MAXIMUM ECONOMIC YIELD AND RESOURCE ALLOCATION IN THE SPINY LOBSTER INDUSTRY*

Joel S. Williams and Fred J. Prochaska

INTRODUCTION

Spiny lobster (*Panulirus argus*) is produced in the warmer ocean waters and is distinguished from the northern American lobster (*Homarus americanus*) by its lack of claws and relatively smaller size. Florida lobstermen currently account for 98 percent of the U.S. spiny lobster landings. This industry has grown from annual landings of less than a million pounds prior to the 1950s to 11 million pounds in 1974, with a value of over $13 million [5, 6]. Although no formal demand analysis has been completed, it appears that U.S. demand for this luxury seafood has increased considerably faster than domestic production. In current dollars, prices at dockside increased 251 percent from 39 cents per pound in 1960 to over $1.36 per pound at dockside in 1975 (an increase of 73 percent in constant dollars). Increased demand in the U.S. is further suggested by the fact that U.S. consumption of total world production increased from 53 to slightly over 80 percent in this same period.

Growth in U.S. demand encouraged increased entry into the industry. In 1973, 399 firms each fished an average of 429 traps per firm in the Florida Keys [5, 6]. The number of firms in the industry increased by 630 percent during the past two decades. Traps fished per firm increased by 60 percent since 1965. One result of this increase in production inputs has been to lower trap yields from over 50 pounds per trap in the early 1960s to approximately 29 pounds currently. The annual rate of decline has been 3.3 pounds per trap since 1952. Annual landings declined from over 20,000 pounds to approximately 13,000 pounds per firm currently [5].

The theoretical possibilities of over-fishing and excessive capital investments resulting from demand-induced entry into a common property resource industry are well developed in the literature [1, 2, 3, 8]. Decreasing catch per unit of effort and other biological indicators, such as a decline in the average size lobster caught, have caused concern in the industry. State and federal management personnel are also concerned with potential over-exploitation of the spiny lobster resource. The purposes of this paper are to: (1) present the maximum economic yield model developed for the spiny lobster industry, (2) discuss conclusions drawn from the model with respect to maximum economic yield and (3) determine level of economic resources required for the most efficient level of fishing effort. Results are of immediate importance for management decisions concerning the spiny lobster industry. In addition, the models and methodological approach presented may serve as a guide to management related research for other fisheries. The Conservation and Management Act of 1976 requires management plans for all non-migratory domestic species living within 200 miles of the U.S. coast. These plans must address some economic questions for which answers can be provided only by research of this type.

BIOECONOMIC MODEL

Theoretical Considerations

The implicit form of the production function representative of the spiny lobster fishery is represented by equation (1).

Joel S. Williams is Assistant Professor, Department of Agricultural Economics, Virginia Polytechnic Institute and State University and Fred J. Prochaska is Associate Professor, Department of Food and Resource Economics, University of Florida.

*Research reported was jointly funded by the Florida Agricultural Experiment Station and the Florida Sea Grant Program, 04-6-158-44055. The co-authors share equally in this paper.

$$Y = f(T, F, E) \qquad (1)$$

where:

Y = pounds of lobster landed
T = traps fished per firm
F = number of firms in the fishery
E = equilibrium level of catch

Traps fished per firm is the principle variable through which traditional factors of production are entered by the firm in the production process. Number of firms, F, represents the number of operating units employing traps in the fishery during a specified time period. Number of traps per firm indicates average size of operating units.

Variations in T are considered to represent changes in variable inputs and, therefore, diminishing marginal returns are assumed for a fixed number of firms within a specified production season. A change in F represents change in size or scale of the industry. Changes in number of firms operating in the fishery can theoretically produce a variety of effects of total industry production. A principle factor determining the nature of production response to additional firms is the equilibrium catch level. Equilibrium catch (E) is defined to be a level of catch available for harvest which would still leave a level of mature progeny sufficient to replace parent stock. This level of catch is a function of: (1) level of fishing effort and (2) biological parameters. T and F represent fishing effort in equation (1). Biological factors of primary importance are the level of mature progeny, parent population and environmental attributes affecting the fish stock. For relatively large equilibrium catch levels, the production response to changes in fishing effort is expected to be greater than for lower equilibrium catch levels, with the same levels of fishing effort and vice versa because of the relatively greater abundance of fish to harvest with given levels of effort.

Empirical Considerations

In recent years firms located in Monroe County, which encompasses the Florida Keys area, accounted for 80 to 90 percent of domestic Florida landings and was thus chosen as the area for study. U.S. Department of Commerce time-series data were available on landings, traps fished and number of boats and vessels in the industry in each year from 1963 through 1973 [5, 6]. Total number of boats and vessels operating in the fishery in each time period was used as a measure of the number of firms.[1] Total number of traps divided by total number of boats and vessels provided the estimate of traps per firm. Unfortunately, no estimates of equilibrium level of catch or of associated variables were available for analysis. Water temperature, however, is an environmental factor affecting the level of fish stocks and has been shown to have a significant effect on the quantity of American lobster landings. Thus, mean seasonal temperature was calculated from unpublished National Oceanic and Atmospheric Administration data and included in the model as a proxy for E in equation (1). Estimated effect of changes in temperature represents the confounded effect of temperature on availability of the biomass as well as its effect on making lobsters more or less easy to catch. This confounded effect was acceptable for present purposes, since temperature can hardly be considered a policy variable for manipulation. Furthermore, the intentions were to derive estimates of effects of fishing effort independent of biological factors.

A reciprocal form mathematical equation was used for estimation.

$$Y = a + b_1 \frac{1}{T} + b_2 \frac{1}{F} + b_3 E \qquad (2)$$

This mathematical form was chosen because it allows total landings to approach a maximum level but does not allow them to decrease beyond some critical level of effort. Florida's current management program provides for a minimum size limit and prohibits taking or stripping egg-bearing females. Both regulations tend to assure minimum stock and thus justify the form chosen. In addition, some biological studies [4] conclude that the Caribbean stock is the source of Florida lobsters, suggesting that Florida fishing effort will not necessarily affect the state's future lobster stocks. Thus, increased fishing effort is not expected to cause total landings to reach a maximum and then decrease but may effect the rate at which the model reaches the maximum. Since stock is not specifically held constant in the model, any externalities resulting from fishing effort can be expected to be confounded in the marginal products resulting from changes in T and F.

STATISTICAL ESTIMATES

Estimated coefficients and standard errors for equation (2) are presented in equation (3). Estimated coefficients for T, F and E are statistically significant

[1] A review of boat registration records and discussions with industry members indicates that essentially all firms in the area operate only one craft. Therefore, the total number of boats and vessels in the industry is assumed to equal the total number of firms in that time period.

at the 99, 90 and 80 percent confidence levels, respectively. The overall explanatory power of the model is 80 percent.

$$Y = 28.38 - 1{,}439.98 \underset{(365.9)}{\frac{1}{T}} - 465.17 \underset{(216.5)}{\frac{1}{F}} - \underset{(.2)}{.24E} \quad (3)$$

where:

- Y = million pounds of lobsters landed annually in the industry during the 1963-1973 time period
- T = number of traps fished per firm
- F = total number of firms in the industry
- E = seasonal mean surface water temperature measured in degrees Fahrenheit.

Marginal effects of variations in T and F are presented in equations (4) and (5), respectively. The expected effect on output of changes in T

$$\frac{\partial y}{\partial T} = \frac{1{,}439.98}{T^2} \quad (4)$$

$$\frac{\partial y}{\partial F} = \frac{465.17}{F^2} \quad (5)$$

is a function of the number of traps employed per firm. Likewise, marginal industry output from changes in number of firms depends on the number of firms in the industry. Marginal products for traps per firm and number of firms in the industry are both positive and are declining at increasing rates [equations (4) and (5)]. At 1973 input levels (429 traps per firm and 399 firms), an additional trap per firm is estimated to produce an additional 7,824 pounds of lobsters in the total industry [equation (4)]. This is equivalent to an additional 19.6 pounds per trap for each of the additional 399 traps which would enter the industry. If one new firm enters, fishing the same number of traps as the 399 firms already established, it will produce 2,923 pounds of lobsters [equation (5)]. In this case, the addition to total traps in the industry is 429, each producing an average of 6.8 pounds. Notice that if the additional 429 traps were allocated among existing firms in the industry, output increase would be substantially greater than if one new firm fished the 429 traps (compare 19.6 pounds with 6.8 pounds per trap). Experience of existing firms and the fact that most productive grounds are taken before new firms enter the industry perhaps explains a large part of this variation. The negative temperature effect in equation (3) suggests increased water temperatures result in lower catch through their effect on the feeding habits of lobster and/or through their longer run effect on the equilibrium catch.

MANAGEMENT IMPLICATIONS

The relatively large positive marginal products indicate that maximum sustained yield has not been reached.[2] Maximum economic yield and the optimum combinations of resources which would result in maximum economic yield involve cost and revenue considerations in addition to physical production. Total revenue estimated as the product of output price and the production function (3) is expressed in terms of inputs employed. In this formulation marginal revenue declines with additional units of inputs because of declining marginal products [equations (4) and (5)], given constant product prices. Total cost expressed as a function of inputs is a linear function when input prices are held constant.

Costs associated with production in each of the years analyzed were not available. A random stratified sample of twenty-five Florida Keys lobster firms was taken to determine cost of the 1974 season. Since all inputs used by the firms are translated in the production process through traps fished, and because equation (3) is specified to be a function of traps per firm and number of firms in the industry, total costs per firm were estimated as a function of a fixed cost component and traps fished per firm. Estimated coefficients and standard error are presented in equation (6).

$$TC = \$1{,}876 + \underset{(2.17)}{\$11.55T} \quad (6)$$

where

TC = annual cost per firm
T = number of traps fished per firm

Traps fished explain 74 percent of the variation in total cost. The constant term, \$1,876, represents fixed cost per firm which do not vary with level of trap use. The \$11.55 per trap is interpreted as an estimate of the marginal factor cost or "price" of a trap.[3] This estimate includes not only the price of the trap but also the cost of fishing it. Total industry costs are the product of per-firm cost function [equation (6)] and the number of firms in the industry.

[2] In the reciprocal form model, maximum sustained yield is approached when marginal products approach zero.

[3] Non-linear formulations of total cost as a function of traps employed were not statistically significant, thus the simple significant linear estimate was accepted.

Maximum Economic Yield

Maximum economic yield with respect to traps per firm and number of firms in the industry is estimated by first determining simultaneously the optimal level of T and F. Optimum levels of T and F are then substituted into equation (3) to predict the maximum economic yield. To first determine optimum levels, the profit function [equation (7)] is differentiated with respect to T and F.

$$\pi = P_y\,(9{,}773{,}481 - 1{,}439{,}976{,}169\,\frac{1}{T} - 465{,}173{,}997\,\frac{1}{F}) - F\,(\$1{,}876 + \$11.55T) \quad (7)$$

where:

π = profits

Profit equation (7) is defined to be the product of lobster price (P_y) and the production function [equation (3)] minus the product of the firm cost function [equation (6)] and the number of firms, F. E is held constant at the mean temperature of 77.6°F and its effect is incorporated with the constant term. Partial derivatives [equations (8) and (9)] are then set equal to zero and input levels are determined simultaneously.

$$\frac{\partial \pi}{\partial T} = P_y\,\frac{1{,}439{,}976{,}169}{T^2} - \$11.55F \quad (8)$$

$$\frac{\partial \pi}{\partial F} = P_y\,\frac{465{,}173{,}997}{F^2} - \$1{,}876 - \$11.55T \quad (9)$$

For 1973 product prices of $1.08 per pound an economic optimum solution calls for 795 traps per firm and 213 firms in the industry.[4] Substituting these values into equation (3) gives an estimated maximum economic yield equal to 5,778,274 pounds for the Florida Keys region.

Estimated maximum economic yield of 5.8 million pounds compares favorably with current levels of landings, which ranged from 4.8 million pounds in 1972 to 6.6 million pounds in 1974. A relatively small percent of the landings were caught outside the domestic fishery. The present combination of resources, however, is considerably different from optimum levels. In 1973, 399 firms were fishing an average of 429 traps each with a predicted level of landings equal to 5.4 million pounds.[5] The optimum solution suggests a reduction of 186 firms and an increase of 366 traps per firm for the remaining firms. This reorganization would cause industry cost to be $2,355,407 instead of the present annual estimated cost of $2,725,549. Savings measured in reduced cost are $370,142. This savings of approximately 14 percent must be compared to political, social and economic costs of displacing the 186 firms before an "optimum" management program can be determined. Reduction in total industry cost with a relatively small increase in total industry revenue divided among 186 fewer firms, however, will result in a considerable increase in profits for remaining firms. Predicted net profits per firm would increase from $6,677 to $18,350 after elimination of the 186 firms presently in the industry. The potential redistribution of income resulting from a maximum economic yield program will require serious consideration by policy makers.

Other Management Goals

The present models may be used for determining consequences of alternative management programs where strict economic efficiency is not the goal, or they may be used to analyze effects of potential changes in industry structure which result in needs for additional management programs. In the first case, management authorities may choose to "grandfather" in all existing firms while setting a quota on total industry landings. In this example, the level of traps to be fished per firm could be determined from equation (3) and cost and revenue effects could be determined from information in equation (7). Other alternatives are possible, given the three policy variables available for manipulation in the model.

The recent decision by the Bahamian government not to allow American lobstermen to fish the Bahamian continental shelf potentially caused a change in the domestic industry structure. Models presented in this paper were used during their development stages to predict economic consequences that would occur if these approximately 160 displaced lobstermen entered the domestic fishery [7]. A substantial redevelopment grant was acquired, partly on the basis of these predictions, to discourage potentially excessive entry into the domestic fishery.

[4] The optimum solution at any one period in time depends on the level of lobster prices, input prices and production coefficients. Thus, current and future trends of these must be considered in development of management programs.

[5] 1973 input data were the latest available at the time of analysis.

REFERENCES

[1] Carlsen, Earnest W. *An Economic Theory of Common Property, Fishery Resources*, National Marine Fisheries Service, Economic Research Division, File Manuscript No. 140, September 1971.

[2] Crutchfield, J. A. "Economic Objectives of Fishery Management," *The Fisheries: Problems in Resource Management*, J. A. Crutchfield, Ed., Seattle, Washington: University of Washington Press, 1965.

[3] Gates, J. M. and V. J. Norton. *The Benefits of Fisheries Regulation: A Case of Study of the New England Yellowtail Flounder Fishery*, Sea Grant Marine Technical Report No. 21, Kingston, Rhode Island: University of Rhode Island, 1974.

[4] Ingle, R. M., et. al. *On the Possible Caribbean Origin of Florida's Spiny Lobster Populations*, Florida State Board of Conservation, Technical Series No. 40, Marine Laboratory, St. Petersburg, Florida.

[5] National Marine Fisheries Service. *Fishery Statistics of the United States*, U.S. Government Printing Office, Annual Issues, Washington, D.C., 1952-1975.

[6] National Marine Fisheries Service. *Florida Landings*, U.S. Government Printing Office, Washington, D.C., Monthly and Annual Issues, 1971-1976.

[7] Prochaska, Fred J. "An Economic Analysis of Effort and Yield in the Florida Spiny Lobster Industry with Management Considerations," *Proceedings: Tropical and Subtropical Fisheries Technological Conference*, Sea Grant, Texas A & M University, College Station, Texas, 1976.

[8] Scott, Gordon H. "The Economic Theory of a Common Property Resource: The Fishery," *Journal of Political Economy*, Volume 62, April 1954, pp. 124-142.