.000)	273.521 (236.000)
EXPRT	1.122 (1.230)	1.264 (1.010)	1.114 (0.900)
AVEXPR	1.202 (1.270)	1.131 (0.985)	1.095 (0.934)

Table- 1.--Continued.

Variables	1981	1982	1983
PSECT	5.532 (5.554)	8.047 (8.510)	8.934 (9.184)
PMEAT	11.909 (12.834)	17.016 (17.596)	18.822 (18.979)
WTAVP	6.118 (6.294)	9.004 (9.527)	9.289 (9.675)
SECTHOLD	12.231 (10.202)	11.005 (11.942)	17.763 (16.761)
SECTPROD	90.252 (80.168)	37.623 (38.588)	37.666 (26.647)
SECTSUP	100.871 (90.296)	38.848 (36.848)	30.908 (21.827)
SECTCONS	77.707 (67.132)	34.694 (32.695)	33.292 (24.211)
QHARVUS	97.070 (86.986)	40.039 (41.004)	37.772 (26.753)
QHARVW	68.303 (53.282)	34.754 (38.003)	37.772 (26.753)
QHARVT	28.767 (33.704)	5.285 (3.001)	0.000 (0.000)
POTLIFTS	0.647 (0.542)	0.161 (0.142)	0.000 (0.000)
WPUE	44.496 (62.136)	32.775 (21.187)	0.000 (0.000)
VESSELS	234.805 (177.000)	94.540 (90.000)	0.000 (0.000)
EXPRT	1.302 (1.500)	2.954 (3.050)	0.000 (0.000)
AVEXPR	1.629 (1.664)	3.079 (3.095)	3.213 (3.213)

Table 1.--Continued.

Variables	1978	1979	1980
FEM5	76.581 (88.450)	52.916 (50.315)	22.222 (28.710)
FEM614	110.129 (110.137)	176.995 (173.858)	63.989 (62.237)
FEM514	186.709 (198.587)	229.910 (224.173)	86.210 (90.947)
MALE5	37.326 (36.285)	13.977 (18.762)	22.675 (26.373)
MALE6	41.724 (42.588)	29.389 (25.956)	16.018 (21.672)
MALE7	73.000 (61.235)	52.371 (59.911)	34.916 (31.776)
MALE8	101.054 (102.907)	79.400 (84.119)	48.353 (51.667)
MALE914	204.172 (209.140)	212.857 (226.620)	190.751 (188.714)
MALE514	457.276 (452.155)	387.995 (415.368)	312.712 (320.202)
FM514	85377.600 (89792.100)	89203.900 (93114.300)	26959.000 (29121.400)
LEGALS	217.016 (222.219)	222.949 (237.312)	196.896 (195.281)
NONLEGALS	426.969 (428.523)	394.956 (402.229)	202.026 (215.868)
QHARDP	21.867 (21.242)	27.032 (35.906)	38.902 (29.215)
QHTDAY	2159.880 (1991.330)	3096.890 (3594.270)	3513.760 (3169.470)

Table 1.--Continued.

Variables	1981	1982	1983
FEM5	26.840 (23.055)	21.384 (22.040)	7.036 (5.365)
FEM614	93.258 (91.581)	57.583 (59.545)	6.318 (6.454)
FEM514	120.098 (114.636)	78.967 (81.585)	13.354 (11.819)
MALE5	30.572 (29.559)	34.512 (35.223)	22.974 (19.647)
MALE6	19.511 (24.192)	23.360 (21.924)	17.614 (13.608)
MALE7	17.174 (20.522)	20.762 (21.515)	12.826 (12.578)
MALE8	28.163 (20.496)	13.069 (14.945)	7.524 (7.686)
MALE914	41.740 (53.684)	16.133 (15.245)	0.594 (3.245)
MALE514	137.158 (148.453)	107.835 (108.852)	61.532 (56.764)
FM514	16472.400 (17018.100)	8515.400 (8880.700)	821.700 (670.900)
LEGALS	45.319 (56.289)	17.794 (17.145)	1.550 (4.222)
NONLEGALS	211.937 (206.800)	169.007 (173.292)	73.336 (64.361)
QHARDP	2.269 (2.753)	0.966 (0.786)	2.084 (2.084)
QHTDAY	309.320 (362.410)	170.480 (96.810)	0.000 (0.000)

Table 2.--Ex post forecast goodness of fit statistics.

Variables	Units	Observed mean	Mean simulation error (ME)	Mean % error (ME%)
PSECT	$/lb	5.526	-0.080	-0.208
PMEAT	$/lb	11.685	-0.253	-1.062
WTAVP	$/lb	6.272	-0.129	-0.708
SECTHOLD	mill. lbs	15.894	1.149	11.747
SECTPROD	mill. lbs	89.423	2.261	7.668
SECTSUP	mill. lbs	88.275	2.118	8.691
SECTCONS	mill. lbs	59.360	2.118	8.844
QHARVUS	mill. lbs	103.100	2.261	7.316
QHARVW	mill. lbs	41.415	2.050	9.248
QHARVT	mill. lbs	61.724	0.210	9.055
POTLIFTS	millions	0.346	0.039	9.490
WPUE	lbs/lift	146.500	-14.035	0.160
VESSELS	units	147.300	15.590	8.298
EXPRT	$/lb	1.257	-0.006	1.980
AVEXPR	$/lb	1.757	0.016	2.452
QHTDAY	1000 lbs	1433.900	0.973	9.055
QHARDP	1000 lbs	14.549	0.123	1.993
FEM5	mill. lbs	32.915	-1.773	0.296
FEM614	mill. lbs	72.613	0.683	1.178
FEM514	mill. lbs	105.500	-1.090	-0.109
MALE5	mill. lbs	27.663	-0.769	-3.423
MALE6	mill. lbs	23.904	-0.657	-1.618
MALE7	mill. lbs	31.492	0.724	1.529
MALE8	mill. lbs	41.907	-0.599	1.352
MALE914	mill. lbs	100.600	-4.778	-20.583
MALE514	mill. lbs	225.600	-6.079	-2.105
FM514	bill. lbs	34.273	-1.631	-2.058
LEGALS	mill. lbs	106.000	-4.854	-17.001
NONLEGALS	mill. lbs	225.200	-2.315	0.203

Table 2.--Continued.

Variables	Units	Mean absolute simulation error (MAE)	Root mean square % error (RMSE%)	Simple correlation (R)
PSECT	$/lb	0.307	9.071	0.988
PMEAT	$/lb	0.718	10.218	0.985
WTAVP	$/lb	0.356	9.154	0.986
SECTHOLD	mill. lbs	4.013	30.677	0.352
SECTPROD	mill. lbs	8.823	18.281	0.978
SECTSUP	mill. lbs	6.565	17.051	0.994
SECTCONS	mill. lbs	6.565	16.818	0.982
QHARVUS	mill. lbs	8.823	17.490	0.983
QHARVW	mill. lbs	12.347	31.439	0.345
QHARVT	mill. lbs	6.594	30.235	0.985
POTLIFTS	millions	0.049	13.767	0.982
WPUE	lbs/lift	21.612	25.624	0.968
VESSELS	units	16.413	14.027	0.978
EXPRT	$/lb	0.140	14.888	0.982
AVEXPR	$/lb	0.072	9.217	0.995
QHTDAY	1000 lbs	166.600	30.235	0.985
QHARDP	1000 lbs	2.874	19.119	0.932
FEM5	mill. lbs	4.075	17.328	0.986
FEM614	mill. lbs	1.285	3.417	1.000
FEM514	mill. lbs	4.728	6.716	0.997
MALE5	mill. lbs	2.306	13.037	0.937
MALE6	mill. lbs	3.193	18.184	0.918
MALE7	mill. lbs	4.050	12.262	0.966
MALE8	mill. lbs	2.807	15.294	0.995
MALE914	mill. lbs	5.613	35.328	0.998
MALE514	mill. lbs	8.904	5.678	0.998
FM514	bill. lbs	1.674	10.683	1.000
LEGALS	mill. lbs	5.501	28.018	0.999
NONLEGALS	mill. lbs	6.347	6.175	0.999

B for readers unfamiliar with their usage and interpretation. Additional detail on each statistic may be found in Pindyck and Rubinfeld (1981).

These statistics generally support the conclusion drawn from comparing predicted and historical data (Table 1) (i.e., the estimated model simulates the history of the king crab fishery very well). For example, the estimated. R exceeds 0.980 for 20 of the 29 endogenous variables in the system with only two of the remaining nine equations having simple correlations below 0.910. There is a strong linear association between the predicted and observed values. Only quantity harvested in areas outside of Bristol Bay (QHARVW) and the inventory of processed sections (SECTHOLD) have somewhat weak simulation fits. QHARVW is a balance equation ensuring market clearing between total harvest and processed production. Accordingly, it is absorbing some of the error produced in these other equations. The mediocre simulation fit of the SECTHOLD equation reflects the weaker underlying statistical fit. Although simulation sometimes improves predictive accuracy of an equation, SECTHOLD was not enhanced. The poorer fits observed for these two dependent variables, however, are acceptable in light of the overall predictive accuracy of the simulation framework.

The third evaluation criterion reinforces the information given by the fit statistics in Table 2. Table 3 is a listing of four statistics developed by Theil (1961, 1966) to evaluate the model's ability to forecast turning points in the data. These four forecast statistics are Theil's inequality coefficient (U) and its three components: a central tendency or bias measure (U^M), the regression proportion (U^R) of an optimal linear correction to the forecast, and the disturbance proportion (U^D) of the forecast correction. Each statistic is described in Appendix B for readers

Table 3 .--Theil forecast error statistics.

Variables	Inequality (U)	Bias (UM)	Regress. (UR)	Disturb. (UD)
PSECT	0.063	0.046	0.144	0.809
PMEAT	0.067	0.091	0.025	0.885
WTAVP	0.066	0.088	0.203	0.709
SECTHOLD	0.306	0.052	0.276	0.672
SECTPROD	0.108	0.043	0.133	0.824
SECTSUP	0.074	0.081	0.440	0.479
SECTCONS	0.113	0.081	0.373	0.546
QHARVUS	0.094	0.043	0.120	0.838
QHARVW	0.354	0.018	0.440	0.542
QHARVT	0.110	0.001	0.107	0.893
POTLIFTS	0.159	0.376	0.288	0.337
WPUE	0.194	0.150	0.197	0.652
VESSELS	0.158	0.350	0.264	0.385
EXPRT	0.106	0.002	0.030	0.968
AVEXPR	0.047	0.029	0.047	0.924
QHTDAY	0.121	0.000	0.000	1.000
QHARDP	0.253	0.001	0.079	0.920
FEM5	0.130	0.105	0.255	0.640
FEM614	0.018	0.166	0.299	0.535
FEM514	0.045	0.035	0.000	0.965
MALE5	0.097	0.078	0.277	0.644
MALE6	0.141	0.034	0.073	0.894
MALE7	0.152	0.017	0.192	0.791
MALE8	0.068	0.025	0.161	0.814
MALE914	0.053	0.423	0.031	0.546
MALE514	0.044	0.256	0.057	0.687
FM514	0.047	0.466	0.507	0.027
LEGALS	0.050	0.442	0.048	0.510
NONLEGALS	0.028	0.098	0.087	0.815

unfamiliar with their usage and interpretation. Additional detail regarding usage and interpretation is available in Folwell et al. (1985).

The inequaiity coefficient estimated for each model equation generally confirms the high predictive accuracy of the overall framework. Slightly elevated U statistics on the SECTHOLD and QHARVW equations is consistent with results from other goodness of fit measures. The combined estimates of U^M and U^R listed in Table 3 are less than 0.5 in all but four variables. (SECTSUP, POTLIFTS, VESSELS, and FM514). Total forecast error (U) for these four variables, however, is small. Although there is some systemic bias in forecasting these variables, it appears to be unimportant because total error is relatively insignificant.

In conclusion, the bioeconomic model is quite accurate inforecasting observed historical data. The estimated framework should provide relatively reliable and realistic simulations of alternative historical and future management scenarios so long as no major structural changes occur within the fishery.

Historical Simulation of an Alternative Management Scenario

The estimated bioeconomic framework is used to simulate how the industry might have responded to alternative management policies in the late 1970s and early 1980s. This type of simulation provides insight into how different regulations might have affected crab resource availability and market conditions within the industry.

A variety of simulations were conducted that focused on more restrictive harvest management preceding and during the period of rapid stock declines. It suffices to discuss the results of a single alternative management scenario. In particular, a more conservative harvest strategy is simulated for the period from 1978 to 1983. The minimum legal size limit is raised to prevent any harvest of 8-year-old males (i.e., $SIZELIM_t = 0$), and each season is reduced to 80% of its historical length. All other predetermined variables retain their historical values.

Results from the more conservative size limit strategy are listed in Table 4. Actual historical values of each endogenous variable are reported parenthetically below the corresponding forecast value. Estimated total harvest revenues for area T in million dollars (REV_t) also are reported. Comparison of the forecast values with their historically observed counterparts suggests that more conservative management may have produced sufficiently abundant legal crab stocks to preclude the 1983 closure.

An important implication of this result is illustrated by Figure 3 in which forecast and observed harvest revenues are compared. Revenues to fishermen would have risen in all but one year despite the curtailed harvests. 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. Using the prime interest rate to. calculate the present value stream of harvest revenues, fishermen would have earned 21.3% additional revenue under the conservative scenario, in contrast to the actual revenue stream produced during the same period ($410.6 million versus $338.5 million, 1978 dollars). The economic welfare of fishermen would have been enhanced even though fewer crab would have been harvested.

More conservative management also may have benefitted the wholesale market. Domestic consumption was simulated to be slightly less than actually observed in 1978, 1979, and 1980. Consumption projections beyond

Table 4. --Forecast results fromhistorical simulation of more conservative management, predicted/ (actual), 1978-83.

Variables	1978	1979	1980
PSECT	4.371	4.140	3.162
	(4.045)	(3.401)	(3.982)
PMEAT	8.916	8.521	6.836
	(9.398)	(6.861)	(8.412)
WTAVP	4.905	4.775	3.664
	(4.673)	(3.884)	(4.575)
SECTHOLD	19.683	20.895	23.169
	(15.148)	(13.212)	(20.330)
SECTPROD	109.838	133.769	165.048
	(96.395)	(136.411)	(173.926)
SECTSUP	104.701	132.557	162.774
	(104.910)	(138.348)	(166.808)
SECTCONS	52.894	68.481	113.580
	(53.103)	(74.272)	(117.614)
QHARVUS	135.941	151.113	182.969
	(122.498)	(153.755)	(191.847)
QHARVW	51.238	66.202	38.475
	(34.880)	(45.927)	(61.899)
QHARVT	84.703	84.911	144.493
	(87.618)	(107.828)	(129.948)
POTLIFTS	0.366	0.295	0.560
	(0.406)	(0.315)	(0.567)
WPUE	231.402	288.169	258.033
	(215.721)	(342.066)	(229.068)
VESSELS	164.334	253.378	314.018
	(162.000)	(236.000)	(236.000)
EXPRT	1.325	1.455	1.145
	(1.230)	(1.010)	(0.900)
AVEXPR	1.342	1.223	1.116
	(1.270)	(0.985)	(0.934)

Table 4 .--Continued.

Variables	1981	1982	1983
PSECT	5.189	7.754	9.100
	(5.554)	(8.510)	(9.184)
PMEAT	11.209	16.419	19.160
	(12.834)	(17.596)	(18.979)
WTAVP	5.707	8.561	9.507
	(6.294)	(9.527)	(9.675)
SECTHOLD	13.105	11.506	17.679
	(10.202)	(11.942)	(16.761)
SECTPROD	98.317	43.650	33.456
	(80.168)	(38.588)	(26.647)
SECTSUP	108.380	45.249	27.283
	(90.296)	(36.848)	(21.827)
SECTCONS	85.216	41.096	29.667
	(67.132)	(32.695)	(24.211)
QHARVUS	105.135	46.066	33.562
	(86.986)	(41.004)	(26.753)
QHARVW	66.182	33.095	29.551
	(53.282)	(38.003)	(26.753)
QHARVT	38.953	12.971	4.012
	(33.704)	(3.001)	(0.000)
POTLIFTS	0.470	0.206	0.098
	(0.542)	(0.142)	(0.000)
WPUE	82.847	62.919	40.980
	(62.136)	(21.187)	(0.000)
VESSELS	286.629	111.841	70.555
	(177.000)	(90.000)	(0.000)
EXPRT	0.959	2.644	4.736
	(1.500)	(3.050)	(0.000)
AVEXPR	1.468	2.970	3.395
	(1.664)	(3.095)	(3.213)

Table 4. --Continued.

Variables	1978	1979	1980
FEM5	76.581 (88.450)	52.916 (50.315)	22.2216 (28.710)
FEM614	110.129 (110.137)	176.995 (173.858)	63.989 (62.237)
FEM514	186.709 (198.587)	229.910 (224.173)	86.210 (90.947)
MALE5	37.325 (36.285)	13.977 (18.762)	22.675 (26.373)
MALE6	41.724 (42.588)	29.389 (25.956)	16.018 (21.672)
MALE7	73.000 (61.235)	52.371 (59.911)	34.916 (31.776)
MALE8	101.054 (102.907)	79.400 (84.119)	48.353 (51.667)
MALE914	213.271 (209.140)	232.984 (226.620)	219.881 (188.714)
MALE514	466.374 (452.155)	408.121 (415.368)	341.842 (320.202)
FM514	87076.500 (89792.100)	93831.200 (93114.300)	29470.300 (29121.400)
LEGALS	213.271 (222.219)	232.984 (237.312)	219.881 (195.281)
NONLEGALS	439.813 (428.523)	405.048 (402.229)	172.000 (215.868)
QHARDP	22.441 (21.242)	28.592 (35.906)	46.771 (29.215)
QHTDAY	2406.330 (1991.330)	3537.950 (3594.270)	4405.280 (3169.470)
REVT	112.256 (107.771)	123.526 (108.906)	165.489 (116.954)

Table 4 .--Continued.

Variables	1981	1982	1983
FEM5	26.840 (23.055)	21.384 (22.040)	7.036 (5.365)
FEM614	93.258 (91.581)	57.583 (59.545)	6.318 (6.454)
FEM514	120.098 (114.636)	78.967 (81.585)	13.354 (11.819)
MALE5	30.572 (29.559)	34.512 (35.223)	22.974 (19.647)
MALE6	19.511 (24.192)	23.360 (21.924)	17.614 (13.608)
MALE7	17.174 (20.522)	20.762 (21.515)	12.826 (12.578)
MALE8	28.163 (20.496)	13.069 (14.945)	7.524 (7.686)
MALE914	71.468 (53.684)	36.376 (15.245)	13.600 (3.245)
MALE514	166.887 (148.453)	128.078 (108.852)	74.539 (56.764)
FM514	20042.800 (17018.100)	10113.900 (8880.700)	995.400 (670.900)
LEGALS	71.468 (56.289)	36.376 (17.145)	13.600 (4.222)
NONLEGALS	215.517 (206.800)	170.669 (173.292)	74.292 (64.361)
QHARDP	3.466 (2.753)	2.664 (0.786)	3.037 (2.084)
QHTDAY	523.560 (362.410)	523.030 (96.810)	573.110 (0.000)
REVT	37.347 (50.556)	34.290 (9.154)	19.001 (0.000)

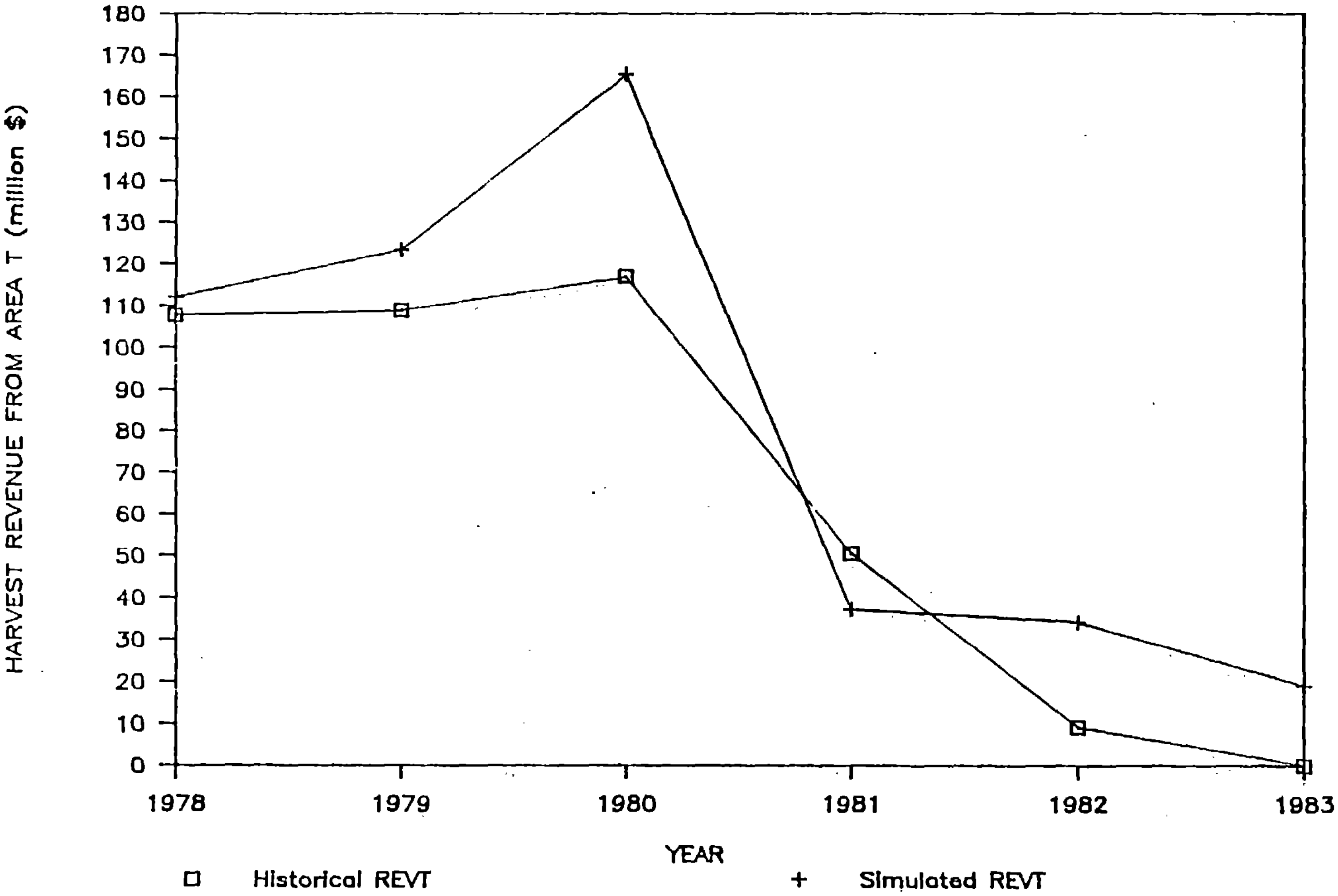


Figure 3.-- Comparison of the simulated conservative management harvest revenue stream with the actual revenue stream, 1978-83.

1980 were at least 20% greater. The income stream to processors also would have had a higher present value under more conservative management.

Results of this simulation suggest that the 1983 closure of the Bristol Bay could have been prevented The industry probably would have experienced a decline, but the destabilizing impacts resulting from complete closure may have been avoided. Agency managers and policymakers, however, could know this only 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 1978-83. Accordingly, this simulation represents only the direct, short-term influence on exploitation. It does not assess whether the rapid decline of 1981-83 could have been mitigated by different harvest policies affecting parent stocks 9 to 16 years earlier. For example, the brood stocks that created the 1981, 1982, and 1983 year classes of $MALE8_t$ were influenced directly by harvest policies in effect during the 1972, 1973; and 1974 fishing seasons. A subset of the parent stocks in 1972 (i-e., the 14-year-old age class) was affected by harvest policies as much as 7 years earlier--in 1965. This simulation only considers alteration of management policies beginning in 1978. Different management during the early 1970s may have enhanced recruitment in the early 1980s.

Another possible limitation of this scenario centers on the underlying breeding stock sex ratio. Results from the biological models suggest that in addition to managing for total brood stock abundance, the sex ratio of that stock may influence recruit abundance and thus, harvestable stock abundance. Maximum recruitment in the i-th age class appears to depend upon the parent- stock being in proper sex ratio. No attempt was made to enforce an optimal sex ratio.

Simulation under more conservative management offers insight toward new directions in the management principles and philosophies, that guide the king crab fishery. The historical basis for managing this fishery has been almost exclusively biological. Despite statements acknowledging the difference between maximumsustainable biological populations and optimal economic yields, there has been no consideration of dynamic market feedback effects between annual harvest policy, future harvestable crab stocks, and current and future prices. Annual regulations have been based primarily on static biological analyses which are akin to one-period-ahead recruit class assessments. Policy formation should explicitly recognize the extremely long and complex lags that characterize king crab population dynamics. If the primary goal of management is to sustain a vital king crab industry, management philosophies and design should articulate the dynamic feedback effects inherent in this complex fishery. Healthy crab stocks will more likely be achieved in the process.

Future Simulation of Alternative Management Policies

Future industry conditions and responsesto alternative management scenarios are simulated in this section. In particular responses to six size limit regulations and two fishing season lengths are predicted. The resultant information provides industry participants with forecasts of how king crab stocks and markets are likely to respond to various regulations.

All future simulations require modifications to the estimated bioeconomic framework. Modifications are needed for three reasons. First numerical solutions to the original equation system are difficult to obtain. Second, closure of the Bristol Bay management unit in 1983 requires recalibration of the entire simulation model. Finally, a complete exogenous variable data set does not exist beyond 1983. Specific model changes resulting from each of these factors are described in Appendix C.

Alternative Size Limit Scenarios

Six alternative size-limit scenarios are simulated for the Bristol Bay fishery. It is assumed that the size limit remains constant for the duration of each simulated scenario. The selected size limits ($SIZELIM_t$) reflect exploitation rates of 0, 12.7 (current policy), 25, 50, 75, and 100% of the 8-year-old males ($MALE8_t$). Season length ($DAYS_t$) is fixed at 7 days and the harvest guideline ($GUIDE_t$) is set at 30% of the legal population ($LEGALS_t$) in all scenarios. The simulation covers an 8-year period beginning in 1985 and ending in 1992. The 8-year horizon allows one to evaluate recruitment of crab in 1992 that was created between the 1984 and 1985 seasons. It illustrates the implications of current management decisions on future industry conditions. These implications have not been available previously to policymakers.

Bristol Bay harvest ($QHARVT_t$) forecasts over the 8-year simulation period are presented in Figure 4 for each of the six size-limit scenarios. Complete enumeration of this and all other dependent variables is presented in Appendix D (Tables D.l-D.6). Forecast changes in biomass, total effort, and market supply follow the same general trends as $QHARVT_t$.

Three general conclusions are suggested by the results illustrated in Figure 4. First, the king crab industry is forecast to sustain relatively stable growth through 1990, regardless of size limit policy. Second, choice of size limit is forecast to cause radically divergent harvest outcomes in 1991 and 1992. Third, policy based on one-period-ahead forecasts that are driven by recruit class strength and that ignore multiperiod, long-term

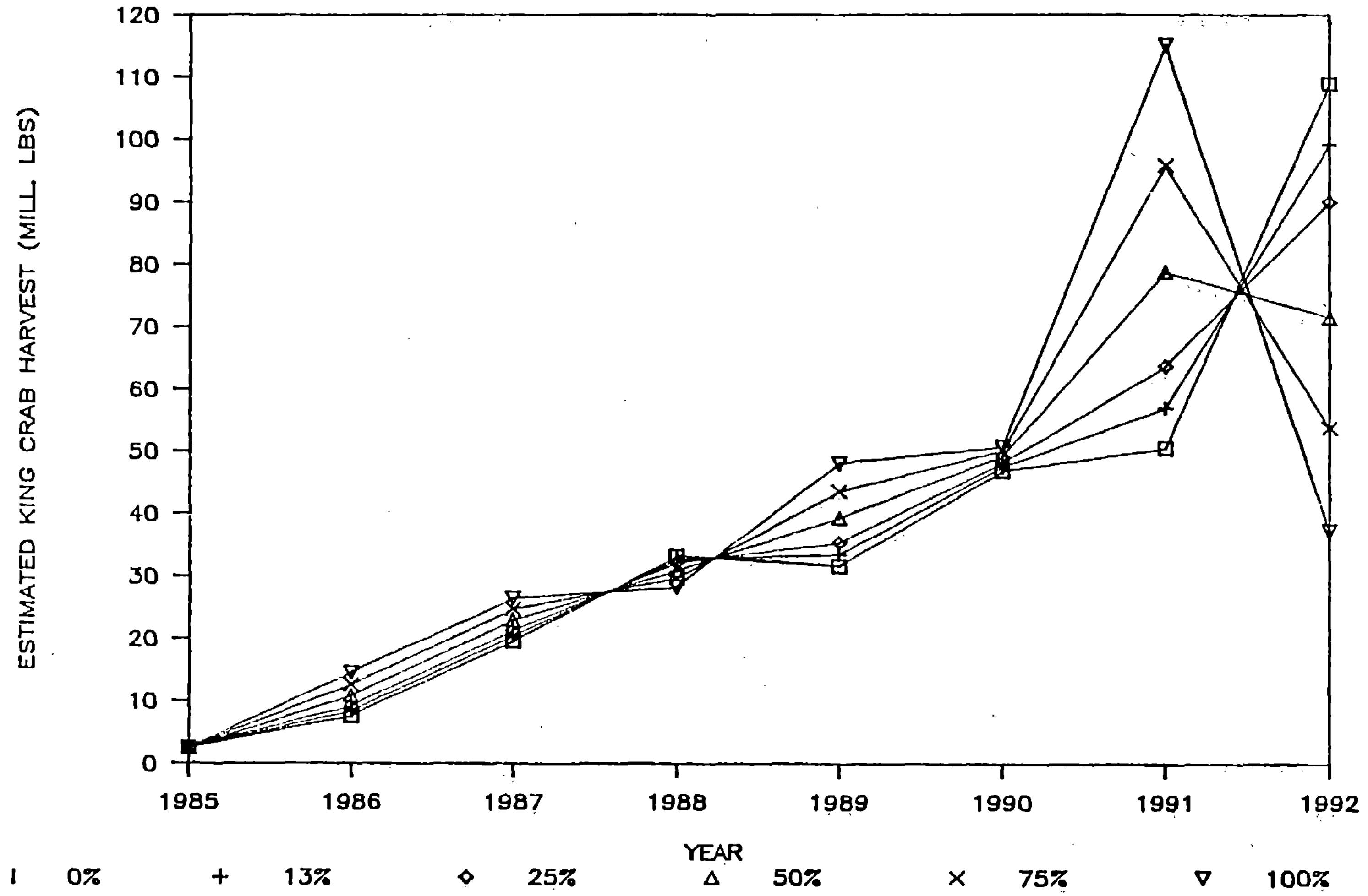


Figure 4 .--Comparison of future Southeastern Bering Sea harvest forecasts for six simulated size limit policies, 1985-92.

consequences of management may precipitate another industry collapse in the early 1990s. Each of these results is examined in more detail below.

Total catch is projected to grow from 2.5 to nearly 50 million pounds during the first 6 years This period of relatively stable growth can be divided into three phases: 1985-87, 1988, and, 1989-90. Nearly linear growth in harvest is projected between 1985 and 1987 due to near constant recruitment. In 1988, recruitment is predicted to drop, in part due to a weak prerecruit class. The final phase (1989-90) is characterized by a dramatic rise in recruitment due to good reproduction 9 and 10 years earlier. Harvest expands under all but the most restrictive size limit policies in 1989. A restriction against harvesting any 8-year-old males causes a slight harvest decline in 1989 primarily due to a buildup of nonlegal crab that create crowding inefficiencies. All scenarios produce greater harvests in 1990.

The radically different harvest forecasts for 1991 and 1992 are predicated on the strongest recruit class since 1977, which then supported the record harvests of 1978, 1979, and 1980. An estimated 87.7 million. pounds of crab are predicted to recruit into the 8-year-old cohort in 1991. This represents a threefold increase above the prior year's recruitment. All 1991 harvest expectations exceed those of 1990. However, only the more conservative size-limit policies are forecast to sustain that growth into 1992. The more liberal policies (i.e., those allowing 50% or more of the $MALE8_t$ crab to be harvested) immediately extract more benefits of the strong recruitment and permit little pass-through or growth of legals from preceding years. Weak recruitment in 1992 results in greatly diminished harvest under these liberal policies. In contrast, more conservative management supports continued harvest growth due to greater pass-through to

1992 and greater accumulation of legals that recruited into the fishery during the preceding years.

The third conclusion calling for a longer-run view of management is implied by the most liberal size-limit trajectory (i.e., $SIZELIM_t$ = 100%). A liberal size-limit policy would be prescribed based solely on current. recruitment since it generates the greatest overall harvest. This liberal policy, however, could trigger conditions similar to those, of 1982 through the present. More conservative management is expected to support a significantly larger harvest in the terminal forecast period. Whether the conservative size-limit policies would sustain large harvest levels beyond. the terminal period is unclear from this analysis. A downturn may result beyond 1992 regardless of size-limit policy more conservative management might only delay a downturn. The historical simulations, however, suggest more conservative management might lessen the extent of collapse, if a downturn were realized.

Such insight 9 or more years into the future is essential if policymakers are to account for long-term consequences of current period management inherent in the population dynamics of king crab. Policy prescriptions derived from one-period-ahead forecasts fail to consider. the dynamic forces influencing legal stock abundance.

Care should be used in evaluating these forecast results in the context of management policy formulation. As with all econometric simulation models, forecast accuracy and confidence diminishes as the forecast horizon lengthens. An additional factor that is intimately related to the estimated biological submodel further motivates cautious use of the 1991 and 1992 projections. The dramatic fluctuations in harvest predicted for these 2 years stem from the large recruitment of $MALE8_t$ crab forecasted for 1991.

This large recruitment may be overly optimistic. The 1991 $MALE8_t$ forecast is derived from low male and female brood stock densities 9 years before (i.e., adult stocks in 1983). This brood stock level corresponds to a point on the 8-year-old recruitment production surface which is regarded tenuous (Matulich, Hanson and Mittelhammer 1988b). The projected harvests in 1991 and 1992 may be overstated. Moreover, the underlying biological models are limited by few degrees of freedom. Since there is no way to verify the forecasts, any conclusions based upon them must be considered preliminary and utilized with some caution. The limitations noted above suggest that the- long-range forecasts should-be updated annually to better guide the policy process. Successive forecasts will help to refine future projections and, thus, future policy recommendations. The philosophy that management recommendations ought to recognize explicitly the dynamic feedback effects that characterize this fishery is inescapable, given the population dynamics of the fishery.

Translation of future harvest forecasts into present value revenue streams that are expected to confront fishermen illustrates one aspect of the economic consequences of management. Using the prime interest rate ($INTR_t$) to estimate the present value revenue stream, a comparison of the harvest revenue streams generated under each size limit policy is presented in Table 5 for three different forecast horizons: 1985-92, 1985-91, and 1985-90. The revenue stream corresponding to the full simulation period (1985-92) reveals remarkable stability despite the divergent catch levels. The 1985-92 revenue streams differ by only 2.4% across all policy scenarios. The most conservative policy yields the greatest revenue stream, totaling $997.6 million (1985 dollars). Exploiting 75% of the 8-year-old males generates the lowest present value at $974.1 million. Both the ranking and

Table 5 .--Present value (1985 dollars) of harvest revenues by size limit for three different forecast horizons (revenue in million dollars).

	Present value by size limit					
Forecast horizon	0%	13%	25%	50%	75%	100%
1985-92	997.6	991.3	985.7	977.4.	974.1	976.9
1985-91	663.0	691.0	718.4	774.6	830.5	885.1
1985-90	486.1	495.4	504.3	521.7	538.5	554.7

absolute revenue: amounts for the 1985-92 period are closely linked to they price elasticities of this fishery. The revenue impacts of exaggerated harvests like those predicted for 1991 and 1992, are muted through the. marketplace; larger harvests translate into lower ex-vessel prices. These results further highlight the importance of considering the feedback between. prices and quantities when evaluating alternative management policies.

The revenue rankings and policy implications change quite dramatically if the forecast horizon excludes 1992. The most liberal policy (i.e., $SIZELIM_t$ = 100%) produces the largest revenue stream when using an 8-year forecast horizon (1985-91). The conservative strategy is projected to be the least profitable over the 7-year period. The most liberal harvest yields a revenue stream 33% greater than the most conservative strategy. Reducing the forecast horizon by an additional year (1985-90) utilizes a terminal period that is linked to a potentially more robust recruitment forecast. Two conclusions are evident from this shortened horizon. First, the most conservative harvest policy yields the lowest present value income stream. Second, the percentage difference in revenue streams between the high and low harvest scenarios is less than one-half that of the 1985-91 simulation period.. This ranking is unchanged if the horizon is reduced even further (e.g., 1985-89).

Collectively, these alternative horizons produce revenue rankings that highlight the policy relevance of longer-run forecasts. Without the 1992 information, these results would favor liberal size-limit management. Conversely, if the 1992 forecast is approximately correct, the conservative plan yields the greatest return and maintains larger ending stocks of adult king crab that may avert another collapse. Uncertainty about the 1991 and 1992 predictions argues for a conservative policy posture. Initial conservation may provide a measure of' safety. that allows time for more information to be developed, and for improved and updated long-term forecasts. Little is sacrificed in the short term given the relative similarity in revenues during the first three periods.

It is important to remember that none of the alternative policy scenarios considered should be construed as optimal, for the same general reasons discussed under "Historical Simulation of an Alternative Management Scenario." There is also no reason to believe that the size limit should be fixed at any single level over time. Such pure strategies fail to account for feedback effects between the biological resource base and the market for king crab. Consider, for example, the implications of harvest level on fishermen revenues that were derived from the ex-vessel price elasticities given in Matulich, Hanson and Mittelhammer (1988a). High harvest levels suppress fishermen revenues according to these results. It follows that conservative size-limit policies, at least under abundant stock conditions (e.g., 1990), will increase the revenue stream to fishermen. Optimal control of this fishery is likely to involve varied size-limit policies over time which offer potential long-term gains to the various participants.

Alternative Season Length Scenarios

Two alternative season length (DAYS_t) scenarios are simulated for the period from 1985 to 1992. One scenario utilizes the same constant season length assumed in the size-limit scenarios. A constant season length policy, however, is unrealistic given fluctuating resource abundance. Thus, a biomass-dependent season length is used as a contrasting alternative. This alternative uses a decision rule based on the harvest guideline (GUIDE_t) , as given by Equation (1).

$$\begin{aligned}&\text{If } GUIDE_t <= 10, \text{ then } DAYS = 7.0;\\&\text{else if } GUIDE_t > 10, \text{ then } DAYS = 7.0 + 0.1(GLJIDE_t - 10).\end{aligned} \tag{1}$$

As the harvest guideline increases beyond the 10 million pound baseline level, seasons length expands in proportion. Admittedly, this alternative is somewhat arbitrary, but it serves: to highlight the impact of varied season length on harvest, fishing effort, and market conditions within the industry. A constant size limit is imposed in both scenarios whereby 25% of the $MALE8_t$ age class is legally harvestable. The harvest guideline again is set at 30% of the legal population.

The major difference in the forecasts generated from these two scenarios centers on fishing effort and the harvest sector. Table 6 is a comparative listing of season length (DAYS), harvest (QHAPVT), potlifts (POTLIFTS), fleet size (VESSELS), and weight per potlift (WPUE) projections for each scenario over the period 1985 to 1992. Complete results are reported in Appendix D (Table D.3 for the constant scenario and Table D.7 for the variable scheme).

Harvest in area T and total potlifts are forecast to increase as the season lengthens. In contrast, fleet size and potlift efficiency both decline. These results suggest that season length can be used to alter the cost of fishing and regulate fleet size within the industry. They also demonstrate that short seasons combined with relatively large legal populations require fleet sizes that previously have not existed. Season length will need to be longer when the number of vessels is limiting.

In summary, these results illustrate the diverse opportunities available within the fishery for alternative management strategies. These

Table 6.--Comparative forecasts of harvest sector dependent variables for the two future season length simulations, 1985-92.

	Year			
Variables	1985	1986	1987	1988
Constant $DAYS_t$ Scenario:				
DAYS	7.000	7.000	7.000	7.000
QHARVT	2.529	9.215	21.299	32.153
POTLIFTS	0.063	0.103	0.153	0.207
VESSELS	53.616	63.731	86.706	113.024
WPUE	40.142	89.689	139.445	155.598
Variable $DAYS_t$ Scenario:				
DAYS	7.000	7.000	7.664	8.207
QHARVT	2.529	9.215	21.612	32.795
POTLIFTS	0.063	0.103	0.157	0.216
VESSELS	53.616	63.731	86.706	112.599
WPUE	40.142	89.689	137.842	151.895

Table 6.--Continued.

Variables	Year 1985	 1986	 1987	 1988
Constant $DAYS_t$ Scenario:				
DAYS	7.000	7.000	7.000	7.000
QHARVT	35.398	48.235	63.861	90.102
POTLIFTS	0.253	0.356	0.499	0.744
VESSELS	137.753	194.620	281.028	462.188
WPUE	140.015	135.339	127.865	121.126
Variable $DAYS_t$ Scenario:				
DAYS	8.451	9.084	9.523	10.066
QHARVT	35.905	49.352	65.057	91.846
POTLIFTS	0.265	0.382	0.540	0.815
VESSELS	136.447	192.436	275.246	448.443
WPUE	135.257	129.127	120.490	112.665

simulations do not begin to exhaust the array of possible alternatives that can be considered. They only serve to document the importance of integrated, long-term evaluation of management impacts on this lucrative shellfish industry. Optimal management prescription over time requires casting the entire bioeconomic analysis into a discrete-time control framework.

SUMMARY

Results reported in this study demonstrate the policy significance of dynamic feedback effects inherent among the king crab resource base, commercial harvest, and processed product markets. A mosaic of complex interrelationships among crab stocks, fishing effort, ex-vessel prices, processed production, inventory holdings, wholesale prices, and domestic consumption defines the proper decision making context of this industry. A 9-year horizon is the minimal time frame needed to evaluate anticipated impacts of current harvest management actions on future recruitment into the legal population. Moreover, effective management requires evaluating information on both price and quantity signals that are expected to predominate when progeny of the current adult population recruit into the commercial fishery. The dynamic effects and interaction of these quantity and price components are of singular importance in guiding the formulation of king crab fishery policy.

The Alaska Board of Fisheries acknowledges the importance of economic considerations in their king crab resource management policy:

> The policy of the Board of Fisheries is to manage the Alaska king crab fishery in a manner that establishes stability and eliminates, as much as possible, extreme fluctuations in annual harvest that have at times characterized this fishery. The Board recognizes that this policy will not maximize physical yield because maximum physical yield will not necessarily produce the

> long-term optimum-economic yield (Alaska Department of Fish and Game 1985, p. 13).

Unfortunately, neither the anticipated current price effects of management, nor the long-term biological or economic impacts of harvest regulation have been formally used by the Board to evaluate and implement policy. Analysis of most management regimeshas been restricted primarily to review of past fishery performance or expected stock conditions for the upcoming harvest season. Policymakers and resource managers have not been able to incorporate the long-run dynamic interactions of prices and quantities into policy formulation because historically they have lacked the necessary analytical tools, timer series data, and empirical models to do so. The bioeconomic framework developed in this study can begin to fill this information gap. It provides the needed linkage between prices and quantities at all levels of the industry to guide future management in a manner consistent with the Board's policy. It further affords an opportunity to evaluate alternative policy goals.

The bioeconomic model is used to simulate two historical scenarios and seven future scenarios based on alternative minimum size limit and season length management policies. The first historical simulation is an ex post forecast of the industry for the period 1977-83. The purpose of this simulation is to evaluate the model's overall goodness of fit, which is excellent. The second historical forecast assumes a more conservative size limit and season length policy than was actually implemented. This simulation suggests that more restrictive management might have prevented the 1983 Bristol Bay fishery closure, although the harvest still would have been quite small, reflecting in part management policies 9-16 years earlier. The future simulations covered the period 1985-92. Six different size-limit policies ranging from total harvest protection of 8-year-old males (MALE8) to complete exploitation of MALE8 crab are analyzed. Protecting all 8-year-old males from commercial harvest not only results in the most abundant adult biomass in the terminal forecast period (1921), but also generates the largest present value revenue stream to fishermen (based on 1985 dollars). This result however should be regarded as somewhat tentative given the nature of the model and data limitations. The season length variation illustrates how effort would change as the harvest period lengthens.

CONCLUSIONS

Bioeconomic modeling of the Alaskan king crab industry yields the following points..

1. Recent closures might have been preventable.
2. The industry is likely to recover from the current decline.
3. The path to recovery may lead to near record harvests as early as 1991, then either to a viable fishery beyond or collapse.
4. It may be desirable to harvest adult female king crab under certain circumstances.
5. Minimum size limits on adult males probably should not be reduced during periods of low abundance or low recruitment.

Historical simulation of a more conservative management strategy than was actually observed over the period 1977-83 suggests the 1983 Bristol Bay closure may have been prevented. Complete protection of all 8-year-old males from commercial harvest and shortened seasons might have led to increased net survival and recruitment into the legal population. Harvests in the initial simulated periods (1978 and 1979) were projected to be lower under stricter size-limit policy, while substantially larger catches were predicted for 1980-83. More importantly, interactions between supply and demand translate the conservative harvest policy into higher estimated seasonal harvest revenues in all but one year (1981). The conservative regime yielded a present value revenue stream $72 million larger (21% greater) than actually realized. Although fewer crab would have been caught in the- first few years, revenues would have been higher and at least some harvest could have been sustained over the entire forecast horizon.

Recovery of the industry from currently depressed conditions is likely. Each of the six alternative size-limit scenarios project generally increasing legal abundance and harvest through 1991. Market conditions are expected to absorb this growth, supporting fairly high ex-vessel and wholesale product prices. It appears the potential exists for another industry boom to occur in the late 1980s and early 1990s.

How long the boom lasts depends upon how well the projected recovery can be sustained. Whether the recovery endures hinges upon the willingness of resource managers and decision makers to formulate a policy perspective not less than 9 years into the future. Only then will the impact of actions today be translated into anticipated price and quantity signals that will predominate as the progeny recruit into the fishery. Significantly different harvest outcomes are predicted for the terminal simulation period (1992). These differences stem from projected variations in 8-year-old abundance in 1991. Whereas one might advocate a liberal size-limit policy based on forecasts for the first 7 years (1985-91), a conservative policy would appear more judicious when simulation is extended to the terminal future period (1992). Forecasts less than 9 years into the future cannot account for the dynamic feedback effects of proposed policies, and therefore will not provide essential information on predictable biological and market ramifications of management.

A males-only harvest policy may have been destabilizing and prevented the industry from achieving its economic potential (even under the record harvest of 1980). The biological models suggest that reproduction efficiency may be optimal only when sexually mature male and female crab are in proper ratio. The implied optimal sex ratio changes as adult male and female stocks fluctuate. If further research confirms this conclusion, management policies should be formulated to achieve and maintain near optimal ratios. Commercial harvest of adult females may complicate the pricing structure for raw and processed crab, but failure to manage for the optimal sex ratio may perpetuate instability and diminish financial returns to industry participants.

The research reported here provides some insight into a contemporary issue being discussed by regulators and participants in the king crab fishery. Resource managers, fishermen, and processors are currently debating whether minimum legal size limits should be reduced when crab populations may be experiencing increases in natural mortality. Some argue that more liberal regulations should be allowed because "the crab will die anyway." Results from the future alternative size-limit simulations. challenge the propriety of this argument. Less restrictive management not only might exacerbate depressed stock conditions resulting from increased mortality, but also may reduce future revenue streams to both fishermen and processors. It would appear that more research on both sides of this debate is desirable before size-limit policy is substantially changed.

This research illustrates that complex, open access resource industries are amenable to bioeconomic modeling and simulation. There is little difference between econometric modeling of most agricultural commodities and many renewable resources. The fact that king crab reside more than 100 fathoms below the ocean's surface complicates, but does not preclude, the modeling of supply. It is this linkage between the biological resource and market interactions that is crucial to effective and successful management of common property resources.

LIMITATIONS

This research represents the first comprehensive bioeconomic study of the Alaskan king crab industry. As such, it should not be regarded as definitive in any aspect--from the biological submodels to the market submodels.

The-most serious problem encountered during the course of this research centered on data. Inadequate and incomplete time series data not only caused considerable noise in the parameter estimates, but also prevented structural modeling of several sectors within the industry that undoubtedly influence the king crab market. These sectors include harvest outside Bristol Bay; the export market for king crab products; and all aspects of meat production, storage, supply, and consumption. These components admittedly were perceived to be considerably less important in understanding how crab resources get allocated, but their treatment as exogenous factors is a deficiency of the model.

Harvest from all other areas (QHARVW) clearly represents more than a market clearing residual catch. Unfortunately, the abundance of missing or questionable data precluded more complete structural specification. Management agencies must begin to enforce complete and accurate reporting of harvest and ex-vessel price data on fish tickets. They also must be more thorough in editing and reporting data in a standardized and timely fashion. This will greatly enhance future research efforts, and lead to more effective policy formation. The importance of Japan as a demand source for frozen king crab sections also warrants further research and model effort on the export market.

Limited data availability also created problems in modeling biological response of the older age class cohorts. For example, it would have been desirable to specify the 8-year-old male (MALE8) recruitment function with the same Trajectory Adjusted Intrinsic Recruitment (TAIR) framework used in the 6- and 7-year-old male relationships. Unfortunately, there were insufficient time series observations on MALE8 biomass to use that structure. The MALE8 equation should be reestimated as more data become available. In fact, this is true for all the biological relationships. Estimates of this recursive, age-structured framework can be used with greater confidence as more observations are obtained. The additional data also will enable estimation of the biological submodel as a system in which certain parameters are shared across cohorts. It is imperative that National Marine Fisheries Service resource assessment surveys be maintained to provide the necessary data for effective policy analysis.

Perhaps the greatest limitation of the biological modeling centers on the composite 6 to 14-year-old female cohort. Nine female cohorts were aggregated because historically they have been unaffected by management. The conclusion that there may be a density dependent optimal sex ratio, however, is a compelling reason to disaggregate this cohort. Future research is needed to develop female models that parallel the male models.

Absence of wholesale market data (e.g., prices and inventory holdings) for 1984 and 1985 during the estimation phase of this research prevented analysis of the industry beyond 1983, and created numerical difficulties in simulating future conditions. A structural break occurred in 1983 due to closure of the Bristol Bay harvest area. Since this break was in the terminal period of the analysis, it was not possible to model industry response following the break. Structural adjustment factors had to be used to recalibrate the model for the future management scenarios. It would have been better to incorporate this structural change explicitly rather than recalibrate the model. Consideration should be given to reestimating the behavioral equations as additional data become available.

No inference should be made regarding optimal management trajectories over time. Such trajectories are critical to formulating policies that maximize the welfare of fishery participants. This bioeconomic model, however, provides the basic foundation for future analysis concerning optimal control of the Alaskan king crab fishery. Updating the model with data that are now available, and resolving the preceding limitations is the first step towards developing the requisite control framework. Representation of the highly nonlinear biological submodel in a simpler numerical form also may be critical to developing both a feasible control theoretic analysis of this multicohort fishery, and an optimal management regime.

Despite the various limitations, this research now provides fishermen, processors, resource managers, and policymakers with important insights into the behavior of this open access fishery. The bioeconomic framework also gives policymakers a means to evaluate future management alternatives. Whether the underlying model accurately simulates the future will be known only in hindsight.

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REFERENCES

Alaska Department of Fish and Game. 1969-83. Catch and production leaflet. Commercial Fish. Div. P.O. Box 3-2000, 1255 W. 8 Street, Juneau, AK 99802.

Alaska Department of Fish and Game. 1970-83. Annual report to the Alaska Board of Fisheries. Commercial Fish. Div., P.O. Box 3-2000,. 1255 W. 8 Street, Juneau, AK 99802.

Alaska-Department of Fish and Game. 1985. 1985. commercial shellfish regulations: regulations of the Alaska Board of Fisheries for commercial fishing in Alaska. Commercial Fish. Div., P.O. Box 3-2000, 1255 W. 8 Street, Juneau, AK 99802.

Butcher, W., J. Buteau, K. Hassenmiller, G. Petry, and S. Staitieh. 1981. Economic impacts of the Alaska shellfish fishery: an input-output analysis. U.S. Dep Commer., NOAA Tech. Memo. NMFS F/NWC-9, 103 p.

Deriso, R. B. 1980. Harvesting strategies and parameter estimation for an age-structured model. Can. J. Fish. Aguat. Sci. 37:268-282.

Folwell, R. J., R. C. Mittelhammer, F. L. Hoff, and P. K. Hennessy. 1985. The federal hop marketing order and volume-control behavior. Aqric. Econ. Res. 37:17-32.

Judge, G. G., W. E. Griffiths, R. C. Hill, and T. C. Lee. 1985. The theory and practice, of econometrics, 2nd edition. John Wiley and Sons, New York.

Magnuson Fishery Conservation and Management Act. 1976. 16 U.S.C.§1801: et seq.

Matulich, S. C., J. E. Hanson, and R. C. Mittelhammer. 1988a. A market model of the Alaskan king crab industry. U.S. Dep. Commer., NOAA Tech. Memo NMFS- F/NWC-157, 62 p.

Matulich, S. C., J. E. Hanson, and R. C. Mittelhammer. 1988b. A recursive age-structured model of Alaskan and king crab. Fish. Res. Bul. 88-06, Commercial Fish. Div., Alaska Dep. Fish and Game, P.O. Box 3-2000, Juneau, AK 99802-2000

National Marine Fisheries-Service. 1969-84. Fishery market news--Seattle. Available from NMFS, Northwest Region, 7600 Sand Point Way NE, Bin. C15700, Seattle, WA 98115-0070.

Pindyck, R. S., and D. L. Rubinfeld. 1981. Econometric models and economic forecasts, 2nd edition. McGraw-Hill Book Co., New York.

Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can., 11:559-623.

SAS Institute. 1984. SAS/ETS User's Guide. Version 5 Edition. SAS Institute, Inc., Cary, North Carolina.

Theil, H. 1961. Economic forecasts, and policy. North-Holland Publishing co., Amsterdam.

Theil, H. 1966. Applied economic forecasting. North-Holland Publishing co., Amsterdam.

U.S. Department of the Interior.. 1947-75. Fisheries statistics of the U.S. Fish and Wildlife Serv., Statistical Digest, Washington, D.C.

APPENDIX A

ECONOMETRIC MODEL OF THE ALASKAN RING CRAB INDUSTRY: BIOLOGICAL SUBMODEL AND MARKET SUBMODEL EQUATIONS AND VARIABLE; DEFINITIONS

I. Biological Submodel

$$\mathrm{MALE5}_t = \underset{(4.98)}{4.1775}\ \mathrm{FEM514}_{t-6}\ e^{(\underset{(-9.74)}{-0.03458}\ \mathrm{FEM514}_{t-6} + \underset{(6.27)}{0.00004497}\ \mathrm{FM514}_{t-6} - \underset{(-1.53)}{0.001696}\ \mathrm{MALE514}_{t-6} + \underset{(6.20)}{0.70734}\ \mathrm{IND77})} \tag{A.1}$$

$R^2 = 0.9402$ df = 7

$$\mathrm{MALE6}_t = \underset{(0.44)}{0.51185}\ [\mathrm{FEM514}_{t-7}^{\underset{(2.35)}{1.50104}}\ e^{(\underset{(-2.20)}{-0.03458}\ \mathrm{FEM514}_{t-7} + \underset{(2.09)}{0.00005303}\ \mathrm{FM514}_{t-7} - \underset{(-2.63)}{0.00714}\ \mathrm{MALE514}_{t-7} + 0.56673\ \mathrm{IND77})}]\ \mathrm{MALE5}_{t-1}^{\underset{(0.80)}{0.22434}} \tag{A.2}$$

$R^2 = 0.9486$ df = 4

$$\mathrm{MALE7}_t = \underset{(18.32)}{0.05833}\ [\mathrm{FEM514}_{t-8}^{\underset{(5.76)}{2.42368}}\ e^{(\underset{(-5.07)}{-0.05442}\ \mathrm{FEM514}_{t-8} + \underset{(4.77)}{0.00008292}\ \mathrm{FM514}_{t-8} - \underset{(-5.62)}{0.01132}\ \mathrm{MALE514}_{t-8} - \underset{(-2.40)}{0.70835}\ \mathrm{IND83})}]\ \mathrm{MALE6}_{t-1}^{\underset{(1.70)}{0.33399}} \tag{A.3}$$

$R^2 = 0.9864$ df = 3

$$\mathrm{MALE8}_t = \underset{(16.77)}{1.16117}\ \mathrm{MALE7}_{t-1} + [\underset{(3.54)}{0.40034}\ \cos(\underset{(595.18)}{5.83152}\ \mathrm{TIME70} - \underset{(-23.80)}{3.52198})]\ \mathrm{MALE7}_{t-1} - \underset{(-3.05)}{8.99610}\ \mathrm{IND83} \tag{A.4}$$

$R^2 = 0.7921$ df = 12

$$MALE914_t = \underset{(15.34)}{1.03582}(MALE8_{t-1} + (MALE914_{t-1} - QHARVT_{t-1})) \tag{A.5}$$

$$+ (\underset{(8.26)}{26.48835} \cos(\underset{(595.18)}{5.83152}\, TIME70 - \underset{(-23.80)}{3.52198})) - \underset{(-0.97)}{33.24420}\, IND81$$

$$+ \underset{(7.52)}{13.46790}\, IND84$$

$R^2 = 0.9431$ df = 11

$$FEM5_t = \underset{(2.40)}{2.57521}\, FEM514_{t-6}\, e^{(\underset{(-8.57)}{-0.02328}\, FEM514_{t-6} + \underset{(1.03)}{0.01578}\, FM514_{t-6}} \tag{A.6}$$

$$^{- \underset{(-0.69)}{0.0016988}\, MALE514_{t-6} + \underset{(7.05)}{1.04231}\, IND7779)}$$

$R^2 = 0.9415$ df = 7

$$FEM614_t = [\underset{(6.95)}{7.83914}\, FEM514_{t-7}\, e^{(\underset{(-25.06)}{-0.03939}\, FEM514_{t-7}} \tag{A.7}$$

$$^{+ \underset{(3.97)}{0.00004421}\, FM514_{t-7} - \underset{(-3.34)}{0.0038566}\, MALE514_{t-7})}]\, e^{(\underset{(13.63)}{0.01061}\, FEM614_{t-1})}$$

$$e^{(\underset{(-15.56)}{-1.04467}\, IND78 + \underset{(12.43)}{1.17412}\, IND81 - \underset{(-1.99)}{1.52166}\, IND83)}$$

$R^2 = 0.9979$ df = 4

$$FEM514_t = FEM5_t + FEM614_t \tag{A.8}$$

$$MALE514_t = MALE5_t + MALE6_t + MALE7_t + MALE8_t + MALE914_t \tag{A.9}$$

$$FM514_t = FEM514_t\, MALE514_t \tag{A.10}$$

$$\text{LEGALS}_t = (\text{SIZELIM}_t\ \text{MALE8}_t) + \text{MALE914}_t \tag{A.11}$$

$$\text{NONLEGALS}_t = (\text{FEM514}_t + \text{MALE514}_t) - \text{LEGALS}_t \tag{A.12}$$

II. Market Submodels

Raw Crab Market

$$\text{QHARVT}_t = \underset{(1.50)}{4.12996}\ \underset{(11.80)}{\text{LEGALS}_t^{1.06872}}\ \underset{(-3.69)}{\text{NONLEGALS}_t^{-0.35311}}\ \underset{(5.08)}{\text{POTLIFTS}_t^{0.55825}} \tag{A.13}$$

$R^2 = 0.9748$ $\qquad$ df = 11

$$\text{POTLIFTS}_t = \underset{(10.69)}{0.001001}\ [\underset{(5.03)}{(\text{EXPRT}_t\ \text{GUIDE}_t)^{0.37371}}\ \underset{(5.69)}{(\text{VESSELS}_t)^{0.76095}} \tag{A.14}$$

$$\underset{(3.80)}{(\text{DAYS}_t)^{0.29166}}\ \underset{(-2.22)}{(\text{LEGALS}_t)^{-0.12653}}] - \underset{(-4.74)}{0.18699}\ \text{IND79}$$

$R^2 = 0.9813$ $\qquad$ df = 9

$$\text{VESSELS}_t = e^{(\underset{(37.88)}{3.77003} + \underset{(3.37)}{0.00602}\ \text{EXPRT}_{t-1}\ \text{QHARVT}_{t-1}} \tag{A.15}$$

$$^{+ \underset{(5.88)}{0.00318}\ \text{LEGALS}_t + \underset{(2.01)}{0.00212}\ \text{VESSELS}_{t-1} - \underset{(-0.03)}{10.35191}\ \text{IND83})}$$

$R^2 = 0.9957$ $\qquad$ df = 9

$$\text{QHARVW}_t = (\text{SECTPROD}_t + \text{MEATPROD}_t) - \text{QHARVT}_t \tag{A.16}$$

$$\text{QHARVUS}_t = \text{QHARVT}_t + \text{QHARVW}_t \tag{A.17}$$

$$WPUE_t = QHARVT_t \;/\; POTLIFTS_t \qquad (A.18)$$

$$QHTDAY_t = (QHARVT_t \;/\; DAYS_t)\; 1000 \qquad (A.19)$$

$$QHARDP_t = \frac{(QHARVT_t\; QHTDAY_t)}{QHARVUS_t} \;/\; PLANTS_t + \frac{(QHARVW_t\; QHWDAY_t)}{QHARVUS_t} \;/\; PLANTS_t \qquad (A.20)$$

$$EXPRT_t = \underset{(-1.705)}{-0.34479} + \underset{(9.856)}{0.52485}\; WTAVP_{t-1} - \underset{(-3.249)}{0.01075}\; QHARVT_t \qquad (A.21)$$

$$- \underset{(-4.515)}{11.91756}\; INTR_t + \underset{(4.857)}{1.96136}\; FUEL_t - \underset{(-0.312)}{0.00039}\; WPUE_t - \underset{(-14.356)}{5.30270}\; IND83$$

$R^2 = 0.9809$ df = 7

$$AVEXPR_t = \frac{(EXPRT_t\; QHARVT_t)}{QHARVUS_t} + \frac{(EXPRW_t\; QHARVW_t)}{QHARVUS_t} \qquad (A.22)$$

Processed Product Market

$$PSECT_t = \underset{(4.193)}{1.18130} + \underset{(1.872)}{0.01646}\; SECTSUP_t + \underset{(1.227)}{1.93266}\; AVEXPR_t \qquad (A.23)$$

$$- \underset{(-0.916)}{0.06724}\; QHARDP_t - \underset{(-0.753)}{5.16925}\; INTR_t + \underset{(0.391)}{0.21348}\; PSECT_{t-1}$$

$R^2 = 0.9726$ df = 8

$$PMEAT_t = \underset{(-2.169)}{-1.77354} + \underset{(7.536)}{2.03793}\; PSECT_t + \underset{(1.038)}{0.28495}\; LABOR_t \qquad (A.24)$$

$R^2 = 0.9704$ df = 12

$$\mathrm{SECTHOLD}_t = \underset{(-5.95)}{-4.20879} + \underset{(5.89)}{0.13502}\ \mathrm{SECTPROD}_t + \underset{(3.08)}{3.53861}\ \mathrm{PSECT}_t \qquad (A.25)$$

$$- \underset{(-0.33)}{0.38722}\ \mathrm{PSECT}_{t-1} - \underset{(-1.88)}{12.37973}\ (\mathrm{PSECT}_t\ \mathrm{INTR}_t) - \underset{(-3.93)}{4.25953}\ \mathrm{IND73}\ .$$

$R^2 = 0.9449$ df = 8

$$\mathrm{SECTPROD}_t = \mathrm{SECTCONS}_t + \mathrm{SECTEXP}_t + \mathrm{SECTHOLD}_t \qquad (A.26)$$

$$- \mathrm{SECTHOLD}_{t-1} - \mathrm{SECTIMP}_t$$

$$\mathrm{SECTSUP}_t = \mathrm{SECTPROD}_t + (\mathrm{SECTHOLD}_{t-1} - \mathrm{SECTHOLD}_t) \qquad (A.27)$$

$$\mathrm{WTAVP}_t = ((\mathrm{PSECT}_t\ \mathrm{SECTSUP}_t) + (\mathrm{PMEAT}_t\ \mathrm{MEATSUP}_t))_t) \qquad (A.28)$$

$$/\ (\mathrm{SECTSUP}_t + \mathrm{MEATSUP}$$

$$\mathrm{SECTCONS}_t = \underset{(-4.687)}{-61.76014} - \underset{(-6.536)}{21.87475}\ \mathrm{PSECT}_t + \underset{(2.143)}{36.40434}\ \mathrm{PLOB}_t \qquad (A.29)$$

$$+ \underset{(2.477)}{0.01675}\ \mathrm{INC}_t - \underset{(-1.617)}{18.77098}\ \mathrm{IND74}$$

$R^2 = 0.9031$ df = 10

III. Variable Definitions

Variable name	Definition	Data source
Endogenous Variables: Biological Response Submodel		
MALE5	Biomass (million pounds) of 5 year old male red and king crab (95-109 mm carapace length) in the southeastern Bering Sea at the start of the ADFG regulation year (1 July). Derived by multiplying the estimated number of n-year-old males by 1.77.	5
MALE6	Biomass (million pounds) of 6-year-old male red king crab (110-119 mm carapace length) in the southeastern Bering Sea at the start of the ADFG regulation year (1 July). Derived by multiplying the estimated number of 6-year-old males by 2.52.	
MALE7	Biomass (million pounds) of 7-year-old male red king crab (120-129 mm carapace length) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by multiplying the estimated number of 7-year-old males by 3.31.	
MALE8	Biomass (million pounds) of 8-year-old male red king crab (130-139 mm carapace length) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by multiplying the-estimated number of 8-year-old males by 4.27.	
MALE914	Aggregate biomass (million pounds) all 9- to 14-year-old male red king crab ($>$139 mm carapace length) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by multiplying the estimated number of 9-, 10-, ll-, 12-, 13- and 14-year-old males by 5.24, 6.25, 6.97, 7.67, 8.42 and 9.17, respectively: then summing these weight equivalent values.	
MALE514	Aggregate biomass (million pounds) of all adult male red king crab (ages 5 to 14) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by summing MALE5, MALE6, MALE7, MALE8 and MALE914.	14

Variable name	Definition	Data source
FEM5	Biomass (million pounds) of 5-year-old female red kinq, crab (95-104 mm carapace: length) in the southeastern Bering Sea at the start of the ADFG regulation year (1 July). Derived by multiplying the estimated number of 5-year-old females by 1.45.	5.
FEM614	Aggregate biomass (million pounds) of. all. 6- to 14-year-old female red king crab (>104 mm carapace length) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by multiplying the estimated number of 6-, 7-, 8-, 9-, 10-, 11-, 12-, 13- and 14-year-old females by 1.72, 1.91, 2.10, 2,31, 2.53, 21.73, 3.00, 3.20, and 3.40, respectively; then summing these weight equivalent values..	5
FEM514	Aggregate biomass (million pounds) of all adult female red king crab (ages 5 to 14) in the southeastern Bering Sea at the start of the ADF&G regulation year (1 July). Derived by summing FEM5 and FEM614.	14
FM514	The product of MALE514 and FEM514 in the southeastern Bering Sea measured at the start of the ADF&G regulation year (1 July) in trillion Founds.	14
LEGALS	Biomass; (million pounds) of legally harvestable male, king crab as determined by minimum size limit in the southeastern Bering Sea for the ADF&G regulation year 1 July-30. June. Derived from the sum of all MALE914 crab and that portion of MALE8 crab that are legally harvestable.	2, 14
NONLEGALS	Biomass (million pounds) of all adult king crab, that are not legally harvestable in the southeast Bering Sea during the ADF&G regulation year 1 July-30 June. NONLEGALS is derived as the difference between all adult king crab (i.e., MALE514 + FEM514) and the legally harvestable biomass (LEGALS).	14

Harvest Sector of Market Submodel

Variable name	Definition	Data source
QHARVT	Total seasonal domestic southeastern Bering Sea (Bristol Bay) king crab harvest (million pounds) for the ADF&G regulation year 1 July-30 June.	

Variable name	Definition	Data source
POTLIFTS	Total seasonal potlifts made by fishermen harvesting king crab in the southeastern Bering Sea (Bristol Bay) reported on an ADF&G regulation year basis (1 July-30 June) in million potlifts.	2
VESSELS	Total seasonal fleet size harvesting king crab in the southeastern Bering Sea (Bristol Bay) reported on an ADF&G regulation year basis (1 July-30 June).	2
EXPRT	Seasonal average ex-vessel price ($/pound) paid to fishermen harvesting king crab in the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June.	2,4
WPUE	Seasonal average. legal biomass of king crab harvested per potlift (i.e., weight per unit effort) in the southeastern Bering Sea (Bristol Bay) during the ADF&G regulation year 1 July-30 June. Derived as the quotient of QHARVT and POTLIFTS.	14
AVEXPR	Seasonal weighted average ex-vessel price ($/pound) paid to fishermen harvesting king crab in all registration areas for the ADF&G regulation year 1 July-30 June Derived as the average of EXPRT and EXPRW (an exogenous variable) weighted by their respective seasonal harvests: QHARVT and-QBARVM.	14
QHARVW	Total seasonal domestic king crab harvest (million pounds) from all areas outside the southeastern Bering Sea for the ADF&G regulation year 1 July-30 June.	
QHARVUS	Total seasonal domestic king crab harvest (million pounds) from all U.S. waters for the ADF&G regulation year 1 July-30 June.	
QHTDAY	Seasonal average king crab biomass harvested domestically per day from the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June. QHTDAY is derived as the quotient of QHARVT and season length in the southeastern Bering Sea (DAYS). The quotient is multiplied by 1,000 to calibrate QHTDAY in 1,000 pounds per day.	14

Variable name	Definition	Data source
QHARDP	Seasonal average king crab biomass caught domestically per day per plant for all Alaskan harvest areas for the ADF&G regulation year 1 July-30 June. QHARDP is derived as the average of QHTDAY and QHWDAY (an exogenous variable) weighted by QHARVT and QHARVW respectively then divided by the exogenously determined total number of king crab processing plants operating in Alaska (PLANTS). This variable is reported in 1,000 pounds per day per plant.	14
Processed Product Sector of Market Submodel		
PSECT	Seasonal average New York wholesale market price ($/pound) for frozen king crab sections corresponding to the ADF&G regulation year 1 July-30 June. PSECT is the simple average of reported monthly prices.	7
PMEAT	Seasonal average New York wholesale market price ($/pound) for frozen king crab meats corresponding to the ADFf&G regulation year 1 July-30 June. PMEAT is the simple average of reported monthly prices.	7
SECTCONS	Total seasonal U.S. domestic consumption of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTCONS is calculated as the sum of domestic section production (SECTPROD) and imports (SECTIMP) less section exports (SECTEXP) and change in stock holdings (SECTHOLD_{t-1} - SECTHOLD_t). All quantities are reported on a live weight equivalent basis (1 pound of processed sections = 1.67 pounds of raw king crab) in million pounds.	14
SECTHOLD	Total domestic season ending cold storage holdings of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTHOLD is derived from monthly holdings data and reported on a live weight equivalent basis (1 pound of processed sections = 1.67 pounds of raw king crab) in million pounds.	7
SECTPROD	Total seasonal U.S. production of frozen king crab sections for the ADF&G regulation year 1 July-30 June. Annual processed king crab production data provided by the ADF&G is used to determine what percentage of all production (on a live weight equivalent basis) is in the section form. This percentage is then multiplied by total domestic seasonal harvest (QHARVUS) to estimate seasonal	3

Variable name	Definition	Data source
	section production. SECTPROD is reported on a live weight basis in million pounds.	
SECTSUP	Total seasonal domestic. supply of frozen king crab sections to U.S. wholesale markets for the ADF&G regulation year 1 July-30 June. SECTSUP is derived as the sum of domestic section production (SECTPROD) plus the change in stock holdings ($\text{SECTHOLD}_{t,1}$ - SECTHOLD) on a live weight equivalent basis in million pounds.	14
WTAVP	Weighted average seasonal New York wholesale market price ($/pound) for both frozen king crab sections and meats corresponding to the ADF&G regulation year 1 July-30 June. WTAVP is the average of section (PSECT) and meat (PMEAT) seasonal wholesale prices weighted by domestic section (SECTSUP) and meat (MEATSUP) supplies to U.S. wholesale markets.	14
Exogenous Variables:		
TIME70	A linear time counter beginning with one in 1970 and increasing by unit increments each year.	NA
GUIDE	Seasonal king crab harvest guideline (million pounds) for the southeastern Bering Sea (Bristol Bay) ADF&G management area.	2
DAYS.	Total season length (in days) for the southeastern Bering Sea (Bristol Bay) king crab harvest.	2
INTR	Third quarter prime interest rate charged by banks as reported by the U.S. Federal Reserve.	11
FUEL	Seasonal average diesel fuel price ($/gallon) paid by farmers in Washington for the ADF&G regulation period 1 July-30 June. FUEL was derived as a simple average of reported monthly average prices.	9
LABOR	Annual average wage rate paid to food and kindred products workers in Alaska ($/hour).	8
PLOB	Annual U.S. ex-vessel price index for American lobster (1967 = 1.00).	6
INC	Annual U.S. per capita, disposable income (nomimal $/person).	10

Variable name	Definition	Data source
EXPRW	Seasonal average ex-vessel price ($/pound) paid to fishermen harvesting king crab in areas other than the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June. EXPRW is derived as an average of ex-vessel prices from the other harvest areas weighted by total catch.	2
MEATPROD	Total seasonal U.S. production of frozen and canned king crab meats for the ADF&G regulation year 1 July-30 June. Annual processed king crab data provided by ADF&G is used to determine what percentage of all production (on a live weight equivalent basis) is in the meat form. This percentage is then multiplied by total domestic seasonal harvest (QHARVUS) to estimate seasonal meat production. MEATPROD is reported on a live weight equivalent basis (1 pound of processed meats = 4 pounds of raw king crab) in million pounds.	3
MEATSUP	Total seasonal domestic supply of frozen and canned king crab meats to U.S. wholesale markets for the ADF&G regulation year 1 July-30 June. MEATSUP is derived as the sum of domestic meat production (MEATPROD) plus the change in meat stock holdings (MEATHOLD$_{t-1}$ -MEATHOLD) on a live weight equivalent basis in million pounds.	14
MEATHOLD	Total domestic season ending holdings of frozen and canned king crab meats for the ADF&G regulation year 1 July-30 June MEATHOLD is derived from monthly holdings data and reported on a live weight equivalent basis in million pounds.	7
QHWDAY	Seasonal average king crab biomass harvested domestically per day outside the southeastern Bering Sea (Bristol Bay) management area for the ADF&G regulation year 1 July-30 June. QHWDAY is derived as the weighted average of quantity harvested per day in each of the non-Bristol Bay management areas. The average is reported in thousand pounds per day.	3
PLANTS	Annual number of plants processing raw king crab in Alaska.	i

Variable name	Definition	Data sources
SECTEXP	Total seasonal U.S. export of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTEXP is reported on a live weight basis, millions of pounds.	12
SECTIMP	Total seasonal U.S. import of frozen king crab sections from the Soviet Union, for the ADF&G regulation year 1 July-30 June. SECTIMP is reported on a live weight basis, millions of pounds.	13

Data sources are as follows:

1. Alaska Department of Fish and Game. "Catch and Production Leaflets." Commercial Fish. Div., Juneau, AK, 1969-83.

2. Alaska Department of Fish and Game. "Report to the Alaska Board of Fisheries." Unpublished report, Commercial Fish. Div., Juneau, AK, 1970-84.

3. Alaska Department of Fish and Game. Summaries of Confidential Processor Annual Reports to ADF&G. Unpublished data. Commercial Fish. Div., Juneau, AK, 1969-83.

4. Commercial Fisheries Entry Commission. "Ex-vessel Price Database." Unpublished computer database, Juneau, AK, 1970-84.

5. National Marine Fisheries Service. "Bristol Bay Trawl Survey Age/ Carapace Length Composition for Red King Crab." Unpublished computer database, Northwest and Alaska Fish Cent. Seattle, WA, 1969-83.

6. National Marine-Fisheries Service. "Current Fisheries Statistics." Washington, D.C., various years.

7. National Marine Fisheries Service. "Economic Database." Unpublished computer database, Northwest and Alaska Fish. Cent., Seattle, WA, 1969-83.

8. U.S. Bureau of Labor Statistics. "Employment and Earnings, States and Areas." Bulletin. Washington, D.C., various years.

9. U.S. Department of Agriculture. "Agricultural Statistics." Washington, D.C., various years.

10. U.S. Department of Commerce. "Economic Report of the President." Bureau of Economic Analysis, Washington, D.C., various years.

11. U.S. Federal Reserve Board. "Survey of Current Business." Washington, D.C., various issues.

12. U.S. Bureau of Census. "U.S. Exports Schedule E, Commodity by Country." Washington, D.C., FT 410, various issues.

13. U.S. Bureau of Census. "U.S. General Imports Schedule A, Commodity by Country." Washington, D.C., FT 135, various issues.

14 Derived from other variables within the model.

APPENDIX B

USE AND INTERPRETATION OF SIMULATION FIT AND FORECAST STATISTICS

Use and Interpretation of Simulation Fit and Forecast Statistics

1. Mean Simulation Error (ME), Mean Percent Error (ME%), and Mean Absolute Error (MAE)

ME measures the average error committed in predicting the dependent variable (i.e., it is the mean deviation of the predicted variable from its observed time path). ME% is the percentage equivalent to ME. Both ME and ME% approach zero as the average deviation declines. These statistics also can approach zero if large positive errors are offset by large negative errors. Small ME and ME%, therefore, may not accurately reflect the overall goodness of fit for a given equation. Low error estimates are necessary but not sufficient to demonstrate a good statistical fit. Additional statistical measures also must be evaluated.

MAE "corrects" for the effect of positive and negative errors canceling one another. This statistic measures the average deviation in absolute value between a simulated variable and historically observed data. It represents the nominal magnitude of ME and also must be evaluated relative to observed magnitudes of the dependent variable (e.g., the observed mean). For example, the MAE of PSECT is estimated to be $0.307 per pound (i.e., the predicted value of PSECT deviates from the observed value by an average of $0.307 per pound). If PSECT averages $0.500 per pound, the degree of error is large and the fit is poor. On the other hand, if the mean of PSECT is $5.526 per pound (as observed here), the estimated relationship predicting PSECT is relatively accurate.

2. Root Mean Square Error (RMSE%) and Simple Correlation Coefficient (R)

Both ME and MAE depend on the units used to measure the dependent variable. Neither statistic allows for objective comparison of different equations within the model system. RMSE% and R, however, are unitless measures that can be used to evaluate different equations within the system. RMSE% conceptually is the average distance between the vector of predicted values for a given dependent variable and the vector of actual values expressed as a percentage of the observed vector in Euclidean space. Predictive accuracy of the equation improves as RMSE% decreases. Alternatively, R measures the degree of linear correlation between the predicted (Y_i) and observed values (Y_i) of the dependent variable. Perfect linear correlation occurs between Y_i and Y_i when R = 1.0. The degree of linear correlation degenerates as R approaches zero. A strong linear correlation does not necessarily imply a near perfect fit, but it does provide a relative measure of predictive accuracy.[1/]

[1/] Theil (1961, p. 31-32) pointed out the limitation- of using simple correlations to evaluate the forecast accuracy of a model system:

> . . . perfect (positive) correlation does not imply perfect forecasting, but only the existence of an exact linear relation with positive slope between the individual predictions (Y_i) and the actual values (Y_i),
>
> $Y_i = a + B Y_1 \qquad B > 0$,
>
> whereas perfect forecasting requires, in addition to this, a = 0 and B = 1.

3. Theil's Forecast Statistics

Theil derived an inequality coefficient (U) ranging between zero and one to measure the absolute difference between simulated and observed values of the dependent variable. The original specification of this statistic is reported here.[2/] Ability of the model to predict turning points in an individual equation improves as the inequality coefficient for that variable approaches zero.

Theil's U statistic is decomposable into three components that necessarily range between zero and one and by definition sum to one: a central tendency or bias measure (U^M), the regression proportion (U^R) of an

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[2/] Theil actually developed two inequality coefficients. The initial version is given by (1) and reported in Table 3.

$$U = [((1/T)(\sum_{i=1}^{T}(\hat{Y}_i - Y_i)^2))^{1/2}]/[((1/T)(\sum_{i=1}^{T}(Y_i)^2))^{1/2}] \tag{1}$$

T corresponds to the number of forecasted observations. The second version resembles. (l) but contains an additional additive square root term in the denominator.

$$[((1/T)(\sum_{i=1}^{T}(\hat{Y}_i)^2))^{1/2}] \ . \tag{2}$$

This second statistic has the same general interpretation as (1). If u = 1, the simulation is the worst it can be; when U = 0, it signifies a perfect fit. Conclusions regarding the use of Y_{i-1} to predict V_i differ between the two formulations when the inequality coefficient equals 1.0. Whereas U = 1, estimated from (1) implies that a naive, no change extrapolation using Y_{i-1} is as accurate as Y_i in predicting Y_i this implication does not follow from the revised statistic (see Theil 1966).

optimal linear correction to the forecast, and the disturbance proportion (U^D) of the- forecast correction. The combined value- of U^M and U^R represents systemic error in the forecast whereas U^D measures that portion of mean squared prediction on error that is due to random disturbances. Ideally, all forecast errors should be attributable to this random disturbance term (U^D) with systemic error (i.e., $U^M + U^R$) equal to zero. Systemic error rarely is zero, but should be as close to zero as possible because the average predicted forecast deviates from the observed mean condition as systemic error increases (Theil 1966, p. 32). Systemic error indicates that forecasts are erring consistently in the same direction (either positively or negatively) in predicting Y_i and suggests that the equation is missing an important explanatory element.

APPENDIX C

MODEL MODIFICATIONS REQUIRED FOR FUTURE SIMULATIONS

Improving Numerical Solution Efficiency of the Model

Initial efforts to simulate alternative future policy scenarios were confounded by the highly nonlinear structure of the simultaneous equation system. Convergence on a stable solution to this complex system was difficult; the large number of endogenous variables appearing as explanatory elements of the model complicated gradient search. Numerical solution was assisted by replacing the market components of the structural model with a partially reduced form. Reduction of the bioeconomic model involves only the market components because the harvest sector is segmentable from the rest of the model. This reduction improves numerical solution efficiency by creating a numerically equivalent, but algebraically more simple system. Simultaneity is reduced without changing the solution space.

The reduction process begins by expressing the entire market side of the model in terms of the wholesale price of king crab sections ($PSECT_t$) and predetermined variables. $PSECT_t$ however is a function of average ex-vessel price ($AVEXPR_t$), average quantity harvested per day per plant ($QHARDP_t$), and several predetermined variables. $AVEXPR_t$ and $QHARDP_t$, in turn, can be expressed as nonlinear functions that include the segmentable $QHARVT_t$ (a constant in this case) and $QHARVW_t$ (the market clearing harvest coming from all other fishing regions). In fact, these two weighted average values (i.e., $AVEXPR_t$ and $QHARDP_t$) can be reduced to functions of only $QHARVW_t$ and predetermined variables. It follows that all quantity and price equations can be expressed as functions of $QHARVW_t$ But $QHARVW_t$ is simply $SECTPROD_t - QHARVT_t$. Substituting in a Value for the segmentable $QHARVT_t$ (e.g., the 1984 observation of 1.851) yields an identity for $QHARVW_t$ in terms of $SECTPROD_t$ Solving this identity simultaneously with the $SECTPROD_t$

equation and substituting the resultant value for $QHARVW_t$ back into each of the other equations, yields the fully reduced form of this system.

Unfortunately, the highly nonlinear character of the $SECTPROD_t$ equation precludes finding an explicit algebraic representation for $SECTPROD_t$ and $QHARVW_t$ in reduced form. Therefore, a partially reduced form involving $AVEXPR_t$ and $QHAPDP_t$ as explanatory endogenous variables in each of the market equations is combined with the harvest and resource equations to simulate future policy scenarios. This process is now presented explicitly.

The original estimated equations (excluding indicator variables) and definitional identities are given by Equation (C.l.a.-e).[3/]

$$SECTCONS_t = -61.76014 - 21.87475\ PSECT_t + 36.40434\ PLOB_t + 0.01675\ INC_t + ADDCON \quad (C.1.a)$$

$$SECTHOLD_t = -4.20879 + 0.13502\ SECTPROD_t + 3.53861\ PSECT_t - 0.38722\ PSECT_{t-1} - 12.37973\ (PSECT_t\ INTR_t) + ADDHOLD \quad (C.1.b)$$

$$SECTEXP_t = 0.199\ SECTCONS_t \quad (C.1.c)$$

$$SECTPROD_t = SECTCONS_t + SECTEXP_t + SECTHOLD_t - SECTHOLD_{t-1} - SECTIMP_t \quad (C.1.d)$$

$$SECTSUP_t = SECTPROD_t + (SECTHOLD_{t-1} - SECTHOLD_t) \quad (C.1.e)$$

Structural adjustment factors are included in the estimated market relationships. (i.e., $SECTCONS_t$ and $SECTHOLD_t$ (ADDCON and ADDHOLD, respectively)) to recalibrate the simulation framework following the 1983

[3/] Indicator variables are given zero values in all future simulations and can be deleted from the partially reduced form.

Bristol Bay closure. Though the structural break caused by closure is included via indicator variables in the estimated model, response of the industry following the closed season (i.e., 1984) could not be modeled. These adjustment factors recalibrate the simulation framework to accurately predict observed 1984 conditions and must be included in the partially reduced form.

Careful observation of (C.l.a-e) reveals that the five quantity market relationships (i.e.,.SECTCONS_t, SECTHOLD_t, SECTEXP_t, SECTPROD_t, and SECTSUP_t) can be expressed as functions of the wholesale price, exogenous variables, lagged endogenous variables, and structural adjustment factors.[4/] The reduction process begins by solving (C.l.a-e) in terms of PSECT_t and predetermined variables. A series of substitutions and algebraic substitutions yields five equations.

$$\text{SECTCONS}_t = -61.76014 - 21.87475\ \text{PSECT}_t + 36.40434\ \text{PLOB}_t \qquad \text{(C.2.a)}$$
$$+ 0.01675\ \text{INC}_t + \text{ADDCON}$$

$$\text{SECTHOLD}_t = -16.42475 - 0.00309\ \text{PSECT}_t - 14.31216\ (\text{PSECT}_t\ \text{INTR}_t) \qquad \text{(C.2.b)}$$
$$- 0.44766\ \text{PSECT}_{t-1} + 6.81341\ \text{PLOB}_t + 0.00313\ \text{INC}_t$$
$$- 0.15610\ (\text{SECTHOLD}_{t-1} + \text{SECTIMP}_t) + 0.18716\ \text{ADDCON}$$
$$+ 1.15610\ \text{ADDHOLD}$$

$$\text{SECTEXP}_t = -12.29027 - 4.35308\ \text{PSECT}_t + 7.24446\ \text{PLOB}_t \qquad \text{(C.2.c)}$$
$$+ 0.00333\ \text{INC}_t + 0.199\ \text{ADDCON}$$

[4/] It is assumed that the United States will not import king crab sections in the future; hence, SECTIMP_t can be dropped from the SECTPROD_t identity.

$$SECTPROD_t = -90.47516 - 26.23092\ PSECT_t - 14.31216\ (PSECT_t\ INTR_t) \qquad (C.2.d)$$

$$- 0.44766\ PSECT_{t-1} + 50.46221\ PLOB_t + 0.02321\ INC_t$$

$$- 1.15610\ (SECTHOLD_{t-1} + SECTIMP_t) + 1.38616\ ADDCON$$

$$+ 1.15610\ ADDHOLD$$

$$SECTSUP_t = -74.05041 - 26.22783\ PSECT_t + 43.64880\ PLOB_t \qquad (C.2.e)$$

$$+ 0.02008\ INC_t - SECTIMP_t + 1.199\ ADDCON$$

The next step is to eliminate $PSECT_t$ from the market equations. The original estimated relationship for $PSECT_t$ is augmented by a structural adjustment factor (ADDPSECT).

$$PSECT_t = 1.18130 + 0.01646\ SECTSUP_t + 0.21348\ PSECT_{t-1} \qquad (C.3)$$

$$- 5.16925\ INTR_t + 1.93266\ AVEXPR_t - 0.06724\ QHARDP_t + ADDPSECT$$

This equation can be expressed as a function of the average ex-vessel price $AVEXPR_t$), average quantity harvested per day per plant ($QHARDP_t$), and several predetermined variables by replacing $SECTSUP_t$ in (C.3) with the right-hand expression of (C.2.e).

$$PSECTt = -0..02599.+ 0.50172\ PLOB_t + 0.00023\ INC_t - 0.01149\ SECTIMP_t \qquad (C.4)$$

$$t\ 0\text{-}01378\ ADDCON + 0.14912\ PSECT_{t-1} - 3.61086\ INTR_t + 1.35001\ AVEXPR_t$$

$$- 0.04697\ QHARDP_t + 0.69853\ ADDPSECT$$

Substituting the right-hand side of (C.4) into (C.2.a-e) for $PSECT_t$ produces a partially reduced form of the market submodel in terms of average ex-vessel price ($AVEXPR_t$), quantity harvested per day per plant ($QHARDP_t$), and predetermined variables.

$$\begin{aligned}\mathrm{SECTCONS}_t ={}& -61.19152 + 25.42940\ \mathrm{PLOB}_t + 0.01170\ \mathrm{INC}_t \\ &+ 0.25144\ \mathrm{SECTIMP}_t + 0.69853\ \mathrm{ADDCON} - 3.26202\ \mathrm{PSECT}_{t-1} \\ &+ 78.98658\ \mathrm{INTR}_t - 29.53121\ \mathrm{AVEXPR}_t + 1.02741\ \mathrm{QHARDP}_t \\ &- 15.28010\ \mathrm{ADDPSECT}\end{aligned} \tag{C.5.a}$$

$$\begin{aligned}\mathrm{SECTHOLD}_t ={}& -16.42467 + (6.81186 - 7.18065\ \mathrm{INTR}_t)\ \mathrm{PLOB}_t \\ &+ (0.00313 - 0.00330\ \mathrm{INTR}_t)\ \mathrm{INC}_t - (0.15606 - 0.16451\ \mathrm{INTR}_t) \\ &\mathrm{SECTIMP}_t + (0.18712 - 0.19725\ \mathrm{INTR}_t)\ \mathrm{ADDCON} - (0.44812 \\ &+ 2.13427\ \mathrm{INTR}_t)\ \mathrm{PSECT}_{t-1} + (0.01115 + 0.37204)\ \mathrm{INTR}_t \\ &+ 51.67914\ \mathrm{INTR}_t^2 - (0.00417 + 19.32161\ \mathrm{INTR}_t)\ \mathrm{AVEXPR}_t \\ &+ (0.00015 + 0.67221\ \mathrm{INTR}_t)\ \mathrm{QHARDP}_t - (0.00216 + 9.99742\ \mathrm{INTR}_t) \\ &\mathrm{ADDPSECT} - 0.15610\ \mathrm{SECTHOLD}_{t-1} + 1.15610\ \mathrm{ADDHOLD}\end{aligned} \tag{C.5.b}$$

$$\begin{aligned}\mathrm{SECTEXP}_t ={}& -12.17711 + 5.06045\ \mathrm{PLOB}_t + 0.00233\ \mathrm{INC}_t \\ &+ 0.05004\ \mathrm{SECTIMP}_t + 0.13901\ \mathrm{ADDCON} - 0.64914\ \mathrm{PSECT}_{t-1} \\ &+ 15.71833\ \mathrm{INTR}_t - 5.87671\ \mathrm{AVEXPR}_t + 0.20445\ \mathrm{QHARDP}_t \\ &- 3.04074\ \mathrm{ADDPSECT}\end{aligned} \tag{C.5.c}$$

$$\begin{aligned}\mathrm{SECTPROD}_t ={}& -89.79330 + (37.30171 - 7.18065\ \mathrm{INTR}_t)\ \mathrm{PLOB}_t \\ &+ (0.01716 - 0.00330\ \mathrm{INTR}_t)\ \mathrm{INC}_t - (0.85459 - 0.16451\ \mathrm{INTR}_t) \\ &\mathrm{SECTIMP}_t + (1.02465 - 0.19725\ \mathrm{INTR}_t)\ \mathrm{ADDCON} - (4.35929 \\ &+ 2.13427\ \mathrm{INTR}_t)\ \mathrm{PSECT}_{t-1} + (94.71606 + 0.37204)\ \mathrm{INTR}_t \\ &+ 51.67914\ \mathrm{INTR}_t^2 - (35.41209 + 19.32161\ \mathrm{INTR}_t)\ \mathrm{AVEXPR}_t \\ &+ (1.23201 + 0.67221\ \mathrm{INTR}_t)\ \mathrm{QHARDP}_t - (18.32300 + 9.99742\ \mathrm{INTR}_t) \\ &\mathrm{ADDPSECT} - 1.15610\ \mathrm{SECTHOLD}_{t-1} + 1.15610\ \mathrm{ADDHOLD}\end{aligned} \tag{C.5.d}$$

$$\begin{aligned} SECTSUP_t = & -73.36863 + 30.48985\ PLOB_t + 0.01402\ INC_t \\ & - 0.69853\ SECTIMP_t + 0.83753\ ADDCON - 3.91117\ PSECT_{t-1} \\ & + 94.70491\ INTR_t - 35.40793\ AVEXPR_t + 1.23187\ QHARDP_t \\ & - 18.32084\ ADDPSECT \end{aligned} \quad (C.5.e)$$

All remaining simultaneity can be eliminated by replacing $AVEXPR_t$ and $QHARDP_t$ with expressions involving only $QHARVW_t$. However, the resulting equations are extremely complex, nonlinear relationships that are difficult to solve. Consequently, the partially reduced form equations given by (C.5.a-e) are used to replace the original estimated market relationships and identities in order to simulate future alternative management strategies.

The partially reduced form produces a secondary benefit. It provides insight into the solution properties of the equation system. The system has three solutions to any given set of exogenous and lagged endogenous variables. Two of the solutions are unrealistic. One predicts negative harvest, while the other produces unlimited catches. The third solution, however, provides realistic simulations relative to history.[5/]

Modeling the 1983/1984 Structural Break

Reopening of. the Bristol Bay king crab fishery in 1984 was accompanied by revised expectations and behavioral adjustments throughout the industry. Accordingly, simulating the future requires that these revised expectations and adjustments be incorporated into the bioeconomic framework.

[5/] In most instances the realistic solution is obtained in the simulation process. When one of the other solutions is derived, careful selection of starting values for the $QHARVW_t$ variable generates the appropriate solution path.

Unfortunately, a complete set of economic data did not exist to explicitly model the adjustments made by fishermen, processors, wholesalers, and consumers to the greatly reduced supply situation. Limited 1984 data, however, are used to recalibrate the model, thereby shifting the trajectories of each system component based on a 1984 starting point.

Structural adjustment factors are developed to recalibrate the system. These adjustment factors are akin to indicator variable shifters--the difference being they were calculated algebraically as constant correction parameters rather than estimated using regression analysis. The factors reset the bioeconomic model to predict the 1984 observations. Once calibrated to 1984, the model can be used to simulate 1985 and beyond The simulations, however, are premised upon the necessary assumption that the same underlying structure characterizing the industry prior to 1984 persists into the future.

Four structural adjustment factors were added to the bioeconomic model. Three factors altered the market trajectory while the fourth adjusted the primary supply framework Adjustment parameters were derived for the wholesale section price ($PSECT_t$), sectionconsumption ($SECTCONS_t$), and the processed sections stock holding ($SECTHOLD_t$) structural equations based on the difference between the predicted and actual 1984 observation of section production ($SECTPROD_t$). This linkage was possible because $SECTPROD_t$ could be expressed as a linear combination of $PSECT_t$ (an inverse market supply function), $SECTCONS_t$, and $SECTHOLD_t$. The supply side factor was incorporated directly into the ex-vessel price ($EXPRT_t$) offer equation (i.e., $EXPRT_t$ was recalibrated to accurately predict the 1984 observation).

The structural adjustment factors altered the corresponding behavioral equations by constant amounts: $PSECT_t$ was increased by 2.373 while

$SECTCONS_t$, $SECTHOLD_t$, and $EXPRT_t$ were decremented by 28.499, 1.531, and 2.16, respectively. These factors have the same general interpretation as a multiperiod, intercept shifting indicator variable in that they alter all 1985-92 predictions of the selected variables by specific, constant amounts.

Estimation of Exogenous Variable Data, 1984-92

Simulation of future conditions in the king crab industry requires data for all exogenous variables in the system. Future values for all eight exogenous variables are actually estimated. Five time-dominated variables that are unaffected by changes in the king crab industry are modeled in an extrapolative context. Three industry-related variables that were exogenous in the historical context are modeled endogenously for future simulation. A fourth exogenous industry-related variable was assumed proportional to an endogenously computed variable. Remaining exogenous industry-related variables pertain to king crab meats which are assumed to be zero in the future.[6/] The only remaining exogenous variables relate to management and are- treated as control variables for future simulations. The eight estimated equations and one proportional relationship are now presented along with them underlying rationale.

[6/] Processors and wholesale brokers in Seattle indicate that market prices for the labor intensive meats are expected to be so high relative to sections that limited secondary meat processing will be adequate to satisfy consumer demands. Accordingly, it was assumed there will be no primary meat production in the future, and thus all meat variables (i.e., production ($MEATPROD_t$), holdings ($MEATHOLD_t$), domestic wholesale supplies ($MEATSUP_t$), exports ($MEATEXP_t$), and the average wholesale price ($PMEAT_t$)) are given zero values in the future simulation data set.

Ex-vessel Price Index for American Lobster ($PLOB_t$)

This variable is a unitless index reported by the National Marine Fisheries Service in the annual Current Fisheries Statistics. The index quantifies how domestic ex-vessel prices for American lobster have changed relative to a base year (1967). It is modeled here as a linear function of the year (YEAR) and lagged ex-vessel price index ($PLOB_{t-1}$). The ordinary least squares (OLS) estimate is given by (C.6).

$$PLOB_t = \underset{(-2.252)}{-213.66320} + \underset{(2.255)}{0.10893}\ YEAR + \underset{(1.126)}{0.32439}\ PLOB_{t-1} \qquad (C.6)$$

$R^2 = 0.9826$

Predictions derived from (C.6) for the period 1984-92 were entered directly into the simulation data set. $PLOB_{t-1}$ was retained in the equation despite the low t-value. The lagged price index improved the ability to predict the historically observed data. Since the equation was used merely to forecast future values, goodness of fit was the most important choice criterion.

U.S. Per Capita Disposable Income (INC_t)

Per capita disposable income in the United States (nominal $/person) was assumed to be a time trended variable. The same general structure used for $PLOB_t$ provided excellent historical predictions of INC_t. More specifically, per capita disposable income was modeled as a linear function of the year (YEAR) and average disposable income in the previous period UNC_{t-1}). The OLS estimate of this relationship is given in C.7.

$$INC_t = \underset{(-2.349)}{-260518.61} + \underset{(2.350)}{132.61324}\ YEAR + \underset{(7.256)}{0.80921}\ INC_{t-1} \qquad (C.7)$$

$R^2 = 0.9962$

Future income, values forecast from (C.7) were added to the simulation data set.

Food and Kindred Products Wage Rate in Alaska ($LABOR_t$)

The average hourly wage rate ($/hour) received by food and kindred products workers in Alaska has tended to increase systematically over time. The wage rate is specified here as a linear function of the year. (YEAR). A relationship including lagged wage rates ($LABOR_{t-1}$) also was estimated but did not predict history with greater accuracy. Therefore, simple OLS extrapolation based on time was chosen to generate the necessary data predictions.

$$\underset{}{LABOR_t} = \underset{(-18.10)}{-731.01752} + \underset{(18.36)}{0.37293}\ YEAR \qquad (2.8)$$

$R^2 = 0.9629$

Data projections for 1984-92 were derived from (C.8) and inserted into the simulation data set.

Prime Interest Rate ($INTR_t$)

The third quarter average prime interest rate charged by banks ($INTR_t$) was initially estimated as a simple linear extrapolation over time. This specification ignored the cyclic nature of interest rates. Consequently, an alternative formulation incorporating a periodic (sine and cosine) function of time was chosen to predict annual average third quarter interest rates for 1985 through 1992. An index initialized at 1.0 in 1970 and increasing by unit increments each subsequent year was used as the time variable (TIME70). Two indicator variables also were included to remove the influence of the 1981 (DUM81) and 1982 (DUM82) observed rates. Uncharacteristically high rates were observed these two years.The nonlinear least squares estimate of the interest rate relationship is given by (C.9).

$$\begin{aligned} INTR_t = {} & \underset{(16.95)}{0.09242} - \underset{(-2.66)}{0.02225}\cos(\underset{(93.28)}{5.94465}\ TIME70 - \underset{(-6.75)}{4.74470}) \qquad (C.9) \\ & + \underset{(1.26)}{0.00944}\sin(\underset{(17.00)}{2.35946}\ TIME70 - \underset{(-3.71)}{5.36951}) + \underset{(3.44)}{0.08849}\ DUM81 \\ & + \underset{(1.67)}{0.04256}\ DUM82 \end{aligned}$$

$R^2 = 0.8421$

Though several t-values were low, this formulation produced the most accurate historical predictions of $INTR_t$ and was selected to estimate future interest rates. These projections of $INTR_t$ were added to the simulation data set.

Diesel Fuel Price ($FUEL_t$)

The seasonal average diesel fuel price paid in Washington ($/gallon) initially was estimated as a linear function of time. This approach generated inaccurate historical predictions and unrealistically large prices over the simulated time period. A more suitable approach was chosen linking fuel price to the consumer price index for all items (CPI). Future fuel prices were estimated as a linear function of lagged fuel price ($FUEL_{t-1}$) adjusted by the average annual change in CPI observed between 1979 and 1984 (assumed to be the most representative of future price changes). The average annual change was 1.0625.

$$FUEL_t =-1.0625 \ FUEL_{t-1} \qquad (C.10)$$

Future, values of $FUEL_t$ derived from (C.10) were inserted into the simulation data set.

Average Ex-vessel Price Outside Area T ($EXPRW_t$).

Ex-vessel price in the other areas (measured in S/lb) was estimated as an inverse harvest supply function. Fishermen likely will expand harvest outside area T ($QHARVW_t$) if the ex-vessel price they receive is higher. Similarly, if the ex-vessel price offered in area T ($EXPRT_t$) increases, fishermen probably will enlarge $QHARVW_t$ only if $EXPRW_t$ rises. Arbitrage between the two competing harvest areas should cause ex-vessel prices to move together. A nonlinear function of these two variables (i.e., $QHARVW_t$ and $EXPRT_t$) is used to estimate future $EXPRW_t$ values.

$$\underset{}{EXPRW_t} = \underset{(5.36)}{0.4523} \ \underset{(3.93)}{QHARVW_t^{0.2339}} \ \underset{(16.00)}{EXPRT_t^{0.9580}} \qquad (C.11)$$

$R^2 = 0.9775$

Although (C.11) is a naive specification of supply (e.g., harvest costs are ignored), it had both statistical significance and excellent goodness of fit properties as evidenced by R^2. Equation (C.11) also was very accurate in predicting historical observations of EXPRW The estimated relationship was added directly to the equation system for all future simulations because $EXPRW_t$ is specified as a function of two current endogenous variables.

Quantity Harvested Per Day Outside Area T ($QHWDAY_t$)

The average quantity of king crab harvested per day in the other areas (reported in thousand pounds per day) not only measures potential dockside congestion, but also reflects daily production from the fleet. Operators make decisions about where and how hard they are going to fish. These decisions are based primarily on revenue expectations and the cost of operation. In this specific case, $QHWDAY_t$ was modeled as a nonlinear function of the relative ex-vessel price difference between area W and the competing area T (i.e., $EXPRW_t - EXPRT_t$), quantity harvested in area W ($QHARVW_t$), an expectation of harvest in area T quantified by the Bristol Bay harvest guideline ($GUIDE_t$), and a *cost* measure based on the prime interest rate ($INTR_t$). An indicator variable (IND8292) also was included marking all time periods beyond 1981 to reflect a possible structural change as to where operators fished. The rapid decline in $QHARVT_t$ observed in 1981 (and persisting in 1982) forced operators to explore alternative fishing areas. Some operators are expected to stay in these new areas despite future potential increases in area T stocks. Thus, IND8292 reflects the permanent

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[7/] The estimated t-value for the constant term tested the null hypothesis around 1.0. All other t-values refer to tests around zero.

shift away from area T by some operators in response to the 1981 downturn in $QHARVT_{81}$. The nonlinear least squares estimate of $QHWDAY_y$ that yielded the best overall fit is given by (C.12).[8/]

$$QHWDAY_t = \underset{(0.22)}{1.56378}\, e^{\left(\underset{(1.39)}{0.20348}\,(EXPRW_t - EXPRT_t) - \underset{(-2.58)}{0.00626}\, GUIDE_t - \underset{(-1.30)}{0.62467}\, IND8292\right)}\, INTR_t^{\underset{(-2.99)}{-0.49097}}\, QHARVW_t^{\underset{(2.50)}{0.95304}} \qquad (C.12)$$

$$R^2 = 0.8845$$

This equation was added to the simulation model due to the presence of current endogenous variables as explanatory elements.

King Crab Processing Facilities ($PLANTS_t$)

The number of plants processing raw king crab throughout Alaska each. season depends, in part, on the existing plant stock in the previous season ($PLANTS_{t-1}$) expected plant revenues, and total harvest expectations. In this case, expected revenues can be measured by the lagged margin between. average wholesale and ex-vessel prices ($WTAVP_{t-1} - AVEXPR_{t-1}$), while anticipated harvest can be proxied by the combined Bristol Bay harvest

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[8/] Statistical significance of the constant term (i.e., 1.56378) was based on the null hypothesis around 1.0. All other t-statistics reported for (C.12) refer to tests around zero.

guideline ($GUIDE_t$) and $QHARVW_{t-1}$ The nonlinear least squares estimate of the $PLANTS_t$ relationship is given-by (C.13)[9/]

$$PLANTS_t = \underset{(0.73)}{1.68246}\, PLANTS_{t-1}^{\underset{(2.51)}{0.45658}}\, (WTAVP_{t-1} - AVEXPR_{t-1})^{\underset{(2.73)}{0.53575}} \tag{C.13}$$

$$(QHARVW_{t-1} + GUIDE_t)^{\underset{(2.28)}{0.23598}} - \underset{(-2.05)}{17.37247}\, DUM83$$

$R^2 = 0.8732$

IND83 was included to reflect the 1983 structural break caused by the Bristol Bay season closure. Equation (3.13) was added directly to the simulation framework given the presence of explanatory endogenous variables in the equation.

Processed Sections Exported ($SECTEXP_t$)

Section exports were treated exogenously in the original bioeconomic framework because of inadequate foreign demand data, but a naive behavioral relationship is used for future market simulation. Section exports historically were proportional to domestic. section consumption. ($SECTCONS_t$), averaging 19.9% of all sections consumed in the United States. This proportional relationship serves to predict future exports and is incorporated into the partially reduced form of the simulation model.

[9/] Statistical significance of the constant term was tested around 1.0. All other t-values were based on tests around zero.

APPENDIX D

DETAILED ENUMERATION OF FUTURE SIMULATION RESULTS

Table D.l.--Simulation results for the future management scenario restricting all harvest of 8-year-old male king crab (i.e., $SIZELIM_t = 0$), 1985-92..

Table D.1.--Simulation results for the future management scenario restricting all harvest of 8-year-old male king crab (i.e., $SIZELIM_t = 0$), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	11.164	11.287	11.552
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	11.164	11.287	11.552
SECTHOLD	17.884	20.267	19.972	26.836
SECTPROD	21.715	12.939	27.738	48.740
SECTSUP	13.881	10.555	28.033	41.876
SECTEXP	2.304	1.752	4.653	6.950
SECTCONS	11.577	8.803	23.381	34.926
QHARVUS	21.715	12.939	27.738	48.740
QHARVW	19.186	5.279	8.135	15.500
QHARVT	2.529	7.660	19.604	33.239
POTLIFTS	0.063	0.097	0.148	0.212
WPUE	40.142	78.820	132.100	156.869
VESSELS	53.616	61.645	84.266	115.298
EXPRT	3.005	3.826	4.091	4.423
EXPRW	2.590	2.414	2.848	3.569
AVEXPR	2.639	3.250	3.727	4.152
QWDAY	40.015	9.965	13.596	29.974
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	52.866	75.599
MALE514	61.282	98.676	108.205	145.406
FM514	814.400	2907.800	4583.800	6360.100
LEGALS	10.582	27.632	52.866	75.599
NONLEGALS	63.990	100.513	97.702	113.548
PLANTS	62.052	71.814	73.702	79.543
GUIDE	3.175	8.290	15.860	22.680
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	9.078	26.909	40.832
QHTDAY	361.200	1094.300	2800.500	4748.500
REVW	49.700	12.741	23.167	55.315
REVT	7.599	29.305	80.205	147.031

Table D.l. --Continued.

Variables	1989	1990	1991	1992
PSECT	12.274	12.467	13.214	10.955
PMEAT	0.000	0.000	0.000	0.000
WTAVP	12.274	12.467	13.214	10.955
SECTHOLD	27.441	30.154	35.100	36.374
SECTPROD	44.302	62.206	65.705	142.140
SECTSUP	43.697	59.494	60.759	140.866
SECTEXP	7.252	9.874	10.084	23.380
SECTCONS	36.444	49.620	50.675	117.487
QHARVUS	44.302	62.206	65.705	142.140
QHARVW	12.706	15.286	15.054	33.143
QHARVT	31.597	46.920	50.652	108.997
POTLIFTS	0.241	0.353	0.437	0.875
WPUE	131.239	132.873	115.812	124.570
VESSELS	131.499	190.805	240.775	544.498
EXPRT	4.688	5.061	5.481	5.198
EXPRW	3.602	4.047	4.352	4.975
AVEXPR	4.377	4.812	5.222	5.146
QWDAY	22.985	26.587	28.542	58.503
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.780	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	77.432	103.262	106.311	154.454
MALE514	196.469	254.460	276.214	278.022
FM514	10496.600	24241.200	37023.100	55062.800
LEGALS	77.432	103.262	106.311	154.454
NONLEGALS	172.463	246.463	303.940	321.620
PLANTS	85.933	94.832	99.341	110.493
GUIDE	23.230	30.979	31.893	46.336
DAYS	7.000	7.000	7.000	7.000
QHARDP	37.540	53.382	56.217	108.188
QHTDAY	4513.800	6702.900	7235.900	15571.000
REVW	45.762	61.862	65.513	164.890
REVT	148.137	237.477	277.602	566.529

Table D.2. --Simulation results for the future management scenario permitting only the largest. 12.7% of 8-7year-old male king crab to be harvested (i.e., $SIZELIM_t$ = 0.1271), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	11.138	11.228	11.561
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	11.138	11.228	11.561
SECTHOLD	17.884	20.299	20.063	26.838
SECTPROD	21.715	13.671	29.363	48.407
SECTSUP	13.881	11.256	29.599	41.632
SECTEXP	2.304	1.868	4.913	6.910
SECTCONS	11.577	9.388	24.686	34.722
QHARVUS	21.715	13.671	29.363	48.407
QHARVW	19.186	5.235	8.899	15.708
QHARVT	2.529	8.436	20.463	32.700
POTLIFTS	0.063	0.100	0.151	0.209
WPUE	40.142	84.337	135.829	156.244
VESSELS	53.616	62.696	85.512	114.180
EXPRT	3.005	3.815	4.067	4.398
EXPRW	2.590	2.403	2.892	3.560
AVEXPR	2.639	3.274	3.711	4.126
QWDAY	40.015	9.849	14.981	30.509
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	52.062	73.876
MALE514	61.282	98.676	107.402	143.683
FM514	814.400	2907.800	4549.800	6284.800
LEGALS	10.582	29.597	54.202	74.743
NONLEGALS	63.990	98.548	95.561	112.681
PLANTS	62.052	72.175	73.905	79.705
GUIDE	3.175	8.879	16.261	22.423
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	10.356	27.628	39.715
QHTDAY	361.200	1205.100	2923.300	4671.400
REVW	49.700	12.578	25.734	55.922
REVT	7.599	32.185	83.217	143.818

Table D.2. --Continued.

Variables	1989	1990	1991	1992
PSECT	12.180	12.396	12.858	11.298
PMEAT	0.000	0.000	0.000	0.000
WTAVP	12.180	12.396	12.858	11.298
SECTHOLD	27.541	30.259	35.426	36.093
SECTPROD	46.867	64.075	75.248	132.541
SECTSUP	46.164	61.357	70.081	131.875
SECTEXP	7.662	10.184	11.632	21.888
SECTCONS	38.502	51.174	58.450	109.987
QHARVUS	46.867	64.075	75.248	132.541
QHARVW	13.366	16.462	18.108	33.171
QHARVT	33.501	47.612	57.140	99.370
POTLIFTS	0.247	0.355	0.469	0.807
WPUE	135.683	134.138	121.937	123.076
VESSELS	134.681	192.817	260.742	501.574
EXPRT	4.671	5.004	5.371	5.115
EXPRW	3.632	4.073	4.457	4.900
AVEXPR	4.375	4.765	5.151	5.061
QWDAY	24.233	28.989	35.087	59.450
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	76.206	100.020	102.236	143.512
MALE514	195.243	251.218	272.138	267.080
FM514	10431.100	23932.300	36476.900	52895.700
LEGALS	80.111	103.864	113.383	147.171
NONLEGALS	168.558	242.619	292.794	317.961
PLANTS	86.754	95.076	100.888	109.496
GUIDE	24.033	31.159	34.015	44.151
DAYS	7.000	7.000	7.000	7.000
QHARDP	39.513	53.238	61.524	97.336
QHTDAY	4785.800	6801.800	8162.900	14195.800
REVW	48.542	67.053	80.712	162.550
REVT	156.484	238.251	306.912	508.295

Table D.3.--Simulation results for the future management scenario permitting only the largest 25% of 8-year-old male king crab to be harvested (i.e., $SIZELIM_t$ = 0.25), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	11.106	11.169	11.571
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	11.106	11.169	11.571
SECTHOLD	17.884	20.336	20.154	26.840
SECTPROD	21.715	14.543	30.964	48.050
SECTSUP	13.881	12.091	31.146	41.364
SECTEXP	2.304	2.007	5.169	6.865
SECTCONS	11.577	10.084	25.977	34.498
QHARVUS	21.715	14.543	30.964	48.050
QHARVW	19.186	5.328	9.665	15.897
QHARVT	2.529	9.215	21.299	32.153
POTLIFTS	0.063	0.103	0.153	0.207
WPUE	40.142	89.689	139.445	155.598
VESSELS	53.616	63.731	86.706	113.024
EXPRT	3.005	3.805	4.040	4.373
EXPRW	2.590	2.406	2.929	3.551
AVEXPR	2.639	3.292	3.693	4.101
QWDAY	40.015	10.009	16.383	31.006
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	51.255	72.175
MALE514	61.282	98.676	106.595	141.982
FM514	814.400	2907.800	4515.600	6210.400
LEGALS	10.582	31.497	55.465	73.881
NONLEGALS	63.990	96.648	93.492	111.842
PLANTS	62.052	72.518	74.193	79.913
GUIDE	3.175	9.449	16.639	22.164
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	11.553	28.278	38.591
QHTDAY	361.200	1316.400	3042.700	4593.300
REVW	49.700	12.822	28.312	56.446
REVT	7.599	35.061	86.036	140.613

Table D.3. --Continued.

Variables	1989	1990	1991	1992
PSECT	12.087	12.329	12.493	11.616
PMEAT	0.000	0.000	0.000	0.000
WTAVP	12.087	12.329	12.493	11.616
SECTHOLD	27.640	30.359	35.760	35.843
SECTPROD	49.406	65.840	85.068	123.626
SECTSUP	48.606	63.121	79.667	123.543
SECTEXP	8.067	10.476	13.222	20.505
SECTCONS	40.539	52.645	66.444	103.038
QHARVUS	49.406	65.840	85.068	123.626
QHARVW	14.008	17.605	21.207	33.525
QHARVT	35.398	48.235	63.861	90.102
POTLIFTS	0.253	0.356	0.499	0.744
WPUE	140.015	135.339	127.865	121.126
VESSELS	137.753	194.620	281.028	462.188
EXPRT	4.654	4.948	5.261	5.024
EXPRW	3.659	4.093	4.534	4.828
AVEXPR	4.372	4.719	5.080	4.971
QWDAY	25.446	31.355	41.831	61.151
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	75.011	96.816	98.272	132.445
MALE514	194.047	248.014	268.174	256.013
FM514	10367.200	23627.100	35945.600	50703.900
LEGALS	82.692	104.377	120.197	139.642
NONLEGALS	164.781	238.903	282.015	314.423
PLANTS	87.571	95.285	102.302	108.261
GUIDE	24.808	31.313	36.059	41.893
DAYS	7.000	7.000	7.000	7.000
QHARDP	41.456	53.069	67.047	86.806
QHTDAY	5056.900	6890.800	9122.900	12871.600
REVW	51.257	72.059	96.162	161.870
REVT	164.755	238.666	335.993	452.644

Table: D.4 .--Simulation results for the future management scenario permitting only the largest 50% of 8-year-old male king crab to be harvested (i.e., SIZELIM$_t$, = 0.50), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	11.027	11.045	11.594
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	11.027	11.045	11.594
SECTHOLD	17.884	20.428	20.348	26.840
SECTPROD	21.715	16.703	34.303	47.243
SECTSUP	13.881	14.158	34.384	40.750
SECTEXP	2.304	2.350	5.707	6.763
SECTCONS	11.577	11.808	28.677	33.987
QHARVUS	21.715	16.703	34.303	47.243
QHARVW	19.186	5.813	11.295	16.272
QHARVT	2.529	10.890	23.008	30.971
POTLIFTS	0.063	0.108	0.157	0.201
WPUE	40.142	100.646	146.833	154.126
VESSELS	53.616	65.887	89.089	110.497
EXPRT	3.005	3.783	3.977	4.322
EXPRW	2.590	2.442	2.993	3.530
AVEXPR	2.639	3.316	3.653	4.049
QWDAY	40.015	10.924	19.410	32.013
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	49.520	68.607
MALE514	61.282	98.676	104.860	138.414
FM514	814.400	2907.800	4442.100	6054.300
LEGALS	10.582	35.362	57.940	72.019
NONLEGALS	63.990	92.783	89.282	110.136
PLANTS	62.052	73.201	74.941	80.424
GUIDE	3.175	10.609	17.382	21.606
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	13.908	29.504	36.202
QHTDAY	361.200	1555.700	3286.900	4424.400
REVW	49.700	14.195	33.803	57.438
REVT	7.599	41.191	91.501	133.850

Table D.4.--Continued.

Variables	1989	1990	1991	1992
PSECT	11.891	12.197	11.678	12.208
PMEAT	0.000	0.000	0.000	0.000
WTAVP	11.891	12.197	11.678	12.208
SECTHOLD	27.847	30.561	36.501	35.420
SECTPROD	54.763	69.302	106.981	106.926
SECTSUP	53.755	66.589	101.041	108.006
SECTEXP	8.922	11.052	16.770	17.926
SECTCONS	44.833	55.537	84.271	90.080
QHARVUS	54.763	69.302	106.981	106.926
QHARVW	15.335	19.954	28.033	35.337
QHARVT	39.428	49.348	78.948	71.588
POTLIFTS	0.265	0.358	0.563	0.621
WPUE	148.949	137.714	140.103	115.275
VESSELS	143.979	197.797	325.162	388.854
EXPRT	4.620	4.832	5.025	4.797
EXPRW	3.711	4.120	4.632	4.677
AVEXPR	4.365	4.627	4.922	4.758
QWDAY	27.954	36.317	56.914	67.387
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	72.539	90.082	90.145	108.399
MALE514	191.576	241.280	260.047	231.967
FM514	10235.200	22985.600	34856.200	45941.400
LEGALS	87.902	105.203	133.995	122.793
NONLEGALS	157.100	231.342	260.090	307.226
PLANTS	89.276	95.624	104.969	104.912
GUIDE	26.371	31.561	40.198	36.838
DAYS	7.000	7.000	7.000	7.000
QHARDP	45.512	52.606	79.432	65.477
QHTDAY	5632.600	7049.700	11278.300	10226.900
REVW	56.905	82.212	129.840	165.271
REVT	182.148	238.451	396.714	343.428

Table D.5. --simulation results for the future management scenario permitting only the largest 75% of 8-year-old male king crab to be harvested (i.e., $SIZELIM_t = 0.75$), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	10.935	10.918	11.620
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	10.935	10.918	11.620
SECTHOLD	17.884	20.536	20.551	26.839
SECTPROD	21.715	19.235	37.744	46.372
SECTSUP	13.881	16.582	37.729	40.084
SECTEXP	2.304	2.752	6.262	6.653
SECTCONS	11.577	13.830	31.467	33.431
QHARVUS	21.715	19.235	37.744	46.372
QHARVW	19.186	6.544	13.015	16.665
QHARVT	2.529	12.690	24.729	29.706
POTLIFTS	0.063	0.114	0.160	0.195
WPUE	40.142	111.722	154.275	152.399
VESSELS	53.616	68.117	91.400	107.794
EXPRT	3.005	3.759	3.907	4.269
EXPRW	2.590	2.496	3.042	3.508
AVEXPR	2.639	3.329	3.609	3.996
QWDAY	40.015	12.335	22.661	33.081
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	47.655	64.893
MALE514	61.282	98.676	102.995	134.700
FM514	814.400	2907.800	4363.100	5891.900
LEGALS	10.582	39.227	60.285	70.011
NONLEGALS	63.990	88.918	85.072	108.430
PLANTS	62.052	73.863	75.762	80.973
GUIDE	3.175	11.768	18.085	21.003
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	16.250	30.653	33.722
QHTDAY	361.200	1812.900	3532.700	4243.800
REVW	49.700	16.332	39.586	58.465
REVT	7.599	47.701	96.614	126.820

Table D.5.--Continued.

Variables	1989	1990	1991	1992
PSECT	11.684	12.071	10.760	12.703
PMEAT	0.000	0.000	0.000	0.000
WTAVP	11.684	12.071	10.760	12.703
SECTHOLD	28.065	30.758	37.329	35.140
SECTPROD	60.392	72.579	131.686	92.827
SECTSUP	59.166	69.886	125.115	95.016
SECTEXP	9.820	11.599	20.766	15.770
SECTCONS	49.346	58.287	103.349	79.246
QHARVUS	60.392	72.579	131.686	92.827
QHARVW	16.708	22.348	35.639	38.934
QHARVT	43.684	50.231	96.047	53.893
POTLIFTS	0.276	0.359	0.628	0.508
WPUE	158.074	140.004	152.870	106.162
VESSELS	150.148	200.227	372.870	324.844
EXPRT	4.584	4.713	4.770	4.509
EXPRW	3.758	4.131	4.661	4.509
AVEXPR	4.355	4.534	4.741	4.509
QWDAY	30.555	41.500	73.875	78.483
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	70.002	83.045	81.941	82.190
MALE514	189.039	234.243	251.844	205.758
FM514	10099.600	22315.200	33756.600	40750.800
LEGALS	93.046	105.727	147.717	103.781
NONLEGALS	149.419	223.781	238.165	300.029
PLANTS	91.002	95.830	107.401	100.339
GUIDE	27.914	31.718	44.315	31.134
DAYS	7.000	7.000	7.000	7.000
QHARDP	49.698	51.957	93.365	44.875
QHTDAY	6240.600	7175.800	13721.000	7699.000
REVW	62.785	92.323	166.115	175.539
REVT	200.241	236.755	458.167	243.015

Table- D.6.--Simulation results. for the future management scenario permitting all 8-year-old male king crab to be harvested (i.e., SIZELIM$_t$ = 1.0), 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	10.832	10.786	11.646
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	10.832	10.786	11.646
SECTHOLD	17.884	20.657	20.763	26.837
SECTPROD	21.715	22.059	41.285	45.466
SECTSUP	13.881	19.285	41.179	39.392
SECTEXP	2.304	3.201	6.835	6.538
SECTCONS	11.577	16.085	34.345	32.854
QHARVUS	21.715	22.059	41.285	45.466
QHARVW	19.186	7.435	14.831	17.098
QHARVT	2.529	14.624	26.454	28.368
POTLIFTS	0.063	0.119	0.164	0.189
WPUE	40.142	122.953	161.790	150.376
VESSELS	53.616	70.422	93.624	104.962
EXPRT	3.005	3.734	3.831	4.215
EXPRW	2.590	2.555	3.078	3.487
AVEXPR	2.639	3.336	3.561	3.941
QWDAY	40.015	14.068	26.146	34.263
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	45.652	61.031
MALE514	61.282	98.676	100.992	130.839
FM514	814.400	2907.800	4278.200	5722.900
LEGALS	10.582	43.092	62.492	67.855
NONLEGALS	63.990	85.053	80.862	106.724
PLANTS	62.052	74.507	76.567	81.511
GUIDE	3.175	12.928	18.748	20.357
DAYS	7.000	7.000	7.000	7.000
QHARDP	1.248	18.653	31.750	31.179
QHTDAY	361.200	2089.100	3779.100	4052.600
REVW	49.700	18.993	45.645	59.616
REVT	7.599	54.601	101.355	119.578

Table D.6. --continued.

Variables	1989	1990	1991	1992
PSECT	11.468	11.952	9.731	13.058
PMEAT	0.000	0.000	0.000	0.000
WTAVP	11.468	11.952	9.731	13.058
SECTHOLD	28.295	30.950	38.252	35.053
SECTPROD	66.308	75.656	159.396	82.510
SECTSUP	64.850	73.000	152.094	85.709
SECTEXP	10.763	12.116	25.243	14.225
SECTCONS	54.086	60.884	126.851	71.484
QHARVUS	66.308	75.656	159.396	82.510
QHARVW	18.138	24.797	44.096	45.080
QHARVT	48.170	50.859	115.300	37.430
POTLIFTS	0.288	0.358	0.692	0.404
WPUE	167.441	142.213	166.567	92.645
VESSELS	156.223	201.826	423.673	270.027
EXPRT	4.546	4.592	4.496	4.152
EXPRW	3.800	2.000	4.628	4.311
AVEXPR	4.342	4.440	4.532	4.239
QWDAY	33.269	46.924	92.656	97.039
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	67.388	75.692	73.674	53.683
MALE514	186.425	226.890	243.576	177.252
FM514	9960.000	21614.700	32648.400	35105.000
LEGALS	98.114	105.934	161.375	82.471
NONLEGALS	141.738	216.221	216.239	292.832
PLANTS	92.728	95.895	109.643	94.318
GUIDE	29.434	31.780	48.412	24.741
DAYS	7.000	7.000	7.000	7.000
QHARDP	54.009	51.094	108.902	26.281
QHTDAY	6881.400	7265.600	16471.400	5347.200
REVW	68.929	102.371	204.098	194.329
REVT	218.968	233.545	518.347	155.396

Table D.7.--Simulation results for the future management scenario permitting variable season lengths and the largest 25% of 8-year-old male king crab to be harvested, 1985-92.

Variables	1985	1986	1987	1988
PSECT	10.248	11.106	11.211	11.676
PMEAT	0.000	0.000	0.000	0.000
WTAVP	10.248	11.106	11.211	11.676
SECTHOLD	17.884	20.336	20.095	26.719
SECTPROD	21.715	14.543	29.796	45.231
SECTSUP	13.881	12.091	30.037	38.607
SECTEXP	2.304	2.007	4.985	6.408
SECTCONS	11.577	10.084	25.052	32.199
QHARVUS	21.715	14.543	29.796	45.231
QHARVW	19.186	5.328	8.184	12.436
QHARVT	2.529	9.215	21.612	32.795
POTLIFTS	0.063	0.103	0.157	0.216
WPUE	40.142	89.689	137.842	151.895
VESSELS	53.616	63.731	86.706	112.599
EXPRT	3.005	3.805	4.037	4.390
EXPRW	2.590	2.406	2.816	3.365
AVEXPR	2.639	3.292	3.701	4.108
QWDAY	40.015	10.009	13.669	23.561
FEM5	5.929	26.841	19.400	30.809
FEM614	7.361	2.628	22.962	12.932
FEM514	13.289	29.469	42.362	43.740
MALE5	9.683	36.133	13.107	26.261
MALE6	15.151	7.470	20.902	17.046
MALE7	12.442	11.981	4.491	19.677
MALE8	15.379	15.460	16.840	6.824
MALE914	8.628	27.632	51.255	71.850
MALE514	61.282	98.676	106.595	141.657
FM514	814.400	2907.800	4515.600	6196.200
LEGALS	10.582	31.497	55.465	73.556
NONLEGALS	63.990	96.648	93.492	111.842
PLANTS	62.052	72.518	74.193	79.150
GUIDE	3.175	9.449	16.639	22.067
DAYS	7.000	7.000	7.664	8.207
QHARDP	1.248	11.553	27.620	36.688
QHTDAY	361.220	1316.420	2819.980	3996.130
REVW	49.700	12.822	23.042	41.848
REVT	7.599	35.061	87.243	143.971

Table D.7.--Continued.

Variables	1989	1990	1991	1992
PSECT	12.262	12.614	12.941	12.277
PMEAT	0.000	0.000	0.000	0.000
WTAVP	12.262	12.614	12.941	12.277
SECTHOLD	27.417	30.001	35.296	34.965
SECTPROD	44.711	58.219	73.200	105.878
SECTSUP	44.013	55.636	67.905	106.210
SECTEXP	7.305	9.234	11.270	17.628
SECTCONS	36.708	46.402	56.635	88.582
QHARVUS	44.711	58.219	73.200	105.878
QHARVW	8.806	8.867	8.143	14.033
QHARVT	35.905	49.352	65.057	91.846
POTLIFTS	0.265	0.382	0.540	0.815
WPUE	135.257	129.127	120.490	112.665
VESSELS	136.447	192.436	275.246	448.443
EXPRT	4.706	5.030	5.401	5.244
EXPRW	3.318	3.542	3.717	4.104
AVEXPR	4.432	4.804	5.214	5.093
QWDAY	15.120	14.380	13.900	22.173
FEM5	22.996	25.382	22.926	33.835
FEM614	30.431	69.883	111.112	164.217
FEM514	53.426	95.265	134.038	198.052
MALE5	32.862	35.610	32.779	42.836
MALE6	35.596	23.254	26.414	23.156
MALE7	19.854	62.091	23.008	28.788
MALE8	30.725	30.242	87.701	28.788
MALE914	74.009	95.254	95.497	128.331
MALE514	193.046	246.452	265.399	251.899
FM514	10313.700	23478.300	35573.600	49889.100
LEGALS	81.691	102.814	117.422	135.528
NONLEGALS	164.781	238.903	282.015	314.423
PLANTS	85.814	92.203	97.567	101.957
GUIDE	24.507	30.844	35.227	40.658
DAYS	8.451	9.084	9.523	10.066
QHARDP	39.795	49.970	62.248	77.661
QHTDAY	4248.760	5432.620	6831.820	9124.480
REVW	29.213	31.408	30.269	57.586
REVT	168.966	248.256	351.385	481.607