A SIMPLE BIOECONOMIC FISHERY MANAGEMENT MODEL: A CASE STUDY OF THE AMERICAN LOBSTER FISHERY[1]

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ABSTRACT

The pressures of world economic expansion have led to more intensive exploitation of living marine resources as a source of protein. The exploitation of these common property resources leads, in many cases, to overfishing and depletion. This paper attempts to develop a simplified management tool to prevent overexploitation and depletion of a fishery resource. A general resource model is postulated embracing both biological and economic relationships. This bioeconomic model approximates the operation of a fishery under free access to the resource. A Schaefer type yield function is combined with a linear demand function, and other standard economic relationships and simulations are performed to evaluate the model. Using computer simulation, we imposed five management strategies on the case example, the American lobster fishery. These strategies include (1) freezing fishing effort by raising license fees; (2) reducing fishing effort to that necessary to harvest at the maximum sustainable yield by raising license fees; (3) reducing fishing effort to an "economic optimum" where marginal cost of doing business is equal to marginal revenue from sales by raising license fees; (4) instituting a "stock certificate plan" where individual fishermen would own portions of the resource and trade catch certificates on the open market; however, the total number of catch certificates would not exceed the maximum sustainable yield; and (5) doing nothing. The economic impact in terms of catch, fishing effort, number of fishermen, ex-vessel prices, license revenues, and returns per boat and fishermen were computed for each management strategy so that policymakers and industry leaders could see the alternative consequences of these management positions. The simplified model also is available for use in evaluation of other management schemes that might be suggested.

In the past few years the world community has become increasingly aware of the sea and its resources. The pressures of world economic expansion have led to more intensive exploitation and, at the same time, to increasing concern over the marine environment. Many management strategies used to protect these resources from overexploitation have resulted in inefficient use of gear and equipment as shown by Crutchfield and Pontecorvo (1969). The purpose of this paper is to develop a bioeconomic model of living marine resource exploitation which can be used to assess the economic impact of alternative management strategies for the U.S. inshore American lobster fishery. The U.S. American lobster fishery is a classic case of rapid increases in consumer demand impinging upon a limited resource (Bell, 1972). It should be made quite clear that this analysis is intended to predict the effects of alternative actions without recommending any specific policy.

SPECIFICATION OF THE GENERAL RESOURCE USE MODEL

Before we are able to evaluate the economic impact of various management strategies, it is necessary to develop a general bioeconomic model of how a fishery functions. The following general model has been developed by Fullenbaum, Carlson, and Bell (1971):

$$X = f(X, Kx) \tag{1}$$

$$Kx = Kg(X, K) \tag{2}$$

or

$$x = g(X, K)$$

$$C = K\widetilde{\pi} \tag{3}$$

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[1] This article was first submitted for publication 7 August 1972. At that time, all data were as current as could be obtained for purposes of the analysis. The views of the authors do not necessarily represent the official position of the U.S. Department of Commerce.

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$$\pi = pKx - C = pKg(X,K) - K\tilde{\pi} \qquad (4)$$

$$\dot{K} = \begin{cases} \delta_1\pi, & \pi>0 \\ \delta_2\pi, & \pi<0 \end{cases} \qquad (5)$$

In the above system, X is the biomass; K equals the number of homogeneous operating units or vessels; x is the catch rate per vessel; C is total industry cost (in constant dollars) or total annual cost per vessel multiplied by the number of vessels; $\tilde{\pi}$ is equal to total annual cost per vessel (in constant dollars) or opportunity cost;[4] π is industry profit in excess of opportunity cost; p is the real ex-vessel price; and δ_1, δ_2 represent the rates of entry and exit of vessels, respectively. Equation (1) represents the biological growth function in which the natural yield or net change in the biomass ($\dot{X}$) is dependent upon the size of the biomass, X, and the harvest rate, Kx. X reflects the influence of environmental factors such as available space or food, which constrain the growth in the biomass as the latter increases. The harvest rate or annual catch, Kx, summarizes all growth factors induced by fishing activity. Equations (2) present the industry and firm production function for which it is normally assumed that

$\frac{\partial g}{\partial X} \equiv g_1 > 0$ and $\frac{\partial g}{\partial K} \equiv g_2 < 0$.[5] In other words,

catch per vessel increases when the biomass increases and declines when the number of vessels increases. Equations (3) and (4) are the industry total cost and total profit function, respectively. Equation (5) is a very important equation since it indicates that vessels will enter the industry when excess industrial profits are greater than zero (i.e., greater than that rate of return necessary to hold vessels in the fishery, or the opportunity cost) and will leave the fishery when excess industrial profits are less than zero (i.e., below opportunity cost).

The equilibrium condition for the industry ($\pi = 0$) may be formulated as shown below:

$$p = \frac{\tilde{\pi}}{g(X,K)} \qquad (6)$$

Equation (6) merely stipulates that ex-vessel price is equal to average cost per pound of fish landed (i.e., no excess profits).

There are two important properties of the system outlined in (1) - (5). First, the optimum size of the firm is given and may be indexed by $\tilde{\pi}$. Thus, the firm is predefined as a bundle of inputs.[6] Second, the long-run catch rate per vessel per unit of time is beyond the individual firm's control.[7] It is, in effect, determined by stock or technological externalities.[8] Finally, we are assuming that the number of homogeneous vessels is a good proxy for fishing effort. Alternatively, we may employ fishing effort directly in our system by determining the number of units of fishing effort applied to the resource per vessel. This will be discussed below.

A QUADRATIC EXAMPLE OF THE RESOURCE USE MODEL

By combining the more traditional theories depicting the dynamics of a living marine resource with some commonly used economic relations, we may derive a quadratic example of the general model specified above. This example effectively abstracts from complications such as ecological interdependence and age-distribution-dependent growth of the biomass on the biological side and, furthermore, assumes the absence of crowding externalities (i.e., $g_2 \equiv 0$) in the production function on the economic side.

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[4] Opportunity cost is defined as the necessary payment to fishermen and owners of capital to keep them employed in the industry or fishery compared to alternative employment or uses of capital.

[5] In some developing fisheries, it is possible that $g_2 > 0$. For example, in the Japanese Pacific tuna fishery, intercommunication between vessels may increase the catch rate as more vessels enter the fishing grounds.

[6] In other words, because we are dealing with a long-run theory of the industry, we are assuming that variations in output result from the entry or exit of optimum-sized homogeneous vessels.

[7] We have implicitly assumed that such short-run changes as longer fishing seasons, etc., are all subsumed in a long-run context. Normally longer fishing seasons, for example, do not change catch rates per unit of time fished; nor do they change costs per unit of time fished. They do, however, change the effective level of K.

[8] A technological externality exists when the input into the productive process of one firm affects the output of another firm. In the context of fishing, an additional firm or vessel entering the fishery will utilize the biomass (as an input) and, as a result, in the long run will reduce the level of output for other vessels in the fleet. (See Worcester (1969)).

The dynamics of a fish stock may be depicted by the logistic growth function (Lotka, 1956).[9]

$$X(t) = \frac{L}{1 + Ce^{-KLt}} \text{ where } L>0, C>0, k>0, \quad (7)$$

where L, C, and K are assumed to be environmental constants. Differentiating (7) and substituting we obtain,

$$\dot{X} \equiv \frac{dX}{dt} = kLX - kX^2 \equiv aX - bX^2 \quad (8)$$

where $a = kL,\ b = k.$

If (8) is set equal to zero, we may solve for the nonzero steady-state biomass, a/b (i.e., L). Alternatively, the limit of $X(t)$ as $t \rightarrow \infty$ yields identical results. The maximum of (8) occurs when X is equal to $a/2b$. Thus

$$\max \frac{dX}{dt} = a^2/4b \quad (9)$$

The introduction of fishing (i.e., harvest or Kx) is assumed to have no interactive effects, so that the instataneous growth rate is reduced by the amount harvested:[10]

$$\frac{dX}{dt} = aX - bX^2 - Kx. \quad (10)$$

The economic component of the model requires the exact specification of an industry production function and an industry revenue relationship. One hypothesis regarding the fish catch is that the proportion of the biomass caught is a direct function of the number of vessels (or equivalent fishing effort) exploiting a given ground.[11] Thus, the total harvest rate is given as,

$$Kx = rKX \quad (11)$$

where r is a technological parameter.[12] Finally, the total revenue function for the industry may take the following form:

$$pKx = (\alpha - \beta Kx)Kx. \quad (12)$$

Equation (12) merely stipulates that the total revenue is a quadratic function of total landings, Kx. Dividing through by Kx will give us the familiar demand function where ex-vessel price is inversely related to landings, holding all other factors constant.[13] With total costs equal to $K\pi$, the profit function becomes

$$\pi = (\alpha - \beta Kx)Kx - K\tilde{\pi}. \quad (13)$$

Given these formulations, the system in (10) - (13) can be reduced to two steady-state functions. The first, which condenses all relevant biotechnological factors, is the ecological equilibrium equation. It plots the relationship between the biomass and the number of vessels (or fishing effort) needed to harvest the yield such that the biomass is in equilibrium. We can derive this equation by setting $\dot{X}$ equal to zero, substituting (11) into (10), and solving for K in terms of X:

$$K = \frac{1}{r}(a - bX). \quad (14)$$

Similarly, the second equilibrium function plots the relationship between X and K under a zero profit state, i.e., under conditions that $K = 0$, or that there is no entry to or exit from the fishery. Thus, by setting (13) equal to zero and substituting (11) into (13), we obtain

$$K = \frac{\alpha}{\beta r X} - \frac{\tilde{\pi}}{\beta r^2 X^2}. \quad (15)$$

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[9] Graham (1935) was the first biologist to apply the logistic growth model to exploited fish populations.

[10] Schaefer, (1954) was the first population dynamicist to develop the function specified in equation (10).

[11] Alternatively, one could assume that the proportion of the biomass caught declines as the number of vessels increases:

$$Kx = [1 - (1 - t)^K]X. \qquad 0<t<1$$

With this specification, t represents the proportion of the biomass taken by the first vessel and also represents the percentage taken by each succeeding vessel of the remaining biomass. This form was first developed by E. W. Carlson (1970. An economic theory of common property resources. Unpubl. manuscr. Econ. Res. Lab., Natl. Mar. Fish. Serv., NOAA College Park, Md.).

[12] A reviewer of this article has pointed out that r is not likely to be constant over any large number of years. Since there are no time series observations on X, r cannot be tested to see whether it varies over time or is a constant. In this case, we are merely following the simplified Schaefer model.

[13] Such complicating factors as per capita income and its influence on ex-vessel prices can be introduced later as changes in the parameter, α.

These two curves are plotted in Figure 1.[14] Their intersection at (X^*, K^*) denotes bioeconomic equilibrium. The direction of the arrows describes the qualitative dynamic changes of a point in phase space. Figure 1 represents the general case of exploitation. When (15) is combined with (14), however, we can simulate either nonexploitation (Figure 2) or extinction as a possible dynamic result (Figure 3).[15] The state of the fishery—exploited, unexploited, or extinct—depends upon the parameters a, b, r, β, $\tilde{\pi}$, and α and their interrelationships. This completes our general model of how a fishery functions. Now let us turn to a specific application of the model.

AN EMPIRICAL CASE STUDY: THE U.S. INSHORE AMERICAN LOBSTER FISHERY

The U.S. inshore American lobster fishery—principally located off the coast of Maine—represents a good case study for a number of reasons. First, the American lobster is considered a high quality seafood item and is a popularly consumed species for which demand has been increasing rapidly (Bell, 1972). Second, because of intensive fishing pressure, the resource has shown signs of overexploitation.[16] Third, the inshore lobster fishery is one of the few grounds for which enough data are available so that some rough measures of needed biological and economic parameters can be derived. Fourth, according to Dow (1961),[17] the inshore lobster fishery is a relatively closed population as our production model assumes. Last, we believe that over the long run the American lobster population has not had a great divergence from the steady-state model employed in our analysis. The gross divergence from the steady-state assumption is significant only when fishing effort changes dramatically from period to period. For modest changes in fishing effort, the steady-state assumption will not yield biased estimates. A check on the fishing effort series for the American inshore northern lobster fishery reveals a steady and gradual increase. The alternative methods of Pella and Tomlinson (1969) do yield biased parameters due to nonlinear fitting methods. Gulland's (1961) method yields biased parameters since effort is averaged and then used as an independent variable. Therefore effort in period t is not independent of effort in period $t + 1$ which violates classical statistical assumptions underlying least squares. Also the predictive value (using the steady- state assumption) or goodness of fit is certainly at an acceptable level, $R^2 = 0.962$ (infra). Our discussion will be subdivided on the basis of production-related and demand-related estimates.

The Production Function and the Supply of American Lobsters

There are four parameters on the supply side for which initial estimates are required: a, b, r,

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[14] In steady state, the reader should be aware that we have not constrained the population stock to its initial size or any other size. Using the Schaefer model (i.e., steady state), the stock size varies inversely with fishing effort, T. Even in a dynamic context, the biomass would asymptotically approach the steady-state solution.

[15] It should be pointed out that Schaefer (1954) discusses economic transitional states which are very similar to the bioeconomic model presented in this paper. He states:

> "To arrive at a particular function to describe the change of the intensity of fishing with the size of the population, we may consider that the incentive for new investment is proportional to the return to be expected, in which case there will be a linear relation between the percentage rate of change of fishing intensity and the difference between the level of fish population and its economically critical level, b. This function will, then, be
>
> $$\frac{dF}{dt} = k_3F(P - b) \text{......} (11)$$
>
> where k_3 is a constant."

His process of transitional states is implicit in our diagrams in Figure 3 since adjustment (i.e., transitional states) will occur anywhere in phase space to the equilibrium values where $\dot{X} = 0$ and $\dot{K} = 0$.

[16] U.S. landings of trap-caught American lobsters increased from approximately 23 million pounds in 1950 to a peak of over 29 million pounds by 1957. Since 1957 landings have fallen off, reaching a low of 22 million pounds in 1967. In 1969 lobster production had recovered to 26.9 million pounds. Despite the poor performance of production over the 1950-69 period, the number of lobster traps fished per year (i.e., a proxy for fishing effort) has increased secularly from approximately 579,000 in 1950 to over 1,060,000 in 1969. Because of these past events, several bills have been presented in the Maine Legislature to apply some sort of stringent licensing scheme to limit entry.

[17] Dow, R. 1971. Effort, environment, supply, and yield in the Maine lobster fishery. Unpublished manuscript submitted to the U.S. Fish and Wildlife Service, Washington, D.C. 125 p. (May be obtained from Sea and Shore Fisheries, Maine.)

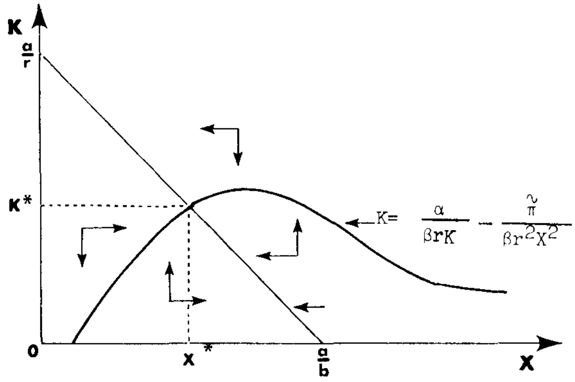

FIGURE 1.—Exploitation.

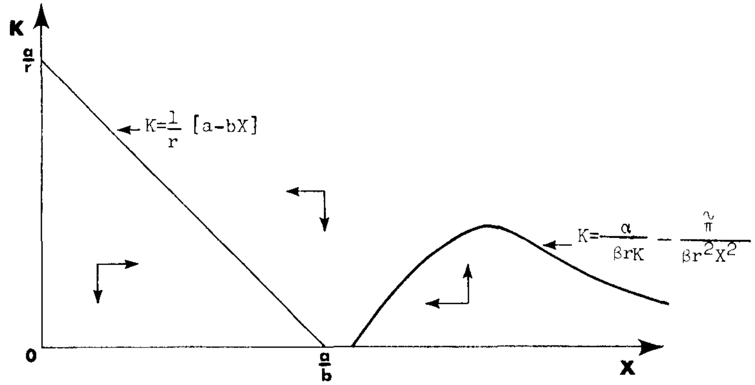

FIGURE 2.—Non-exploitation.

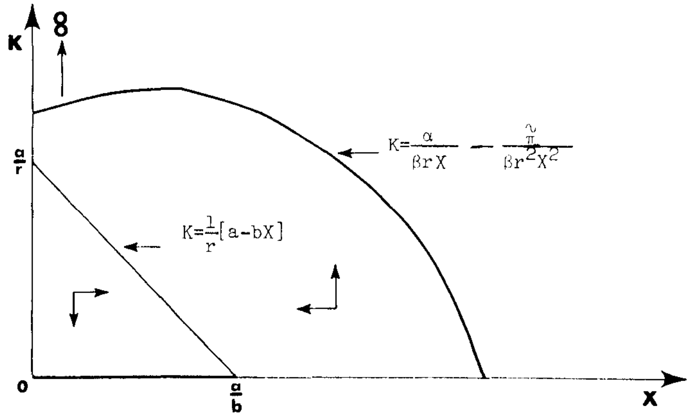

FIGURE 3.—Extinction.

and $\tilde{\pi}$.[18] The first three can be developed by combining statistical estimation and independently derived data. Assume that the biomass is instantaneously in equilibrium (i.e., $\frac{dX}{dt} = 0$). Then, taking the inverse of (14) and substituting it for X in (11), we obtain:

$$Kx = cK - dK^2 \tag{16}$$

where $$c = \frac{ar}{b},\ d = \frac{r^2}{b}$$

and $$x = c - dK. \tag{17}$$

Equation (16) is the familiar parabolic yield function postulated by Schaefer (1954).[19] Notice that both the harvest rate, Kx, and output per vessel, x, may be specified solely in terms of the number of vessels or fishing effort. Similarly, the common property resource externality, as given in (17), is a function only of the level of K. Over a longer period of time the basic assumption underlying equations (16) and (17) may reflect a valid representation; i.e., effort or K is the only instrumental variable affecting output. There are three different parameters embedded in estimates of c and d. The only way that a, b, and r can be derived is if some independent biological information is given. More specifically, suppose that we have an estimate of the biomass consistent with maximum sustainable yield, call it $\hat{X}^\circ$. Since $\hat{X}^\circ$ is equal to $a/2b$, it follows that the following parameters may be estimated (designated by ^):

$$\hat{r} = \hat{c}/2\hat{X}^\circ \tag{18}$$

$$\hat{b} = [\hat{d}/\hat{r}^2] - 1 \tag{19}$$

$$\hat{a} = \hat{c}\hat{b}/\hat{r}. \tag{20}$$

Thus, (17) will be estimated subject to one modification concerning the introduction of an environmental variable. Several biologists, including Dow et al. (1961),[20] have argued that a long-term trend of declining seawater temperature is partially responsible for the decline in U.S. coastal catches.[21] It will be assumed in this study that seawater temperature (°F) affects the a term in the growth function so that,

$$\frac{dX}{dt} = a(^\circ\mathrm{F})X - bX^2, \tag{21}$$

where °F is equal to the mean annual seawater temperature, in degrees Fahrenheit Boothbay Harbor, Maine, with $\frac{\partial a}{\partial(^\circ\mathrm{F})} \equiv a' > 0$. Seawater temperature can easily be incorporated into (17) in the following way:

$$x = c' - dK + z(^\circ\mathrm{F}), \tag{22}$$

where z represents the change in output per boat as a result of a one-degree change in water temperature.[22]

Data on the number of traps fished per year for the entire inshore American lobster fishery

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[18] An alternative approach suggested by Thomas (1970) uses the Beverton-Holt model in developing a yield/recruit relationship. However, because a stock-recruitment equation is not specified, it cannot be incorporated into our bioeconomic model at this time.

[19] The reader should recognize that it does not follow that (17) can be derived from a generalized growth equation [$\dot{X} = F(X) - Kx = 0$] and production function $Kx = f(X,K)$. Only under certain specifications of the previous two functions will it follow that x can be defined as a unique function of K (or X) only. In addition, this production function could have been more generally specified as $Kx = rK^{\alpha}X^{\beta}$. However, two compelling factors make it desirable to employ this function. First, there are no observations on the biomass, X, so that empirical tests cannot be made to estimate β. Second, the equation $Kx = rKX$ combined with the logistic gives an excellent empirical fit to past behavior in the fishery (i.e., $R^2 = 0.962$ for yield function equation 23). In addition, Schaefer makes the same assumption as we did, and this assumption is generally accepted as plausible for most fisheries. In conclusion it is difficult for us to imagine how a different assumption could lead to superior predictive results (i.e., goodness of fit).

[20] Dow, R., D. Harriman, G. Pontecorvo, and J. Storer. 1961. The Maine lobster fishery. Unpublished manuscript submitted to the U.S. Fish and Wildlife Service, Washington, D.C. 71 p. (May be obtained from Sea and Shore Fisheries, Maine.)

[21] Higher seawater temperature can affect the natural yield of lobsters by providing a climate in which molting is facilitated. A larger number of molts will tend, *ceteris paribus*, to increase the yield associated with any given level of the biomass.

[22] Implicit in the way the effect of seawater temperature is measured is the relationship:

$$[a = a_0 + d(^\circ\mathrm{F})].$$

are available for the 1950-69 period (see Appendix Table).[23] Output per trap was regressed against the number of traps and seawater temperature on the assumption that the number of traps per boat was constant. The regression estimates yielded the following results:

$$x = -31.82 - 0.00002807(T) + 1.846(^{\circ}\mathrm{F}) \qquad (23)$$

$$(6.55) \qquad\qquad (4.99)$$

$R^2 = 0.962$

D-W = 2.38

where $T = 562.8(K)$: $\hat{d} = 0.0156$; $\hat{c} = -31.82 + 1.846(^{\circ}\mathrm{F})$. In (23), T is equal to the number of traps fished per year, and t-ratios are in parentheses.[24] Both T and °F are statistically significant at the 5% level and exhibit the correct sign; the Durbin-Watson statistic indicates no significant autocorrelation.

The only step required to obtain the biotechnological parameters is an estimate of the biomass consistent with maximum sustainable yield. It has been calculated that (assuming a temperature of 46°F) the fishable stock of U.S. inshore American lobsters consistent with maximum sustainable yield is equal to 31 million pounds.[25] For the Gulf of Maine (where most of the resource is located), estimates of the biomass were made through sampling experiments.[26]

Finally, on the basis of recent cost studies, we have derived an estimate of $\hat{\pi}$ for 1966 equal to $12,070.[27, 28] Therefore, on the supply side, the estimated parameters for 1969 are the following:

$$\hat{a} = 1.85379$$
$$\hat{b} = 2.9899 \times 10^{-8}$$
$$\hat{r} = 5.1562 \times 10^{-4}$$
$$\hat{\pi} = \$13{,}191 \text{ (see footnote 27).}$$

The Demand Function for American Lobsters

Only knowledge of $\hat{\alpha}$ and $\hat{\beta}$ is needed in order to complete the empirical component of the study. The estimation procedure is rather straightforward. We may specify the following demand function for all lobsters:

$$\frac{C}{N} = F - m(P'/\mathrm{CPI}) + g(Y/N) \qquad (24)$$

where C is equal to consumption of all lobsters, P' is the money ex-vessel price of American lobsters, Y is aggregate U.S. personal income (1967 prices), N is U.S. population, and CPI is the consumer price index. Since there are no exports of lobster, the following identity holds:

$$C = I + Q_o + Q_{\mathrm{in}} \qquad (25)$$

where I, Q_o, and Q_{in} are the level of imported lobsters, U.S. production of all other lobsters, and U.S. production of inshore American lobsters, respectively. Given (25), equation (24) may be solved in terms of P, or,

$$P = \frac{P'}{\mathrm{CPI}} = \left[\frac{F}{e} - \frac{1}{mN}(Q_{\mathrm{in}} + Q_o + I) + \frac{gY}{mN}\right] \qquad (26)$$

If Q_o, I, Y, CPI, and N are held constant, equation (26) gives a unique relationship between the ex-vessel price of American lobsters and quantity landed.

Using data over the 1950-69 period (see Appendix Table), the parameters of equation (24) were estimated using least squares:

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[23] The assumption of a constant number of traps per boat is necessary in order to solve for a coefficient on "K", and thereby, to obtain the biotechnological parameters embedded in the yield-effort relationship. The relationship for 1966, derived on the basis of cost data obtained from the National Marine Fisheries Service's Division of Financial Assistance was 562.8 traps per full-time equivalent northern lobster boat. However, it should be pointed out that when the stock is large and the catch high, it may pay to increase the number of traps per boat; therefore, this might bias the number of "standardized boats", but not total amount of effort.

[24] However, the reader should note that the empirical estimates themselves (1950-69) make no assumption with respect to the relation between K and T. x was regressed on T and °F. Only in the simulation was a relationship assumed ($T = 562.8K$).

[25] U.S. Department of the Interior. 1970. Joint master plan for the northern lobster fishery. Unpublished manuscript. 130 p. (May be obtained from the National Marine Fisheries Service, Washington, D.C.)

[26] No attempts were made to run the simulation model with varying sizes of the MSY biomass as this would unnecessarily complicate this paper which is intended to be simplistic as possible.

[27] Cost data from the National Marine Fisheries Service's Division of Financial Assistance (1966) reveal the following cost breakdown for a representative lobster boat: operating expenses, $4,965.16; fixed expenses, $1,180.20; returns to capital and labor, $5,825.48. This gives a total of $12,070.84. The latter figure was updated to 1969 by income increases in Maine to obtain $13,191.

[28] We will assume that $\hat{\pi}$ remains constant in real terms. This is equivalent to keeping our estimate of $\hat{\pi}$, $\hat{\pi}$ constant, while deflating all nominal variables on the demand side.

$$\frac{C}{N} = -0.0632 - 0.005029\left(\frac{P'}{\mathrm{CPI}}\right) + 0.00051\,\frac{Y}{N} \qquad (27)$$

$$(2.06) \qquad\qquad (5.38)$$

$R^2 = 0.816$

D-W = 0.619

All of the independent variables are significant at the 0.05 level. However, the Durbin-Watson statistic indicates the strong possibility of positive autocorrelation. Nonetheless, we will use these estimates as rough approximations to obtain the price-dependent relationship as shown in (26). Given 1969 values of exogenous variables (N = 199,100,000; Y = \$567,635 million; CPI = 109.8 with a base of 1967 = 100; $Q_0 + I$ = 158.8 million pounds), we have,

$$P = 1.179 - (0.99853 \times 10^{-8})Q_{in}. \qquad (28)$$

Thus initial values for $\hat{\alpha}$ (1.179) and $\hat{\beta}$ (0.99853 $\times 10^{-8}$) have been obtained.[29]

HOW THE MODEL WORKS: THE IMPACT OF CRITICAL VARIABLES

To illustrate the power of the model in explaining the impact of changes in critical variables, we may derive initial quantitative estimates of the ecological equilibrium and economic steady-state functions. In this section we will illustrate the power of the model in explaining the impact of changes in critical variables. The year 1969 is selected for initial quantitative estimates of the ecological equilibrium and economic steady-state functions. Table 1 shows what happens to the value of (X^*, K^*) as well as the equilibrium harvest level, $(Kx)^*$, when the following changes take place:

a) A 25% increase in opportunity costs of labor caused by the development of greater regional industrial activity;
b) A 25% increase in the supply of other lobsters traceable to the discovery of a new lobster ground;
c) A 5% increase in personal per capita income; and
d) A decrease in water temperature from 48° to 47° F.

Notice that these changes are for illustrative purposes; however they do come about on a routine basis in the real world. Perhaps 25% changes in selected variables do not come about in one year so the reader can view the new equilibrium

TABLE 1.—The impact of exogenous shocks to the inshore American lobster fishery on the effort, catch, and biomass.

	Vessels, full-time equivalent K^*	Traps E^*	Catch Kx^*	Biomass X^*
	Number	*Number*	*Million pounds*	
Initial equilibrium (1969) (computed by model)	1,936	1,089,000	28.56	28.62
New equilibrium:				
(a) Increase (25%) in opportunity cost of labor	1,531	861,718	28.1	35.6
(b) Increase (25%) in exogenous supply of lobsters	947	533,000	22.3	45.7
(c) Increase (5%) in personal per capita income	2,182	1,228,310	27.4	28.0
(d) Decline in water temperature by 1°	1,851	1,041,710	26.8	29.0
(e) Changes (a)-(d) simultaneously	905	509,356	20.7	45.9

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[29] For purposes of simplification, the parameters of the model are all assumed constant. Certainly, one could argue that the parameters, so tacitly assumed to be constants, are at best random variables. Therefore, a stochastic treatment might be used with criteria like maximal expected present value or minimal maximum expected loss for evaluating the management alternatives rather than simple deterministic computations. Possibly, the parameters are random variables and conditional on some of the suggested management alternatives. For example, freezing effort might accelerate r, leading to shifts in season or age structure harvested, hence a change in a/b.

positions shown in Table 1 to result over a period of years from the 1969 initial equilibrium. We may incorporate all of the four changes given separately in (a) - (d) to ascertain their net impact. The strength of the simulation model is that we can study the separate and combined influences on the fishery of important variables. Because we have both positive and negative influences on fishing effort, it is likely to be such that complete extinction of a particular species would be somewhat difficult.[30]

ECONOMIC IMPACT OF SELECTED MANAGEMENT ALTERNATIVES

Up to this point, we have been concerned largely with building a bioeconomic model that considers all important variables. The model is based upon the fact that open access to the American lobster fishery is permitted. However, all States restrict gear to pots and traps. Each State (Maine, Massachusetts, New Hampshire, and Rhode Island) has a minimum length requirement; permitted minimum lengths vary from 3⅛ to 3³⁄₁₆ inches. We are taking the array of existing regulations as given. We shall consider the economic impact of five alternative policies that could be adopted to manage or to limit entry to the entire American lobster fishery. These management strategies assume that some central authority such as a regional commission could impose these regulations.[31] The specific objectives of these management strategies will be discussed below. All strategies have two objectives in common which are (1) to protect the resource from overexploitation and (2) to allow maximum freedom for operators to function in a free enterprise fashion. Further, the following strategies are meant to be illustrative and do not exhaust all possible alternatives. Also, two other management strategies suggested by Reeves (1969) and Sinclair (1960) will be reviewed. As other management strategies are suggested both inside and outside government, the model formulated above may be used to predict their impact.

Some Possible Alternative Management Strategies for Inshore American Lobsters

1. *Freeze on existing (1969) fishing effort by placing a license fee on traps:* Under this scheme, the regulatory authority would calculate a license fee on traps which would keep the level of fishing effort constant despite an increase in the demand for lobsters.[32] A license fee could not be levied on the individual vessel because this would not control the number of traps fished per vessel. The increased cost of operations due to the license fee would make it uneconomical for vessels to enter the fishery even though ex-vessel prices have increased. In essence, the license fee would siphon off increased revenue (or profits) from an increase in ex-vessel prices assuming the latter increases faster than cost of operations. For purposes of illustration, let us assume that we desire to manage the inshore American lobster fishery commencing in 1974. Given the estimated trend in important variables in the fishery (i.e., $\hat{\hat{\pi}}$, I, Q_0, Y, N, CPI) to the year 1974, it would be necessary to place an estimated annual license

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[30] This is subject to two qualifications. First, since we are plotting only equilibrium relationships, extinction is a possible dynamic outcome (as was mentioned previously). Second, we have implicitly assumed that in the case of American lobster, the rate of technological advance is minimal. This is a fairly realistic assumption for the inshore trap fishery. However, in general, $r = r(t)$, with $r' > 0$.

[31] With the steady-state assumption, the management policies would in fact maximize the present value of the stream of net benefits over time.

[32] The model can derive the "correct tax" (or license fee) in a number of ways. Suppose, the regulatory authority wishes to freeze effort at some specified level K^0. We can derive the equilibrium yield consistent with K^0, call it $(Kx)^0$, from the yield-effort relationship. The total tax and the tax per vessel are then respectively given by:

$$T_x \quad (\hat{\alpha} - \hat{\beta}(Kx)^0)(Kx)^0 - K^0\hat{\hat{\pi}}$$

$$T_x/K = \frac{[(\hat{\alpha} - \hat{\beta}(Kx))\,x - \hat{\hat{\pi}}]}{K}$$

In similar fashion, if the regulatory authority wishes to freeze effort at a level consistent with maximum sustainable yield, we can obtain the tax that will insure this level of exploitation.

The only other taxing scheme that requires further explanation is a tax that will insure marginal cost pricing. Long-run industry marginal cost can be defined as:

$\hat{\hat{\pi}} / \frac{\partial Kx}{\partial K}$, where $\frac{\partial Kx}{\partial K}$ is the first derivative of (16). Total industry cost can then be redefined as,

$$\left(\frac{\hat{\hat{\pi}}}{\partial Kx/\partial K}\right)Kx$$

This expression can be substituted into the total revenue function and solution for K, Kx can be found by iteration. The tax consistent with these solutions can then be derived by using the formulas given above, i.e., Tx, Tx/K.

fee of \$3.34 (in 1972 dollars) on each lobster trap fished. This is shown in Table 2. The regulatory authority would collect over \$3.5 million in license fee revenue which could be used to finance resource research, enforcement, and surveillance. It should be emphasized that these calculations are merely rough estimates and only serve to give the reader some idea of the magnitude of such license fee. The illustrative license fee is also based upon an extrapolation of trends 5 yr ahead of 1969. If we did nothing, it is estimated that the catch would be lower and more fishermen and traps would be employed in the fishery by 1974. Obviously, the situation would worsen as demand for lobsters expanded and the fishery became increasingly overfished. The license fee plan does have many disadvantages. First, a license fee on traps fished does not really get at the utilization rate. One might expect that a license fee on an individual trap might induce fishermen to fish each trap more intensively and thereby reduce their number of traps. At this point, we do not have any information on utilization rates whereby the tax could be adjusted upward if utilization increased. Second, enforcement and surveillance might be difficult along the coastline from Maine to North Carolina. Third, and most important, the quantitative tools and projected figures needed to calculate a license fee are at best crude and would have to be used for calculations each year.

2. *Reduce the existing level of fishing effort to that necessary to harvest MSY by placing a license fee on traps:* With this scheme, the regulatory authority would calculate a license fee on traps which would reduce the level of existing effort to that necessary to harvest maximum sustainable yield (i.e., estimated to be about 1,011,910 traps) despite an increase in demand for lobsters.[33] Because we are actually reducing fishing effort as opposed to freezing it at the 1969 level, the estimated 1974 license fee per trap must be higher or \$5.58 (in 1972 dollars). Actual catch will not be significantly higher. The regulatory authority would receive approximately \$5.6 million in license fee revenue. However, this plan has the same disadvantages of a general license fee plan indicated under alternative one.

3. *Reduce the existing level of fishing effort to that necessary to make the marginal cost of*

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[33] The fishing effort needed to harvest MSY was obtained from equation (23) with the 1950-69 average water temperature.

TABLE 2.—The impact of various management schemes imposed on the inshore American lobster fishery in 1974.[1]

		Impact after the imposition of selected management strategies for 1974				
		(1)	(2)	(3)	(4)	(5)
Economic variables	Estimated values before imposition of management strategies (1969)	Freeze at 1969 level of fishing effort	Reduce fishing effort to E_{MAX}	Reduce fishing effort so $MC = P$	Issue "stock certificate" to vessel owner while freezing effort at 1969 level	Do nothing
Catch (million lb)	28.6	28.6	28.7	23.9	28.6	28.1
Value of catch (million \$)	28.0	36.8	36.9	31.9	36.8	36.4
Vessels (full-time equivalent)	1,900	1,900	1,798	1,060	1,900	2,070
Traps (million)	1.069	1.069	1.011	0.597	1.069	1.165
Ex-vessel price	0.98	1.29	1.29	1.33	1.29	1.30
Total license fees collected (million \$)	0	3.56	5.58	13.3	0	0
License fee/vessel (\$)[2]	0	1,877	3,119	12,622	0	0
License fee /trap (\$)	0	3.34	5.54	22.43	0	0
Return per vessel and fisherman	6,365	8,400	8,400	8,400	10,278	8,400

[1] Projection of 1974 impact of selected management strategies. Assumes that F° = 48°; Y = \$677.9 billion, (1969 prices); POP = 212.4 million; $Q_0 + I =$ 183.6 million pounds and $\hat{\pi} =$ \$15,292. All prices and dollar values projected for 1974 are expressed in 1972 dollars.

[2] The license fee per vessel was obtained by multiplying the tax per trap by the average number of traps (562.8) fished per full-time vessel.

landings equal to ex-vessel price by placing a license fee on traps: The idea here is to obtain the greatest "net economic benefit" and has been suggested by such economists as Crutchfield and Pontecorvo (1969).[34] If a regulatory authority were to try this for 1974, it would have a drastic impact on the fishery as the number of full-time equivalent vessels and traps would be reduced by approximately 47%. To accomplish this objective an estimated 1974 license fee of $22.43 (in 1972 dollars) per trap would be needed. This would yield the regulatory authority approximately $13.3 million in revenue. From an economic point of view, it is argued that this management strategy will result in the most efficient operation of the fishery if fishermen and vessels can easily move to other fisheries or industries. However, this strategy may be particularly unwise in rural areas such as Maine where labor mobility is low. A drastic cutback in the number of fishermen may create social problems where the cost would greatly exceed any benefits derived from this management strategy. Therefore this management strategy is difficult, if not impossible, to justify on economic grounds for many rural areas where the fishing industry is located and also has the same disadvantages of a general license fee plan on traps as discussed above.

4. *Issue "stock certificates" to each vessel owner based upon average catch over last 5 yr while freezing the existing level of fishing effort:* Under this scheme, the historic rights of each fishing firm would be recognized. In a similar manner to a private land grant procedure, the regulatory authority would simply grant each fisherman a "private" share of an existing resource or catch. The stock certificate would be evidence of private ownership. Individual fishermen would be free to catch up to their allotted share through the use of pots or other biologically permissible technology or, if they desired, trade their stock certificates to others for cash. Suppose the regulatory authority were to freeze the level of fishing effort at the 1969 level and distribute the estimated catch via a stock certificate to the existing fishermen. It should be pointed out that the regulatory authority fixes effort when it selects a given catch. The selected catch could be either MSY or any other level of catch deemed by the regulatory authority not injurious to the viability of the stock. The expansion in demand for lobsters by 1974 would generate excess profits for those individual fishermen who were initially endowed with the property right. By 1974, it is estimated that a full-time lobsterman would be earning $10,278 (in 1972 dollars) a year of which $1,878 would be excess profits (i.e., above opportunity cost). If profits become excessive a license fee would be levied on the fishermen holding stock certificates to insure against increased abnormal returns and provide the regulatory authority with funding to conduct scientific investigations and enforcement. It should be noted that this plan is identical to the license fee scheme which freezes effort at its 1969 level. However, in the latter case, excess profits are taken by the regulatory authority while for this strategy, fishermen are allowed to hold onto the profits generated in the fishery. Since many fisheries are located in rural areas where earnings are traditionally low, this strategy might be justified on the basis that it will raise income levels and thereby help improve living standards to comparable levels to those received in urban areas. This management strategy would, of course, be popular with those already in the fishery. However, new entrants would have to buy stock certificates from those initially in the fishery. This would bring up certain questions of equity and legal precedent which are beyond the scope of this article.

5. *No management strategy:* When considering the economic consequences of alternative management strategies (1-4), it is always wise to assess the results of doing nothing. This gives policymakers a better perspective in evaluating the benefits from taking action. The consequence of doing nothing would be overcapitalization by 1974 with an expansion in the number of full-time equivalent fishermen and traps fished. Approximately 96,000 excess traps (i.e., above that necessary to take MSY) would be in the fishery, and the catch would fall to 28.1 million pounds.

The fishery would grow increasingly overcapitalized, and the resource would be greatly overexploited as demand increased for lobsters during the 1970's. On economic grounds, these

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[34] When price is constant, maximization of net economic benefit becomes identical to the goal of maximization of rent to the fishery. This, however, is not the case when the normally downward sloping demand curve is specified.

results are hardly acceptable because more fishermen and vessels will probably be catching less.

6. *Other suggested management strategies:* Reeves (1969) has proposed a hike in license fees to eliminate the marginal or part-time fishermen. He suggests that the present $10 yearly fee in Maine be raised $10 a year over the next 9 yr to a top of $100. In 1969, a little less than one-half of the lobster fishermen were part-time. A part-time lobster fisherman is defined as one who gains less than one-half of his annual income from lobstering. The first step in most suggested limited entry schemes is usually to restrict the fishery to full-time utilization of capital and labor. Two problems occur with this policy. First, the part-time fishermen may represent the most efficient way of taking the catch. If so, the full-time fishermen may be eliminated by increased license fees. Second, license fees do not directly control fishing effort since fishermen may fish more traps. However, Reeves also goes on to argue strongly for limiting the number of traps each fisherman is allowed to set. It is not quite clear whether anyone knows the optimum number of traps per vessel.

Rutherford, Wilder, and Frick (1967) in their study of the Canadian inshore lobster fishery endorse the system suggested by Sinclair (1960). They state:

> "An alternative management system is that suggested by Sinclair (1960) for the salmon fisheries of the Pacific Coast. This would use the licensing of fishermen to limit entry into the fishery. In the first stage, lasting about five years, licenses would be reissued at a fee but no new entries would be licensed, and it would be hoped that during the period there would take place a reduction in the labour and capital input, to take the maximum sustainable catch of salmon at a considerably lower cost. After the end of the first stage, licenses would be issued by the government under competitive bidding and only in sufficient numbers to approximate the most efficient scale of effort; the more competent fishermen would be able to offer the highest bids and it would be expected that the auction would recapture for the public purse a large portion of the rent from the fisheries that would otherwise accrue to the fishing enterprises under the more efficient production conditions in the fishery.
>
> "An arbitrary reduction in the number of fishermen by restriction of licenses to a specified number would entail injustice and inequity as well as grave administrative problems in determining who should be allowed to continue fishing. The auctioning of licenses to exploit a public property resource is justifiable in a private enterprise system of production, particularly when the state is incurring heavy expense to administer and conserve the resource; the recovery by the state of some part of the net economic yield by means of a tax on fishermen (or on the catch) would recoup at least part of such public expenditures, or could be used to assist former fishermen (see strategies discussed above) for instance, by buying their redundant equipment. A tax on fishermen through the auctioning of licenses has, at least, the merit of using economic means instead of arbitrary regulations to achieve a desired economic objective—the limitation of fishing effort to increase the net economic yield from the fishery. Regulations have to be enforced, usually at considerable cost, but economic sanctions tend to be, if not impartial, at least impersonal and automatic in their operation."

Actually, this latter management scheme is similar to the taxing scheme, but uses an auction rather than a direct tax.

Conclusions

The purpose of this article is to explain the use of bioeconomic models in assessing alternative management strategies. For this purpose the data are less than optimal. However, this does not mean that we cannot take steps in the direction of fishery management. In fact, these steps must be taken to protect the resource from destruction and to achieve a better use of vessels and fishermen. It is hoped that the following conclusions will provide a helpful framework in which to consider the merits of limited entry:

1. For the inshore American lobster resource, there is every indication that the fishery has achieved maximum sustainable yield and is fully capitalized. This has been brought about by a rapid expansion in effort (i.e., traps fished) produced by (1) free access to the resource, (2) a rising market for lobsters of all species, and (3) a secular decline in seawater temperature.
2. We have presented the bioeconomic impact of alternative management strategies to both conserve the resource and use it efficiently. The choice of which strategy to pursue is in the public domain and beyond the scope of this paper. However, the economic alternatives are pointed out.

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APPENDIX TABLE—Economic variables associated with the U.S. inshore American lobster fishery, 1950-69.

Year	Catch by traps	Value	Traps fished	Catch per trap	Ex-vessel price	Ex-vessel price divided by consumer price index	Year	Per capita consumption of lobsters	Per capita disposable personal income divided by consumer price index	Consumer price index (1967 = 100)	Mean annual seawater temperature at Boothbay Harbor, Maine
	Thousand pounds	*Thousand dollars*	*Number*	*Pounds*	*Cents per pound*	*Cents per pound*		*Pounds (live weight)*	*Dollars*		*Degrees Fahrenheit*
1950	22,914	8,283	578,930	39.6	36.1	50.1	1950	0.585	1,892	72.1	49.3
1951	25,749	9,328	512,812	50.2	36.2	46.6	1951	.651	1,888	77.8	51.4
1952	24,681	10,469	544,730	45.3	42.4	53.4	1952	.638	1,909	79.5	50.2
1953	27,509	10,687	569,081	48.3	38.8	48.5	1953	.710	1,976	80.1	52.0
1954	26,628	10,250	628,209	42.4	38.5	47.8	1954	.690	1,969	80.5	50.3
1955	27,886	11,003	669,229	41.7	39.5	49.2	1955	.734	2,077	80.2	50.0
1956	25,386	11,584	666,887	38.1	45.6	56.1	1956	.704	2,141	81.4	48.6
1957	29,358	11,263	688,815	42.6	38.4	45.6	1957	.806	2,136	84.3	48.8
1958	26,143	12,890	753,503	34.7	49.3	56.9	1958	.736	2,114	86.6	47.4
1959	27,752	14,043	856,794	32.4	50.6	58.0	1959	.763	2,182	87.3	47.0
1960	29,345	13,657	844,110	34.8	46.5	52.5	1960	.830	2,185	88.7	47.9
1961	25,621	13,662	895,098	28.6	53.3	59.5	1961	.810	2,214	89.6	47.3
1962	26,728	13,770	909,318	29.4	51.5	56.9	1962	.855	2,280	90.6	46.6
1963	27,210	15,299	866,900	31.4	56.2	61.3	1963	.938	2,333	91.7	47.9
1964	26,844	17,689	904,233	29.7	65.9	70.9	1964	.935	2,459	92.9	46.9
1965	24,737	18,764	949,045	26.1	75.9	80.3	1965	.884	2,578	94.5	45.8
1966	25,606	19,517	947,113	27.0	76.2	78.4	1966	.873	2,680	97.2	45.7
1967	22,098	18,162	907,956	24.3	82.2	82.2	1967	.882	2,751	100.0	45.1
1968	26,918	20,648	966,335	27.9	76.7	73.6	1968	.960	2,827	104.2	46.6
1969	26,930	22,997	1,061,807	25.4	85.4	77.8	1969	.999	2,851	109.8	48.0

Source: Fishery Statistics of the United States, various years, U.S. Department of Commerce, Bureau of Labor Statistics, and Robert Dow.