AN ANALYSIS TO DETERMINE OPTIMUM SHRIMP FISHING EFFORT BY AREA

by

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(continued on inside back cover)

ABSTRACT

In this study vessels from 13 major shrimp ports were surveyed to determine the cost and earning structure for Gulf shrimp vessels. This information was combined with effort data for a sample of vessels spending 50 percent or more of their time on the Tortugas shrimp grounds.

Using both these series of data, broken down into vessel size categories and specifying the distribution of landings between three Florida ports, a linear programming model was developed for the express purpose of determining the optimal distribution of vessels between ports based upon the effort patterns, the distribution of species and the cost components of vessel operations.

Using constraints based on various assumptions results were derived which suggested considerable differences from current port use patterns. Social benefits derived from their application demonstrate the value of this technique.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Shrimp is the most valuable fishery resource in the United States. It has held this position since 1952 with the exception of 1961 (Table 1). Domestic landings in 1966 were valued at $95.8 million and were $28.7 million greater than the value of salmon, the nation's second most valuable fishery. Historically, approximately 80 percent of the domestic annual catch has been landed in the Gulf of Mexico. Landings in the Gulf have increased from 84.5 million pounds (heads off weight),[1] valued at $2.76 million in 1936 to 139.6 million pounds (heads off weight) valued at $70.8 million in 1965.[2] The disproportionate growth between pounds of shrimp landed and dollar value has resulted from rapidly expanding markets and increasing domestic demand for fresh and frozen shrimp. Domestic demand increasing at a more rapid rate than domestic supply has increased the

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[1]Heads off weight is defined as the weight of shrimp after removal of the head (protocephalon) and the thorax (gnathothorax) or the weight of the abdominal section.

[2]The increase in value relative to quantity landed is further demonstrated by deflating the 1965 values to 1936 levels via the wholesale price index for all commodities. A value of $30.53 million for 1965 is yielded by such deflation.

Table 1.--Ex-vessel value relationships of the three most valuable fishery resources.

Year	Relative value (000)$			Percent of total value of landed fishery resources		
	Shrimp	Salmon	Tuna	Shrimp	Salmon	Tuna
1966	95,800	67,100	44,608	21.1	14.8	9.8
1965	82,409	65,159	41,734	18.5	14.6	9.4
1964	70,376	55,995	39,398	18.1	14.4	10.1
1963	70,044	49,012	40,170	18.6	13.0	10.6
1962	73,236	56,353	45,112	18.5	14.2	11.4
1961	51,688	52,027	42,346	14.3	14.4	11.7
1960	66,932	44,730	37,571	18.9	12.7	10.6
1959	58,133	35,741	37,429	16.8	10.3	10.8
1958	72,930	45,904	43,184	19.7	12.4	11.6
1957	73,145	39,830	37,523	20.8	11.3	10.7
1956	70,894	46,220	43,574	20.2	12.5	11.8
1955	61,782	40,704	39,516	17.4	11.4	11.1
1954	60,831	43,948	53,375	17.1	12.4	15.0
1953	76,641	37,806	47,173	21.8	10.7	13.4
1952	55,103	45,241	49,456	15.3	13.0	13.7
1951	51,862	52,509	47,887	14.4	14.6	13.3
1950	43,452	37,450	61,419	12.6	10.9	17.9

ex-vessel price[3] for fresh shrimp and has made the United States market attractive for foreign shrimp and shrimp products. Similarly, rising ex-vessel prices have stimulated investment by entrepreneurs in shrimp fishing vessels.

Between World War II and 1950 the number of vessels engaged in shrimp fishing activity increased 260 percent to a fleet numbering 2,200 vessels. The established fishery during this period was concentrated in the northern Gulf of Mexico in sounds, bays, bayous, and adjacent coastal waters of the Gulf states out to a distance of approximately ten miles. The rapid growth in the number of vessels resulted in intense competition among hundreds of vessels for the stock of shrimp in the established fishery.

The discovery of offshore and distant water shrimp fishing grounds in 1950 altered the spatial distribution of vessels among ports and across the fishing grounds and somewhat eased the competition among individual producers exploiting the inshore waters, but set the stage for an increase in the overall intensity of competition for shrimp resources in the Gulf of Mexico. Today the Gulf fishery extends from the Florida Keys around the Gulf coast of the United States and Mexico to the eastern tip of the Yucatan Peninsula. Shrimp populations to a depth of 40 fathoms are being exploited (Figure 1).

The alteration of the spatial distribution of fishing activity

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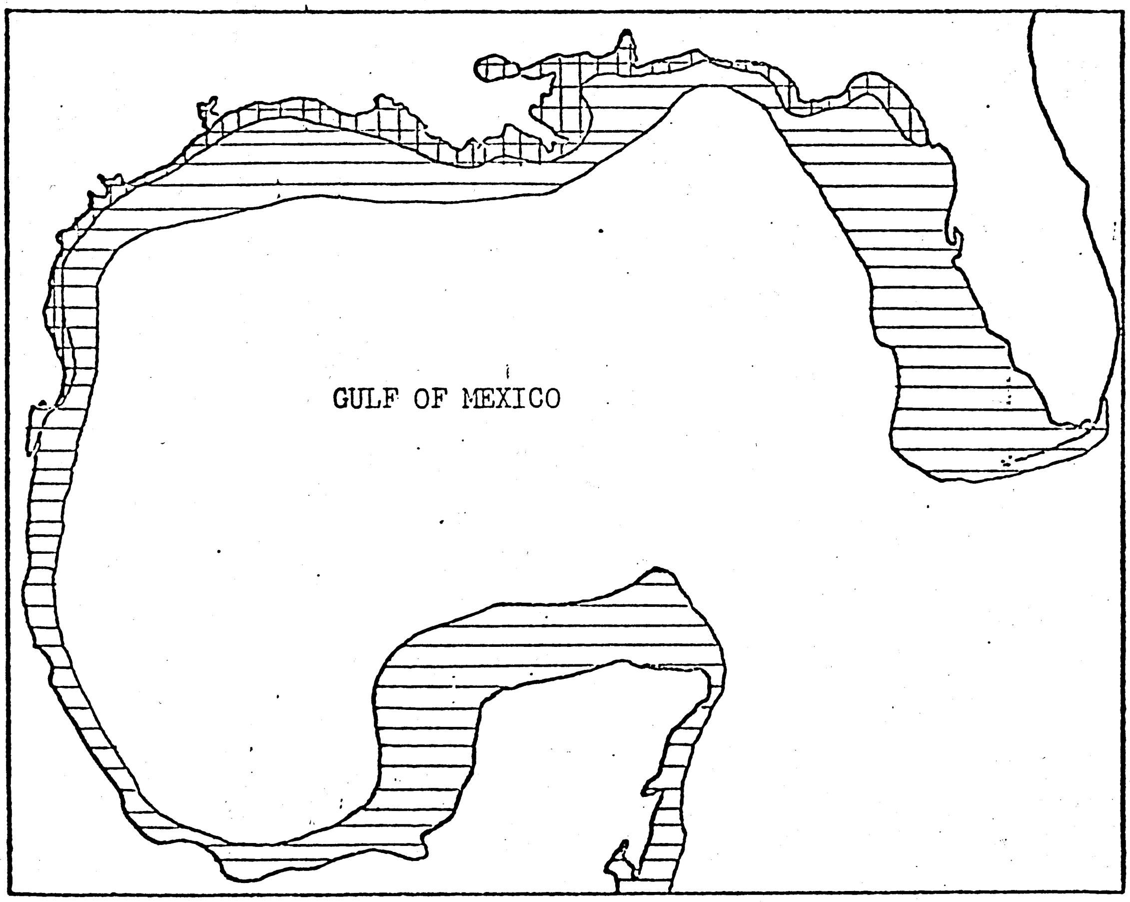
[3]Ex-vessel price is the dockside price paid the vessel owner for fresh shrimp. The only processing that has occurred is the heading process (removal of the head and thorax) and has been accomplished by the vessel's crew while at sea.



Shrimp fishing grounds prior to 1950	Shrimp fishing grounds in 1965

Figure 1. Gulf of Mexico shrimp fishing grounds.

has shifted the investment pattern from relatively small inshore vessels requiring investment of approximately $30,000 to larger, more powerful vessels requiring investments ranging from $50,000 to $80,000. The shifting investment pattern is a result of the individual decision maker's attempt to enhance his competitive position by investing in vessels that are physically capable of fishing the new distant water fishing grounds for extended periods of time, which in turn would enable him to increase his landings.

Currently there exists a fishing fleet which includes 2,849 vessels ranging from 5 gross tons to those exceeding 150 tons (Table 2). Preliminary analysis has shown that today's fleet is characterized by vessels that are underutilized in terms of their potential productive fishing time.[4] Interviews by this author with vessel owners disclosed that the production planning by the individual firm within the shrimp fishing fleet is concentrated on increasing physical production. The current trend in the Gulf shrimp fishing industry is still toward larger vessels, but increased horsepower and increased size of nets are now being emphasized. Individual decision makers in the industry believe that such investment patterns will increase revenue because of increased production. Little concern is directed by individual members

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[4]Roy L. Lassiter, Jr., Utilization of U.S. Otter Trawl Shrimp Vessels in the Gulf Areas, 1959-1961 (Gainesville: Bureau of Economic and Business Research, University of Florida, 1964).

Carter C. Osterbind and Robert A. Pantier, Economic Study of the Shrimp Industry in the Gulf and South Atlantic States (Gainesville: Bureau of Economic and Business Research, University of Florida, 1965).

Table 2.--Distribution of Gulf of Mexico shrimp vessels by gross tonnage.

Gross Tonnage	1964 (number)	1965 (number)
5-9	104	124
10-19	483	512
20-29	340	321
30-39	387	379
40-49	399	385
50-59	265	260
60-69	535	534
70-79	211	220
80-89	41	50
90-99	9	53
100-109	4	8
110-119	1	1
130-139	1	1
140-149	1	---
160-169	1	1
Total vessels	2,782	2,849
Total gross tonnage	116,837	121,693
Average gross tonnage	41.99	42.71

Percent increase in average tonnage -- 1.7

of the industry toward production costs or returns to capital. Similarly, little effort has been devoted to the most effective way to utilize a given fleet of vessels to minimize the costs of producing given quantities of raw headless shrimp or to maximize returns to given levels of investment.

Scope of the Study

The purpose of this study is to analyze the existing shrimp fleet which is now exploiting a portion of the offshore fishing grounds in the Gulf of Mexico. Analysis will be directed toward determining the necessary conditions of fleet use which minimize the total production costs for a predetermined level of physical production from the fishing grounds. Emphasis will be on the optimal allocation of fishing effort in time and space to achieve this objective. Chapter II includes a review of the current literature in fishery economics and develops the individual fishing firm concept in the short and long run and its relationship to the industry. The equilibrium of a fishing industry characterized by unregulated entry is described, as are problems confronted by developers and exploiters of common property resources. Biological sustained yield concepts are treated as a static variable and as a stochastic variable, and are presented in the literature review section. Chapter III covers the biological and economic characteristics of the shrimp fishing grounds that will be utilized in the empirical analysis followed by methodology, empirical analysis, interpretation of empirical analysis, and policy implications in subsequent chapters.

CHAPTER II

LITERATURE REVIEW AND ECONOMIC THEORY

Externalities and Common Property Resources

Exploiters of marine fishery resources are confronted by external economies and diseconomies similar to those faced by users of any other natural resources which have no formal property structures. These resources have been aggregated and called common property resources.[5] Natural resources often classified under this general term are air; in some cases water, i.e. groundwater; public grazing land; petroleum deposits; and marine resources.

A common property resource is characterized by its ability to be utilized simultaneously by more than one individual or economic unit. No user has exclusive rights to the resource, nor can he prevent others from sharing in its exploitation. Common property resource externalities are primarily fostered by this characteristic. Externalities as defined by McKean[6] are the uncompensated effects on the costs or receipts of any industry caused by the actions of another

[5] An exception to this case is the public park. It has a formal property structure but is still considered a common property resource.

[6] Roland McKean, Efficiency in Government Through Systems Analysis, With Emphasis on Water Resource Development (New York: Wiley & Sons, 1958), p. 134.

industry or productive unit. Hartman and Seastone[7] define externalities as "a concept applied to those economic effects which lie outside the decision making scope of micro units. . . ."

The term externality is an ambiguous concept for it includes external costs, external benefits, and monetary as well as nonmonetary externalities. Inclusion of such diverse components make quantification of externalities an extremely difficult task. One should note, however, that some individual(s) or producing unit(s) always enjoy or suffer from the effects of externalities. Observing a harmful or beneficial effect, and noting that the costs of bringing the effect to bear on the decisions of one or more of the interacting persons are too high to make it worthwhile, will qualify an effect to be considered an externality. In the marine fisheries an individual vessel engaging in fishing a particular portion of a fishing ground immediately subsequent to another vessel having just fished the same portion of the fishing ground would be a case in which an externality is being absorbed by the second vessel. The second vessel would incur additional costs per unit of catch because of the decrease in the fishable biomass caused by the first vessel's effort.

External economies could be incurred if there are vessels engaged in fishing on a fishing ground with no adjacent port facilities. As the number of vessels fishing on the ground increased, adjacent port

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[7]L. M. Hartman and D. A. Seastone, "Welfare Goals and Organization of Decision Making for the Allocation of Water Resources," Committee on the Economics of Water Resources Development of the Western Agricultural Economists Research Council Report No. 12 (Salt Lake City, 1963), p. 15.

facilities may be constructed, thus offering the vessels economies in transporting fish from the fishing ground to port.

Basically there are four externality characteristics for marine common property resources:[8]

1. The private costs of appropriating and defending exclusive use rights may be higher than the added returns that such an appropriation and defense might bring. The reasoning behind this is that common property resources can extend indivisibly over larger geographic areas because of their mobility and fluidity.
2. Private ownership of the resources may have low extra anticipated returns. Appropriating and defending exclusive rights which insure restricting the freedom of use of a resource may be considered to be of little or no advantage to the users. Anticipation of low extra returns usually occurs when the resource appears to be of such magnitude that its use by one individual will not diminish the use of the resource by others. This basic philosophy was instrumental in establishing the "freedom of the seas" doctrine under which individual commercial fishermen argue: "fish as long and as hard as you wish because there will always be fish." There is biological evidence available that demonstrates the fallaciousness of such an argument.

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[8]Francis T. Christy, Jr. and Anthony Scott, The Common Wealth in Ocean Fisheries, Resources for the Future (Baltimore: Johns Hopkins Press, 1965), pp. 6-7.

The concept will be developed theoretically in the following section.

3. The production decision for members of the industry, in terms of labor and capital that is applied in the exploitation of a common property resource, is not subject to the economic constraints that govern the rational exploitation of resources that have formal institutional property relationships. Within the framework of common property the individual user is in competition with all other users of the same resource base. Thus, the individual will attempt to exploit the largest share of the resource that is economically possible from his individual production decision. It would be unreasonable to assume that the individual would restrain his efforts and not exploit this share because any portion he does not exploit will be exploited by other users of the same resource.

4. There are social costs incurred through customs, laws, and other institutional arrangements that prevent acquisition of exclusive rights to the use of a common property resource. Acquisition of such rights could internalize many of the externalities. Marine fisheries have "grandfather clauses" in most fishing treaties and international agreements to insure the use of the resource by individuals, provinces, or countries who were exploiters of the resource during the initial use phase.

The marine fisheries serve as an excellent example to discuss the four preceeding externality characteristics in economic terms. Direct unrestrained competition for use of a common property resource requires the individual exploiter within the industry to consider the firm production decisions in terms of average productivity rather than marginal productivity. The individual firm engaged in commercial fishing in a short run marine fishery situation is forced, by the motive of self interest, to harvest the largest quantity of fish that is physically possible under his given short run labor-capital combination. To reduce uncertainty in his decision process the individual firm will consider the average productivities of each fishing ground. For example: assume two fishing grounds, A and B; A having the higher average productivity. Individual firms will allocate fishing effort to ground A until the average productivities of the two fishing grounds are equated. At this level a long run stable equilibrium between fishing grounds is achieved. Under these decision conditions, many firms will allocate effort to ground A and increase the probability of over-investment, i.e. over allocation of labor and capital to ground A and production in stage III on the fishing ground.

Frank Knight, discussing the allocation of resources to intermarginal and marginal farmland, concludes,[9] "It is the social function of ownership to prevent this excessive investment in superior situations." He further states,[10] "The owner of a

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[9]F. H. Knight, "Some Fallacies in the Interpretation of Social Cost," Quarterly Journal of Economics, Vol. 38, 1924, p. 586.

[10]Ibid., p. 587.

superior opportunity for investment can set the charge for its use at any amount not greater than the excess of the product of the first unit of investment above what that unit could produce on the free opportunity."

Internalizing externalities frequently requires a shift in the institutional property arrangement to bring the external effects to bear on all interacting individuals. External effects may be ignored and a second best alternative selected, the classical tax-subsidy policy could be adopted,[11] or the affected parties might engage in bargaining and attempt to arrange a solution between themselves.

The difficulty of quantifying externalities has led this author to consider externalities only to the effect that they are expressed in the empirical cost data. It was felt, however, that the existence of externalities should be brought to the attention of the reader.

Biological and Economic Theory

A review of fishery economics literature reveals the occurrence of a metamorphic process. Early considerations were by fishery biologists who developed physical relationships between the fishable biomass and its environment. The natural resource exploiter, i.e. the commercial fisherman, was treated as an exogenous variable in the biological-economic analysis. As the developmental stages of economic analysis occur, the fisherman becomes an endogenous variable in much of the literature.

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[11]Alfred Marshall, Principles of Economics (London: The Macmillan Company, 1961), pp. 467-476.

The present study begins a short review of the literature at the endogenous variable stage and traces the development of fishery economic analysis through the sustainable-yield concept, the effects of an unrestricted entry fishery, and a bionomic equilibrium model.

Biological Model

The biological concept of sustainable yield has been concisely summarized by Crutchfield.[12] He maintains:

> The key variable determining production possibilities from a fish population can be grouped under four headings: rate of entry into the 'fishable' age (recruitment); growth rates of individual fish; natural mortality (from disease, old age, and nonhuman predators); and fishing mortality. In the absence of human intervention, any marine population tends toward a maximum aggregate weight, or biomass, at which net increments to stock from recruitment and growth are exactly offset by decrements from natural mortality. Thus, at zero and at maximum population the instantaneous rate of change in the weight of the fishery population is zero. At intermediate levels, the aggregate weight of the stock, in the absence of other disturbances, will tend to rise toward its maximum value, and the instantaneous rate of change in weight will be positive.[13]
>
> Assuming for the moment that recruitment and growth rates are independent of population size, these relationships can be translated into a simple physical production function. As fishing effort (expressed in terms of standard units) is increased from zero level, sustainable yield--that is, the catch equal to the instantaneous rate of change in the biomass in the absence of fishing by man increases at a decreasing rate while the number and average size of fish will decline continuously. If the selectivity of the gear with respect to fish of different sizes is held constant, the sustainable yield will peak at some level of fishing effort. Further increases in fishing effort will produce an absolute decline in sustained physical yield. The common sense of this is apparent.

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[12] James Crutchfield, "The Marine Fisheries: A Problem in International Cooperation," American Economic Review, Vol. 54, No. 3, May 1964, pp. 207-218.

[13] Ibid., p. 209.

Assuming a recruitment rate independent of population and a sigmoid growth function, fishing by man would yield a larger net physical product as long as the marginal reduction in weight losses from natural mortality is greater than the marginal rate loss resulting from capture of individual fish before they achieve maximum weight.[14]

Effort expended at level X_1 will yield a catch of OA (Figure 2) per unit of time. At this level of effort incremental increases of effort would increase the aggregate weight of the catch.

Most biologists subscribe to the expansion of effort to level X_2. This level of effort would result in a catch of OB per unit of time or a maximum sustainable yield. Incrementally increasing units of effort beyond level X_2 would decrease the weight of the total catch. For example: effort expended to level X_3 would result in marginal weight loss from capture and natural mortality exceeding the weight gains from growth and recruitment, thus affecting the population size. The extent of the effects are dependent on the level of effort expended beyond X_2. A level of effort could be expended that results in a fish population reaching the critical or nonrenewable zone[15] and the fishery "destroyed" by human action.

Crutchfield asserts:

The assumption that recruitment is independent of population obviously cannot be of completely general validity. For anadromous fish such as salmon the relationship is critical. Nature is so

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[14]Crutchfield, op. cit., pp. 209-210.

[15]S. V. Ciracy-Wantrup, Resource Conservation Economics and Policies (Berkeley: University of California Press, 1963), p. 39. "Critical zone means a more or less clearly defined range of rates below which a decrease in flow cannot be reversed economically under presently foreseeable conditions."

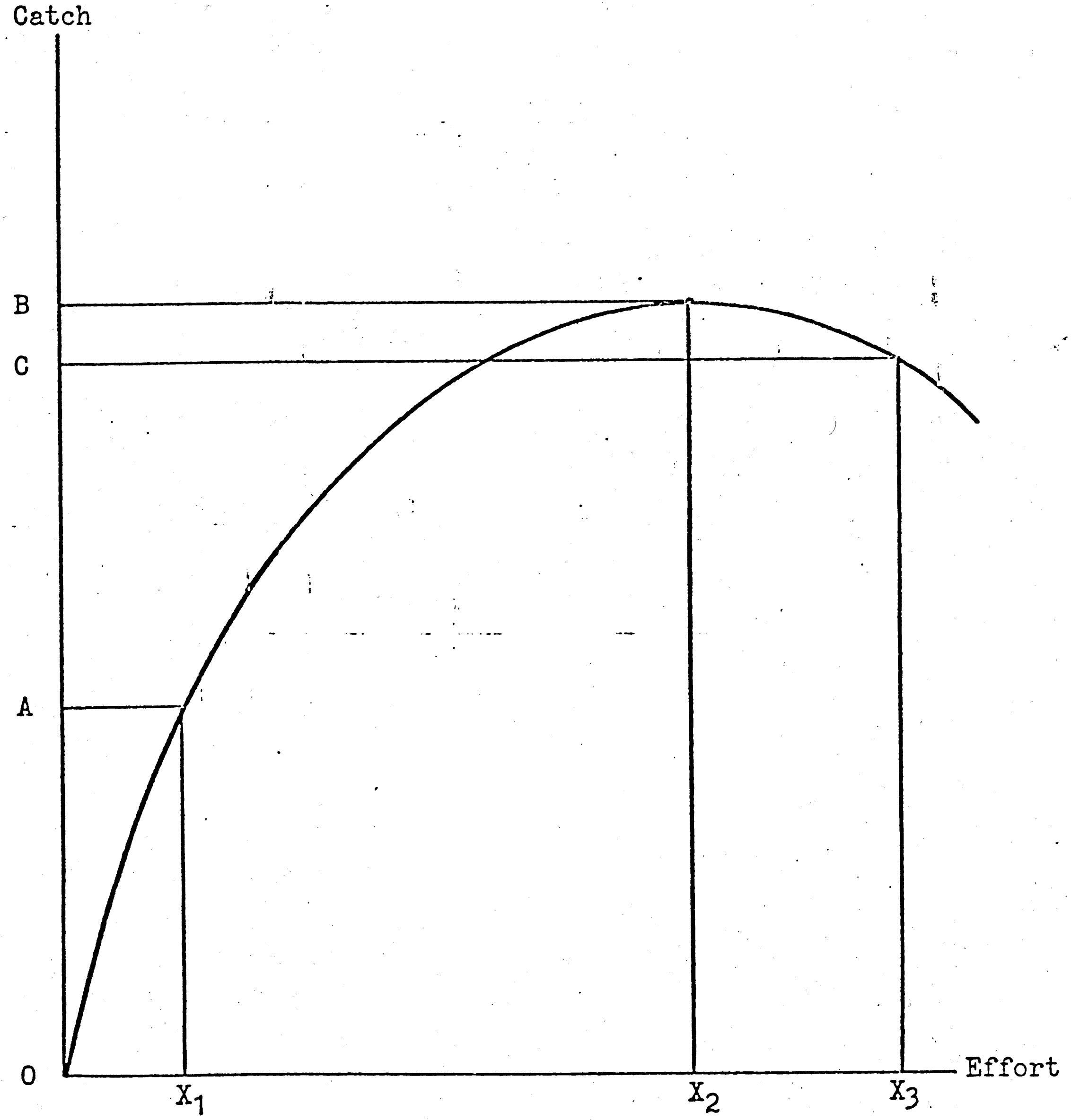

Figure 2. Biological sustainable yield.

> prolific in her production of fertilized eggs, however, that the case in which the number of fish surviving to catchable size is independent of the total biomass over relevent ranges is the rule rather than the exception. The other assumptions are less tenable. Growth rates are almost certain to be density dependent as are some types of natural mortality and the production possibilities implicit in the foregoing analysis are not necessarily reversible. As the size of the desired stock is reduced through commercial fishing, permanent shifts in predator prey relations and in relative numbers of competing food users may occur. Moreover, large and frequent shifts in parameters are inevitable in the ecological setting of the sea.[16]

Most fishery biologists associate the maximum sustained yield with optimum yield despite the insistence by a few that the optimum yield involves social considerations that are not explained by the physical relationships. Dr. Martin D. Burkenroad, an eminent fishery biologist, has written, "The management of fisheries is intended for the benefit of man, not fish; therefore, the effect of management upon fish stocks cannot be regarded as beneficial per se."[17]

Economic Model

H. Scott Gordon,[18] in his pioneering paper in the field of fishery economics, explains the social consideration by combining physical and economic relationships to consider the optimum degree of utilization of a fishing ground. Construction of his initial model views the optimum degree of utilization as the maximization of net

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[16]Crutchfield, op. cit., p. 210.

[17]M. D. Burkenroad, "Some Principles of Marine Fishery Biology," Publications of the Institute of Marine Fishery Biology, Vol. 2, No. 1, University of Texas, September 1951.

[18]H. Scott Gordon, "The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economics, Vol. 62, 1954, pp. 124-142.

economic yield (total revenue minus total costs) of the fishery. Total cost and total revenue are considered to be functions of the intensity of fishing effort.

Gordon, using a production-function approach (Figure 3), assumes a linear decreasing functional relationship between average productivity (productivity per unit of fishing effort)--as well as marginal productivity--and the quantity of fishing effort expended.

Marginal factor cost is equal to average factor cost under the assumption that costs (including opportunity costs) do not affect the quantity of effort expended. The optimum intensity of effort on the fishing ground and the resource is OX which provides a maximum net economic yield of apqc. Maximum physical sustained yield occurs when marginal productivity equals zero with a corresponding fishing effort of OZ.[19] Gordon concludes that the optimum fishing intensity, in economic terms and directed toward the fishing grounds, is less than the intensity which would maximize physical sustainable yield. Area apqc reflects the rent yielded by the fishery resource and the economic productivity of the fishing ground. This simplified analysis describes the intensive margin of utilization of the intramarginal fishing ground.

Gordon complicates his analysis by introducing the common property aspect of the fishery resource. Under this condition, entry to the fishing industry is unrestricted and fishermen are free to fish wherever they please. Rent yielded by the intramarginal fishing ground

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[19] H. Scott Gordon, "Misinterpretation of the Law of Diminishing Returns," Canadian Journal of Economics and Political Science, February 1952.

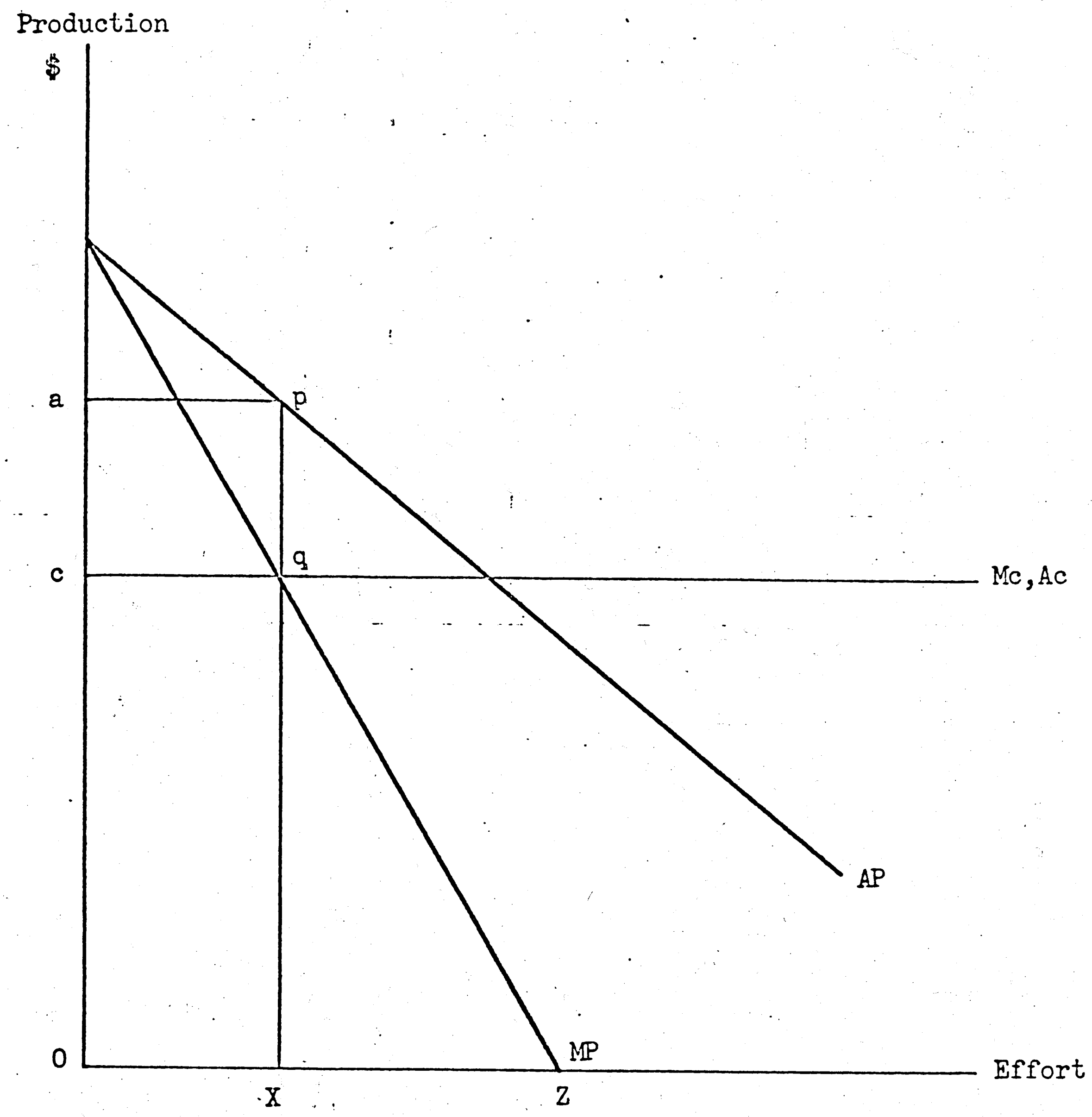

Figure 3. Gordon's "optimum" degree of utilization of a fishing ground.

cannot be appropriated by a single individual. The result is a pattern of spatial competition among fishermen that culminates in a dissipation of the rent yielded by the intramarginal grounds.

Any expended effort of fishing grounds number 2 (Figure 4) will yield a lower average revenue product than on fishing grounds 1. Maximization of net economic yield on grounds 1 and 2 is accomplished when the marginal revenue products are equal on both grounds, i.e. when marginal cost equals C, OX and OY effort intensities will maximize net economic yield. Fishermen, however, are not interested in marginal revenue product, but in average revenue product and, being free to fish any fishing ground, will fish ground 1 because the average revenue product ac (ground 1) is greater than bc (ground 2). The allocation of effort on ground 1 would predominate until the average revenue product of ground 1 is equal to the average revenue product of ground 2. When the average revenue products are equal, a stable equilibrium for both fishing grounds will exist.

On the extensive margin, average cost equals average revenue product; average revenue product for all fishing grounds equated by the free competition of fishing. Since it is assumed that average cost is equal for all grounds, other intramarginal grounds will yield no rent because fishing effort has been misallocated. Through gross misallocation of fishing effort it is feasible for a fishing ground to exist that is being exploited in the range of negative marginal productivity. This situation clearly represents an over-expenditure of fishing effort.

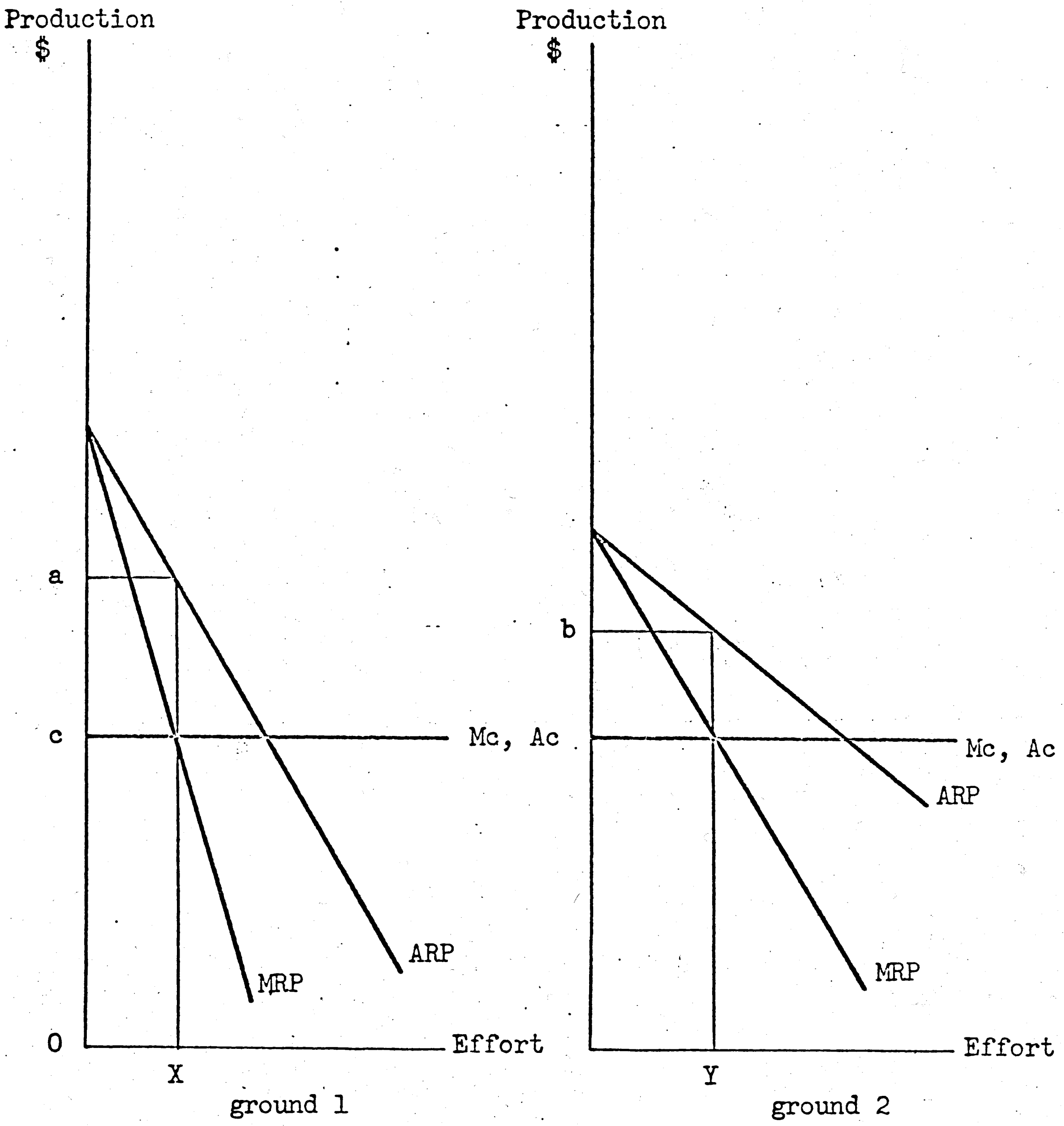

Figure 4. Dissipation of rent on intramarginal fishing grounds.

Developing the long-run static equilibrium concept one step further, Gordon considers a bionomic equilibrium for a fishing industry. Under simplifying assumptions of constant product prices, fixed prices of factor inputs, and a nonlinear landings function, the relative quantities of expended effort, total cost involved in fishing activity, and the value of landings are described. Generation of a stable equilibrium results in the derivation of four basic equations:

$$P = P(L) \tag{1}$$

$$L = L(P,E) \tag{2}$$

$$C = C(E) \tag{3}$$

$$C = L \tag{4}$$

P = population of fish or the fishable biomass.

L = landings in value terms.

E = intensity of fishing effort.

C = total cost of expenditure of fishing effort.

Point A (Figure 5) describes the stable equilibrium as the equalization of total costs for expended fishing effort and landings in value terms. Crutchfield and Zellner[20] explain this analysis and point out:

> At this point, total receipts just cover total costs including a minimum necessary return to the vessel owner. At any lower level of fishing effort profits in excess of this minimum would be earned and vessels would enter the fishery. At higher levels returns would not cover total costs and fishing effort would be curtailed. Some vessels would be diverted to other operations and the usual reductions in number of vessels due to depreciation

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[20] James Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," Fishery Industrial Research, Vol. I, No. 1, Fish and Wildlife Service, April 1962, pp. 14-15.

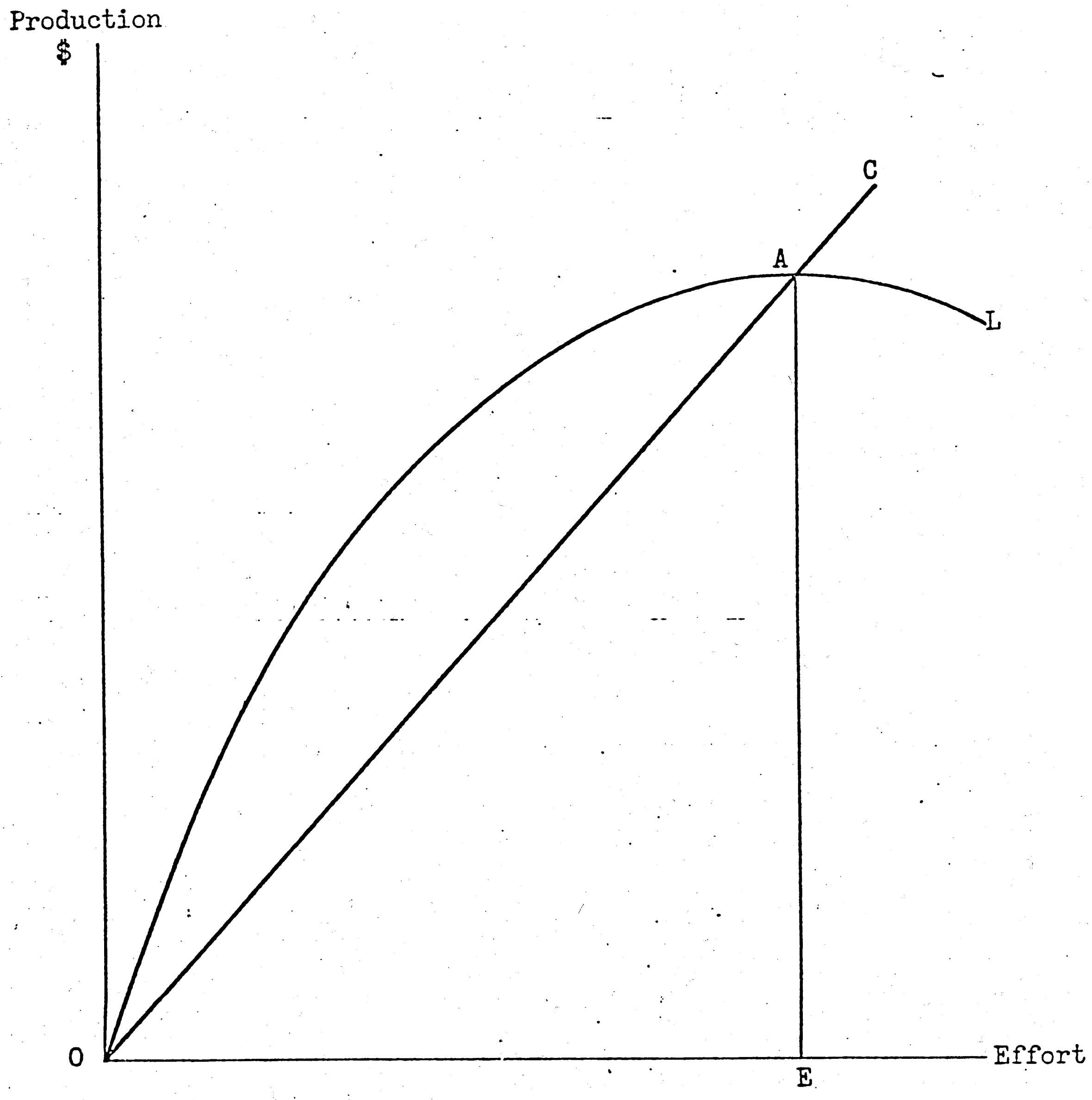

Figure 5. Stable equilibrium of a fishing ground.

and losses would not be fully replaced. Obviously any increase or decrease in prices received by fishermen whether caused by an increase in retail demand or a reduction in the cost of marketing services would increase or decrease the fishing effort. Similarily, increases or decreases in fishing costs would restrict or stimulate fishing activity.

It is interesting to note that, given the yield-revenue function, the point of stable equilibrium of total costs and landings in value terms is dependent upon the slope of the cost function. Figure 6 poses three possible general stable equilibriums for alternatively sloped cost functions. Effort, landings, and total costs in Figure 6a would be stable equilibrium at a point less than the maximum sustainable yield; in Figure 6b equilibrium is reached at the maximum sustainable yield level; and in Figure 6c equilibrium is reached at a level greater than maximum sustainable yield.

Scott, Crutchfield, Zellner, Turvey, and Christy do not differ in their interpretation of an unrestricted fishery.[21] All have considered a long-run equilibrium of a fishery in generally the same terms as Gordon in his analysis.

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[21] Christy and Scott, op. cit.

James A. Crutchfield, "The Economic Objectives of Fishery Management," The Fisheries: Problems in Resource Management (Seattle: University of Washington Press, 1965).

Crutchfield and Zellner, op. cit.

Anthony Scott, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economics, Vol. 66, 1955, pp. 116-124.

Ralph Turvey, "Optimization and Suboptimization in Fishery Regulation," American Economic Review, Vol 54, No. 4, March 1964, pp. 64-76.

Ralph Turvey and Jack Wiseman, Editors, The Economics of Fisheries (Rome: Food and Agriculture Organization of the United Nations, 1957).

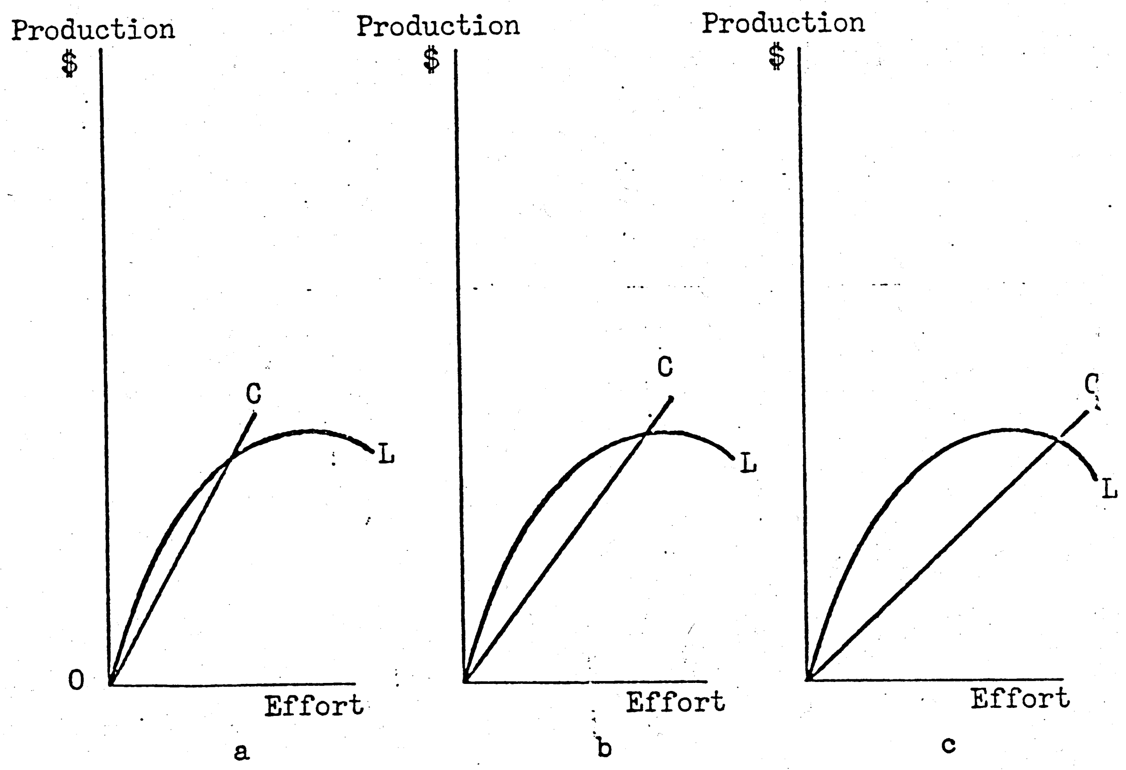

Figure 6. Equilibrium of a fishing ground under alternative cost functions.

These authors advocate a management practice that would maximize the social gain, and propose that a fishery be fished at a point where the net economic yield is maximized. Graphically, (Figure 7) this would be a point less than the maximum sustainable yield. Under these conditions the fishery would operate as a monopoly or as a single firm would operate. Gordon summarizes by saying, "In this case we are maximizing the yield of a natural resource, not a privileged position, as in standard monopoly theory. The rent here is a social surplus yielded by the resource, not in any part due to artificial scarcity, as in monopoly or rent."[22]

The Static Sustainable Yield vs. A Stochastic Sustained Yield

The static industry approach considered by all fishery economists is a valuable contribution to the literature, but has shortcomings when applied to real life situations. Such is the case with the preceeding analysis. Consideration of the minimization of production costs for a particular fishing ground within an industry requires an understanding of the actions and reactions of the individual firm under the assumption of unrestricted entry. There is a definite gap in the literature that must be filled if continuity between the theory of the fishing firm and the theory of the fishing industry is to be achieved.

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[22] H. Scott Gordon, "The Economic Theory of a Common Property Resource: The Fishery," op. cit., p. 141.

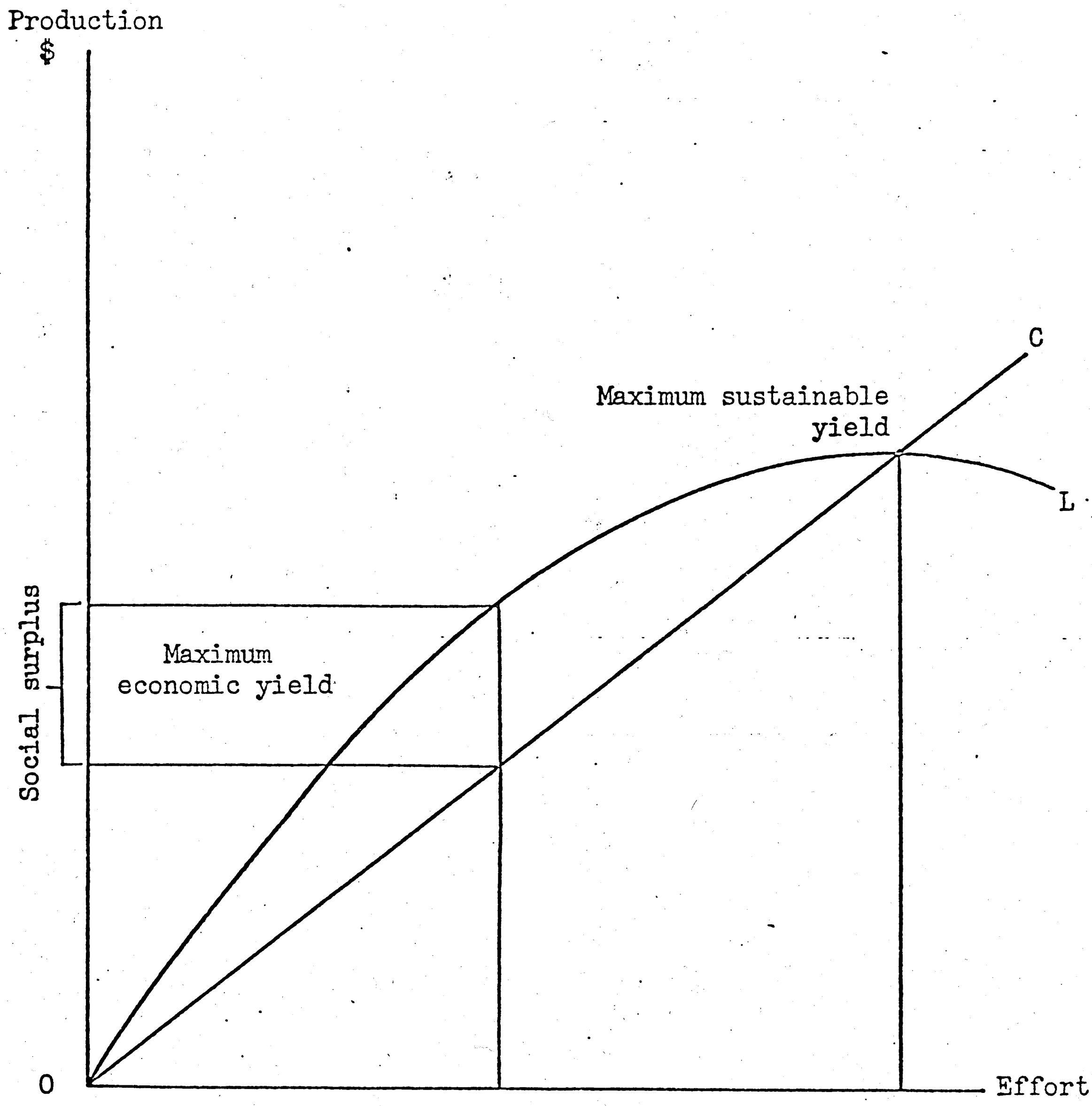

Figure 7. Maximization of social gain from a fishing ground.

A second shortcoming of the current literature and its application to real life situations is the development of a theoretical body of knowledge that considers only the stable sustainable yield curve. As population dynamics theory increases in sophistication, the biologist is becoming increasingly aware of considerable short run variations around the sustained yield curve.[23] The variations are phenomena resulting from natural causes such as large and sudden changes in salinity, water temperature, availability of food supplies, etc. McHugh explains, ". . . rational development of a single species fishery usually cannot be accomplished under the single concept of a single maximum sustainable yield."[24]

The sustainable yield curve (Figure 8) is actually an expected or mean yield curve. The expenditure of effort (X_1, Figure 8) will yield an expected catch of OA. The actual catch varies within a range of about catch level OA (Figure 8) with effort expended at level X_1. The actual catch will be a stochastic variable following some distribution around the long run expected sustainable yield.[25]

The implications of the stochastic variation have the most impact on the individual firm. The uncertain variations in yield per

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[23]J. L. McHugh, "Conservation of Fishery Resources," An Appendix to Food from the Sea and World Protein Deficiency, unpublished.

[24]Ibid.

[25]This stochastic variation concept was applied by Drs. Virgil Norton, Darrel Nash, and Harvey Hutchings, economists with the Bureau of Commercial Fisheries, Fish and Wildlife Service, Department of the Interior, to long run fishery industry analysis.

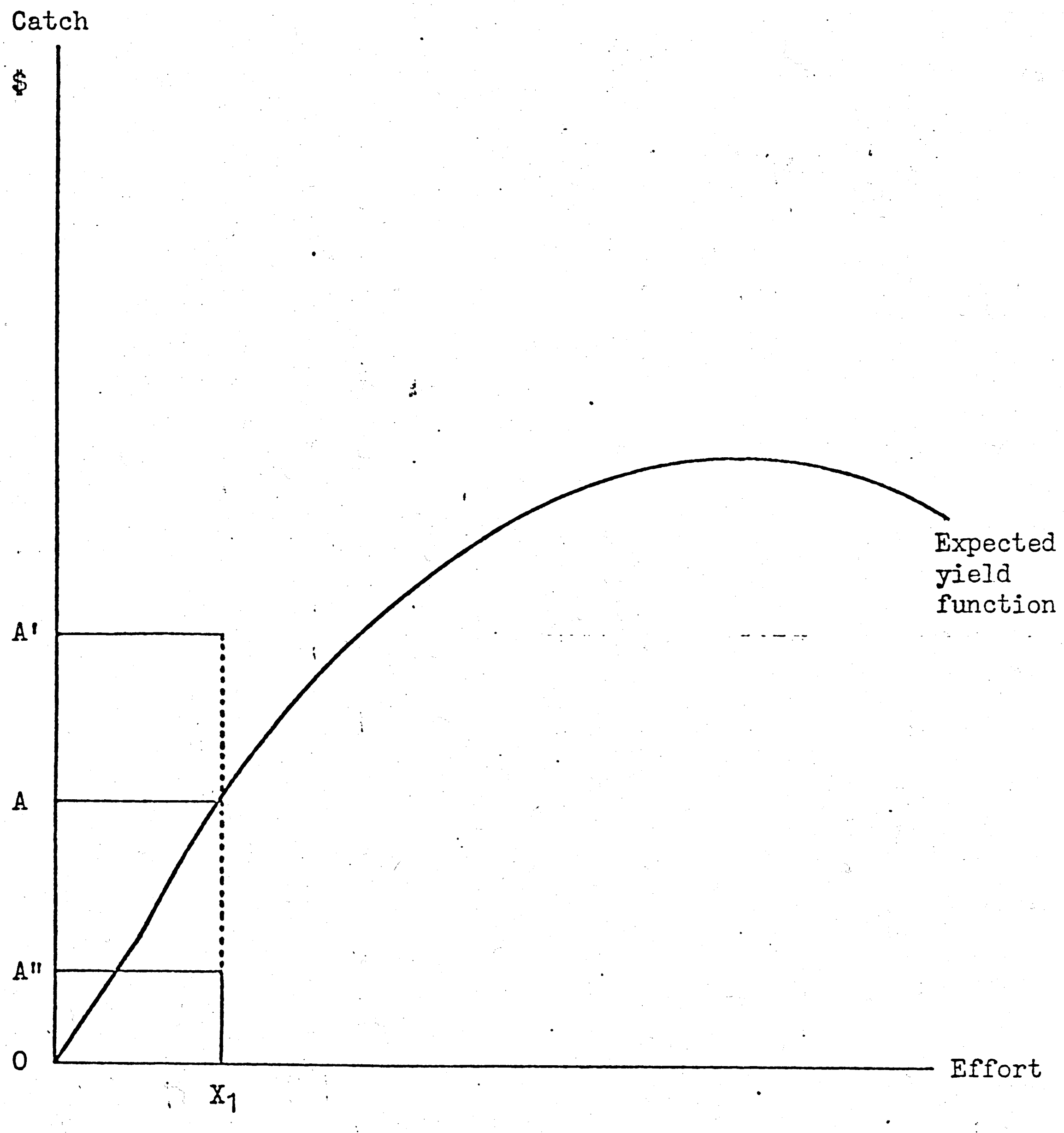

Figure 8. Sustainable yield curve under conditions of stochastic variation.

unit of effort has made the short run production decision similar to one based on game theory. The "player" under conditions of game theory is completely ignorant of what act or strategy his so-called opponent will follow.[26] The individual fishing firm in a short run situation is uncertain of the combinations of variable factor inputs to utilize in order to maximize profit under stochastically variable yield conditions. The firm's logical alternative is to assume the expected yield function and constant prices and develop decision criteria under these conditions. Essentially, the rational firm will calculate expected marginal costs, average costs, and average variable costs and develop an expected output level (Figure 9). The absence of a stochastic variation in the yield per unit of effort would result in an output level of X_1 per unit of time and profit of APCE. The occurrence of a stochastic variation that increased the yield per unit of effort would result in a downward shift, to the right in the SAC and SMC curves relative to the increase in yield per unit of effort. A "windfall" gain in production $X_2 - X_1$ would occur with a "windfall" gain in profit, area ADBFCE.

The occurrence of a stochastic variation that decreased the yield per unit of effort would increase and shift the SAC" and SMC" upward and to the left relative to the increase in yield per unit of

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[26]Two introductory books are available to the reader who wishes to expand the concepts of game theory presented here:

W. J. Baumol, Economic Theory and Operations Analysis (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.)

C. West Churchman, Russel L. Ackoff and E. Leonard Arnoff, Introduction to Operations Research (New York: John Wiley and Sons, 1957).

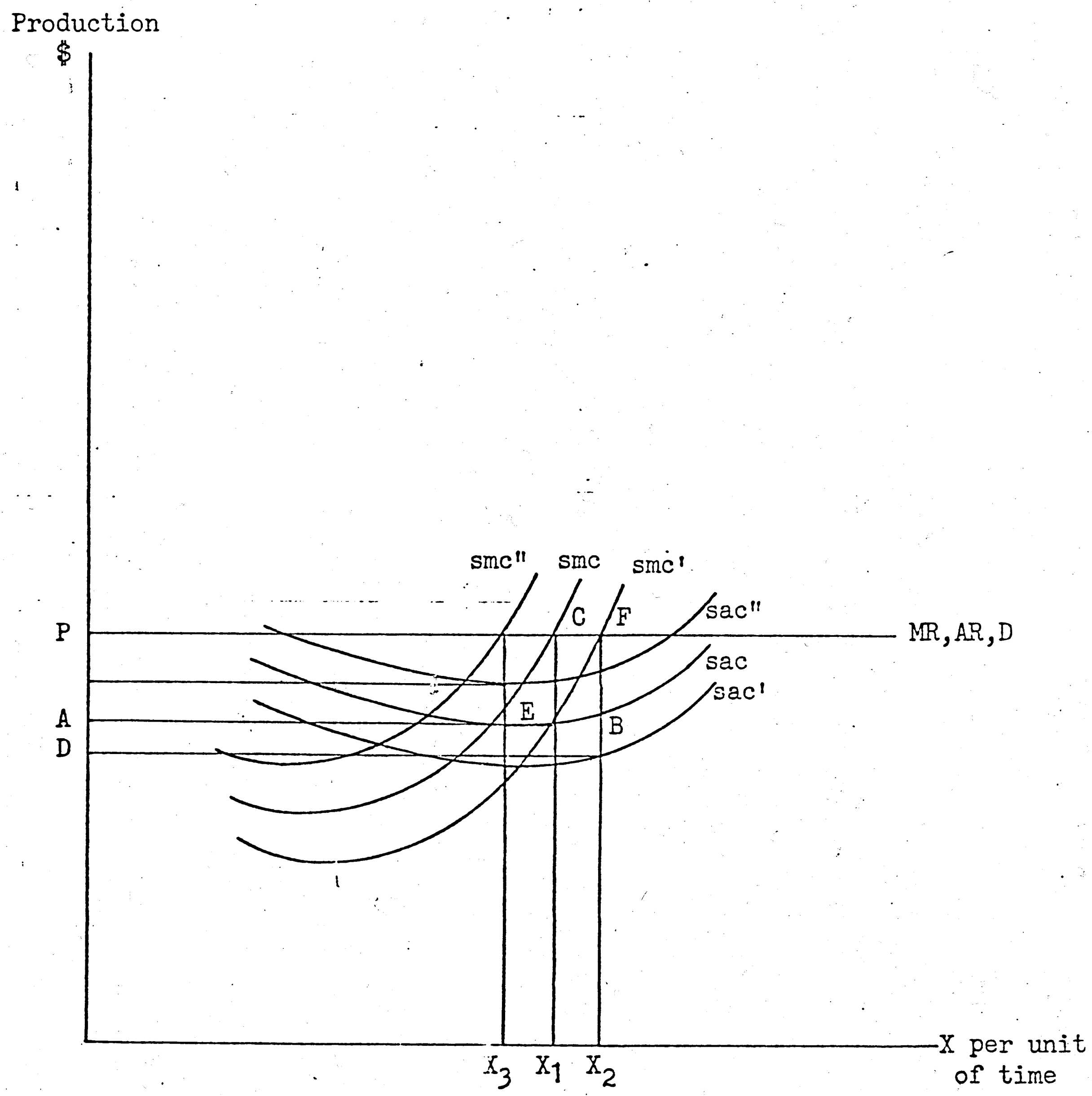

Figure 9. Production under stochastic variation of a fishery population.

effort. A decrease in profit, zero profit, or a short run loss could occur, depending upon the relative shift in the cost curves.

The short run equilibrium of the industry under conditions of stochastic variations is simplified considerably by the assumption: constant ex-vessel prices. In effect, this simplifying assumption assumes the short run equilibrium of the industry away.[27]

The long run situation and its relationship to the individual firm allows for greater variation in the level of output for any individual firm. The long run allows for changes in the utilization of the existing facilities and changes in the number and scale of the fishing vessels. Assumptions of freedom of entry and exit allow new firms to enter the industry as well as existing firms to leave. These assumptions will increase the elasticity of the individual firm's supply curve because fixed costs become fewer as the time period is extended.

The short run analysis of the firm implied the cost curves of the firm were dependent on the law of variable proportions and considered capital and management as fixed factor inputs. In the long run the rational individual firm will "consider" a finite series of short run average cost curves, and "fit" a long run cost curve that is tangent to some short run cost curve at each scale of plant and level of output.[28]

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[27]The assumption is realistic for the Dry Tortugas shrimp analysis because the intrayear price variation is relatively stable between periods of high and low productivity (Appendix B).

[28]A finite series of short run average cost curves will be considered because of the indivisibilities associated with the scale of fishing vessels.

The freedom of entry assumption will allow for new firms to enter the industry if profits are present and may bid up the price of the factor inputs. The increased competition for the resource base will also give rise to externalities which will increase the long run average cost curve of the industry via the short run average cost curves. Theoretically, firms will be attracted to the industry as long as profit is present, and a long run equilibrium (Figure 10) will result in which long run average cost is tangent and equal to the marginal revenue and long run marginal cost.

The entry of new firms in the long run causes an increase in output, i.e. a shifting of the industry supply curve to the right; to maintain the constant price it is also assumed that the industry demand will shift upward and to the right relative to the increase in demand.

The long run analysis can be complicated, as was the short run analysis, by the short run stochastic variation in yield per unit of effort. The individual firm in the long run attempts to develop a scale of plant and, hence, a long run average cost curve that considers the expected mean yield per unit of effort. The individual firm also considers the distribution of the stochastic variation in yield per unit of effort. These two factors are prime input in the decision process for the optimum scale of the primary production unit. It should be clearly evident that any catch which results in total revenue exceeding total cost will be inducement for the new firms to enter the industry. The result is an industry that is perhaps overcapitalized and underutilized in relation to the expected sustainable

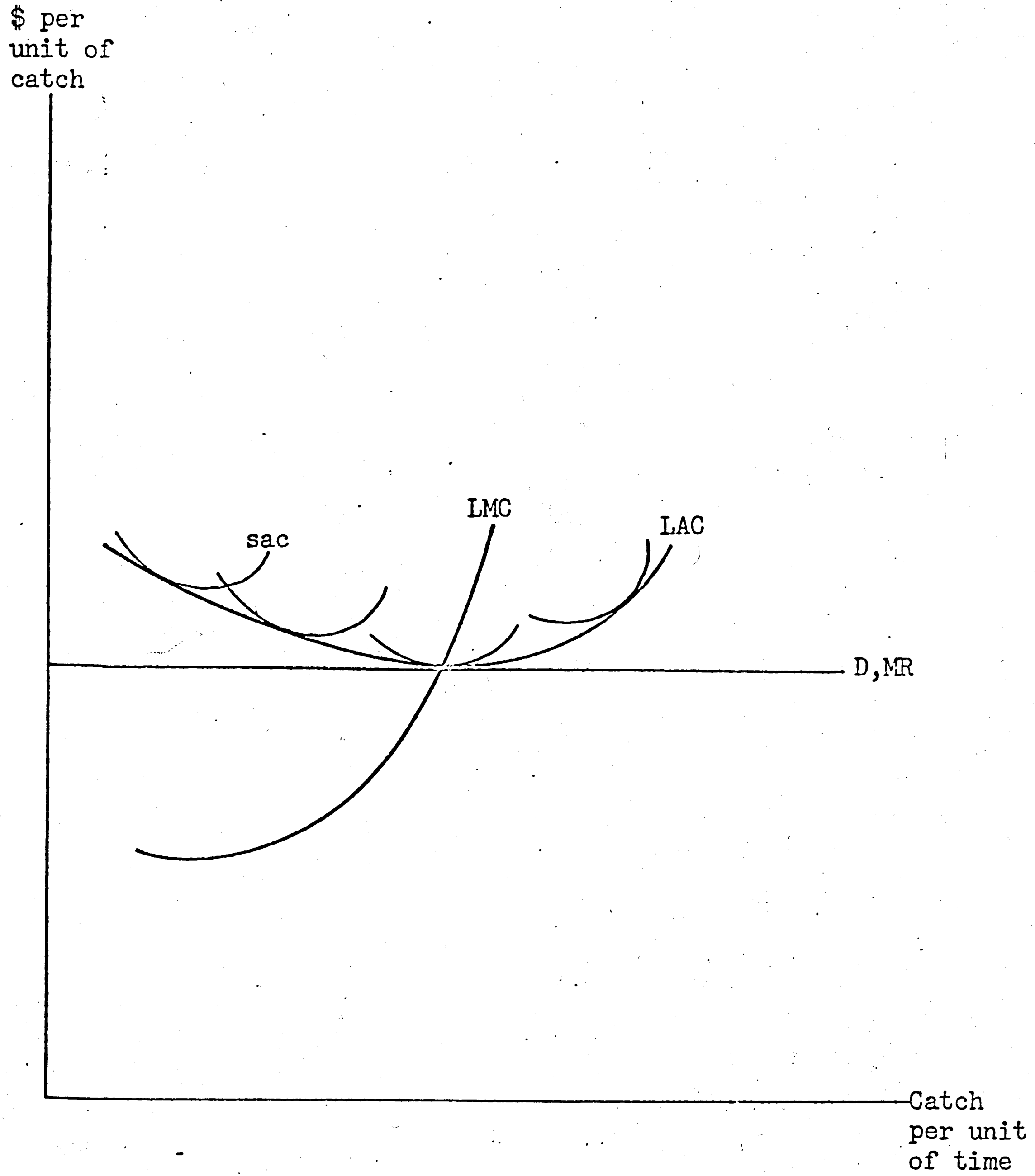

Figure 10. Long run equilibrium of a fishing industry.

yield concept. This is to say that the total costs incurred by the industry exploiting a fishery, in the short run, may exceed the total revenue.

Empirical Analysis in Fishery Economics

Fishery economics literature to date has been theoretical in context with very little emphasis placed on extensive empirical analysis. This should not be interpreted as a harsh criticism because there have been numerous impediments to detailed empirical analysis.

Fishery economics is a relatively new area of research endeavor for the economist. The first detailed economic literature contribution was made by H. Scott Gordon in 1954. His efforts were directed toward developing a theoretical framework for common property fishery resources for the serious fishery economics student.[29] Additional efforts have been undertaken by other economists to develop a sound theoretical economic framework.[30]

A second impediment is the lack of economic data. Any empirical analysis requires reliable data as the major input. The Bureau of Commercial Fisheries has been engaged in gathering biological and secondary economic statistics on a systematic basis for the last decade, but to date no provisions have been made to collect primary economic statistics. Canada has made demonstrable efforts to collect

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[29]H. Scott Gordon, "The Economic Theory of a Common Property Resource: The Fishery," op. cit.

[30]See footnote 9, literature review and economic theory section, for a brief bibliography.

economic statistics as testified by their current publications.[31] Canadian economists are presently engaged in an empirical bio-economic study of a limited entry lobster fishery in southeastern Canada, and published results will be available in late 1967.

Pressing public policy issues have necessitated research emphasis to be directed toward management problems. Crutchfield and Zellner[32] and Turvey[33] have engaged in hypothesizing the effects of various management techniques on the allocation of labor and capital to a fishery resource.

Another major impediment to empirical analysis has been the lack of financial assistance to the development of mathematical models. The construction of general economic mathematical models requires the aid of skilled professional personnel to develop mathematical relationships, both biological and economic, and generate the necessary data to test these models.

The preceding impediments to empirical analysis are recognized by public policy makers, however, and serious efforts are being undertaken to rectify the situation. It is through this recognition that this study has been made physically and financially possible. The purpose of this study is to develop one general empirical approach to fishery economics and to extend the preceding theoretical and

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[31]For example: John Proskie, "Costs and Earnings of Selected Fishing Enterprises Atlantic Provinces 1962," Primary Industry Studies, Vol. 12, No. 1 (Ottawa: Department of Fisheries of Canada, 1964).

[32]Crutchfield and Zellner, op. cit.

[33]Turvey, op. cit.

incomplete empirical analyses into a more sophisticated economic approach which will be useful to the public policy decision maker and to members of the fishing industry. By increasing the knowledge of how and why the fishing industry acts and reacts as it does, it is hoped that the economic efficiency of the industry can be increased.

CHAPTER III

BIOLOGICAL AND ECONOMIC CHARACTERISTICS OF THE DRY TORTUGAS SHRIMP FISHERY

The fishing ground to be emphasized in the development of a general production cost minimization model is the Dry Tortugas fishing ground in the Gulf of Mexico. The Dry Tortugas is an offshore fishing ground north and south of the Florida Keys and west of Key West, Florida (Figure 11). It is bounded geographically by 81° and 84° longitude and 24° and 26° latitude. The fishery is distinguished by four characteristics which make it suitable for initial empirical analysis:

1. The fishery has an indigenous species: Penaeus duorarum (commonly called pink shrimp). There is little or no interaction with populations found in other fisheries.
2. The Tortugas fishery is a year-round fishery and the population exploited throughout the calendar year (Table 3).
3. The fishery is exploited by numerous vessel sizes. These sizes range from 10 gross tons to over 80 gross tons (Table 4).
4. The fishery has received prime consideration in biological research. Biological research programs have been underway in this fishery since the mid-1950's. Shrimp life cycles, population movement, and population dynamics have all

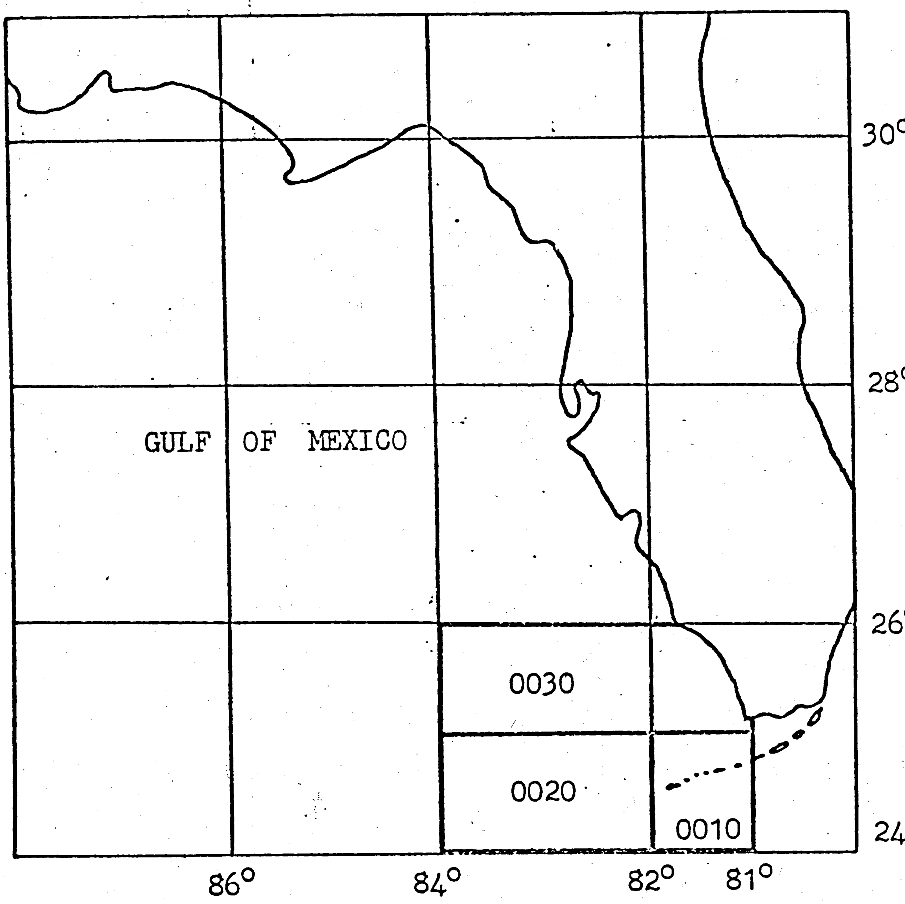

Figure 11. Dry Tortugas fishing ground, Gulf of Mexico.

Table 3.--Total trips for all vessels, by month, in the Dry Tortugas fishery, 1964 and 1965.*

Month	1964 Trips	1965 Trips
January	1,687	997
February	1,102	735
March	927	866
April	555	877
May	470	386
June	385	240
July	145	128
August	176	200
September	348	276
October	422	599
November	648	728
December	862	824

*Trips vary in length by area fished and size of vessel. The length of the trips range from 4 to 7 days.

Table 4.--Vessels fishing Dry Tortugas, by size class, 1964 and 1965.

Size class	Gross tons	1964 (number)	1965 (number)
1	5-9	0	0
2	10-19	6	4
3	20-29	23	19
4	30-39	123	103
5	40-49	148	131
6	50-59	59	50
7	60-69	127	152
8	70-79	32	50
9	80+	10	24

been studies on the Dry Tortugas and numerous biological publications are available.[34]

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[34]Kenneth N. Baxter, "Abundance of Postlarval Shrimp--One Index of Future Shrimping Success," Gulf and Caribbean Fisheries Institute, 15th Annual Session, November 1962, pp. 79-87.

Albert Walker Collier, The Shrimp Fishery of the Gulf of Mexico, Bio notes and recommendations, Gulf States Marine Fisheries Commission, 1959.

T. J. Costello and Donald M. Allen, "Migration and Geographic Distribution of Pink Shrimp, Penaeus duorarum, of the Tortugas and Sanibel Grounds, Florida Fishery Bulletin, Vol. 65, No. 2, pp. 449-459.

T. J. Costello and Donald M. Allen, Migrations, Mortality, and Growth of Pink Shrimp in Galveston Biological Laboratory, Fishery Research, U.S. Fish and Wildlife Service, Cir. 129, pp. 18-21.

T. J. Costello and Donald M. Allen, "Notes on the Migration and Growth of Pink Shrimp (Penaeus duorarum)," Gulf and Caribbean Fisheries Institute, 12th Annual Session, November 1959, pp. 5-9.

William C. Cummings, "Maturation and Spawning of Pink Shrimp, Penaeus duorarum, Burkenroad," Transactions of the American Fisheries Society, Vol. 19, No. 4, pp. 462-468.

Sheldon Dobkin, Early Developmental Stages of Pink Shrimp, Penaeus duorarum, From Florida Waters, Fishery Bulletin 190, U.S. Fish and Wildlife Service, Vol. 6, 1961, pp. 321-349.

Bonnie Eldred, Robert M. Ingle, Kenneth D. Woodburn, Robert Hutton, and Hazel Jones, Biological Observations on the Commercial Shrimp, Penaeus duorarum Burkenroad, in Florida Waters, Professional Papers Series, No. 3 (St. Petersburg, Florida: Florida State Board of Conservation, October 1961).

Clarence P. Idyll, The Commercial Shrimp Industry of Florida, Florida State Board of Conservation, Educational Service, No. 6, p. 6.

Edwin S. Iverson, Andrew E. Jones, and C. P. Idyll, Size Distribution of Pink Shrimp, Penaeus duorarum, and Fleet Concentrations on the Tortugas Fishing Grounds, Special Scientific Report--Fisheries No. 356, U.S. Fish and Wildlife Service, August 1960.

The fishery, established in 1950 during the rapid growth period of the Gulf of Mexico shrimp fishery, has produced approximately 11 million pounds of heads off shrimp annually (Table 5). The fishing grounds are comprised of approximately three thousand square nautical miles of sea, but fishing activity is concentrated in an area 60 miles long, east and west, and 25 miles wide, north and south; and is located west and northwest of Key West, Florida. The southeast corner of this actively fished area is approximately 50 miles west of Key West. The shrimp population occurs outside this area of concentrated activity; but the ocean bottom is covered by loggerhead sponges, coral, and rock outcroppings, making fishing difficult. For purposes of this study, however, the entire Dry Tortugas fishing ground will be considered to maintain continuity with the statistical area designations developed by the Bureau of Commercial Fisheries for their catch-landing statistics. The statistical areas designated for the Dry Tortugas are 0010, 0020, and 0030 (Figure 11).

The commercially exploited shrimp population on the Tortugas grounds is almost entirely pink shrimp, _Penaus duorarum_. The life cycle of the pink shrimp is approximately 13 months. The pink shrimp spawn at sea and the larvae migrate via tides and currents to the estuarine and bay area adjacent to the Florida Keys and the southwest

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34(Continued) Edwin A. Joyce, Jr. and Bonnie Eldred, _The Florida Shrimping Industry_, Florida State Board of Conservation, Educational Series, No. 15, November 1966.

Joseph H. Kutkuhn, _Dynamics of a Penaeid Shrimp Population and Management Implications_, Fishery Bulletin, Vol. 65, No. 2, pp. 313-338.

Table 5.--Yearly production of shrimp from the Dry Tortugas.

(Pounds, heads off weight)

Year	Total	Percent of ten-year total	Percent of Gulf of Mexico yearly production
1956	12,366,554	11.41	6.00
1957	9,664,755	8.92	5.00
1958	13,733,249	12.68	7.00
1959	7,658,696	7.07	3.00
1960	14,068,192	12.99	6.00
1961	10,113,859	9.33	7.00
1962	8,281,319	7.64	5.00
1963	9,620,137	8.88	4.00
1964	10,919,561	10.08	6.00
1965	11,867,562	10.96	6.00
Ten-year total	108,294,763	100.00	

Ten-year average -- 10,829,476.3

coast of Florida. Generally, the juvenile shrimp remain in these areas until they attain a body length of approximately 100 millimeters. Upon attaining this length, the shrimp begin migrating from the estuarines and bays in northwesterly, westerly, and southwesterly directions onto the fishing grounds. Biological research and observation have established that most of the migration occurs in a northwesterly direction.

Annual periods of peak spawning activity are typical of the Tortugas pink shrimp. These periods result in a population "wave" migrating onto the fishing grounds in September of each year. The population wave is reflected in the fishing effort and catch statistics from October through March of the following year (Table 6). The shrimp are rapidly increasing in size during the early phases of migration, but are subject to natural mortality estimated by Costello and Allen to be 19.7 percent per two-week period.[35] The migration from inshore waters to offshore waters is accompanied by a direct relationship between size of shrimp and ocean depth.[36] Dispersion of the shrimp population is also occurring as the migration of the population continues over time. It is estimated that the dispersion rate is of such magnitude that fishing becomes uneconomical after a depth of 40 fathoms.

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[35] T. J. Costello and Donald M. Allen, "Mortality Rate in Pink Shrimp, Penaeus duorarum, Populations of the Sanibel and Tortugas Grounds, Florida," unpublished report of the U.S. Fish and Wildlife Service.

[36] See Appendix C.

Table 6.--Shrimp landings by month, Dry Tortugas fishery, 1964 and 1965.

Month	1964	1965
January	1,526,403	1,478,744
February	1,090,877	902,843
March	1,099,618	1,262,147
April	898,876	828,827
May	678,570	421,988
June	519,798	239,076
July	251,200	172,627
August	413,022	304,546
September	736,909	638,842
October	719,859	1,900,437
November	1,734,954	2,067,341
December	1,232,307	1,644,911

The Dry Tortugas fishing fleet, ranging at various points in time from 300 to 500 vessels, intercepts the population "wave" migration in 9 to 11 fathoms of water in the southeast corner of the actively fished portion of the Tortugas grounds. Weather permitting, the fleet follows the migration pattern of the population until the dispersion reaches a level where there is no established or identifiable migration direction.

The fishing fleet exploiting the Dry Tortugas is concentrated in four ports in southwest Florida--Key West, Marathon, Fort Myers, and Tampa. The vessel size typically ranges from 10 gross tons to over 80 gross tons and the vessels are generally of wood construction.[37] The vessels generally return to their homeports upon completion of a trip. A typical trip of a vessel fishing the Dry Tortugas is 5 to 10 days in duration, of which 4 to 7 nights are engaged in the fishing process.[38] A vessel traveling from its homeport over the fishing ground tows a try net on the bottom until a concentration of shrimp is located. When a vessel comes in contact with a concentration, two large nets ranging in width from 40 to 65 feet are attached to cables which are in turn attached to booms extending over the gunnels of the vessel. The vessel then tows the nets along the substrata and picks up shrimp, fish, benthic organisms, and debris. During peak periods of dense shrimp population movement, the nets are towed along the bottom for approximately three hours. The nets are then raised

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[37]See Appendix D for vessel and crew characteristics.

[38]Pink shrimp are nocturnal in habit; consequently, fishing activity is conducted at night.

to the vessel and the contents of the nets are emptied on the stern deck. The boat crew--typically consisting of the vessel captain; the rig man whose duties include lowering the net, controlling the net on the bottom, and raising the net; and a header who is responsible for deheading the shrimp--begin sorting the shrimp from other organisms and debris.

Heading shrimp is a manual process and occurs after the shrimp have been separated from the extraneous materials and organisms. Headed shrimp are then placed in the hold of the vessel and are "iced down" in a one to one ratio by weight with shaved ice. Shrimp remain in this condition until the vessel reaches port. Upon returning to their homeports, the shrimp are unloaded at dockside intermediate processing facilities.[39] Remuneration per pound of shrimp varies with size, thus the intermediate processing facilities grade the shrimp by size and weigh each size count before the payment is made. A processing and handling fee is usually exacted and the burden of payment falls on the vessel owner.

Remuneration of the crew is on a share basis. A typical crew share agreement in southwestern Florida is two-thirds of the gross receipts for the boat owner and one-third for the crew. The boat crew agrees to purchase groceries utilized during the fishing trip and the boat owner usually agrees to cover all other expenses, both fixed and variable, associated with the fishing trip.

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[39]Intermediate processing facilities are facilities where shrimp are landed, weighed, graded, sometimes headed, and repacked in ice for shipment by truck to fresh wholesale markets or secondary processing facilities.

With the exception of Tampa, the major ports servicing the Tortugas fishery (Key West, Marathon, and Fort Myers) are unloading and intermediate processing ports. Tampa is the only Tortugas port with substantial secondary processing capacity.[40] Fresh, raw headless shrimp are transported from the other ports to Tampa for packaging and freezing, breading, and portion packing and wholesale distribution. Key West, Marathon, and Fort Myers merely offer dockage and vessel supply facilities adjacent to the fishing grounds. Most of the fresh raw shrimp landed in these three ports are transferred by truck to secondary processing facilities or to fresh wholesale markets.

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[40] A secondary processing facility is a facility where shrimp are packaged whole or peeled and deveined and packaged, breaded, or portion packed for wholesale distribution.

CHAPTER IV

METHOD

Alternative Spacial Models

The optimum allocation of fishing effort in time and space to minimize total production costs for a predetermined level of physical production can be attained via two alternative spatial models: (1) The standard equilibrium formulation utilizing demand and supply relations; or (2) activity analysis models involving physical production activities and demand relationships. "The two groups of models are not mutually exclusive--both may portray partial or complete equilibrium, their representation of shipping and consumption activities are similar, and the simplest model of each is the standard transportation model with preassigned regional quantities produced and consumed." [41]

The activity analysis transportation model is appropriate for this study because this type model usually specifies discrete regions, representative producing points, and representative consuming points. Regional consumption can be preassigned, perfectly elastic at a constant price, or a function of a price range. Supply functions are replaced by production costs for at least one level of the production process and are specified for each region.

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[41] D. Lee Bawden, "An Evaluation of Alternative Spatial Models," Journal of Farm Economics, Vol. 46, No. 5, December 1964, p. 1372.

The regional resources may be assumed geographically fixed or mobile between regions. Likewise, the physical plant may be assumed to be fixed or variable. Transportation costs are specified between regions for all mobile resources, intermediate goods, and final products. A purely competitive market system is also assumed to be present.[42]

Linear Programming

Standard linear programming techniques for minimizing an objective function were found to be most applicable to this study; hence, they were utilized. The standard techniques have three basic components which reflect the data specifications:

1. A linear objective function stating the objectives of the model. The objective function can be either maximization of the objective or minimization of the objective. Formulated, a general linear objective is:

$$F(X) = \sum_{j=1}^{n} C_j X_j \tag{5}$$

$j = 1, 2, 3, \ldots, n$; i.e. activities
C_j = price or cost coefficient
X_j = structural variable; i.e. competing activities

2. Linear structural constraints which embody the technical specification and resource capacities:

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[42] *Ibid.*, pp. 1372-1373.

$$\sum_{j=1}^{n} \sum_{i=1}^{n} A_{ij}X_j \leq bi \qquad (6)$$

$i = 1, 2, 3, \ldots, n$
$j = 1, 2, 3, \ldots, n$
A_{ij} = set of structural coefficients reflecting the technical specifications of the problem
bi = set of constants reflecting the maximum resource capacities or minimum resource requirements

3. Nonnegativity constraints for:

(a) structural variables

$$X_j \geq 0 \qquad (7)$$

$j = 1, 2, 3, \ldots, n$

These constraints do not allow negative production or shipments.

(b) slack variables

$$S_i \geq 0 \qquad (8)$$

$i = 1, 2, 3, \ldots, m$

These variables prevent resource use in excess of the original supply.

(c) artificial slack variables

$$A_i \geq 0 \qquad (9)$$

$i = 1, 2, 3, \ldots, m$

The constraints denote the use of requirements of resources by the artifical variables.

The general concept of the transportation problem in linear programming restricts the values that can be assigned the structural coefficients (A_{ij}) and limits the constraints to only one type of unit. One can conclude that the general linear programming concept can be reduced to the transportation problem if two conditions are met:

1. The A_{ij}'s are restricted to values of zero or a positive coefficient; i.e. the decision to be made is simply whether or not to transport goods from origin to destination.

2. There exists homogeneity of units among the constraints.

Model I

Nine vessel size classes were chosen from the Gulf of Mexico shrimp fishing fleet. These classes are:

1. 5 to 9 gross tons
2. 10 to 19 gross tons
3. 20 to 29 gross tons
4. 30 to 39 gross tons
5. 40 to 49 gross tons
6. 50 to 59 gross tons
7. 60 to 69 gross tons
8. 70 to 79 gross tons
9. Over 80 gross tons

Also noted is the absence of vessel size class one (5-9 gross tons) utilization in the exploitation of the Dry Tortugas fishery.

Utilizing the standard Bureau of Commercial Fisheries regional biological catch data techniques, it was noted that the Dry Tortugas comprises 13 separate production regions (Table 7). Landings are recorded for three ports in the Dry Tortugas--Key West, Fort Myers, and Tampa. Landings in other ports are of such insignificant magnitude that they can easily be assumed zero and the capacity assigned to the nearest major port (Table 8).

Table 7.--Shrimp production by region, Dry Tortugas, 1965.

Production region	Area	Depth (fathoms)	Pounds Production
1	1	6-10	116,550
2	1	11-15	9,527
3	1	16-20	1,600
4	2	6-10	301,354
5	2	11-15	8,604,223
6	2	16-20	2,028,821
7	2	21-25	301,419
8	2	26-30	19,149
9	2	31-35	5,153
10	3	11-15	140,071
11	3	16-20	331,296
12	3	21-25	6,584
13	3	26-30	1,815
		Total	11,867,562

Table 8.--Landings of Dry Tortugas shrimp by ports, 1965.

Port	Pounds landed	Combined landings	Port number	Port name
Key West, Florida	8,986,729	9,084,425	Port 1	Key West, Florida
Marathon, Florida	97,696			
Fort Myers, Florida	2,505,450	2,573,936	Port 2	Fort Myers, Florida
Punta Gorda, Florida	68,486			
Tampa, Florida	207,937	209,201	Port 3	Tampa, Florida
Bayou La Batre, ~~Louisiana~~ Alabama	1,264			

Total = 11,867,562

Substituting the Dry Tortugas characteristics into standard linear programming jargon, the following objective function and constraints are obtained:

$$\text{Minimize:} \quad \sum_{b=1}^{13} \sum_{i=2}^{9} \sum_{j=1}^{3} C^b{}_{ij} X^b{}_{ij} \qquad (10)$$

$$\text{i.e. minimize} \quad C^1{}_{21}X^1{}_{21} + C^1{}_{31}X^1{}_{31} + C^1{}_{41}X^1{}_{41} + \ldots$$
$$C^{13}{}_{93}X^{13}{}_{93}$$

b = 1, 2, 3, . . . , 13 production regions
i = 2, 3, 4, . . . , 9 vessel size classes
j = 1, 2, 3 ports

$C^b{}_{ij}X^b{}_{ij}$ = Cost of traveling to the fishing ground, catching, and transporting X quantity of raw headless shrimp from region b by vessel size class i to port j.

$C^b{}_{ij}$ = Cost of traveling to region b, catching in region b, and transporting from region b by vessel size class i to port j one pound of raw headless shrimp.

$X^b{}_{ij}$ = Quantity of raw headless shrimp caught in region b by vessel size class i from port j.

$$\text{subject to:} \quad \sum_{b=1}^{13} \sum_{i=2}^{9} X^b{}_{ij} = A_j \qquad (11)$$

Sum of all production in regions 1 through 13 by vessel size classes 2 through 9 and landed in port j is equal to the capacity of port j.[43]

A_j = Capacity of port j.

$$\sum_{i=2}^{9} \sum_{j=1}^{3} X^b{}_{ij} \leq B^b \qquad (12)$$

Sum of all production by vessel size classes 2 through 9 and landed in ports 1 through 3 from region b is equal to or less than the production capacity of region b.

B^b = Production capacity of region b.

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[43] Capacity of port j is defined as the number of pounds landed in port j during the time period under consideration.

$$\sum_{b=1}^{13} X^b_{ij} \leq D_{ij} \qquad (13)$$

Sum of all production by vessel size class i in port j from regions 1 through 13 is equal to or less than the production capacity of vessel size class i in port j.

D_{ij} = Production capacity of vessel size class i in port j.

$$\sum_{b=1}^{13} B^b = \sum_{j=1}^{3} A_j \qquad (14)$$

Production capacity of region 1 through 13 is equal to the capacities of ports 1 through 3.

The purpose of this simplifying assumption equating supply of raw headless shrimp from the Dry Tortugas with the demand, i.e. port capacity, for raw headless shrimp from the Dry Tortugas during the time period under consideration is to insure that no accumulation, inventory, or waste of fresh raw headless shrimp occurs.

$$X^b_{ij} \geq 0 \qquad (15)$$

This is a nonnegativity constraint to insure negative production or shipment of raw headless shrimp does not occur in the model.

Available Data Requirements

Data requirements for the model are production capacity in pounds of each of the 13 individual regions in the Dry Tortugas; port capacities for shrimp caught in the Dry Tortugas; capacity coefficients for each vessel size class within each of the three principal ports; and traveling, production, and transporting cost per pound coefficients for each individual size class within each of the three principal ports.

Constructing a general linear programming model and performing an empirical analysis of the minimization of total production costs for a predetermined level of physical production from a fishing ground requires the introduction of a time element. The decision was made to pattern the general model and analysis to 1965, the latest calendar year for which complete statistics were available for the Dry Tortugas.

Regional production capacity[44] for the Dry Tortugas for 1965 was obtained from the biological catch data. Bureau of Commercial Fisheries personnel stationed in each major shrimp landing port collect landings statistics by individual vessel for each trip. Also, recorded on a random interview basis, is the area, depth fished, size composition, and value of the landings. Table 7 reveals the quantity of shrimp caught in each region.

Recording the individual vessel's landings in each port automatically records the total pounds of shrimp landed in individual ports. Summing over individual vessels will yield this figure (Table 8).

Synthesized Data Requirements and Sampling Procedure

Capacity coefficients for all vessels within a size class for an individual port and travel, production, and transport cost-per-pound

[44] The simplifying assumption--physical production capacity for each region is equal to the total number of pounds of raw headless shrimp landed in each region--has been made in this analysis. Consideration was not given to the size composition of the shrimp landed. Such consideration would be essential if the objective function was to maximize total or net revenue because of the value differential between size counts.

coefficients required data not available to this author. Consequently, a vessel technological characteristic and operating cost questionnaire (Appendix A) was developed and administered to shrimp vessel owners who exploited shrimp populations in the Gulf of Mexico. The questionnaire was administered in a manner that would generate data which would be readily accessible were the general model expanded to consider the entire Gulf of Mexico shrimp fishery.[45] The author administered the questionnaire to vessel owners on a personal interview basis. Vessel owners responding to the questionnaire had vessels actively participating in shrimp fishing during the calendar years 1964 and 1965, or 1965.[46] The population for the survey was obtained from the landings, value, and area fished data held in computer storage by the Bureau of Commercial Fisheries, Division of Economics, Branch of Statistics. Essentially, all vessels actively participating in the Gulf of Mexico shrimp fishery are recorded in this data.

To expedite the sampling procedure, 13 ports from which samples were taken were selected. These ports were selected on the basis of two criteria. First, when they are aggregated, the selected interview ports must adequately cover the geographical areas currently comprising the shrimp fishery (Figure 12 and Table 9.) Second, the ports must give adequate representation of the vessel size classes

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[45]The sampling process relates to the entire Gulf of Mexico shrimp fishery, but the empirical analysis in this study is confined to the Dry Tortugas fishery. The entire Gulf was sampled to generate data concerning the aggregate Gulf of Mexico shrimp fishery. This data can be utilized to expand the current study.

[46]Two calendar years were used to reduce intra-year variations in characteristics and costs.

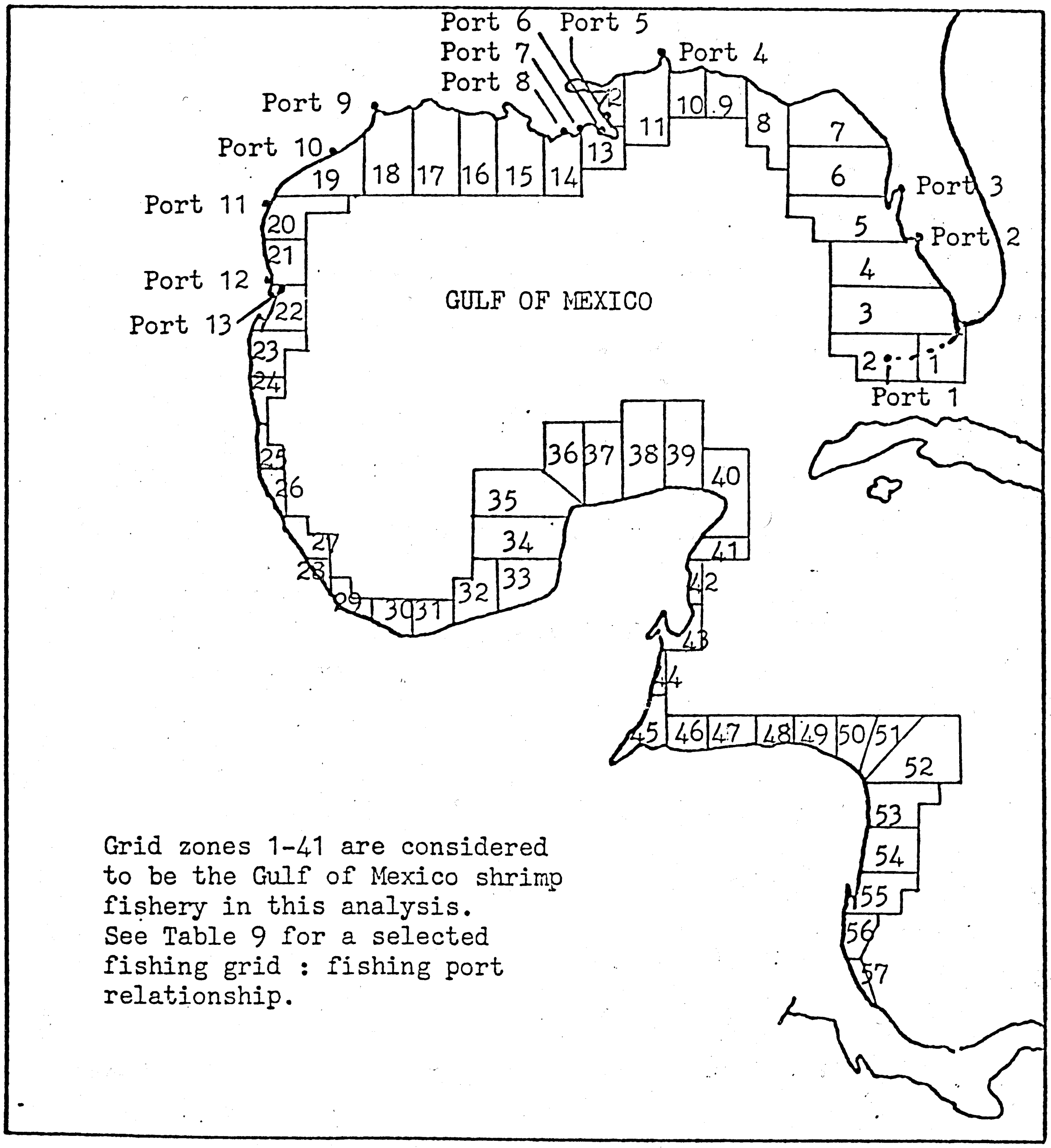

Figure 12. Gulf of Mexico shrimp fishing grid zones.

Table 9.--Thirteen selected ports; geographical pattern of fishing.

Zone	Port 1	2	3	4	5	6	7	8	9	10	11	12	13
1	x	x	x										
2	x	x	x										
3	x	x	x										
4		x	x										
5			x										
6			x										
7				x									
8				x									
9				x	x								
10				x	x	x							
11				x	x	x	x						
12				x	x	x	x						
13					x	x	x	x					
14							x	x					
15								x		x			
16								x		x			
17									x	x	x		
18									x	x	x		
19										x	x		
20											x	x	
21											x	x	
22											x	x	
23											x	x	
24												x	
25												x	
26												x	
27												x	
28												x	
29												x	
30													x
31													x
32													x
33													x
34			x										x
35		x	x										x
36		x	x										x
37		x	x										x
38		x	x										x
39		x	x										x
40		x	x										x
41			x										x

being considered in the sample (Table 10).

The vessels and vessel owners were selected on the basis of a stratified random sample drawn from the major strata based on vessel size class. The vessel size class limits for each stratum were 5-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80 and over gross tons. Stratum sample sizes were determined by consideration of two factors: (1) size of the stratum, and (2) expected variations within the stratum.

Sampling size was at least 10 percent of the population in the 5-9, 10-19, 20-29, 30-39, 70-79, and 80 and over gross ton classes; and at least 15 percent in the 40-49, 50-59, and 60-69 gross ton classes (Table 11). The reason for an increase sampling percentage in the 40-49, 50-59, and 60-69 gross ton classes is that these vessels are in a transition zone. These vessels are physically capable of fishing both inshore and offshore, whereas the vessel classes smaller than 40 gross tons generally are limited to inshore fishing and those vessels larger than 69 gross tons are primarily offshore fishing vessels. A set of alternatives for each stratum was chosen. If needed, alternatives were brought into the study in the order that they were drawn. If the vessel owner was at sea or was unavailable for interview, two additional contact attempts were made. If, after three attempts, the vessel owner was not contacted, an alternate was selected. Likewise, alternates were chosen for elements of the sample who had sold their vessel, moved, died, retired, quit fishing, or refused to cooperate. The questionnaire was pretested on ten vessel owners chosen at random from the population,

Table 10.--Distribution of vessel size classes within sample ports, 1965.

Port	City and State	BCF code	Vessel size class 1	2	3	4	5	6	7	8	9	Total
1	Key West, Florida	1	0	2	15	68	88	31	33	11	5	253
2	Fort Myers, Florida	2	0	1	1	30	31	21	64	19	12	179
3	Tampa, Florida	4	0	0	0	1	2	3	84	34	17	141
4	Bayou La Batre, ~~Fla.~~ Ala.	21	19	43	28	22	14	10	11	5	1	153
5	Lafitte, Louisiana	45	0	12	13	12	20	11	17	6	3	94
6	Golden Meadow, La.	47	6	47	32	35	28	13	9	7	8	185
7	Houma, Louisiana	48	21	57	34	16	23	8	4	1	0	164
8	Morgan City, La.	49	1	0	8	12	20	20	27	5	8	101
9	Galveston, Texas	72	3	40	12	16	9	6	5	1	3	95
10	Freeport, Texas	73	1	15	6	20	33	26	32	13	6	152
11	Aransas Pass, Texas	78	2	14	21	18	25	11	51	27	6	175
12	Port Isabel, Texas	81	0	0	1	11	14	25	67	39	21	178
13	Brownsville, Texas	82	0	1	0	6	16	24	80	34	18	179
	Total		53	232	171	267	323	209	484	202	108	2,049
	Total fleet		124	512	321	379	385	260	534	220	114	2,849
	Percent of fleet		42.7	45.3	53.2	70.4	83.8	80.3	90.6	91.8	94.7	71.9

Table 11.--Dry Tortugas vessels random sample breakdown, 1964-1965.*

Vessel size class	Number sampled in Ports 1, 2, 3
1	0
2	2
3	6
4	10
5	15
6	5
7	36
8	13
9	3
Total	90

*During the analysis it was decided that 4 vessels in size class 6 were not conducive to the sample, hence were not included. The 15 percent quota in this size class was not met for the Dry Tortugas, but this investigator believes this will not affect the analysis.

but were not included in the sample.

The number of Dry Tortugas sample vessels was 63 for 1964, and 88 for 1965. These sample vessels were then subjected to analysis in order to derive capacity coefficients for each vessel size class within each of the three principal Dry Tortugas ports, and traveling, production, and operating cost per pound coefficients for each individual size class within each of the three principal Dry Tortugas ports.

Capacity coefficients for each vessel size class within each of the three principal ports are determined via the equation:

Port j capacity coefficient for vessel size class i = (Average catch per trip of vessels in class i) (Average number of trips per year by vessels in class i) (Number of vessels of size class i in port j) (16)

j = 1, 2, 3
i = 2, 3, 4, . . . , 9

Average catch per trip in the Dry Tortugas per vessel size class is determined by summing the 1964 and 1965 landings of sample vessels within size class i and the number of trips within size class i for 1964 and 1965 (Table 12).

$$\text{Average catch per trip} = \frac{\text{Total catch 1964 and 1965 per size class i}}{\text{Total trips 1964 and 1965 per size class i}} \quad (17)$$

Average number of trips per year is derived from Bureau of Commercial Fisheries data. These data record all trips for all vessels fishing the Dry Tortugas fishery. A two-year average (1964-1965) was determined (Table 13).

Table 12.--Tortugas sample vessels, 1964 and 1965; total catch and number of trips.

Size class	Catch			Trips			2-yr. average catch*
	1964	1965	Total	1964	1965	Total	
2	81,605	47,680	129,285	35	23	58	2,229.052
3	172,891	160,831	333,722	116	95	211	1,581.621
4	297,791	286,023	583,814	221	206	427	1,367.246
5	649,806	553,195	1,203,001	361	301.8	662.8	1,815.029
6	82,311	136,460	218,771	39.5	59	98.5	2,221.025
7	355,385	542,659	898,044	141.3	230.4	371.7	2,416.045
8	25,255	102,109	127,364	12	42	54	2,358.593
9	15,356	55,351	70,707	6	25	31	2,280.871

*2-year average catch figure represents average catch per trip.

Table 13.--Average number of trips to Tortugas per vessel size class, 1964 and 1965.*

Vessel size class	Two-year average (number of trips)
2	10
3	16
4	17
5	17
6	13
7	8
8	8
9	5

*Includes all vessels fishing the Tortugas in 1964 and 1965.

The number of vessels of size class i in port j is also taken from Bureau of Commercial Fisheries data (Table 14).

The computed capacity coefficient for each vessel size class within each port is reflected in Table 15.[47]

Throughout this portion of the data input computation it is assumed that the average catch per trip and the average number of trips per year per vessel size class is constant among ports 1, 2, and 3. Examination of the data offers no reason why such an assumption is invalid.

An interesting sidelight in the determination of port capacity coefficients within vessel size classes is the noticeable lack of individual vessel capacity utilization on a trip basis (Table 16). This study, in trying to maintain a realistic approach, will not alter this inadequate utilization in the first portion of the analysis.

The development of traveling, production, and transport cost coefficients for raw headless shrimp relies on the data generated in the questionnaire administered to the industry.

Traveling to the fishing ground and transporting raw headless shrimp from a region to port can be aggregated and referred to as transport rates. This reference is valid because a vessel, in order to transport raw headless shrimp from a fishing region to a port must

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[47]A sample computation of capacity coefficient for vessel size class 2 in port 1 is shown below:

Size class 2--Average catch per trip: 2,229 pounds
Size class 2--Average number of trips per year: 10
Size class 2--Vessels of size class 2 in port 1: 2

Substituting into the general formula (equation 16): Port 1 capacity coefficient for vessel size class 2 = (2,229) (10) (2) = 44,580 pounds.

Table 14.--Distribution of shrimp fishing vessels, Ports 1, 2, and 3; 1965.*

Vessel size class	Port 1	Port 2	Port 3	Total
2	2	1	--	3
3	15	1	--	16
4	68	30	1	99
5	88	31	2	121
6	31	18	3	52
7	33	64	84	181
8	11	19	34	64
9	5	12	17	34
Total	253	176	141	570

*Port 1: Key West, Florida
Port 2: Fort Myers, Florida
Port 3: Tampa, Florida

Table 15.--Capacity coefficient per vessel size class within Ports 1, 2, and 3.

Vessel size class	Port 1 (pounds)	Port 2 (pounds)	Port 3 (pounds)
2	44,580	22,290	---
3	379,680	25,312	---
4	1,580,252	697,170	23,239
5	2,715,240	956,505	61,710
6	895,063	519,714	86,619
7	637,824	1,236,992	1,623,552
8	207,592	358,568	641,648
9	57,025	136,860	193,885

Table 16.--Average percent capacity utilized per average trip, Tortugas sample vessels.

Vessel size class	Average net tons*	Shrimp capacity in pounds**	Average catch per trip	Percent capacity utilization per trip
2	10.0	8,500	2,229	26.22
3	15.0	12,750	1,582	12.40
4	12.4	10,540	1,367	12.96
5	18.4	15,640	1,815	11.60
6	28.6	24,310	2,221	9.13
7	32.2	27,370	2,416	8.82
8	38.8	32,980	2,359	7.15
9	68.3	58,055	2,281	3.92

*One net ton equals 100 cu. ft. of cargo space.

**8.5 pounds of shrimp mixed with an equal volume by weight of shaved ice occupies one cu. ft. of cargo space.

incur a cost in traveling to the region to catch the shrimp it will transport. Development of the transport rate requires a round trip mileage coefficient from each port to the center of each fishing region in the Dry Tortugas. Average traveling speed, average fuel consumption, and average fuel price per gallon data were generated from the questionnaire for each vessel size class. The average transport rate per vessel size class per port was developed via the equations:

$$\text{Travel hours to and from fishing region } b \text{ for vessel size class } i = \frac{\text{Miles round trip port } j}{\text{Average mph vessel size class } i} \quad (18)$$

Gallons of fuel consumption of vessel size class i on round trip to region b from port j = (equation 18) (gallons of fuel consumption per hour by vessel size class i) (19)

Average cost of round trip of vessel size class i to region b from port j = (equation 19) (fuel cost per gallon in port j[48] (20)

$$\text{Average transport rate per pound of raw headless shrimp for vessel size class } i \text{ fishing in region } b \text{ to port } j = \frac{\text{Equation 20}}{\text{Average catch per trip for vessel size class } i} \quad (21)$$

A complete tabular description of the transport rates is presented in Appendix E.

Assuming constant production costs for a given vessel size class within ports and regions fished in the Dry Tortugas, fixed and variable cost coefficients can be developed for each vessel size class

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[48]The determination of the transport rate is simplified by considering no fixed costs and only one variable cost: fuel.

from the questionnaire data.

Individual vessels within the sample that fished the Dry Tortugas have been stratified according to size class. Migration characteristics[49] were noted when the data were subjected to analysis (Table 17 and Appendix F).

It has become necessary to adjust every cost element for each sample vessel so that realistic costs would be allocated to the Dry Tortugas within vessel size classes. Adjustment is merely multiplying the cost elements of an individual vessel by the percentage of effort allocated by the owner-decision-maker to the Dry Tortugas for the calendar years 1964 and 1965.[50]

Vessels were then reaggregated according to size class and cost elements summed over vessels within the size class and a two-year average calculated for each cost element per vessel size class. Cost elements were then aggregated into one of the two groups: fixed cost

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[49]It has been noted that vessels migrate freely throughout the Gulf of Mexico and fish alternative fishing grounds. Producers have concluded that they should fish grounds during their peak periods of production. This practice, however, is not necessarily the best allocation of fishing effort because little consideration has been given to transport differentials. Such a practice is visible evidence of the consideration of average productivity of a fishing ground discussed in Chapter 2.

[50]The general equation is:

(Yearly cost element of individual vessel) (% of total effort by individual vessel in Dry Tortugas during calendar year under consideration) (22)

Example:

Individual vessel's yearly cost of fuel = $100
Individual vessel allocated 20% of fishing effort in Dry Tortugas during 1965.

($100) (.20) = $20 = cost of fuel allocated to Dry Tortugas for individual vessel in 1965

Table 17.--Percentage of migratory vessels in Tortugas, 1965.

Vessel size class	Total vessels fished in Tortugas	Number of migratory vessels	Percentage migratory
2	4	2	50.00
3	19	2	10.53
4	103	8	7.77
5	131	20	15.27
6	50	8	16.00
7	152	60	39.47
8	50	27	54.00
9	24	9	37.50
Total	533	136	25.52

and variable cost (Table 18).

Average variable cost per vessel size class was computed:

$$\frac{\sum \text{variable cost elements (2-year average) size class i}}{\text{(Average number of trips per year in size class i) (Average number of pounds of raw headless shrimp landed per trip by vessel size class i)}} \quad (23)$$

Table 19 lists the average variable cost per pound of raw headless shrimp per vessel size class.

Average fixed cost per vessel size class was computed:

$$\frac{\sum \text{fixed cost elements (2-year average) size class i}}{\text{(Average number of trips per year in size class i) (Average number of pounds of raw headless shrimp caught per trip by vessel size class i)}} \quad (24)$$

Table 19 lists the average fixed cost per pound of raw headless shrimp per vessel size class.

Production cost per pound of raw headless shrimp in each region per vessel size class i in port j is computed:

Production cost per pound of shrimp in each region for vessel class i in port j = (Variable cost per pound of raw headless shrimp in size class i) + (Transport rate of vessel size class i to region b from port j) (25)

Appendix G lists the total production cost incurred by each vessel size class fishing each region from each port.

Total cost incurred by the vessels, computed after the model is optimized:

$$\text{Total cost} = \sum_{i=2}^{9} \text{(Total production cost per vessel size class i) + (Total fixed cost per vessel size class i)} \quad (26)$$

Table 18.--Categories of vessel operating expenses included in the analysis.*

Fixed	Variable
Hull Depreciation	Repairs
Engine Depreciation	Salaries
Electrical Gear Depreciation	Fuel
Other Depreciation	Galley
Taxes Business Property	Ice
Insurance	Packaging and Handling
Legal	Supplies
Interest	Nets
Association Dues	FICA
Bank Charges	
Office Supplies	
Travel	
Miscellaneous	
Licenses	
Taxes	
Telephone	
Radio	

*The expenses (on a per pound basis) are presented in Tables 19 and 20.

Table 19.--Average fixed and variable costs (1964 and 1965) per pound of raw headless shrimp per vessel size class.

Vessel size class	Average fixed cost	Average variable cost
2	.022	.086
3	.055	.361
4	.155	.416
5	.067	.283
6	.082	.386
7	.084	.352
8	.173	.410
9	.153	.541

Table 20.--Total costs (1964 and 1965) per pound of raw headless shrimp per vessel size class.

Vessel size class	Total cost
2	.108
3	.416
4	.571
5	.350
6	.468
7	.436
8	.483
9	.694

$$\text{Total fixed cost} = \sum_{i=2}^{9} \text{(Pounds of raw headless shrimp caught per vessel size class i) (Fixed cost per pound of raw headless shrimp per vessel size class i)} \qquad (27)$$

A social cost will be derived because the total vessel-port capacities exceed the total demand for raw headless Dry Tortugas shrimp.

$$\text{Social cost} = \sum_{i=2}^{9} \sum_{j=1}^{3} \text{(Pounds of excess capacity per size class i) (Fixed cost per pound per size class i)} \qquad (28)$$

The derived social cost will reflect the magnitude of the cost to society for idle vessel capacity in the "optimal" solution.

Simplifying Assumptions

An analysis of so broad a topic requires certain basic assumptions and specifications, in addition to those already specified in this chapter, to narrow the problem to workable proportion. Although these assumptions and specifications (stated below) simplify the analysis considerably, they are not unrealistic since they retain basic regional relationships.

1. The abstract, perfectly competitive market in space, form, and time, is assumed throughout.
2. The individual firm and, therefore, the producing region has minimum total production costs as an objective; thus will produce and transport to the port from the region which yields the lowest total production cost per pound of raw headless shrimp.

3. Supply and consumption areas are treated as points. Supply points are chosen as the center of presently important producing regions. Consumption points are chosen where raw headless shrimp from the Dry Tortugas are landed in large quantities.
4. Producers are considered to be indifferent as to the source of this production as long as it is at least cost. This assumes absence of size or other inherent characteristic differentials among shrimp or different regions or indifferences on the part of producers concerning existing differences.
5. Producers will return to the port from which they departed and, if a shortage of vessel capacity occurs in another port, the producers are mobile and will migrate to the port with the shortage of vessel capacity if there is existing over-capacity within vessel size classes after the homeport demand has been satisfied.
6. The estimated costs of producing and transporting on a pound basis are considered to be representative for vessels within the vessel size class landing shrimp at each port.
7. Shrimp are readily available on the Dry Tortugas fishing grounds throughout the calendar year. Peak production periods do not exist.
8. Vessels do not migrate out of the Dry Tortugas fishery until all Dry Tortugas port demands are satisfied.

9. The individual firms within the industry exploiting the Dry Tortugas fishery are treated as members of one large firm in the effort allocation process. This will insure rational allocation of effort at minimum total production cost.

CHAPTER V

EMPIRICAL ANALYSIS

Model I: Allocation of Fishing Vessels and Effort Under Existing Conditions

Considering the assumptions in the previous chapter, the next step was to utilize the generated data in the linear programming model. The objective function, to minimize $\sum_{b=1}^{13} \sum_{i=2}^{9} \sum_{j=1}^{3} C^b_{ij} X^b_{ij}$, for the calendar year 1965 under conditions in this model was equal to $4,336,478. This figure represents the total variable cost plus transport rate incurred by the vessel owners in the production of 11,687,562 pounds of raw headless shrimp. The allocation of vessels from their respective ports is summarized in Table 21.

The fixed cost incurred per vessel size class is equal to the number of pounds landed in the optimum solution for each unique vessel size class multiplied by the fixed cost per pound coefficient for the respective vessel class (Table 22). Under Model I, the aggregate fixed cost incurred by vessel owners fishing the Dry Tortugas during calendar year 1965 is estimated to be $1,121,889.

Model I total cost involved in the production of raw headless shrimp from the Dry Tortugas is estimated to be $5,368,367.[51]

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[51]Total cost equals total variable production cost plus total fixed cost.

Table 21.--Optimal allocation of vessels from port to fishing ground in the Dry Tortugas, 1965.

	Vessel class	Number of vessels	Area	Pounds landed	Total production cost : VC + TR*
Port 1					
Key West	2	2.00	5	44,580	$ 4,101
	3	15.00	5	379,680	140,102
	4	5.00	1	116,550	48,834
	4	.41	2	9,527	4,001
	4	.07	3	1,600	672
	4	62.52	5	1,452,575	618,797
	5	88.00	5	2,715,240	790,135
	6	31.00	5	895,063	350,865
	7	30.35	5	586,653	210,022
	7	2.65	6	51,171	18,422
	8	11.00	5	207,592	86,566
	9	5.00	4	57,025	31,193
Migration of vessels to assist in fulfilling Port 1 demand					
From Port 2	6	6.47	5	186,877	73,256
2	6	3.00	5	86,619	33,955
3	7	12.64	4	244,329	87,225
3	7	63.73	5	1,231,732	440,960
2	8	19.00	5	358,568	149,523
3	8	24.32	5	459,044	191,421
		Port 1	Σ =	9,084,425	Σ = $3,280,050
Port 2					
Fort Myers	2	1.00	6	22,290	$ 2,318
	3	1.00	7	25,312	9,694
	5	12.66	6	390,684	119,549
	5	2.85	7	87,870	26,976
	5	4.54	10	140,071	41,461
	5	10.74	11	331,296	98,395
	5	.21	12	6,584	1,962
	6	11.53	6	332,837	134,466
	7	63.73	6	1,231,839	454,549
	7	.27	9	5,153	1,907
		Port 2	Σ =	2,573,936	Σ = $ 891,277
Port 3					
Tampa	5	1.32	7	40,747	12,916
	5	.62	8	19,149	6,070
	5	.06	13	1,815	561
	7	7.63	7	147,491	55,604
		Port 3	Σ =	209,201	Σ = $ 75,151
			ΣΣ =	11,867,562	ΣΣ = $4,336,478

*TR = Total transport cost.

Table 22.--Total fixed cost incurred in 1965 under Model I effort allocation conditions.

Vessel size class	Pounds landed	Fixed cost* Coefficient	Total fixed cost by vessel size class
2	66,870	.022	$ 1,471
3	404,992	.055	22,275
4	1,580,252	.155	244,939
5	3,733,455	.067	250,142
6	1,501,396	.082	123,114
7	3,498,368	.084	293,863
8	1,025,204	.173	177,360
9	57,025	.153	8,725
			Fixed cost = $1,121,889

$$* \quad \frac{\sum \text{ fixed cost element (2-year average) size class i}}{\text{(Average number of trips per year in size class i) (Number of pounds of raw headless shrimp caught per trip by vessel size class i)}}$$

Estimated real total costs are approximately $5,920,923.[52] Comparison of this figure with the Model I total cost (Table 23) reveals a possible total cost savings of $552,556 available to the Dry Tortugas fishing industry through more efficient allocation of fishing effort. Equal distribution of the savings among the estimated 1,300 fishermen (Table 24) employed in the Model I allocation solution would result in an increase in real income of $425 for each individual fisherman. An important implication when comparing this figure with the average income per fisherman derived from the Dry Tortugas is that there is a potential increase in yearly income from the Tortugas ranging from 16 percent to 53 percent (Table 25).

Model II: Reallocation of Fishing Vessels and Effort Under Increased Vessel Capacity Utilization

It was noted in Chapter IV that, under existing conditions, the Dry Tortugas shrimp fleet did not utilize their carrying capacity effectively. Model II was developed to examine the effects of increased vessel capacity utilization on a trip basis. One method of increasing capacity utilization is to force the vessel to spend as many days at sea engaged in fishing as is physically possible. Economies could be gained by decreasing the transport cost. A constraining physical characteristic would be the fuel capacity. In this section of the empirical analysis fuel capacity is treated as the constraining element limiting the number of days a vessel can stay at sea.

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[52]Based on actual distribution of effort, actual total cost = (Σ actual pounds of shrimp landed per vessel class) (Average transport rate per vessel class + variable cost per vessel size class + fixed cost per vessel class).

Table 23.--Estimated real total cost of production, Dry Tortugas, 1965.

Vessel size class	Estimated total cost
2	$ 8,292
3	205,027
4	1,459,185
5	1,475,342
6	754,412
7	1,345,676
8	484,067
9	188,922

Table 24.--Estimated employment of fishermen in Model I allocation of vessels and fishing effort, 1965.

Vessel size class	Average number in Crew	Number of vessels utilized in optimum	Estimated number of fishermen
2	2	3	6
3	2	16	32
4	2	68	136
5	2	121	242
6	3	52	156
7	3	181	543
8	3	54	162
9	3	5	15
			Σ = 1,292

Additional simplifying assumptions in this section of the analysis are:

1. The average number of days fished per year within each vessel class remains constant.
2. Landings per day is a linear function.
3. Transshipment of raw headless shrimp is allowed to occur but the average cost functions are not affected by such action.

The model II total catch per trip and the percentage of carrying capacity utilized for each unique vessel size class is reflected in Table 26.[53] The port capacity coefficients for each unique vessel class are listed in Table 27.[54]

The Model II objective function, minimize $\sum_{b=1}^{13} \sum_{i=2}^{9} \sum_{j=1}^{3} C_{ij}^{b} X_{ij}^{b}$, for the calendar year 1965 under Model II conditions equals $4,162,665.

---

[53]Model II total catch per trip per size class i computed:

Model II days fished per trip per size class i =

$$\frac{\text{Average fuel capacity per size class } i}{\text{Gallons of fuel consumption per 15-hour day per size class } i} \quad (29)$$

minus 2 days travel adjustment

Model II total catch per trip per size class i = (Catch per day per vessel class i) (Equation 29) (30)

[54]Model II port capacity coefficient per size class i:

Model II trips per year per size class i =

$$\frac{\text{Average total days fished per year per size class } i}{\text{Model II days fished per trip per size class } i} \quad (31)$$

Model II port capacity coefficient per size class i per port j = (Equation 30) (Equation 31) (Number of vessels of size class i in port j) (32)

Table 26.--Model II catch per trip and percent capacity utilization, Dry Tortugas, 1965.

Vessel size class	Catch/day fished/ vessel size	Adjusted days at sea/trip	Capacity per trip	Model II total catch/trip	Percent of capacity utilized/trip
2	557.25	8	8,500	4,458	52.4
3	395.50	14	12,750	5,537	43.4
4	273.40	14	10,540	3,828	36.3
5	302.50	18	15,640	5,445	34.8
6	317.29	23	24,310	7,298	30.0
7	345.14	33	27,370	11,390	41.6
8	393.17	41	32,980	16,120	48.9
9	325.86	43	58,055	14,012	24.1

Table 27.--Model II port capacity coefficients, Ports 1, 2, and 3,* by vessel size class, Dry Tortugas, 1965.

Vessel size class	Port 1 (pounds)	Port 2 (pounds)	Port 3 (pounds)
2	44,580	22,290	---
3	415,275	27,685	---
4	1,561,825	689,040	22,968
5	2,874,960	1,012,770	65,340
6	904,952	525,456	87,576
7	1,503,480	2,915,840	3,827,040
8	177,320	306,280	548,080
9	70,060	168,144	238,204
	Σ = 7,552,451	Σ = 5,667,505	Σ = 4,789,208

$\Sigma\Sigma$ = 18,009,164

*Port 1: Key West, Florida
Port 2: Fort Myers, Florida
Port 3: Tampa, Florida

The allocation of vessels from their respective ports is summarized in Table 28.

The fixed cost incurred is computed as in the preceeding section, and is estimated to be $1,043,179 (Table 29).

Model II total cost of production in 1965 is an estimated $5,205,844. Comparison with the estimated real cost of $5,920,923 reveals a savings of $715,079 through reallocation of fishing effort. Equal distribution of this savings among the 867 estimated fishermen (Table 30) in the reallocation solution offers a potential increase in real income of approximately $825 for each individual fisherman. The average increase in earnings ranges from 31 percent to 102 percent (Table 31).

Social Cost

Social cost as defined in Cahpter IV reflects the magnitude of the cost to society for idle vessel capacity in the "optimal" solution.

Model I allocation of effort at least cost indicates the existence of 1,233,758 pounds excess vessel capacity or 70 vessel equivalents (Table 32). The presence of excess vessel capacity can be interpreted as overcapitalization in terms of labor and capital among the fishing firms exploiting the Dry Tortugas. Reflecting overcapitalization as a social cost reveals an estimated social cost of $193,857 for calendar year 1965.

An additional social cost can be imputed for the excess undepreciated capital investment in the excess vessels. This social cost is estimated to be $2,815,041 (Table 33).

Table 28.--Model II allocation of vessels from port to fishing ground in the Dry Tortugas, 1965.

	Vessel class	Number of vessels	Area	Pounds landed	Total production cost : VC + TR*
Port 1					
Key West	2	2.00	5	44,580	$ 4,101
	3	15.00	5	415,275	153,236
	4	5.07	1	116,550	48,834
	4	.42	2	9,527	4,001
	4	.07	3	1,600	672
	4	62.44	5	1,434,147	610,947
	5	88.00	5	2,874,960	836,613
	6	31.00	5	904,952	354,741
	7	33.00	5	1,503,480	538,246
	8	7.83	5	126,149	52,604
	8	3.17	6	51,171	21,441
	9	5.00	4	70,060	38,323
Migration of vessels to assist in fulfilling Port 1 demand					
From Port 2	7	5.08	4	231,294	82,572
2	7	25.15	5	1,145,670	410,150
3	7	3.40	5	155,010	55,494
		Port 1	Σ =	9,084,425	Σ = $3,211,975
Port 2					
Fort Myers					
	2	1.00	6	22,290	$ 2,318
	5	12.90	6	421,637	129,021
	5	3.41	7	111,367	34,190
	5	4.29	10	140,071	41,461
	5	10.14	11	331,296	98,395
	5	.20	12	6,584	1,962
	5	.06	13	1,815	543
	7	33.66	6	1,533,723	565,944
	7	.11	9	5,153	1,907
		Port 2	Σ =	2,573,936	Σ = $ 875,741
Port 3					
Tampa	5	1.41	7	46,191	14,643
	5	.59	8	19,149	6,070
	7	3.16	7	143,861	54,236
		Port 3	Σ =	209,201	Σ =$ 74,949
			Σ Σ =	11,867,562	ΣΣ= $4,162,665

*TR = Total transport cost.

Table 29.--Total fixed cost incurred in 1965 under Model II effort allocation conditions.

Vessel size class	Pounds landed	Fixed cost coefficient	Total fixed cost by vessel size class
2	66,870	.022	$ 1,471
3	415,275	.055	22,840
4	1,561,824	.155	242,083
5	3,953,070	.067	264,856
6	904,952	.082	74,206
7	4,718,191	.084	396,328
8	177,320	.173	30,676
9	70,060	.153	10,719
	Σ = 11,867,562		Σ = $1,043,179

Table 30.--Estimated employment of fishermen in the Model II allocation of vessels and fishing effort, 1965.

Vessel size class	Average number in crew	Number of vessels utilized in optimized optimum solution	Estimated number of fishermen
2	2	3	6
3	2	15	30
4	2	68	136
5	2	121	242
6	3	31	93
7	3	104	312
8	3	11	33
9	3	5	15
		$\Sigma = 358$	$\Sigma = 867$

Table 31.--The effects of equal distribution of the savings in Model II on the individual fisherman's income, Dry Tortugas, 1965.

Vessel size class	Average individual fisherman's income	Average percent change in income with equal distribution
2	1,242	66
3	1,670	49
4	2,032	41
5	2,699	31
6	1,797	46
7	1,167	71
8	1,337	62
9	806	102

Table 32.--Excess capacity reflected in pounds, vessels, and social cost, Model I solution, Dry Tortugas, 1965.

Vessel size class	Port	Pounds excess capacity	Number of vessel equivalents	Social cost (pounds x fixed cost/size class)
4	2	697,170	30	$108,061
9	2	136,860	12	20,940
4	3	23,239	1	3,602
8	3	182,604	10	31,590
9	3	193,885	17	29,664
		Σ = 1,233,758	Σ = 70	Σ = $193,857

Table 33.--Model I excess undepreciated capital investment in Dry Tortugas, 1965.

Vessel size class	Number of vessels	Average cost per vessel	Total investment
4	31	21,063	$ 652,953
8	10	46,611	466,110
9	29	58,482	1,695,978
			Σ = $2,815,041

Model II, the reallocation of effort under increased vessel capacity utilization per trip reflects excess vessel capacity amounting to 6,141,602 pounds or 212 vessel equivalents (Table 34). The over-capitalization interpreted as a social cost amounts to approximately $668,492 (Table 34).

Additional social cost imputed for excess undepreciated capital investment in the excess vessels is estimated to be $9,167,950 (Table 35).

Table 34.--Excess capacity reflected in pounds, vessels, and social costs, Model II solution, 1965.

Vessel size class	Port	Pounds excess capacity	Number of vessel equivalents	Social cost (pounds x fixed cost/size class)
3	2	27,685	1	$ 1,523
4	2	689,040	30	106,801
6	2	525,456	18	43,087
8	2	306,280	19	52,986
9	2	168,144	12	25,726
4	3	22,968	1	3,560
6	3	87,576	3	7,181
7	3	3,528,169	77	296,366
8	3	548,080	34	94,817
9	3	238,204	17	36,445
		Σ = 6,141,602	Σ = 212	Σ = $668,492

Table 35.--Model II excess undepreciated capital investment in Dry Tortugas, 1965.

Vessel size class	Number of vessels	Average cost per vessel	Total Investment
3	1	$ 9,800	$ 9,800
4	31	21,063	652,953
6	21	36,357	763,497
7	77	46,407	3,573,339
8	53	46,611	2,470,383
9	29	58,482	1,695,978
	Σ = 212		Σ = $9,167,950

CHAPTER VI

SUMMARY AND CONCLUSIONS

The application of linear programming techniques to empirical problems in ocean fisheries has demonstrated its usefulness to public policy decision-makers and firm decision-makers by elucidating the possibilities of reducing the aggregate production cost for a specified quantity of raw headless shrimp.

Utilizing existing vessel capacity coefficients it has shown that a reallocation of fishing effort could reduce the total cost of production in 1965 by $552,556. The solution of Model I revealed an excess vessel capacity of 1,233,758 pounds, or a social cost of $193,857. In addition, this excess capacity reflected in vessels amounted to an estimated 70 excess vessel equivalents. These vessels represented approximately $2.8 million in excess undepreciated capital investment. The total social cost of overcapitalization amounted to $3,008,898 during calendar year 1965 for the Dry Tortugas.

Increasing the vessel capacity utilization of the existing fleet on a trip basis and constrained by fuel carrying capacity Model II revealed a reduction in total production costs of $715,079 under efficient fishing effort allocation conditions. Based on this model, excess vessel capacity in 1965 is estimated to have been 6,141,602 pounds, or a social cost of approximately $668,492. There are 212 excess vessel equivalents, or $9,167,950 in excess undepreciated capital investment. The total social costs of overcapitalization amounted to $9,836,442 during calendar year 1965 for the Dry Tortugas.

The implication of the entire empirical analysis is that the total production cost of harvesting and transporting raw headless shrimp to intermediate processing facilities can be reduced through more efficient spacial allocation of fishing effort. This implication, however, is perhaps not the most important contribution of the analysis. Overcapitalization occurs and is reflected as excess capacity. The social cost of such overcapitalization is a substantial sum in each phase of the empirical analysis. The presence of overcapitalization substantiates Knights' hypothesis which was elucidated in Chapter II. Common property ownership of natural resources will result in excessive allocation of labor and capital because average product is considered instead of marginal product.

The most efficient vessel size classes are implicit in the analysis, but tabulation of average fixed and variable costs in Table 36 describes the vessel size classes which are most efficient in terms of production cost. Vessel size classes 2 and 5 are clearly most efficient. The emphasis by vessel owners on maximum physical production with little concern for production costs results in investment in the most inefficient (in terms of production cost) vessel class. Vessel owners are apparently not extremely rational in investment decisions. This conclusion is further substantiated when comparison is made between average total cost per pound per vessel size class and 1965 average ex-vessel value of raw headless shrimp per vessel size class (Table 37). Vessels of size class 9

Table 36.--Average fixed and variable costs per pound of raw headless shrimp per vessel size class, 1964-1965, Dry Tortugas.

Vessel size class	Average fixed cost/lb.	Average variable cost/lb.	Average total cost/lb.
2	.022	.086	.108
3	.055	.361	.416
4	.155	.416	.571
5	.067	.283	.350
6	.082	.386	.468
7	.084	.352	.436
8	.173	.410	.583
9	.153	.541	.694

Table 37.--Average profit margin per pound of raw headless shrimp per size class, Dry Tortugas, 1965.

Vessel size class	Average value per pound	Average total cost per pound	Average profit margin per pound
2	$ .370	$ .108	$ .262
3	.428	.416	.012
4	.533	.571	-.038
5	.577	.350	.207
6	.577	.468	.109
7	.570	.436	.134
8	.636	.583	.053
9	.633	.694	-.061

lost an average 6.1 cents per pound of shrimp while fishing in the Dry Tortugas, while vessels in size classes 2 and 5 received an average profit per pound of raw headless shrimp of 26.2 and 20.7 cents, respectively.

Dry Tortugas fishermen appear to be exploited in a social sense of the word. Emphasis on larger vessels has resulted in a lower average income for fishermen on the larger vessels than for any other vessel size class. It should not be inferred that the exploitation of the fisherman is intentional, but rather they are exploited because of lack of knowledge on the part of the individual investor.

The major conclusion of this analysis is that an economic and social problem does exist in the Dry Tortugas fishery. The magnitude of this problem can be expected to increase over time if emphasis is maintained on larger, more costly vessels in anticipation of increased physical production, and if the vessel capacity utilization does not change significantly.

CHAPTER VII

POLICY IMPLICATIONS

The results of the preceeding analysis clearly indicate that management policies for the Dry Tortugas should be re-evaluated. Currently the State of Florida has a closed area (Figure 13) that insures against over-exploitation of the Dry Tortugas shrimp fishery. The area was established under the assumption, "It is desirable to catch the greatest possible number of pounds of shrimp, this desirability being enhanced as the sizes of shrimp caught are increased."[55] The law establishing a portion of the Dry Tortugas fishing grounds as a closed area was passed in the 1957 session of the Florida Legislature. It was incorporated into the Florida Statute as Chapter 370.151 (Ervin and Henderson, 1957). The controlled area is sampled periodically, and when the survey shows that the shrimp in the area are of a size less than 50 to the pound (heads off), the area is closed. If the survey finds the shrimp larger than 50 to the pound (heads off) the area is opened to commercial shrimp fishing. The law was to expire in 1962, but was reinstated for another five years. The 1967 Florida legislature is debating the benefits of a 70 count law for the Dry Tortugas. Such a law would make it illegal to catch shrimp smaller than 70 to the pound (heads off).

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[55] Robert M. Ingle, "Synoptic Rationale of Existing Florida Shrimp Regulations," Proceedings of the Gulf and Caribbean Fisheries Institute, Thirteenth Annual Session, November 1960, p. 22.

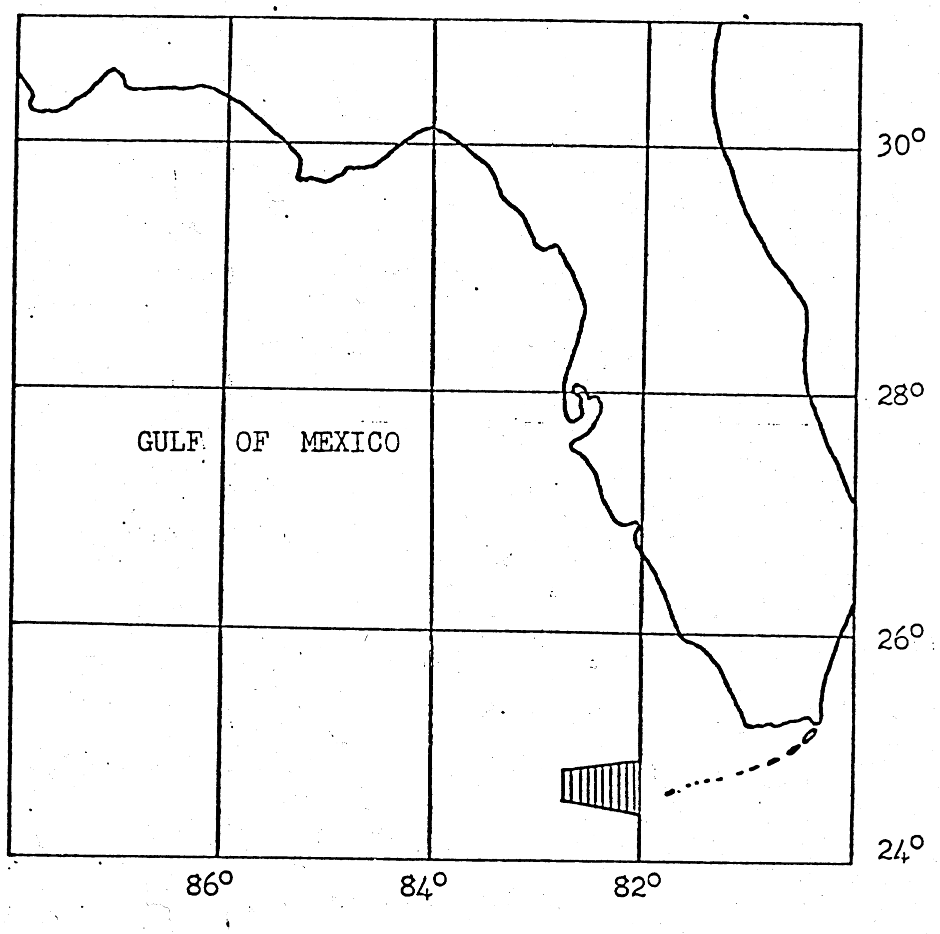

Figure 13. Legislated Dry Tortugas closed fishing area.

Clearly evident is the lack of economic consideration in either regulatory measure. The emphasis is on maintaining a stock of shrimp. Such a goal is noble, but should be integrated with economic analysis.

A Note on Regulatory Policy Measures

There are two immediate policy recommendations that can be made based on the preceeding analysis. The Florida legislature should begin consideration of management policy that treats economic and technological, as well as biological, implications. Such consideration would necessitate establishing precise resource management policy objectives which would be useful in comparing alternative regulatory measures.

The Bureau of Commercial Fisheries, which has initiated vessel loan and vessel subsidy programs for United States fisheries, should consider the effects that such programs have on overcapitalization in the Gulf of Mexico shrimp fishery. If the effects are determined to be positive, a recommendation would be to cease such programs in the Gulf for a period sufficient to retire a significant portion of the excess fleet. When the excess vessels have been retired from the fleet the programs could be reinitiated and act to direct the construction of vessels that are technologically and economically efficient. Such action would have a positive effect by improving the competitive position of the firms in the Gulf shrimp industry in the world market.

In the long run there are many alternative objectives for management policy:

1. Maximize the physical production of this fishery.
2. Maximize the aggregate revenue to the industry.
3. Maximize regional income.
4. Minimize total production costs of harvesting specified levels of output and transporting to onshore processing facilities.
5. Maximize the opportunity for employment of labor and capital in the fishery.
6. Facilitate the continued availability of fish and fishery products to meet projected demand in the United States.
7. Maintain the status quo of the fishery and attempt to increase the physical production of individual vessels.
8. Maximize the net yield from the resource.

The important point is that policy decision-makers should be completely aware of their objectives before management criteria are established. It is apparent that maximization of physical production may not be conducive with the overall objectives. State and federal agencies are becoming increasingly aware of the complexity of establishing objectives for management programs, and some are attempting to specify them as precisely as possible. The Bureau of Commercial Fisheries, for example, is currently engaged in evaluating the objectives of management programs. This is clearly a step in the correct direction in attempting to establish "optimal" resource management.

Suppose the management objective is to minimize the total production cost of a specified level of raw headless shrimp from the Dry Tortugas in the short run, as it was in this analysis, the management policy decision-maker is confronted with the problems of excess capacity, i.e. overcapitalization in terms of labor and capital, and numerous alternative regulations that could be established:[56]

1. Restricting the size of fishing gear
2. Regulation by size and weight limit
3. Sex or condition limits
4. Closed fishing areas
5. Limitation of landings by gear efficiency[57]
6. Limitation of landings by quota
7. Limited entry into the fishery

Limitation of the number of fishing units is probably the most unpopular method of regulation, but perhaps the most efficient in terms of economics. Opponents to this method see it as a step toward a managed economy. To the economist a concept of limited entry is most appealing; it seems to be the most efficient method of regulation. The most efficient means of fishing could be applied and the fishing effort could be reduced. Assuming correct decision processes, the actual yield would approach the point where maximum

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[56]For a summary of methods of fishery regulations, see: Donald E. Bevan, "Methods of Fishery Regulation," The Fisheries, Problems in Resource Management, James A. Crutchfield, editor (Seattle: University of Washington Press, 1965), pp. 25-40.

[57]See Turvey, "Optimization and Suboptimization in Fishery Regulations," *op. cit*.

economic yield is obtained. As pointed out in Chapter II this point could be well below the maximum sustained yield. Is this an undesirable position?--no, because of the opportunity cost. Society is interested in conserving the natural resources, as well as the labor and capital that is necessary to utilize them. If the fishing effort is forced beyond the point of maximum economic yield, the value of other products sacrificed is greater than the value of the additional catch. In terms of regulation, the limited entry concept would be difficult to establish, but would render the greatest return to society. It is now proper to ask how such a regulation can be established. The state of the fishery today is not conducive to limited entry. Most of today's commercial fishing occurs in international waters, and much conflict over fishing rights in international waters is evident.

Establishment of an international fishery jurisdiction group is perhaps a long run method to initiate such a proposed regulation. This group must be allowed to settle all grievances and controversies of all fishing nations. To do so requires that each fishing nation be a member of the group. The group could also be endowed with the power to sell rights to the highest bidder for every major fishing ground in the world. A power such as this could insure that only the most efficient methods of fish capture would be employed. This proposal sounds radical in terms of freedom of the seas, but remembering opportunity costs, could be most efficient and beneficial to the world society. At present the data requirements and research endeavors that would need to be undertaken to make such a plan feasible would be enormous. However, it must be remembered that, as population pressure increases, demand for protein will also increase. Perhaps we must change basic institutions in order to satisfy this increase in demand.

CHAPTER VIII

RECOMMENDATIONS FOR FUTURE RESEARCH

The current status of the economic theory of common property fishery resources leaves much to be desired and, therefore, many profitable avenues for basic research.

Immediate research should be directed to applying economic theory to common property resources. The theory in this area is still in its embryonic stages and has not been emphasized by economic theoreticians. Increasing demands by a growing population on common property resources require rational and efficient allocation of economic resources in the exploitation and management so that utility is maximized. Elucidation of relationships of common property resources and current economic theory of the markets would provide a useful first step in understanding the economics of this unique institutional concept.

Research should be directed toward continuation of the general model presented in this study. Minimizing the aggregate production cost of a specified quantity of raw headless shrimp with a given time period for the entire Gulf of Mexico would focus attention on the extensiveness of excess capacity and overcapitalization in the Gulf of Mexico shrimp industry.

Models should also be developed for testing various alternative objective functions, such as those discussed in

Chapter VI for the Gulf of Mexico shrimp industry. Comparisons between various objectives would be useful to the policy-maker in specifying objectives that would be most beneficial to society.

The average cost functions developed in this study should be extended by regression analysis to develop more realistic cost functions for the vessel size classes discussed. A step supply function for labor and capital might be developed to illustrate the most cost effective vessel classes for various levels of fishing effort.

Coordinated research efforts should be attempted by the economist, biologist, and technologist. The economist should develop demand and market studies; the biologist should develop more explicit population dynamics for shrimp population and the short and long run stochastic variations which occur; and the technologist should devote effort to the development of cost-reducing harvesting and processing facilities, together with more efficient vessel designs. These efforts could be major inputs in a simulation model testing various objective functions.

Finally, the research efforts described above should not be limited to the shrimp fishery, but should be attempted for various species of fish. The output of such research should prove beneficial in the development of overall policy and management techniques.

APPENDIX A

Gulf of Mexico Shrimp Vessel Operating Cost and
Physical Characteristic Questionnaire

Budget Bureau No. 42-66020
Expires May 31, 1967
Bureau of the Budget Approved
October 19, 1966
Questionnaire No.

1964 and 1965
Gulf of Mexico Shrimp Vessel Operating Costs
and Physical Characteristics Questionnaire

UNITED STATES
Department of the Interior
Bureau of Commercial Fisheries
Division of Economics
Confidential
For Statistical Purposes Only

"The United States Bureau of Commercial Fisheries is updating a study of the production costs of shrimp by various vessel size classes conducted by the Federal Trade Commission during the calendar years 1952 through 1954.

By updating this study we can determine and classify economic problems confronting the shrimp fishing industry today and point out areas where economic problems may arise in the future. Analyses will then be conducted to recommend courses of action designed to alleviate existing economic difficulties and to avoid such problems in the future.

Would you be willing to provide us data on the expenses incurred in operating your shrimp fishing vessel during the calendar years 1964 and 1965?

This information will be used for scientific studies and only summary data will be published. Individual reports will be kept strictly confidential."

I. Owner Information

A. Name of owner

B. Address

C. Indicate the number of shrimp vessels you own or in which you have controlling interest.

Own ______ Controlling interest ______

D. Indicate your method of marketing raw shrimp. Check the appropriate method(s).

_____ your own processing facilities

_____ dealer

_____ co-op

II. Individual Vessel Information

A. General

		Code
1. Vessel's registered name	______________	
2. Documentation number	______________	_____
3. Overall length	______________	_____
4. In what year did you purchase the vessel?	______	_____
5. Cost of the vessel when purchased	______________	_____
6. Horsepower rating of engine when the vessel was purchased	______________	_____
7. How many engines have been installed since you purchased this vessel?	______________	_____

Please list horsepower rating of each engine

	horsepower	year installed	
Present engine	______	______	_____
Previous engines	______	______	_____
	______	______	_____
	______	______	_____

Code

8. Number of hours the engine was operated: ____

previous engine		present engine		
1964 ________ hrs.		1965 ________ hrs.		____
1964 ________ hrs.		1965 ________ hrs.		____

9. Under ideal conditions, the

   a. cruising speed to the fishing grounds ____
      ________ mph ________ rpm ____
   b. trawling speed ____
      ________ mph ________ rpm ____
   c. cruising speed to port ____
      ________ mph ________ rpm ____

10. Fuel capacity ______________ gallons ____

11. Estimated fuel consumption per hour of running time at speeds indicated in 9:

   a. on the trip to the grounds ________ gal/hr ____
   b. pulling trawl ______________________ gal/hr ____
   c. on the trip to port ________________ gal/hr ____

12. Fresh water capacity _____________ gallons ____

13. In how many states is this vessel licensed to fish and land shrimp ______________________ ____

14. Did you land any shrimp outside the U.S.? 1964 __yes __no 1965 __yes __no ____
    If yes, what percent of yearly catch? _____% 1964 ____
    _____% 1965 ____

15. Have any of the following major vessel alterations been made since the vessel was constructed? (If yes, indicate the last time the alteration was made and the cost of the alteration.

	yes	no	year of last major alteration	cost	
a. engine change	___	___	___________	_____	_____
b. rebuild hull	___	___	___________	_____	_____
c. rebuild cabins	___	___	___________	_____	_____
d. rebuild wheelhouse	___	___	___________	_____	_____
e. rebuild galley	___	___	___________	_____	_____
f. insulate hold	___	___	___________	_____	_____
g. install freezer unit	___	___	___________	_____	_____
h. change rigging or winches	___	___	___________	_____	_____

Code

16. Have any significant changes been made in the net type or net size in the last five years? ____ yes ____ no ____
If yes, specify type of change and date the change occurred ______________________ ____

17. Does the vessel have as standard equipment:

	no	on vessel when purchased	installed after purchased	date	Code
a. insulated hold	__	______	______	____	____
If yes, indicate type and thickness					
___styrofoam thickness___					
___mortar thickness___					
___other (specify type) thickness___					
b. freezer	__	______	______	____	____
If yes, specify type					
___shelf or plate					____
capacity/hr___					____
___blast					____
capacity/hr___					____
___immersion					____
capacity/hr___					____
c. auto pilot	__	______	______	____	____
d. ship to shore radio	__	______	______	____	____
e. radar	__	______	______	____	____
f. loran	__	______	______	____	____
g. depthfinder (fathometer)	__	______	______	____	____
h. electronic fishfinder	__	______	______	____	____
i. ice machine	__	______	______	____	____
j. spare try nets	__	______	______	____	____
If yes, indicate number _______					
k. spare trawl nets	__	______	______	____	____
If yes, indicate number _______					
l. spare otter boards	__	______	______	____	____

Code

B. Captain and crew information

1. Captain's shrimp fishing experience as of December 31, 1965 ____ years ____ months ____

2. Does the captain own any share of the vessel?
____ yes ____ no ____
If yes, specify percent ________% ____

3. Crew number during the peak season ______ ____

4. Crew number during the slack season ______ ____

5. Crew share (check correct crew share)

1964	1965	Code
___a. 60% owner-40% crew	___a. 60% owner-40% crew	____
___b. 50% owner-50% crew	___b. 50% owner-50% crew	____
___c. 2/3 owner-1/3 crew	___c. 2/3 owner-1/3 crew	____
___d. other	___d. other	____
If other, specify ________ ________	If other, specify ________ ________	

6. Crew expenses

a. groceries (check correct breakdown of expenses)

1964	1965	Code
___(1) crew buys all	___(1) crew buys all	____
___(2) crew buys 1/2	___(2) crew buys 1/2	____
___(3) crew buys none	___(3) crew buys none	____
___(4) other	___(4) other	____
If other, specify ________	If other, specify ________	

b. ice (check correct breakdown of expenses)

1964	1965	Code
___(1) crew buys all	___(1) crew buys all	____
___(2) crew buys 1/2	___(2) crew buys 1/2	____
___(3) crew buys none	___(3) crew buys none	____
___(4) other	___(4) other	____
If other, specify ________	If other, specify ________	

C. Operating cost breakdown for individual vessel

	1964 Dollars	1964 Code	1965 Dollars	1965 Code
Depreciation hull	______	____	______	____
depreciated life ____ years				
Engine	______	____	______	____
depreciated life ____ years				
Electronic gear	______	____	______	____
depreciated life ____ years				
Winches	______	____	______	____
depreciated life ____ years				
Other (pumps, generating plant, water pressure system)	______	____	______	____
depreciated life ____ years				
Taxes on business property	______	____	______	____
Repairs (vessel and engine, including parts)	______	____	______	____
Salaries (including crew share)	______	____	______	____
Insurance				
personal and indemnity	______	____	______	____
hull	______	____	______	____
Legal and professional fees	______	____	______	____
Interest on business indebtedness	______	____	______	____
Association dues	______	____	______	____
Bank charges	______	____	______	____
Fuel				
cost per gallon	______	____	______	____
Galley provisions	______	____	______	____
Ice				
cost per ton	______	____	______	____
Packing and handling	______	____	______	____
Supplies (rope, baskets, etc.)	______	____	______	____
Office supplies	______	____	______	____
Car, truck and travel expenses	______	____	______	____
Miscellaneous (butane gas,etc.)	______	____	______	____
Licenses	______	____	______	____
Taxes (city, county, etc.)	______	____	______	____
Telephone	______	____	______	____
Netting and net repairs	______	____	______	____
Radio repairs (including electronic gear)	______	____	______	____
FICA taxes	______	____	______	____
Office and storage rental	______	____	______	____

D. Gross revenue from shrimp sales ______ ____ ______ ____

III. What are your future investment plans as an individual enterprise for the next five years in the Gulf shrimp industry?

IV. What are your goals and objectives in the Gulf shrimp industry for the future?

To: ______________________________ Date: ____________________
Name of Accountant or Bookkeeper

____
Street Address

____
City State

This is to certify that Victor Lewis Arnold, Economist, Department of Interior, Bureau of Commercial Fisheries, has my permission to examine the standard U.S. Treasury Department, Internal Revenue Service Schedule C (Form 1040) and other operating costs records for calendar years 1964 and 1965 for the ___________________________.
Name of Vessel

____
Documentation Number

This data will be used in an economic study of the Gulf of Mexico shrimp fishery.

____
Signature of Owner

APPENDIX B

1965 Pink Shrimp Price Variations Based on
Key West, Florida, Ex-vessel Prices

APPENDIX B Table 1.--Key West shrimp prices, 1965 (pink, heads off).

Week ending		Shrimp sizes* 10-15	16-20	21-25	26-30	31-40	41-50	51-67	68+
January	7	$	$.84	$.77	$.72	$.65	$.56	$.44	$.20
	14		.84	.77	.72	.65	.56	.44	.20
	21		.84	.77	.72	.65	.56	.44	.20
	28		.81	.77	.72	.64	.55	.44	.21
February	4		.81	.76	.71	.63	.54	.43	.21
	11		.81	.76	.71	.63	.54	.43	.21
	18		.81	.76	.71	.63	.54	.43	.21
	25		.81	.76	.71	.63	.54	.43	.21
March	4		.81	.76	.71	.63	.54	.43	.21
	11		.81	.76	.71	.63	.54	.43	.21
	18		.81	.76	.71	.63	.54	.43	.21
	25		.81	.76	.71	.63	.54	.43	.21
April	1		.81	.76	.71	.63	.54	.43	.21
	8		.81	.76	.71	.63	.54	.43	.21
	15		.81	.76	.71	.63	.54	.43	.21
	22		.81	.76	.71	.63	.54	.43	.21
	29		.81	.76	.71	.63	.54	.43	.21
May	6		.81	.76	.71	.63	.54	.43	.21
	13		.81	.76	.71	.63	.54	.43	.21
	20		.81	.76	.71	.63	.54	.43	.21
	27		.81	.76	.71	.63	.54	.43	.21

*Size count refers to the number of raw headless shrimp per pound.

APPENDIX B Table 1.--Continued.

Week ending		Shrimp sizes						
	10-15	16-20	21-25	26-30	31-40	41-50	51-67	68+
June 3	$	$.81	$.76	$.71	$.63	$.54	$.43	$.21
10		.81	.76	.71	.63	.54	.43	.21
17		.81	.76	.71	.63	.54	.43	.21
24		.81	.76	.71	.63	.54	.43	.21
July 1			.73	.68	.60	.51	.43	.21
8			.66	.61	.54	.46	.43	.21
15			.66	.61	.54	.46	.35	.21
22			.66	.61	.54	.46	.36	
29		.76	.69	.63	.55	.46	.33	.17
August 5			.71	.65	.55	.47		.21
12		.76		.65	.56	.48	.35	.21
19		.76		.66	.58	.49	.36	.21
26			.71	.66	.58	.49	.36	.21
September 2								
9		.76	.71	.66	.58	.49	.33	.21
16		.76		.66		.49	.36	.21
23		.76	.71	.66	.58	.49	.36	.21
30	.81	.76	.71	.66	.58	.49	.37	.21
October 7					.58	.47	.35	.20
14		.76	.71	.66	.54	.44	.34	.19
21		.76	.71	.66	.54	.44	.34	.19
28		.78	.73	.67	.56	.48	.34	.21

APPENDIX B Table 1.--Continued.

Week ending	Shrimp sizes 10-15	16-20	21-25	26-30	31-40	41-50	51-67	68+
November 4	$	$	$.73	$.67	$.56	$.48	$.34	$.21
11			.73	.67	.57	.47	.36	.21
18			.74	.68	.58	.48	.37	.22
25		.80	.75	.69	.59	.49	.38	.23
December 2		.81	.76	.70	.60	.50	.39	.23
9		.82	.77	.71	.61	.51	.40	.23
16		.84	.78	.72	.62	.52	.41	.25
23		.84	.79	.73	.63	.53	.42	.26
30			.79	.73	.63	.53	.42	.26

APPENDIX B Table 2.--Key West average monthly shrimp prices, 1965 (pink, heads off).

Month	Shrimp sizes*							
	10-15	16-20	21-25	26-30	31-40	41-50	51-67	68+
January	$	$.83	$.77	$.72	$.65	$.56	$.44	$.20
February		.81	.76	.71	.63	.54	.43	.21
March		.81	.76	.71	.63	.54	.43	.21
April		.81	.76	.71	.63	.54	.43	.21
May		.81	.76	.71	.63	.54	.43	.21
June		.81	.76	.71	.63	.54	.43	.21
July		.76	.68	.63	.55	.47	.38	.20
August		.76	.71	.66	.57	.48	.36	.21
September	.81	.76	.71	.66	.58	.49	.36	.21
October		.77	.72	.67	.56	.46	.34	.20
November		.80	.74	.68	.58	.48	.36	.22
December		.83	.78	.72	.62	.52	.41	.25

*Size count refers to the number of raw headless shrimp per pound.

APPENDIX B Table 3.--Key West weighted average shrimp prices, 1965 (pink, heads off).

Month	Shrimp sizes* 16-20	21-25	26-30	31-40	41-50	51-67	68+
January	$.0830	$.1309	$.1440	$.0845	$.0672	$.0396	$.0140
February	.1134	.0912	.0568	.0441	.0324	.0301	.0126
March	.1296	.1444	.0994	.0567	.0378	.0516	.0189
April	.1458	.1292	.0994	.0504	.0324	.0301	.0105
May	.0891	.0380	.0213	.0378	.0378	.0172	.0021
June	.0324	.0228	.0213	.0189	.0162	.0043	--
July	--	.0068	.0252	.0165	.0094	--	--
August	--	.0142	.0066	.0114	.0144	.0108	.0063
September	.0152	.0142	.0066	.0116	.0098	.0252	.0399
October	.0154	.0144	.0536	.0784	.0598	.0476	.0740
November	.0640	.0592	.0884	.0986	.1056	.0828	.0176
December	.1245	.0936	.0720	.0992	.0884	.0533	.0125
Weighted average price (rounded)	$.81	$.76	$.69	$.61	$.51	$.39	$.21

*Size count refers to the number of raw headless shrimp per pound.

APPENDIX C

1965 Dry Tortugas Pink Shrimp
Depth-Shrimp Size Relationships

APPENDIX C Table 1.--1965 Dry Tortugas pink shrimp depth-shrimp size relationships.

Area	Depth (fathoms)	Shrimp sizes* 16-20	21-25	26-30	31-40	41-50	51-67	68+	Total
		pounds							
1	6-10	88	221	2,936	8,801	6,209	42,903	55,392	116,550
1	11-15		33	1,350	2,192	4,594	877	481	9,527
1	16-20					1,600			1,600
2	6-10	330	3,412	9,708	55,542	87,916	92,165	52,281	301,354
2	11-15	65,000	309,185	401,891	1,532,201	2,338,523	2,339,542	1,617,881	8,604,223
2	16-20	78,741	406,800	404,066	561,092	446,736	108,902	22,484	2,028,821
2	21-25	36,052	99,502	66,465	55,635	33,940	8,476	1,349	301,419
2	26-30		3,044	3,548	7,089	4,912	556		19,149
2	31-35			1,075	2,163		1,465		5,153
3	11-15		7,507	15,712	57,472	40,704	13,928	4,578	140,071
3	16-20	13,220	63,476	66,640	109,346	63,675	10,963	3,976	331,296
3	21-25		2,403		1,170	3,011			6,584
3	26-30		1,048		767				1,815

*Size count refers to the number of raw headless shrimp per pound.

APPENDIX D

Dry Tortugas Sample Vessel Characteristics

APPENDIX D Table 1.--Total landings and landings in the Dry Tortugas, vessel size class 2, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
314	31	31	100.00	80,086	80,086	100.00
590	4	4	100.00	1,519	1,519	100.00

APPENDIX D Table 2.--Total landings and landings in the Dry Tortugas, vessel size class 3, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
856	28	28	100.00	56,604	56,604	100.00
626	39	39	100.00	49,118	49,118	100.00
205	20	9	45.00	10,420	2,675	25.67
142	13	13	100.00	11,820	11,820	100.00
382	28	27	96.42	53,415	52,674	98.61

APPENDIX D Table 3.--Total landings and landings in the Dry Tortugas, vessel size class 4, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
713	38	38	100.00	51,265	51,265	100.00
714	40	40	100.00	49,743	49,743	100.00
737	42	42	100.00	59,585	59,585	100.00
488	42	32	76.19	54,464	44,944	82.52
366	7	3	42.85	9,269	2,354	25.39
843	38	32	84.21	52,129	42,567	81.65
650	26	2	7.69	47,996	2,613	5.44
488	33	9	27.27	50,631	17,820	35.19
888	17	6	35.29	19,710	6,901	35.01
059	35	17	48.57	51,968	19,999	38.48

APPENDIX D Table 4.--Total landings and landings in the Dry Tortugas, vessel size class 5, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
966	35	35	100.00	58,986	58,986	100.00
010	39	39	100.00	92,681	92,681	100.00
896	18	10	55.55	59,291	41,843	70.57
019	39	31	79.48	62,166	52,175	83.92
627	15	15	100.00	26,909	26,909	100.00
352	22	12	54.54	37,576	27,585	73.41
501	42	42	100.00	57,484	57,484	100.00
044	43	23	53.48	55,110	30,649	55.61
528	40	31	77.50	60,316	47,431	78.63
744	38	33	86.84	64,347	56,845	88.34
250	37	10	27.02	56,354	13,135	23.30
143	35	21	60.00	50,720	32,058	63.20
508	39	34	87.17	74,781	65,467	87.54
270	30	23	76.66	58,206	44,904	77.14
706	13	2	15.38	20,779	1,654	7.95

APPENDIX D Table 5.--Total landings and landings in the Dry Tortugas, vessel size class 6, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
963	29	7	24.13	48,347	11,273	23.31
536	33	18	54.54	58,267	42,105	72.26
693	29	3	10.34	49,277	2,755	5.59
521	19	2	10.52	52,255	4,348	8.32
364	28	10	35.70	57,948	21,830	37.67

APPENDIX D Table 6.--Total landings and landings in the Dry Tortugas, vessel size class 7, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
157	25	6	24.00	31,605	10,056	31.81
177	22	8	36.36	43,612	25,891	59.36
576	15	10	66.67	51,433	37,797	73.48
831	32	4	12.50	37,321	4,121	11.04
464	33	10	30.30	45,646	13,130	28.76
857	14	1	7.14	59,656	2,015	3.37
051	32	3	9.37	39,743	4,570	11.49
722	16	3	18.75	53,130	5,984	11.26
743	36	5	13.88	48,354	6,250	12.92
878	20	6	30.00	43,531	12,839	29.49
979	15	1	6.66	51,654	1,963	3.80
098	22	9	40.90	31,386	14,393	45.85
318	35	7	20.00	53,614	24,491	45.68
530	27	4	14.81	57,061	9,113	15.97
422	27	7	25.92	35,119	12,671	36.08
621	9	2	22.22	29,045	6,535	22.49
112	33	25	75.75	75,262	63,275	84.07
113	32	21	65.62	93,071	74,947	80.52
781	19	5	26.31	54,618	12,865	23.55
449	16	4	25.00	61,392	11,484	18.70
982	17	1	5.88	55,198	995	1.80

APPENDIX D Table 7.--Total landings and landings in the Dry Tortugas, vessel size class 8, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
510	20	1	5.00	73,682	4,300	5.83
541	27	7	25.92	41,034	11,124	27.10
415	10	3	30.00	20,687	6,407	30.97
250	21	1	4.76	53,506	3,424	6.39

APPENDIX D Table 8.--Total landings and landings in the Dry Tortugas, vessel size class 9, 1964.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
316	37	6	16.21	81,770	15,356	12.17

APPENDIX D Table 9.--Total landings and landings in the Dry Tortugas, vessel size class 2, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
314	23	23	100.00	47,680	47,680	100.00

APPENDIX D Table 10.--Total landings and landings in the Dry Tortugas, vessel size class 3, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
856	30	30	100.00	65,979	65,979	100.00
626	33	33	100.00	50,626	50,626	100.00
205	9	7	77.77	6,413	5,707	88.99
142	16	13	81.25	28,367	19,792	69.77
382	11	8	72.72	20,078	17,188	85.60
872	4	4	100.00	1,539	1,539	100.00

APPENDIX D Table 11.--Total landings and landings in the Dry Tortugas, vessel size class 4, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
713	35	35	100.00	46,272	46,272	100.00
714	44	44	100.00	52,226	52,226	100.00
737	30	30	100.00	56,428	56,428	100.00
488	28	25	89.28	26,676	24,478	91.76
366	28	5	17.85	36,286	10,196	28.09
843	36	36	100.00	52,608	52,608	100.00
650	29	5	17.24	57,117	8,611	15.07
488	33	5	15.15	49,043	7,123	14.52
888	2	2	100.00	950	950	100.00
059	32	19	59.37	56,615	27,131	47.92

APPENDIX D Table 12.--Total landings and landings in the Dry Tortugas, vessel size class 5, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
966	34	25	73.52	57,451	42,455	73.89
010	45	39	86.66	96,251	82,523	85.73
896	18	12	66.66	59,217	44,126	74.51
019	36	25	69.44	54,610	33,371	61.10
627	3	3	100.00	5,922	5,922	100.00
352	25	14	56.00	45,404	29,962	65.98
501	28	28	100.00	35,332	35,332	100.00
044	38	20	52.63	66,188	30,981	46.80
528	32	20	62.50	47,875	25,490	53.24
744	36	36	100.00	70,450	70,450	100.00
250	31	8	25.80	41,764	7,987	19.12
143	33	20	60.60	72,893	41,075	56.34
508	33	32	96.96	66,290	66,067	99.66
270	33	19	57.57	69,622	37,454	53.79

APPENDIX D Table 13.--Total landings and landings in the Dry Tortugas, vessel size class 6, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
963	26	9	34.61	68,550	25,097	36.61
536	26	16	61.53	71,872	45,326	63.06
693	29	9	31.03	55,161	13,826	25.06
521	28	14	50.00	67,063	30,218	45.05
364	29	11	37.93	69,457	21,993	31.66

APPENDIX D Table 14.--Total landings and landings in the Dry Tortugas, vessel size class 7, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
157	28	12	42.85	50,091	18,558	37.04
177	23	11	47.82	41,227	23,808	57.74
576	16	11	68.75	53,440	39,529	73.96
659	26	26	100.00	45,510	45,510	100.00
831	30	5	16.66	55,527	12,163	21.90
464	29	11	37.93	38,302	12,331	32.19
857	19	5	26.31	60,143	12,492	20.77
051	27	5	18.50	49,369	5,879	11.90
689	24	3	12.50	47,094	7,846	16.66
722	32	6	18.75	48,415	9,757	20.15
878	24	9	37.50	33,380	12,622	37.81
979	27	10	37.03	56,517	18,369	32.50
098	9	4	44.44	11,077	6,103	55.09
318	31	12	38.70	85,039	41,481	48.77
530	22	4	18.18	54,482	7,012	12.87
465	27	6	22.22	51,639	13,648	26.42
673	8	2	25.00	43,720	4,882	11.16
422	23	10	43.47	52,634	24,246	46.06
602	14	2	14.28	54,356	6,346	11.67
802	20	5	25.00	54,540	13,364	24.50
319	16	4	25.00	47,197	9,540	20.21
112	37	18	48.64	95,804	55,496	57.92
113	32	17	53.12	98,806	56,766	57.45
727	20	3	15.00	47,125	8,124	17.23

APPENDIX D Table 14.--Continued.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
909	16	3	18.75	52,928	8,640	16.32
910	19	4	21.05	58,384	9,938	17.02
910	19	1	5.26	63,521	2,778	4.37
911	13	3	23.07	54,714	4,742	8.66
348	17	3	17.64	57,189	6,200	10.85
981	16	1	6.25	78,098	1,235	1.58
982	26	2	7.69	79,336	2,415	3.04
570	13	2	15.38	67,956	3,272	4.81
040	18	3	16.66	76,116	3,484	4.57
341	17	1	5.88	54,175	2,280	4.20
846	5	4	80.00	21,722	19,767	90.99
847	5	3	60.00	14,731	12,036	81.70

APPENDIX D Table 15.--Total landings and landings in the Dry Tortugas, vessel size class 8, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
891	23	3	13.04	67,493	9,743	14.43
541	30	12	40.00	53,408	21,912	41.02
240	27	7	25.92	66,586	16,796	25.22
290	16	4	25.00	38,095	8,019	21.05
805	6	1	16.66	44,112	3,100	7.02
449	16	1	6.25	91,377	2,873	3.14
666	17	1	5.88	62,642	3,047	4.86
724	17	4	23.52	81,933	7,131	8.70
642	18	2	11.11	78,760	13,190	16.74
126	14	1	7.14	71,661	2,007	2.80
127	18	1	5.55	88,278	3,793	4.29
704	23	3	13.04	72,308	6,817	9.42
705	15	2	13.33	67,978	3,681	5.41

APPENDIX D Table 16.--Total landings and landings in the Dry Tortugas, vessel size class 9, 1965.

I.D. number	Total trips	Trips in Tortugas	Percent trips in Tortugas	Total pounds	Pounds in Tortugas	Percent pounds in Tortugas
316	38	17	44.73	108,016	31,115	28.80
594	6	1	16.66	37,417	5,839	15.60
477	8	7	87.50	19,338	18,397	95.13

APPENDIX D Table 17.--Two-year average of days fished and catch per day per size class for Dry Tortugas vessels, 1964 and 1965.

Vessel size class	Average number of calendar days fished per trip	Average landings per trip	Average catch per day per size class (pounds)
2	4	2,229	557.25
3	4	1,582	395.50
4	5	1,367	273.40
5	6	1,815	302.50
6	7	2,221	317.29
7	7	2,416	345.14
8	6	2,359	393.17
9	7	2,281	325.86

APPENDIX D Table 18.--Dry Tortugas fishery: average value of shrimp per pound by vessel size class.

Vessel size class	1964	1965
2	$.3123	$.3701
3	.3661	.4281
4	.5141	.5333
5	.4992	.5567
6	.5340	.5772
7	.5023	.5703
8	.6454	.6358
9	.6482	.6333

APPENDIX D Table 19.--Dry Tortugas fishery: average age of sample vessels per vessel size class, 1964-65.

Vessel size class	Average age (years)
2	25.0
3	15.9
4	10.8
5	7.6
6	8.9
7	8.7
8	5.0
9	5.2

APPENDIX D Table 20.--Dry Tortugas fishery: average net tonnage of sample vessels per vessel size class, 1964-65.

Vessel size class	Average net tonnage
2	10.00
3	15.00
4	12.40
5	18.43
6	28.60
7	32.19
8	38.77
9	68.33

APPENDIX D Table 21.--Dry Tortugas fishery: Days at sea per trip, average number of trips, average number of hours fished per year, and average hourly wage per crew member, 1964-1965.

Vessel size class	Days at sea/trip	Average number of trips	Average number wk. hours at sea/year*	Average number wk. hours at sea/trip	Average crew share per trip**	Average individual crew share/trip***	Average hourly wage/crew member	Average yearly income for Tortugas	Percent time fishing Tortugas
2	5	10	600	60	$247.95	$123.98	$2.07	$1,242.00	100.00
3	5	16	960	60	208.78	104.39	1.74	1,670.40	88.47
4	6	17	1,224	72	238.61	119.31	1.66	2,031.84	66.05
5	7	17	1,428	84	318.07	159.04	1.89	2,698.92	71.88
6	8	13	1,248	96	415.33	138.44	1.44	1,797.12	34.86
7	8	8	768	96	437.66	145.89	1.52	1,167.36	29.54
8	7	8	672	84	501.38	167.13	1.99	1,337.28	16.01
9	8	5	480	96	483.98	161.33	1.68	806.40	49.63

*The days at sea assume a 12-hour work day.

**Crew share equals 1/3 of the average value of the shrimp per trip.

***Assumes two crew members on vessel size classes 2, 3, 4, and 5, and three crew members on vessel size classes 6, 7, 8, and 9, and equal distribution of the gross crew income.

APPENDIX D Table 22.--Dry Tortugas fishery: Average percent capacity utilized per average trip by sample vessels, 1965.

Vessel size class	Average net tonnage	Cubic feet of hold capacity*	Pound capacity**	Average catch/trip	Percent capacity utilization
2	10.0	1000	8,500	2229	26.22
3	15.0	1500	12,750	1582	12.40
4	12.4	1240	10,540	1367	12.96
5	18.4	1840	15,640	1815	11.60
6	28.6	2860	24,310	2221	9.13
7	32.2	3220	27,370	2416	8.82
8	38.8	3880	32,980	2359	7.15
9	68.3	6830	58,055	2281	3.92

*Hold capacity = (100 cubic feet) (Net tonnage).

**8.5 pounds of heads off shrimp per cubic foot mixed in a 1:1 ratio with ice.

APPENDIX D Table 23.--Derivation of net ton capacity coefficient for empirical analysis.

Bureau of Commercial Fisheries indicates that:

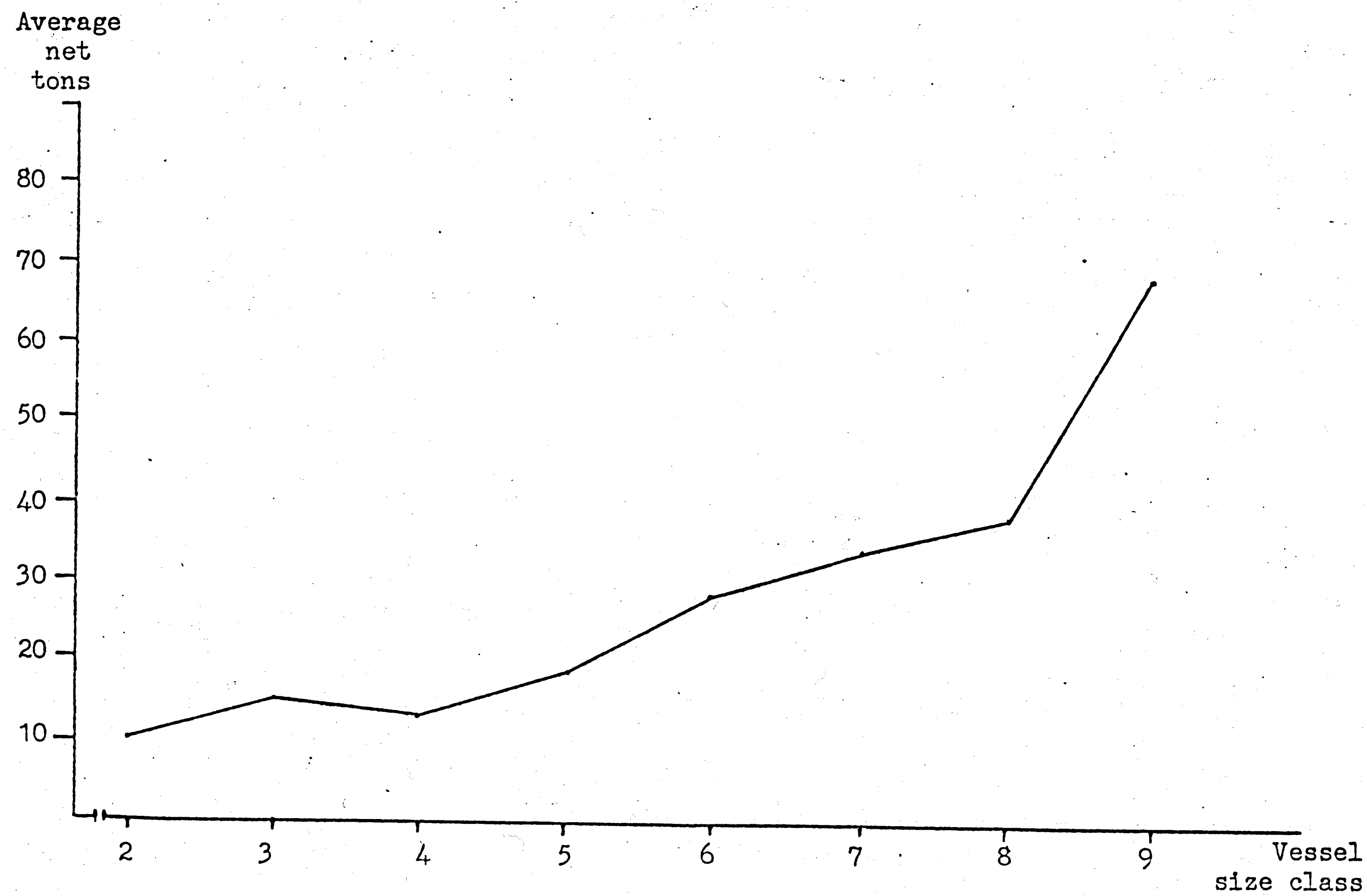
1 pound of shrimp and crushed ice at a 1:1 ratio occupies 101.87 cubic inches.

1728 cubic inches = 1 cubic foot

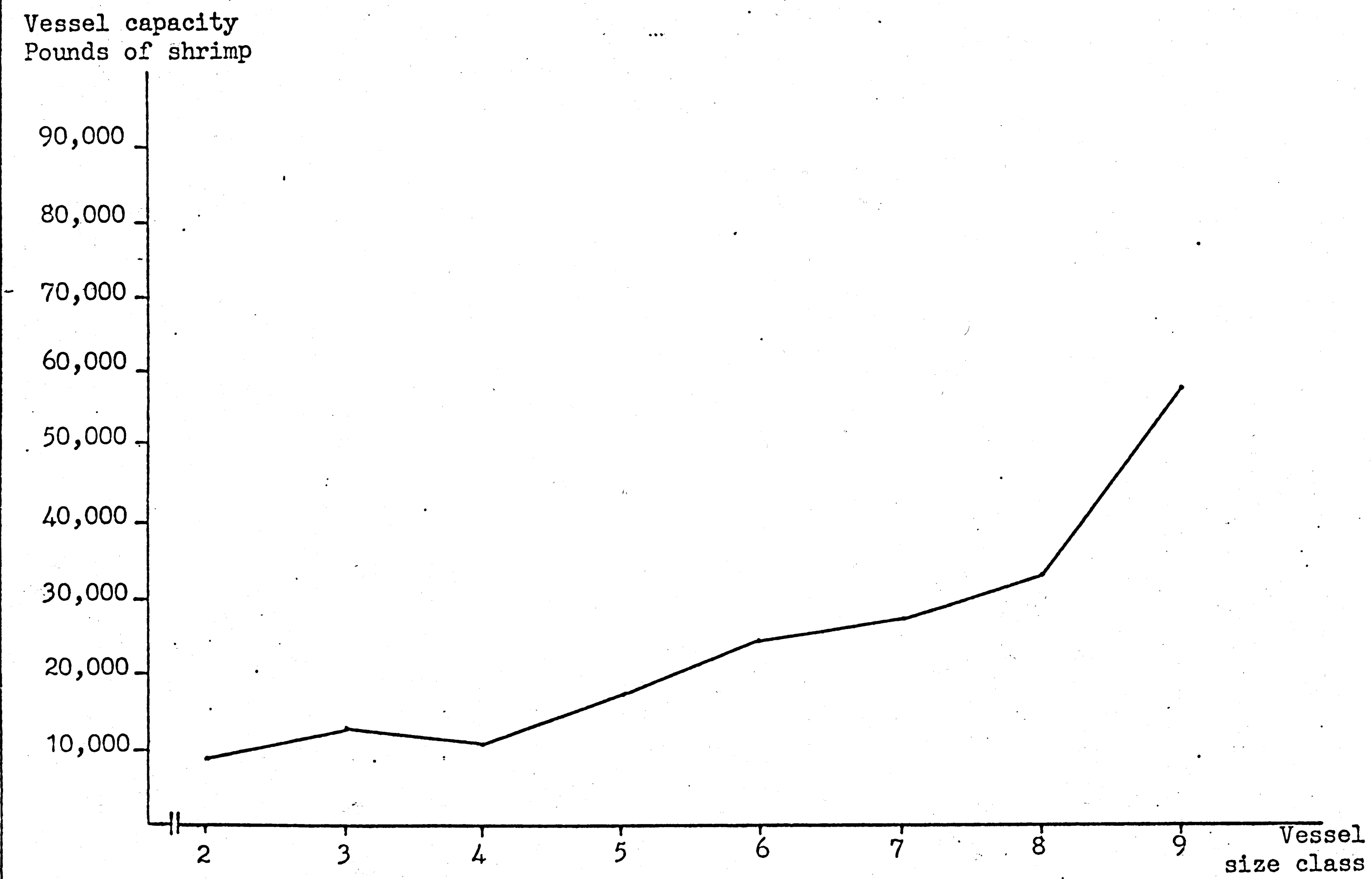
$\frac{1728}{101.87}$ = 16.96 = 17 (half of which is shrimp)

1 cubic foot contains 8.5 pounds of shrimp

1 net ton = 100 cubic feet = 850 pounds of shrimp

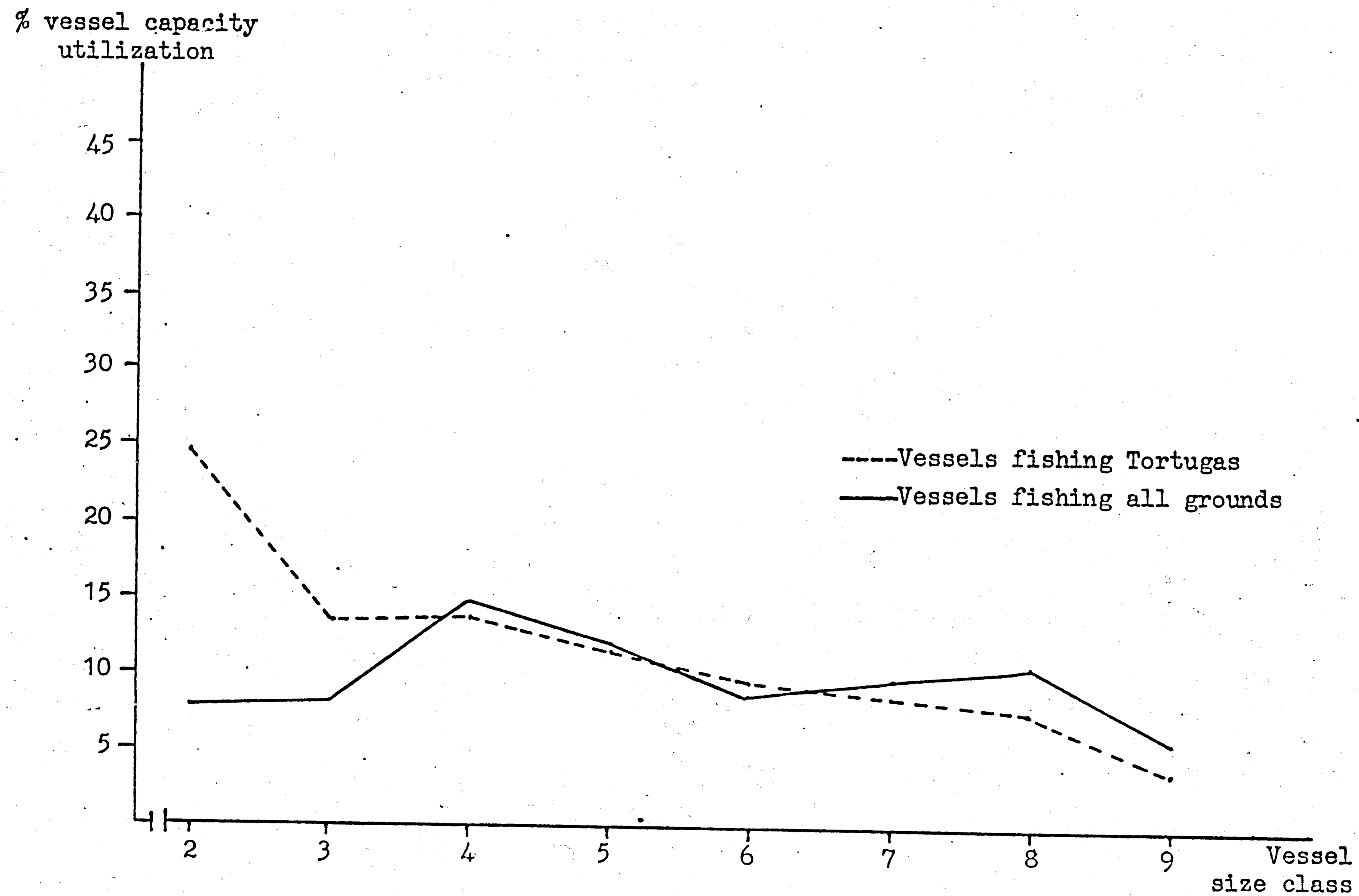


APPENDIX D Figure 1. Average net tons per vessel size class, Tortugas sample vessels, 1965.

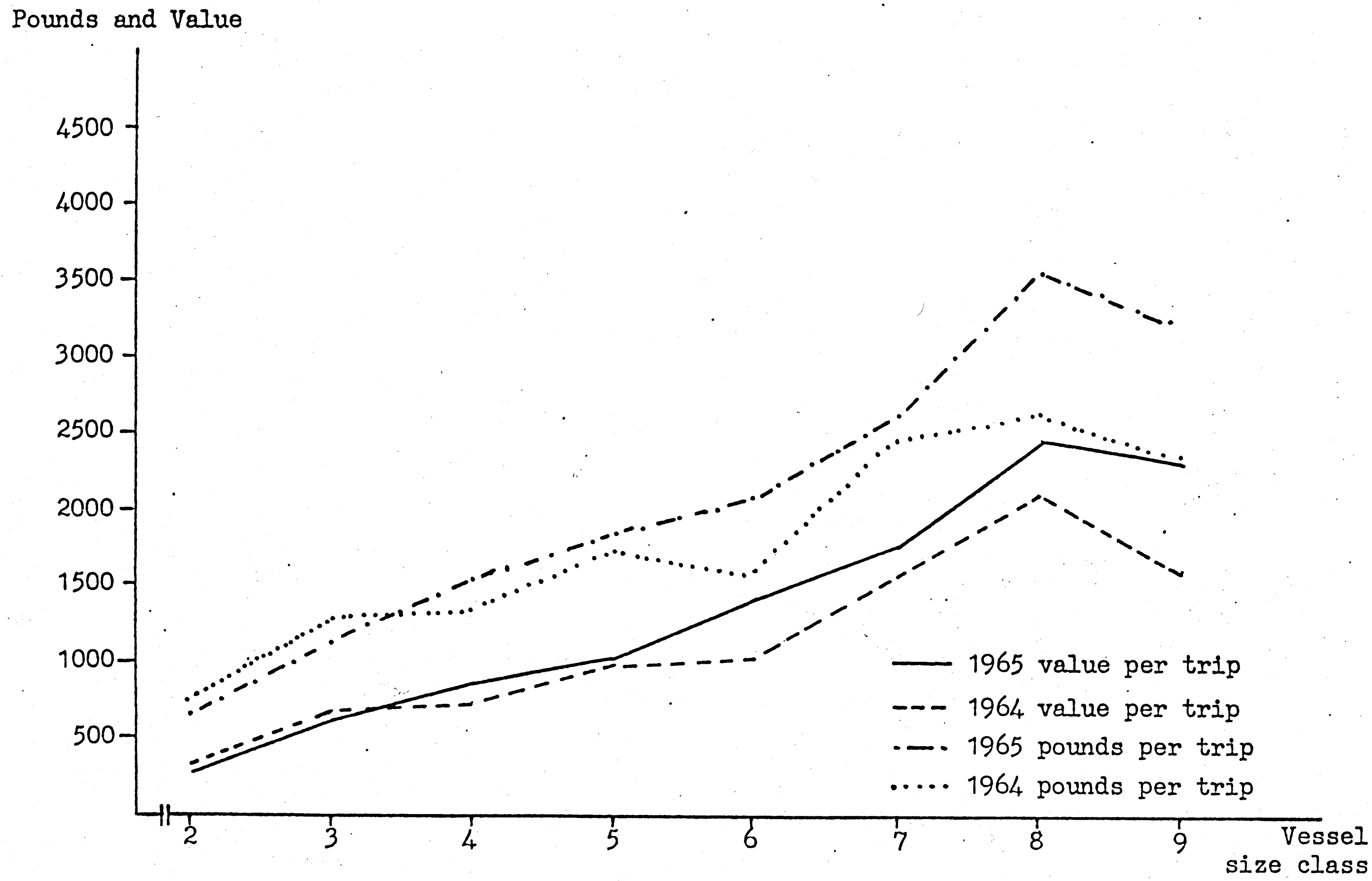


APPENDIX D Figure 2. Vessel capacity for raw headless shrimp by vessel size class,* 1965.

*It is assumed that this is the weight of the shrimp mixed with 1:1 ratio of crushed ice.



APPENDIX D Figure 3. Percent vessel capacity utilized per average trip, 1965 sample vessels.



APPENDIX D Figure 4. Average pounds and value per trip for all vessels in sample.

APPENDIX E

Transport Rate Matrix of the Dry Tortugas Fishing Vessels by Port and Vessel Size Class

APPENDIX E Table 1.--Dry Tortugas sample vessels: average speed (mph), gallons of fuel consumed per hour, and price per gallon of fuel.

Vessel size class	Average speed (mph)	Average gallons of fuel consumed per hour	Average fuel price per gallon
2	7.57	8.20	$.14
3	8.35	8.45	.14
4	9.00	9.22	.14
5	8.73	9.49	.14
6	8.83	9.52	.14
7	9.27	9.79	.14
8	9.83	11.70	.14
9	10.23	13.31	.14

APPENDIX E Table 2.--Port 1: travel hours to and from fishing grounds.

Area	Miles round trip	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	30	4.00	3.60	3.33	3.44	3.40	3.24	3.05	2.93
A1 11-15	36	4.75	4.31	4.00	4.12	4.08	3.88	3.56	3.52
A1 16-20	36	4.75	4.31	4.00	4.12	4.08	3.88	3.56	3.52
A2 6-10	75	10.00	8.98	8.33	8.59	8.49	8.09	7.63	7.33
A2 11-15	94	12.42	11.25	10.44	10.77	10.65	10.14	9.56	9.19
A2 16-20	124	16.38	14.85	13.78	14.20	14.04	13.38	12.61	12.12
A2 21-25	154	20.34	18.44	17.11	17.64	17.44	16.61	15.67	15.05
A2 26-30	170	22.45	20.36	18.88	19.47	19.25	18.34	17.29	16.62
A2 31-35	190	25.09	22.75	21.11	21.76	21.52	20.50	19.33	18.57
A3 11-15	140	18.49	16.76	15.55	16.03	15.86	15.10	14.24	13.69
A3 16-20	160	21.14	19.16	17.77	18.33	18.12	17.26	16.28	15.64
A3 21-25	180	23.77	21.56	20.00	20.62	20.39	19.42	18.31	17.59
A3 26-30	200	26.42	23.95	22.22	22.91	22.65	21.57	20.35	19.55

APPENDIX E Table 3.--Port 2: travel hours to and from fishing grounds.

Area	Miles round trip	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	250	33.03	29.94	27.78	28.64	28.31	26.97	25.43	24.44
A1 11-15	285	37.65	34.13	31.67	32.65	32.27	30.74	28.99	27.86
A1 16-20	285	37.65	34.13	31.67	32.65	32.27	30.74	28.99	27.86
A2 6-10	270	35.67	32.34	30.00	30.93	30.58	29.13	27.47	26.39
A2 11-15	260	34.35	31.14	28.89	29.78	29.45	28.05	26.45	25.42
A2 16-20	270	35.67	32.34	30.00	30.93	30.58	29.13	27.47	26.39
A2 21-25	290	38.31	34.73	32.22	33.22	32.84	31.28	29.50	28.35
A2 26-30	295	38.97	35.33	32.78	33.79	33.41	31.82	30.01	28.84
A2 31-35	300	39.63	35.93	33.33	34.36	33.98	32.36	30.52	29.33
A3 11-15	150	19.82	17.96	16.67	17.18	16.99	16.18	15.26	14.66
A3 16-20	165	21.80	19.76	18.33	18.90	18.69	17.80	16.79	16.13
A3 21-25	180	23.78	21.56	20.00	20.62	20.38	19.42	18.31	17.60
A3 26-30	195	25.76	23.33	21.67	22.34	22.08	21.04	19.84	19.06

APPENDIX E Table 4.--Port 3: travel hours to and from fishing grounds.

Area	Miles round trip	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	430	56.80	51.50	47.78	49.26	48.70	46.39	43.74	42.03
A1 11-15	470	62.09	56.29	52.22	53.84	53.23	50.70	47.81	45.94
A1 16-20	470	62.09	56.29	52.22	53.84	53.23	50.70	47.81	45.94
A2 6-10	430	56.80	51.50	47.78	49.26	48.70	46.39	43.74	42.03
A2 11-15	416	54.95	49.82	46.22	47.65	47.11	44.88	42.32	40.66
A2 16-20	410	54.16	49.10	45.56	46.96	46.43	44.23	41.71	40.08
A2 21-25	410	54.16	49.10	45.56	46.96	46.43	44.23	41.71	40.08
A2 26-30	410	54.16	49.10	45.56	46.96	46.43	44.23	41.71	40.08
A2 31-35	418	55.22	50.06	46.44	47.88	47.34	45.09	42.52	40.86
A3 11-15	315	41.61	37.72	35.00	36.08	35.67	33.98	32.04	30.79
A3 16-20	310	40.95	37.13	34.44	35.51	35.11	33.44	31.54	30.30
A3 21-25	310	40.95	37.13	34.44	35.51	35.11	33.44	31.54	30.30
A3 26-30	310	40.95	37.13	34.44	35.51	35.11	33.44	31.54	30.30

APPENDIX E Table 5.--Port 1: (Hours travel time to and from fishing grounds)
(Gallons fuel consumption per hour).

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	32.80	30.42	30.70	32.65	32.37	31.72	35.69	39.00
A1 11-15	38.95	36.42	36.88	39.10	38.84	37.99	41.65	46.85
A1 16-20	38.95	36.42	36.88	39.10	38.84	37.99	41.65	46.85
A2 6-10	82.00	75.88	76.80	81.52	80.82	79,20	89.27	97.56
A2 11-15	101.84	95.06	96.26	102.21	101.39	99.27	111.85	122.32
A2 16-20	134.32	125.48	127.05	134.76	133.66	130.99	147.54	161.32
A2 21-25	166.79	155.82	157.75	167.40	166.03	162.61	183.34	200.32
A2 26-30	184.09	172.04	174.07	184.77	183.26	179.55	202.29	221.21
A2 31-35	205.74	192.24	194.63	206.50	204.87	200.70	226.16	247.17
A3 11-15	151.62	141.62	143.37	152.12	150.99	147.83	166.61	182.21
A3 16-20	173.35	161.90	163.84	173.95	172.50	168.98	190.48	208.17
A3 21-25	194.91	182.18	184.40	195.68	194.11	190.12	214.23	234.12
A3 26-30	216.64	202.38	204.87	217.42	215.63	211.17	238.10	260.21

APPENDIX E Table 6.--Port 2: (Hours travel time to and from fishing grounds) (Gallons fuel consumption per hour).

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	270.85	252.99	256.13	271.79	269.51	264.04	297.53	325.30
A1 11-15	308.73	288.40	292.00	309.85	307.21	300.94	339.18	370.82
A1 16-20	308.73	288.40	292.00	309.85	307.21	300.94	339.18	370.82
A2 6-10	292.49	273.27	276.60	292.53	291.12	285.18	321.40	351.25
A2 11-15	281.67	263.13	266.37	282.61	280.36	274.61	309.47	338.34
A2 16-20	292.49	273.27	276.60	293.53	291.12	285.18	321.40	351.25
A2 21-25	314.14	293.47	297.07	315.26	312.64	306.23	345.15	377.34
A2 26-30	319.55	298.54	302.23	320.67	318.06	311.52	351.12	383.86
A2 31-35	324.97	303.61	307.30	326.08	323.49	316.80	357.08	390.38
A3 11-15	162.52	151.76	153.70	163.04	161.74	158.40	178.54	195.12
A3 16-20	178.76	166.97	169.00	179.36	177.93	174.26	196.44	214.69
A3 21-25	195.00	182.18	184.40	195.68	194.02	190.12	214.23	234.26
A3 26-30	211.23	197.14	199.80	212.01	210.20	205.98	232.13	253.69

APPENDIX E Table 7.--Port 3: (Hours travel time to and from fishing grounds)
(Gallons fuel consumption per hour)

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	465.76	435.18	440.53	467.48	463.62	454.16	511.76	559.42
A1 11-15	509.14	475.65	481.47	510.94	506.75	496.35	559.38	611.46
A1 16-20	509.14	475.65	481.47	510.94	506.75	496.35	559.38	611.46
A2 6-10	465.76	435.18	440.53	467.48	463.62	454.16	511.76	559.42
A2 11-15	450.59	420.98	426.15	452.20	448.49	439.38	495.14	541.18
A2 16-20	444.11	414.90	420.06	445.65	442.01	433.01	488.01	533.46
A2 21-25	444.11	414.90	420.06	445.65	442.01	433.01	488.01	533.46
A2 26-30	444.11	414.90	420.06	445.65	442.01	433.01	488.01	533.46
A2 31-35	452.80	423.01	428.18	454.38	450.68	441.43	497.48	543.85
A3 11-15	341.20	318.73	322.70	342.40	339.58	332.66	374.87	409.81
A3 16-20	335.79	313.75	317.54	336.99	334.25	327.38	369.02	403.29
A3 21-25	335.79	313.75	317.54	336.99	334.25	327.38	369.02	403.29
A3 26-30	335.79	313.75	317.54	336.99	334.25	327.38	369.02	403.29

APPENDIX E Table 8.--Port 1: (Gallons fuel consumption) (Fuel price).

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	$ 4.59	$ 4.26	$ 4.30	$ 4.57	$ 4.53	$ 4.44	$ 5.00	$ 5.46
A1 11-15	5.45	5.10	5.16	5.47	5.44	5.32	5.83	6.56
A1 16-20	5.45	5.10	5.16	5.47	5.44	5.32	5.83	6.56
A2 6-10	11.48	10.62	10.75	11.41	11.31	11.09	12.50	13.66
A2 11-15	14.26	13.31	13.48	14.31	14.19	13.90	15.66	17.12
A2 16-20	18.80	17.57	17.79	18.87	18.71	18.34	20.66	22.58
A2 21-25	23.35	21.81	22.09	23.44	23.24	22.77	25.67	28.04
A2 26-30	25.76	24.09	24.37	25.87	25.66	25.14	28.32	30.97
A2 31-35	28.80	26.91	27.25	28.91	28.68	28.10	31.66	34.60
A3 11-15	21.23	19.83	20.07	21.30	21.14	20.70	23.33	25.51
A3 16-20	24.27	22.67	22.94	24.35	24.15	23.66	26.67	29.14
A3 21-25	27.29	25.51	25.82	27.40	27.18	26.62	29.99	32.78
A3 26-30	30.33	28.33	28.68	30.44	30.19	29.56	33.33	36.43

APPENDIX E Table 9.--Port 2: (Gallons fuel consumption) (Fuel price).

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	$37.92	$35.42	$35.86	$38.05	$37.73	$36.97	$41.65	$45.54
A1 11-15	43.22	40.38	40.88	43.38	43.01	42.13	47.49	51.94
A1 16-20	43.22	40.38	40.88	43.38	43.01	42.13	47.49	51.94
A2 6-10	40.95	38.26	38.72	40.95	40.76	39.93	45.00	49.18
A2 11-15	39.43	36.84	37.29	39.57	39.25	38.45	43.33	47.37
A2 16-20	40.95	38.26	38.72	41.09	40.76	39.93	45.00	49.18
A2 21-25	43.98	41.09	41.59	44.14	43.77	42.87	48.32	52.83
A2 26-30	44.74	41.80	42.31	44.89	44.53	43.61	49.16	53.74
A2 31-35	45.50	42.51	43.02	45.65	45.29	44.35	49.99	54.65
A3 11-15	22.75	21.25	21.52	22.83	22.64	22.18	25.00	27.32
A3 16-20	25.03	23.38	23.66	25.11	24.91	24.40	27.50	30.06
A3 21-25	27.30	25.51	25.82	27.40	27.16	26.62	29.99	32.80
A3 26-30	29.57	27.60	27.97	29.68	29.43	28.84	32.50	35.52

APPENDIX E Table 10.--Port 3: (Gallons fuel consumption) (Fuel price).

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	$65.21	$60.93	$61.67	$65.45	$64.91	$63.58	$71.65	$78.32
A1 11-15	71.28	66.59	67.41	71.53	70.95	69.49	77.14	85.60
A1 16-20	71.28	66.59	67.41	71.53	70.95	69.49	77.14	85.60
A2 6-10	65.21	60.93	61.67	65.45	64.91	63.58	71.65	78.32
A2 11-15	63.08	58.94	59.66	63.31	62.79	61.51	69.32	75.77
A2 16-20	62.18	58.09	58.81	62.39	61.88	60.62	68.32	74.68
A2 21-25	62.18	58.09	58.81	62.39	61.88	60.62	68.32	74.68
A2 26-30	62.18	58.09	58.81	62.39	61.88	60.62	68.32	74.68
A2 31-35	63.39	59.22	59.95	63.61	63.10	61.80	69.65	76.14
A3 11-15	47.76	44.62	45.18	47.94	47.54	46.57	52.48	57.37
A3 16-20	47.01	43.93	44.46	47.18	46.80	45.83	51.66	56.46
A3 21-25	47.01	43.93	44.46	47.18	46.80	45.83	51.66	56.46
A3 26-30	47.01	43.93	44.46	47.18	46.80	45.83	51.66	56.46

APPENDIX E Table 11.--Port 1: $\frac{\text{Cost of fuel}}{\text{Average catch per trip per size class i}}$

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	$.002	$.003	$.003	$.003	$.002	$.002	$.002	$.002
A1 11-15	.002	.003	.004	.003	.002	.002	.002	.003
A1 16-20	.002	.003	.004	.003	.002	.002	.002	.003
A2 6-10	.005	.007	.008	.006	.005	.005	.005	.006
A2 11-15	.006	.008	.010	.008	.006	.006	.007	.008
A2 16-20	.008	.011	.013	.010	.008	.008	.009	.010
A2 21-25	.010	.014	.016	.013	.010	.009	.011	.012
A2 26-30	.012	.015	.018	.014	.012	.010	.012	.014
A2 31-35	.013	.017	.020	.016	.013	.012	.013	.015
A3 11-15	.010	.013	.015	.012	.010	.009	.010	.011
A3 16-20	.011	.014	.017	.013	.011	.010	.011	.013
A3 21-25	.012	.016	.019	.015	.012	.011	.013	.014
A3 26-30	.014	.018	.021	.017	.014	.012	.014	.016

APPENDIX E Table 12.--Port 2: $\frac{\text{Cost of fuel}}{\text{Average catch per trip per size class i}}$

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	$.017	$.022	$.026	$.021	$.017	$.015	$.018	$.020
A1 11-15	.019	.026	.030	.024	.019	.017	.020	.023
A1 16-20	.019	.026	.030	.024	.019	.017	.020	.023
A2 6-10	.018	.024	.028	.023	.018	.017	.019	.022
A2 11-15	.018	.023	.027	.022	.018	.016	.018	.021
A2 16-20	.018	.024	.028	.023	.018	.017	.019	.022
A2 21-25	.020	.026	.030	.024	.020	.018	.020	.023
A2 26-30	.020	.026	.031	.025	.020	.018	.021	.024
A2 31-35	.020	.027	.031	.025	.020	.018	.021	.024
A3 11-15	.010	.013	.016	.013	.010	.009	.011	.012
A3 16-20	.011	.015	.017	.014	.011	.010	.012	.013
A3 21-25	.012	.016	.019	.015	.012	.011	.013	.014
A3 26-30	.013	.017	.020	.016	.013	.012	.014	.016

APPENDIX E. Table 13.--Port 3: $\frac{\text{Cost of fuel}}{\text{Average catch per trip per size class i}}$

Area	Vessel size class 2	3	4	5	6	7	8	9
A1 6-10	---	---	$.045	$.036	$.029	$.026	$.030	$.034
A1 11-15	---	---	.049	.039	.032	.029	.033	.038
A1 16-20	---	---	.049	.039	.032	.029	.033	.038
A2 6-10	---	---	.045	.036	.029	.026	.030	.034
A2 11-15	---	---	.044	.035	.028	.025	.029	.033
A2 16-20	---	---	.043	.034	.028	.025	.029	.033
A2 21-25	---	---	.043	.034	.028	.025	.029	.033
A2 26-30	---	---	.043	.034	.028	.025	.029	.033
A2 31-35	---	---	.044	.035	.028	.026	.030	.033
A3 11-15	---	---	.033	.026	.021	.019	.022	.025
A3 16-20	---	---	.033	.026	.021	.019	.022	.025
A3 21-25	---	---	.033	.026	.021	.019	.022	.025
A3 26-30	---	---	.033	.026	.021	.019	.022	.025

APPENDIX F

Migration Characteristics of the Shrimp Fishing Vessels in the Dry Tortugas Fishery

APPENDIX F Table 1.--Migratory vessels in Dry Tortugas, 1964.

Vessel size class	Total vessels fishing in Tortugas	Number of migratory vessels	Percent migratory
1	2	1	50.00
2	6	2	33.33
3	23	1	4.35
4	123	13	10.57
5	148	19	12.84
6	59	10	16.95
7	127	44	34.65
8	32	11	34.38
9	10	4	40.00
Total	530	105	19.81

APPENDIX F Table 2.--Average number of days fished per trip on Dry Tortugas by sample vessels, 1964-1965.

Vessel size class	Average number of calendar days fished
2	4
3	4
4	5
5	6
6	7
7	7
8	6
9	7

APPENDIX F Table 3.--Average number of days fished per trip on grounds other than Dry Tortugas by sample vessels, 1964-1965.*

Vessel size class	Average number of calendar days fished
2	0
3	1
4	5
5	5
6	7
7	7
8	8
9	6

*Vessels included in this sample fished a portion of the calendar years 1964 and 1965 on the Tortugas.

APPENDIX F Table 4.--Port distribution of vessels fishing Dry Tortugas, 1964.

Port Code	Vessel size class 1	2	3	4	5	6	7	8	9	Total
1	1	4	21	76	103	33	30	9	3	280
2	0	0	0	1	0	0	0	0	0	1
3	0	0	1	33	26	16	53	12	3	144
4	0	0	0	1	2	2	19	5	3	32
6	1	0	0	2	1	1	3	2	0	10
21	0	1	0	0	0	0	0	0	0	1
45	0	0	0	1	0	0	1	0	0	2
48	0	1	0	0	0	0	0	0	0	1
49	0	0	0	0	0	0	1	0	0	1
52	0	0	0	0	1	0	0	0	0	1
72	0	0	0	1	0	0	0	0	0	1
73	0	0	0	5	10	5	13	1	0	34
78	0	0	0	3	3	1	5	2	1	15
80	0	0	0	0	1	0	0	0	0	1
81	0	0	1	0	0	0	1	0	0	2
82	0	0	0	0	1	1	1	1	0	4
Total	2	6	23	123	148	59	127	32	10	530

APPENDIX F Table 5.--Port distribution of vessels fishing Dry Tortugas, 1965.

Port Code	Vessel size class 1	2	3	4	5	6	7	8	9	Total
1	0	2	13	63	84	29	33	10	5	239
2	0	0	1	1	1	0	1	0	0	4
3	0	0	3	31	26	13	58	13	10	154
4	0	0	0	2	4	2	40	21	8	77
6	0	1	0	0	2	0	0	1	0	4
20	0	0	0	1	0	0	0	0	0	1
30	0	1	0	0	0	0	0	0	0	1
73	0	0	0	3	11	5	11	1	0	31
78	0	0	0	2	3	1	7	4	1	18
81	0	0	2	0	0	0	2	0	0	4
Total	0	4	19	103	131	50	152	50	24	533

APPENDIX G

Variable Production Cost Coefficients by Port,
Vessel Size Class and Region of the Dry Tortugas Fished;
1964, 1965

APPENDIX G Table 1.--Variable production cost coefficients by port, vessel size class, and region of the Dry Tortugas fished, 1964-1965.*

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c121	$.002	$.086	$.088
c131	.003	.361	.364
c141	.003	.461	.419
c151	.003	.283	.286
c161	.002	.386	.388
c171	.002	.352	.354
c181	.002	.410	.412
c191	.002	.541	.543
c122	.017	.086	.103
c132	.022	.361	.383
c142	.026	.416	.442
c152	.021	.283	.304
c162	.017	.386	.403
c172	.015	.352	.367
c182	.018	.410	.428
c192	.020	.541	.561
c143	.045	.416	.461
c153	.036	.283	.319
c163	.029	.386	.415
c173	.026	.352	.378
c183	.030	.410	.440
c193	.034	.541	.575
c221	.002	.086	.088
c231	.003	.361	.364
c241	.004	.416	.420
c251	.003	.283	.286
c261	.002	.386	.388
c271	.002	.352	.354
c281	.002	.410	.412
c291	.003	.541	.544
c222	.019	.086	.205
c232	.026	.361	.387
c242	.030	.416	.446
c252	.024	.283	.307
c262	.019	.386	.405
c272	.017	.352	.369
c282	.020	.410	.430
c292	.023	.541	.564

*Variable cost + transport rate = c^b_{ij}.

APPENDIX G Table 1.--Continued.

Linear Programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c243	$.049	$.416	$.465
c253	.039	.283	.322
c263	.032	.386	.418
c273	.029	.352	.381
c283	.033	.410	.443
c293	.038	.541	.579
c321	.002	.086	.088
c331	.003	.361	.364
c341	.004	.416	.420
c351	.003	.283	.286
c361	.002	.386	.388
c371	.002	.352	.354
c381	.002	.410	.412
c391	.003	.541	.544
c322	.019	.086	.105
c332	.026	.361	.387
c342	.030	.416	.446
c352	.024	.283	.307
c362	.019	.386	.405
c372	.017	.352	.369
c382	.020	.410	.430
c392	.023	.541	.564
c343	.049	.416	.465
c353	.039	.283	.322
c363	.032	.386	.418
c373	.029	.352	.381
c383	.033	.410	.443
c393	.038	.541	.579
c421	.005	.086	.091
c431	.007	.361	.368
c441	.008	.416	.424
c451	.006	.283	.289
c461	.005	.386	.391
c471	.005	.352	.357
c481	.005	.410	.415
c491	.006	.541	.547
c422	.018	.086	.104
c432	.024	.361	.385
c442	.028	.416	.444
c452	.023	.283	.306
c462	.018	.386	.404

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c472	$.017	$.352	$.369
c482	.019	.410	.429
c492	.022	.541	.563
c443	.045	.416	.461
c453	.036	.283	.319
c463	.029	.386	.415
c473	.026	.352	.378
c483	.030	.410	.440
c493	.034	.541	.575
c521	.006	.086	.092
c531	.008	.361	.369
c541	.010	.416	.426
c551	.008	.283	.291
c561	.006	.386	.392
c571	.006	.352	.358
c581	.007	.410	.417
c591	.008	.541	.549
c522	.018	.086	.104
c532	.023	.361	.384
c542	.027	.416	.443
c552	.022	.283	.305
c562	.018	.386	.404
c572	.016	.352	.368
c582	.018	.410	.428
c592	.021	.541	.562
c543	.044	.416	.460
c553	.035	.283	.318
c563	.028	.386	.414
c573	.025	.352	.377
c583	.029	.410	.439
c593	.033	.541	.574
c621	.008	.086	.094
c631	.011	.361	.372
c641	.013	.416	.429
c651	.010	.283	.293
c661	.008	.386	.394
c671	.008	.352	.360
c681	.009	.410	.419
c691	.010	.541	.551
c622	.018	.086	.104
c632	.024	.361	.385

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c642	$.028	$.416	$.444
c652	.023	.283	.306
c662	.018	.386	.404
c672	.017	.352	.369
c682	.019	.410	.429
c692	.022	.541	.563
c643	.043	.416	.459
c653	.034	.283	.317
c663	.028	.386	.414
c673	.025	.352	.377
c683	.029	.410	.439
c693	.033	.541	.574
c721	.010	.086	.096
c731	.014	.361	.375
c741	.016	.416	.432
c751	.013	.283	.296
c761	.010	.386	.396
c771	.009	.352	.361
c781	.011	.410	.421
c791	.012	.541	.553
c722	.020	.086	.106
c732	.026	.361	.387
c742	.030	.416	.446
c752	.024	.283	.307
c762	.020	.386	.406
c772	.018	.352	.370
c782	.020	.410	.430
c792	.023	.541	.564
c743	.043	.416	.459
c753	.034	.283	.317
c763	.028	.386	.414
c773	.025	.352	.377
c783	.029	.410	.439
c793	.032	.541	.573
c821	.012	.086	.098
c831	.015	.361	.376
c841	.018	.416	.434
c851	.014	.283	.297
c861	.012	.386	.398
c871	.010	.352	.362
c881	.012	.410	.422
c891	.014	.541	.555

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c822	$.020	$.086	$.106
c832	.026	.361	.387
c842	.031	.416	.447
c852	.025	.283	.308
c862	.020	.386	.406
c872	.018	.352	.370
c882	.021	.410	.431
c892	.024	.541	.565
c843	.043	.416	.459
c853	.034	.283	.317
c863	.028	.386	.414
c873	.025	.352	.377
c883	.029	.410	.439
c893	.033	.541	.574
c921	.013	.086	.099
c931	.017	.361	.378
c941	.020	.416	.436
c951	.016	.283	.299
c961	.013	.386	.399
c971	.012	.352	.364
c981	.013	.410	.423
c991	.015	.541	.556
c922	.020	.086	.106
c932	.027	.361	.388
c942	.031	.416	.447
c952	.025	.283	.308
c962	.020	.386	.406
c972	.018	.352	.370
c982	.021	.410	.431
c992	.024	.541	.565
c943	.044	.416	.460
c953	.035	.283	.318
c963	.028	.386	.414
c973	.026	.352	.378
c983	.030	.410	.440
c993	.033	.541	.574
c1021	.010	.086	.096
c1031	.013	.361	.374
c1041	.015	.416	.431
c1051	.012	.283	.295
c1061	.010	.386	.396

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c1071	$.009	$.352	$.361
c1081	.010	.410	.420
c1091	.011	.541	.552
c1022	.010	.086	.096
c1032	.013	.361	.374
c1042	.016	.416	.432
c1052	.013	.283	.296
c1062	.010	.386	.396
c1072	.009	.352	.361
c1082	.011	.410	.421
c1092	.012	.541	.553
c1043	.033	.416	.449
c1053	.026	.283	.309
c1063	.021	.386	.407
c1073	.019	.352	.371
c1083	.022	.410	.432
c1093	.025	.541	.566
c1121	.011	.086	.097
c1131	.014	.361	.375
c1141	.017	.416	.433
c1151	.013	.283	.296
c1161	.011	.386	.397
c1171	.010	.352	.362
c1181	.011	.410	.421
c1191	.013	.541	.554
c1122	.011	.086	.097
c1132	.015	.361	.376
c1142	.017	.416	.433
c1152	.014	.283	.297
c1162	.011	.386	.399
c1172	.010	.352	.362
c1182	.012	.410	.422
c1192	.013	.541	.554
c1143	.033	.416	.449
c1153	.026	.283	.309
c1163	.021	.386	.407
c1173	.019	.352	.371
c1183	.022	.410	.432
c1193	.025	.541	.566

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c1221	$.012	$.086	$.098
c1231	.016	.361	.377
c1241	.019	.416	.435
c1251	.015	.283	.298
c1261	.012	.386	.398
c1271	.011	.352	.363
c1281	.013	.410	.423
c1291	.014	.541	.555
c1222	.012	.086	.098
c1232	.016	.361	.377
c1242	.019	.416	.435
c1252	.015	.283	.298
c1262	.012	.386	.398
c1272	.011	.352	.363
c1282	.013	.410	.423
c1292	.014	.541	.555
c1243	.033	.416	.449
c1253	.026	.283	.309
c1263	.021	.386	.407
c1273	.019	.352	.371
c1283	.022	.410	.432
c1293	.025	.541	.566
c1321	.014	.086	.100
c1331	.018	.361	.379
c1341	.021	.416	.437
c1351	.017	.283	.300
c1361	.014	.386	.400
c1371	.012	.352	.364
c1381	.014	.410	.424
c1391	.016	.541	.557
c1322	.013	.086	.099
c1332	.017	.361	.378
c1342	.020	.416	.436
c1352	.016	.283	.299
c1362	.013	.386	.399
c1372	.012	.352	.364
c1382	.014	.410	.424
c1392	.016	.541	.557
c1343	.033	.416	.449
c1353	.026	.283	.309
c1363	.021	.386	.407
c1373	.019	.352	.371

APPENDIX G Table 1.--Continued.

Linear programming activity	Transport rate per pound	Variable cost per pound	Total variable production cost per pound
c1383	$.022	$.410	$.432
c1393	.025	.541	.566

APPENDIX H

Model II Coefficients

APPENDIX H Table 1.--Model II adjusted days at sea per trip.

Vessel size class	Average fuel capacity (00's gallons)	Gallons fuel consumption per hour	Unadjusted days at sea per trip	Adjusted days at sea per trip*
2	12.5	8.20	10.2	8
3	20.8	8.45	16.4	14
4	22.7	9.22	16.4	14
5	28.4	9.49	19.95	18
6	36.3	9.52	25.4	23
7	52.0	9.79	35.4	33
8	76.1	11.70	43.4	41
9	90.7	13.31	45.4	43

*A two-day allowance was made for travel time.

APPENDIX H Table 2.--Model II number of trips per year.

Vessel size class	Trips 2-year average	Average number of days fished	Total number of days fished per year	Model II number of trips per year*
2	10	4	40	5
3	16	4	64	5
4	17	5	85	6
5	17	6	102	6
6	13	7	91	4
7	18	7	126	4
8	8	6	48	1
9	5	7	35	1

*Model II number of trips per year =

$$\frac{\text{Total number of days fished per year}}{\text{Adjusted days at sea per trip}}$$

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(continued from inside front cover)

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In the process of working towards these goals an array of written materials has been generated representing items ranging from interim discussion papers to contract reports. These items are available to interested professionals in limited quantities of offset reproduction. These "Working Papers" are not to be construed as official BCF publications and the analytical techniques used and conclusions reached in no way represent a final policy determination endorsed by the U. S. Bureau of Commercial Fisheries.