SYSTEMS ANALYSIS OF U.S. MANAGEMENT STRATEGIES
IN THE GULF OF MEXICO SHRIMP INDUSTRY

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1972

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ACKNOWLEDGMENTS

My debt of gratitude for assistance during my graduate career exceeds my ability to provide acknowledgment. I trust that my many unrecognized benefactors will forgive me for citing only a few of the debts that I perceive to be the greatest.

The greatest debt should be acknowledged first. Mine is due my wife, Martha, for her moral support during my graduate career and my young daughter, Kerry, for making that career worthwhile.

Leo Polopolus has served as Chairman of my Supervisory Committee, academic and professional advisor, and friend. Max R. Langham has provided good advice during my graduate career and his thorough reviews of my dissertation research materials have been invaluable. W. W. McPherson has provided a wellspring of experience from which I have freely drawn as a student and as author of this dissertation. C. C. Osterbind brought the expertise of an economist with experience in the Gulf of Mexico shrimp industry to bear in his review of the dissertation manuscript. For these contributions, as well as many left unmentioned, I wish to thank the members of my Supervisory Committee.

I wish to thank K. R. Tefertiller, Chairman of the Department of Food and Resource Economics of the University of Florida, for providing financial assistance during the course of research on this project. In addition, I wish to acknowledge departmental support of the project which allowed use of the facilities of the University of Florida Computing Center.

Mrs. Cindy Bass, with the pictorial aid of Mrs. Patti Pesmire, has accomplished the transformation of this dissertation from a longhand manuscript into its present form. For this feat she has earned my gratitude and admiration of her considerable ability.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	x
ABSTRACT	xi
CHAPTER I	
INTRODUCTION	1
CHAPTER II	
BIOECONOMIC THEORY	3
Fish Population Theory	3
A Theory of Open Access and Common Property Resource Exploitation	17
Bioeconomic Theory of a Fishery	33
CHAPTER III	
GULF OF MEXICO SHRIMP INDUSTRY: DESCRIPTION AND MODEL . . .	38
Description of the Industry	38
The Gulf Shrimp Resource	38
The Gulf Shrimp Fleet	46
Processing and Marketing the Gulf Shrimp Catch . .	56
A Model of the Gulf Shrimp Industry	58
A Model of the Gulf Shrimp Resource	59
A Model of the Gulf Shrimp Fleet	62
A Model of the Marketing and Demand Sector of the Gulf Shrimp Industry	69
CHAPTER IV	
METHODOLOGY AND DATA	73
Simulation as a Tool for Model Building and Policy Evaluation	74
Data	84
The Computer Program	95

TABLE OF CONTENTS--Continued

	Page
CHAPTER V	
RESULTS OBTAINED WITH THE SIMULATION MODEL AND POLICY IMPLICATIONS	97
Model Validation	97
Simulated Results for the Policies Considered	114
Policy Implications	122
CHAPTER VI	
RECAPITULATION OF THE PRESENT STUDY WITH SUGGESTIONS FOR IMPROVEMENTS AND FURTHER WORK	130
Recapitulation of Objectives and Evaluation of Achievements	130
Improvements Needed in the Present Model and Suggestions for Further Work	131
APPENDIX I	134
APPENDIX II	148
LIST OF REFERENCES	180
ADDITIONAL REFERENCES	183
BIOGRAPHICAL SKETCH	185

LIST OF TABLES

Table		Page
3.1.	Landings of Gulf shrimp by area and species for the years 1967, 1968, and 1969	41
3.2.	Percentage distribution of Gulf shrimp landings by area and species for the years 1967, 1968, and 1969 . . .	43
3.3.	Average landings and percentage distribution of average landings of Gulf shrimp by area and species over the years 1967, 1968, and 1969	44
3.4.	Summary of shrimp otter trawl boats, vessels, fishermen, and gear in the Gulf states, 1966	47
3.5.	Summary of shrimp otter trawl vessels of the Gulf states, by tonnage groups, 1966	51
3.6.	Marine economics data - 65 foot Gulf of Mexico shrimp vessels	53
4.1.	Age (in months of 4.33 weeks each) distribution by size and sex of brown, pink, and white shrimp in the Gulf of Mexico	86
4.2.	Coefficients to convert 24-hour days fished to fishing mortality and estimated square nautical miles fished by area	87
4.3.	Vessel size classes and sweep capacity of nets along headrope in hundreds of feet	89
4.4.	Mean 24-hour days fished per month by a vessel in each size class	90
4.5.	Factors to adjust days fished by a vessel in a size class to reflect variations in average days fished by vessels in different areas	91
4.6.	Number of vessels in each size class estimated to have home ports in each area and number of vessels in each size class assumed to be fishing in each area in December of a typical year	93
4.7.	Reduced form coefficients for quarterly shrimp model, 1956-1967	94

LIST OF TABLES--Continued

Table	Page
5.1. Adjusted coefficients to convert 24-hour days fished to fishing mortality and factors (ADPACJ's) by which initial estimates of the mean number of shrimp recruits were multiplied for final use in the model	99
5.2. Size composition of actual shrimp catches in the Gulf and South Atlantic states for the years 1964-1970 and average size composition of thirty years catch data generated by the computer model	101
5.3. Simple correlation coefficients between selected variables based on values generated by the computer model	106
5.4. Comparison of percentage distribution of effort by area in each month of the year of sample vessels with the percentage allocation generated by the computer model in the 30th year for vessels (vessel size classes 2-5)	109
5.5. Comparison of percentage distribution of effort among aggregated areas in each month of sample vessels with the allocation generated by the model	110
5.6. Annual fixed cost charges per vessel employed by the computer model and the capitalized values that these sums represent	113
5.7. Value of the fleet under different assumptions about average life of vessel and gear and using values given in [1]	115
5.8. Average annual returns from the Gulf shrimp catch, costs to the industry and fixed investment in the industry assuming a five year investment life under various settings of the policy variables	118
5.9. Rate of return to fixed investment in the Gulf shrimp fleet under various settings of the policy variables	119
5.10. Changes in average annual returns, costs, and investment occasioned by the imposition of controls	120
5.11. Average annual total production costs incurred by the Gulf of Mexico shrimp fleet per pound of shrimp produced and average annual wholesale price of shrimp produced and average annual wholesale price under alternative policies	124

LIST OF FIGURES

Figure		Page
2.1.	Curves Describing the Population Dynamics of a Single Year-Class Within a Fishery	5
3.1.	Major Shrimp Fishing Areas in the Gulf of Mexico	40
3.2.	Shrimp Vessel with Otter Trawl Nets Deployed	49
3.3.	Shrimp Processing and Marketing Channels	57
4.1.	Schematic Representation of a Framework for Validation of Simulation Models	80
4.2.	Flow Diagram of the Computer Model of the Gulf of Mexico Shrimp Industry	96
5.1.	Annual Values Generated by the Computer Model for Wholesale and Ex-vessel Prices, Total Landings, Imports, and Effort in Adjusted Days Fished	104
5.2.	Annual Values Generated by the Computer Model for Total Production Costs, Adjusted Days Fished, Value of the Fleet Assuming a Fixed Year Investment Life and Net Return	105
5.3.	Simple Correlation Coefficients Between Selected Variables Based on Values Generated by the Computer Model	108

Abstract of Dissertation Presented to the
Graduate Council of the University of Florida in Partial Fulfillment
of the Requirements for the Degree of Doctor of Philosophy

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March, 1972

Chairman: Leo Polopolus

Major Department: Food and Resource Economics

The shrimp resource is an open access resource. Except for situations attributable to territorial waters, the shrimp resource is open to exploitation by anyone possessing the physical capability to exploit it. A priori theoretical reasoning suggests that the economic return attributable to the shrimp resource as a productive input will be dissipated so long as it retains an open access status. A problem of immediate practical importance is to determine the extent of dissipation of the returns to the shrimp resource in its open access status and the relative efficiency of different institutional schemes in capturing this return.

The first objective of this study was to determine the responses of individual fishing firms in the Gulf of Mexico shrimp industry and the resultant aggregate effect for the industry to changes in the shrimp population in the Gulf of Mexico, technological conditions of harvesting

and processing, and demand conditions. A second objective was to determine whether alternative management strategies exist which will improve industry efficiency in a social sense, reducing overinvestment and/or the extent of non-optimal husbandry practices that occur as a result of the free use of an open access resource.

A theory of the basic resource was developed to describe the behavior of a particular year-class in a fishery over time in terms of growth in weight, recruitment patterns, and natural and fishing mortality rates. An economic theory of exploitation of an open access resource was developed and the divergency between behavior that is optimal for the industry as a whole and the behavior resulting from uncoordinated individual actions was derived. The basic resource and economic theories were then synthesized into a bioeconomic theory of an exploited fishery and the on-vessel entry and fish landings charges needed to manage the fishery in an efficient manner were specified as theoretical aggregates.

An abstract model of the Gulf shrimp industry was constructed based on the developed theory. The industry model took the form of three sub-models, one each for the basic resource, harvesting, and demand sectors. The interface between the basic resource and harvesting sector models was composed of the availability of shrimp by size and area and the amount of effort applied by the shrimp fleet to capturing the basic resource. The interface between the harvesting and demand sector models encompassed the catch produced by the fleet and the ex-vessel price paid for this catch by the demand sector. The model provided policy variables in the age (size) at which shrimp first become subject to capture, the barriers to vessel entry into the fleet as expressed in annual

license fees, and per pound taxes charged the fleet members on the shrimp landed as expressed in reduced ex-vessel prices.

The first objective was satisfied and the abstract model transformed into an empirical model by drawing on published research results as well as estimating model parameters from primary secondary data. The empirical model of the Gulf shrimp industry was developed as a simulation model and a computer program was developed to generate model behavior over time. Information generated by the simulation model on selected indicators of industry performance was used to satisfy the second objective by establishing tentative conclusions, subject to the limitations of the model, as to the relative effectiveness of the policies considered in attaining alternative objectives.

CHAPTER I

INTRODUCTION

There are both academic and practical reasons for this particular study. The shrimp resource is an open access resource. Except for situations attributable to territorial waters, the shrimp resource is open to exploitation by anyone possessing the physical capability to exploit it. The problems involved in creating institutions for effective public or private ownership of open access resources and in determining the relative efficiency of exploitation of the resource under various institutional forms are particularly intriguing from the academic point of view.

These problems are not without practical importance. For example, the annual value of the Gulf shrimp resource at point of first sale has been in the neighborhood of \$100 million in recent years. A priori theoretical reasoning suggests that all the return attributable to the shrimp resource as a productive input will be dissipated so long as it retains an open access status. Thus, a problem of immediate practical importance is to determine the extent of the potential return available from the resource and the relative efficiency of different institutional schemes in capturing this return.

The objectives of this study are to:

1. Determine the responses of individual fishing firms in the Gulf of Mexico shrimp industry and the resultant aggregate effect for the industry to changes in:

- a. The shrimp population in the Gulf of Mexico;
 - b. Technological conditions of harvesting and processing; and
 - c. Demand conditions.
2. Determine whether alternative management strategies exist which will improve industry efficiency in a social sense, reducing overinvestment and/or the extent of non-optimal husbandry practices that occur as a result of the free use of an open access resource.

The plan of attack for fulfilling the above objectives is briefly as follows. Chapter II presents some theoretical considerations with respect to open access resources, especially fishery resources. (The term "fishery resources," as used here, includes the crustaceans.) These considerations involve economic, as well as biological, theories of the fishery resources. Chapter III presents a description and abstract model of the Gulf shrimp resource involving both economic and biological considerations--thus, it is a bioeconomic model. Chapter IV discusses the methodology used and data limitations. Chapter V contains the results of the application of the model to the available data, simulated results from operating the system under alternative management strategies, and a discussion of policy implications. Chapter VI, the concluding chapter, is devoted to a review of the study and a critical evaluation of the analysis with suggestions for improvement and further research.

CHAPTER II

BIOECONOMIC THEORY

A fishery is a prime example of a system involving man as an economically viable predator on a natural population. To adequately describe such a system, biological theory describing the behavior of the natural population must be meshed with economic theory describing the behavior of man as the predator. The result of this synthesis may best be called "bioeconomic theory." The biological stock enters into the economic model as an input. Consequently, when dealing with bioeconomic theory, biological theory is appropriately treated first. After a discussion of fishery population theory, the economic theory of exploitation of open access resources is presented. The chapter concludes with a combination of the two theories into a bioeconomic theory of a fishery.

Fish Population Theory

This section draws heavily on some recent work in fish population analysis by J. A. Gulland [20], although generalized functional forms are used in place of Gulland's specific functional notation.

Considering a closed stock subject to exploitation, the factors (rates) determining changes in the stock over time are [see also 20, p. 3]:

1. Recruitment or the rate at which young fish reach a size and/or age at which they are considered to become part of the stock

subject to exploitation; e.g., larval shrimp and pelagic flounder are not considered part of the commercially exploited stocks of shrimp and flounder. If there is no clear-cut natural recruitment size, then the recruitment size may be arbitrarily set.

2. Growth of individuals or the time rate of gain in length and/or weight or some other measure of growth.
3. Deaths due to fishing or the catch rate; these will be roughly correlated with landings and will be ascertained by "fishing effort" which is determined outside the biological framework of the fishery.
4. Deaths due to other causes or the natural mortality rate.

Figure 2.1, corresponding roughly to Gulland's Figure 1.1 [20, p. 4], depicts the behavior over time of the length, weight, and number of individuals in a particular year-class (the progeny of the stock in a given year) and the behavior over time of the total weight of the year-class.

The ordinate of Figure 2.1 is assumed to be arranged in units appropriate to the particular curve of interest. The abscissa measures time. The reproductive process is assumed to be essentially complete at t_0 ; t_r is the time at which the individuals are recruited to the stock while t_c is the point in time at which they become subject to mortality from fishing. Beyond t_c , the solid portion of the line representing number of individuals is drawn under the assumption of zero fishing mortality, while the dashed portion represents numbers of individuals when the year-class is subjected to some constant level of fishing mortality.

Figure 2.1. Curves Describing the Population Dynamics of a Single Year-Class Within a Fishery

The total weight curve is calculated under the assumption of an unexploited stock. The total weight of the year-class in the absence of fishing is assumed to increase, at first at an increasing rate until time t_{B1} and then at a decreasing rate until some maximum weight is reached at time t_B . Then total weight declines, more and more rapidly at first but eventually at an algebraically increasing rate, until the year-class is eliminated from the stock. Individual fish are assumed to grow in length throughout their lives at a decreasing rate. Individual fish gain in weight throughout their lives at an increasing rate during the first part and at a decreasing rate during the latter part of their lives. The number of individuals in a year-class decreases over time, slowly approaching and finally reaching zero, implying that the natural mortality rate is positive and decreases over time; i.e., the rate of survival is negative but increasing algebraically at any point in time. The individual weight and number factors combine to produce the aggregate weight behavior described above.

The recruitment and fishing mortality factors do not lend themselves to straightforward description so well as the other factors. If the population has a well-defined and short spawning season and homogeneous development of young so that all members of each year-class are essentially the same size, then the recruitment function will take the form of a series of points, zero at all times other than the instant of time in which year-classes enter the exploitable stock, at which time the function takes on the value of the size of the year-class in question. However, if, as is more likely, the spawning period occupies a more or less significant portion of the year and subsequent development is not homogeneous, then recruitment will not occur at an instant of time. Rather, it will be spread over an interval of time during which

the proportion of the year-class being recruited into the stock increases at first at an increasing and later at a decreasing rate. Given that the juveniles are in the same area as is the exploited stock, the time pattern of recruitment is of interest with respect to determining optimal time patterns of fishing and gear selectivities. An alternative situation is one in which juveniles are segregated from the exploited stock by location and recruitment occurs by migration. In this situation, the proportions of the year-class of different length (size) being recruited are of interest. Until a mean recruitment length is reached, the proportion of the year-class entering the exploited stock increases at an increasing rate while it increases at a decreasing rate beyond this mean length. To place the appropriate emphasis on the recruitment rate and to relate it to an aspect of fishing effort--gear selection--the following quote from Gulland is helpful:

Recruitment is, by its nature, much less easy to express in quantitative terms than mesh selection. As the main interest is in the combined effect of recruitment and selection--i.e., the pattern of entry into the catch--the recruitment pattern is very important when it is above, or overlaps, the range of gear selection, but not when it is complete before gear selection starts. If, therefore, all fish have been recruited at a size below the selection range of any likely mesh size, then the precise pattern of recruitment may be ignored, and it can be taken arbitrarily as occurring at some convenient length or age below the selection range ... [20, p. 86].

The importance of the recruitment rate seems to lie in its relationship to gear selectivity. The interaction of these two factors produce the commercially important result: the rate of entry of juveniles into the catch.

Gear appears to fall into three general groups: completely non-selective gear; e.g., a fine-mesh purse seine; gear that is non-selective above some size of fish; e.g., certain trawls; and gear that is selective

over a certain range of fish size, allowing those smaller and larger to escape; e.g., gill-nets. There is little to say about the completely non-selective gear except to point out that if legal size restrictions on landings are placed on a fishery (thus arbitrarily defining the size at which juveniles are recruited into the exploited stock) and juveniles are subjected to the non-selective gear, then a certain portion of the catch will be discarded at sea. If part or all of this discarded catch dies, the various year-classes will be reduced by the extra mortality not reflected in landings. Thus, the stock will be reduced beyond what would be expected from measured fishing mortality (landings). The implication is that in order to properly assess the population, measured fishing mortality (landings) must be adjusted to allow for the mortality experienced by the juveniles.

Gear that is selective to the extent that escapement of individuals below some size is allowed is of particular interest in this study. Shrimp trawls allow small individuals to pass through the netting while larger individuals are retained. The selectivity is not perfect, however, and over some size range, the proportion of individuals retained increases with size and varies from zero to one. It seems reasonable to assume that the proportion of individuals retained (recruited into the catch) increases at first at an increasing and then at a decreasing rate over the relevant size range, producing a sigmoid curve in a plot of fraction retained against size. If a size limitation is placed on landings at a size falling within this selection range and if all or part of the resultant discarded catch dies, the yield curves estimated from recorded landings data will underestimate the potential yield by not taking into account the fishing mortality experienced by the juveniles. In this situation restrictions on gear selectivity, if

feasible, restrictions on time of fishing, if the recruitment pattern is time-oriented, and/or restrictions on location of fishing, if recruitment is by migration, may present superior alternatives from the standpoint of maximizing yield for a given amount of effort in that simultaneously the year-classes being recruited are strengthened and a larger proportion of the catch handled is actually landed.

Gear that is selective over a certain size range is probably the most effective as far as selection is concerned. Gill-net selectivity typifies this type of gear, having a selectivity curve (plot of proportion retained on size) that is normal in shape. Size limitations are, apparently, seldom used in conjunction with restrictions on mesh size as gill-net selectivity curves appear to be sufficiently sharp so as to cause size of fish retained and mesh size to be closely related. It is apparently easier to regulate mesh size than to enforce minimum size limits on fish in the catch, thus the former course of action is taken. This action usually serves to eliminate the problems involved in estimating "true" selectivity or yield curves when legally defined recruitment sizes and gear selectivity ranges overlap. Gear that is selective only below some certain size (so that proportion of fish retained varies from zero to one over the selection range) is the gear considered below.

Deaths due to fishing are determined in large part by the amount of fishing effort expended and are thus determined by forces exogenous to the biological system. However, a constant level of fishing effort per unit area and per unit time produces mortality behavior similar to natural mortality. A constant fishing mortality coefficient (defined as an increasing linear function of a measure of fishing effort such as

number of trawl tows per unit area per unit time) implies that the number of fish surviving over time from a given recruited year-class decreases but at an algebraically increasing rate.

The above discussion of factors affecting a particular year-class of a fish stock, and the stock itself by extension to all year-classes making up the stock, is conveniently summarized by presenting the theory in generalized notational form. The expressions that follow represent a modification and extension of Culland's derivation of a simple yield curve for a single year-class [20, section 9]. The variables of interest are:

N_t = number of fish surviving at age $(t - t_0)$ during a unit time interval t .

N_t^* = number of fish considered to be recruited during t , either by migrating to a different area or by reaching a particular size.

$N_t^\dagger$ = number of fish retained by gear during t .

C_t = number of fish caught during t .

Y_t = the weight of the catch, C_t , during t .

L_t = average length at age $(t - t_0)$.

W_t = average weight at age $(t - t_0)$.

B_t = biomass (total weight of year-class) at age $(t - t_0)$.

M = instantaneous natural mortality coefficient.

F = instantaneous fishing mortality coefficient defined to be a linear function of fishing effort per unit area per unit time.

The time index, t , ranges from time of completion of reproductive process, t_0 , to infinite time, t_∞ and thus, $(t - t_0)$ is the age of an average member of the year-class. Two ages of interest are $(t_r - t_0)$,

the mean recruitment age of the year-class at which all individuals may be assumed recruited, and $(t_c - t_o)$, the mean age at which the year-class becomes subject to fishing mortality. These ages may be the same in time-varying recruitment or, especially in location-varying recruitment, they may be different. In any event, they are defined to represent the ages in the intervals during which recruitment and selectivity occur at which one half of the year-class is considered recruited and/or is retained by gear when contacted. It is oftentimes convenient to assume that the full year-class is recruited or becomes subject to fishing mortality at the relevant mean age.

The theoretical relationships with directions of change are:

1. Number of fish and total mortality rate with direction of change:

$$(2.1) \quad N_t = N(M, F, t - t_o)$$

$$(2.2) \quad dN_t/dt = N'(N_t) < 0$$

$$(2.3) \quad d^2N_t/dt^2 = N''(N_t) > 0$$

(2.2) and (2.3) also hold when $F = 0$ or $M = 0$.

2. Length

$$(2.4) \quad L_t = L(t)$$

$$(2.5) \quad dL_t/dt > 0$$

$$(2.6) \quad d^2L_t/dt^2 < 0$$

3. Weight

$$(2.7) \quad W_t = W(t)$$

$$(2.8) \quad dW_t/dt > 0$$

$$(2.9) \quad d^2W_t/dt^2 > 0 \quad , \quad t < t_r$$

$$(2.9a) \quad d^2W_t/dt^2 < 0 \quad , \quad t > t_r$$

where t_w is such that $d^2W_t/dt^2|_{t=t_r} = 0$.

4. Biomass

$$(2.10) \quad B_t = N_t W_t$$

$$(2.11) \quad dB_t/dt = W_t \, dN_t/dt + N_t \, dW_t/dt$$

$$(2.11a) \quad dB_t/dt > 0 \quad , \quad t < t_B$$

$$(2.11b) \quad dB_t/dt < 0 \quad , \quad t > t_B$$

$$(2.11c) \quad dB_t/dt = 0 \quad , \quad t = t_B$$

$$(2.12) \quad d^2B_t/dt^2 = W_t \, d^2N_t/dt^2 + 2 \frac{dW_t}{dt} \frac{dN_t}{dt} + N_t \, d^2W_t/dt^2$$

$$(2.12a) \quad d^2B_t/dt^2 > 0 \quad , \quad t < t_{B1} \quad , \quad t > t_{B2}$$

$$(2.12b) \quad d^2B_t/dt^2 < 0 \quad , \quad t_{B1} < t < t_{B2}$$

$$(2.12c) \quad d^2B_t/dt^2 = 0 \quad , \quad t = t_{B1} \quad , \quad t = t_{B2}$$

Conditions (2.11a), (2.11b), and (2.11c) describe the relative offsetting effects of decreases in biomass due to reduction in numbers of individuals versus increases in biomass due to increase in individual weight. Equation (2.12) expresses the variation in rate of change in biomass in terms of rates of change and direction of rates of change of numbers of individuals and individual weight. Conditions (2.12a), (2.12b), and (2.12c) state the direction of rate of change over different periods of time and are consistent with (2.2), (2.3), (2.8), (2.9), and (2.9a).

5. Recruitment with proportion of year-class recruited ($R_t = N_t^*/N_t$) expressed as a function of age, (2.13), and length, (2.16).

$$(2.13) \quad R_t = N^*(M, F, t - t_0) / N(M, F, t - t_0)$$

$$t_1^* < t < t_2^*$$

$$(2.13a) \quad R_t = 0 \quad , \quad t \leq t_1^*$$

$$(2.13b) \quad R_t = 1 \quad , \quad t \geq t_3^*$$

$$(2.14) \quad dR_t/dt > 0 \quad , \quad t_1^* < t < t_3^*$$

$$(2.15) \quad d^2R_t/dt^2 > 0 \quad , \quad t_1^* < t < t_2^*$$

$$(2.15a) \quad d^2R_t/dt^2 < 0 \quad , \quad t_2^* < t < t_3^*$$

$$(2.15b) \quad d^2R_t/dt^2 = 0 \quad , \quad t = t_2^*$$

In equations (2.16) - (2.18), L_t must be considered a length measure, not an average, and $N^*(L_t)$ is the number of fish of length less than L_t that are considered to be recruited.

$$(2.16) \quad R_t = N^*(L_t) / N(M, F, t - t_0) \quad , \quad L_{R1} < L_t < L_{R3}$$

$$(2.16a) \quad R_t = 0 \quad , \quad L_t \leq L_{R1}$$

$$(2.16b) \quad R_t = 1 \quad , \quad L_t \geq L_{R3}$$

$$(2.17) \quad dR_t/dL_t > 0 \quad , \quad L_{R1} < L_t < L_{R3}$$

$$(2.18) \quad d^2R_t/dL_t^2 > 0 \quad , \quad L_{R1} < L_t < L_{R2}$$

$$(2.18a) \quad d^2R_t/dL_t^2 < 0 \quad , \quad L_{R2} < L_t < L_{R3}$$

$$(2.18b) \quad d^2R_t/dL_t^2 = 0 \quad , \quad L_t = L_{R2}$$

6. Selectivity (trawl-type) with proportion of fish retained by gear ($S_t = N_t^+ / N_t$) expressed as a function of length (a measure of size proportional to the positive square root of surface area and to the cube root of volume or weight). In equations

(2.19) - (2.21), as in (2.16) - (2.18), L_t should be interpreted as a measure of length, not an average related to the population.

$$(2.19) \quad S_t = N_t^+(L_t)/N(M, F, t - t_o) \quad , \quad L_{S1} < L_t < L_{S3}$$

$$(2.19a) \quad S_t = 0 \quad , \quad L_t \leq L_{S1}$$

$$(2.19b) \quad S_t = 1 \quad , \quad L_t \geq L_{S3}$$

$$(2.20) \quad dS_t/dL_t > 0 \quad , \quad L_{S1} < L_t < L_{S3}$$

$$(2.21) \quad d^2S_t/dL_t^2 > 0 \quad , \quad L_{S1} < L_t < L_{S2}$$

$$(2.21a) \quad d^2S_t/dL_t^2 < 0 \quad , \quad L_{S2} < L_t < L_{S3}$$

$$(2.21b) \quad d^2S_t/dL_t^2 = 0 \quad , \quad L_t = L_{S2}$$

7. Catch in numbers of fish

$$(2.22) \quad C_t = C(F, N_t)$$

$$(2.23) \quad \partial C_t / \partial F > 0$$

$$(2.24) \quad \partial^2 C_t / \partial F^2 > 0 \quad , \quad 0 < F < F_C$$

$$(2.24a) \quad \partial^2 C_t / \partial F^2 < 0 \quad , \quad F_C < F < \infty$$

$$(2.25) \quad \partial C_t / \partial N_t > 0$$

$$(2.26) \quad \partial^2 C_t / \partial N_t^2 > 0 \quad , \quad 0 < N_t < N_C$$

$$(2.26a) \quad \partial^2 C_t / \partial N_t^2 < 0 \quad , \quad N_C < N_t < \infty$$

$$(2.27) \quad \partial^2 C_t / \partial F \partial N_t > 0$$

$$(2.28) \quad dC_t = \frac{\partial C_t}{\partial F} dF + \frac{\partial C_t}{\partial N_t} dN_t$$

$$(2.29) \quad d^2C_t = \frac{\partial^2 C_t}{\partial F^2} dF^2 + 2 \frac{\partial^2 C_t}{\partial F \partial N_t} dF dN_t + \frac{\partial^2 C_t}{\partial N_t^2} dN_t^2$$

Conditions (2.23), (2.24), and (2.24a) state that the marginal return to effort, assuming numbers of fish constant, is everywhere positive but declines after some level of effort is reached. Conditions (2.25), (2.26), and (2.26a) describe a different type of marginal behavior, namely that as numbers increase, assuming effort constant, catch increases but at a decreasing rate beyond some population level. Condition (2.27) states that as numbers increase, the return to marginal units of effort increases or, conversely, as effort increases, the marginal increment due to increasing numbers increases. Equation (2.28), expressing the total change in catch for changes in effort and numbers, is especially interesting when divided through by the incremental change in fishing mortality, dF , a proxy for effort. Recalling that number of fish is a declining function of fishing mortality, it becomes apparent that the change in catch due to a change in effort is not readily predictable as to sign or direction of change--given by equation (2.29)--when allowance is made for the negative effect of increasing effort on fish numbers.

8. Weight of catch

$$(2.30) \quad Y_t = Y(F, N_t, W_t)$$

or

$$(2.30a) \quad Y_t = Y(F, B_t)$$

$$(2.31) \quad \partial Y_t / \partial F > 0$$

$$(2.32) \quad \partial^2 Y_t / \partial F^2 > 0 \quad , \quad 0 < F < F_Y$$

$$(2.32a) \quad \partial^2 Y_t / \partial F^2 < 0 \quad , \quad F_Y < F < \infty$$

$$(2.33) \quad \partial Y_t / \partial N_t > 0$$

$$(2.34) \quad \partial^2 Y_t / \partial N_t^2 > 0 \quad , \quad 0 < N_t < N_Y$$

$$(2.34a) \quad \partial^2 Y_t / \partial N_t^2 < 0 \quad , \quad N_Y < N_t < \infty$$

$$(2.35) \quad \partial Y_t / \partial W_t > 0$$

$$(2.36) \quad \partial^2 Y_t / \partial W_t^2 > 0 \quad , \quad 0 < W_t < W_Y$$

$$(2.36a) \quad \partial^2 Y_t / \partial W_t^2 < 0 \quad , \quad W_Y < W_t < \infty$$

$$(2.37) \quad \partial^2 Y_t / \partial F \partial N_t > 0$$

$$(2.38) \quad \partial^2 Y_t / \partial F \partial W_t > 0$$

$$(2.39) \quad \partial^2 Y_t / \partial N_t \partial W_t > 0$$

$$(2.40) \quad dY_t = \frac{\partial Y_t}{\partial F} dF + \frac{\partial Y_t}{\partial N_t} dN_t + \frac{\partial Y_t}{\partial W_t} dW_t$$

$$(2.41) \quad d^2 Y_t = \frac{\partial^2 Y_t}{\partial F^2} dF^2 + \frac{\partial^2 Y_t}{\partial N_t^2} dN_t^2 + \frac{\partial^2 Y_t}{\partial W_t^2} dW_t^2 + 2 \frac{\partial^2 Y_t}{\partial F \partial N_t} dF dN_t \\ + 2 \frac{\partial^2 Y_t}{\partial F \partial W_t} dF dW_t + 2 \frac{\partial^2 Y_t}{\partial N_t \partial W_t} dN_t dW_t$$

Equations and conditions (2.30) - (2.39) describe the weight of the catch and the partial effects of changes in effort, numbers of fish, and average weight of fish. Equations (2.40) and (2.41) describe the total effect on weight of catch of simultaneous changes in effort, numbers, and individual weight and are most interesting when divided through by the incremental change in effort. As is the case in (2.28), the change in weight of catch due to a change in effort is not predictable a priori when the decreasing effect on numbers of increases in

effort is taken into account. A consideration of (2.41) indicates that the direction of rate of change in weight of catch due to changes in fishing mortality is as unpredictable as the rate of change itself.

Equations and conditions (2.22) - (2.41), especially those dealing with changes in fishing mortality, represent that part of fish population theory that may provide a link with an economic theory of common property resource exploitation.

A Theory of Open Access and Common Property Resource Exploitation

In the opening chapter, a distinction between open access resources and common property was implied. Before erecting a theory of exploitation, more explicit definitions of the resources are needed. Open access resources are those that are open to exploitation by any who possess, or may ever possess, the physical ability to exploit the resource. In terms of ownership, the resource is not owned by any group comprising fewer people than the world population. The effectiveness of world ownership as an institution to implement management goals is sufficiently limited to permit acceptance of "open access" as synonymous with "no ownership" when applied to resources.

The term "common property," when applied to resources, implies that ownership exists by use of the word "property" but that ownership is exercised by a group of people in "common," for example, the citizens of a state or country. Institutions for attaining optimal exploitation rates may or may not exist but the implication is that the "common" group is not so large as to make their creation impossible. The key difference between "common" and "private" property resources lies in the behavior of the individual exploiter. In the common property situation, each individual, playing an unrestrained profit-seeking role,

will follow a course of action that is inconsistent with an optimal use rate for the resource as a whole and that does not maximize profit for the group exercising the common property rights. In the case of private property, the expectation is that the individual, in pursuing a profit maximizing course, will act in a manner consistent with optimal use of the resource as a whole assuming no technical externalities. Examples illustrating these essential differences exist in the form of land and oil pools in common and private property situations and fish in open access (high seas) and regulated common property (territorial waters) situations. When arraying resources on a scale denoting them to be open access, common property, or private property, a continuum forms with no sharp demarcation between the various classes. A different and helpful classification of resources by their reaction to time-varying use rates is presented by S. V. Ciriacy-Wantrup [12, pp. 42, 43].

Some relevant literature on fisheries economics includes the seminal articles by H. Scott Gordon [19] and Anthony Scott [28], as well as the work of Christy and Scott [11], Crutchfield and Pontecorvo [14], Crutchfield and Zellner [15], and Daniel Bromley [9]. The paper by Bromley presents a provocative literature review. A comprehensive review of the work just cited would be redundant in view of Bromley's [9] work. However, acknowledgment must be made of the significant contributions to fishery theory of these authors. The theory developed here undoubtedly owes much to these authors but the debt is in the form of general knowledge rather than specific contributions.

The resource to be exploited is assumed to be a flow resource in that it provides an exploitable flow of goods or services--fish, wildlife, scenic beauty, water, or capacity to absorb man-made effluent--from a given area over time. The resource may or may not be affected

by exploitation rates, but some exploitation rate must, at some time, be positive in order for the resource to be of interest and maintain its resource character. In addition, the marginal utility derived from exploiting the resource must be positive in the absence of externalities. That is, the resource must not be a "free good." This qualification leaves the definition broader than may be immediately apparent. For example, stars of the seventh order of magnitude provide a flow of star-shine that is exploited at a positive rate by astronomers who delight in viewing seventh order stars. The qualification does state that for something to attain resource character, it must somehow affect humans. In this sense, orbital bodies under the direct gravitational influence of seventh order stars do not qualify as resources at the present time.

The resources of interest are those that require human effort to maintain a positive exploitation rate and thus have positive costs associated with their exploitation. The effort required for positive resource exploitation will vary over resources and is considered to be composed of inputs combined in constant proportions (linear expansion path) and treated as a single input. Physical returns to effort are assumed to increase but at a decreasing rate beyond some level of input. The condition of the resource, including qualitative factors, is assumed to be expressed by a single quantity index at any point in time. This assumption is, admittedly, heroic, but does much to facilitate the following exposition and, for a fishery, may not be so unreasonable as it first sounds. Demand for the product and factor supply curves are assumed to be less than perfectly elastic to the industry but perfectly elastic as viewed by the individual firm.

The variables involved in open access or common property resource exploitation are:

Y_{it} = output of producer i during a unit interval of time, t ; e.g.,
a week, month, year, decade, etc.

Y_t = total output for the industry during unit time interval t .

X_{it} = input or effort of producer i during t .

X_t = total industry input during t .

P_{yt} = price of the output during t , assumed constant over producers.

P_{xt} = input price, identical for all producers, during t .

R_t = a quantity index reflecting the condition of the resource
during t .

n_t = number of producers involved in the resource industry during
 t .

TR_{it} = total revenue for producer i during t .

TR_t = industry total revenue during t .

TC_{it} = total cost to producer i during unit time interval t including
a "normal" return to "fixed" resources.

TC_t = industry total cost during t .

$NR_{it} = TR_{it} - TC_{it}$, net revenue of producer i during t or "pure
profits."

$NR_t = TR_t - TC_t$, industry net revenue (pure profits) during t .

In generalized functional notation, the relationships of interest,
their rates of change, and the directions of rates of change are as
follows:

9. Individual output

$$(2.42) \quad Y_{it} = Y_i(X_{it}, R_t)$$

$$(2.43) \quad \partial Y_{it} / \partial X_{it} > 0$$

$$(2.44) \quad \partial^2 Y_{it} / \partial X_{it}^2 > 0 \quad , \quad X_{it} < X_i^1$$

$$(2.44a) \quad \partial^2_{Y_{it}} / \partial X_{it}^2 < 0 \quad , \quad X_{it} > X_i^1$$

$$(2.45) \quad \partial Y_{it} / \partial R_t > 0$$

$$(2.46) \quad \partial^2_{Y_{it}} / \partial R_t^2 > 0 \quad , \quad R < R^1$$

$$(2.46a) \quad \partial^2_{Y_{it}} / \partial R_t^2 < 0 \quad , \quad R > R^1$$

$$(2.47) \quad \partial^2_{Y_{it}} / \partial X_{it} \partial R_t > 0$$

$$(2.48) \quad dY_{it} = \frac{\partial Y_{it}}{\partial X_{it}} dX_{it} + \frac{\partial Y_{it}}{\partial R_t} dR_t$$

$$(2.49) \quad d^2_{Y_{it}} = \frac{\partial^2_{Y_{it}}}{\partial X_{it}^2} dX_{it}^2 + 2 \frac{\partial^2_{Y_{it}}}{\partial X_{it} \partial R_t} dX_{it} dR_t + \frac{\partial^2_{Y_{it}}}{\partial R_t^2} dR_t^2$$

10. Individual effort and numbers of individual producers

$$(2.50) \quad X_{it} = X_i(NR_{it-r}) \quad , \quad r = 1, \dots, k \quad , \quad 0 \leq X_i(NR_{it-r}) < X_i^1$$

$$(2.50a) \quad X_{it} = X_i^1, X_i(NR_{it-r}) \geq X_i^1$$

$$(2.51) \quad \partial X_{it} / \partial NR_{it-r} > 0 \quad , \quad r = 1, \dots, k \quad , \quad 0 \leq X_i(NR_{it-r}) < X_i^1$$

$$(2.52) \quad \partial^2_{X_{it}} / \partial NR_{it-r} \partial NR_{it-s} > 0 \quad , \quad 1 \leq r \leq s \quad , \quad s = 1, \dots, k \quad , \\ X_i(NR_{it-r}) < X_i^1$$

$$(2.53) \quad n_t = n(NR_{t-r}) \quad , \quad r = 1, \dots, k \quad , \quad 0 \leq n(NR_{t-r}) < n^1$$

$$(2.53a) \quad n_t = n^1, n(NR_{t-r}) \geq n^1$$

$$(2.54) \quad \partial n_t / \partial NR_{t-r} > 0 \quad , \quad r = 1, \dots, k$$

$$(2.55) \quad \partial^2_{n_t} / \partial NR_{t-r} \partial NR_{t-s} > 0 \quad , \quad 1 \leq r \leq s \quad , \quad s = 1, \dots, k$$

11. Total effort

$$(2.56) \quad X_t = \sum_{i=1}^{n_t} X_{it}$$

$$(2.57) \quad \partial X_t / \partial X_{it} = 1$$

$$(2.58) \quad \partial X_t / \partial n_t \equiv \sum_{i=1}^{n_t} X_{it} / n_t \quad (\text{A definition})$$

12. Resource condition

$$(2.59) \quad R_t = R(X_t)$$

$$(2.60) \quad dR_t / dX_t < 0$$

$$(2.61) \quad d^2 R_t / dX_t^2 > 0$$

13. Total output

$$(2.62) \quad Y_t = \sum_{i=1}^{n_t} Y_{it}$$

$$(2.63) \quad \partial Y_t / \partial Y_{it} = 1$$

$$(2.64) \quad \partial Y_t / \partial n_t \equiv \sum_{i=1}^{n_t} Y_{it} / n_t + \sum_{i=1}^{n_t} \partial Y_{it} / \partial n_t$$

where, from (2.49), (2.66), and (2.64),

$$\partial Y_{it} / \partial n_t = (\partial Y_{it} / \partial R_t) (\partial R_t / \partial X_t) (\partial X_t / \partial n_t) < 0$$

$$(2.65) \quad dY_t = \frac{\partial Y_t}{\partial n_t} dn_t + \sum_{i=1}^{n_t} \frac{\partial Y_t}{\partial Y_{it}} dY_{it}$$

Equation (2.42) describes individual output (harvest in pounds, numbers, board feet, acre feet, etc., per time unit) as a function of individual effort expended and the condition of the resource. Equations (2.43), (2.44), and (2.44a) describe the return to an increment of effort, assuming resource condition constant, as increasing at first at an increasing rate but eventually (beyond input level X_i^1) increasing at a declining rate. In more technical economic terms, equation (2.42) is a production function which exhibits diminishing marginal returns to effort beyond input level X_i^1 . Further, given constant input (effort) and product prices, the profit-maximizing producer will operate at or

beyond input level X_i^1 if at all. Equations (2.45), (2.46), and (2.46a) indicate that increases in the resource condition (effort constant) increase individual output along a sigmoid path, at an increasing rate at first but eventually at a decreasing rate. Viewed another way, equations (2.45) - (2.46a) indicate that the efficiency of a given amount of effort increases as it is applied to increasingly dense resource stocks but at a decreasing rate throughout. In fisheries, effort may be divided into search time, actual harvest time, and on-board processing time. For a given amount of effort, increases in density of fish will at first add to catch at an increasing rate as both search time and actual harvest time are large in relation to on-board processing time and are decreasing while processing time increases. As processing time, which is independent of stock density, comes to dominate in the total effort, increases in stock density will increase catch at a decreasing rate. Equation (2.47) says that effort and resource condition are complementary in their effect on output, increases in resource condition increasing the rate of increase in product due to increases in effort and vice versa.

Equation (2.48) expresses the unconstrained ("total") change in individual output in terms of partial rates of change and unconstrained increments of effort and resource condition. The direction of change in output is predictable from (2.48) alone only when effort and resource condition move in the same direction in which case output will move in the same direction as effort and resource condition. The direction of change in the rate at which output is changing, as given by (2.49), depends upon the relative directions of change in effort and resource conditions as well as the level of effort and resource conditions. For similar movements in effort and resource condition below X_i^1 and R^1 ,

output will increase at an increasing rate. The direction of rate of change above input levels X_i^1 and R^1 for movements of effort and resource condition in the same direction will depend on the relative magnitudes of (2.44a) and (2.46a) versus (2.47) and the relative size of the changes in inputs. Equation (2.48) is particularly interesting when divided through by the increment in effort, dX_{it} , and written as (2.66) in which form it expresses the unconstrained change in output resulting from a change in effort (numbers of firms constant).

$$(2.66) \quad dY_{it}/dX_{it} = \partial Y_{it}/\partial X_{it} + \frac{\partial Y_{it}}{\partial R_t} \frac{dR_t}{dX_{it}}$$

To the individual member of an industry with many producers, the term dR_t/dX_{it} is zero. That is, he neglects changes in the resource condition that result from changes in the effort he expends. This may be rational for the individual since the cost of considering this small change in his decision process probably outweighs the benefits to be obtained from considering it. However, for the industry as a whole, the effect of changes in effort on the resource condition is not negligible. This discrepancy leads to the difference between the sum of changes in output expected by individuals from individual changes in effort and the change in output for the industry as a whole resulting from the sum of individual changes in effort. The sum of changes expected by individuals is:

$$(2.67) \quad \sum_{i=1}^{n_t} dY_{it}/dX_{it} = \sum_{i=1}^{n_t} \partial Y_{it}/\partial X_{it}$$

while the actual change for the industry is:

$$(2.68) \quad \sum_{i=1}^{n_t} dY_{it}/dX_{it} = \sum_{i=1}^{n_t} \partial Y_{it}/\partial X_{it} + \sum_{i=1}^{n_t} \frac{\partial Y_{it}}{\partial R_t} \frac{dR_t}{dX_{it}}$$

Since dR_t/dX_{it} is negative (it is the product of (2.60) and the total derivative of (2.56) assuming n_t constant and $dX_{jt}/dX_{it} = 0$ for $i \neq j$) the actual change in total output from an increase in effort is smaller by the positive amount $-\sum_{i=1}^{n_t} \frac{\partial Y_{it}}{\partial R_t} \frac{dR_t}{dX_{it}}$ than is the sum of changes expected by individuals. This discrepancy, derived assuming the number of producers in the industry constant, is part of the reason that individual producers, following profit-maximizing courses of action, will not behave in a manner consistent with maximizing industry profits.

Equations (2.50) and (2.50a) describe the effort of individual firms as a function of past net revenues up to a ceiling (X_i^1) beyond which individual firms find themselves incapable of increasing effort. Condition (2.51) says that higher past net revenues increase current effort, and condition (2.52) (for $r = s$) describes the rate of increase as constant or increasing for the range over which the function is defined on past net revenues. The sign of (2.52) (for $r = s$) is interpreted to mean that, when hypothetical sets of past net revenues are compared, the increment in effort called forth by an increment in net revenue at a higher level of net revenue is at least as large as the increment of effort called forth at lower levels of net revenue. Such behavior is taken to be typical up to the ceiling (X_i^1) at which the individual cannot effectively increase effort. The plausibility of (2.52) (for $r = s$) rests on the assumption that individuals are more sensitive to changes in net revenue at high levels of net revenue (their adjustments are larger) than they are at low levels of net revenue. Equation (2.52) (for $r < s$) states that higher levels of net revenue in a given period reinforce the effects of net revenues from subsequent periods. Equations (2.53) - (2.55) describe numbers of

producers in any time interval as a function, similar to individual effort, of past net revenues of the industry. That is, entrants are seen to increase at a constant or increasing rate as a function of past levels of industry net revenue with levels in previous periods having a reinforcing effect on those in subsequent periods.

Equation (2.56) states that total effort during any time interval is the sum of individual effort over the number of producers in the industry during that interval. Equation (2.57) indicates that aggregate effort is measured in the same units as individual effort. Equation (2.58) defines the effort level of new entrants as being at the average for the industry. Were equations (2.53) - (2.55) to be developed for different size classes of producers, then (2.58) would be modified to reflect the effect of entry into each size class. Definition (2.58) is a sort of "minimum knowledge" relation and should be replaced if more information is known about entrants.

Equation (2.59) describes the condition of the resource as an instantaneously adjusted function of effort. Conditions (2.60) and (2.61) state that the resource condition declines as a function of effort but at an algebraically increasing rate. While the particular form of (2.59) will depend upon the theory of the behavior of the resource under study, there are probably few exceptions to the limits imposed by (2.60) and (2.61). A resource may be depleted as effort increases but it will be depleted less and less efficiently so that very large amounts of effort are required to finally destroy the resource. Equation (2.10) in the section on fish population theory, after modification to represent the biomass of all year-classes comprising the fish stock, may be substituted for (2.59) in a bioeconomic model of a fishery.

Equation (2.62) expresses total output as the sum of individual outputs over producers in the industry during time interval t . Equation (2.63) states that individuals make contributions to total output in the same magnitude in which individual output is measured. Definition (2.64) gives the change in total output resulting from new entry (or exit) as the sum of changes in individual output due to the additional depletion of the resource by the entrant, plus the product of the new entrant which is defined to be the average product of all producers in the industry. Definition (2.64) could be improved by reflecting productivity of entrants by size class or incorporating more complete information on the productivity of entrants when such information is available.

Equation (2.65) adds to the sum over producers of the behavior indicated by equation (2.48), the change in total output resulting from a change in the number of producers. That is, (2.65) takes into account the effect on total output of changes in established producer output (the sum over producers of the product of (2.48) and (2.63) as well as the effect on total output of new entrants (2.64)). Rewriting (2.65) as (2.69) using the rules of differential calculus and equation (2.66) helps to delineate these effects and to point out the discrepancy in situations arising from individual behavior as opposed to industry-oriented behavior.

$$\begin{aligned}
 (2.69) \quad dY_t = & \sum_{i=1}^n \left(\frac{\partial Y_{it}}{\partial R_t} \right) \left(\frac{\partial R_t}{\partial X_t} \right) \left(\frac{\partial X_t}{\partial n_t} \right) dn_t \\
 & + \sum_{i=1}^n \left(Y_{it} / n_t \right) dn_t \\
 & + \sum_{i=1}^n \left(\frac{\partial Y_t}{\partial Y_{it}} \right) \left(\frac{\partial Y_{it}}{\partial X_{it}} \right) dX_{it} \\
 & + \sum_{i=1}^n \left(\frac{\partial Y_t}{\partial Y_{it}} \right) \left(\frac{\partial Y_{it}}{\partial R_t} \right) \left(dR_t / dX_{it} \right) dX_{it}
 \end{aligned}$$

The first and fourth terms on the right-hand side of (2.69) are negative while the second and third terms are positive.

Assume, for the moment, constant product and input prices and past net revenues high enough to encourage increases in effort by individual firms as well as entry by new firms. Individual producers believe that they affect only the elements of term three from the right-hand side of (2.69) and will, individually, increase effort so long as that direct increment in value of output is greater than the increment in value of input required for its production, halting further increases when the two are equal. The ex ante equilibrium position for all producers together, when each pursues his selfish interests in an unregulated manner, is given by:

$$(2.70) \quad P_{yt} \sum_{i=1}^n (\partial Y_{it} / \partial X_{it}) dX_{it} = P_{xt} \sum_{i=1}^n dX_{it}$$

$$\text{or, if } \sum_{i=1}^n dX_{it} = 1$$

$$(2.70a) \quad P_{yt} \sum_{i=1}^n (\partial Y_{it} / \partial X_{it}) dX_{it} = P_{xt}$$

$$\text{or, if } dX_{it} = 1$$

$$(2.70b) \quad \sum_{i=1}^n P_{yt} (\partial Y_{it} / \partial X_{it}) = n_t P_{xt}$$

or

$$(2.70c) \quad \sum_{i=1}^n P_{yt} (\partial Y_{it} / \partial X_{it}) / n_t = P_{xt}$$

Equations (2.70) - (2.70c) state an ex ante condition that individuals attempt to attain, namely to equate, on an individual basis, the value of the marginal product of the input with its price. This translates, on an industry-wide basis, to equating the value of the marginal product of a one-unit increase in industry-wide effort to the price of the input (2.70a) or to equating the value of marginal product averaged over members of the industry to the price of the input (2.70c). These

conditions cannot obtain ex post and the left-hand side of (2.70) will (assuming numbers of firms constant) be reduced by the product of P_{yt} and the fourth term on the right-hand side of (2.69) so that the average for the industry of the actual value of marginal product of effort is less than the price of that effort as indicated in (2.71).

$$(2.71) \quad P_{yt} \sum_{i=1}^n [(\partial Y_{it}/\partial X_{it}) + (\partial Y_{it}/\partial R_t)(dR_t/dX_{it})] dX_{it}/n_t < P_{xt}$$

This is not the final situation for the industry as a whole. Past net revenues were assumed to be high enough to entice new entrants. New entrants have a mixed effect on output: they tend to reduce it by depleting the resource through increases in effort (term one on the right-hand side of (2.69)) but they increase it by the average productivity for the industry (term two of (2.69)). Thus, new entrants may have a positive, negative, or neutral effect on total output. However, new entrants will expect to receive the average revenue for the industry as a whole and will plan to enter, ex ante, so long as industry net revenue (or average net revenue) is positive, stopping when average industry revenue (marginal revenue to entrant) equals average industry cost (marginal cost to entrant). However, all the entrants together affect the resource by depleting it so that, ex post, the increment to industry revenue from entry will be less than average factor cost by the value of the marginal depletion caused by the new entrants (P_{yt} times term one of (2.69)). Thus, the increment in value of total output (all prices constant) is made up of the increment due to entrants and the increment due to expansion of effort by established members of the industry. For both increments, ex post value of marginal product for the industry is less than cost of the marginal input although individuals seek ex ante to equate apparent value of marginal product and cost

of marginal input. Since costs must equal revenues ex post, the negative net marginal revenues must be borne by the individual firms in the industry and may be evident as low incomes or less than "normal" returns. Thus, high past net revenues lead to low net revenues in the current time period and the unstable nature of the situation is apparent.

A stable situation may prevail only if firms continuously accept less than "normal" returns or if all firms in the industry luckily discover that proper ratio of privately expected value of marginal product to marginal factor cost that equates the increment in value of output for the industry to the increment in industry cost. A third alternative, in which firms learn to reckon all costs (voluntarily take the viewpoint of the industry) seems unworkable since firms would not be likely to have the information or incentives to take the viewpoint of the industry. The first alternative of sustained below "normal" returns may explain part of the behavior of some open access or common property resource industries, especially when "normal" returns originally are based on acquisition value of inputs and not salvage value (see [9]). The second alternative may contain some explanatory power also if the marginal returns indicated do not (as they do not here) recognize uncertainty. That is, due to uncertainty, firms may attempt to maintain a ratio of value marginal product to input price that is consistently greater than one so that the ex post result from uncertainty planning may be closer to the value marginal product expected by the individual firm than is predicted by theory under certainty. Although these factors may contribute to a partially stable situation, they do not lead to an equilibrium in the sense of equating marginal factor returns with marginal factor cost.

This section is best summarized by presenting, as briefly as possible, the conclusions of the theory of open access resource exploitation under variable prices, i.e., where input and product prices are, respectively, functions of input and product quantities. A given increment in total output, dY_t given by (2.75), is attributable to increments in the effort of established firms, $\sum_{i=1}^{n_t} dX_{it}$, as well as in effort due to entry, $\sum_{i=1}^{n_t} X_{it}/n_t dn_t$, which sum to give the total increment in effort, dX_t . To maximize industry revenue, the increment to total revenue is equated to the increment in total cost or:

$$(2.72) \quad (P_{yt} + Y_t dP_{yt}/dY_t) dY_t = (P_{xt} + X_t dP_{xt}/dX_t) dX_t$$

Individual established producers see their marginal products as a function of their effort alone and, taking price as constant, collectively try to equate marginal revenue product to marginal factor cost as given by equation (2.70). Entrants, who enter at average levels of productivity and average effort expenditure, perceive the marginal return to entry as the average return for the industry or $P_{yt} Y_t/n_t$ and the marginal cost of entry as the average cost for the industry or $P_{xt} X_t/n_t$. (The marginal cost of a unit of effort from expansion by established firms is assumed to be the same as the marginal cost of a unit of effort by entry.) The marginal conditions for a static entry situation from the individuals' point of view, are:

$$(2.73) \quad P_{yt} Y_t/n_t dn_t = P_{xt} X_t/n_t dn_t$$

The condition that established industry members and entering firms, acting as individuals, attempt to attain is given by the sum of (2.70) and (2.73) or:

$$(2.74) \quad P_{yt} [\sum_{i=1}^{n_t} (\partial Y_{it}/\partial X_{it}) dX_{it} + (Y_t/n_t) dn_t] = P_{xt} [\sum_{i=1}^{n_t} dX_{it} + (X_t/n_t) dn_t]$$

The right-hand side of (2.74) corresponds to the right-hand side of (2.72) if input supply is assumed to be infinite at a constant price (as it is assumed by individuals). The left-hand side of (2.74), in addition to considering the effect of a change in output on output price to be zero (as individual producers consider it), neglects to take into account the depleting effect of increased effort on the resource. To equate the value of the marginal increment in output for the industry to the cost of the marginal increments in effort required to produce it involves, ignoring price effects, satisfaction of:

$$(2.75) \quad P_{yt} \, dY_t = P_{xt} \left(\sum_{i=1}^{n_t} dX_{it} + (X_t/n_t) \, dn_t \right)$$

Theory indicates that for maximum industry profits to be obtained (monopoly and monopsony profits) equation (2.72) must be satisfied for the industry. The competitive industry situation (zero profits, normal returns included as a cost, guaranteed by the satisfaction of (2.73) under freedom of entry) is realized by satisfaction of (2.75). A condition of chronic below-normal returns is attained when individual producers and entrants attempt to satisfy (2.74). The crux of the problem at hand is that individuals involved in exploiting an open access or unregulated common property resource will attempt to satisfy equation (2.74), resulting in chronically low returns in resource industries involving no, or ineffective, ownership of the resource. The ensuing chapters will be concerned with determining the extent of possible gains from institutions (policies) designed to correct the problem of low returns. Any possible gains must, of course, be weighed against costs of implementing the policies necessary to attain the gain. The following section describes a bioeconomic model of a fishery, necessary for empirical work, in theoretical terms.

Bioeconomic Theory of a Fishery

Earlier sections of this chapter were concerned with the theoretical behavior of a particular year-class in a closed stock of fish and with the theory of exploitation of an open access resource. This section combines the efforts of earlier sections into a bioeconomic theory of a fishery that will be useful in analyzing the shrimp industry. For a slightly different development, and one that incorporates the effects of "vessel crowding"---assumed negligible here--see the article by V. L. Smith [29].

Equation (2.30a) describes the weight of the catch from a particular year-class as a function of effort and the biomass of the year-class. In most fisheries, the catch is actually made up of fish from several year-classes, in general J year-classes, so that (2.30a) should be rewritten in terms of a year-class j where $j = 1, \dots, J$. Equation (2.42) gives the output of an individual producer in terms of individual effort and resource condition while equation (2.62) defines the output for the industry. Modifying and combining (2.30a), (2.42), and (2.62), total industry output is seen to be (2.76), the sum over individuals of the catches from different year-classes.

$$(2.76) \quad Y_t = \sum_{i=1}^{n_t} \sum_{j=1}^J Y_{ij}(X_{it}, B_{jt})$$

The biomass of a particular year-class is (abstracting from the effects of varying stock density on growth and mortality rates) a function of the growth and mortality rates natural to the species, the fishing mortality the year-class has suffered, and the size (in numbers) of the parent (spawning) population or $\sum_{j=j_1}^J N_{jt_0}$ where all year-classes at least as old as j_1 are spawners and t_0 is the "birth" year of the year-class in question.

Total revenue to the industry, the sum of total revenues to individuals, involves the product of the weight of each year-class in the catch times the price per unit weight commanded by the year-class (for example, different size shrimp, corresponding to different ages, bring different prices per pound). That is:

$$(2.77) \quad TR_t = \sum_{i=1}^n \sum_{j=1}^J P_{yjt} Y_{ij} (X_{it}, B_{jt})$$

Total cost is the sum of individual total costs as given by the product of total effort (2.56) and price per unit effort P_{xt} :

$$(2.78) \quad TC_t = P_{xt} X_t = P_{xt} \sum_{i=1}^n X_{it}$$

Demand price, P_{yjt} , is taken to be a declining function of output while input price, P_{xt} , is assumed to be an increasing function of input quantity. However, individuals, and the industry, are assumed to treat prices as if there were no quantity effects on prices, thus eliminating monopoly- and monopsony-type price effects. For equilibrium to occur in the industry, the value of increases in output due to increases in effort must exactly offset the increase in costs due to increases in effort (due to expansion by established firms and entry). Further, the value of an increase in effort due to expansion by established firms (the "intensive margin," see [29]) must equal the value of an increase in output due to entry in order for stability to occur on the "capital" side of the production system. Stability of the fish stock requires that decreases in the stock due to fishing and natural mortality are just offset by the sum of increases in biomass due to growth in weight and recruitment. In addition, the number of spawners, $\sum_{j=1}^J N_{jt}$, must remain constant if that number is equal to or less than the number required to produce the maximum size spawn that the biological system will support. (For example, there may be some number of eggs above which further egg production is superfluous so far as maintaining or adding to the adult stock is concerned.)

At some level of net revenue (zero, if net revenue is synonymous with pure profits and certainty is assumed) equilibrium may occur in the fishery in the sense that increments to value equal increments to cost and fish stock is stable (catch equals sustainable yield where sustainable yield is that yield that may be taken in perpetuity without affecting the stock). The condition (2.73) applied to the fisheries assures that the net revenue level at industry equilibrium is zero. Mathematically, the equilibrium conditions are formed by setting the total derivative of net revenue, equation (2.77) less equation (2.78), equal to zero and satisfying the additional constraints that the time rate of change in biomass is zero as is the change in number of spawners. The conditions are:

$$(2.79) \quad \sum_{i=1}^n \sum_{j=1}^J P_{yjt} \left[\left(\frac{\partial Y_{ijt}}{\partial X_{it}} + \frac{\partial Y_{ijt}}{\partial B_{jt}} \frac{\partial B_{jt}}{\partial X_{it}} \right) dX_{it} + \frac{\partial Y_{ijt}}{\partial n_t} + \frac{Y_{ijt}}{n_t} dn_t + \frac{\partial Y_{ijt}}{\partial B_{jt}} dB_{jt} \right] - P_{xt} \left(\sum_{i=1}^n dX_{it} + \frac{X_t}{n_t} dn_t \right) = 0$$

$$(2.80) \quad \sum_{j=1}^J dB_{jt} = 0$$

$$(2.81) \quad \sum_{j=j_1}^J dN_{jt} = 0$$

While (2.79) represents the conditions for competitive industry equilibrium (zero profits), individuals do not take into account the indirect effects of their actions and will, as pointed out in the preceding section, attempt to expand output by increasing efforts, thus raising marginal factor costs (by raising P_{xt}) and lowering value marginal products (by lowering P_{yjt} , through the effect of diminishing returns to effort and through depletion of the resource), resulting in the left

side of (2.79) being less than zero. If (2.80) and (2.81) are satisfied, (2.79) may be persistently below zero, the negative net marginal value products being absorbed in incomes to the fishermen below acquisition cost incomes (but above salvage value incomes).

In order to assure equilibrium by satisfaction of (2.79), some management authority need only levy on the industry a tax on entry (license fee, L) equal to the value of the reduction in output caused by entrants or

$$(2.82) \quad L = \sum_{i=1}^n \sum_{j=1}^J P_{yjt} \frac{\partial Y_{ijt}}{\partial B_{jt}} \frac{\partial B_{jt}}{\partial X_t} \frac{\partial X_t}{\partial n_t} dn_t$$

and a tax on individual landings (landings fee, D) equal to the reduction in value caused by expansion of effort by established firms or

$$(2.83) \quad D = \sum_{i=1}^n \sum_{j=1}^J P_{yjt} \frac{\partial Y_{ijt}}{\partial B_{jt}} \frac{\partial B_{jt}}{\partial X_{it}} dX_{it}$$

where P_{yjt} is the prevailing price at contemporaneous industry output. If tax-incidence problems are solved, this Pareto-efficient competitive industry equilibrium is as optimal as any other Pareto-efficient point. If a social welfare function is devised that acquiesces to the consumer desires expressed in the demand function, then this equilibrium is socially optimal.

Although the charges needed (L and D) to manage a fishery in an efficient zero-profit manner can be specified as theoretical aggregates, the pattern of license fees for vessels of varying sizes and efficiencies and the pattern of landings fees for fish of different sizes and per unit values are not so readily apparent. For heterogeneous firms and landings sizes, the charge levied may well influence the pattern of landings sizes and/or the characteristics of entering firms. The direction of such influence is not obvious from the static considerations given here and requires modification and adaptation of the theory, by

specific industry, into a workable dynamic model capable of evaluating alternative control strategies (policies). The theory presented here is modified and extended into a dynamic model capable of analyzing the Gulf of Mexico shrimp industry in Chapter III.

CHAPTER III

GULF OF MEXICO SHRIMP INDUSTRY: DESCRIPTION AND MODEL

The Gulf of Mexico shrimp industry may be divided into three segments. The basic segment is formed by the natural shrimp resource and the dynamics of its population behavior. A second segment is the fleet of boats and vessels that is involved in capturing the basic resource. The third segment consists of the processing and marketing channels that facilitate the movement of shrimp from the point of first sale at dockside to the consumer's table. This chapter presents a brief description of the Gulf of Mexico shrimp industry and then, in somewhat more detail, an abstract model that represents the essential workings of the industry.

Description of the Industry

The descriptive portion draws heavily on work done at the University of Florida by David A. Whittaker, Jr. [33], C. C. Osterbind and R. A. Pantier [27], and Roy L. Lassiter [22], as well as National Marine Fisheries Service (formerly Bureau of Commercial Fisheries) publications by John P. Doll [16] and Kenneth W. Osborn, Bruce W. Maghan, and Shelby B. Drummond [26], and a dissertation completed at the University of Rhode Island by Richard James Berry [7].

The Gulf Shrimp Resource

The commercially important Gulf shrimp resource is comprised largely of three species of shrimp: brown shrimp, Penaeus aztecus; pink shrimp,

P. duorarum; and white shrimp, P. setiferus. In addition, small numbers of a smaller shrimp called seabob, Xiphopenaeus kroveri, are taken near the outlets of Louisiana rivers. The royal red shrimp, Hymenopenaeus robustus, is harvested in depths of from 200 to 300 fathoms (one fathom equals six feet) in the waters off the east and southwest coasts of Florida and southwest of the Mississippi River Delta.

The Penaeus species have similar life cycles and habits. The adult shrimp spawn offshore and the larvae make their way back into the coastal estuarine systems, where they develop into juvenile shrimp. The juvenile shrimp begin to migrate back to the open sea where, upon reaching adulthood and spawning, the cycle is completed. Individual shrimp may live from eighteen months to two years and reach lengths of 170 mm. (6.7 in.) for males and 200 mm. (7.9 in.) for females. Shrimp are generally considered an annual crop, however, and are harvested from the time they are juveniles in the estuaries. Brown and pink shrimp are nocturnal in habit and burrow during the day into the mud and coral silt bottoms which they respectively seem to prefer. White shrimp, on the other hand, are active during daylight hours and burrow into the mud bottom at night.

Brown shrimp are found in heaviest concentrations along the Texas coast, white shrimp along the Louisiana coast, and pink shrimp off the coast of Florida near the Dry Tortugas and Sanibel Island and in the Gulf of Campeche off the northwestern coast of the Yucatan Peninsula. Figure 3.1 (after Lassiter [22, p. 2]) depicts the seven areas of the Gulf of Mexico that comprise the study area and Table 3.1 gives landings by area and species for the years 1967, 1968, and 1969 (see also [2]). Together, these references depict the recent occurrences of shrimp in commercial harvests and, presumably, the distribution of the various shrimp species.

Figure 3.1. Major Shrimp Fishing Areas in the Gulf of Mexico

Table 3.1. Landings of Gulf shrimp by area and species for the years 1967, 1968, and 1969

Year	Species	Area							Total ^a
		I	II	III	IV	V	VI	VII	
-----1,000 pounds of shrimp tails-----									
1967	Brown	b	566.8	15,358.5	29,587.6	49,906.9	5,076.8	153.5	100,650.1
	Pink	9,217.3	979.1	177.7	0.6	12.2	3.1	4,835.2	15,225.2
	White	b	349.3	2,601.9	16,294.4	5,561.5	31.6	84.0	24,922.8
	Seabobs and Royal Red	31.1	31.8	5.0	182.5	b	b	b	250.4
	Total ^a	9,248.4	1,927.1	18,143.2	46,065.1	55,480.6	5,111.6	5,072.7	141,048.5
1968	Brown	0.2	1,365.0	16,797.7	25,651.8	27,287.8	7,541.4	217.0	75,860.9
	Pink	9,702.8	1,516.1	219.5	13.3	14.9	15.9	6,057.9	13,540.4
	White	b	673.7	2,207.2	16,073.7	11,348.8	511.6	37.4	30,852.4
	Seabobs and Royal Red	9.5	61.7	54.3	637.3	b	b	b	762.8
	Total ^a	9,712.5	3,616.5	19,278.8	42,376.1	38,651.5	8,068.9	6,312.3	128,016.5
1969	Brown	1.5	208.3	13,482.0	23,524.1	24,301.2	3,940.1	154.9	65,612.1
	Pink	9,746.9	938.4	434.4	3.1	33.2	2.8	4,032.7	15,191.5
	White	3.7	794.6	6,791.4	26,065.2	10,880.0	165.1	34.3	44,734.3
	Seabobs and Royal Red	110.3	28.8	84.7	567.1	b	b	b	790.9
	Total ^a	9,862.4	1,970.1	20,792.5	50,159.5	35,214.3	4,108.0	4,222.0	126,328.8

^aMay not add due to rounding.^bNone reported.Source: Gulf Coast Shrimp Data, annual summaries for 1967, 1968, and 1969, U.S.D.C., N.O.A.A., N.M.F.S., Washington, D. C. [2].

Table 3.2 transforms the actual landings of Table 3.1 into percentages of total landings which more readily indicate the importance of the major species within areas, their relative contribution to total landings, and the relative importance of the seven areas in their contribution to total landings. Differences between years are associated with 1) differences in total shrimp abundance, 2) differences in relative species abundances, 3) shifts among areas in shrimp concentrations, and 4) changes in the fishing effort applied by area and among years. In Table 3.3 the results of Tables 3.1 and 3.2 are averaged over the three years. Table 3.3 shows brown shrimp to comprise about 62 percent, pink shrimp about 12 percent, and white shrimp about 25 percent of average total landings. Seabobs and royal red shrimp comprise less than one percent of total landings and are thus not considered further in this study.

Areas III, IV, and V, where brown and white shrimp concentrations are found, are the most consistent heavy-producing areas with Area IV showing the greatest concentration of white shrimp and Area V the largest concentration of brown shrimp. Area I follows in importance and contains pink shrimp almost exclusively. The high seas off the Mexican coast (Area VI) produces brown shrimp while Obregon and Campeche (Area VII) produces largely pink shrimp. Area II, contributing the smallest amount to total catch, contains all three species in roughly equal numbers although pink shrimp may be slightly more abundant.

A word of caution must be added against interpreting Tables 3.1 - 3.3 as indicators of absolute shrimp abundance. These data reflect commercial landings and thus, in addition to the availability of shrimp, they reflect the shrimpers' choice of where to fish. The fishermen's choice of trawling area is influenced by bottom conditions, i.e., whether

Table 3.2. Percentage distribution of Gulf shrimp landings by area and species for the years 1967, 1968, and 1969

Year	Species	Area								
		I	II	III	IV	V	VI	VII	Total ^a	
1967		-----percent of total landings of all species in all areas-----								
	Brown	b	0.40	10.89	20.98	35.38	3.60	0.11	71.36	
	Pink	6.53	0.69	0.13	0.00 ^c	0.01	0.00 ^c	3.43	10.80	
	White		0.25	1.84	11.55	3.94	0.02	0.06	17.67	
	Seabobs and Royal Red	0.02	0.02	0.00	0.13	b	b	b	0.17	
	Total ^a	6.56	1.37	12.86	32.66	39.33	3.62	3.60	100.00	
1968	Brown	0.00 ^c	1.07	13.12	20.04	21.32	5.89	0.17	61.60	
	Pink	7.58	1.18	0.17	0.01	0.01	0.01	4.73	13.70	
	White	b	0.53	1.72	12.56	8.87	0.40	0.03	24.10	
	Seabobs and Royal Red	0.01	0.05	0.04	0.50	b	b	b	0.60	
	Total ^a	7.59	2.83	15.06	33.10	30.19	6.30	4.93	100.00	
1969	Brown	0.00 ^c	0.16	10.67	18.62	19.24	3.12	0.12	51.94	
	Pink	7.72	0.74	0.34	0.00 ^c	0.03	0.00 ^c	3.19	12.02	
	White	0.00	0.63	5.38	20.63	8.61	0.13	0.03	35.41	
	Seabobs and Royal Red	0.09	0.02	0.07	0.45	b	b	b	0.63	
	Total ^a	7.81	1.56	16.46	39.70	27.88	3.25	3.34	100.00	

^aMay not add due to rounding.^bNone reported.^c0.00 indicates less than 0.005 percent.

Source: Compiled from data in Table 3.1.

Table 3.3. Average landings and percentage distribution of average landings of Gulf shrimp by area and species over the years 1967, 1968, and 1969

Species	Area						
	I	II	III	IV	V	VI	VII
-----1,000 pounds of shrimp tails-----							
Brown	0.6	710.0	15,212.7	26,254.5	33,832.0	5,519.4	175.1
Pink	9,555.7	1,144.5	277.2	5.7	20.1	7.3	4,975.3
White	1.2	605.9	3,866.8	19,477.8	9,263.4	236.1	51.9
Seabobs and Royal Red	50.3	40.8	48.0	462.3	b	b	b
Total ^a	9,607.8	2,504.6	19,404.8	46,200.2	43,115.5	5,762.8	5,202.3
-----percent of total landings of all species in all areas-----							
Brown	0.00 ^c	0.54	11.54	19.92	25.67	4.19	0.13
Pink	7.25	0.87	0.21	0.00 ^c	0.02	0.01	3.77
White	0.00 ^c	0.46	2.93	14.78	7.03	0.18	0.04
Seabobs and Royal Red	0.04	0.03	0.04	0.35	b	b	b
Total ^a	7.29	1.90	14.72	35.05	32.72	4.37	3.95

^aMay not add due to rounding.

^bNone reported.

^c0.00 indicates less than 0.005 percent.

Source: Compiled from data in Table 3.1.

grass is present or the bottom is studded with coral, large sponges or other obstructions, and distance from port. Thus, Tables 3.1 - 3.3 should be interpreted as indicating commercially important concentrations of shrimp, given current technology and knowledge of bottom conditions.

In addition to variation by area, shrimp concentrations vary in a seasonal pattern by species. Osborn et al. [26] have summarized five years of data (1959-63) to indicate shrimp concentrations by area, species, and month of year. Their findings on density by area are roughly the same as those presented above. The seasonal patterns of abundance of the three species are such that shrimp are available in heavy concentrations the year round. Brown shrimp concentrations support a summer and early fall fishery with 80 percent of the landings occurring from June to October and the peak catches occurring in July and August [26, p. 6]. Pink shrimp support a year-round fishery although landings are somewhat lower during June through September and peak in December [26, p. 14]. Nearly 80 percent of the white shrimp landings are made in the fall from September to December [26, p. 10].

Although all three species of shrimp are harvested from the time they are juveniles in the estuarine systems (inshore) until they reach adulthood offshore, there are some striking differences in the percentages of the various species landed inshore versus offshore and in the depths of landing. For the study period 1959-63, [26] found that 80 percent of the brown shrimp landed were taken offshore, most of them in water between 11 and 30 fathoms in depth. Ninety-eight percent of the pink shrimp landed were taken offshore with the heaviest concentration (nearly 80 percent) taken in 11 - 20-fathom depths. In contrast to the brown and pink species, 42 percent of the white shrimp landed

were taken in inshore waters. By depth, about 90 percent of the white shrimp landed were taken in less than 10 fathoms of water.

In summary, brown shrimp, Penaeus aztecus, are most abundant in the summer and early fall in the offshore waters of Texas, Louisiana, and, to a lesser extent, Mississippi and Alabama. Pink shrimp are abundant at all times except the late summer in the offshore waters of southwestern Florida (Dry Tortugas and Sanibel Island) and the western Yucatan Peninsula (Obregon and Gulf of Campeche). White shrimp are most abundant during the fall of the year about equally in the inshore and offshore waters of the coast of Louisiana and, to a lesser extent, Mississippi and eastern Texas. The concentrations of shrimp reported here doubtless reflect activity patterns of the shrimp fleet in that they are inferred from commercial landings. However, the commercially important concentrations of shrimp would seem to be fairly well indicated by these data.

The Gulf Shrimp Fleet

In 1966 there were 7,739 boats and vessels in the Gulf shrimp industry operated by 13,756 regular and casual fishermen. These 7,739 craft were equipped with 9,969 otter trawl net units having a sweep capacity of 141,472 yards at mouth [23, p. 645]. Table 3.4 contains a breakdown of these statistics by state and by vessel and boat fisheries for 1966.

By the definitions followed by the U.S. Department of Interior, a boat is a craft of less than five net register tons while a vessel is a craft of at least five net register tons. A register ton is a volume of 100 cubic feet which displaces 6,242.5 pounds of fresh water of maximum density. The designation "gross" refers to register tonnage calculated from the volume between decks below the tonnage deck and

Table 3.4. Summary of shrimp otter trawl boats, vessels, fishermen, and gear in the Gulf states, 1966

		Fishermen			Otter Trawls	
State		Number Boats	Number Regular	Number Casual	Number	Yds. at Mouth
Boat Fishery	Fla., W.C.	98	142	24	99	1,281
	Alabama	203	311	43	203	3,900
	Mississippi	380	178	285	380	3,680
	Louisiana	3,261	2,919	1,220	3,305	42,016
	Texas	861	772	406	861	9,149
Total, excl. of dupl.		4,797	4,312	1,978	4,842	59,942
		Vessels		Fishermen	Otter Trawls	
State		Number	Gross Tonnage	Number	Number	Yds. at Mouth
Vessel Fishery	Fla., W.C.	886 ^a	43,686	2,140	1,664	25,912
	Alabama	366	14,050	882	598	9,730
	Mississippi	410	16,835	1,020	665	10,878
	Louisiana	1,342	59,007	3,524	2,354	37,289
	Texas	1,409	77,348	3,787	2,646	41,697
Total, excl. of dupl.		2,942	132,149	7,466	5,127	81,530
		Boats and Vessels		Fishermen	Otter Trawls	
State		Number		Number	Number	Yds. at Mouth
Total	Fla., W. C.	984		2,306	1,763	27,193
(Boat	Alabama	569		1,236	801	13,630
and	Mississippi	790		1,483	1,045	14,558
Vessel	Louisiana	4,603		7,663	5,659	79,305
Fishery)	Texas	2,270		4,965	3,507	50,846
Total, excl. of dupl.		7,739		13,756	9,969	141,472

^aPrinted as 386, apparently a misprint.

Source: Fishery Statistics of the United States, 1966, Stat. Dig. No. 60, U. S. Dept. of the Int., Fish and Wildlife Service, Bureau of Commercial Fisheries, 1968.

within permanent structures above the tonnage deck, while the "net" designation refers to the gross tonnage adjusted for certain allowable exemptions. A regular fisherman earns more than half his income from fishing while a casual fisherman earns less than half his income from fishing. An otter trawl net (see Figure 3.2) is designed to be towed along the bottom, collecting shrimp at the mouth and funneling them into the cod end of the net.

Table 3.4 indicates that there are 2,942 vessels in the Gulf shrimp industry manned by 7,466 regular fishermen. These vessels operate 5,127 otter trawl net units having a combined sweep of 81,530 yards at mouth. Since each vessel operates either one or two net units, there must be $(5,127 - 2,942) = 2,185$ double rig vessels operating 4,370 net units and $(2,942 - 2,185) = 757$ single rig vessels operating 757 net units. Assuming single rig net units are twice as large across the mouth as double rig net units [26, p. 4], there are $4,370 + 2(757) = 5,884$ double rig net unit equivalents operating in the Gulf shrimp industry measuring 81,530 yards at mouth. The average double rig net unit is 13.86 yards (41.58 feet) across the mouth while a single rig net unit is 27.72 yards (83.16 feet) across the mouth. The average vessel in the Gulf shrimp industry tows nets having a sweep capacity of 27.72 yards (83.16 feet) across the mouth. In addition to the main nets, each vessel usually carries a ten-foot try-net used to locate profitable shrimp concentrations before the main nets are deployed.

The distribution of vessels by states as shown in Table 3.4 corresponds closely to the distribution of landings by areas. Louisiana and Texas (Areas IV and V) lead in number of vessels and landings followed by Florida (Areas I, II, and to a large extent VII so far as vessels are concerned) and Mississippi and Alabama (Area III). Landings from

Figure 3.2 Shrimp Vessel with Otter Trawl Nets Deployed

Area VI are probably largely accounted for by Texas vessels while landings from Area VII are accounted for by Florida and, to a lesser extent, Texas vessels. Table 3.5 indicates the relative size composition of the fleets landing shrimp in each state. The vessels landing catches in Alabama, Mississippi, and Louisiana tend to be relatively smaller than those landing catches in Texas and Florida.

There are 4,797 boats in the Gulf shrimp industry (Table 3.4) of which the majority (3,261) are based in Louisiana. Florida has the smallest number of boats (98). These 4,797 boats are manned by 4,312 regular and 1,978 casual fishermen and carry 4,842 otter trawl net units with a sweep capacity of 59,942 yards at mouth. Assuming single rig nets are twice as large as individual double rig nets, there are 530 double-rigged boats equipped to tow two nets having a width at mouth of 6.25 yards (18.75 feet) each. The majority of boats are single-rigged, towing one net having a sweep capacity of 12.5 yards (37.5 feet) at mouth.

Many boats are manned by casual fishermen who, as a primary source of income, either engage their boats in another fishery or leave their boats idle and take jobs as shore workers or crew on craft employed outside the shrimp industry. As Table 3.4 indicates, the largest numbers of casual fishermen are found in Louisiana and fish the highly seasonal (late fall) white shrimp resource in the inshore or near off-shore waters. Alternative maritime employment for the Louisiana casual fisherman is available on oil company tugboats and service boats [22, p. 39].

Although boats outnumber vessels in the Gulf shrimp industry, vessels represent the most important segment of the industry, so far as fishing capacity is concerned, controlling 51.4 percent of the nets and

Table 3.5. Summary of shrimp otter trawl vessels of the Gulf states, by tonnage groups, 1966

Gross Tonnage	Number by State					Total, excl. of dupl.
	Fla., W.C.	Alabama	Mississippi	Louisiana	Texas	
5 - 9	38	30	7	41	22	122
10 - 19	89	88	62	235	138	512
20 - 29	41	42	83	166	83	318
30 - 39	134	56	71	167	124	370
40 - 49	152	45	58	176	161	374
50 - 59	78	29	38	141	154	264
60 - 69	217	28	51	231	392	531
70 - 79	69	24	19	113	191	239
80 - 89	22	3	9	32	52	73
90 - 99	40	9	7	23	66	93
100 - 109	3	--	3	9	16	23
110 - 119	2	3	1	2	5	9
120 - 129	1	6	--	4	4	9
130 - 139	--	3	--	2	--	3
160 - 169	--	--	--	--	1	1
190 - 199	--	--	1	--	--	1
Total vessels	886	366	410	1,342	1,409	2,942
Total gross tonnage	43,682	14,050	16,835	59,007	77,348	132,149

Source: Fishery Statistics of the United States, 1966, Statistical Digest No. 60, United States Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, 1968.

57.6 percent of the sweep capacity. In terms of utilization, the vessel fleet probably accounts for a larger percentage of the catch than the percent of sweep capacity indicates since nearly all the vessels fish on a year-round basis. To the extent that the offshore vessel fleet catch is of larger shrimp than the boat fleet catch, the vessel fleet accounts for an even larger proportion of the value of the shrimp catch since larger shrimp are more valuable.

As for profitability of operation of the fleet and of vessels versus boats, no data are available on boat operations since statistics are not gathered separately for boats. Table 3.6 presents costs and returns for a typical offshore Gulf shrimp vessel (see also [3]). The "return to management (gross return less all costs)" or net return is negative in this case. As shown in Table 3.6, this negative net return may serve to reduce owner share as in "return to investment" or operator share as in "return to labor and management." Caution must be used in applying these figures to vessels in different size classes or ultra-modern vessels of different efficiency.

C. C. Osterbind and R. A. Pantier [27] and Roy L. Lassiter [22] present and analyze data from the 1950's and early 1960's on costs and returns in, and utilization of the Gulf shrimp fleet. These studies are valuable for a historical review as is the more recent Basic Economic Indicators: Shrimp, Atlantic and Gulf [1] published by the National Marine Fisheries Service.

A feature of shrimp vessel operation bearing on costs and returns and adequately described elsewhere [27, 33] is the "share system." The "share system" is an arrangement whereby captain (whether or not he is the vessel owner) and crew share in the proceeds of the catch--and in part of the variable trip cost--in lieu of guaranteed salaries. Under

Table 3.6. Marine economics data - 65-foot Gulf of Mexico shrimp vessels

Vessel Description: 65 feet, 80 gross tons and 3-man crew (1967-1968 data)

Expected Production and Prices: 183 fishing days, 100,000 pounds (50 tons) shrimp at \$.694/pound.

<u>Variable Costs</u>	<u>Shrimp Season Total</u>
Vessel Repair	\$ 5,798
Gear Repair	5,450
Fuel	4,655
Galley	2,269
Ice	1,456
Other	1,190
Crewshare	16,553
Operator Share ^a	8,276
Total Variable Costs	\$ 45,647
<u>Fixed Costs</u>	
Interest on Investment (8%) ^b	\$ 9,168
Depreciation ^c	8,604
Insurance	3,791
Interest on Operating Capital (1/2 of 10%) ^b	2,188
Administrative	2,597
Total Fixed Costs	\$ 26,348
<u>Summary</u>	
Variable and Fixed Costs	\$ 71,995
Gross Returns	69,400
Gross Returns Less Variable Costs	23,753
Return to Management (Gross Returns Less All Costs)	-2,595
Return to Investment (Return to Management Plus 8% of \$114,600)	6,573 (5.7%)
Return to Labor and Management (Return to Management Plus Operator Share)	5,681

^aCaptain's commission and wages actually received.

^bInterest is charged against all investment and average operating capital whether or not borrowed. Investment is based upon returns to the vessel, a 15-year useful life and a 12 percent discount rate as determined by the National Marine Fisheries Service and for this vessel is \$114,600.

^cDepreciation is not standardized as in other marine economics data sheets but is as given in Working Paper No. 57 [1].

Source: Marine Advisory Program, Sea Grant, Oregon State University, Corvallis, Oregon. Prepared February 1971 from Working Paper No. 57, [1] Division of Economic Research, National Marine Fisheries Service [3].

the share arrangement, the captain and crew receive a percentage of the value of the catch, this percentage varying over vessels and ports and according to whether or not the captain is the vessel owner. The share of the captain and crew in variable costs usually includes food and gear (net) repair, these costs being deducted from crew share. The obvious advantages of this arrangement are that it gives the crew an incentive to maximize catch while holding down certain variable costs that are directly dependent on crew performance. The share system also guarantees short-run profit-maximizing behavior by a captain who is not the vessel owner and does not encourage loyalty of the crew to their employer. Such behavior may be at odds with the longer-run interests of the vessel owner. Since the share system is widely used, apparently many vessel owners feel that the advantages outweigh the disadvantages.

Francis J. Captiva in a recent paper on "Changes in Gulf of Mexico Shrimp Trawler Design" [10] describes the recent shift in the Gulf shrimp industry to slightly larger vessels (80 to 100 feet) of steel, fiberglass, or aluminum construction in place of the traditional wooden vessel. He describes the newly constructed vessels as being higher powered (from 400 up to 750 horsepower as compared to 150 - 200 horsepower on older vessels) with more comfortable crew quarters and more mechanized gear-handling and processing equipment, as well as design oriented toward diversification to allow handling various gears with little or no equipment modification. Modern electronic aids installed in duplicate, power steering with automatic, hand and remote controls, powerful remotely controlled trawl winches, and relocation of the control bridge to provide a better view of the working deck are attributes of many of the newly constructed vessels. Mr. Captiva envisions in the future an even larger vessel (150 feet in length) incorporating computer

designed hull, the capability to handle a wide variety of gears, new concepts in propulsion and auxiliary power (specifically, a diesel-electric or gas turbine-electric system) and other innovations. This "dream" vessel, with its increased hold and supply space and mechanized processing and freezing equipment, could serve as a mother-ship-catcher-ship, towing four electro-shrimp trawls simultaneously.

While changes in vessel design, equipment, and fishing techniques must meet the test of economic efficiency as well as technical feasibility, there are two recent developments that may be important for the Gulf shrimp industry. One of these concerns the development of the electro-shrimp trawl, which uses pulsed electric current to force shrimp up from their burrows, thus permitting 24-hour per day fishing with an increase in catching efficiency over the conventional trawl. Adoption of the electro-shrimp trawl by the Gulf shrimp fleet would have the effect of greatly increasing the potential effort (measured in 24-hour periods spent in actual fishing) of the fleet since vessels could, theoretically, fish continuously once they reached the fishing grounds and found profitable concentrations of shrimp. The other development concerns the discovery that royal red shrimp concentrate about the 49°F thermocline. By locating the 49°F thermocline and fishing at that depth, improved catches of royal red shrimp can be made [4]. The Expendable Bathythermograph System, originally developed for use by the U. S. Navy in locating the thermocline, is currently being used in experiments. Its cost apparently prohibits commercial adoption. The development of economically feasible gear with which to locate thermoclines should lead to greater utilization of the royal red shrimp resource, thus expanding the shrimp supply.

Processing and Marketing the Gulf Shrimp Catch

Shrimp processing begins on board the catching vessel where shrimp are beheaded (thus losing about 38 percent of their body weight). They are then packed in ice or, on some of the larger modern vessels, frozen in five-pound cartons for direct marketing or in blocks for later thawing and further processing. An exception occurs when heavy shrimp concentrations are located and/or fishing is close to shore. Under these conditions, the catch rate may be so high that beheading on board requires more fishing time than does returning the shrimp to shore. In this case, shrimp may be iced down whole and beheaded during shoreside processing.

Once the domestic shrimp catch is ashore, most of it is sold as raw material to processing plants either directly or through "packing houses" which assemble shrimp for sale to processors. Figure 3.3 presents a detailed analysis of shrimp processing and marketing channels. About 80 percent of the U. S. shrimp catch is processed as a frozen product while the remainder is canned or dried. Much of the Pacific coast catch, especially Alaska's, as well as part of the New England catch is processed into canned or dried products. Thus at least 80 percent of the Gulf shrimp landings may be said to enter the frozen product market. The frozen shrimp are converted into three major product forms: raw headless, breaded, and peeled and deveined, in order of importance, with raw headless accounting for about 40 percent and the latter categories about 30 percent each of the weight of raw headless shrimp processed into these products in 1969. According to Miller et al. [24, p. 29] trends indicate that breaded and peeled and deveined products will account for a growing share of the frozen shrimp total at

Source: [33, p. 28].

Note: Solid lines indicate movement of shrimp by possession or title while broken lines indicate where brokers facilitate movement of shrimp through the market although they may not take possession or title.

Figure 3.3. Shrimp Processing and Marketing Channels

the expense of raw headless. These proportions do not initially hold for imported shrimp, which made up about 53 percent of the total of imported and domestic landings in recent years [30]. Upon importation, about 90 percent of the foreign shrimp are in raw headless or peeled and deveined form. Part of the imports are further processed in U. S. plants so that the distribution of imported shrimp in final product form is about the same as for domestic shrimp. To the consumer, imported shrimp are indistinguishable from domestic shrimp other than by designation of place of origin on branded products.

Shrimp products are readily accepted by consumers. Miller et al. [24, p. 45] report that the retail demand for shrimp is price inelastic, a rise in price being associated with a less than proportionate decline in quantity demanded. The retail demand for shrimp is reported to be income-elastic [24, pp. 45, 46]; i.e., an increase in income is associated with a more than proportionate increase in quantity demanded.

The Gulf shrimp industry falls more or less naturally into the three segments or subsectors described briefly above. While description may be interesting and is important in gaining a working knowledge of the industry, it does not provide a firm base for management or policy decisions. The following section outlines an abstract model of the shrimp industry that may serve as the basis for policy and management decisions.

A Model of the Gulf Shrimp Industry

Following the precedent set in earlier sections of this chapter, the model developed here will follow the general subdivisions of "Gulf shrimp resource," "Gulf shrimp fleet," and "processing and marketing." The model is designed to be used to provide simulated output of variables

of interest over time and, as will be apparent, is designed specifically for the Gulf shrimp resource with data-imposed restrictions clearly in mind.

A Model of the Gulf Shrimp Resource

All three shrimp species considered here--brown, pink, and white--are landed at ports in each of the seven statistical reporting areas (see Figure 3.1 and Table 3.3) and must be presumed to be found in these areas. However, each species has different, specific seasonal characteristics with respect to abundance so that each species must be considered separately. In addition, there are differences in growth rates between sexes of shrimp [7, p. 93] so that males and females must be considered separately with respect to their effect on size composition of a particular recruit class. Berry [7, p. 29] indicates that there is no spawner-recruit relationship operative on the Tortugas shrimp grounds and the simplest assumption is that there is no spawner-recruit relationship operative in other areas of the Gulf as well. However, Berry [7, p. 54] does note that apparent fluctuations in shrimp abundance are similar among species and result from environmental changes affecting large parts of the Gulf.

The problem is to devise a model that will reflect the seasonal pattern of recruitment of different species in different areas of the Gulf, as well as allow for inter-period randomness in the size of recruit classes. In addition, the model must include the effect of natural and fishing mortality and the differential growth rates between sexes. The assumption is made that, at any point in time, the shrimp stock is equally divided in members between the sexes. Drawing on the theory presented in Chapter II, the following variables are defined:

R_{ijk} = Size, in numbers, of recruit class of species i ($i = 1, 2, 3$ for brown, pink, and white shrimp, respectively) in area j ($j = I, \dots, VII$, see Figure 3.1) considered recruited at the end of time period k ($k = 1, \dots, T$ where T defines an arbitrary time horizon).

N_{ijkt} = Number of shrimp remaining of species i in area j of recruit class R_{ijk} at the end of interval t ($t = 1, \dots, T$). Then $t - k$ is the elapsed time since shrimp in recruit class R_{ijk} were "recruited" or $t - k$ represents their "age" in the fishery.

W_{ijkmt} = Weight of shrimp of species i and sex m ($m = 1, 2$ for female and male, respectively) in area j of "age" $t - k$.

F_{ijkt} = Fishing mortality coefficient measured as a pure number per time period applying to species i in area j of age $t - k$ during time period t .

M_{ijkt} = Natural mortality coefficient measured as a pure number per time period applying to species i in area j of age $t - k$ during time period t .

B_{ijt} = Biomass of species i in area j at the end of time interval t .

X_{jt} = Standardized units of effort expended in area j during interval t .

By assuming shrimp numbers to be equally divided between the sexes and shrimp to survive in the fishery for T_1 time periods, B_{ijt} may be expressed in terms of N_{ijkt} and W_{ijkmt} as:

$$B_{ijt} = (1/2) \sum_{k=t-T_1}^t \sum_{m=1}^2 N_{ijkt} W_{ijkmt}$$

The important relationships required are those relating (1) the fishing mortality coefficient and effort, (2) the survival characteristics (in numbers) of a recruit class, and (3) the growth (in weight) characteristics of a recruit class. The fishing mortality coefficient (F_{ijkt}) is assumed to be a direct linear function of the effort expended in the area after shrimp reach some age in the fishery, say V , and zero before this age.

$$(3.1) \quad F_{ijkt} = 0 \quad , \quad t - k < V$$

$$F_{ijkt} = \beta_{nj} X_{jt} \quad , \quad t - k \geq V$$

Number of shrimp surviving at the end of interval t is a declining exponential function of the mortality rates and the number present at the beginning of period t (end of period $t - 1$). The number surviving when $t = k$ is the original recruit class, that is $N_{ijkk} = R_{ijk}$.

$$(3.2) \quad N_{ijkt} = N_{ijkt-1} e^{-(F_{ijkt} + M_{ijkt})}$$

The weight of an individual of age $t - k$ is given by:

$$(3.3) \quad W_{ijk1t} = \beta_{3lij} \left[1 - e^{\beta_{32i}(t-k) + \beta_{33i}} \right] \beta_{34i}$$

for females and for males is given by:

$$(3.4) \quad W_{ijk2t} = \beta_{4lij} \left[1 - e^{\beta_{42i}(t-k) + \beta_{43i}} \right] \beta_{44i}$$

Shrimp are classified commercially according to number of tails per pound. If individual weight is measured in pounds, then the reciprocal of W_{ijkmt} times a factor to arrive at heads-off weight represents number of tails per pound.

Given size of recruit classes and effort, equations (3.1) - (3.4) and aggregations of these equations describe the behavior of the shrimp population in the Gulf in terms of numbers and weight. In addition, a

policy variable is provided by V , the age in the fishery at which shrimp begin to be subjected to fishing mortality. The variable V may be manipulated by, for example, restrictions on mesh size, closed seasons or areas, or any combination of these measures. Variability in the model comes in the form of inter-period variation in sizes of recruit classes and varying fishing effort. The effort expended provides a link between the basic shrimp resource and the harvesting sector, the Gulf shrimp fleet.

A Model of the Gulf Shrimp Fleet

The craft in the Gulf shrimp fleet may be divided into H size classes, vessels in each size class having a different sweep capacity and, possibly, different cost characteristics. Larger vessels usually have greater sweep capacity and a day spent trawling¹ by a vessel of $2X$ yards sweep capacity may be considered as contributing roughly twice as much to fishing mortality as a day of trawling time by a vessel having X yards of sweep capacity. Thus, an arbitrarily chosen "standard" vessel size class having a "standard" sweep capacity may be established and the days spent trawling by vessels in other size classes may be adjusted by the ratio of sweep capacity of the vessel size class in question to that of the "standard" class. Thus, the model of the harvesting sector must be able to aggregate effort of diverse vessel size classes into the single effort index required by the basic resource sector model. In addition, the harvesting sector model must specify catch and gross revenue of vessels in each size class. Since prices vary according to

¹Effort data are available in "days fished"--24-hour periods spent in actual fishing activity.

size of shrimp (as expressed in tails per pound) the size composition of the catch must be known. In addition, cost per unit of effort is required to derive a measure of profitability. Profitability must be related to the intensity of fishing effort and to the entry and exit of fishing vessels to areas and the industry in order to determine effort which is needed as an input to the basic resource sector. The interface between the harvesting sector and the marketing and demand sector is characterized by the weight and size composition of the catch and the ex-vessel price, by size class, paid for the catch.

The following variables delineate the factors to be considered in a model of the Gulf shrimp fleet:

C_{hijkt} = Catch (in numbers) of a craft of size class h ($h = 1, \dots, H$) of species i in area j of recruit class R_{ijk} (age in fishery $t - k$) during interval t .

$Y_{hijkt} = (1/2) \sum_{m=1}^2 C_{hijkt} W_{ijkmt}$ = weight of catch C_{hijkt} .

P_{jkmt} = Price per pound of shrimp in area j of age $t - k$ and sex m and thus of count per pound $1/\alpha W_{ijkmt}$ where α is a factor to convert to headless weight.

$GR_{hjt} = (1/2) \sum_{i=1}^3 \sum_{k=t-T_1}^t \sum_{m=1}^2 P_{jkmt} C_{hijkt} W_{ijkmt}$
= Gross revenue of a craft of size class h in area j during period t .

X_{hjt} = Effort in 24-hour periods (days fished) spent in actual fishing activity by a vessel of size class h in area j during interval t .

n_{hjt} = Number of craft of size class h fishing in area j during interval t .

n_{lhjt} = Number of craft of size class h with home port in area j during interval t .

n_{2hjt} = New vessels of size class h having home port in area j entering fleet at beginning of time interval t so that

$$n_{1hjt} = n_{1hjt-1} + n_{2hjt}$$

S_{hjt} = Sweep capacity (in yards along footrope of nets) of a vessel of size class h in area j during interval t.

$$X_{jt} = \sum_{h=1}^H n_{hjt} (S_{hjt}/S_{rjt}) X_{hjt}$$

= Effort in standardized "days fished" in area j during interval t when vessel size class r is chosen as the "standard" class.

V_{hjt} = Cost (variable) of a day fishing by a marginal vessel of size class h in area j during time period t.

W_{ht} = Per time period value of sunk capital plus interest on this sum at a competitive rate prorated over the expected life of the sunk capital.

$$D_{hjt} = R_{hjt} - V_{hjt} X_{hjt} - W_{ht}$$

= Net revenue of a vessel of size class h in area j during period t.

The relationships of interest are those leading to D_{hjt} and the relationships relating effort and profitability. The number of shrimp of species i and age t - k caught by a vessel of size class h during period t is given by:

$$(3.5) \quad C_{hijkt} = \frac{\beta_{11j} (S_{hjt}/S_{rjt}) X_{hjt}}{F_{ijkt} + M_{ijkt}} n_{ijkt-1} \left[1 - e^{-(F_{ijkt} + M_{ijkt})} \right]$$

From (3.5) total catch, weight of catch, gross revenue, and net revenue per vessel may be calculated from their definitions.

Firms owning vessels in the Gulf shrimp fleet must decide in which area their vessels will fish and how intensely they should fish. The

cost structure of vessels in each size class will depend, in addition to size characteristics, on the area of home port and the port area of current operation. Vessels fishing an area out of a temporary port may have higher costs than vessels fishing the same area who are permanently based in a port in that area. Similarly, vessels of the same size class fishing the same area but from ports at different distances from the fishing ground will have different costs due to differences in steaming time to and from the grounds. Thus, the cost of a unit of effort of a marginal vessel in an area will appear as a step function when plotted against the number of vessels fishing in the area. This cost will take on one value when a marginal vessel has its home port in the area and a higher value when the marginal vessel has a home port in some other area. It is probably reasonable to assume that migration patterns are such that the cost of fishing an area other than the home port area from the home port area is greater than or equal to the cost of fishing out of a temporary port in that area. Thus, vessels fishing an area other than their own may be considered to be fishing out of a temporary port in that area so that there will be only two values for V_{hjt} for a given vessel size class in a given area during a given time interval. Since vessels of a given size class have identical revenue functions but different cost functions depending on home port area, all vessels of a given size class based in an area will be fishing in that area before other vessels of the same size class migrate to the area. Thus, the cost, by size class, of a unit of effort by a marginal vessel in an area will depend on the relationship between number of vessels fishing the area and number of vessels based in the area. Specifically:

$$(3.6) \quad V_{hjt} = V_{1hjt} \text{ if } n_{hjt} \leq n_{1hjt}$$

$$V_{hjt} = V_{2hjt} > V_{1hjt} \text{ if } n_{hjt} > n_{1hjt}$$

Net revenue by vessel size class may be calculated for each area once number of vessels and effort are determined. Entry into the fleet by new vessels is based on the profitability over a number (t_1) of previous time periods by vessels of the size class and area in question. Entry and exit are probably asymmetrical so that new vessels begin to be attracted only after cumulative net revenue reaches some positive level (say D_{1hj}) but vessels may not begin to exit until cumulative net revenue is lower or even negative (say D_{2hj}). Over the range between these two values, vessels neither enter nor leave the fishery. That is:

$$(3.7) \quad n_{2hjt} = \beta_{71hj} \sum_{\tau=t-t_1}^{t-1} D_{hj\tau}, \quad \sum_{\tau=t-t_1}^{t-1} D_{hj\tau} \geq D_{1hj}$$

$$n_{2hjt} = \beta_{72hj} \sum_{\tau=t-t_1}^{t-1} D_{hj\tau}, \quad \sum_{\tau=t-t_1}^{t-1} D_{hj\tau} \leq D_{2hj}$$

$$n_{2hjt} = 0, \quad D_{2hj} < \sum_{\tau=t-t_1}^{t-1} D_{hj\tau} < D_{1hj}$$

Movements of vessels between areas from one time period to the next will occur by moving vessels to the area with highest net revenue in the previous time period from all other areas. In the event that the area with highest net return has fewer vessels fishing in it than have their home port there, so that the lower cost coefficient (V_{1hjt}) is in effect, the number of vessels required to bring the higher cost coefficient (V_{2hjt}) into effect will be moved to that area on a prorated basis from the other areas. In terms of behavioral relations:

$$(3.8) \quad n_{hjt} = n_{hjt-1} + \sum_{r=1}^7 \beta_{8hrj} (D_{hjt-1} - D_{hrt-1}) n_{hrt-1} + n_{2hjt}$$

$$\text{where } D_{hjt-1} = \max_s D_{hst-1}$$

$$\text{and } n_{hjt-1} \geq n_{1hjt-1}$$

and:

$$(3.9) \quad n_{hrt} = n_{hrt-1} - \beta_{8hrj} (D_{hjt-1} - D_{hrt-1}) n_{hrt-1} + n_{2hrt} \\ r = 1, \dots, j-1, j+1, \dots, 7$$

except that, if $n_{hjt-1} < n_{1hjt-1}$, the following reallocation is performed.

$$(3.10) \quad n_{hjt} = n_{1hjt-1} + n_{2hjt}$$

and:

$$(3.11) \quad n_{hrt} = n_{hrt-1} - [\beta_{8hrj} (D_{hjt} - D_{hrt}) n_{hrt-1} / \\ \sum_{s=1}^7 \beta_{8hsj} (D_{hjt} - D_{hst}) n_{hst-1}] (n_{1hjt-1} - n_{hjt-1}) + n_{2hrt} \\ r = 1, \dots, j-1, j+1, \dots, 7$$

Equations (3.8) and (3.9) indicate that new vessels begin to fish, or retiring vessels leave the fishery, in their home port area. These propositions are not unreasonable since new vessels will probably make some test runs near their home port until the vessel is deemed seaworthy. If the time interval used is short these test runs will probably require most of one time period to complete. Likewise, vessels retiring from the fleet will most likely be found fishing in their home port area since cost conditions are most favorable there.

Once vessels are located on a particular ground, they must decide how intensely to fish, that is, how many days fishing time per time interval to expend. Variability in fishing days per time interval is probably not large since, if it is profitable to initiate a trip at all, it pays to fish as intensely as possible while on the trip. However, to the extent that profitability affects the attitude of the crew about length of trip and layover time between trips, effort may vary. In addition, number of trips per time period may be varied for a particular vessel by postponing equipment maintenance and thus reducing layover time

in port. However, maintenance may be postponed only for a finite amount of time so that for the average vessel in the area, this is probably an ineffective method of varying effort. Expected returns below the level at which average variable cost is covered will preclude fishing altogether. However, data are obtained on ex post results, not a priori expectations, so that a formulation indicating cessation of fishing activity is probably not reasonable unless expectations can be discovered and are homogeneous throughout the vessel size class in the area. The most reasonable proposition is that effort in days fished per time period varies between minimum and maximum levels as a linear function of net revenue in the preceding time period.

$$(3.12) \quad X_{hjt} = X_{1hjt} \quad , \quad D_{hjt-1} \geq D_{1hj}$$

$$X_{hjt} = \beta_{(12)1} D_{hjt-1} \quad , \quad D_{1hj} \geq D_{hjt-1} \geq D_{2hj}$$

$$X_{hjt} = X_{2hjt} \quad , \quad D_{2hj} \geq D_{hjt-1}$$

Given the behavior described by equations (3.5) - (3.12), various totals of interest may be calculated by taking the proper sums. For example:

$$\text{Weight of total catch in period } t = \sum_{h=1}^H \sum_{i=1}^3 \sum_{j=1}^7 \sum_{k=t-t_1}^t Y_{hijkt}$$

or:

$$\text{Total standardized effort in period } t = \sum_{j=1}^7 X_{jt}$$

By combining over vessel size classes, species, and areas, catches of shrimp of the opposite sex and different age that are of the same size, total weight of shrimp of a given size count may be obtained. Totals such as these are necessary input to the model of the shrimp resource as well as the model of the marketing and demand sector.

A Model of the Marketing and Demand Sector
of the Gulf Shrimp Industry

Rather than attempt to build an original model of the marketing and demand sector of the Gulf shrimp industry, the approach followed here is to take advantage of the work of John Doll entitled, An Econometric Analysis of the U. S. Shrimp Market, [16]. Doll's quarterly model [16, Chapter IV] is presented below with modification in symbols. In addition, a relation is presented to convert the single ex-vessel price appearing in his model into a range of prices for each size class of shrimp.

The model is simultaneous, involving four jointly determined (endogenous) variables and nine predetermined variables. The jointly determined variables are [16, p. 65]:

A_t = Total consumption, per quarter (t represents one quarter here and does not necessarily correspond to the time period of the basic resource or harvesting sector models) in millions of pounds, heads-off weight.

B_t = Stocks held in cold storage at the end of the quarter, in millions of pounds, heads-off weight.

D_t = Wholesale price, frozen processed, 26-30 count, Chicago, BLS (Bureau of Labor Statistics).

E_t = Ex-vessel price, weighted average for South Atlantic and Gulf states.

The predetermined variables are [16, pp. 65-66]:

Y_t = Landings per quarter in the South Atlantic and Gulf states in millions of pounds, heads-off weight.

I_t = Imports per quarter, in millions of pounds, heads-off weight.

E_{t-1} = Ex-vessel price lagged one quarter.

B_{t-1} = Stocks held in cold storage at the beginning of the quarter.

G_t = Quarterly total disposable income.

Q_2, Q_3, Q_4 = Quarterly intercept dummies for quarters two, three, and four, respectively.

1 = The intercept dummy.

The structural quarterly model for which Doll estimated parameters is composed of four equations.

Wholesale demand

$$(3.13) \quad A_t = \beta_{(13)1} + \beta_{(13)2} Q_2 + \beta_{(13)3} Q_3 + \beta_{(13)4} Q_4 \\ + \beta_{(13)5} G_t + \beta_{(13)6} D_t$$

Price linkage

$$(3.14) \quad D_t = \beta_{(14)1} + \sum_{i=2}^4 \beta_{(14)i} Q_i + \beta_{(14)5} E_{t-1} \\ + \beta_{(14)6} G_t + \beta_{(14)7} E_t$$

Ex-vessel demand

$$(3.15) \quad E_t = \beta_{(15)1} + \sum_{i=2}^4 \beta_{(15)i} Q_i + \beta_{(15)5} Y_t + \beta_{(15)6} I_t \\ + \beta_{(15)7} G_t + \beta_{(15)8} B_{t-1} + \beta_{(15)9} D_t$$

Stock balance

$$(3.16) \quad B_t = \beta_{(16)1} + \beta_{(16)2} Y_t + \beta_{(16)3} I_t \\ + \beta_{(16)4} B_{t-1} + \beta_{(16)5} A_t$$

The difference in length of time interval between Doll's model and the time interval used in the rest of the model presented here raises the difficulty of obtaining quarterly landings with a model that requires prices for all time periods within the quarter except the last. This

difficulty may be partly overcome by using the prices determined in one quarter for all time periods occurring during the subsequent quarter. For example, if the shrimp and fleet models employ monthly time periods, then the prices determined at the end of the preceding quarter could be used in each month during the current quarter to generate catch. At the end of the current quarter, monthly catches may be totaled and used to generate a set of prices which are used for each month in the subsequent quarter. Thus, prices are constant for the entire quarter. However, if the number of time periods per quarter is not large, this procedure may give reasonable results. An alternative is to use a month corresponding to the moving average of prices obtained in a hypothetical quarter employing data from current, previous, and subsequent months in the preceding few years. While this would allow shorter lags in the harvesting sector and thus more immediate seasonal responses, it builds into the model an incapacity to react to extremely volatile conditions resulting from large inter-year price variation. A third alternative is to use quarterly data in the models of the harvesting sector and basic shrimp resource. This alternative may prove reasonable also. Choice of an alternative must rest upon empirical considerations.

The problem of disaggregating the ex-vessel price into prices for each size class of shrimp is serious but a workable solution can be more readily proposed than for the time period problem. The price of a given size class of shrimp most likely depends on the relative abundance of the various-sized shrimp available in the market. Although imports and cold storage holdings influence the size composition of available shrimp, the relationship postulated here is between current landings and price. The price of a given size class of shrimp is postulated to

be a direct function of the aggregate price determined by equation (3.15) and an inverse function of the proportion of that size shrimp in total landings. That is:

$$(3.17) \quad P_{jnt} = \sum_{j=2}^7 \beta_{(17)j} Q_j + \beta_{(17)8n} P_t \\ + \beta_{(17)9} \left(\frac{Y_t}{Y_{nt}} - \frac{Y_o}{Y_{no}} \right) P_t$$

where the Q_j , $j = 2, \dots, 7$ are dummies for areas II - VII; i.e., the equation is normalized on Area I, Y_{nt} is landings of shrimp of size n ($n = 1, \dots, N$ different sizes) in time period t , Y_t is landings in time period t , P_t is the ex-vessel price derived from the quarterly ex-vessel price determined in (3.15), Y_o and Y_{no} are landings in some base period, and the $\beta_{(17)8n}$ are coefficients derived from the price spread between size classes in the base period.

Equations (3.1) - (3.17) are the relations needed to describe the dynamic workings of the Gulf of Mexico shrimp industry with the exception noted in the model of the marketing and demand sector. In addition, modifications in the variables of the model of this sector to make them correspond more closely to conditions in the Gulf shrimp industry may be needed. Further refinement will be dictated by the estimation techniques and programming procedures involved in the application of a simulation model.

CHAPTER IV

METHODOLOGY AND DATA

The objectives of this study, listed in Chapter I, may be presented as a set of objectives relating to the behavior of individual firms and a set of objectives relating to industry behavior. The objectives relating to firms concern the description of the behavior of firms in the Gulf of Mexico shrimp industry in response to changes in the shrimp population, the technological conditions of harvesting and processing, and demand conditions. The objectives relating to the industry concern the behavior of the industry in the aggregate and particularly its response to management strategies. The management strategies or policies to be considered are: (1) varying age of shrimp at first capture; (2) imposing an annual entry fee (license fee) on vessels in the industry; and (3) imposing a landings fee or tax per pound on shrimp landed by vessels in the industry.

The procedure for attaining the objectives relating to industry behavior involved constructing a simulation model of the Gulf of Mexico shrimp industry that simulates the behavior of the industry under various conditions. The objectives relating to firm behavior were realized by drawing on published results of research into various phases of the industry and, where such results were not available, by resorting to synthesis of needed parameters. The major thrust of this study is to develop a bioeconomic theory of a fishery, to build an abstract model of the Gulf of Mexico shrimp industry based on this theory, and to

develop an empirical model that gives plausible results. There was no attempt to elaborate upon the objectives relating to individual firm behavior as the emphasis of this study is to determine the effects on the industry of selected regulatory strategies. This chapter describes simulation as a tool for policy evaluation, the available data, and the computer model employed in this simulation study.

Simulation as a Tool for Model
Building and Policy Evaluation

The dog trots freely in the street
and sees reality
and the things he sees
are bigger than himself
and the things he sees
are his reality

["Dog," from Lawrence Ferlinghetti, A Coney Island
of the Mind, Copyright 1958 by Lawrence
Ferlinghetti, reprinted by permission of New
Directions Publishing Corporation.]

In order to describe simulation as a tool for evaluating management strategies, one must first define simulation. Simulation is not a well-defined technique in the sense that linear programming or regression analysis are well-defined techniques. As is the case in most descriptions of simulation, several definitions are given and then a comprehensive definition is made for the purpose of this study.

Describing simulation as a research method, Fred H. Tyner [31, p. 13] says: "Simulation involves the application of logical reasoning to a scale model of selected real-world phenomena, whether the scale model be one of equations or the prototype of a physical plant." In a paper discussing the reasons for using simulation J. E. Creameans [13, p. 6] writes: "The best that one can say about any simulation model is that it describes the object process using those characteristics which are important to the results that the model builder wishes to study."

G. H. Orcutt [25, p. 893] furnishes an open-ended definition of simulation: "Simulation is a general approach to the study and use of models." Defining simulation for the purposes of a paper, Boutwell and McMinimy [8, p. 1] say: "A mathematical simulation model is defined as a model that traces a series of events through time and/or space in such a manner that the cost and benefit streams of the resulting time path are measured." In a Rand Corporation publication, M. A. Geisler [18, p. 1] gives a hint as to the birthplace of the term simulation:

The study of large and complex systems in recent years, combined with the development of large-scale computers, has led to the representation of these systems in mathematical form for programming and calculation on high-speed computers. Calculations so obtained have been essentially pseudo-observations of these systems, which accounts to some extent for applying the term simulation to this technique.

Jay W. Forrester [17, p. 14], while dealing with industrial dynamics (which may be thought of as a specific type of simulation technique), states:

The first and most important foundation for industrial dynamics is the concept of servo-mechanisms (or information-feedback systems) as evolved during and after World War II.

.

An information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions.

As can be seen from the above definitions, there is no general accord in defining simulation. However, there are commonalities in nearly all definitions of simulation.

Most of the definitions indicate that systems with interacting components are involved and that the systems are dynamic as opposed to static. Simulation is defined, for the purposes of this study, to be a technique for studying the performance of dynamic systems whose

components interact to form an environmental setting which may change as a result of component interaction through time. A simulation model is an abstract representation of the system to be studied. It is usually, but not necessarily, formulated in terms such that a computer may be used to trace out the interaction of the model components over time. The model components correspond more or less closely to their real system counterparts in a degree that serves best the purposes for which the study is being conducted. Further, as implied above, a system refers to a set of real-world components whose decisions in reaction to their environment either wholly or in large part determine their future environment. Simulation involves building a model of this real-world system and operating the model over time, observing its behavior which supposedly reflects that of the real system.

At this point, legitimate questions arise. It is very well to be able to represent a system symbolically and even to have a machine manipulate these symbols to simulate the system's behavior, but what is to be gained from this? Cannot the real system be observed as easily as its machine-bound counterpart? To answer these questions is to specify the value of simulation as a research tool. If a system is relatively simple and well-understood and its behavior predictable without error, then there is no point in simulating the system since nothing is to be gained from such a simulation. However, many systems are not well-understood and/or their behavior not readily predicted. It is in studying these systems that simulation is of use.

In many large and dynamic systems, the components of the system and the ways in which these components interact may not be readily identifiable. Building a simulation model of the system forces the researcher to (1) identify the various components of the system,

(2) specify how they interact, and (3) decide the relative importance of components and interactions to the behavior of the system. The test of the researcher's skill is the degree to which selected model results approximate the behavior of the system. (While it is possible that the model may behave correctly for the wrong reasons, this chance must be taken in lieu of a better validation.) The researcher may use all the conventional econometric analysis at his command to identify the relationships between the components and the components themselves. Then, by fitting these relationships into a simulation framework, the researcher may discover important areas of omission or misspecification. Thus, a value of the simulation technique is that it provides insight into the components and interactions of a system, i.e., how the system actually works.

Given that a system may be readily identified and that an accurate model may be devised, often the complexity of the system prevents accurate prediction of future behavior, especially if some component or relation of the system is changed. Using a simulation model, the system's behavior may be traced out through time under different sets of conditions (different levels or states of the policy variables). That is, if an accurate model of the system can be devised, then it will be possible to experiment on the model, gaining valuable (and often less costly) information about the probable effect of proposed management strategies on the system itself. Thus, a second value of simulation and the one of primary interest in this study is that it gives the researcher and his decision-making clientele an opportunity to test new management strategies on a realistic model without fear of a possibly disastrous result that could occur from testing on the system itself.

Thus, simulation is a research technique that has the potential to provide valuable information about the system being modeled and possible effects of proposed policies affecting the system. A drawback to employing simulation as a research technique is that there currently exists no standardized method for evaluating the reliability of the information provided by a simulation model. Lack of a standardized validation technique for simulation models may be partly due to the youth (relative to standard econometric methods) of simulation as a research technique. In addition, simulation models tend to be unique, problem-oriented models that may not lend themselves well to standardized validation techniques. However, simulation has been defined for this study in a rather general sense and an attempt is made here to develop a general approach to the problem of model validation.

For purposes of exposition, a situation is assumed involving an analyst employed by a client to provide information about the possible effects of proposed policies on selected indicators of the performance of some system.¹ To provide this information, the analyst employs

¹The terms "analyst" and "client" are used for convenience' sake. The "analyst" may actually be a group of investigators which may include all or a part of a group of individuals represented here by the term "client." The situation assumed here presupposes a "client" who recognizes a problem in a system for which he has authority to implement policies designed to correct that problem. In addition, the client is assumed to possess an array of alternative policies among which he will choose on the basis of information provided by the analyst. This is an idealistic situation. More likely, the "client" is likely to have confused and/or conflicting views about the problem and policies designed to correct it. In addition, as is the case in the present study, there may not exist a "client" with the ability to implement policies even after problems have been identified and corrective policies proposed. Alternatively, the analyst may not be able to conceive of or comprehend the system and/or the problems involved in a manner that leads to the generation of meaningful information. These problems are not unique to studies employing simulation as a research technique and represent needless complication to the framework to be developed here.

simulation modeling as his primary research technique. Figure 4.1 presents a flow diagram of a possible framework in which the simulation model, as initially constructed by the analyst, may be subjected to progressively more rigorous validation procedures. The model is refined by the analyst as a result of the validation procedures and as a result of the assessment by the client and the analyst as to the usefulness of the information generated by the model. As the model becomes more refined and capable of providing information worthy of more confidence, so do the validation procedures become more sophisticated and capable of detecting less obvious aberrations in model performance.

As represented in Figure 4.1, the validation process begins after initial construction of a model by the analyst. During the process of model construction the analyst may gain insights into the system that prove to be valuable information to his client.² The analyst and his client can evaluate this information in terms of its implications for model revision. In addition, the analyst may select model output quantities that he believes to be reliable indicators of system performance and compare the means, ranges, and standard deviations over the simulation period of these quantities with the means, ranges, and standard deviations of their real-world counterparts over some base period. Since the model parameters are usually estimated with data generated by the actual system for a period in which the system exhibited enough stability to survive, the model will likely prove stable if it is properly specified. Model stability is not a goal within itself, however. There may be inherent instabilities in the system that are

²These insights may be the most valuable product of the entire research effort.

Figure 4.1. Schematic Representation of a Framework for Validation of Simulation Models. (Parentheses in the heading indicate the parties involved in a particular activity.)

Figure 4.1. Schematic Representation of a Framework for Validation of Simulation Models.
 (Parentheses in the heading indicate the parties involved in a particular activity.)---Continued

isolated as a result of model construction or that the model must capture in order to provide information on policies designed to eliminate the instabilities. The comparisons involved in Phase I of the validation process are not of the type that lend credibility to information provided by the model. They merely provide crude indicators of the performance of the model and, together with the information provided by the interaction of analyst and client, provide input into the process of revising the initial model.

Phase II of the validation process involves experimenting with the model to determine the type of policy information the model provides. This information, after evaluation by the analyst and his client, may indicate needed model revisions. In addition, the analyst may compute simple correlation coefficients between selected indicators of the performance of the model. These coefficients, together with a graphic analysis of selected model quantities, serve to indicate relative direction of serial movement between model quantities. The relative movements of model quantities over time can be compared with expectations based on theory as well as the relative movements of actual quantities over time. These comparisons together with the information provided by analyst-client interaction provide the basis for further revision of the model and comprise Phase II of the validation process. The revised model is used to provide information to the client which the analyst and client assess for implications for further model revision. In addition, values generated by the model for selected aggregated (over time or variable subsets) output quantities may be subjected to spectral analysis. The resultant time path parameters relating to trend as well as amplitude, frequency, and phase angle of cycles may be

compared with those resulting from spectral analysis of actual data. The information thus provided by Phase III of the validation process may be used to direct further revision of the model. Phase IV of the validation process involves considering model-generated values of disaggregated output quantities produced by the model after its revision at the end of Phase III. These quantities may be analyzed by graphic methods and calculation of simple correlation coefficients as in Phase II or by spectral analysis as in Phase III or both. The results of this procedure, together with the information obtained through analyst-client interaction may be used to attain a fourth level of revision of the model.

The framework for model validation presented here may be modified or extended to meet the needs of a particular situation. At each phase in the validation process the client receives information from the model through the analyst. On the completion of any phase (possibly even before Phase I begins) the client may decide he has enough information. The analyst and his client may choose to cease revising the model after any phase of the validation process, considering any increase in model reliability not worth the cost of the required model revision and validation. The analyst may be hindered in his validation procedures by the absence of actual time series data on variables of interest with which to compare model results. Thus, it becomes clear that the process of model construction, revision, validation, and use remains as much an art as it is a science. Even within the framework presented here, the analyst must effectively allocate his resources (presumed to be scarce) between model "validation" and model revision and maintain a balance between the sophistication of his validation procedures and the level of development of his model.

Data

Models that represent complex systems make stringent demands on the data. In the case of the Gulf of Mexico shrimp industry data in the form of parameter estimates that can be used directly in building a model of the industry do not exist for many of those needed. Those parameters that could not be adapted from published literature were synthesized from available data using basic statistical techniques. Estimates of the parameters describing the behavior of the Gulf shrimp resource were derived from estimates made by Berry [7]. The work of John Doll [16] provided most of the parameter estimates for the marketing and demand sector of the model were synthesized from primary data published in Osterbind and Pantier [27], Lassiter [22], Lyles [23, for the years 1965 and 1966], Osborn et al. [26], Surdi and Whittaker [30], and Arnold [5].

A model of the Gulf shrimp resource requires an individual growth equation and a survival equation which incorporates estimates of natural mortality and mortality due to fishing. Equations (4.1) and (4.1a), derived from equations given by Berry [7, p. 127] are the growth (in weight) equations for male and female pink shrimp, respectively, on the Dry Tortugas grounds utilizing a monthly time period. These equations are used in this study to represent weight in grams of individual shrimp of brown, white, and pink species on all grounds.

$$(4.1) \quad W_t(\text{males}) = 42.3 \left[1 - e^{-.1992(t + 1.062)} \right] 3.134$$

$$(4.1a) \quad W_t(\text{females}) = 73.3 \left[1 - e^{-.2382(t - .2633)} \right] 3.115$$

The time variable, t , is measured in months of 4.33 weeks each from time of hatching (zero age of shrimp). By multiplying equations (4.1) and (4.1a) by factors to convert to heads-off weight, convert from grams to

pounds, and taking the reciprocals of the results, the number of shrimp per pound at a given age may be determined. Factors to convert heads-on to heads-off weight are (as derived from E. J. Barry [6, p. XVI]) for brown shrimp, 0.521; pink shrimp, 0.625; and white shrimp, 0.649. The size classification of shrimp considered are: (1) very small, over 65 tails per pound; (2) small, 41-65 tails per pound; (3) medium, 26-40 tails per pound; and (4) large, 25 and under tails per pound. Table 4.1 gives the age, in months, of male and female shrimp in the four size categories. Shrimp are assumed to become subject to capture at three months of age. The variation in heads-on to heads-off weight conversion factors made no difference between species in these gross size categories.

The survival equation used in this study is of the form specified in equation (3.2). The natural mortality coefficient, M , is not differentiated by species, time, or area and the initial value used was 0.22 [7, p. 88]. Fishing mortality (F_{jt}) was related to effort (in standardized 24-hour days fished $-X_{jt}$) by area and time as shown by equation (4.2).

$$(4.2) \quad F_{jt} = b_j X_{jt}$$

Initial estimates of the b_j 's were derived for each area from the b value given by Berry [7, p. 88] of 11×10^{-6} by multiplying by 1125 and dividing by the square nautical miles fished in the area (as estimated from maps presented in [26]) to convert to an equivalent area basis and multiplying by 24 to convert to an equivalent time basis. The initial estimates of the b_j 's and the estimated area fished in square nautical miles in each area are given in Table 4.2 for each statistical area. Standardized days fished are derived from reported 24-hour days fished

Table 4.1. Age (in months of 4.33 weeks each) distribution by size and sex of brown, pink, and white shrimp in the Gulf of Mexico

Size Category (tails/pound)	Age	
	Males	Females
1) over 65	3 through 4 months	3 months
2) 41 - 65	5 through 6 months	4 months
3) 26 - 40	7 through 9 months	5 through 6 months
4) 25 and under	10 months and over	7 months and over

Table 4.2. Coefficients to convert 24-hour days fished to fishing mortality and estimated square nautical miles fished by area

Area j	b_j	Estimated square nautical miles fished
I	1.13×10^{-5}	26,185.50
II	2.26×10^{-5}	13,092.75
III	2.50×10^{-5}	11,902.50
IV	1.19×10^{-5}	24,995.25
V	1.25×10^{-5}	23,805.00
VI	3.12×10^{-5}	9,522.00
VII	0.92×10^{-5}	32,136.75

per vessel size class by multiplying days fished by each vessel size class by the estimated sweep capacity per vessel in hundreds of feet. The vessel size classes used and their sweep capacity in hundreds of feet are given in Table 4.3.

The computer model calculates number of recruits each month by adding to the mean recruits each month the product of a normally distributed random number with zero mean and variance of one and the standard deviation of recruits in that month. The estimated means and standard deviations of recruits for species in each month in each area are presented in Appendix II in the data required for initialization of the simulation program. Appendix I presents the computer program and data required to estimate recruits by species by month and area.

The model of the harvesting sector--the fleet--of the Gulf of Mexico shrimp industry is required to generate 24-hour days fished by vessels in each size class in each area. To do this, the computer program adjusts average days fished per month by a vessel of a given size class in a given area by a factor depending on net revenue in the preceding month. Adjusted average days fished per vessel is then multiplied by the number of vessels in that size class fishing in the given area. Adjusted days fished by vessels of all size classes are then standardized by multiplying by vessel size class sweep capacity in hundreds of feet and added together to determine 24-hour days fished in that area. Table 4.4, adapted from tables by Lassiter [22, pp. 40-46], presents estimates of the average 24-hour days fished by a vessel in each size class in each month of the year. Table 4.5 gives the adjustment factors by which the data in Table 4.4 are adjusted to arrive at average 24-hour days fished per month by a vessel in each size class in each area in each month of the year. These factors are based on the ratio

Table 4.3. Vessel size classes and sweep capacity of nets along headrope in hundreds of feet

Vessel size class	Gross register tonnage	Sweep capacity
		100 feet
1	less than 5	.375
2	5 - 19	.500
3	20 - 49	.800
4	50 - 79	1.000
5	80 and over	1.250

Table 4.4. Mean 24-hour days fished per month by a vessel in each size class

Month	Vessel size class				
	1 ^a	2	3	4	5
January	1.0	2.9	4.2	5.4	4.9
February	0.5	2.7	3.7	5.9	5.0
March	0.5	3.2	4.6	6.6	7.9
April	0.5	2.7	4.1	6.5	5.2
May	1.0	3.2	4.5	7.2	6.8
June	1.0	4.9	5.4	6.7	6.7
July	0.75	5.8	6.4	7.4	7.1
August	1.5	5.2	6.5	7.7	7.0
September	2.5	4.5	5.3	6.9	7.2
October	3.0	5.5	6.2	7.2	7.3
November	3.0	3.8	5.0	6.3	6.3
December	2.0	2.7	4.2	6.5	6.4

^aEstimated from closed seasons in 1969, personal knowledge, and the distribution of white shrimp landings as given in [26].

Table 4.5. Factors to adjust days fished by a vessel in a size class to reflect variations in average days fished by vessels in different areas

Area	Adjustment factor
I	1.15
II	.83
III	.73
IV	.83
V	1.13
VI	1.13
VII	1.15

of the average days fished per year by vessels in an area to the average days fished per year by vessels in all areas.

The number of vessels estimated to have home ports in each area is given in Table 4.6, along with the number of vessels assumed to be fishing in each area in December of a typical year. The latter figures are needed to initialize the simulation model.

The model of the marketing sector employs a quarterly time interval. Given catch for the quarter, this model calculates ex-vessel price as well as consumption, ending stocks in cold storage, and wholesale price. The calculated ex-vessel price is used to determine the ex-vessel prices used in the model of the harvesting sector for each month in the succeeding quarter. The model of the marketing sector is based on the quarterly model estimated by Doll [16] and the reduced form coefficients of Doll's model are presented in Table 4.7 for the variables as identified in Chapter III. In addition, Doll [16, p. 104] presents an import equation that is employed here.³ The equation is given as (4.3) using the same variable defined as in Chapter III.

$$(4.3) \quad I_t = -9.212 - 0.1952Y_{t-1} - 8.4988Q_2$$

In order to be consistent with the model of the harvesting sector, the ex-vessel price computed with the parameters presented in Table 4.7 is converted to ex-vessel prices for each size class of shrimp and further

³There is an exception. Doll [16, p. 104] reports the coefficient of Q_2 in equation (4.3) as -88.4988. Use of this value, holding Y_{t-1} and G at mean values, produced negative imports which did not occur in the data he reported using. Since imports were nearly the same in the second and third quarters in this data [16, pp. 98-99], the value of -8.4988 was used as the coefficient for Q_2 , approximating the coefficient of Q_3 , and reflecting the assumption of an error in the reported coefficient.

Table 4.6. Number of vessels in each size class estimated to have home ports in each area and number of vessels in each size class assumed to be fishing in each area in December of a typical year

Area	Vessels estimated to have home ports in each area by vessel size class				
	1	2	3	4	5
I	0	7	170	191	41
II	98	101	52	21	3
III	582	158	242	110	29
IV	3,257	233	347	283	46
V	860	135	251	429	93
Area	Vessels assumed to be fishing in each area in December of a typical year by vessel size class				
	1	2	3	4	5
I	0	7	170	291	61
II	98	101	52	21	3
III	582	158	242	110	14
IV	3,257	233	347	283	26
V	860	135	251	229	23
VI	0	0	0	100	10
VII	0	0	0	0	75

Table 4.7. Reduced form coefficients for quarterly shrimp model, 1956-1967

Jointly determined variables	Predetermined variables								
	Intercept value I	Landings Y_t	Imports I_t	Lagged ex-vessel price E_{t-1}	Intercept dummies			Total income G	Beginnings stocks B_{t-1}
					Q_2	Q_3	Q_4		
Consumption- A_t	11.6156	0.1416	0.1048	-30.4200	2.4418	4.4336	3.9324	0.1254	0.1148
End Stocks- B_t	-11.5304	0.6391	0.8422	29.1241	-2.3378	-4.2447	-3.7649	-0.1201	0.8911
Wholesale Price- P_t	0.1387	-0.0044	-0.0032	0.9369	-0.0589	0.0722	0.0937	0.0013	-0.0035
Ex-vessel Price- E_t	0.2608	-0.0055	-0.0041	0.4731	-0.1221	0.0064	0.0717	0.0013	-0.0045

Source: Doll, John P., An Econometric Analysis of the U.S. Shrimp Market, Working Paper No. 79, Division of Economic Research, National Marine Fisheries Service, College Park, Maryland, February 1971.

adjusted to reflect variations in the proportion of total catch that each size class represents.

The Computer Program

The model was reduced to a computer program using the Fortran IV Level E language designed for the IBM System/360 [21]. The program and initialization data are presented in Appendix II. Figure 4.1 is a flow chart of the essential workings of the program, denoting input and output of the main program and the subroutines.

Figure 4.2. Flow Diagram of the Computer Model of the Gulf of Mexico Shrimp Industry. The main program calls the subroutines in order from left to right.

CHAPTER V

RESULTS OBTAINED WITH THE SIMULATION MODEL AND POLICY IMPLICATIONS

In order to gain credibility for results from simulation under various levels of the policy variables, a simulation model must be verified to possess some desired degree of validity. This chapter describes the phases of the validation framework presented in Chapter IV that were completed with the present model. The policies considered and the results obtained with the simulation model for specified policy levels are presented along with a discussion of the implications of the policies for the attainment of various objectives.

Model Validation

The validation procedures described in Phases I and II of the framework for model validation presented in Chapter IV (see Figure 4.1) were applied to selected annual summary data generated by the present model. After the comparisons described in Phase I were made, the model, as originally constructed, was revised and a 30-year¹ period was simulated. The model revision segment of Phase II was not accomplished.

¹Thirty years was an arbitrarily chosen period that promised to be sufficiently long to allow any unsuspected cyclical behavior to be discovered and yet allow the required computer storage space for the program to remain small enough to qualify the program for the lowest hourly rate for machine time as determined by storage requirements. Actually, all cycles appeared complete within five years, the "length of run" chosen for policy experimentation.

In addition to the comparisons involving annual summary data, monthly values generated by the model for allocation of effort are presented to indicate how the procedures described in Phase II for aggregated quantities might be applied to disaggregated quantities during Phase IV.

The output data describing shrimp landings, prices, and imports were compared with equivalent summary data found in Shellfish: Situation and Outlook: 1970 Annual Review [30] covering most of the decade of the 1960's. The output data concerning vessel numbers, allocation of vessels among areas, fishing intensity, and profitability were compared to the figures presented in the tables of Chapters III and IV, as well as to the data presented in Osterbind and Pantier [27], Lassiter [22], and Lyles [23]. There was no attempt to determine correlation of simulated output with actual data through statistical techniques.

Operation of the model using initial parameter estimates indicated two areas where adjustments were needed. Landings were extremely low, indicating that either the coefficients used to convert effort into fishing mortality (the b_j 's) were too low or estimates of mean recruits were too low, or both. In order to maintain a proper ratio of shrimp in each size class of catch, both sets of estimates were adjusted upward until catch levels approximating those actually occurring in the industry were obtained. Table 5.1 presents the b_j estimates used in the model as well as the factors by which the initial estimates of the mean number of shrimp recruited by month and area were multiplied. In addition to the adjustments required to produce landings similar to those occurring in the industry, the imports equation presented by Doll [16, p. 104] was further adjusted to reduce predicted imports to a level approximating actual occurrences. The adjustment made was to change

Table 5.1. Adjusted coefficients to convert 24-hour days fished to fishing mortality and factors (ADFACJ's) by which initial estimates of the mean number of shrimp recruits were multiplied for final use in the model

Area j	b_j	ADFACJ _j
I	4.93×10^{-5}	4.00
II	9.85×10^{-5}	4.00
III	7.26×10^{-5}	2.00
IV	3.31×10^{-5}	1.75
V	3.49×10^{-5}	1.75
VI	9.08×10^{-5}	1.00
VII	5.81×10^{-5}	3.00

the intercept value used from the -9.212 presented in equation (4.3) to the value -19.212 used in the model as presented in Appendix II. No further adjustments in the model parameters were made as a result of Phase I validation procedures. Phase I comparisons based on output from the model as presented in Appendix II are given below.

Surdi and Whittaker [30, p. 7] report annual Gulf shrimp landings from 1960 to 1970. During this period landings varied from a low of 79.6 million pounds (heads-off weight) in 1961 to a high of 145.2 million pounds (heads-off weight) in 1970 with average annual landings for the period 1960-1970 at 119.1 million pounds. The model listed in Appendix II, using the initialization data listed there, generated annual landings values ranging from a low of 93.6 million pounds to a high of 113.9 million pounds with an annual average of 104.4 million pounds and a standard deviation of 5.0 million pounds. Thus, the model generates landings in the ranges of actual landings occurring during the decade of the 1960's; however, model landings show more stability. Average generated landings were below average actual landings during the 1960's by 14.7 million pounds per year for an average percentage error of 12.3 percent per year. This discrepancy may result from low estimates of mortality, shrimp recruits, or both. It may also result from the intra-year cyclical patterns of shrimp abundance by area and effort allocation being out of phase in the model as compared with the real world and may be altered during later revision.

Table 5.2 presents information on the size composition of actual catches in the Gulf and South Atlantic states from 1964 through 1970 and the average composition of 30 years of catches generated by the computer model. While the size classifications used in the model

Table 5.2. Size composition of actual shrimp catches in the Gulf and South Atlantic states for the years 1964-1970 and average size composition of 30 years catch data generated by the computer model

	Percent of actual catch			
Year	Large (30 & under tails/lb.)	Medium (31-50 tails/lb.)	Small (over 50 tails/lb.)	
1964	39.5	35.8	24.7	
1965	35.3	35.9	28.8	
1966	36.8	31.1	32.1	
1967	37.8	34.8	27.4	
1968	34.7	33.3	32.0	
1969	32.9	31.7	35.4	
1970	36.3	30.3	33.4	
Mean	36.2	33.3	30.5	
Standard Deviation	2.15	2.30	3.73	
	Percent of average catches generated by the computer model			
	Large (25 & over tails/lb.)	Medium (26-40 tails/lb.)	Small (41-65 tails/lb.)	Very small (over 65 tails/lb.)
Mean	27.9	29.8	21.7	20.6
Standard Deviation	1.31	1.71	1.48	1.56
	Large ^a (30 & under tails/lb.)	Medium ^a (31-50 tails/lb.)	Small ^a (over 50 tails/lb.)	
Mean	37.9	28.5	33.6	

^aCalculated from catches generated by the model on the assumption that catches in the medium (26-40) and small (41-65) categories are uniformly distributed over the five tails/lb. intervals making up these classifications.

are not the same as those reported by Surdi and Whittaker [30, p. 8], the data in Table 5.2 indicate that the shrimp catches generated by the computer model have a similar size composition to that of actual catches.

Surdi and Whittaker [30, p. 16] report ex-vessel prices occurring for brown, white, and pink shrimp at Brownsville-Port Isabel, Texas, Morgan City, Louisiana, and Tampa, Florida, respectively, for each month of the years 1969 and 1970 for three sizes of shrimp. There are thus 72 observations on prices for each size of shrimp. The ex-vessel price for 15 - 20 tails per pound count shrimp ranged from a low of \$1.07 per pound to a high of \$1.48 per pound. Prices for large shrimp generated by the computer model fell within this range. The ex-vessel price for shrimp counting 31 - 35 tails per pound ranged from a low of \$0.75 per pound to a high of \$1.10 per pound, a range which contained the prices generated for medium shrimp as defined in the model. The prices for shrimp counting 51 - 65 tails per pound ranged from a low of \$0.41 per pound to a high of \$0.77 per pound. The prices generated by the model for small shrimp were generally near the top of this range while the prices for very small shrimp concentrated near the bottom of the range. As with landings, model prices showed somewhat more stability than real-world prices.

The computer model generated average imports of 180.3 million pounds (heads-off weight) per year with a standard deviation of 0.8 million pounds. About 23 percent of the imports occurred in the first quarter, about 20 percent in each of the next two quarters with about 37 percent of the imports entering the country in the last quarter. Thus, generated imports were slightly lower than the average annual

imports of 182.1 million pounds per year reported by Surdi and Whittaker [30, p. 12] for the years 1960-1970.

The above comparisons of means and standard deviations of model quantities with actual data for the 1960's indicate that the model as presented in Appendix II did not explode; it reproduced values within the ranges established from actual data. The comparisons of Phases II through IV of the validation framework presented in Chapter IV are intended to provide indications of the underlying economic relationships contained in the model. Relative movements in selected model quantities are presented below.

In the present model total personal disposable income is held constant, thus eliminating shifts in demand due to population and/or productivity effects. In addition, to the extent that personal disposable income is correlated with time (as it was in Doll's data [16, pp. 29, 97]), holding this variable constant removes any trend in demand. Thus, the movements in values generated by the model reflect variations in shrimp supply resulting from resource availability and effort variability. Figure 5.1 presents the values generated over a 30-year time period by the model for average wholesale and ex-vessel prices, total landings, imports, and effort in adjusted days fished. Figure 5.2 presents the values generated by the model for total production costs, adjusted days fished, value of the fleet assuming a five-year investment life, and net return (ex-vessel value of the catch less total production costs). Table 5.3 presents simple correlation coefficients for the variables presented in Figures 5.1 and 5.2 plus ex-vessel value of the catch. These comparisons correspond to those indicated in Phase II of the validation framework described in Chapter IV. As indicated in Figure 5.1 and Table 5.3, wholesale and ex-vessel prices

Figure 5.1. Annual Values Generated by the Computer Model for Wholesale and Ex-vessel Prices, Total Landings, Imports, and Effort in Adjusted Days Fished

Figure 5.2. Annual Values Generated by the Computer Model for Total Production Costs, Adjusted Days Fished, Value of the Fleet Assuming a Fixed Year Investment Life and Net Return (ex-vessel value of the catch less total production cost).

Table 5.3. Simple correlation coefficients between selected variables based on values generated by the computer model

	Net return	Total landings	Ex-vessel value of the catch
Total Production Costs	-0.923	a	a
Value of the Fleet (5-yr. investment life)	-0.809	a	a
Adjusted Days Fished	-0.950	0.847	0.577
Wholesale Price	a	-0.093	a
Ex-vessel Price	a	-0.380	a
Imports	a	-0.774	a
Net Return	1.0	-0.689	a

^aNot calculated.

generally move in directions opposite to that for total landings consistent with the predictions of demand theory (increasing quantities supplied results in lower prices). The relationship between landings and prices was moderated somewhat by the negative correlation between total landings and imports and the dependence, in the model, of prices on total supplies (landings plus imports). Total landings and adjusted days fished (effort) are positively correlated. This result is consistent with production theory for stages I and II of the classical production function. The data presented in Table 5.3 and depicted in Figure 5.3 indicate that net return is negatively correlated with total production costs, value of investment in the fleet, and adjusted days fished. These comparisons indicate that effort and investment in the fleet are in excess of the levels needed for maximization of net return. The positive correlation between adjusted days fished and ex-vessel value of the catch suggests that the point of decreasing total returns to effort has not been reached.

Tables 5.4 and 5.5 present data on the intra-year cyclical allocation of vessels among areas by the computer model. Comparisons of these data with the data presented by Lassiter [22, p. 34] correspond to the types of comparisons outlined as part of Phase IV of the validation framework presented in Chapter IV. Lassiter [22, p. 34] presents information on the percentage of total monthly activity spent in each area by a sample of otter trawl shrimp vessels for the years 1959, 1960, and 1961. Since the computer model allows vessels to fish in only one area per month, the number of vessels fishing in an area expressed as a percentage of vessels fishing in all areas is a measure of the effort spent in that area. Boats (vessel size class one) do not readily migrate between areas in the real world and were not allowed to migrate in the

Figure 5.3. Simple Correlation Coefficients Between Selected Variables Based on Values Generated by the Computer Model

Table 5.4. Comparison of percentage distribution of effort by area in each month of the year of sample vessels with the percentage allocation generated by the computer model in the 30th year for vessels (vessel size classes 2-5)

Month ^a		Area						
		I	II	III	IV	V	VI	VII
January	S	23.5	1.4	4.5	31.5	17.4	16.6	4.6
	M	9.9	3.9	60.9	4.6	16.6	3.7	0.3
February	S	29.9	1.0	2.1	21.5	15.8	15.8	13.9
	M	38.9	2.6	37.4	4.2	13.0	3.7	0.2
March	S	26.9	2.3	1.8	21.1	18.7	14.5	14.7
	M	30.5	2.5	18.9	36.3	8.4	3.4	0.2
April	S	25.7	8.2	2.9	24.1	23.6	6.8	13.0
	M	19.7	2.4	8.5	60.6	5.7	3.0	0.0
May	S	15.0	6.2	3.9	31.5	28.8	6.7	7.4
	M	15.0	3.5	6.6	64.5	5.4	2.8	2.3
June	S	7.1	1.5	27.4	27.2	21.0	8.3	7.8
	M	13.2	6.7	5.5	62.0	5.4	2.8	4.4
July	S	2.8	0.6	21.0	22.9	46.2	2.8	3.6
	M	11.9	6.7	4.9	50.4	18.5	2.2	5.4
August	S	2.6	0.7	17.9	23.8	50.2	3.3	1.2
	M	9.6	6.5	4.3	28.6	45.7	1.1	4.2
September	S	2.8	1.0	14.0	23.0	52.7	4.9	1.4
	M	8.8	5.1	12.2	25.0	44.0	1.1	3.9
October	S	5.8	1.4	11.0	25.5	44.4	8.5	3.1
	M	6.2	3.0	54.2	9.0	25.5	1.0	1.0
November	S	11.7	1.3	10.7	28.3	35.7	7.3	5.3
	M	5.4	2.1	55.1	7.1	16.7	13.3	0.4
December	S	14.3	1.7	8.0	27.5	25.8	11.1	11.3
	M	5.9	3.2	48.6	6.6	12.8	22.7	0.2

^a"S" denotes sample values while "M" denotes values generated by the model.

Table 5.5. Comparison of percentage distribution of effort among aggregated areas in each month of sample vessels with the allocation generated by the model

Month ^a		Area		
		I-II-VII	III-IV	V-VI
January	S	29.5	36.0	34.0
	M	14.1	65.5	20.3
February	S	44.8	23.6	31.6
	M	41.7	41.6	16.7
March	S	43.9	22.9	33.2
	M	33.2	55.2	11.8
April	S	46.9	27.0	30.4
	M	22.1	69.1	8.7
May	S	28.6	35.4	35.5
	M	20.8	71.1	8.2
June	S	16.4	54.6	29.3
	M	24.3	67.5	8.2
July	S	7.0	43.9	49.0
	M	24.0	55.3	20.7
August	S	3.8	41.7	53.5
	M	20.3	32.9	46.8
September	S	5.2	39.0	57.6
	M	17.8	37.2	45.1
October	S	10.3	36.5	52.9
	M	10.2	63.2	26.5
November	S	18.3	39.0	43.0
	M	7.9	62.2	30.0
December	S	27.3	35.5	36.9
	M	9.3	55.2	35.5

^a"S" denotes sample results while "M" denotes model values generated. Rows may not add to 100% due to rounding.

model. Since boats presumably were not presented in Lassiter's figures, they are not used in calculating monthly activity in the model as shown in Tables 5.4 or 5.5. Table 5.4 compares the three-year average percentage of total activity spent in each area in each month by the sample vessels with the percentage allocation generated by the model for vessels (vessel size classes two - five) in the last year of simulated results. The sample results as reported by Lassiter [22, p. 34] included marked differences in patterns of effort allocation between years. The most notable departure of the simulated results from the actual effort allocation occurs in Areas III and IV. This is partially explained by the fact that the model, over the simulated period, added 689 vessels of size class four to the fleet in Area IV. The model allows a rapid migration rate between Areas III and IV and thus, effort becomes concentrated in one area very quickly. A second area where agreement between model results and simulated results is poor is the intra-year cyclical variation in effort by month. Areas I, II, III, and VII appear to be completely out of phase. Table 5.5 aggregates the figures presented in Table 5.4 for areas between which vessels migrate easily. The figures in Table 5.5 represent percentage allocation of effort to areas which have relatively low rates of migration between them. Again, the additional vessels assigned by the model to Area IV affect the results. The intra-year cyclical variation in effort by the model appears to be completely out of phase with that reported for the sample in the aggregate area containing Areas I, II, and VII. The cyclical variation in model results and sample results is unclear.

The model is capable of adding vessels to or deleting vessels from the fleet in response to profitability considerations. Over the 30-year period simulated, the model deleted two vessels of size class two

from the fleet in Area I, a 28.6 percent decrease in that size category for that area, and added 689 vessels of size class four to the fleet in Area IV, a 198.6 percent increase in that size category in that area. After the first five years of simulation, the model had deleted the two vessels from size class two in Area I and added 448 vessels to size class four in Area IV. There were no additions to or deletions from the fleet other than those mentioned for Areas II and IV.

Recent data on the cost structure of the industry are available only in very aggregated form. Consequently, the following discussion of cost estimates used in the model does not correspond precisely to any of the phases of the validation framework presented in Chapter IV. It is presented to indicate the basis used to estimate the value of the fleet. Firm cost data may be found in Osterbind and Pantier [27] and the National Marine Fisheries Service publication Basic Economic Indicators: Shrimp, Atlantic and Gulf [1]. The annual fixed cost charges employed in the model are given for each vessel size class in Table 5.6. These figures were derived from data presented in Osterbind and Pantier [27] and in Table 3.6.

If the annual fixed cost charges are assumed to represent some proportion of the total investment in vessel, gear, and necessary shore facilities, then dividing the annual fixed cost charge by this proportion would yield the amount of the total investment. The proportion of total investment charged as annual fixed cost will depend on the average length of life of the investment. Table 5.6 presents the values of the total investment in vessels, gear, and necessary shore facilities derived from the fixed charges used in the model under three assumptions about the average life of the investment. An investment life of 5.0 years corresponds to an annual fixed charge of 20 percent of the total

Table 5.6. Annual fixed cost charges per vessel employed by the computer model and the capitalized values that these sums represent

Vessel size class	Annual fixed cost charges	Value of investment assuming an average life of:		
		5.0 years	6.7 years	10.0 years
1	\$ 1,800	\$ 9,000	\$ 12,000	\$ 18,000
2	3,600	18,000	24,000	36,000
3	9,600	43,000	64,000	96,000
4	14,400	72,000	96,000	144,000
5	24,400	120,000	160,000	240,000

investment while a 6.7-year life corresponds to an annual charge of 15 percent and a 10.0-year life corresponds to an annual charge of 10 percent. Current acquisition costs for average vessels and gear in each size class are in the range of investment values derived using average investment life-spans of 5.0 and 6.7 years. Assuming a fleet size as given in Table 4.6, the estimated value of the total investment in the Gulf shrimp fleet is given in Table 5.7 under the three assumptions about average vessel and gear life employed in constructing Table 5.6.

° Table 5.7 also includes the value of the boats and vessels in the fleet as they were given by the model at the end of five and 30 years of simulation. Values presented in Table 5.6 were used in calculating total investment in fleet, gear, and shore installations necessary to vessel operation presented in Table 5.7. As a check on these figures, the value of capital and liabilities per vessel of \$71,200 as given in Basic Economic Indicators: Shrimp, Atlantic and Gulf [1, p. 9] was used along with a value for boats and gear of \$9,000 per unit to estimate the total investment in the fleet. Examination of Table 5.7 reveals that the assumptions of average investment life of 5.0 and 6.7 years give total industry investment values that bracket the value calculated from National Marine Fisheries Service data.

Simulated Results for the Policies Considered

One of the objectives of this study is to determine whether alternative management strategies exist which improve industry efficiency from the point of view of various groups of participants in the industry as well as reduce overinvestment in the industry. Gordon Tullock [32] presents a discussion of regulatory measures for a fishery designed to achieve various objectives. The charges needed to manage a fishery in

Table 5.7. Value of the fleet under different assumptions about average life of vessel and gear and using values given in [1]

Fleet size	Value of the fleet assuming average vessel and gear life of:			Value of the fleet assuming average vessel and gear value of \$71,200 and average boat and gear value of \$9,000
	5.0 years	6.7 years	10.0 years	
As given in Table 4.6 (7739 craft)	\$205,449,000	\$273,933,370	\$410,898,000	\$252,643,400
As given in Table 4.6 less 2 vessels in size class 2 and plus 448 vessels in size class 4 (8185 craft)	\$237,633,000	\$316,893,370	\$475,338,000	\$284,398,600
As given in Table 4.6 less 2 vessels in size class 2 and plus 689 vessels in size class 4 (8426 craft)	\$255,021,000	\$340,029,370	\$510,042,000	\$301,557,800

an efficient, zero-profit manner are specified as theoretical aggregates in Chapter II. These charges correspond to the landings fee and vessel entry charges considered here. In addition, the regulating agencies of the various states involved in the Gulf shrimp fishery pursue some management policies, including closed areas, closed seasons, and gear regulations, designed to increase the age (size) at which shrimp first became subject to capture. The specific policies considered here (based on Tullock's discussion, the development in Chapter II, and current practices) are:

1. No controls;
2. A set of policies possibly including closed seasons, closed areas, and gear regulations designed to increase the age at which shrimp begin to enter the catch (called simply, age at first capture) from three months to four months;
3. An annual vessel entry fee, by vessel size class of:

vessel size class (GRT)	less than 5	5-19	20-49	50-79	80 & over
annual entry fee (\$)	750	1,000	1,600	2,000	2,500
4. A per pound landings tax of \$0.10 on all shrimp sizes. (Viewed as a percentage of ex-vessel price, this tax is relatively higher on the smaller sizes of shrimp which command lower prices.); and
5. A combination of the vessel entry fee charges in (3.) and the per pound landings tax described in (4.).

The \$0.10 per pound landings tax was arbitrarily chosen. The annual vessel entry fees were derived from an arbitrarily chosen fee for vessel size class four of \$2,000 per year by multiplying this fee by the average sweep capacity per vessel. The rationale for this adjustment

is that, in order not to discriminate among vessels on the basis of productivity, the annual vessel entry fee should be based on a measure of vessel productivity. The most convenient measure of vessel productivity available during the present study was vessel sweep capacity by size class.

The computer model was used to simulate the behavior of the Gulf shrimp industry over five-year time periods for the five different settings of the policy variables. Table 5.8 presents the levels of the policy variables and the associated average annual values generated by the computer model for the total catch, wholesale value of the catch, ex-vessel value of the catch, total production costs, revenue to the control authority (the authority imposing the policies and collecting the fees), the difference between total production costs and ex-vessel value of the catch (which may be considered a net return to fixed investment if all variable costs, specifically labor costs, are considered to be covered), and the value of fixed investment in the fleet under the assumption of a five-year average life of vessels and gear.

Table 5.9 presents the rate of return to investment represented by the net return and value of investment figures in Table 5.8 for each of the policy levels. The revenue collected by the control authority may be considered a return to the shrimp resource. The disposition of this return and the welfare implications of alternative dispositions of this return are beyond the scope of the present study. However, the figures presented in Table 5.10 make possible some interesting comparisons. Table 5.10 presents the changes, occasioned by instituting the policy variables, in the quantities listed in Table 5.8 from the situation of no controls. In addition, Table 5.10 presents the sum of the revenue to the control authority and the changes in wholesale value and net

Table 5.8. Average annual returns from the Gulf shrimp catch, costs to the industry and fixed investment in the industry assuming a five-year investment life under various settings of the policy variables

Policy settings ^a	Total catch	Wholesale value	Ex-vessel value
1	96,498,298 lbs.	\$136,067,890	\$95,391,740
2	96,498,224 lbs.	136,067,840	95,391,680
3	94,303,328 lbs.	133,811,552	94,883,072
4	92,724,624 lbs.	132,358,080	88,322,608
5	92,199,424 lbs.	131,798,112	87,940,096

Policy settings ^a	Total prod. costs	Rev. to cont. auth.	Net return	Value of investment
1	\$114,826,888	\$ 0	\$-19,435,148	\$237,633,000
2	114,826,800	0	-19,435,120	237,633,000
3	119,989,504	8,694,105	-25,106,432	217,833,000
4	102,985,264	9,272,454	-14,662,656	205,431,000
5	11,158,576	17,748,080	-23,218,480	205,431,000

^aRefer to text, page 116.

Table 5.9. Rate of return to fixed investment in the Gulf shrimp fleet under various settings of the policy variables

Policy settings ^a	Percentage rate of return
1	- 8.18
2	- 8.18
3	-11.53
4	- 7.14
5	-11.30

^aSee text, page 116.

Table 5.10. Changes in average annual returns, costs, and investment occasioned by the imposition of controls

Policy settings ^a	Changes in:			
	Total catch	Wholesale value	Ex-vessel value	Total prod. costs
1	0 lbs.	\$ 0	\$ 0	\$ 0
2	-74 lbs.	-50	-60	-88
3	-2,194,970 lbs.	-2,256,338	-508,668	-5,162,616
4	-3,773,600 lbs.	-3,709,810	-7,069,132	-11,841,624
5	-4,298,874 lbs.	-4,269,778	-7,451,644	-3,668,312

Policy settings ^a	Changes in:			Revenue to cont. authority plus changes in wholesale value and net return
	Net return	Value of investment	Rev. to cont. auth.	
1	\$ 0	\$ 0	\$ 0	\$ 0
2	28	0	0	-22
3	-5,671,281	-19,800,000	8,694,105	766,486
4	4,772,492	-32,202,000	9,272,454	10,335,136
5	-3,783,332	-32,202,000	17,748,080	9,694,970

^aSee text, page 116.

return (which reflect the difference between changes in ex-vessel value and production cost). This sum is a measure of what is left over from revenue to the control authority after adding any changes in wholesale and ex-vessel values of the catch and deducting any changes in the cost of producing the catch. Thus, it is a measure of the net money returns obtained from instituting a particular policy exclusive of the cost of implementing the policy. It is what is left (after compensating all losers and taxing away all gains) to apply to the cost of implementing the policy.

Increasing the age of shrimp at first capture to four months has essentially no effect on the quantities considered in Tables 5.8 and 5.10. Imposing an annual vessel entry fee, differentiated by size class as shown in Table 5.8, reduces total catch, the wholesale and ex-vessel values of the catch, and the net return. This policy increases total production costs and revenue to the control authority. The vessel entry fee policy considered produces a surplus after revenue to the control authority is adjusted for changes in wholesale value and net return although this surplus is probably not large enough to implement the policy. Imposing a landings tax on shrimp decreases wholesale value but increases net return since production costs are decreased more than the ex-vessel value of the catch. Thus, the revenue to the control authority, after being adjusted for changes in wholesale value and net returns, is significant, amounting to 11.7 percent of the ex-vessel value of the catch. Imposing both a vessel entry fee and a landings tax produces the greatest gross revenue to the control authority but a slightly smaller adjusted revenue than a landings tax alone due to the larger decline in wholesale value of the catch and a decline in net return rather than an increase. Both the entry fee and landings tax

policies reduce investment in the fleet although when the policies are used singly the landings tax policy seems to more effectively reduce investment.

Policy Implications

Considering the relatively primitive nature of the model used to obtain the results presented here, caution must be used in drawing implications about the various regulatory measures considered on the basis of those results. In addition, different conclusions may be drawn as to the relative desirability of a proposed regulatory policy depending on whether one takes the point of view of the consumer, the vessel owners, the vessel crew, or processors. The benefit to society of a policy will vary depending upon the segment of society that the individual estimating the benefit is most closely associated with. Such conflicts seem to be inevitable and the approach taken here is to rank the policies on their effectiveness in attaining several alternative objectives. The assumption is made that all the policies are equally costly to implement with the exception of the policy of no controls, which may be implemented at zero administrative cost. No estimates of implementation costs have been made.

If the revenue to the control authority is considered to be a return to the resource and the objective of maximizing this return is assumed, then the results presented in Tables 5.8 and 5.10 indicate that a combination of the entry fee and the landings tax policies is most effective in obtaining this objective. The landings tax policy ranks second in effectiveness. The vessel entry fee policy ranks third. The other policies give no return to the control authority. Since implementation costs are unknown, the net effects of the landings tax and vessel entry

fee policies cannot be determined and they cannot be compared on a "net" basis with the costless alternative of no controls. The policy relating to age at first capture, since it produces no revenue to the control authority and has positive implementation costs, is clearly inferior to the alternative of no controls on the basis of maximizing returns to the resource.

If maximization of net return to investment in the Gulf of Mexico shrimp fleet is taken as the objective and policy implementation costs are ignored, then based on the results presented in Table 5.8, a tax on landings seems to be the most effective means of attaining this objective. The policy relating to age at first capture ranks second while a policy of no controls ranks a very close third. A combination of entry fees and a landings tax ranks fourth in effectiveness. Imposition of entry fees alone is the least desirable policy for attaining the objective of maximization of net revenue to the fleet.

If maximization of the total catch is taken as the objective, a policy of no controls is most effective. Regulating age at first capture ranks second while an entry fee, landings tax, and combination of the two rank third, fourth, and fifth, respectively.

If the objective of industry regulation is to reduce the value of investment in the Gulf of Mexico shrimp fleet, the per pound landings tax policy and a combination of the landings tax and entry fee policies are equally effective in reducing total investment. The entry fee used alone is the next most effective policy while the age at first capture and no controls policies do not reduce investment in the fleet.

Table 5.11 contains the total production costs incurred by the fleet per pound of shrimp produced under the different policies. If the objective of regulation is to minimize per pound product cost by

Table 5.11. Average annual total production costs incurred by the Gulf of Mexico shrimp fleet per pound of shrimp produced and average annual wholesale price of shrimp produced and average annual wholesale price under alternative policies

Policy ^a	Per pound production costs	Wholesale price
1	\$1.19	\$1.41
2	\$1.19	\$1.41
3	\$1.27	\$1.42
4	\$1.11	\$1.43
5	\$1.22	\$1.43

^aSee text, page 116.

the fleet, a per pound landings tax is the most effective policy. No controls and regulating age at first capture are tied for the second position. A combination of landings tax and entry fee is the next most effective while a vessel entry fee alone produces the highest costs per pound.

The model does not presently provide information that can be used directly to evaluate the effects of the policies on consumers. However, if the wholesale value of the catch is accepted as a proxy for retail value of the catch and some assumptions concerning retail demand are accepted, then some tentative inferences concerning the effects of the policies on consumers can be made. Doll [16, pp. 35, 70-71] finds that the price elasticity of retail demand (in his annual model) at the mean of price and consumption is -0.63 and that the price elasticity of wholesale demand (in his quarterly model) is -0.50 at the means of the variables. Thus, retail and wholesale demands as reported by Doll appear to be relatively inelastic, a finding corroborated by Miller et al. [24, p. 45].² The significance of these results for evaluating the effect of the policies on consumers lies in the fact that, given a downward sloping demand curve, changes in quantity taken in the neighborhood of the quantity used to calculate the price elasticity produce

²The fact that as catch is reduced in Table 5.8 wholesale value of the catch is reduced also might seem to contradict the assertion that wholesale demand is price inelastic in this range of landings. However, as domestic landings decrease in the model, imports increase after a quarter lag (see equation 4.3). Thus, the effect of decreased domestic landings on the total annual supplies of shrimp available to meet wholesale demand is not readily predictable. It would appear from the results in Table 5.8 that, as landings decrease, imports increase by enough so that the increase in the wholesale price is not enough to produce the increase in wholesale value of the catch that would be expected if landings were to decrease and imports were to remain constant.

larger changes in consumer surplus (measured as the area under the demand curve and above the price line) for price inelastic demand curves than for price elastic demand curves. For example, there is no change in consumer surplus as defined here in response to quantity changes when consumer demand is perfectly elastic; there is, in fact, no consumer surplus. For a complete inelastic consumer demand curve, minute changes in quantity supplied produce infinitely large changes in consumer surplus.

The average annual wholesale prices occurring under each policy setting are presented in Table 5.11. The policies do not cause large changes in wholesale price. If retail price behavior is similar, most of the effect on consumers of the reduction in domestic landings resulting from implementation of the policies would seem to be offset by increases in imports. However, with apparent annual consumption of fresh and frozen shrimp of 357.3 million pounds in 1970 [30, p. 13, preliminary estimate] coupled with an inelastic retail demand at that quantity, even a small increase in retail price resulting from a proportionately smaller decrease in quantity available will result in a sizeable loss in consumer surplus. Assuming that the increase in average wholesale prices indicated in Table 5.11 represents the extent of the price increase at the consumer level, then the annual loss in consumer surplus occasioned by implementing a vessel entry fee is on the order of 3.5 million dollars as compared to no controls. The annual loss in consumer surplus occasioned by imposing a landings tax or a combination of a landings tax and an entry fee is on the order of 7.0 million dollars. Regulating age at first capture produces no significant reduction in consumer surplus. Thus, assuming that consumers do not pay for implementing the regulatory policies, do not share in the

revenues these policies produce, and desire to minimize loss of consumer surplus, policies of no controls or regulating age at first capture would seem to be preferable to consumers. A vessel entry fee ranks second in minimizing loss of consumer surplus while a per pound landings tax and a combination of a per pound landings tax and a vessel entry fee cause the largest losses in consumer surplus as measured here.

The column in Table 5.10 headed "Revenue to control authority plus changes in wholesale value and net return" presents an alternative criterion for ranking the policies. Assume that the decreases in wholesale value represent losses to society while increases in net return to the fleet (changes in ex-vessel value less changes in total production costs) and revenue to the control authority represent gains to society (ignoring costs of policy implementation). Then the sum of changes in wholesale value of the catch, net return to the fleet, and revenue to the control authority represents the net gain to society from implementing any one of the policies. Of course, implementation costs cannot be ignored and in choosing between a policy of no controls and one involving some regulation, the gain to society from implementing a policy must be calculated net of the cost of implementation. Assuming that all the policies involving regulation are equally costly and that the objective is to maximize net gain (minimize net loss) to society, the policy involving a per pound tax is most effective based on the information in Table 5.10. A policy involving both a tax on landings and a vessel entry fee is a close second while the vessel entry fee alone ranks a poor third. Regulating age at first capture produces negative gain to society and thus, is inferior to a policy of no controls even without considering the costs of regulating age at first capture.

As is evident from the discussion in this section, no one policy is clearly superior for attaining all objectives. The ranking of the effectiveness of the policies depends on the objective to be attained. The one clear implication to emerge from this discussion is that a policy designed to increase age at first capture is never preferable to one involving no controls, especially when costs of implementation are considered.³ However, even this conclusion must be accepted cautiously, remembering that many of the parameter estimates used in the model are initial estimates. The ordering of the remaining policies by effectiveness changes as objectives are changed. It is possible that the policy types would change ordering for a given objective if the regulatory variables were set at different relative levels. Thus, it must be remembered that the above discussion is specific to stated levels of the policy variables. It is quite possible that different combinations of values for the annual vessel entry fee and/or landings tax, for example, would result in different sets of rankings of the policy alternatives for given objectives. What is really needed is additional research to vary each policy variable to determine its optimum level with respect to a given objective or criterion. A comparison of policies set at their optimum levels with regard to given objectives would lead to more meaningful rankings.

The implications stated here are meant to describe the relative effects of different and specific types of policies, not to endorse a particular policy in a given case. Also, more meaningful policy

³It is interesting to note that policies designed to increase age at first capture are the only regulations currently in effect in the industry and these are enforced by individual states.

rankings will be possible in an environment in which the objectives and limitations of the policy-makers are known and taken into account. In addition, there are improvements and extensions needed in the model that will increase the reliability of the information it provides. Some of these improvements and suggestions for further research are discussed in Chapter VI.

CHAPTER VI

RECAPITULATION OF THE PRESENT STUDY WITH SUGGESTIONS FOR IMPROVEMENTS AND FURTHER WORK

The present study is summarized in this chapter and attainment of the objectives is assessed. A simulation model is not easily brought to perfection and certain improvements needed in the present model are cited. In addition, this study provides the basis for several suggestions that may prove fruitful for further research.

Recapitulation of Objectives and Evaluation of Achievements

As listed in Chapter I, the objectives of this study were to:

1. Determine the responses of individual fishing firms in the Gulf of Mexico shrimp industry and the resultant aggregate effect for the industry to changes in:
 - a. The shrimp population in the Gulf of Mexico;
 - b. Technological conditions of harvesting and processing; and
 - c. Demand conditions.
2. Determine whether alternative management strategies exist which will improve industry efficiency in a social sense, reducing overinvestment and/or the extent of non-optimal husbandry practices that occur as a result of the free use of an open access resource.

The steps involved in pursuing the objectives involved developing a bioeconomic theory of a fishery and applying it to the shrimp resource.

A rather general abstract model of shrimp resource resulted from this application. Based on the abstract model, a simulation model of the Gulf of Mexico shrimp industry was developed. Experimentation with the simulation model produced empirical results relating to alternative policies.

Objectives 1.a. and 1.c. did not emerge as the primary objectives of the study. They were achieved, however, to the extent that a model incorporating estimates of the indicated responses was realized. Objective 1.b., relating to responses of firms and the industry to changes in technology, was not satisfied. The model resulting from this study could, however, incorporate certain types of technological changes such as changes in trawling effectiveness or ability of a vessel to fish more days per month.

Objective 2. emerged as the primary concern of this study. The part of the second objective relating to non-optimal husbandry practices was approached only indirectly through the effect of the policies on measures of the value of the catch. The effects of the specified regulatory measures on investment in the harvesting sector of the industry were determined. In addition, the relative effects of the regulatory policies on several measures of industry performance were discussed. Part of the objectives set forth at the beginning of this study were attained to a limited degree. In order to more fully achieve the stated objectives, there are certain parameter improvements and model extensions that need to be made.

Improvements Needed in the Present Model and Suggestions for Further Work

Most of the work that seems to be needed involves obtaining more complete data to improve parameter estimates within the model. In this

regard, sensitivity analysis on the present parameter estimates to determine which ones are the most critical and thus, need more careful estimation would seem to be a logical starting place. Model improvements are, however, not without cost, and potential gains from model improvements must be weighed carefully against the costs of making and implementing the improvements before research is undertaken to improve the model.

Improvements are needed of estimates of the frequency distribution of shrimp recruits by species, area, and month of year. The means and standard deviations used in the model to generate recruits are very rough estimates indeed. Other areas for improvement in the basic resource model include improving the mortality estimates used in the survival equations, differentiating the growth of shrimp by species and season, as well as relating the fishing mortality suffered by a size class of shrimp to the fishing effort of specific size classes of vessels. As an example of this latter recommendation, it is unlikely that vessels over 80 gross registered tons contribute very much to the fishing mortality of the smaller size classes of shrimp that are taken in relatively shallow water. On the other hand, boats (craft of less than five net registered tons) do not contribute to the fishing mortality suffered by the larger size classes of shrimp in the deep-water grounds away from the coastal areas. This problem may be solved by considering fishing effort by vessel size class to be specific to parts of an area by depth or by inshore versus offshore classification. In addition, more accurate description of the geographic range of shrimp of different size classes may contribute to more accurate mortality rates.

The model of the harvesting sector of the industry needs refinement with respect to the process by which vessels enter and leave the fleet, allocate fishing effort among areas, and determine degree of fishing intensity. The improvement in these areas could come in the form of more complete specification rather than restructuring of the model.

A study that would perhaps add much to the present model involves identifying the relative magnitudes of the determinants of cost per day fished by vessels in different size classes fishing in different areas of the Gulf of Mexico. The vessel costs per day fished obtained from such a study could be combined with the catch rate and returns figures of this study to determine net revenue more accurately. Given accurate data on net revenue and effort by vessel size class and area, a study to determine the causal relationships between net revenue and effort should improve the vessel allocation and effort intensity schemes.

The model of the marketing and demand sector is the product of Doll [16]. If this model were respecified to conform to a monthly time interval and expanded to provide an estimate of retail demand and ex-vessel price by size class of shrimp, it would be more conformable to the data requirements of the simulation model. This extension of the model would allow development of a more refined measure of consumer surplus and, consequently, a more complete evaluation of the effects of proposed regulatory policies on consumers as well as other segments of the industry.

Meaningful systems analysis projects are evolutionary in that they require models which are continually updated to keep them relevant from the point of view of the current physical, biological, and decision environments. All of the above suggestions for further work would not, of course, result in a perfect model.

APPENDIX I

Computer program, SHRIMP, and data needed to
estimate recruits by species by month and area

SHRIMP

THIS PROGRAM IS DESIGNED TO CALCULATE THE MEAN, RANGE AND RANGE
 DIVIDED BY FOUR FOR SHRIMP RECRUITS (SHRIMP ATTAINING THREE MONTHS
 OF AGE) BY SPECIES, AREA AND MONTH OF YEAR. THE CALCULATIONS ARE
 PERFORMED USING TWO YEARS (24 MONTHS) OF DATA ON TOTAL SHRIMP
 CATCH AND CATCH OF SHRIMP NUMBERING 53 OR MORE PER POUND BY
 SPECIES, AREA AND MONTH OF YEAR. IN ADDITION, DATA ON DAYS FISHED
 AND NUMBER OF TRIPS BY INTERVIEWED CRAFT AND TOTAL TRIPS BY THE
 FLEET IN EACH AREA AND MONTH, NUMBER OF CRAFT IN THE FLEET AND
 SWEEP CAPACITY BY VESSEL SIZE CLASS, AND NUMBER OF VESSELS FISHING
 AND AVERAGE DAYS FISHED PER MONTH BY VESSELS IN EACH SIZE CLASS
 BY AREA AND MONTH WERE UTILIZED IN ESTIMATING SHRIMP RECRUITS BY
 SPECIES, AREA AND MONTH OF YEAR. THE INDEXES AND VARIABLES USED IN
 THIS PROGRAM ARE:
 H DENOTES VESSEL SIZE CLASS AS 10 LESS THAN 5 GRT
 20 5-19 GRT
 30 20-49 GRT
 40 50-79 GRT
 50 80 GRT AND OVER

I DENOTES SHRIMP SPECIES AS 10 BROWN

20 PINK

30 WHITE

J DENOTES AREA AS 10 SANIDEL # TORTUGAS

20 APPALACHICOLA

30 PENSACOLA TO MISSISSIPPI RIVER

40 MISSISSIPPI RIVER TO TEXAS

50 TEXAS COAST

60 HIGH SEAS OFF MEXICAN COAST WEST OF LONG 94

70 HIGH SEAS OFF OREGON AND CAMPECHE.

K DENOTES MONTH OF YEAR (K=10 JAN., ..., 12 DEC) AND YEARLY TOTALS

(K=13)

L DENOTES YEAR (L=1, 2) OR A WORK AREA TO COMPUTE MEANS AND RANGES

(L=3, 4, 5)

RIJKL(I, J; K, L) RECRUITS (SHRIMP ATTAINING THREE MONTHS OF AGE) BY

SPECIES, AREA AND MONTH OF YEAR
 DAYS FISHED BY VESSEL SIZE CLASS AND MONTH.
 CATCH OF SHALP OF COUNT LESS THAN 68 PER POUND BY
 SPECIES, AREA, MONTH AND YEAR.
 24-HR DAYS FISHED BY VESSEL SIZE CLASS, AREA,
 MONTH AND YEAR.
 24-HR DAYS FISHED BY AREA, MONTH AND YEAR.
 NUMBER OF VESSELS IN EACH SIZE CLASS FISHING IN EACH
 AREA
 FISHING MORTALITY COEFFICIENT BY AREA, MONTH AND YEAR
 24-HR DAYS FISHED STANDARDIZED FOR VESSEL SWEEP
 CAPACITY BY AREA, MONTH AND YEAR.
 SWEEP CAPACITY IN FEET ALONG FOOTROPE OF NETS BY VESSEL SIZE
 CLASS
 COEFFICIENT TO CONVERT STANDARDIZED 24-HR DAYS FISHED INTO
 FISHING MORTALITY COEFFICIENT BY AREA.
 24-HR DAYS FISHED BY INTERVIEWED CRAFT BY AREA,
 MONTH AND YEAR.
 TRIPS MADE BY INTERVIEWED CRAFT BY AREA, MONTH AND
 YEAR
 ESTIMATED TRIPS MADE BY THE FLEET BY AREA, MONTH
 AND YEAR
 THE SUM OVER VESSEL SIZE CLASSES OF THE PRODUCT OF
 ENHJ(H,J) AND XHK(H,K), THE RESULT HAVING THE
 DIMENSIONS OF AREA AND MONTHS.
 STANDARDIZED 24-HR DAYS FISHED BY VESSEL SIZE
 CLASS, AREA, MONTH AND YEAR.
 FISHING MORTALITY AS A PER CENT OF TOTAL MORTALITY
 BY AREA, MONTH AND YEAR.
 RECRUITS ADJUSTED TO BE CONSISTENT WITH ANNUAL
 CATCH BY SPECIES, AREA, MONTH AND YEAR.
 AN ARRAY CONTAINING THE ACTUAL YEAR THAT THE DATA IN
 EACH MONTH AND (ACCOUNTING) YEAR CORRESPONDS TO.
 IN ORDER TO BE GENERAL, THIS PROGRAM MUST BE REVISED TO ACCEPT

C A VARIABLE NUMBER OF YEARS OF DATA AND EXPANDED TO INCLUDE A
 C ROUTINE TO CALCULATE MEANS AND STANDARD DEVIATIONS. THE PROGRAM
 C BIGONE, LISTED IN APPENDIX TWO, CONTAINS SUCH A ROUTINE IN MS.
 C THE SUBROUTINE MSD CALCULATES A MEAN (R1) AND STANDARD DEVIATION
 C (R2) WHEN GIVEN THE OBSERVATION VECTOR (S1) AND NUMBER OF
 C OBSERVATIONS (NYTP).

C READ FORMATS FOLLOW

101 FORMAT(I2,T6,F7.1,2F6.1,F11.0,2F10.0)

102 FORMAT(T6,5F5.2)

103 FORMAT(7F10.7)

104 FORMAT(5F5.1)

105 FORMAT(T6,5F5.0)

C WRITE FORMATS FOLLOW

151 FORMAT('O','***** THERE WAS NO EFFORT REPORTED IN AREA ',I1,' IN M
 MONTH ',I2,' YEAR 19',I2,'. THUS THE ESTIMATE OF ZERO RECRUITS IS N
 XGT RELIABLE *****')

152 FORMAT('I',I25,'***** AREA ',I1,' MONTH ',I2,' YEAR ',I1,'
 X (CORRESPONDING TO DATA IN YEAR 19',I2,') *****')

153 FORMAT('O',SHRIMP SPECIES '*****',T63,'BROWN',T97,'PINK',
 X,T129,'WHITE')

154 FORMAT('O',RECRUITS AT BEGINNING OF MONTH '*,3F33.0)

155 FORMAT('O',CATCH DURING MONTH '*,3F33.0)

156 FORMAT('O',FISHING MORTALITY (FROM ADJUSTED DAYS FISHED) '*,5F16.
 X12,' FISHING MORTALITY AS A PER CENT OF TOTAL MORTALITY '*,5F16.
 XF5.2)

157 FORMAT('O',VESSEL SIZE CLASS (IN GRT) '*****',T42,'LESS THAN 5',T61,
 X15 THRU 19',T76,'20 THRU 49',T92,'50 THRU 79',T107,'80 AND OVER',T
 X128,'TOTAL')

158 FORMAT('O',UNADJUSTED 24-HR DAYS FISHED '*,6F16.2)

159 FORMAT('O',ADJUSTED 24-HR DAYS FISHED '*,6F16.2)

```

160 FORMAT('1BROWN SHRIMP IN AREA ',I1,T51,'AVERAGE RECRUITS',T95,'RAN
XGE',T113,'RANGE DIVIDED BY FOUR')
161 FORMAT('1PINK SHRIMP IN AREA ',I1,T51,'AVERAGE RECRUITS',T95,'RANG
XE',T113,'RANGE DIVIDED BY FOUR')
162 FORMAT('1WHITE SHRIMP IN AREA ',I1,T51,'AVERAGE RECRUITS',T95,'RAN
XGE',T113,'RANGE DIVIDED BY FOUR')
163 FORMAT('OMONTH ',I2,' *****',3F33.2)
164 FORMAT('1YEAR ',I1,' DATA')
165 FORMAT('OAREA ',I1,T33,'YEAR',T38,'ESTIMATED TRIPS',T55,'INTERVIEW
XTRIPS',T71,'INTERVIEW DAYS',T89,'BROWN SHRIMP',T106,'PINK SHRIMP',
XT122,'WHITE SHRIMP')
166 FORMAT(' ',T33,'19',I2,T37,'F16.2)
167 FORMAT('OBROWN SHRIMP IN YEAR ',I1,' IN AREA ',I1,' *****',F13.0)
168 FORMAT('OWHITE SHRIMP IN YEAR ',I1,' IN AREA ',I1,' *****',F13.0)
169 FORMAT('OPINK SHRIMP IN YEAR ',I1,' IN AREA ',I1,' *****',F13.0)
170 FORMAT('O')
171 FORMAT('O',T39,'***** RECRUITS ADJUSTED FOR ANNUAL (MONTH I3) CATC
IH *****')

```

C

TYPE DECLARATION AND INITIALIZATION

```

REAL*8 RIJKL(3,7,13,5)/1365*0.0/,XHK(5,13)/65*0.0/,CIJKL(3,7,13,2)
X/546*0.0/,XHJKL(5,7,13,2)/910*0.0/,XJKL(7,13,2)/182*0.0/,ENHJ(3,7)
X/35*0.0/,FJKL(7,13,2)/182*0.0/,XSJKL(7,13,2)/182*0.0/,SH(5)/5*0.0/
X,BJ(7)/7*0.0/,XINJKL(7,13,2)/182*0.0/,TINJKL(7,13,2)/182*0.0/,TESJ
XKL(7,13,2)/182*0.0/,SHNJXK(7,13)/91*0.0/,XSHJKL(5,7,13,2)/91*0.0/
X,PCFJKL(7,13,2)/182*0.0/,RIJKL(3,7,13,2)/546*0.0/
INTEGER LACKL(13,2)/26*0/,M

```

C READ IN DATA

```

1 DO 200 L=1,2
2 DO 200 K=1,13
3 DO 201 J=1,7
201 READ(5,101) NY, TESJKL(J,K,L), TINJKL(J,K,L), XINJKL(J,K,L), CIJKL(I,
XJ,K,L), I=1,3)
200 LACKL(K,L)=NY
READ(5,103) (BJ(J),J=1,7)

```

C


```

READ(5,104) (SH(H),H=1,5)
DO 202 J=1,7
202 READ(5,105) (ENPJ(H,J),H=1,5)
DO 203 K=1,13
203 READ(5,102) (XHK(H,K),H=1,5)
C COMPUTE DESIRED STATISTICS
DO 204 K=1,13
DO 204 J=1,7
DO 205 H=1,5
205 SHNJXK(J,K)=SHNJXK(J,K)+ENPJ(H,J)*XHK(H,K)
DO 204 L=1,2
IF(TESJKL(J,K,L).EQ.0.0) GO TO 214
XJKL(J,K,L)=TESJKL(J,K,L)*XINJKL(J,K,L)/TINJKL(J,K,L)
DO 206 H=1,5
XHJKL(H,J,K,L)=XHK(H,K)*ENPJ(H,J)*XJKL(J,K,L)/SHNJXK(J,K)
206 XSJKL(J,K,L)=XSJKL(J,K,L)+SH(H)*XHJKL(H,J,K,L)/SH(4)
FJKL(J,K,L)=BJ(J)*XSJKL(J,K,L)
DO 209 I=1,3
208 RIJKL(I,J,K,L)=100.*CIJKL(I,J,K,L)*(FJKL(J,K,L)+.22)/FJKL(J,K,L)*{
X1.-DEXP(-FJKL(J,K,L)-.22)}
IRIJKL=RIJKL(I,J,K,L)
IF((RIJKL(I,J,K,L)-IRIJKL)-GE.0.5)RIJKL(I,J,K,L)=RIJKL(I,J,K,L)+1,
C THIS STATEMENT EMBODIES THE ASSUMPTION THAT THE AVERAGE SIZE (=
C THE TOTAL CATCH IS 50 TAILS PER POUND
IF(K.EQ.13) RIJKL(I,J,K,L)=.5*RIJKL(I,J,K,L)
209 CONTINUE
PCFJKL(J,K,L)=FJKL(J,K,L)*100./{FJKL(J,K,L)+.22)
DO 210 H=1,5
210 XSHJKL(H,J,K,L)=SH(H)*XHJKL(H,J,K,L)/SH(4)
214 CONTINUE
204 CONTINUE
DO 217 I=1,3
DO 217 L=1,2
DO 217 J=1,7

```

```

SRIJK=0.0
DO 218 K=1,12
218 SRIJK=SRIJK+RIJKL(I,J,K,L)
IF(SRIJK.EQ.0.0) SRIJK=i.0
DO 219 K=1,12
219 RIJKL(I,J,K,L)=RIJKL(I,J,K,L)*RIJKL(I,J,L3,L)/SRIJK
RIJKL(I,J,L3,L)=RIJKL(I,J,L3,L)
217 CONTINUE
C WRITE OUTPUT OF INTEREST
DO 220 L=1,2
DO 220 J=1,7
DO 220 K=1,13
XHTOT=0
DO 222 H=1,5
XHTOT=XHTOT+XHJKL(H,J,K,L)
222 CONTINUE
WRITE(6,152) J,K,L,LACKL(K,L)
IF(YESJKL(J,K,L).EQ.0.0) WRITE(6,151) J,K,L
WRITE(6,153)
WRITE(6,154) (RIJKL(I,J,K,L),I=1,3)
WRITE(6,155) (CIJKL(I,J,K,L),I=1,3)
WRITE(6,156) FJKL(J,K,L)* PCFJKL(J,K,L)
WRITE(6,157)
WRITE(6,158) (XHJKL(H,J,K,L),H=1,5),XHTOT
WRITE(6,159) (XS+JKL(H,J,K,L),H=1,5),XSJKL(J,K,L)
DO 221 M=1,2
221 WRITE(6,170)
WRITE(6,171)
WRITE(6,153)
WRITE(6,154) (RIJKL(I,J,K,L),I=1,3)
220 CONTINUE
DO 211 K=1,12
DO 211 J=1,7
DO 211 I=1,3

```

```

RIJKL(I,J,K,3)=(RIJKL(I,J,K,1)+RIJKL(I,J,K,2))/2.
RIJKL(I,J,K,4)=DABS(RIJKL(I,J,K,1)-RIJKL(I,J,K,2))
211 RIJKL(I,J,K,5)= RIJKL(I,J,K,4)/4.
DO 212 I=1,3
DO 212 J=1,7

```

```

IF(I.EQ.1) WRITE(6,160) J
IF(I.EQ.2) WRITE(6,161) J
IF(I.EQ.3) WRITE(6,162) J
DO 212 K=1,12

```

```

212 WRITE(6,163) K, (RIJKL(I,J,K,L),L=3,5)
DO 215 L=1,2
DO 215 I=1,3
DO 215 J=1,7
SUMC=0.
DO 216 K=1,12
SUMC=SUMC+RIJKL(I,J,K,L)
216 CONTINUE
IF(I.EQ.1) WRITE(6,167) L,J,SUMC
IF(I.EQ.2) WRITE(6,169) L,J,SUMC
IF(I.EQ.3) WRITE(6,168) L,J,SUMC
215 CONTINUE
C WRITE DATA
DO 213 L=1,2
WRITE(6,164) L
DO 213 J=1,7
WRITE(6,165) J
DO 213 K=1,12
213 WRITE(6,166) LACKL(K,L),TESJKL(J,K,L),TINJKL(J,K,L),
X(CIJKL(I,J,K,L),I=1,3)
STOP
END
C
68011 9952 1425 3625
68012 2450 390 306
DATA 56772
1063

```

68013	2790	370	1010	5875		272
68014	25186	2755	3684			527964
68015	7855	495	911	127		28980
68016	2600	480	1685			
68017	103	210	1819			
67021	9012	2395	6290		50861	
67022	1310	290	203		398	111
67023	1508	203	520			5975
67024	18129	3833	5238			235954
67025	4428	1024	2168			14494
67026	2380	770	2355			
67027	1523	415	1407			
68031	9275	1116	2994		62699	
68032	3170	470	165		2028	
68033	2137	546	882		130	1150
68034	13370	2730	2744	1231		86910
68035	6001	701	1453			14463
68036	1640	440	1625	562		
68037	1827	447	3049		93	
68041	8125	1851	5599		74829	
68042	12265	1256	870		54239	
68043	3343	894	884	812	2311	
68044	11714	869	2018			10963
68045	11738	851	1702	1358		145
68046	2180	660	2040			
68047	1945	629	4091		455	
68051	6199	1052	2738		24500	
68052	21938	1597	1280		56710	
68053	35767	8057	3867		471	
68054	170879	12913	6695			2781
68055	19334	768	1908			
68056	4020	1070	3889			
68057	2023	403	3422			
68061	3430	425	1248		7228	

68062	17330	1730	1009	233744	17354	926
68063	120845	24351	9799	3609677		740
68064	373570	29737	9607	6347279		3254
68065	35586	2046	4188	158247		
68066	2724	480	1673			
68067	1255	291	2274			
68071	1580	280	909		8246	
68072	15610	1540	919	61449	1253	
68073	63660	11420	6859	751640		
68074	201214	19462	6990	2450453		24642
68075	41662	2998	6579	39660		3340
68076	2680	300	818			
68077	224	20	365			
68081	1787	607	1522		29547	
68082	9786	846	678	1507	13586	
68083	56607	7618	7113	76615		59174
68084	143429	15498	6354	220514		606166
68085	73037	2721	6942	7354		210555
68086	2340	590	1714			
68087	64	30	270			
68091	2204	690	1471	163	74840	
68092	10900	1690	490	160	15874	14590
68093	65884	10966	4964	10747		30844
68094	171264	11859	6098	54777		480368
68095	100042	2365	6819	5654		275735
68096	2480	320	1314			
68097	76	10	175			
68101	2504	654	1562		53215	7282
68102	13657	2261	858	27	6076	62713
68103	92327	18456	8333	3863		950479
68104	211866	19290	9712	51014		216121
68105	98196	2009	6186	3695		
68106	3050	610	2413			
68107	90	40	397			

68111	6420	1503	3800		93614	38523
68112	9000	1440	583	407	3053	13747
68113	29769	7880	5013	3715		1305714
68114	135273	13569	4165	1054		184731
68115	51390	3048	6899	686		
68116	1901	220	1065	80		
68117	187	20	190			
68121	8440	992	2952		35240	37327
68122	3680	670	279		1342	10183
68123	13138	677	1433	470		1059907
68124	74889	2414	1721	1160		38100
68125	19549	2250	4311			
68126	3120	60	215			
68127	884	47	543			
68131	71758	12017	32544	163	9702828	673701
68132	121196	14160	7593	1365016	1516092	2207215
68133	488293	91455	50767	16797706	219463	16073668
68134	1572303	134816	64588	25651823	13328	11348751
68135	469476	20492	48377	27287772	14932	511622
68136	32235	5740	20481	7541351	15910	37408
68137	11146	2435	19438	217005	6057862	
69011	8800	1513	4284		36062	
69012	1960	390	191			6701
69013	3242	461	1016	1815	262	5344
69014	47488	828	3079	1193		386593
69015	11100	1491	3665			11055
69016	2530	110	345			
69017	650	167	917			
69021	9799	1482	3774		73266	169
69022	1223	190	85		31	463
69023	2520	370	954	256	437	222689
69024	18060	864	2448	156		13187
69025	9060	1246	3432			
69026	2780	200	932			

67125	24999	982	2066																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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APPENDIX II

Simulation program, BIGONE, and initialization data

BIGONE

THIS PROGRAM IS DESIGNED TO PROVIDE INFORMATION ON THE IMPACT OF THREE POLICY VARIABLES -- AGE AT FIRST CAPTURE, VESSEL ENTRY FEE AND A LANDINGS TAX ON SHRIMP -- ON THE ANNUAL WHOLESAL AND EXVSEL VALUES OF THE CATCH AND TOTAL PRODUCTION COSTS. THE MAIN PROGRAM, BIGONE, KEEPS SUMMARY STATISTICS AND CONTROLS AND TRANSMITS VALUES BETWEEN THE SUBROUTINES, SHRIMP FLEET AND MARKET. THE TIME INCREMENT IS ONE MONTH, EXCEPT FOR SUMMARY STATISTICS, WHICH ARE ANNUAL, AND THE SUBROUTINE MARKET WHICH EMPLOYS A QUARTERLY TIME INCREMENT. THE VARIABLES AND THE PROGRAM(S) IN WHICH THEY APPEAR (DENOTED BY B, S, F OR M IN PARENTHESES FOLLOWING THE VARIABLE NAME) ARE DEFINED BELOW:

H DENOTES VESSEL SIZE CLASS AS 10 LESS THAN 5 GRT
20 5-10 GRT
30 20-49 GRT
40 50-79 GRT
50 80 GRT AND OVER

I DENOTES SHRIMP SPECIES AS 10 BROWN
20 PINK
30 WHITE

J DENOTES AREA AS 10 SANICEL + TORTUGAS
20 APPALACHICOLA
30 PENSACOLA TO MISSISSIPPI RIVER
40 MISSISSIPPI RIVER TO TEXAS
50 TEXAS COAST
60 HIGH SEAS OFF MEXICAN COAST WEST OF LONG 94
70 HIGH SEAS OFF OREGON AND CAMPECHE.

N DENOTES SHRIMP SIZE AS 10 VERY SMALL, OVER 55 TAILS/LB
20 SMALL, 41-65 TAILS/LB

30 MEDIUM, 26-40 TAILS/LB
 40 LARGE, 25 TAILS/LB AND UNDER.
 K IS AN INDEX REFERRING TO THE PREVIOUS 18 MONTHS.
 M INDEXES VARIABLE COSTS FOR CRAFT FISHING IN THEIR HOME AREA
 (M=1) AND IN AN AREA NOT THEIR HOME AREA.
 CHJN(H,J,N)O(B,S,F) CATCH OF VESSELS IN SIZE CLASS 4 IN AREA J OF
 SHRIMP OF SIZE N IN POUNDS
 XHJ(H,J)O(B,S,F) EFFORT IN 24-HR DAYS FISHED OF VESSELS IN SIZE
 CLASS H IN AREA J (TOTAL-NOT PER VESSEL).
 PEXVN(N)O(B,M,F) EXVESSEL PRICE IN DOLLARS FOR SHRIMP I,J SIZE
 CLASS N (QUARTERLY)
 FFEH(H)O(B,F) ANNUAL ENTRY FEE PER VESSEL IN DOLLARS FOR VESSELS
 IN SIZE CLASS H.
 XLFEEN(N)O(B,F) LANDING TAX IN DOLLARS PER POUND FOR SHRIMP OF
 SIZE N.
 CJN(J,N)O(B,M) CATCH IN AREA J OF MILLIONS OF POUNDS OF SHRIMP OF
 SIZE N
 TCY(JY) (JY=1,...,30 YEARS)O(B) TOTAL PRODUCTION COST IN YEAR JY
 VEXCVY(JY)O(B) EXVESSEL VALUE OF THE CATCH IN YEAR JY
 VCWHLY(JY)O(B) WHOLESAL VALUE OF THE CATCH IN YEAR JY
 RCA(JY)O(B) REVENUE TO THE CONTRL AUTHORITY IN YEAR JY
 VSSHJY(JY)O(B) CATCH OF VERY SMALL SHRIMP IN YEAR JY.
 SMSSHJY(JY)O(B) CATCH OF SMALL SHRIMP IN YEAR JY.
 XMSHJY(JY)O(B) CATCH OF MEDIUM SHRIMP IN YEAR JY.
 XLSSHJY(JY)O(B) CATCH OF LARGE SHRIMP IN YEAR JY.
 CATCH(JY)O(3) TOTAL SHRIMP CATCH IN YEAR JY.
 CN(N)O(M) CATCH IN MILLIONS OF POUNDS OF SHRIMP OF SIZE N
 CJ(J)O(M) CATCH IN MILLIONS OF POUNDS OF SHRIMP IN AREA J
 CTCO(M) TOTAL CATCH OF SHRIMP IN MILLIONS OF POUNDS IN THE CURRENT
 TIME PERIOD
 CTLO(M) CTC LAGGED ONE TIME PERIOD
 XIMPTSO(M) IMPDRTS OF SHRIMP IN MILLIONS OF POUNDS
 STKSTCO(M) ENDING STOCKS OF SHRIMP IN COLD STORAGE IN MILLIONS OF
 POUNDS

STKSTLO(M) STKSTC LAGGED ONE PERIOD
 PWHSLO(B,M) WHOLESale PRICE IN DOLLARS
 PEXVTCO(M) EXVESSEL PRICE IN DOLLARS
 PEXVTLQ(M) PEXVTC LAGGED ONE PERIOD
 CHJ(H,J)O(F) POUNDS OF SHRIMP CAUGHT BY VESSELS OF SIZE CLASS H IN
 AREA J
 ENHJ(H,J)O(B,F) NUMBER OF CRAFT OF SIZE CLASS H FISHING IN AREA J.
 ENHAHJ(H,J)O(F) NUMBER OF CRAFT OF SIZE CLASS H HAVING AREA J AS
 THEIR HOME AREA.
 SHARHJ(H,J)O(F) PROPORTION OF GROSS RECEIPTS CLAIMED BY UNLOADING
 FEES AND CREW SHARE FOR CRAFT OF SIZE CLASS H IN
 AREA J.
 FCHJ(H,J)O(F) MONTHLY FIXED COST ASSOCIATED WITH CRAFT OF SIZE
 CLASS H IN AREA J (INCLUDES EFFE(H)/12.0).
 VCHJM(H,J,M)O(F) VARIABLE COST PER 24-HR DAY FISHED OF OPERATING A
 CRAFT OF SIZE CLASS H IN AREA J WHEN AREA J IS HOME
 AREA (M=1) AND WHEN IT IS NOT (M=2).
 PRHJK(H,J,K)O(F) RETURN TO MANAGEMENT (GROSS RETURNS LESS ALL
 COSTS) FOR A CRAFT OF SIZE CLASS H IN AREA J IN
 THE (K-1)TH PRECEDING MONTH (K=1,...,12)
 UT(H,J)O(F) CRAFT ADDED TO THE FLEET IN SIZE CLASS H IN AREA J
 BHJJ(H,J,J1)O(F) MIGRATION COEFFICIENTS FOR VESSELS IN SIZE CLASS
 H FROM AREA J TO AREA J1.
 AVMXHK(H,K)O (F) AVERAGE 24-HR DAYS FISHED PER VESSEL BY VESSELS
 IN SIZE CLASS H IN MONTH K (1=FEB,...,12=JAN)
 SDMIJK(M,I,J,K)O(S) STANDARD DEVIATION (M=2) AND MEAN (M=1) OF
 NUMBER OF RECRUITS OF SPECIES I IN AREA J
 IN MONTH K (K=1=JAN,2=FEB,...,12=DEC)
 SHRIJK(I,J,K)O(S) NUMBER OF SHRIMP OF SPECIES I IN AREA J OF AGE
 K+2 MONTHS (K=1,...,18)
 SH(H)O(S) SWEEP CAPACITY IN HUNDREDS OF FEET OF VESSELS OF SIZE
 CLASS H.
 BJ(J)O(S) COEFFICIENTS TO CONVERT STANDARDIZED DAYS FISHED INTO A
 FISHING MORTALITY COEFFICIENT IN AREA J

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C      K10(B,S) AGE AT FIRST CAPTURE IN MONTHS MINUS 3 (K1=1,2,3,4)
C      XNRAND0(8,5) A NORMAL (0,1) RANDOM VARIABLE
C      INITIAL VALUES NEEDED INCLUDE, BY PROGRAM0
C      BIGONE0 K1,EFEEN(H),ALFEEN(W),NYTP,XHJ(H,J),PEXVN(N)
C      SHRIMP0 SOMIJK(M,I,J,K),SH(H),BJ(J)
C      FLEETO AVXKHJ(H,J),BHJ(H,J),VCHJM(H,J,M),FCHJ(H,J),ENHJ(H,J)
C      ENPAHJ(H,J),SHARHJ(I,J)
C      MARKETO NONE
C      CJ(J)0(F) RATIO OF DAYS FISHED BY VESSELS IN AREA J TO AVERAGE FOR
C      THE GULF.
C
C
C      MAIN
C
C      COMMON Nzed, IT1, IT2, NYTP
C      REAL*8 CHJN(5,7,4)/140*0.0/,XHJ(5,7)/35*0.0/,PEXVN(4)/4*0.0/,EFEEN
C      1(5)/5*0.0/,XLFEEN(4)/4*0.0/,CJN(7,4)/28*0.0/,TCY(30)/30*0.0/,VCEXV
C      2Y(30)/30*0.0/,VCWHLY(30)/30*0.0/,RCA(30)/30*0.0/,RANDIS(30)/30*0.0
C      3/,CATCH(30)/30*0.0/,VSSHJY(30)/30*0.0/,SMSSHJY(30)/30*0.0/,XMSHJY(3
C      40)/30*0.0/,XLSSHJY(30)/30*0.0/,SH(5)/5*0.0/,XAR(20)/30*0.0/,ADF(30)
C      5/30*0.0/,UDF(30)/30*0.0/,KIC(30)/30*0.0/,VF5(30)/30*0.0/,VF67(30)/
C      630*0.0/,FIMP(30)/30*0.0/,INWP(30)/30*0.0/,AVCP(30)/30*0.0/,ENPAHJ(
C      75,7)/35*0.0/,ACPJ(5,7)/35*0.0/,PCR5(30)/30*0.0/,PCR6(30)/30*0.0/
C      REAL*4 RMNS(30)/30*0.0/
C      INTEGER H,I,T1,T2
C      101 FORMAT(F3.0,5F6.0,4F4.2)
C      102 FORMAT(5F7.2)
C      103 FORMAT(I3)
C      104 FORMAT(4F10.2)
C      105 FORMAT('2///T21,WHOLESALE VALUE OF THE CATCH IN THE CURRENT
C      1TIME PERIOD IS .....',F16.3//T21,'EX/ESS
C      2EL VALUE OF THE CATCH IN THE CURRENT TIME PERIOD IS.....')

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3.....$,F16.3//T21,'TOTAL PRODUCTION COSTS FOR THE CUR
4RENT TIME PERIOD AMOUNT TO.....$,F16.2//T
521,'REVENUE TO THE CONTROL AUTHORITY DURING THE CURRENT TIME PERIO
6D.....$,F16.3)
106 FORMAT('1THE FOLLOWING SUMMARY STATISTICS PRESENT ANNUAL VALUES OF
1 THE WHOLESALE AND EXVESSEL VALUES OF THE CATCH, TOTAL PRODUCTION
2COSTS AND//',TOTAL REVENUE TO THE CONTROL AUTHORITY'//T41,'WHOLE
3ALE VALUE',T61,'EXVESSEL VALUE',T81,'PRODUCTION COSTS',T101,'REV T
4C CUNT AUTH')
107 FORMAT('0',T40,'$',F16.3,T60,'$',F16.3,T80,'$',F16.3,T100,'$',F16.
13)
108 FORMAT('1FOR THE ',I2,' YEAR PERIOD SIMULATED, YEARLY MEANS AND ST
1ANDARD DEVIATIONS ARE GIVEN BELOW//T66,'MEAN',T82,'STANDARD DEVI
2TION'//', WHOLESALE VALUE OF THE CATCH',T52,'$',F19.5,T82,'$',F19.
35//', EXVESSEL VALUE OF THE CATCH',T52,'$',F19.5,T82,'$',F19.5//',
4 TOTAL ANNUAL PRODUCTION COSTS',T52,'$',F19.5,T82,'$',F19.5//', AN
5NUAL REVENUE TO THE CONTROL AUTHORITY',T52,'$',F19.5,T82,'$',F19.5
6//', LANDINGS OF VERY SMALL SHRIMP',T53,F19.5,' LBS.',T83,F19.5,'
7LBS.'//', LANDINGS OF SMALL SHRIMP',T53,F19.5,' LBS.',T83,F19.5,'
8LBS.'//', LANDINGS OF MEDIUM SHRIMP',T53,F19.5,' LBS.',T83,F19.5,'
9 LBS.'//', LANDINGS OF LARGE SHRIMP',T53,F19.5,' LBS.',T83,F19.5,'
A LBS.'//', TOTAL LANDINGS',T53,F19.5,' LBS.',T83,F19.5,' LBS.'//',
B NET RETURN',T52,'$',F19.5,T82,'$',F19.5//', ADJUSTED DAYS FISHED',
C,T53,F19.5,T83,F19.5//', UNADJUSTED DAYS FISHED',T53,F19.5,T83,F19
D.5//', NUMBER OF CRAFT',T43,F19.5,T83,F19.5//', VALUE OF THE FLEET
E (5-YR INV LIFE)',T52,'$',F19.5,T82,'$',F19.5//', VALUE OF THE FLE
FET (6.7-YR INV LIFE)',T52,'$',F19.5,T82,'$',F19.5//', IMPORTS',T52
G,F19.5,' LBS.',T83,F19.5,' LBS.'//', WHOLESALE PRICES',T52,'$',F19.5,
HT83,'$',F19.5//', EXVESSEL PRICE',T52,'$',F19.5,T82,'$',F19.5//',
I PERCENTAGE RETURN TO FLEET INV (5-YR LIFE)',T53,F19.5,' ',T83,F19
J.5,' '///T31,'(6.7-YR LIFE)',T53,F19.5,' ',T83,F19.5,' ')
109 FORMAT('0THE RANDOM NUMBER FOR TIME PERIOD ',I3,' IS ',F10.5)
110 FORMAT('1')
111 FORMAT('///', THE FOLLOWING SUMMARY STATISTICS PRESENT SHRIMP LAND

```

```

111INGS BY SIZE OF SHRIMP AND TOTAL LANDINGS IN POUNDS'//T21,'OVER 5
25 TAILS/LB.',T41,'41-65 TAILS/LB.',T61,'26-40 TAILS/LB.',T81,'25 D
3R LESS TAILS/LB. TOTAL')
112 FORMAT('O',T21,5F20.1)
113 FORMAT('I FOR THE ',I2,' YEAR PERIOD SIMULATED, SIMPLE CORRELATION
1COEFFICIENTS FOR SELECTED VARIABLES (ANNUAL VALUES) ARE GIVEN BELOW
2W'//', NET RETURN AND PRODUCTION COSTS ',T60,F7.3//', NET RETURN A
3ND VALUE OF THE FLEET (5-YR INV LIFE) ',T60,F7.3 //', NET RETURN A
4ND VALUE OF THE FLEET (6.7-YR INV LIFE) ',T60,F7.3//', NET RETURN
5AND ADJUSTED DAYS FISHED',T60,F7.3//', NET RETURNS AND UNADJUSTED
6DAYS FISHED',T60,F7.3//', NET RETURNS AND NUMBER OF CRAFT',T60,F7.
73//', CATCH AND WHOLESALE PRICE',T60,F7.3//', CATCH AND EXVESSEL P
8RICE',T60,F7.3//', CATCH AND IMPORTS',T60,F7.3//', CATCH AND NET R
9ETURN',T60,F7.3//', CATCH AND ADJUSTED DAYS FISHED',T60,F7.3//', C
AATCH AND UNADJUSTED DAYS FISHED',T60,F7.3//', CATCH AND NUMBER OF
BCRAFT',T60,F7.3//', EXVESSEL VALUE OF THE CATCH AND ADJUSTED DAYS
CFISHED',T60,F7.3//', EXVESSEL VALUE OF THE CATCH AND UNADJUSTED DA
YS FISHED',T60,F7.3//', EXVESSEL VALUE OF THE CATCH AND NUMBER OF
ECRAFT',T60,F7.3)
114 FORMAT('O$',F12.2,' $',F12.2,' ',F10.0,'LES $',F12.2*2F14.2,F14.2,
1' $',F12.2,' $',F12.2)
115 FORMAT('I FOLLOWING ARE ANNUAL VALUES FOR THESE VARIABLES'//', AVE
1RAGE',T15,'AVERAGE',T57,'ADJUSTED',T71,'UNADJUSTED',T99,'VALUE OF',
2,T113,'VALUE OF',', WHOLESAL',T15,'EXVESSEL',T43,'NET',T57,'DAYS',
3,T71,'DAYS',T85,'NUMBER',T99,'FLEET (5-YR',T113,'FLEET (6.7-YR PRI
4CE',T15,'PRICE',T29,'IMPORTS',T43,'NET JRN',T57,'FISHED',T71,'FISHE
50',T85,'OF CRAFT',T99,'INV LIFE)',T113,'YR INV LIFE)')
READ(5,101) K1,(EPEEH(H),H=1,5),(XLFEE(H),H=1,4)
READ(5,103) NTP
JY=3
PWSL=1.0
IGC=15107
NYP=NTP/12
DO 1 T=1,NTP

```

```

IT1=(T-1)/12+1
IT2=T-(IT1-1)*12
IF((T-1)/12).EQ.(JY) JY=JY+1
IF(T.NE.(12*IT1-11)) GO TO 28
CALL RSEED(500,0)
ZED=RNDRMF(1000,0)
ZED=12.0*ZED/1000.0
IF((ZED-AINT(ZED)).GE.0.5) ZED=ZED+1.0
NZED=ZED
28 CONTINUE
IF((NZED.NE.IT2).AND.(IT1.GT.3).AND.(IT1.LT.NYTP)) GO TO 30
WRITE(6,110)
30 CONTINUE
CALL NDIST(30,100,0,25.0,100,0,D,RHHS)
DO 7 I=1,30
  RANBS(I)=RMNS(I)
7 CONTINUE
CALL MSD(XNRAND,DUM,RANBS,30)
XNRAND=(XNRAND-100.0)/(25.0/SQRT(30.0))
IF((NZED.NE.IT2).AND.(IT1.GT.3).AND.(IT1.LT.NYTP)) GO TO 31
WRITE(6,109) T, XNRAND
31 CONTINUE
IF(T.NE.1) GO TO 2
DO 3 J=1,7
  READ(5,102) (XHJ(H,J),H=1,5)
3 CONTINUE
  READ(5,104) (PEXVN(N),N=1,4)
2 CONTINUE
  CALL SHRIMP(CHUN,XHJ,K1,XNRAND,T,SH)
  DO 33 J=1,7
    DO 33 H=1,5
      ADF(JY)=ADF(JY)+XHJ(H,J)*SH(H)
      UDF(JY)=UDF(JY)+XHJ(H,J)
33 CONTINUE

```

```

XT=T
T1=(T-1)/3
XT1=T1
T2=T/3
XT2=T2
DO 4 J=1,7
DO 4 N=1,4
IF((XT-1.0)/3.0-XT1).EQ.0.0) CJN(J,N)=0.0
DO 4 H=1,5
CJN(J,N)=CJN(J,N)+CHJN(H,J,N)/(10.0**6.0)
4 CONTINUE
IF((XT/3.0)-XT2).NE.0.0) GO TO 8
DO 10 J=1,7
VSSHJY(JY)=VSSHJY(JY)+CJN(J,1)*10.0**6
SMSSHJY(JY)=SMSSHJY(JY)+CJN(J,2)*10.0**6
XPMSSHJY(JY)=XPMSSHJY(JY)+CJN(J,3)*10.0**6
XLSHJY(JY)=XLSHJY(JY)+CJN(J,4)*10.0**6
10 CONTINUE
8 CONTINUE
CALL FLEET(XHJ,CHJN,PEXVN,EFEEN,XLFEEN,T,TC,UT4,ENHAHJ,RCHJ)
IF((T/12).NE.JY) GO TO 34
DO 35 J=1,7
DO 35 H=1,5
XNC(JY)=XNC(JY)+ENHAHJ(H,J)
VF5(JY)=VF5(JY)+ENHAHJ(H,J)*RCHJ(H,J)/0.20
VF67(JY)=VF67(JY)+ENHAHJ(H,J)*RCHJ(H,J)/0.15
35 CONTINUE
34 CONTINUE
TCY(JY)=TCY(JY)+TC
IF(PEXVN(N).NE.0.0) PEXVN(N)=PEXVN(N)-XLFEEN(N)
V1=0.0
V2=0.0
U1=0.0
U2=0.0

```



```

DO 5 H=1,5
DO 5 J=1,7
DO 5 N=1,4
V1=V1+PEXVN(N)*CHJN(H,J,N)
U1=U1+CHJN(H,J,N)
U2=U2+XLFEEN(N)*CHJN(H,J,N)
5 CONTINUE
CATCH(JY)=CATCH(JY)+U1
V2=U1*PWHSL
VCEXVY(JY)=VCEXVY(JY)+V1
VCWHLY(JY)=VCWHLY(JY)+V2
RCA(JY)=RCA(JY)+U2+UT4
UT=UT+UT4
IF((NZED.NE.IT2).AND.(IT1.GT.3).AND.(IT1.LT.NYTP)) GO TO 32
WRITE(6,105) V2,V1,TC,U2
32 CONTINUE
IF((XT/3.0)-XT2).EQ.0.0) CALL MARKET(PEXVN,CJN,I2,PWHSL,XIMPTS)
IF((XT/3.0)-XT2).EQ.0.0) FIMP(JY)=FIMP(JY)+XIMPTS*10.0**6
1 CONTINUE
WRITE(6,106)
DO 6 JY=1,NYTP
WRITE(6,107) VCWHLY(JY),VCEXVY(JY),TCY(JY),RCA(JY)
AVWP(JY)=VCWHLY(JY)/CATCH(JY)
AVSP(JY)=VCEXVY(JY)/CATCH(JY)
XNR(JY)=VCEXVY(JY)-TCY(JY)
PCR5(JY)=XNR(JY)*100.0/VF5(JY)
PCR6(JY)=XNR(JY)*100.0/VF67(JY)
6 CONTINUE
WRITE(6,111)
DO 9 JY=1,NYTP
WRITE(6,112) VSSHJY(JY),SSHJY(JY),XMSHJY(JY),XLCHJY(JY),CATCH(JY)
9 CONTINUE
WRITE(6,115)
DO 40 I=1,NYTP

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```

WRITE(6,114) AVWP(I),AVEP(I),FIMP(I),XNR(I),ADF(I),UDF(I),XNC(I),V
1F5(I),VF67(I)
40 CONTINUE
CALL MSD(VCNM,VCM5D,VCMFLV,NYTP)
CALL MSD(VCEM,VCE5D,VCEXV,NYTP)
CALL MSD(TCM,TC5D,TCY,NYTP)
CALL MSD(RCAM,RCASD,RCA,NYTP)
CALL MSD(CATM,CAT5D,CATCH,NYTP)
CALL MSD(VSSH,VSSH5D,VSSHJY,NYTP)
CALL MSD(SMSHM,SMSSH5D,SMSSHJY,NYTP)
CALL MSD(XNSHM,XNSH5D,XNSHJY,NYTP)
CALL MSD(XLSHM,XLSH5D,XLSHJY,NYTP)
CALL MSD(XNRY,XNRS5D,XNR,NYTP)
CALL MSD(ADF5,ADF55D,ADF,NYTP)
CALL MSD(UDF5,UDF55D,UDF,NYTP)
CALL MSD(XNCM,XNC5D,XNC,NYTP)
CALL MSD(VF5M,VF55D,VF5,NYTP)
CALL MSD(VF67M,VF675D,VF67,NYTP)
CALL MSD(FIMP5,FIMP55D,FIMP,NYTP)
CALL MSD(AVWPM,AVWPS5D,AVWP,NYTP)
CALL MSD(AVEPM,AVEPS5D,AVEP,NYTP)
CALL MSD(PCRS5M,PCRS55D,PCRS,NYTP)
CALL MSD(PCRS6M,PCRS65D,PCRS6,NYTP)
CALL CORREL(RNRTC5,XNR,TCY,NYTP)
CALL CORREL(RNRVF5,XNR,VF5,NYTP)
CALL CORREL(RNRVF6,XNR,VF67,NYTP)
CALL CORREL(RNRADF,XNR,ADF,NYTP)
CALL CORREL(RNRUDF,XNR,UDF,NYTP)
CALL CORREL(RMPCAT,AVWP,CATCH,NYTP)
CALL CORREL(REPCAT,AVEP,CATCH,NYTP)
CALL CORREL(RNRXNC,XNR,XNC,NYTP)
CALL CORREL(RIMCAT,FIMP,CATCH,NYTP)
CALL CORREL(RNRCAT,XNR,CATCH,NYTP)
CALL CORREL(RADCAT,ADF,CATCH,NYTP)

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```

CALL CORREL(RUDCAT,UDF,CATCH,NYTP)
CALL CORREL(RNCCAT,XNC,CATCH,NYTP)
CALL CORREL(RVCADF,VCEXVY,ADF,NYTP)
CALL CORREL(RVCUDF,VCEXVY,UDF,NYTP)
CALL CORREL(RVCXNC,VCEXVY,XNC,NYTP)
WRITE(6,104) NYTP,VCRM,VCFSD,VCEM,VCESD,TCM,TCSD,RCAN,RCASD,VSSHM,
IVSSHSD,SMASHM,SMASHSD,XMSHM,XASHSD,XLSHM,CATSD,XGRM,XJES
2D,ADFM,ADFSD,UDFM,UDFSD,XTCM,XNCSD,VF5,VF5SD,VF67M,VF67SD,FI,PH,F
3IMPSC,AVAPH,AVWPSD,AVEPM,AVEPSD,PCR5M,PCR5SD,PCR6M,PCR6SD
WRITE(6,113) NYTP,RARTCY,URVF5,RNRVF5,RNRADF,RHRUDF,RNRKNC,RKPCAT
1,REPCAT,RIMCAT,RNRCAT,RADCAT,RUDCAT,RUDCAT,RVCCAT,RVCCAT,RVCCAT,
STOP 9
END

```

SHRIMP

```

SUBROUTINE SHRIMP(CHJN,XHJ,K1,XNRAND,T,SH)
COMMON NZED, IT1, IT2, NYTP
REAL*8 CHJN(5,7,4),XHJ(5,7),SDMIJK(2,3,7,12)/594*0.0/,SHRIJK(3,7,1
18)/378*0.0/,SH(5),BJ(7)/7*0.0/,FJ,ADFACJ(7)/7*0.0/
INTEGER H,T
101 FORMAT(I11,6F10.0/T11,6F10.0)
102 FORMAT(5F10.3)
103 FORMAT(7F10.7)
104 FORMAT('FISHING MORTALITY -- FJ -- IV AREA ',I1,' WAS ',F11.9)
105 FORMAT(7F10.4)
IF(T,NE.1) GO TO 2
K14=1.0
K15=1.0
K16=1.0
K17=1.0

```

```

IF(K1.EQ.1.0) K14=0.0
IF(K1.NE.2.0) GO TO 11
K14=0.0
K15=0.0
11 CONTINUE
IF(K1.NE.3.0) GO TO 12
K14=0.0
K15=0.0
K16=0.0
12 CONTINUE
IF(K1.NE.4.0) GO TO 13
K14=0.0
K15=0.0
K16=0.0
K17=0.0
13 CONTINUE
READ(5,105) (ADFACJ(J),J=1,7)
READ(5,103) (BJ(J),J=1,7)
DO 3 M=1,2
DO 3 I=1,3
DO 3 J=1,7
READ(5,101) (SDMIJK(M,I,J,K),K=1,12)
IF(M.NE.1) GO TO 3
DO 16 K=1,12
SDMIJK(M,I,J,K)=SDMIJK(M,I,J,K)*ADFACJ(J)
16 CONTINUE
3 CONTINUE
READ(5,102) (SH(H),H=1,5)
2 CONTINUE
DO 9 J=1,7
SXSHJ=0.0
DO 7 H=1,5
SXSHJ=SXSHJ+XPJ(H,J)*SH(H)
7 CONTINUE

```

```

FJ=BJ(J)*SXSHJ
IF((NZED.NE.IT2).AND.(IT1.GT.3).AND.(IT1.LT.NYTP)) GO TO 30
WRITE(6,104) J,FJ
30 CONTINUE
IF(T.NE.1) GO TO 15
DO 4 I=1,3
DO 4 N=1,12
SHRIJK(I,J,N)=SUMIJK(1,I,J,13-N)*DEXP(-(FJ+0.22)*DFLOAT(N-1))
4 CONTINUE
DO 5 I=1,3
DO 5 N=1,6
SHRIJK(1,I,J,12+N)=SUMIJK(1,I,J,13-N)*DEXP(-(FJ+0.22)*DFLOAT(N+1))
5 CONTINUE
15 CONTINUE
DO 6 H=1,5
FHJ=BJ(J)*XHJ(H,J)*SH(H)
DO 8 N=1,4
CHJN(H,J,N)=0.0
8 CONTINUE
PRCAHJ=(FHJ/(FJ+0.22))*(1.0-DEXP(-(FJ+0.22)))
DO 6 I=1,3
CHJN(H,J,1)=CHJN(H,J,1)+PRCAHJ*(SHRIJK(1,I,J,1)*K14+SHRIJK(1,I,J,2)*K1
15/2.0)
CHJN(H,J,2)=CHJN(H,J,2)+PRCAHJ*(SHRIJK(1,I,J,2)*K15+SHRIJK(1,I,J,3)*K1
16+SHRIJK(1,I,J,4)*K17)/2.0
CHJN(H,J,3)=CHJN(H,J,3)+PRCAHJ*(SHRIJK(1,I,J,3)*K16+SHRIJK(1,I,J,4)*K1
17+SHRIJK(1,I,J,5)+SHRIJK(1,I,J,6)+SHRIJK(1,I,J,7))/2.0
CHJN(H,J,4)=CHJN(H,J,4)+PRCAHJ*(SHRIJK(1,I,J,5)+SHRIJK(1,I,J,6)+SHRIJ
1K(1,I,J,7))/2.0)
ALTHOUGH SHRIMP EXIST IN THE FISHERY UNTIL EIGHTEEN MONTHS OF AGE,
THE FOLLOWING STATEMENT ASSUMES THAT SHRIMP BEYOND TWELVE MONTHS
OF AGE DO NOT CONTRIBUTE TO CATCH.
DO 6 K=8,12
CHJN(H,J,4)=CHJN(H,J,4)+PRCAHJ*SHRIJK(1,I,J,K)

```

```

6 CONTINUE
  DO 9 I=1,3
    DO 10 K=1,13
      SHRIJK(I,J,19-K)=SHRIJK(I,J,18-K)*DEXP(-(FJ+0.22))
10 CONTINUE
    SHRIJK(I,J,5)=SHRIJK(I,J,7)*DEXP(-(FJ*K17+0.22))
    SHRIJK(I,J,4)=SHRIJK(I,J,3)*DEXP(-(FJ*K16+0.22))
    SHRIJK(I,J,3)=SHRIJK(I,J,2)*DEXP(-(FJ*K15+0.22))
    SHRIJK(I,J,2)=SHRIJK(I,J,1)*DEXP(-(FJ*K14+0.22))
    SHRIJK(I,J,1)=SD*SHRIJK(1,I,J,T-((T-1)/12)*12)+SD*SHRIJK(2,I,J,T-((T-1)/
      12)*12)*XNRAND
9 CONTINUE
  DO 14 H=1,5
    DO 14 J=1,7
      CHJN(H,J,1)=CHJN(H,J,1)/100.0
      CHJN(H,J,2)=CHJN(H,J,2)/53.0
      CHJN(H,J,3)=CHJN(H,J,3)/35.0
      CHJN(H,J,4)=CHJN(H,J,4)/20.0
14 CONTINUE
    RETURN
  END

      FLEET

SUBROUTINE FLEET(XHJ,CHJN,PEXVN,EPEEH,XLFEEN,T,TC,UT4,ENHAHJ,RCHJ)
COMMON NZED, IT1, IT2, NYTP
REAL*8 XHJ(5,7),CHJN(5,7,4),PEXVN(4),XLFEEN(5),CHJ(5,7)/3
15*0.0,ENHJ(5,7),ENHAHJ(5,7),RCHJ(5,7),PARHJ(5,7)/35*0.0,FCHJ(5,
27)/35*0.0,VCHJN(5,7,2)/TC*0.0,PRHJK(5,7,12)/420*0.0,UT(5,7)/35*
30.0,UT1,BHJJ(5,7,7)/245*0.0,AVMXHK(5,12)/60*0.0,DJ(7)/7*0.0/
  INTEGER H,T

```

C
C
C
C
C
C


```

101 FORMAT(5F10.5)
102 FORMAT('IFOLLOWING IS INFORMATION CONCERNING THE BEHAVIOR OF THE
1 FLEET DURING TIME PERIOD ',I3,' CORRESPONDING TO MONTH ',I2,' OF
2YEAR ',I2)
103 FORMAT('///' PROFITABILITY PER CRAFT DURING THE CURRENT TIME PERI
100 BY AREA AND VESSEL SIZE CLASS')
104 FORMAT('0',T60,'AREA')
105 FORMAT('0VESSEL SIZE CLASS ',T31,'1',T43,'2',T55,'3',T67,'4',T79,'
15',T91,'6',T103,'7')
106 FORMAT('0',T10,'11,T23,7F12.2)
107 FORMAT('///' CUMULATIVE PROFITABILITY PER CRAFT OVER THE MOST REC
1ENT 12 TIME PERIODS BY AREA AND VESSEL SIZE CLASS')
108 FORMAT('1NUMBER OF CRAFT FISHING DURING THE CURRENT TIME PERIOD BY
1 AREA AND VESSEL SIZE CLASS')
109 FORMAT('///' NUMBER OF CRAFT WITH HOME PORT IN A GIVEN AREA DURI
1G THE CURRENT TIME PERIOD BY VESSEL SIZE CLASS')
110 FORMAT('///' NUMBER OF CRAFT ADDED TO THE FLEET AT THE END OF THE
1 CURRENT TIME PERIOD BY AREA AND VESSEL SIZE CLASS')
111 FORMAT('///' AVERAGE 24-HR DAYS FISHED PER CRAFT DURING THE CURRE
1NT TIME PERIOD BY AREA AND VESSEL SIZE CLASS')
112 FORMAT(7F5.2)
113 FORMAT('///' MAXIMUM PROFIT IS $',F13.4,' IN AREA ',I2)
IF(T.NE.1) GO TO 2
READ(5,101) ((AVMXHK(H,K),H=1,5),K=1,12)
READ(5,101) ((BPJJ(H,J,J),H=1,5),J=1,7),J1=1,7)
READ(5,101) ((VCHJM(H,J,M),H=1,5),J=1,7),M=1,2)
READ(5,101) ((FCHJ(H,J),H=1,5),J=1,7)
READ(5,101) ((ENHJ(H,J),H=1,5),J=1,7)
READ(5,101) ((ENHAHJ(H,J),H=1,5),J=1,7)
READ(5,101) ((SHARHJ(H,J),H=1,5),J=1,7)
READ(5,112) (DJ(J),J=1,7)
DO 31 H=1,5
DO 31 J=1,7
RCHJ(H,J)=12.0*FCHJ(H,J)

```

```

FCHJ(H,J)=FCHJ(H,J)+EIEEE(H)/12.0
31 CONTINUE
2 CONTINUE
TC=0.0
DO 3 H=1,5
DO 3 J=1,7
CHJ(H,J)=0.0
DO 4 N=1,4
CHJ(H,J)=CHJ(H,J)+CHJN(H,J,N)*(PEXVM(N)-XLFEEN(N))
4 CONTINUE
M=2
IF(ENHJ(H,J).LT.ENPAHJ(H,J)) M=1
TC=TC+XHJ(H,J)*VCHJM(H,J,M)+FCHJ(H,J)*ENHJ(H,J)+CHJ(H,J)*SHARHJ(H,
1J)
IF(ENHJ(H,J).EQ.0.0) GO TO 25
CHJ(H,J)=(CHJ(H,J)*(1.0-SHARHJ(H,J))-VCHJM(H,J,M)*XHJ(H,J))/ENHJ(H
1,J)-FCHJ(H,J)
GO TO 3
25 CONTINUE
CHJ(H,J)=0.0
3 CONTINUE
UT4=0.0
DO 5 H=1,5
DO 5 J=1,7
UT4=UT4+ ENPAHJ(H,J)*EIEEE(H)/12.0
DO 6 K=1,11
PRHJK(H,J,13-K)=PRHJK(H,J,12-K)
6 CONTINUE
PRHJK(H,J,1)=CHJ(H,J)
DO 7 K=2,12
CHJ(H,J)=CHJ(H,J)+PRHJK(H,J,K)
7 CONTINUE
ENEMPJ=0.0
IF(CHJ(H,J).GE.(0.1*12.0*FCHJ(H,J))) ENPAHJ(H,J)

```

```

IF(CHJ(H,J).LE.(-1.1*12.0*FCHJ(H,J))) ENWHJ=-0.1*ENHAHJ(H,J)
IF(ENWHJ.GT.0.0.AND.ENWHJ.LT.0.5) ENWHJ=ENWHJ+1.0
INWHJ=ENWHJ
XINWHJ=INWHJ
IF(ABS(ENWHJ-XINWHJ).LT.1.5) ENWHJ=XINWHJ
IF(ABS(ENWHJ-XINWHJ).GE.1.5) ENWHJ=XINWHJ+ENWHJ/ABS(ENWHJ)
UT(H,J)=ENWHJ
5 CONTINUE
DO 24 H=1,5
DO 24 J=1,7
IF(ENHJ(H,J).EQ.0.0) GO TO 24
XHJ(H,J)=XHJ(H,J)/ENHJ(H,J)
24 CONTINUE
IF(IT1.LE.3.OR.IT1.EQ.NYTP) GO TO 29
IF(NZED.NE.IT2) GO TO 27
29 CONTINUE
WRITE(6,102) T,IT2,IT1
WRITE(6,103)
WRITE(6,104)
WRITE(6,105)
DO 8 H=1,5
WRITE(6,106) H,(PRHJK(H,J,1),J=1,7)
8 CONTINUE
WRITE(6,107)
WRITE(6,104)
WRITE(6,105)
DO 9 H=1,5
WRITE(6,106) H,(CHJ(H,J),J=1,7)
9 CONTINUE
WRITE(6,111)
WRITE(6,104)
WRITE(6,105)
DO 23 H=1,5
WRITE(6,106) H,(XHJ(H,J),J=1,7)

```

```

23 CONTINUE
  WRITE(6,103)
  WRITE(6,104)
  WRITE(6,105)
  DO 10 H=1,5
    WRITE(6,106) H, (ENHJ(H,J), J=1,7)
10 CONTINUE
  WRITE(6,109)
  WRITE(6,104)
  WRITE(6,105)
  DO 11 H=1,5
    WRITE(6,106) H, (ENHAHJ(H,J), J=1,7)
11 CONTINUE
  WRITE(6,110)
  WRITE(6,104)
  WRITE(6,105)
  DO 12 H=1,5
    WRITE(6,106) H, (UT(H,J), J=1,7)
12 CONTINUE
27 CONTINUE
  ALLOCATE FLEET
  DO 13 H=1,5
    PR1=PRHJK(H,1,1)
    PR2=PRHJK(H,2,1)
    PR3=PRHJK(H,3,1)
    PR4=PRHJK(H,4,1)
    PR5=PRHJK(H,5,1)
    PR6=PRHJK(H,6,1)
    PR7=PRHJK(H,7,1)
    IF(H.EQ.1) PR1=-(10.0*10.3)
    IF(H.EQ.4) PR7=-(10.0*10.9)
    IF(H.EQ.4.OR.H.EQ.5) GO TO 26
    PR6=-(10.0*10.0)
    PR7=-(10.0*10.0)

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26 CONTINUE
   UT1=AMAX1(PR1,PR2,PR3,PR4,PR5,PR6,PR7)
   DO 14 J=1,7
     IF(SNGL(UT1).EQ.SNGL(PRHJK(H,8-J,1))) J1=8-J
14 CONTINUE
   IF((NZED.NE.IT2).AND.(IT1.GT.3).AND.(IT1.LT.NYTP)) GO TO 30
   WRITE(6,113) UT1,J1
30 CONTINUE
   IF(ENHJ(H,J1).LT.ENHJ(H,J1)) GO TO 15
   DO 16 J=1,7
     IF(SNGL(UT1).EQ.0.0.AND.PRHJK(H,J,1).EQ.0.0) GO TO 16
     ENHJ(H,J1)=ENHJ(H,J1)+8*PJ(H,J,J1)*((UT1-PRHJK(H,J,1))/(DABS(UT1)+
1DABS(PRHJK(H,J,1))))*ENHJ(H,J)
     IF(J.NE.J1) ENHJ(H,J)=ENHJ(H,J)-BHJJ(H,J,J1)*((UT1-PRHJK(H,J,1)))/(
1DABS(UT1)+DABS(PRHJK(H,J,1))))*ENHJ(H,J)
     IF(J.NE.J1.AND.ENHJ(H,J).LT.0.0) ENHJ(H,J)=0.0
16 CONTINUE
   GO TO 17
15 CONTINUE
   WAG=0.0
   DO 18 J=1,7
     IF(SNGL(UT1).EQ.0.0.AND.PRHJK(H,J,1).EQ.0.0) GO TO 18
     IF(J.EQ.J1) GO TO 18
     WAG=WAG+BHJJ(H,J,J1)*((UT1-PRHJK(H,J,1))/(DABS(UT1)+DABS(PRHJK(H,J
1,1))))*ENHJ(H,J)
18 CONTINUE
   DO 19 J=1,7
     IF(WAG.EQ.0.0) GO TO 19
     IF(SNGL(UT1).EQ.0.0.AND.PRHJK(H,J,1).EQ.0.0) GO TO 19
     IF(J.EQ.J1) GO TO 19
     ENHJ(H,J)=ENHJ(H,J)-BHJJ(H,J,J1)*((UT1-PRHJK(H,J,1))/(DABS(UT1)+DA
1BS(PRHJK(H,J,1))))*(ENHJ(H,J1)-ENHJ(H,J))*ENHJ(H,J)/WAG
19 CONTINUE
     ENHJ(H,J1)=ENHJ(H,J1)

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17 CONTINUE
DO 21 J=1,7
  ENHJ(H,J)=ENHJ(H,J)+UT(H,J)
  IF(ENHJ(H,J).NE.0.0.AND.EHJ(H,J).LT.1.0) ENHJ(H,J)=1.0
  ENHAHJ(H,J)=ENHAHJ(H,J)+UT(H,J)
  XN1=ENHJ(H,J)
  XN2=ENHAHJ(H,J)
  IF(ABS(XN1-AINT(XN1)).GE.0.5) XN1=XN1-XN1/ABS(XN1)
  IF(ABS(XN2-AINT(XN2)).GE.0.5) XN2=XN2-XN2/ABS(XN2)
  ENHJ(H,J)=AINT(XN1)
  ENHAHJ(H,J)=AINT(XN2)
21 CONTINUE
13 CONTINUE
DO 22 H=1,5
DO 22 J=1,7
  XHJ(H,J)=AVX*CHK(H,IT2)*CJ(J)
  IF(PRHJK(H,J,1).GE.(0.1*PRHJ(H,J))) XHJ(H,J)=1.1*XHJ(H,J)
  IF(PRHJK(H,J,1).LE.(-1.1*PRHJ(H,J))) XHJ(H,J)=0.9*XHJ(H,J)
  XHJ(H,J)=XHJ(H,J)*ENHJ(H,J)
22 CONTINUE
RETURN
END

MARKET

SUBROUTINE MARKET(PEXVN,CJN,T2,PWHS,XIMPTS)
COMMON NZEO, IT1, IT2, N*TP
REAL*8 PEXVN(4),CJN(7,4),CN(4)/4*0.0/CJ(7)/7*0.0/
REAL*8 PPNX(4,2)/8*0.0/
INTEGER H,IT2,T3,T4
101 FORMAT('1','T34','MARKET DATA IN YEAR ',I2,' AT THE END OF QUARTER ',

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1,11,' (QUARTERLY TIME PERIOD NUMBER ',I3,') FOLLOWS')
102 FORMAT('O',T34,'LANDINGS.....',F20.6//T34,'IMPORT
1S.....',F20.6//T34,'ENDING STOCKS IN COLD STORAGE
2E.',F20.6//T34,'WHOLESALE PRICE.....',F14.9)
3EXVESSEL PRICE.....',F14.9)
103 FORMAT('O',T82,'SIZE//T34,'AREA',T57,'1',T76,'2',T95,'3',T116,'4',
1,T129,'TOTAL')
104 FORMAT('O',T36,I1,T39,5F10.6)
105 FORMAT('O',T34,'TOTAL',5F10.6)
106 FORMAT('O',T34,'EXVESSEL PRICE FOR SIZE ',I1,'.....',F14.9)
107 FORMAT('O',T34,'CATCH FOR THE FOLLOWING SIZE CLASS WAS ZERO AND NO
1 PRICE WAS ESTABLISHED')
108 FORMAT(4F10.5)
109 FORMAT('O',T34,'LANDINGS IN MILLIONS OF POUNDS BY AREA AND SHIP
1SIZE DURING THE CURRENT QUARTER')
  IF (T2.NE.1) GO TO 2
  CTC=35.758
  PEXVIL=0.76
  STKSTL=45.584
  POI=359.6
  READ(5,108) ((PPNN(N,M),N=1,4),M=1,2)
2 CONTINUE
  T3=T2-((T2-1)/4)*4
  Q2=0.0
  Q3=0.0
  Q4=0.0
  IF (T3.EQ.2) Q2=1.0
  IF (T3.EQ.3) Q3=1.0
  IF (T3.EQ.4) Q4=1.0
  CTL=CTC
  CTC=0.0
  DO 3 J=1,7
  DO 3 N=1,4
  CTC=CTC+CJN(J,N)*1.1333

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3  CONTINUE
  XIMPTS=-19.212-.1952*CTL-9.4988*Q2-8.1932*Q3+13.3106*Q4+0.1255*PDI
  IF(XIMPTS.LT.0.0) XIMPTS=0.0
  CONS=11.6156+0.1416*CTC+0.1048*XIMPTS-37.4200*PEXVTL+2.4418*Q2+4.4
1326*Q3+3.9324*Q4+0.1254*PDI+0.1146*STKSTL
  STKSTC=-11.5304+0.6391*CTC+0.8422*XIMPTS+29.1241*PEXVTL-2.3378*Q2-
14.2447*Q3-3.7649*Q4-0.1201*PDI+0.8911*STKSTL
  PWHSLS=0.1337-0.0044*CTC-0.0032*XIMPTS+0.9369*PEXVTL-0.0589*Q2+0.07
122*Q3+0.0937*Q4+0.0013*PDI-0.0035*STKSTL
  PEXVTC=0.2698-0.0055*CTC-0.0041*XIMPTS-0.4371*PEXVTL-0.1221*Q2+0.0
1064*Q3+0.0717*Q4+0.0013*PDI-0.0045*STKSTL
  PEXVTL=PEXVTC
  STKSTL=STKSTC
  CTC=CTC/1.1333
  DO 4 N=1,4
    CN(N)=0.0
    DO 5 J=1,7
      CN(N)=CN(N)+CJN(J,N)
5  CONTINUE
  IF(CH(N).EQ.0.0) GO TO 9
  PEXVN(N)=PPNM(N,1)*PEXVTC+0.0190*(CTC/CN(N)-PPNM(N,2))*PEXVTC
  GO TO 4
9  CONTINUE
  PEXVN(N)=0.0
4  CONTINUE
  DO 6 J=1,7
    CJ(J)=0.0
    DO 6 N=1,4
      CJ(J)=CJ(J)+CJN(J,N)
6  CONTINUE
  T4=(T2-1)/4+1
  IF(((INZED-1)/3+1).NE.T3).AND.(IT1.GT.3).AND.(IT1.LF.NYTP)) GO TO
130
  WRITE(6,101) T4,T3,T2

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WRITE(6,102) CTC,XIMPTS,STKSTC,PWHS�,PEXVTC
DO 8 N=1,4
IF(CN(N).EQ.0.0) WRITE(6,107)
WRITE(6,106) N,PEXV(N)
8 CONTINUE
WRITE(6,109)
WRITE(6,103)
DO 7 J=1,7
WRITE(6,104) J,(CJN(J,N),N=1,4),CJ(J)
7 CONTINUE
WRITE(6,105) (CN(N),N=1,4),CTC
30 CONTINUE
RETURN
END

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MSD

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SUBROUTINE MSD(R1,R2,S1,NYTP)
REAL*8 S1(30)
101 FORMAT('1THERE WERE TOO FEW OBSERVATIONS TO CALCULATE A STANDARD D
1EVIATION')
S2=NYTP
R1=0.0
R2=0.0
IF(NYTP.LE.1) GO TO 2
DO 4 I=1,NYTP
R1=R1+S1(I)
4 CONTINUE
R1=R1/S2
DO 5 I=1,NYTP
R2=R2+((S1(I)-R1)*(S1(I)-R1))/(S2-1.0)

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5 CONTINUE
  R2=SQRT(R2)
  GO TO 3
2 CONTINUE
  WRITE(6,101)
3 CONTINUE
  RETURN
  END

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CORREL

SUBROUTINE CORREL(V1,V2,V3,NYTP)
  REAL*8 V2(30),V3(30)
  V2M=0.0
  V3M=0.0
  XN=NYTP
  DO 2 I=1,NYTP
    V2M=V2M+V2(I)
    V3M=V3M+V3(I)
2 CONTINUE
  V2M=V2M/XN
  V3M=V3M/XN
  V2A=0.0
  V3A=0.0
  V23=0.0
  DO 3 I=1,NYTP
    V2A=V2A+(V2(I)-V2M)**2
    V3A=V3A+(V3(I)-V3M)**2
    V23=V23+(V2(I)-V2M)*(V3(I)-V3M)
3 CONTINUE
  V1=V23/SQRT(V2A*V3A)

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RETURN
END

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DATA

(BLANK CARD REPRESENTING ZERO LEVELS OF THE POLICY VARIABLES)

360

16268	2608	8211	142773	30176
84972	22624	18148	1134	1593
540662	31126	74294	5225	6538
19436	52192	156003	15232	13906
	41175	119225	168315	16629
			735	748
				512

37	64	87	104				
4	4	20	175	175	1	2	581
493	985	726	331	349	903		0
	0	0	0	0	0		0
	0	0	0	0	0		0
2	6831827	289455	1195506	272730	5230173	23969153	
3	2405454	163192	541583	566723	193551	702472	
	68654617	28276670	1286548	572667	137892811	347645902	
4	85279	85279	85579	55579	1531464	157154	
	185788721	23266579	3083255	3791479	371236532	457645495	
5	1660941	4750000	7967347	14876152	149630	96326	
	139316684	34627002	11305793	10398051	282071514	696826449	
6	1000000	2	3	7	1578.45	150000	
	69	17	5	5	141	348	
7		0	0	0	1	1	
	0	0	0	0	0	0	

BRMNI

PKMNI	12089921	15305132	21920639	21110948	12900254	16436248
2	10177017	52090601	53980359	54178945	26066265	10733168
	1422670	910398	5090913	14260658	11466083	4794560
3	262820	3538220	12007615	3197116	1503546	1696710
	209963	1645641	403051	11292836	372301	0
4	0	0	0	0	0	0
	0	0	0	0	0	0
5	0	0	0	0	0	0
	0	0	0	0	0	0
6	0	0	0	0	0	0
7	120	153	219	211	129	164
	101	520	639	841	268	197
WHMNI	0	0	0	0	0	0
	0	0	0	0	0	0
2	4395050	1318800	7743474	9477906	8075117	8802163
	0	633725	2946576	0	0	382746
3	1604650	6774104	15417111	97167228	4827526	3119032
	834740	44945986	38192524	7165081	5725531	47764
4	78622027	50033006	65547089	170733613	255056862	167011162
	2006464	49930347	22303495	11995126	12453564	1747891
5	37236450	32768569	59390978	63426415	93928652	114655514
	1608555	71780041	0	0	0	0
6	0	0	0	0	0	0
	0	0	0	0	0	0
7	0	0	0	0	0	0
	0	0	0	0	0	0
BRSDI	0	0	0	0	0	0
	0	0	0	0	0	0
2	2468902	24311	554397	68433	1307543	8942012
	28494	40798	206201	44567	48388	175610
3	10894914	19129370	141807	50273	544837	20669047
					324467	343351

4	23320	4819	21395	1837	17588794	21269139
	6191837	737368	715946	947667	37410	24556
5	415010	1187500	1991837	1683483	42205465	27173258
	2525427	6225383	2682463	251074	396322	37550
6	250000	50000	75	175	3525	87
	1725	425	125	125	25	25
7	0	0	0	0	0	0
	0	0	0	0	0	0
PKSDI	2361116	233396	1664610	670041	1239097	5855605
	1920	5291990	17770140	13905238	6572187	172024
2	355675	227599	308621	1424615	776035	107348
	62031	687568	930454	89147	418490	287935
3	52491	411365	4736	1955076	93083	0
	0	0	0	0	0	0
4	0	0	0	0	0	0
	0	0	0	0	0	0
5	0	0	0	0	0	0
	0	0	0	0	0	0
6	0	0	0	0	0	0
	0	0	0	0	0	0
7	30	3825	538	4225	3225	41
	2525	130	15975	211	67	2675
WHSDI	0	0	0	0	0	0
	0	0	0	0	0	0
2	1098762	27408	0	0	0	0
	0	158431	2167857	4198200	89337	4050543
3	643088	2798654	167677	0	0	45235
	208685	13403667	1107601	37410603	1718631	675022
4	962338	9876012	6755602	7727655	2760010	11941
	501616	4569339	13230773	51002190	34991972	35028507
5	6439714	1345154	2411967	2998782	6226782	456973
	402139	6710596	24084481	10852536	4733164	41597144
6	0	0	0	0	0	0
	0	0	0	0	0	0

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113 113 115

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113 83 83

14054
48567

11757
41911

8649
33944

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38344

C END OF DATA

LIST OF REFERENCES

1. Anonymous, Basic Economic Indicators: Shrimp, Atlantic and Gulf, Working Paper No. 57, Division of Economic Research, National Marine Fisheries Service, College Park, Maryland, May 1970.
2. Anonymous, Gulf Coast Shrimp Data, United States Department of Commerce, National Oceanic and Atmospheric Association, National Marine Fisheries Service, Washington, D. C., in cooperation with Fishery Agencies of Florida, Alabama, Mississippi, Louisiana, and Texas. Annual Summaries for 1967, 1968, and 1969.
3. Anonymous, Marine Economics Data, Oregon State University Sea Grant, Marine Advisory Program, Oregon State University Cooperative Extension Service, Corvallis, Oregon.
4. Anonymous, "Water Temperature Guide to Shrimp and Tuna," Fishing News International 10, No. 1, 34, 37 (January 1971) as abstracted in Commercial Fisheries Abstracts, National Marine Fisheries Service, United States Department of Commerce, July 1971, pp. 7-8.
5. Arnold, V., An Analysis to Determine Optimum Shrimp Fishing Effort by Area, Working Paper No. 40, Division of Economic Research, National Marine Fisheries Service, College Park, Maryland, January 1970, 196 pages.
6. Barry, E. J., "Gulf Fisheries (Selected Areas): 1969," Division of Statistics and Market News, National Marine Fisheries Service, New Orleans, Louisiana, February 1971.
7. Berry, Richard James, "Dynamics of the Tortugas (Florida) Pink Shrimp Population," Doctoral Dissertation, University of Rhode Island, 1967.
8. Boutwell, Ken and McMinimy, Vernon, "Use of Mathematical Simulation Models in Analyzing Agricultural Policies," draft of an Unpublished Memorandum, 1967.
9. Bromley, Daniel, Economic Efficiency in Common Property Natural Resource Use: A Case Study of the Ocean Fishery, Working Paper No. 28, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, July 1969, 162 pages. Also published as a Doctoral Dissertation in the Department of Agricultural Economics at Oregon State University, Corvallis, Oregon, 1969.
10. Captiva, Francis J., "Changes in Gulf of Mexico Shrimp Trawler Design," paper presented at Conference on Canadian Shrimp Fishery, Saint-John, N. B., October 27-29, 1970.

11. Christy, Francis T., Jr. and Anthony Scott, The Control of Wealth in Ocean Fisheries: Some Problems of Growth and Economic Allocation, published for Resources for the Future, Inc., by The Johns Hopkins Press, Baltimore, Maryland, 1965.
12. Ciriacy-Wantrup, S. V., Resource Conservation: Economic and Policy, University of California Press, Berkeley, California, 1952.
13. Creameans, J. E., "Why Simulation," paper originally given at a symposium of the Washington, D. C. Chapter of the Association for Computing Machinery, May 18, 1967.
14. Crutchfield, James P. and Giulio Pontecorvo, The Pacific Salmon Fisheries, published for Resources for the Future, Inc., by The Johns Hopkins Press, Baltimore, Maryland, 1969.
15. Crutchfield, James P. and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," Fishery Industrial Research, Vol. I, No. 1, Fish and Wildlife Service, April 1962.
16. Doll, John P., An Econometric Analysis of the U. S. Shrimp Market, Working Paper No. 79, Division of Economic Research, National Marine Fisheries Service, College Park, Maryland, February 1971.
17. Forrester, Jay W., Industrial Dynamics, 2nd printing, The M.I.T. Press, Cambridge, Massachusetts, June 1962.
18. Geisler, M. A., Haythorn, W. W., and Steger, W. A., "Simulation and the Logistics Systems Laboratory," Memorandum RM-3281-PR prepared for United States Air Force Project Rand, September 1962.
19. Gordon, H. Scott, "The Economic Theory of a Common-Property Resource: The Fishery," Journal of Political Economy, Vol. LXII, No. 2, April 1954, pp. 124-142.
20. Gulland, J. A., Manual of Methods for Fish Stock Assessment: Part 1. Fish Population Analysis, Food and Agriculture Organization of the United Nations, Rome, 1969.
21. IBM System/360 Fortran IV Language, IBM Corporation, Programming Systems Publications, New York, New York, 1966.
22. Lassiter, Roy L., Utilization of U.S. Otter-Trawl Shrimp Vessels in the Gulf Area, 1959-1961, Bureau of Business and Economic Research, University of Florida, Gainesville, Florida, 1964.
23. Lyles, Charles H., Fishery Statistics of the United States, Bureau of Commercial Fisheries, Washington, D. C., 1939-1967.
24. Miller, M., D. Nash, and F. Schuler, Industry Analysis of Gulf Area Frozen Processed Shrimp and an Estimation of Its Economic Adaptability to Radiation Processing, Working Paper No. 16, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, October 1969, 100 pages.

25. Orcutt, G. H., "Simulation of Economic Systems," The American Economic Review, Vol. 50, No. 5, December 1960, pp. 893-907.
26. Osborn, Kenneth W., Bruce W. Maghan, and Shelby B. Drummond, Gulf of Mexico Shrimp Atlas, United States Department of the Interior, Bureau of Commercial Fisheries, Circular 312, Washington, D. C., May 1969.
27. Osterbind, C. G. and R. A. Pantier, Economic Study of the Shrimp Industry in the Gulf and South Atlantic States, Bureau of Economic and Business Research, University of Florida, Gainesville, Florida, 1965.
28. Scott, Anthony, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy, Vol. LXIII, No. 2, April 1955, pp. 116-124.
29. Smith, V. L., "Economics of Production from Natural Resources," The American Economic Review, Vol. LXIII, No. 3, Part 1, June 1968, pp. 409-431.
30. Surdi, Richard W. and Donald R. Whittaker, principal contributors, Shellfish: Situation and Outlook: 1970 Annual Review, Current Economic Analysis S-20, National Marine Fisheries Service, United States Department of Commerce, Washington, D. C., March 1971.
31. Tyner, Fred H., Jr., "A Simulation Analysis of the Economic Structure of U. S. Agriculture," Doctoral Dissertation, Oklahoma State University, Stillwater, Oklahoma, May 1967.
32. Tullock, Gordon, The Fisheries ... Some Radical Proposals, Essays in Economics No. 6, University of South Carolina, Bureau of Business and Economic Research, School of Business Administration, Columbia, South Carolina, February 1962, 29 pages.
33. Whittaker, David A., Jr., "Economic Effects of Trade Policies on the Shrimp Fisheries of the United States and the Latin American Nations," Doctoral Dissertation, University of Florida, Gainesville, Florida, 1971.

ADDITIONAL REFERENCES

Bator, Francis M., "The Simple Analytics of Welfare Maximization," The American Economic Review, Vol. XLVII, No. 1, March 1957, pp. 22-59.

Bell, F. W., Estimation of the Economic Benefits to Fishermen, Vessels and Society From Limited Entry to the Inshore U. S. Northern Lobster Fishery, Working Paper No. 36, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, March 1970.

Bell, F. W. and J. E. Hazleton, Recent Developments and Research in Fisheries Economics, published for The New England Economic Research Foundation by Oceana Publications, Inc., Dobbs Ferry, New York, 1967.

Carlson, E., Bio-Economic Model of a Fishery (Primarily Demersal), Working Paper No. 12, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, March 1969.

Cleary, Donald P., Demand and Price Structure for Shrimp, Working Paper No. 15, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, June 1969.

Crutchfield, J. A., "Economic Objectives of Fishery Management, The Fisheries: Problems in Resource Management," University of Washington Press, Seattle, Washington, 1965, pp. 43-65.

Food and Agricultural Organization of the United Nations, Yearbook of Fishery Statistics, Vols. 26 and 27, FAO, Rome, Italy, 1968.

Nash, D. and F. Bell, An Inventory of Demand Equations for Fishery Products, Working Paper No. 10, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, July 1969.

Ricker, William E., Methods of Estimating Vital Statistics of Fish Populations, Indiana University Publications Science Series No. 15, Bloomington, Indiana, 1948, 101 pages.

Samuelson, Paul A., "Contrast Between Welfare Conditions for Joint Supply and for Public Goods," The Review of Economics and Statistics, Vol. LI, February 1969, pp. 26-30.

Scott, A. D., Economics of Fisheries Management: A Symposium, Institute of Animal Resource Ecology, The University of British Columbia, Canada, 1970.

Sokoloski, A., Some Elements of an Evaluation of the Effects of Legal Factors on the Utilization of Fishery Resources, Working Paper No. 8, Division of Economic Research, Bureau of Commercial Fisheries, College Park, Maryland, February 1969.

Sugiri, G. K. A., "A Description of the Tortugas Shrimp Fishery and its Maximum Sustainable Yield," Master's Thesis, University of Miami, Coral Gables, Florida, January 1971.

Turrey, Ralph, "Optimization and Suboptimization in Fishery Regulation," The American Economic Review, Vol. LIV, March 1964, pp. 64-76.

Turrey, Ralph and Jack Wiseman, The Economics of Fisheries, Food and Agriculture Organization of the United Nations, Rome, 1957.

Zellner, A., "On Some Aspects of Fishery Conservation Problems," reprinted from the Bulletin of the International Statistical Institute, Vol. XXXVIII, Part III, Tokyo, 1961.

BIOGRAPHICAL SKETCH

Paul Jerome Hooker was born on August 29, 1943, at Homestead, Florida. In August, 1960, he was graduated from North Marion High School, Reddick, Florida. In August, 1966, he received the degree of Bachelor of Science with a major in zoology from the University of Florida. During the 1966-67 school year, he taught biology and chemistry at North Marion High School. In 1966 he enrolled in the Graduate School of the University of Florida. From August, 1967, to December, 1971, he has held an NDEA Title IV fellowship, worked for two quarters as a teaching assistant, and has been employed as a graduate research associate in the Department of Food and Resource Economics while pursuing the degree of Doctor of Philosophy. He is currently employed as Interim Assistant Professor of Food and Resource Economics with the University of Florida on assignment to the Ministry of Agriculture of Guyana.

Paul Jerome Hooker is married to the former Martha Jean Yongue, and is the father of one child. He is a member of Gamma Sigma Delta, Omicron Delta Epsilon, and the American Agricultural Economics Association.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Leo Polopolus, Chairman
Professor of Food and Resource
Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Max R. Langham, Professor
Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. W. McPherson, Professor
Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Carter C. Osterbind
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This dissertation was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March, 1972

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