BIOECONOMIC MODELING OF THE GULF SHRIMP FISHERY: AN APPLICATION TO GALVESTON BAY AND ADJACENT OFFSHORE AREAS

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The concept of laissez-faire is widely recognized in capitalistic economies. At the core of this operating philosophy is the belief that individualistic competition will result in an economic improvement, not only for the individual but also for society. However, when this approach is tied to the exploitation of a common property resource, the outcome is just the opposite—in terms of economic efficiency the common property resource is overexploited because the factor cost to the firm does not equal the opportunity cost to society [5, 15]. That is, although a common property resource is a scarce good to society, it is a free good to individuals. The usual result is a level of exploitation which may endanger the future biological viability of the resource [3]. With shrimp, however, this concern is not critical because shrimp is an annual crop; fishing will cease as a result of economic, and not biological, considerations.

The negative impact of laissez-faire on such resources as the public rangeland, national forests, and air and water has been abated because of public management of the resources and enactment laws regulating their use. One common property resource in which laissez-faire still prevails is fisheries. Reasons for this condition include the belief that fishery resources are inexhaustible, tradition, and the unorganized nature of fisheries industries. The recently passed Fishery Conservation and Management Act of 1976 may indicate a change in this philosophy by industry, government, and the public.

The shrimp fishery is an important element of the common property fishery resource. It is by far the most valuable one, contributing 24.5 percent of the total dollar value at dockside for U.S. fish products ($1,352.7 million) though accounting for only 7.5 percent of the 5.4 billion pounds landed in 1976 [12, p. 3]. The Gulf of Mexico shrimp fishery is the major shrimp area as it accounts for just over half of the total shrimp catch and 83.0 percent of the dollar value.

Until very recently there has been little management of this fishery, except by individual states which have set closing seasons and established minimum harvest size. In this unregulated state, economic conditions in the industry have varied considerably from year to year. Of course, some degree of disequilibrium may always occur because of natural biological fluctuations. Shrimp landings and prices have fluctuated widely, as has investment in vessels and shore facilities which require large capital outlays. The return to these investments for the firm and for the industry has been rather uncertain as the economic environment changes from year to year. Better management tools should facilitate investments and other activities in the shrimp industry.

The purpose of this article is to incorporate a nonlinear optimization procedure into the simulation model developed by Grant and Griffin [6]. The simulation model, which integrates the biological relationships among the shrimp biomass and shrimp fleet characteristics, is combined with economic theory into a 12-month analysis[1] which maximizes net income to the industry (gross returns over costs) over a shrimping season. The analysis can also evaluate changes in several institutional parameters which affect the utilization of the common property shrimp resource.

This article demonstrates the potential utility of such a model and suggests some general management approaches to the brown shrimp fishery that deserve further considera-

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[1] This length of time is based on the perennial nature of the shrimp population.

tion. Another example of this integrated framework is that of Gages [4]. The authors do not present these models as definitive arguments for or against specific management alternatives, but as tools for consideration.

METHODOLOGY

The framework of the model is very general in that it allows analysis of one or more shrimp species of commercial importance, a variety of economic variables, and time periods for analysis ranging from one month to several years. The model thus has ample flexibility by simply allowing relationships between shrimp species and between economic variables to be added or deleted. The simulation model contains basically two parts, biological and economic. Discussion of the bioeconomic aspects is followed by a description of the optimization procedure.

Bioeconomic Aspects

A simple conceptualization of the major biological aspects of the Gulf shrimp fishery is shown in the upper half of Figure 1. Shrimp enter the inshore fishery by moving from the shallow nursery grounds into the deeper water in the bays, and then move out of the bays into the offshore fishery [11] which has been divided into 1-10 fathom and 11-50 fathom depths on the basis of biological information [6]. As they move, the shrimp grow according to the Bertalanffy function [1] and are subject to both natural and fishing mortality. Fishing mortality at each depth, and the resulting harvest, is determined by the characteristics of the fishing fleet which is active at that depth [13].

The conceptualization of the major economic aspects of the Gulf shrimp fishery is shown in the lower half of Figure 1. The biological and economical aspects are interrelated through effort and landings. The demand for shrimp is determined by the prices of related goods and consumer incomes. Supply, which with demand detemines the price of shrimp, is composed of the Gulf landings (which is a function of effort), imports, and other U.S. landings. Price and unit cost determine the amount of nominal days fished and, therefore, the effort that will be expended on the Gulf shrimp resource. In this article the monthly prices of shrimp are held constant by size of shrimp when they are harvested from the inshore and two offshore depths. Also, fleet characteristics such as horsepower and net size are held constant in the short run and nominal days fished are allowed to vary.

Optimization Procedure

The purpose of this section is to provide the framework for evaluating annual rent to the fishery in (1) the simulation model and (2) the optimization routine. The optimizing routine must evaluate a nonlinear objective function due to the dynamic relationships between shrimp growth, fishing mortality, and seasonally changing prices for the size classes. The particular algorithm selected for this maximization process is the Quasi-Newton procedure, wherein derivaties of the function are not necessary for a solution [10][2].

Maximizing rent to the fishery insures that the fishery operates a maximum economic efficiency for the year. At the optimal level of catch, marginal revenue equals marginal cost for the firm, and demand equals the summation of all firms' marginal costs.[3] Annual rent is defined as the summation of monthly total revenue minus monthly total costs. Total revenue is made up of the landings by size class multiplied by prices for each size. Prices here remain constant over any change in landings because of the small impact a change in landings for the area has on the national market. (We assume a normal level of shrimp landings for other areas.) Total costs consist of costs proportional to catch and those proportional to effort [8].

The formulation for rent is from the following relation:

$$\text{Monthly Rent} = \underbrace{\sum_{j=1}^{4} P_j Y_j}_{(1)} - \underbrace{\$0.065(1\text{-}.32)\sum_{j=1}^{4} Y_j}_{(2)} \underbrace{-(.32)\sum_{j=1}^{4} P_j Y_j}_{(3)} \underbrace{-\sum_{i=1}^{3} C_i DFN_i}_{(4)} \underbrace{-FC}_{(5)}$$

where total revenue is expressed in (1) for the first four largest size (j) classes; the vessel owner's share (1-.32) of the packing charge ($0.065/lb.) for the catch (Y) is (2); the crew's

[2]The simulation itself becomes a subroutine in the algorithm, ZXMIN, to maximize rent.

[3]Marginal revenue equal to average cost for the firm and demand equal to industry average cost is the usual outcome with individualistic competition and exploitation of a common property resource.

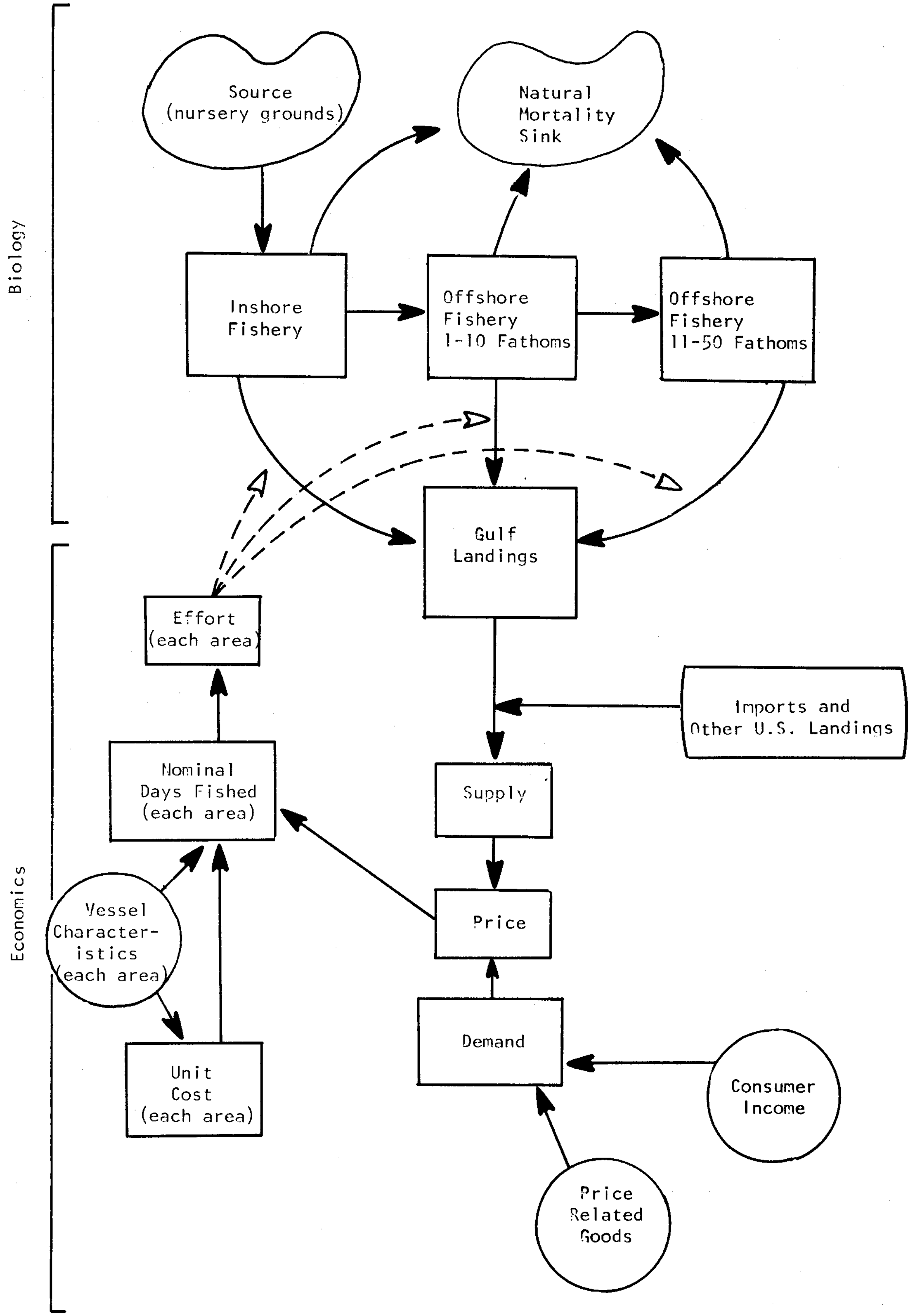

FIGURE 1. BIOECONOMIC RELATIONSHIPS IN GULF OF MEXICO SHRIMP FISHERY

share of total revenue is (3); variable costs (C) per day fished (DFN) is expressed in (4) for the three areas (i) in the study region, $225/day for the inshore area, $525/day for 1-10 fathoms, and $675/day for 11-50 fathoms; and fixed cost is (5).

Simplifying the rent function, we derive

$$\text{Monthly rent} = .68 \sum_{j=1}^{4} P_j Y_j - \$0.044 \sum_{j=1}^{4} Y_j - \sum_{i=1}^{3} C_i DFN_i - FC$$

where the sufficient parameters necessary for discussion are the vessel's and captain's percentage of total revenue, packing charge, and variable cost per fishing day.

In the optimizing program, days fished is the control variable. That is, any change in days fished affects total revenue (through catch) and the four cost components. Because there are 12 months and three areas there could be as many as 36 control variables.

DATA AND SCOPE OF ANALYSIS

The data used in the model are monthly. Monthly averages of shrimp landings [13] during the 1963-71 period were used to construct the biological part of the simulation [6]. Monthly prices for 1976 brown shrimp, in various sizes, quoted from Brownsville-Port Isabel, Texas, and cost data for vessels and boats from 1976 developed by Griffin [6] were used.

The geographic area considered is Statistical Area 18 (S.A. 18), so designated by the National Marine Fisheries Service (NMFS), which encompasses Galveston Bay and an adjacent area in the Gulf of Mexico. Shrimp landings and value, by species and by size, are reported monthly by NMFS. This area is important for Texas' shrimp industry, contributing approximately 13 percent of total shrimp landings and dollar value for Texas in 1976.

Small boats fish in the Galveston Bay system and just offshore when weather permist. Vessels from 50 to 90 feet long fish the offshore area. The Galveston Bay system is closed to commercial fishing from January to mid-April; however, bait and recreational shrimpers are allowed to operate in the bay year-round. Recreational shrimpers take approximately 6 percent of the total harvest from the inshore area [2]. Bait shrimpers take approximately one million pounds per year from the inshore area [2]. Though there is no size restriction on shrimp landed for recreation and bait, there is a 68 count (headless) maximum for commercial shrimping.

The analysis uses a partial equilibrium approach. As brown shrimp extend from the Alabama-Florida border to the western half of the Yucatan Peninsula of Mexico, analyzing S.A.

TABLE 1. ANNUAL RESULTS FROM VARIOUS SIMULATIONS CALCULATING RENT FOR THE BROWN SHRIMP FISHERY IN STATISTICAL AREA 18.

Item	Baseline[a] (A)	Inshore Area Closed All Year (B)	Inshore Area Closed Jan.-Apr.[b] (C)	Fishery Closed March-May (D)	Maximize Rent (E)
Landings (Mil. lbs.)	4.9	4.7	4.9	4.9	11.1
Rent[c] (Mil. dllrs.)	4.0	3.9	4.0	4.1	14.1
Total Revenue[d] (Mil. dllrs.)	14.0	14.0	14.0	14.0	33.6
Owner Packing Charge "	0.2	0.2	0.2	9.2	0.5
Crew Share "	4.4	4.3	4.4	4.3	10.7
Cost/Day Fished[e] "	5.2	5.1	5.2	4.9	8.2
Total Days Fished (24 hrs)	6231	5782	6231	5801	11261

[a]Reflects average monthly landings for 1963-71.

[b]The effort from the inshore area during April was reallocated to the 1-10 fathom area in May.

[c]May not add due to truncating error.

[d]Prices, 1976 Brownsville, Texas, vary by size by month.

[e]Includes $1.3 million in total annual fixed costs for shrimp fleet from baseline estimate.

18 by no means assures a general equilibrium. Unfortunately, progress in modeling the shrimp population is only complete for S.A. 18, and for brown shrimp only. Shrimp do cross S.A. 18 boundaries; however, it is assumed that the shrimp moving into and out of S.A. 18 are proportionally the same size and that the net movement is zero. If one desired a general equilibrium solution, all statistical areas would have to be considered for brown shrimp as well as the other two important shrimp species.

RESULTS

The results of five simulations are summarized in Table 1. The first is a baseline simulation (A) which reflects the average monthly landings for 1963-71, and thus establishes a base or average period for shrimp growth and landings. Physical parameters, such as fleet characteristics and nominal days fished, are also based on this time period. Institutional parameters relating to commercial, bait, and recreational shrimping are the same as those described above. Shrimp prices and vessel costs for 1976 are used to calculate baseline revenue and costs; annual baseline fixed costs amount to $1.3 million.

The second two simulations, (B) and (C), evaluate changes in the opening and closing of the season in the inshore area. Several biologists and industry members contend that delays in the opening of the season would allow greater shrimp growth and hence increased revenues. In simulation (B) the inshore area is closed all year whereas in (C) the latter half of April is closed and the days fished are reallocated to the 1-10 fathom area in May. In making comparisons between the various simulations, we assume that the annual baseline fixed costs of the fleet must be chargeable to the shrimp fishery in any situation.

The first three simulations indicate very little change in the economic indices for rent, total revenue, and the various costs. Inspection of the first three runs suggests that closing the bays for at least a month or all year to allow greater shrimp growth and net income does not provide any improvement over the baseline. Simulation (B) actually shows a decline in rent; run (C) implies a trade-off in income between those boats and vessels fishing inshore and those fishing in the 1-10 fathom area. If the effort reallocated to the 1-10 fathom area in May does not come from inshore, then the result is likely to be a Pareto inefficient solution.

The fourth run was executed with some forethought to maximizing economic efficiency. The baseline simulation indicated that total revenue is less than total variable cost in the fishery for March through May. Therefore, simulation run (D) attempted to gauge the effect of not allocating any days fished in any area for March through May.

Simulation run (D), in which the fishery operates in such a way that total revenue is greater than or equal to variable costs, provides interesting results. Although landings remains the same as the baseline and rent increases by only 2.5 percent, less effort is involved—7 percent fewer days fished. The fewer days fished could allow fishermen to engage in other (fishing) activities to increase their income, although the possible disequilibrium effect of additional resources in other markets should be analyzed.

Simulation run (E) is the maximizing simulation using the Quasi-Newton routine. Simulation run (E) showed the most dramatic change in the level of physical and economic variables. The baseline indicated that total costs exceed total revenue from January through June. Therefore, the first six months of the year for the two offshore areas and the entire year for the inshore area were arbitrarily "blocked out." In this situation, the optimizing routine allocated approximately 4890 and 6380 days fished for the last 6 months (days fished divided equally among months) to the 1-10 and the 11-50 fathom areas, respectively. Annual landings increased to 11.1 million pounds and rent more than tripled over the baseline to $14.1 million. The preliminary analysis indicates that the seasonal distribution of effort, as well as its magnitude, has an important effect on the efficiency of the fishery.

LIMITATIONS OF MODEL

The results generated by the simulation, parametric runs on days fished, and the optimizing technique must be qualified by the present structure of the basic model.

The first limitation is that in the short run the total days fished for all areas should have an upper limit. This upper limit would reflect the maximum fishing time for the total number of vessels in the fishery. For an area as small as S.A. 18, a survey of all vessels in the area would underestimate this limit because vessels from other areas can and do fish there. Perhaps a better measure for a small area is some historical average. One must also recognize that vessels are capable of fishing in the next deeper and the next shallower depth ranges.[4] Once the

[4]This was the case in the optimal solution, as the days fished allocated to the 1-10 fathom area included inshore vessels.

limit is established, a penalty function can be programmed into the optimizing routine to reduce the level of rent if the total number of days fished exceeds the limit.

Another limitation of the model is that costs proportional to effort are assigned to days fished per depth range. When more data are available on these costs for various sized vessels for each depth range, then the optimizing program can estimate the most efficient use of various sized vessels in each depth range and for the area as a whole.

One final limitation in the model is that monthly shrimp prices by size are constant over variations in landings. We would suggest building into the model monthly demand equations for each size where price is function of quantity landed (for that size).

SUMMARY AND CONCLUSIONS

We have attempted to demonstrate the applicability of a bioeconomic simulation model for management of the Gulf of Mexico shrimp fishery. At present the model needs more realistic features built into it; also it only analyzes one shrimp species and one small fishing area. However, we believe substantial progress has been made on adequately modeling and analyzing physical and economic indices.

Initial computer runs using the model resulted in several measures for the indices. A baseline forecast, which attempted to reflect monthly averages during 1963-71, indicated annual landings of 4.9 million pounds and annual rent to the fishery of $3.9 million. Several runs gauged the effect of varying institutional parameters such as delineation of fishing areas and timing of the season opening. A final run to maximize rent indicated landings of 11.1 million pounds and rent of $14.1 million.

RECOMMENDATIONS FOR FURTHER RESEARCH

We recommend that the limitation discussed be resolved in the simulation; then several questions can be properly addressed.

A complete model could analyze the rent to a fishery (brown, white, or pink shrimp) with open access (total revenue equals total cost) or assuming maximum economic efficiency (maximize rent). The simulation also can evaluate the optimal timing of seasons for several shrimp species where there are differences in growth patterns. Institutional questions such as those raised above also can be analyzed. Estimates can be made of the response by firms and/or vessels to the level of prices in terms of days fished. Then the supply relation for days fished can be estimated. Finally, with supply and demand functions in the simulation, consumer and producer surplus can be evaluated by sensitivity analysis on days fished, prices, and cost factors.

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