AN ECONOMIC ANALYSIS OF POLICY ALTERNATIVES FOR MANAGING THE GEORGES BANK HADDOCK FISHERY

by

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FOR

MANAGING THE GEORGES BANK HADDOCK FISHERY

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CHAPTER I

INTRODUCTION

AN ECONOMIC ANALYSIS OF POLICY ALTERNATIVES
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The basis for a public interest in commercial fishery resources is the same as for any other natural resource, namely, in the ability of the resource to absorb labor and capital, and yield a flow of goods that have greater value than any other combination of goods that could be produced with that labor and capital. Even though the United States is blessed with a high level of per capita food supplies from land resources, the consuming public and various industrial uses still call forth a substantial and ever-increasing quantity of fish and fishery products. In 1966, the United States utilized about 12.4 billion pounds of fish, representing a retail value of approximately $2.7 billion. This is an increase of 63 percent in volume and 145 percent in value over the utilization in 1956 of 7.6 billion pounds of fish with a retail value of approximately $1.1 billion.

During this period of rapid increase in utilization of fishery products, domestic catch declined somewhat and imports rose sharply. In 1966, imports of fish and fishery products totaled 8.1 billion pounds, round weight basis, and represented 65 percent of the total utilization of fish in the United States. The value of imports amounted to $720.4 million in contrast with exports of $84.8 million.

The decline in domestic catch is due to a wide range of factors which vary from fishery to fishery. Regardless of the factors explaining the decline in United States catch, it is significant to note that in spite of an increasing demand for fish and fishery products, earnings to capital and labor in fishing have not been adequate to result in an expanding industry.

Although fishery resources in many of the traditional fisheries of the United States are now fully exploited, or even overexploited, preliminary investigations indicate that there are large stocks of latent fishery resources in the ocean. To develop an industry on these latent resources will necessitate considerable investment in research on a number of problems such as locating commercial concentrations, new methods of harvesting, new product forms, and so forth. Aside from the problem of developing new fisheries, there is also the question of maintaining employment in the traditional fisheries. Will the fishery resources now being exploited by the domestic fleet be able to support the present level of employment 10 years from now? One of the major problems to be solved in regard to both our present fisheries as well as potential fisheries is the question of fishery management.

Fishery management is one of the most complex and serious problems facing the commercial fishing industry today. This is true not only for the United States fishing industry but for the world fishing industry in general. The world catch of fish and shellfish has doubled approximately every 10 years since 1940. This increase in catch has been confined largely to a limited number of species of fish. Thus, the fishing pressure on certain stocks has been increasing rapidly and likely will continue to increase in the future--not only due to expanding effort on the part of several of the major fishing nations, but also due to the entry of nations into the fisheries. The consequence of this rapid expansion of fishing effort has been declining catch rates and decreased earnings to capital and labor employed in the fishery.

The problem of fishery management derives from the fact that most fishery resources are common property resources. The fish stocks are open to exploitation by any and all who care to expend effort to harvest the resource. An industry based on a common property resource lacks a mechanism to delegate responsibility for management of the resource. More specifically, such management responsiblity must answer the important question of how much labor and capital should be employed in combination with the natural resource, i.e., how far beyond the point of diminishing returns should exploitation of the resource be carried. As long as the degree of exploitation of the resource falls significantly short of its productive capability, the lack of a management mechanism is not noticed.

However, as the industry expands, consequences of the lack of management not only become evident but critical. In fact, the lack of management over the use of the resource likely will result in over-expansion of the industry in economic terms and perhaps in physical terms as well.

In the case of fishery resources involving international waters where they are common property to the world, an additional management problem arises. If some concept of economic welfare is desirable in the use of the resource, a necessary condition would be to assure that the products of the resource go into the highest value use. If world markets were completely free, the market would accomplish this. However, there are a number of market imperfections and restraints that could result in fishery products going into low value uses. One of the most important market restrictions is that most countries do not allow foreign fishing vessels to land fish directly at domestic ports. Furthermore, most countries have varying degrees of tariff protection against the importation of fish and fish products. The legal restriction on landing may in effect mean that certain markets may be closed to many fishing nations and thus result in the fish being diverted into lower valued uses. Thus, in the case of international fisheries, the resource management program also would have to address itself to the problem of directing the products of the fishery into the highest valued uses.

The common property status of fishery resources also has an important bearing on risk and uncertainty of the individual firm and thus on the ability of the firm to make sound long-range business decisions. In the case of industries based on resources held and managed under delegated property rights, the production function of the firm, i.e., the technical coefficients relating inputs of labor and capital to output, are not affected by action of other firms in the industry. But, where an industry is comprised of a number of firms utilizing a common property resource, the production function of the individual firm is not only dependent upon decisions of the respective firm but decisions of all other firms in the industry as well as on the possibility of new firms entering the industry. Thus, in the commercial fishing industry, the firm must make decisions within an area of uncertainty that defies sound business management and can better be called economic roulette.

Fishery management is a concept that does not yet have a universally accepted definition. Crutchfield and Zellner defined fishery management as "...control exercised by public authority over fishing activities."[1] On the other hand, Rounsefell and Everhardt have adopted the definition,

> "Fishery management is the application of scientific knowledge concerning fish populations to the problems of obtaining the maximum production of fishery products, whether stated in terms of factory material or in hours of angling pleasure."[2]

For the purpose of this study, a more limited and specific definition is proposed:

> Fishery management is an institutional arrangement delegated the responsibility of solving the problems

of (1) to what end use will common property fishery resources be put, and (2) how much capital and labor, in total, will be combined with the common property resource.

Thus, the responsibility of fishery management does not involve the question of the optimum proportion of capital to labor in a specific fishing firm, but only the extent to which that input of capital and labor will be carried beyond the point of diminishing returns. We would expect the fishery management decisions to be made in such a way as to promote economic efficiency in both the short- and long-run.

The concept of fishery management is not new. The earliest involvement of the United States in management of a marine resource was the Fur Seal Treaty of 1911. Today, the United States is a member of nine international conventions which have resource management as their objective. Four of these conventions administer catch quotas and a fifth has administered mesh regulations for 15 years.

Fishery management, until relatively recently, has been of concern mainly to the fishery biologist. This apparently resulted from the fact that economists in general overlooked the question, and administrators and individuals involved with fishery commissions did not call on the assistance of professional economists. Consequently, management policy and programs tended to reflect biological goals and attitudes even though the problem is essentially one of political-economics.

Generally, the biological approach to fishery management was one of conservation in a physical yield context. The definition of fishery management by Rounsefell and Everhardt is somewhat typical of the view of many biologists where emphasis is on achieving the maximum physical yield from a resource. Another example of earlier attitude toward fishery management is the following statement excerpt from a paper presented by William C. Herrington to the Atlantic States Marine Fisheries Commission in 1942:

> "To simplify and limit discussion, it will be assumed that the primary purpose of the desired measures is to establish or permit a fishery which will produce the optimum yield from a given stock of fish, for our primary objective is conservation. Improved economic and social conditions would be very important, but secondary, objectives."[3]

And again a statement by Clarence P. Idyll:

> "...The last situation, and the one of interest here, is the circumstances where populations are being exploited by sport and commercial operations, or both. Here it is conceived that conservation involves the establishment of a level of fishing effort which exploits the population to a maximum extent possible without harm to the species in the future. This means striving to encourage the fishery to take all usable fish which are not needed for reproduction. It is conceived, under this idea, that under-exploitation is as bad as over-exploitation, since both involve waste, in terms of food and recreation. (This is only true, of course, where the fish are needed, and where there are men willing and able to catch them.)"[4]

At the same time some biologists recognized that fishery management involved important economic problems. The following quotes reflect this fact:

> "The magnitude of the fishing rate is a function of the number of operating units and the efficiency with which they are operated. Each operating unit is capable of taking a definite percentage of the population when operated normally and on a full-time basis. If the rate

be excessive, it can be reduced only by eliminating some of the units or by requiring each unit to operate at less than capacity, i.e., to operate inefficiently.

"The biological effects of both methods for reducing the fishing rate are the same. But the social and economic consequences are vastly different."[5]

And an excerpt from the works of Martin D. Burkenroad:

"Marine fishery biology is an applied science concerned with improvement of exploitation of the living resources of the sea. The discovery of exploitable stocks and the improvement of techniques of utilization through application of biological knowledge are within its sphere, but its present major function is to discover the cause of change in availability and quality of stocks in use, to predict the future course of such changes, and to describe the biological requirements for control or modification of these changes.

"Marine fishery biology thus at present serves chiefly as one of the basis for fishery management. The latter is, as Sette observes (1943, p. 4), essentially a branch of political economy. Considerable confusion among fishery biologists has been caused by failure of some to realize clearly that the advantage sought by their science is that of man, not fish; while equal confusion seems to have been caused among political economists by failure to realize that social advantages of management depend at bottom upon biological reactions and environmental changes which are as yet not fully predictable."[6]

"The management of fisheries is intended for the benefit of man, not fish, therefore, effect of management upon fish stocks cannot be regarded as beneficial per se. Nevertheless, economic benefits of management depend on biological response to differences in mode of exploitation, the theory of which is fundamental to an understanding of fishery economics."[7]

An even broader understanding of the economic aspects of fishery management is reflected in a more recent statement by Schaefer:

"The question is, rather, from among the wide range of fishing intensities between zero and the maximum that is economically possible, to choose that which is most desirable, both in the sense of being most beneficial to mankind at present and of avoiding any diminution of the benefits which will be obtainable, on a sustained basis, in the future. A conservation programme consists, therefore, in controlling man's predation in such a fashion as to continue to maintain man's benefits from the resources at the highest sustainable level.

"It is, in general, considered desirable to maximize total production in a form useful to man, or, in other terms, to maximize the total catch of commercial sizes of fish. This general objective must, however, be subject to modification in some degree in particular fisheries. One of the results of increased fishing intensity is the decreased average age and size of the individuals of the fish population, so that an increased total catch is accompanied by a greater share of smaller fish. Since different sizes of fish are, in some fisheries, not equally desirable in the market, a compromise must be reached between maximum total poundage and the most desirable size composition of the catch. In some fisheries, of course, it is possible to control the size of fish capture, independently of the intensity of fishing; but in others this is not practicable, and in these cases changes in the quality of the catch go hand in hand with changes in the level of the average total catch.

"Other economic considerations must also sometimes be taken into account. Where as in the case of a number of clupeids, fish may be used by man in different forms (for example, as human food, or as fish meal for animal feed,) the relative desirability of such uses needs to be considered. Further, it is not always desirable to maximize the sustainable total yield regardless of the effort expended in making the harvest. In some cases, economy of fishing effort may be of at least temporary importance, even though the total yield is thereby somewhat diminished. Indeed, it has been asserted by Gordon (1953), and implied by Burkenroad (1951), Beverton (1953) and others, that it may be more desirable to maximize the net economic yield, rather than the sustainable total production."[8]

Thus, it is evident that the process of administering control over the utilization of a common property fishery resource involves infinitely more complex choices than merely preventing the taking of more than the maximum annual yield of the resource. The first and most important step in managing fishery resources is to develop a policy for management, i.e., the goal to be achieved by the management program. Two alternative management policies are reflected in the quotations given above. There is the biological goal of maximum sustainable annual harvest as called for by Herrington, Rounsefell and Everhardt, and Idyll. An alternative is the goal of maximum net economic yield cited by Schaefer. However, these two alternatives do not exhaust the range of possibilities for consideration.

The purpose of this study is to investigate the possibility of additional policy alternatives for fishery management and to evaluate all of the alternatives. Policy alternatives will be developed on the basis of an a priori bio-economic model for a closed demersal fishery and then evaluated with the cost and yield data for the Georges Bank haddock fishery. The use of a case study will permit an analysis of the outcome of policy alternatives in terms of fish provided to society, employment of labor and capital, and the returns to labor and capital in the fishery.

1. James Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," U.S. Fish and Wildlife Service, Fishery Industrial Review, Vol. 1, No. 1, April 1962, p. 10

2. George A. Rounsefell and W. Harry Everhardt, Fishery Science, Its Methods and Applications, John Wiley & Sons, Inc., New York, 1953, p. ix.

3. William C. Herrington, "Some Methods of Fishery Management and Their Usefulness in a Management Program," U.S. Fish and Wildlife Service, Special Scientific Report No. 18, 1943, p. 6.

4. Clarence P. Idyll, "A Concept of Conservation in Marine Fisheries and Its Implications in Fishery Management," Contribution No. 82, Marine Laboratory, University of Miami, 1952, p. 368.

5. Robert A. Nesbitt, "Biological and Economic Problems of Fishery Management," U.S. Fish and Wildlife Service, Special Scientific Report No. 18, 1943, p. 23.

6. Martin D. Burkenroad, "Some Principles of Marine Fishery Biology," Institute of Marine Sciences, University of Texas, Vol. 2, No. 1, 1951, p. 181.

7. Martin D. Burkenroad, "Theory and Practice of Marine Fishery Management," Institute of Marine Sciences, University of Texas, Vol. 2, No. 1, 1951, p. 300.

8. Milner B. Schaefer, "The Scientific Basis for a Conservation Programme," from papers presented at the International Technical Conference on the Conservation of Living Resources of the Sea, Rome, Italy, 18 April-10 May 1965, pp. 16-17.

CHAPTER II

REVIEW OF LITERATURE

Although passing reference to fisheries can be found in Marshall,[1] and references to economic aspects of fisheries can be found in various sources, the formulation of economic models specifically directed to fisheries was not recorded in literature until the early 1950's. Since that time, a limited number of articles and one book has been published on economic aspects of fisheries. Inasmuch as the field of literature is limited, a brief chronological history of the subject can be developed within the scope of this study. It is not intended that this review of literature exhaust all references to economic aspects of fisheries, but rather to summarize the main points developed by the pioneering authors who have set forth a model for fishery exploitation.

G. M. Gerhardsen

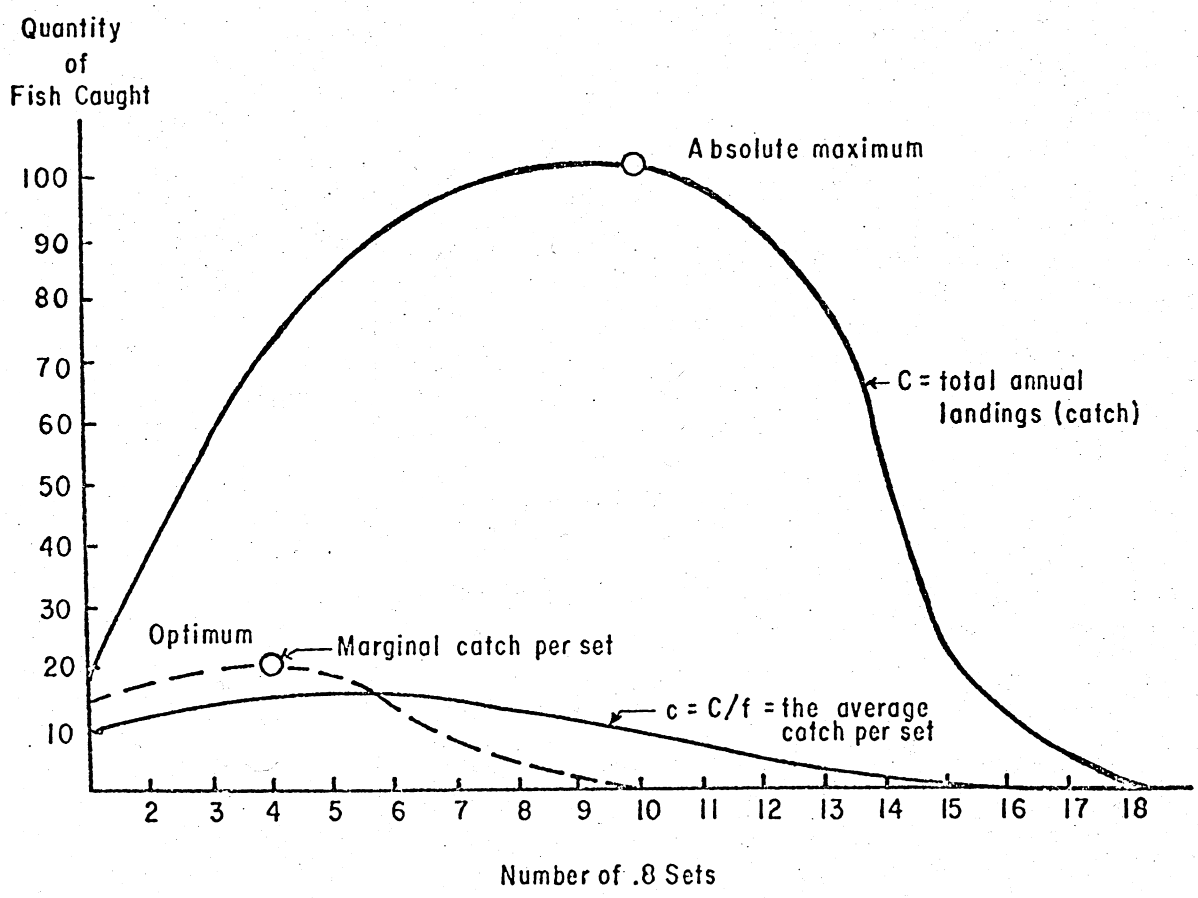
The earliest work located which represented an effort to apply economic theory to fisheries was that of Gerhardsen. Gerhardsen cites the law of diminishing returns as a point of departure and then establishes the maximum annual output of the fishery as resulting from the law of diminishing returns.

> "In fisheries work one sometimes finds reference to the law of diminishing returns. What does it mean? On a fishing boat employing too few fishermen, experience may show that for each unit (fisherman) added the return per unit increases.

At the point where the additional man added the same quantity to the production as was added by the man before him, we say that the efficiency is at the optimum point. When added effort results in less yield on the margin, the marginal efficiency is on the decline...

"If we continue theoretically the adding of one kind of effort (factor of production) without increasing the other, we should find that the marginal efficiency will continue to decline until it reaches zero. We will then be at the maximum point of production, the point beyond which there can be no possible increase in the total quantity produced. Each additional effort after that point is reached, will cause so much undue interference that the total production will remain constant or, more likely, decrease."[2]

Gerhardsen illustrates his point with the following graph:



He proceeds to draw the conclusion:

> "...It will be seen in the chart that, by the time the total catch reaches its maximum, the average catch per unit of effort, that is, per set, is considerably below the highest average obtained during this development; production has reached its absolute maximum, the average technical efficiency of the individual units of effort has suffered. Considering the vast areas where fish are caught it is quite unusual that the maximum catch in this sense is ever reached. When we talk about 'maximum yield' we usually do not refer to this consideration at one point of time, but in connection with comparison of yields from year to year. This must be taken into account in the graphical description."[3]

Gerhardsen then utilizes a second figure in which a second abscissa representing time is added. The second figure shows two sets of catch and effort curves in which the second set differs from the first only by the magnitude of the constant in the equations. Thus all catch values on the second set of curves are lower than on the first set for the corresponding number of sets (fishing effort). The significance of the downward shift is explained as follows:

> "Our curves in figure 1 refer to one point of time, or if we stretch it, to such a short period of time that nature does not add anything to the stock. Let us turn then to a comparison of two points of time. In figure 2 we have assumed that fishing as illustrated in figure 1 has been so extensive that it changes in character from the first to the second point of time. The curves in the second point of time are therefore lower--both marginal, average and total yield are lower. There is, then, a possibility that this represents exactly the situation which the biologists want to prevent, but it is also possible that the change is caused by change in weather, run of fish or difference in fishing techniques. One should therefore proceed to observe the various factors which might be involved."[4]

Gerhardsen's treatment of the production function and the principle of diminishing returns is somewhat misleading. The production function is a long run static concept in which the basic parameters are held constant in order to illustrate the technical relationship of output (catch of fish) as a function of input of labor and capital (number of sets or fishing effort) to a fixed natural resource (a specific fishery). Generally, the parameters themselves are stochastic variables but independent of the input of capital and labor. Therefore, the points on the production function are "expected" or mean-values of the random variation resulting from year-to-year variation of the parameters. Consequently, an observation at one point in time can fall either above or below the mean-value represented by the production function. If the entire production function changes, i.e., a permanent change in each mean-value associated with the respective input (fishing effort), a change in one or more of the parameters is indicated.

Biological "overfishing" does not imply a change in a parameter but merely the carrying of fishing effort beyond the point which will yield the maximum sustainable annual catch. Therefore, biological overfishing would be represented by all points on the branch of the total catch curve to the right of the point of "absolute maximum catch" on Gerhardsen's figure 1.

After his discussion of diminishing returns, Gerhardsen proceeds to develop an iso-product function relating alternative combinations of labor and capital to a given catch of fish and presents graphically a contour map of a series of iso-product functions for differing levels of catch. He explains management of the inputs and long run equilibrium as follows:

> "A manager of an individual fishing enterprise who expands production will follow this guiding principle: That the relation between the marginal efficiency of the producing agents (in the above case: labour and capital) should be

the same as the relations between (prices) for the two. This can also be expressed in the following way: The quantity of each agent of production used depends on (a) its efficiency and (b) its price.

"In the long run, adjustment takes place so that the total of all recompenses equals the amount which is obtained through the sale of the product. We may express this statement by a formula:

p = price for fish
q = recompense (price) to each gear unit
fq = total recompense (cost)
pC = total money value obtained for fish

"In the simplest equation the relationship is thus:

$$fq = pC$$

"When we use two agents (f_1 and f_2 with recompense per unit being q_1 and q_2 it becomes:

$$f_1q_1 + f_2q_2 = pC$$

"A change in the price of the product may lead to a change in the recompense in one or more producing agents. It may also lead to a change in the qualitative relationship between the agents.

"Finally, a change in the recompense to the agents of production may result in a change in their quantitative relationship or in a change in the prices of the end product. Crisscrossing with these considerations are the results of changes and innovations of technique, and so on, all of which influence the efficiency urge readjustments which in turn lead to different recompense, or different prices for end products or perhaps both."[5]

Gerhardsen did not speculate on the relationship between fishing effort and catch that would obtain at long run equilibrium, nor did he conclude as to what policy should be, in terms of the extent of fishing effort exerted on a fishery.

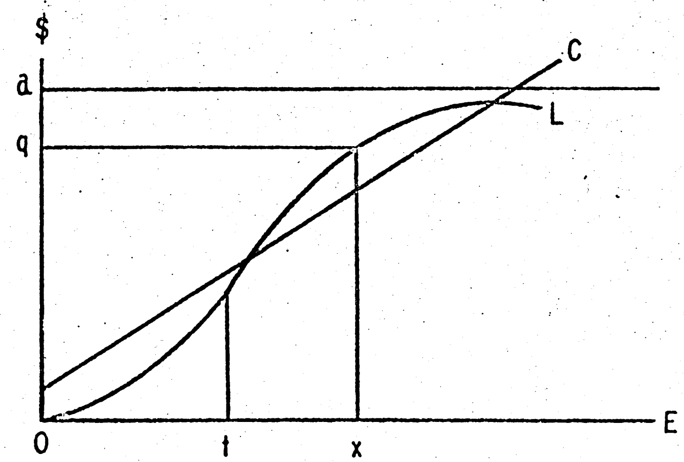
H. Scott Gordon

The next contribution in time was made by Professor Scott Gordon. Gordon sets the stage for his analysis by stating:

"We can then define the economic objective of a commercial fishery as the achievement of the maximum net economic yield.

The level of fishing effort which achieves this maximum will be described as the 'optimum degree of fishing.'"[6]

He then proceeds to illustrate the conditions for maximizing the net economic yield. Two principal factors are cited--the catch of fish and the cost of fishing. Both of these are functions of fishing effort. Therefore, the problem is to determine the amount of effort that will maximize the difference between landings (measured in money terms) and costs.



The landings function, OL, becomes asymptotic to some value which would be the maximum sustainable yield of the fishery. During early stages of fishing, increasing physical returns might occur, but eventually the point Ot is reached, whereafter, landings increase at a decreasing rate as fishing effort increases--the principle of diminishing returns at work in fisheries. Gordon uses an example of two fishing areas, one adjacent and one more remote, to demonstrate the existence of diminishing returns in fisheries. For, as he points out, if diminishing returns did not apply in fisheries, there would never be any need to apply inputs to the more distant fishery. All the fish needed could be taken from the near fishery if the production function were linear.

Having dispensed with the landings function, he describes the cost relationship. Fixed costs (OF in figure 1) represent the public expenditure for wharves, harbors, and so forth. These are necessary for fishing, but are independent of fishing effort. All other costs, which will change as fishing effort increases, such as boats, fuel, nets, labor, etc., are treated as variable costs. He assumes that the variable costs will be a linear function of fishing effort as depicted by line FC in figure 1.

With the landings and cost functions both related to fishing effort, Gordon states the conditions for maximizing net economic yield:

> "The net economic yield of the fishery which is represented by the landings and cost functions of figure 1 is the vertical distance between L and C. This distance is at a maximum where the slope of the landings function is equal to the slope of the cost function, or where
>
> $$\frac{dL}{dE} = \frac{dC}{dE}$$
>
> "In the language of economic theory, the optimum level of production is where 'marginal production equals marginal cost.' With the functions as drawn in figure 1, the optimum level of fishing effort is OX and the catch obtained at the optimum is OQ. As one would expect, the economic optimum is at a level of fishing intensity somewhat less than that which would produce the maximum physical landing, even the latter is a quantity that could be indefinitely sustained."7

Gordon did not specifically describe whether he was dealing with the production function (landings function) in terms of value of catch or volume of catch.

The vertical axis is labeled as representing monetary units. However, in the quote above, and earlier in his article, his discussion of the landings function implies physical catch of fish. If he did intend the landings function to be pounds of fish, then the conditions stated above would not represent the maximum net economic yield. It is meaningless to equate the derivative of physical yield to the derivative of monetary costs. On the other hand, if he intended that landings be expressed in terms of value of catch, he would have to amplify his treatment of the landings function to justify the shape of OL as a revenue function of fishing effort. Gordon is treating the industry as a single firm (i.e., a single decision-making unit). Therefore, this monopolist would be cognizant of its impact on price. In this case, price would not be a constant to the firm, but would tend to decrease as landings increased with fishing effort. The result on revenue would depend on the elasticity of consumer demand. Revenue would be a positively inclined function of landings if, and only if, the consumer demand were relatively elastic. If demand approximated unit elasticity, the revenue curve would be a constant, and if demand were inelastic, the revenue function would decrease as fishing effort increased. If either of these latter two cases obtained for a fishery, the net economic yield would be achieved by allowing only a small amount of fishing effort in the fishery. If costs increase as fishing effort increases, and revenue either remains constant or decreases with fishing effort, obviously the maximum net revenue above costs will occur at the first input of labor and capital.

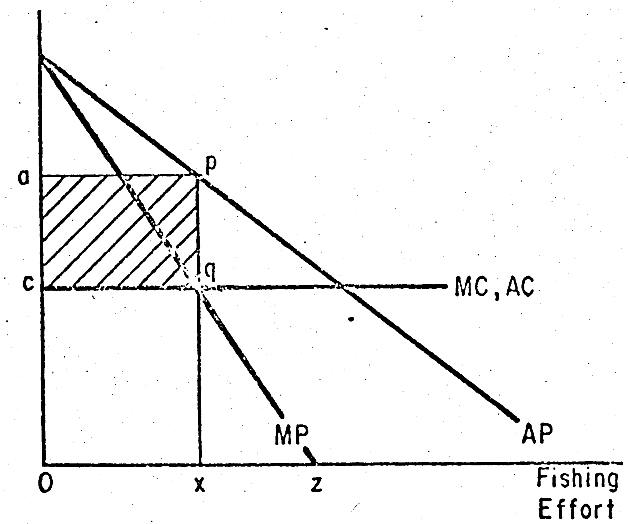
Gordon published a second paper on the economics of fishery exploitation in 1954, a year after his first contribution. The general theme and argument of the second paper are similar to those of his earlier contribution.

> "We can define the optimum degree of utilization of any particular fishing ground as that which maximizes the net economic yield, the difference between total cost, on one hand, and total revenue (or total value production), on the other.[17] Total cost and total production can be expressed as a function of the degree of fishing intensity or, as the biologists put it, 'fishing effort', so that a simple maximization solution is possible. Total cost will be a linear function of fishing effort, if we assume no fishing--induced effects on factor prices, which is reasonable for any particular regional fishery."[8]
>
> "17. Expressed in these terms, this appears to be the monopoly maximum, but it coincides with the social optimum under the conditions employed in the analysis, as will be indicated below."

Thus, in his second paper, again Gordon indicates that net economic yield to be the difference between costs and revenue. However, when he proceeds to demonstrate the "optimum degree of utilization," he reverts to a physical catch effort relationship:

> "Our analysis can be simplified if we retain the ordinary production function instead of converting it to cost curves as is usually done in the theory of the firm. Let us further assume that the functional relationship between average production (production-per-unit-of-fishing-effort) and the quantity of fishing effort is uniformly linear. This does not distort the results unduly, and it permits the analysis to be presented more simply and in graphic terms that are already quite familiar.
>
> "In figure 1 the optimum intensity of utilization of a particular fishing ground is shown. The curves AP and MP represent, respectively, the average productivity and marginal productivity of fishing effort. The relationship between them is the same as that between average revenue and marginal revenue in imperfect competition theory, and MP bisects any horizontal between the ordinate and AP. Since the costs of fishing supplies, etc., are assumed to be

unaffected by the amount of fishing effort, marginal cost and average cost are identical and constant, as shown by the curve MC, AC. These costs are assumed to include an opportunity income for the fisherman, the income that could be earned in other comparable employments. Then OX is the optimum intensity of effort on this fishing ground, and the resource will, at this level of exploitation, provide the maximum net economic yield indicated by the shaded area apqc. The maximum sustained physical yield that the biologists speak of will be attained when marginal productivity of fishing effort is zero, at Oz of fishing intensity in the chart shown. Thus, as one might expect, the optimum economic fishing intensity is less than that which would produce the maximum sustained physical yield."[9]



The technique used by Gordon for illustrating the optimum degree of fishing effort gives rise to some serious questions. As he indicates, he is using the model for monopoly equilibrium with some modifications. He uses average and marginal physical production in lieu of demand marginal revenue. Thus he must assume a constant price throughout in order for average and marginal product to be monotonic linear decreasing functions of fishing effort. However, in the case of a single decision making unit (the monopoly model), the firm would be cognizant of consumer demand in which price would have to decrease in order to market the increased catch that would result from increased fishing effort. In order for marginal revenue to be positive, the demand curve would have to be relatively elastic. If the demand curve were of unit elasticity or inelastic, the marginal revenue would be either zero or a negative quantity respectively.

The marginal cost concept used in the graph is also not consistent with the definition of marginal cost in the theory of the firm. Gordon has used marginal cost as a function of fishing effort, whereas it normally is defined as a function of output in the theory of the firm. Granting the prerogative to define a marginal cost of fishing effort, the conclusion cannot be drawn that the firm will maximize net economic returns where marginal physical product and marginal dollar cost are equal. It does not make sense to equate a physical unit to a monetary unit. If Gordon intended that marginal cost be expressed in physical product, then a fixed price would have had to have been used to convert the constant marginal cost into pounds of fish and again one runs into the question of elasticity of demand and what price could be used for such conversion. The concept that the monopoly firm will maximize net returns where MC=MR is true, but it would seem that the graphic analysis presented by Gordon is not accurate in representing the marginal revenue and marginal costs of the firm.

Following his discussion of the optimum degree of fishing effort, Gordon proceeds to point out that the economic rent implicit in the resource likely will be dissipated through the entry of more fishermen into the fishery. He further uses this as an explanation as to why fishermen are generally not wealthy.

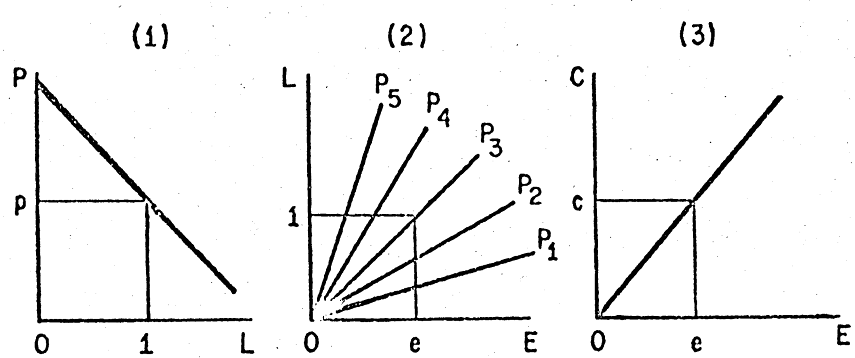
> "We now come to the point that is of greatest importance in understanding the primary production phase of the fishing industry and in distinguishing it from agriculture. In the sea fisheries the natural resource is not private property, hence the rent it may yield is not capable of being appropriated by anyone. The individual fisherman has no legal title to a section of ocean bottom. Each fisherman is more or less free to fish wherever he pleases. The result is a pattern of competition among fishermen which culminates in the dissipation of the rent of the intramarginal grounds...
>
> "...What happens is that the rent which the intramarginal grounds are capable of yielding is dissipated through misallocation of fishing effort.
>
> "This is why fishermen are not wealthy, despite the fact that the fishery resources of the sea are the richest and most indestructible available to man."[10]

The point that the economic rent may be dissipated through the entrance of additional firms to the industry is a valid one. However, it does not follow that this is a reason for fishermen to be poor. If the fishing firm is earning its opportunity costs for labor and capital, the inability to draw economic rent from the natural resource involved is no reason that the industry be a poverty industry. The economic rent could be taxed away without disturbing the level of fishing effort and thus one could not claim that the tax was the result of lack of earnings on the part of the firm. Similarly, in agriculture and industry, a highly profitable firm may not own the land it uses but instead pays the economic rent for the use of the land. Therefore, the low earning capacity of fishermen, if it is an industry characteristic, must be explained by some other factors than the dissipation of the economic rent.

Gordon completes his article with a "bionomic" equilibrium model for a fishery. The model includes four variables:

> "Let P represent the population of the particular fish species on the particular fishing bank in question; L the total quantity taken or "landed" by man, measured in value terms; E the intensity of fishing or quantity of 'fishing effort' expended; and C the total cost of making such effort. The system, then, is as follows:
>
> $P = P(L),$ (1)
> $L = L(P,E),$ (2)
> $C = C(E),$ (3)
> $C = L.$"[11]

The graphic representation of the model is as follows:



His explanation of these relationships is:

> "Thus, for example, if population were P_3, effort of Oe would produce Ol of fish. For each given level of population, a larger fishing effort will result in larger landings. Each population contour is, then, a production function for a given population level. The linearity of these contours indicates that the law of diminishing returns is not operative, nor are any landings-induced price effects assumed to affect the value landings graphed on the vertical axis. These assumptions are made in order to produce the simplest determinate solution; yet each is reasonable, since our analysis deals with one fishing ground not the fishery as a whole."[12]

Gordon proceeds to point out that where the equilibrium condition is L=C, no solution would exist if the individual production functions were linear. If the slope of C(E) were greater than the slope of L(E), no fishing effort would be forthcoming. Conversely, if the opposite is true, fishing effort would expand without bounds. Finally, if C(E)=L(E) there would be an infinite number of solutions to the model. Therefore, either the L(E) function, or the C(E) function, or both, must be non-linear. The case then becomes one in which the population is reduced by fishing and the function L=L(E,P), must be characterized by a positive first derivative and a negative second derivative.

Gordon then proceeds to point out:

> "The analysis of the conditions of stable equilibrium raises some points of general theoretical interest. In the foregoing we have assumed that stability results from the effect of fishing on the fish population. In the standard analysis of economic theory, we should have employed the law of diminishing returns to produce a landings function of the necessary shape. Market factors might also have been so employed; a larger supply of fish, forthcoming from greater fishing effort, would reduce unit price and thereby produce a landings function with the necessary negative second derivative. Similarly, greater fishing intensity might raise the unit cost of factors, producing a cost function with a positive second derivative. Any one of these three-population effects, law of diminishing returns, or market effects - is alone sufficient to produce stable equilibrium in the ecosystem."...
>
> "In point of fact, the law of diminishing returns is much more difficult to sustain in the case of fisheries than in agriculture or industry. The 'proof' one finds in standard theory is not empirical, although the results of empirical experiments in agriculture are frequently adduced as subsidiary corroboration. ...In fisheries, however, the pattern of reality can easily be explained on other grounds. In the case at least of developed demersal fisheries, it cannot be denied that the fish population is reduced by fishing, and this relationship serves perfectly well to

explain why an infinitely expansible production is not possible from a fixed fishing area."[13]

Two points might be made in relation to the above quote. First, most likely both cost and revenue functions in a fishery will be non-linear due to both the law of diminishing returns and market factors. Second, if the principle of diminishing returns is interpreted to represent time limitations in the complex set of interrelationships involved in an ecosystem rather than trying to explain it on the basis of a population of fish, the law of diminishing returns is quite feasible and consistent.

Anthony D. Scott

The third author to publish on the subject of economics of fishery exploitation was Anthony D. Scott. Scott states the purpose of his paper as:

> "In this paper I wish to compare the use of a fishery by competing fishermen with the mode of management that would be most profitable to a 'sole owner' of the same fishery. In particular, I wish to show that long-run considerations of efficiency suggest that sole ownership is a much superior regime to competition but that in the short-run in the ordinary case there is little difference between the efficiency of common property and private property."[14]

Scott leaves some doubt in the mind of the reader as to just what he had in mind by "sole owner." He defines the concept in a footnote as:

> " 'Sole ownership' is not monopoly but merely complete appropriation of all of a natural resource in a particular location. Putting a resource into sole ownership is sometimes called making a resource 'specific' to one owner."[15]

He further qualifies the role of the sole owner as:

> "In the second place, I have assumed that the sole owner is not the monopolist of the product. If he were a monopolist

> and could influence the price by his output, he would be confronted with a nonlinear total revenue curve in Fig. 2, and it is conceivable that his landings per period would be even smaller than those of a corresponding solely-owned fishery competing with many other fisheries."[16]

However, at other points in his discussion, he does extend the power of restricting inputs into the fishery to the sole owner in the long run. If the sole owner arrangement is not a monopoly, or at least has a monopolistic effect in controlling the amount of fish placed on the market, then it must be tantamount to dividing a fishery into sub-areas and extending the right of private property to an individual firm for each sub-area.

An important contribution of Scott is his distinction between short-run and long-run considerations.

> "In the short-run, fishermen do not expand their catch indefinitely because they do experience increasing costs in attempting to increase their landings. Gordon depends upon the omnibus variable 'effort' to cover the changeable combinations of men, boats, and other equipment used by individual fishermen. But, if we look through this omnibus variable, we see that in fact the short-run situation in a fishery exploited by competing fishermen will be very like the standard situation in pure competition. The supply curve of this fishery (with price given by the world market situation) will be made up by the addition of the relevant portions of the supply curves of the individual fishermen. These curves will slope upward because, with fixed equipment and a fixed number of boats, there will be some number of landings per boat which has a least cost; if the crew is worked long hours, or the fleet is kept running without time for maintenance or repair, the cost per landing will begin to rise. Each boat will increase its landings until its supply price (marginal cost) is equal to the going price. The 'surplus' that might be captured in this situation is the usual quasi-rent, available to each boat by operating at the point where marginal costs are equal to marginal revenue."[17]

Scott then proceeds to investigate the question of whether sole ownership would produce different results than allowing the resource to be exploited competitively. He distinguished between two possible situations, the first in which the sole owner takes over an existing fishery, boats, canneries, and crews; and second, a case in which he reorganizes the fishery in the most efficient way. It is not entirely clear that these are clear-cut alternatives. Supposedly in the first case, the sole owner would gain title to all capital but in the second instance he would merely have authority to make production and management decisions. In the first case, he concludes that the sole owner, if given control for only one fishing season, would operate the fishery identically as it would have been operated under the competitive regime, that is, at the output at which marginal cost were equal to price and at the extent of fishing for which marginal value product of labor equaled the price of labor. It is difficult to vision how a sole owner would not see himself as having some effect on price by his decisions in regard to the fishery. It would seem logical for him to weigh the alternatives of laying off some vessels and fishermen and saving the variable costs involved, particularly if he is now fully integrated through having full control of not only catching but processing the fish.

Scott points out that if the sole owner is given permanent tenure, then even in the short run he will tend to reorganize the fishery. However, the sort of changes he describes (substituting traps for vessels, achieving economies of scale, and eliminating wasteful interference of fishermen with each other) are mainly long-run changes, except for the latter. He still concludes:

"Hence, we can say that, as a general rule, the mere fact of sole ownership does not bring about a significant change in the exploitation of the fishery in the short-run. Both the sole owner and the competing fisherman will operate at an output which is theoretically similar (in its equality of marginal cost and marginal revenue) to that in other industries."[18]

This might be interpreted that if a management commission were set up to manage a fishery, it would not reduce the number of vessels and fishermen immediately as long as the vessels and crews were covering opportunity or even variable costs. The commission would then tend to limit fishing effort in the long-run through preventing the replacement of vessels as they wore out and needed to be replaced.

In developing the long-run equilibrium of the industry, he introduces another important concept.

"As long as the user of a fishery is sure that he will have property rights over the fishery for a series of periods in the future, he can plan the use of the fishery in such a way as to maximize the present value (future net returns discounted to the present) of his enterprise."[19]

Therefore, the optimum position of the "sole owner" in the long run will not be simply the maximum net revenue over current costs but rather the maximum net revenue over user costs where the user costs include the value of future landings discounted to present value. It should be pointed out that future value of landings foregone only will be relevant if fish left in the ocean today will add permanently to future catches. However, this would be a function of mesh size and not of fishing effort.

Milner B. Schaefer

The next contribution in time was a paper by Milner B. Schaefer. Schaefer opens his article by questioning whether the law of diminishing returns can be applied to fisheries as it is to land. Within the category of renewable natural resources, he draws a distinction between non-self-regulating resources and self-regulating resources:

> "A more familiar example, which has been the basis of much classical economic theory, is the use of agricultural land to produce cultivated crops from planted seed. As we have noted above, the land is considered to be a fixed factor of production, the amount of which can neither be increased nor diminished by man's action. Since the quantity of this factor is fixed, the application of increasingly large quantities of other factors of production (labour and capital) to the land results in a decreasing return per unit of these other factors. So long as the inherent natural properties of the land are not destroyed, increasing effort will give increasing return but the return per 'dose' of capital and labour decreases..."
>
> "Population of sea fisheries belong to a different type of natural resources, for which the annual rate of renewal of the resource is a function both of the physical environment, which is presumably constant, on the average, over the long run, and of the magnitude of the standing crop, or population of the resource which is diminished by the rate of harvesting."[20]

This distinction seems to be overstated in terms of interpreting the law of diminishing returns as it may apply to fisheries. The principle of diminishing returns is a long-run concept representing the technical relationship between combinations of variable inputs of certain factors with a fixed quantity of another factor within a stated period of time. The points on the production function (the functional relationship illustrating the law of diminishing returns) are simultaneous possibilities, only one of which can be realized within one time period. As long as the points of a yield/effort relationship for a fishery are sustainable yields, the productivity of the fishery is not being diminished for future time periods by increasing catch. The important thing is, in fisheries as in the cultivation of land, as succeeding higher levels of inputs of variable factors are considered, the sustainable production will increase at a decreasing rate after the application of the variable inputs has been carried beyond a certain point. Furthermore, "mining the resource," i.e., utilizing it in such a way as to decrease its innate productive capability, is equally as possible in land use as in fisheries. Furthermore, reversing the effects of mining the resource might be more costly for cultivatable land than for fisheries.

Schaefer gives an excellent brief description and mathematical representation of the biological model on which his analysis is based. The meaningful conclusion of his biological model is that population of a fishery is a linear decreasing function of fishing effort and that the annual sustainable landing from a fishery has the property:

$$L = K_2E \left(M \frac{k_2}{K_1} E\right)$$

Where: L = Landings
E = Fishing Effort
K_1, K_2, and M are constants

Thus landings have the general property of a second degree parabola open in the negative direction of the landings axis. This means that as effort is increased, landings will rise to some maximum value and then will decrease if effort is increased further. This landings function then is in reality the best representation of the principle of diminishing returns in fisheries.

In developing his economic model, Schaefer gives a good description of the effect of price elasticity of demand on the value of landings as a function of fishing effort but then proceeds to adopt the same assumption as Gordon and Scott:

> "For most individual stocks of sea fish, the catch is a rather small share of the total production of all fish with which it competes in the market, and, therefore, it seems reasonable to assume that for the products of a particular fish stock the elasticity of demand is large. Indeed, we should not go far wrong in assuming, as has Gordon (1954) that the price does not vary with landings."[21]

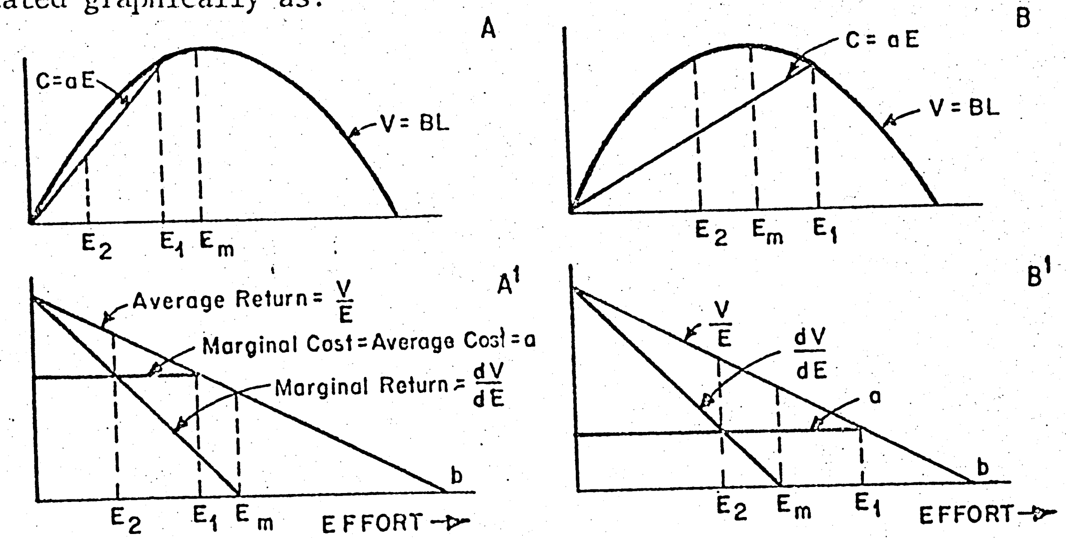
The assumption of perfectly elastic demand means that the value of landings as a function of fishing effort is the landings function multiplied by a constant price and thus the value function will have the shape and mathematical properties as the landings function itself has. The complete model then becomes:

$L = aE(b-E)$
$V = \beta L$
$C = \alpha E$

Where: L = Landings
V = Value of Landings
C = Total Cost of Fishing Effort
E = Fishing Effort

a, b, β, α, are constants.

With total cost defined as a linear function, marginal cost and average cost are identical and are constant. Likewise, with price a constant, average and marginal revenue will both be linear decreasing functions of fishing effort. The maximum net economic yield will then occur at that level of fishing effort at which the marginal revenue is equal to marginal cost. The results are indicated graphically as:



Schaefer then proceeds to explain what will happen under freedom of entry for a common property resource:

> "In a fishery which is common property resource, where anyone who wishes to do so is free to enter, new operators will be attracted to come into the fishery so long as the average cost is less than the average return (cost of course, including all the costs of factors of production, including interest on capital investment and the normal entrepreneurs' fee), so that in the unrestricted common property fishery the effort will grow until E_1, where average cost equals average return and the net economic yield is zero.
>
> "If unit cost is high relative to unit price of product (Fig. 4A,A^1), E_1 may be at a level of effort below that corresponding to maximum sustainable yield (E_m). In this case no increase in total yield can be obtained from restrictions on fishing effort. Any increase in yield must involve increasing unit prices or decreasing unit costs by some artificial means, such as price supports, subsidies, etc.
>
> "If, on the other hand, unit price is sufficiently high relative to unit costs (Fig. 4B, B^1), E_1 may be at a level of effort higher than the level E_m where maximum yield is obtainable. In this case, the yield can be increased by restricting the amount of fishing effort."[22]

In turning to the question of fishery management policy, Schaefer points out that two alternatives can be considered, increasing total production of food and increased net economic return, but that these are to some extent mutually exclusive. He proceeds to discuss the food problem of the world and problem of whether food supplies can increase sufficiently to meet the expanding world needs. On this basis he concludes:

> "It would seem, therefore, that there is adequate reason to give first priority to maximizing the yield of the sea fisheries. This choice has been the basis of fishery management in general, in the United States, and has, as noted by Graham (1956), been explicit in all the recent international conventions, in the New World."[23]

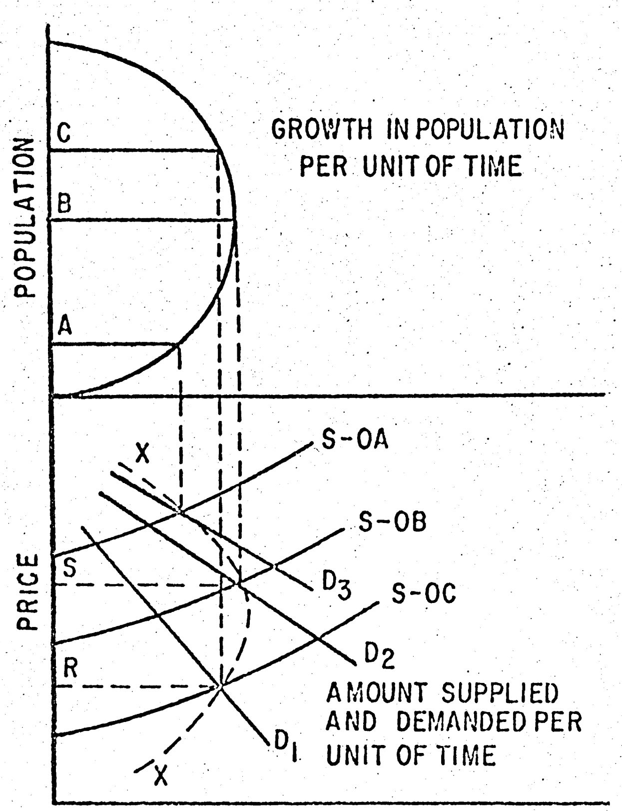
Introducing the problem of nutritional needs of the world bring an entire set of new considerations into the picture. The question is not just one of total world production but equally as important is the problem of distribution. Maximizing food production from the oceans likely would add more to the diets of the "haves" than the "have nots" under present arrangements. Furthermore, if the question of increasing world food production is considered, there is still the economic question of what is the best distribution of labor and capital between agriculture and fishing to achieve a given increase in caloric output. Production is not now carried to the point of absolute maximum returns on land. Thus before the maximum sustainable yield was reached in fisheries, it would be economically advantageous to increase inputs of labor and capital into agriculture.

James Crutchfield and Arnold Zellner

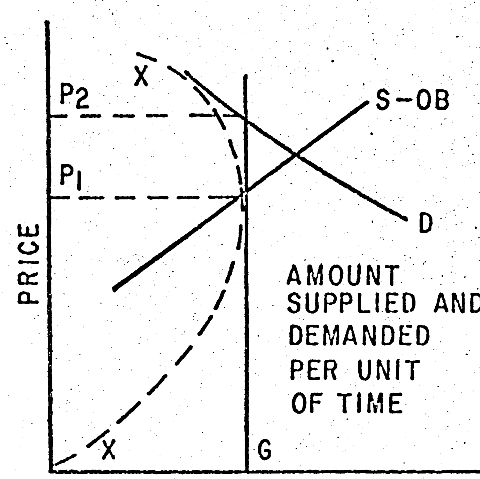
The next contribution to economic analysis of fisheries was made by Crutchfield and Zellner. The biological model employed by Crutchfield and Zellner is basically the same as that developed by Schaefer. However, they introduce the concept of "eumetric" fishing which requires some clarification. The eumetric yield curve is the production function resulting from the simultaneous variation of both gear selectivity and fishing effort. Thus, it is a "ridge line" of the production surface generated by all possible combinations of gear selectivity and fishing effort. If discreet changes in gear selectivity are made, the eumetric yield curve could be considered as passing through the maximum for the individual yield/effort curves for each gear size.

The eumetric curve, as it is generally presented, is somewhat misleading in that it does not reach a finite maximum but becomes asymptotic to some value. However, once a gear size is fixed, and fishing effort increased for that gear size, it would still be consistent to eventually reach a maximum sustainable yield followed by a declining catch if fishing effort were increased beyond that point. Inasmuch as a specific gear must be selected for a given fishery, the yield/effort relationship for that gear would seem to be more relevant. This is the landings function developed by Schaefer and is also the yield/effort relationship used by Crutchfield and Zellner in their final analysis. Moreover, if fishing effort is held constant and gear size increased, declining catch rates will occur at some point.

Crutchfield and Zellner use a perfectly competitive long-run equilibrium model to illustrate how an unrestricted fishery will behave over time. Thus, in their model, price and quantity are determined by supply and demand, and at the equilibrium price, costs are being fully covered so that no new firms will enter the industry nor will any firms in the industry drop out. The biological condition for equilibrium is that the yield being taken at long-run equilibrium must be a sustainable yield for the fishery involved. This condition then demonstrates that final equilibrium can exist only after the fishery population has adjusted to its stable state for the level of fishing effort involved in producing the equilibrium quantity of fish. Their model is graphically illustrated as follows:



Biological and economic equilibrium



Equalibrium with restricted catch

The curve in the upper graph represents the rate of change in the population per unit of time as a function of the size of population. Thus the greatest growth increment will occur at population size B, which will, in turn, be the population size that will support the maximum sustainable yield for the fishery. If the population is stabilized at a level larger than B, for example C, or less than B, for example A, then the annual net increment of bio-mass produced by that population will be less, and therefore, the yield that can be taken out of the fishery by fishing effort will be less. D_1, D_2, and D_3 represent successive demand curves at different points in time. Similarly, S-OC, s-OB, and S-OA represent different supply responses over time. The long-run equilibrium of demand and supply must fall on the dotted curve in order for the fishery population to be able to support that quantity of fish harvested over time.

The equilibrium point indicated by the intersection of D_1 and S-OC would result in the fishery population being stabilized at size C in the upper graph. Now an increase in demand to D_2 would result in a decrease in supply (i.e., a higher price is now necessary to call forth each given level of output due to the drop in catch per unit of effort on the part of the individual firms as new firms enter the industry in response to the profit resulting initially from the increase in demand). However, because the increase in demand has been relatively greater than the decrease in supply, the output of the industry has expanded in response to the higher price. The fishery population has now been reduced to B, but at B, the growth increment is larger, and thus, the harvest of fish by the industry can be larger. This equilibrium takes place at the maximum sustainable yield. A further increase in demand to D_3 again results in short-run profits and an inducement for new firms to enter the industry. However, this increase in fishing effort has reduced the population to a size where its annual growth increment is lower, thus the total sustainable harvest of the industry is decreased. This is reflected in the further decrease in supply from S-OB to S-OC. The new long-run equilibrium then results in a smaller total output for the industry than was true at the equilibrium resulting from D_2. The equilibrium at D_3 and S-OC would represent the case of biological overfishing in which the fishery was being exploited beyond the maximum sustainable yield for the resource.

From the above analysis it is evident that unregulated use of a common property resource can result in an end result where everybody loses. That is, the total amount of fish available to society is decreased, the price paid by the consumer is higher, and the amount of capital and labor necessary to harvest the decreased volume of fish is greater. Obviously, all would be better off by not letting fishing effort be carried to this extreme. This takes them then to the next question. If common property resources are going to be controlled, what objective should be sought in administering the limitations on use of the resource?

Their definition for the economic optimum for fishing is as follows:

> "If we may assume that market prices for goods reflect with reasonable accuracy the preferences of consumers, the basic economic objective, from the standpoint of society, is to see that the fisheries maximize net economic yield--

the difference between the aggregate money value of output and the aggregate money cost of input needed to produce it (excluding, of course, money returns based on monopolistic restriction of output).

"It is desirable that this result be achieved by providing a situation in which the pursuit of profit by businessmen will result in output, prices, and costs that also maximize the industry's contribution to society as a whole."...

"Viewed in this light, the performance of a fishing industry should be judged by the standards that have been developed as guides to public policy toward private enterprise generally. These may be summarized as follows:

"1. Output and factor allocation: At first glance it might seem that, other things equal, the more production of a marketable fish the better. If our economy is at full employment, however, more fish can be produced only by giving up some output of other things. Thus, the proper objective is that output of fish at which the value of the last unit caught is just equal to the value of other things that would have been produced with the required inputs of labor, capital and management (including additional fish that could be taken later by restricting output in the current period)."[24]

In all of the articles reviewed, the maximization of net economic yield has been demonstrated as occurring at the level of fishing effort where marginal cost and marginal revenue are equal. If marginal revenue is viewed from an industry basis and not from the viewpoint of the individual firm, this would not eliminate the possibility of building monopoly profits into the industry optimum. Crutchfield and Zellner do specify that this maximum should exclude money returns based on monopolistic restriction of output. The necessary condition for this to be achieved is that the marginal cost of the individual firm be equated to the marginal revenue of the firm, where the marginal revenue of the firm is equal to the equilibrium price determined in the industry. This is one point that has been glossed over in all of the preceding articles but is still an important point in the definition of the optimum economic level for exploitation of a common property fishery resource.

Ralph Turvey

The next contribution to the field of economic analysis of fisheries was an article by Ralph Turvey. Turvey states the objective of his study as:

> "The purpose of this article is to show that fishery regulation is one of those spheres of economic policy where what is the best thing to do depends on what can be done." ... "If the optimum optimorum is to be reached (the highest mountain scaled), then regulation must extend not only to the scale but also to the mode of operation."[25]

His analysis is a long-run static equilibrium for a single trawl fishery. Only one fish stock is involved and this is fished from ports which are equal distance from the fishery. The markets for the product are all competitive and there is freedom of entry into the fishery. Thus one would conclude that the fishery resource would be a common property resource. In the biological model, mortality and growth are both functions of age, recruitment to the fish stock is an exogenous variable (i.e., dependent on the mesh size used by the fishermen) and fishing mortality rate is proportionate to fishing effort. Fluctuations in the natural process are small and random (i.e., no trend).

Turvey points out that costs in fishing are complicated by the fact that fishermen do not draw a wage but rather are paid on a share-of-catch basis. He circumvents this problem as follows:

"Such matters are not relevant to the argument of the present paper, however, so I shall exclude them by simply assuming that over the relevant range of catch, the total cost of fishing effort rises more than proportionately to the amount of fishing effort because the minimum earnings necessary to attract and retain labor and capital at the margin rise as more of these resources are employed in fishing. Total cost is defined to include "rents" of the intramarginal factors, i.e., the excess of their actual earnings over minimum required to retain them in the industry. This is the only aspect of costs that we require in the present argument, so I need not discuss whether few ships fish many hours or vice versa, since fishing effort as defined above is the independent variable of the cost function. What is significant in this formulation is the implicit assumption that mesh size has no noticeable effect upon the costs of fishing effort."[26]

This treatment of costs gives rise to some questions. It is difficult to agree that marginal cost of inputs, particularly for capital, will have to rise for a specific fishery as the amount of labor and capital used in that fishery is increased. If the labor force is a homogeneous labor force, and the individual fishery is small in its demand for labor in relation to the total labor force, it would not seem likely that an increase in wage rates would be necessary to attract more fishermen. However, if one considered that fishing includes certain hazards and unpleasantness as an occupation, and that the labor force was not homogeneous in its willingness to undergo the rigors of "life on the sea" one might pose the case that wage rates would have to rise to overcome the reticence of people to go to sea. But there seems to be no basis for assuming that the rate of return to capital will have to rise in order to attract more capital into the industry.

A second question in regard to his treatment of costs is the inclusion of "intramarginal rents" in costs. If this is a common property resource, there is no conceivable way in which the market would build implicit economic rents into the cost structure. The earnings of a part of the labor force and some of management would no doubt include a "quasi-rent" if labor and management costs had to rise at the margin to attract more of these resources into the industry. However, it would not seem likely that capital could earn a "quasi-rent" in the long run in a fishery in which there was freedom of entry, unless economies of scale were such that capital requirements presented a practical impediment to entry. However, it would seem almost impossible to measure such quasi-rents in a fishery.

Finally, can one neglect the number of ships and fishing time achieved by each vessel? Certainly the total cost in the industry would be different if there were many ships fishing few days each as compared with fewer ships fishing more days each. In fact, this is one of the main problems to consider in the question of fishery regulation.

The matter of revenue is dismissed as follows:

> "The price of fish, given income levels and the price of other foods, depends not only upon the total weight of the catch but also upon its size distribution and upon its freshness. Here we shall assume that there is some given minimum marketable size of fish; otherwise I neglect these points. Thus I postulate a given function relating total revenue to weight of catch."[27]

It is perfectly permissable to postulate a revenue function. However, in the process of postulating such a function, the author should specify his assumptions as to price elasticity of demand. Turvey does not mention price elasticity but he shows revenue to be a positive function of the weight of fish landed. Therefore, he must have assumed a relatively elastic demand for fish.

Turvey also makes the following assumption about behavior of fishermen:

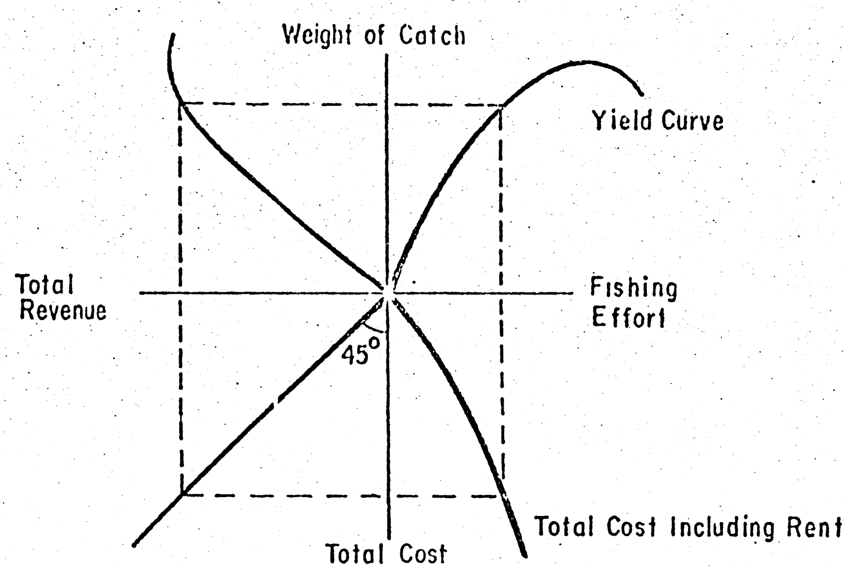
> "Each fisherman will want to maximize the marketable value of his catch at any given level of costs. This means, on our assumptions, that he will wish to maximize the weight of his catch of fish above the minimum marketable size for any given level of costs. Thus for the present argument we will assume that he will choose a mesh which limits his catch to fish above that size. If he uses a smaller mesh, he would have to throw part of his catch back into the sea, which would involve unnecessary trouble."[28]

The real significance of this assumption is that the mesh size which will assure the individual fisherman of getting the maximum weight of fish above marketable size is not the mesh size that will place the industry on the highest sustainable yield effort function for the fishery. Turvey's last sentence about the effect on costs of throwing fish back is not a meaningful explanation. In the process of trawling, a wide array of fish are taken, thus, necessitating sorting and discarding, not only small fish, but fish which sell at such a low price that it does not pay the fisherman to keep them. The validity of the assumption that fishermen likely would use a mesh size smaller that would be most advantageous for the industry as a whole is borne out in experience. The imposition of a mesh regulation in a fishery generally requires an enforcement program to keep the fishermen from slipping a "liner" in the cod end of the trawl, or devising some other modification of the gear that tends to negate the effect of selectivity of the mesh size.

On the basis of his description of cost and revenue factors, the long-run equilibrium is defined as that point at which total revenue is equal to total costs including the rent of intra-marginal factors. The adjustment is stated as, "If total revenue exceeds total costs, resources not in the industry will find that it is worthwhile to move into it, while in the reverse case some resources at the margin will be earning less than is required to retain them in the industry, and they will leave it."[29]

It is difficult to accept that the long-run equilibrium in a common property resource will occur at the level of inputs (fishing effort) which will retain the economic rent in the fishery (the rent accruing to the scarcity of the natural resource). As long as the fishery is open to entry, the economic rent would represent a payment above the opportunity costs of labor and capital and hence would tend to attract more labor and capital into the industry. Therefore, it would seem that fishing effort would continue to increase until all economic rent was dissipated and total revenue would equal total cost where total costs represented only payments to labor and capital (this would, of course, include quasi-rent to labor and management). This situation would have to be where average revenue would equal long-run marginal cost, which would be equal to the long-run minimum average cost per ton of fish produced by the individual firm.

The graphic illustration of Turvey's equilibrium is as follows:



Turvey points out that either an increase in demand or a decrease in cost of fishing could result in fishing effort increasing to the right of the point that would produce the maximum weight of catch for the resource. This would mean a greater total utilization of inputs in the fishery but at the same time a reduction in the amount of total product available to society.

This peculiar result indicates that there is something special about the industry. This unique problem is really twofold:

> "But from what has been said it should be apparent that two problems are involved, not one. The first is that while the catch of the individual fisherman is proportionate to his own fishing effort, the same is not true of all fishermen together; ...
>
> "Each fisherman imposes an external diseconomy upon his brethren; the marginal private product of his fishing effort exceeds the marginal social product.
>
> "The second problem involves mesh size. By catching small fish, fishermen are reducing the number of large fish to be caught later. If an individual fisherman were to raise his mesh size, he would lose by increasing the number of hauls necessary to achieve any given weight of catch. Yet in the long run, his use of a larger mesh may lower the costs of

all fishermen together and, if all of them used larger meshes, all would benefit. Here again, social and private product diverge.

"When external economies are involved both in the level of fishing effort and in the choice of mesh size, it is clear that to achieve the optimum resource allocation requires regulation of both of these variables."[30]

This develops a rather widely accepted principle in fisheries that mesh size alone will not suffice as a program for fishery management but that both mesh size and limitation of fishing effort are needed.

Turvey then proceeds to develop the conditions for the optimum allocation of fishery resources:

"Let us assume for the present that the conditions for optimal resource allocation are fulfilled in the rest of the economy, so that no problems of 'second best' arise. Let us further assume, first, that the effect of changes in the price of fish upon the distribution of real income between fish consumers and other is unimportant and, second, that a level of earnings in the industry which is equal (at the margin) to the earnings those resources could obtain elsewhere is socially acceptable. Finally, let us consider only those cases where the fishery is a very small part of the economy.

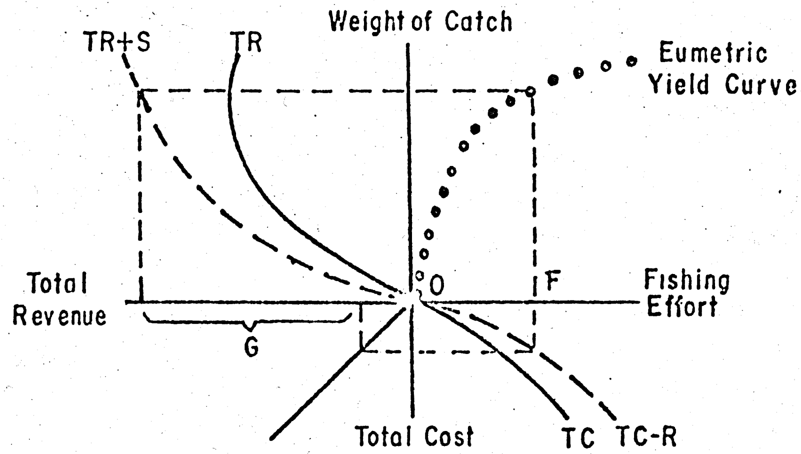
"Under these conditions, the <u>optimum optimorum</u> is reached when G is maximized, G being the excess of the value of the catch to consumers over the value to them of the alternative goods and services sacrificed by devoting resources to fishing. Now the value of the catch to consumers is the maximum they would pay rather than go without it, i.e., what they do pay (total revenue) plus consumer surplus: TR + S, the area under the demand curve. The value of the goods and services sacrificed is equal to the contribution to production that the resources used in fishing would make if they were not so used and this, on our assumptions, is what they could earn elsewhere. It is therefore measured by the total costs of the fishery less the rents of the intramarginal resources, TC-R. Thus the <u>optimum optimorum</u> is to be reached by maximizing:

$$G = (TR + S) - (TC - R)$$"[31]

Here as against his earlier analysis, an increase in mesh size would have an effect on cost of producing fish, but not on fishing effort. Inasmuch as Turvey has been discussing the cost of fishing effort, a change in mesh size would be reflected through the revenue of the firm and not cost.

> "A necessary, but sufficient condition for maximization is that mesh size be such as to maximize the catch for the actual level of fishing effort.
>
> "In terms of Figure 1 this means that the fishery must be 'on' the dotted envelope curve, known as the 'eumetric yield curve' (Beverton and Holt (1)). It is a property of this curve that, unlike the individual yield curve for given mesh sizes, it is asymptotic to the horizontal, thus rising throughout its length."[32]

The <u>optimum optimorum</u> is illustrated graphically as follows:



G is maximized then where the price of fish times the marginal catch is equal to the marginal cost of labor and capital into the fishery, or:

Price x marginal catch = Marginal cost of fishing effort.

Turvey maintains that this condition will result in the two following conditions:

Price x marginal catch = Average cost of fishing effort including rent

Price x average catch = Average cost of fishing effort including rent.

Thus Turvey concludes:

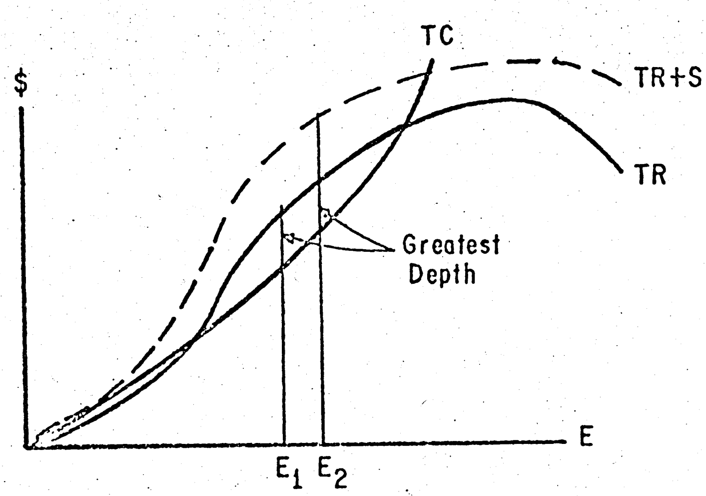
> "... which means that total revenue exceeds total costs including rent. G=S+R+(TR-TC), the maximum gain is the sum of consumer's surplus, producer's surplus, (the rents of intramarginal labor and capital), and the rent of that other scarce resource, the fish stock." 33

It can be agreed that it would be desirable to increase fishing effort just to the point where the price times the marginal increment of catch would be equal to the marginal cost of fishing effort. However, it does not follow that the price times marginal catch will equal the average cost of fishing effort, including rent. It would be sufficient for the marginal value product to the firm (price x marginal catch) to just cover the average cost of effort at the minimum point on the average cost excluding economic rent. The summation of the marginal value products over the range of fishing effort of the firm would exceed price times average cost by the amount of economic rent earned by the firm.

Turvey identifies a change in the mesh size as determining S (the consumer surplus) and the amount of fishing effort as affecting only R (the rents in the industry). However, it would seem that the consumer surplus and rent both are a product of the combination of mesh size and amount of fishing effort, and no useful purpose seems to be identified with trying to sort them out.

The maximization of economic welfare out of the use of fishery resources will require both optimization of mesh size and fishing effort; however, it is still questionable whether the maximum to be realized would be the economic rent or the maximum combination of economic rent and consumer surplus. It would not seem possible to maximize both. Therefore, if an increment is to be included for consumer surplus, it would have to be achieved through lowering the economic rent left in the industry.

Turvey would utilize a toll or fee to approximate the economic rent as a means of maximizing the rent after the consumer surplus had been maximized through the suboptimization of mesh size. Such a toll would have to be somewhat less than the economic rent implicit in the natural resource if credit is to be given to increasing consumer surplus.



Assume that in the above graph, the total revenue function is developed by allowing the marginal cost of fishing effort for the firm to equal its marginal value product. Thus for the individual firm the revenue would not include monopoly profits. The maximum difference between cost and this revenue would represent the economic rent. However, if the difference between TC and TR+S were achieved in the industry, this would have to occur at a level of fishing effort to the right of E_1, for example, E_2, and the economic rent, i.e., the difference between costs and revenue in the industry would be less than if fishing effort were limited to E_1, the level that would produce the maximum economic rent.

Some confusion seems to arise out of Turvey's treatment due to failure to distinguish between the functions for the individual firm and industry aggregates. This same problem seems apparent in a discussion of Turvey's article by J. Hayden Boyd:

> "In words, additional fish ought to be caught up to the point where the increment in costs associated with an additional pound of fish just equals the value the market places on that additional pound of fish. In the absence of a toll or charge for the use of the fish stock, long-run competitive equilibrium will be achieved when P=C/f, the average cost to the fishing industry.
>
> "Now average cost equals marginal cost only when the former is a constant. If this is the case, additional industry output will be proportionate to the extra fishing effort expended. This is equivalent to stating that increases in industry output have a negligible effect on the fish stock, and, hence, that the marginal product of the fishing banks is zero." [34]

The firm will realize a marginal cost equal to average cost where the marginal cost curve cuts through the average cost curve and this does not require that average costs are constant nor that the marginal product of the fishing banks is zero. If the marginal product of the fishing banks were zero, an increase in fishing product of the fishing banks were zero, an increase in fishing effort would certainly have to result in average cost increasing.

Francis T. Christy, Jr., and Anthony Scott

The most recent contribution to economic analysis of fisheries is that of Christy and Scott. Their conclusion is that the maximum net economic revenue should be sought from the fishery. Their analysis is as follows:

> "... Thus where there are OA fishermen engaged, each receives an average revenue of OD, and where there are OB fishermen engaged, the average revenue declines to OC.
>
> "With OA fishermen, the additional revenue to the industry would equal the costs that each fisherman bears. This is the point where marginal costs and marginal revenues are equal and where the industry will produce the greatest net revenue, profit, or rent. ...
>
> "At this point a sole owner of the fishery resource would stop hiring additional fishermen because at this point the profit to the owner is maximized. ...
>
> "The goal of economic efficiency can be approached by preventing excessive entry into the industry, so that those who fish would be producing the maximum net economic revenue (to be shared by them, or appropriated by the public) and so that those who are prevented from participating will be able to produce other goods and services of value to the community."[35]

If the range of choice were limited to the two alternatives, i.e., operating the industry under conditions of freedom of entry so that all the economic rent would be dissipated and a redundant quantity of labor and capital would be tied up in fishing; or achieving the monopoly outcome for the industry and to maximize the monopoly profits of the industry; perhaps the latter would be socially more desirable than the former. However, the field of choice is not limited solely to these alternatives. Again it would seem possible to achieve a goal superior to either in which something akin to only the economic rent of the resource were allowed to exist over and above capital and labor costs in appropriating fishery resources. This would allow a somewhat larger amount of labor and capital to be employed in the fishery than would Christy's and Scott's goal, but at the same time would not result in the redundancy of labor and capital that would obtain under complete freedom of entry.

Summary and Conclusions

The literature reviewed indicates four policy goals for consideration. Schaefer cited the goal of maximum production of food from the oceans. Gordon, and Scott and Christy would seek to maximize the net economic yield above costs or in effect seek the monopoly outcome for the industry. Crutchfield and Zellner called for the maximum net economic yield but qualified this by excluding "money returns based on monopolistic restriction of output." Thus one would conclude that they intended basically the net economic yield to be that of the economic rent implicit in the resource. The solution by Turvey is close to this with the exception that he would include consumer surplus in the quantity to be maximized and thus would merit extension of the fishing effort as long as the sacrifice in economic rent was offset by a gain in consumer surplus.

Apart from the policy goal proposed by the various authors, some confusion arises from three deficiencies in the literature. The first is the lack of attention to explanation of the individual firm and means by which the firms are aggregated into industry totals. The second is the lack of treatment of short-run and long-run equilibrium. The third is the treatment of the principle of diminishing returns as it may apply to fisheries. The development of the bio-economic model for this study is expanded to attempt to bring out more clearly what is involved in the first two areas.

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7. IBID, pp. 446-447.

8. __________. "The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economy, Vol. 62, No. 2, April 1954, pp. 124-142.

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14. Anthony D. Scott, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy, Vol. 63, April 1955, p. 117.

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24. James Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," U.S. Fish and Wildlife Service, Fishery Industrial Research, Vol. 1, No. 1, 1962, pp. 23-24.

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34. J. Hayden Boyd, "Optimization and Suboptimization in Fishery Regulation: Comment," American Economic Review, Vol. LVI, No. 3, June 1966, pp. 511-517.

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CHAPTER III

THE BIO-ECONOMIC MODEL

The model is based on a closed demersal trawl fishery. A demersal fish is a bottom-dwelling fish. A closed fish population is one which neither loses nor gains members through migration. Therefore, the fishery is represented by a self-contained set of factors embodied in the ecosystem of which it is a part. This species of fish are harvested with bottom trawl gear and the technology of fishing and efficiency of fishing equipment will be assumed constant during the period of time needed for all adjustments to long-run equilibrium of the fishery.

The Biological Model

The fishery, in its natural state, is characterized by a set of differential equations relating the fish population (P), recruitment (R), growth (G), and natural mortality (M).

Population:	The bio-mass weight of fish in the fishery at the beginning of a time period.
Recruitment:	The bio-mass weight of fish entering the population during a time period.
Growth:	The bio-mass weight added by all fish within the population during the time period.

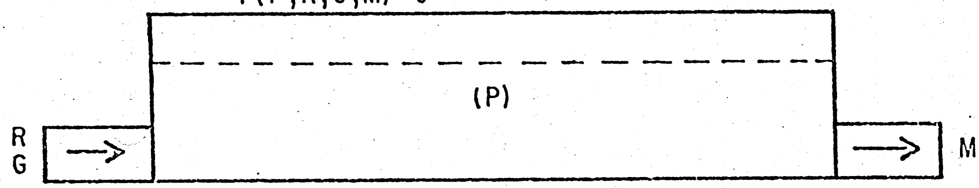
Natural mortality: The bio-mass weight of fish lost from the population during the time period due to natural death and predation.

This species of fish spawn one time a year and the young follow a consistent pattern of development until they reach the age at which the survivors at that point in time are considered to enter the fishery population. Thus the time differential will be 1 year.

In addition to the above variables, the ecosystem has several parameters which are considered fixed and independent of changes in the above variables. Some of these parameters are salinity, temperature, prevailing currents, other species of fish, radiated solar energy, the rate of photosynthesis, and the rate at which mineral elements in the environment are replaced. Although these parameters are considered fixed, they are fixed in the sense of being stochastic variables with constant expected values about which random variation may occur.

The fishery can be considered as a sub-system of the broader eco-system of which it is a part. The fishery sub-system is similar to any system containing a volume which changes over time due to differential rates of inflow and outflow. The implicit functional relationship involved is:

$$f(P, R, G, M) = 0$$



and $P_t = P_{t-1} + R + G - M$

In the fishery sub-system, the rate of change of the population bio-mass weight, will be the net result of the rates of recruitment, growth, and natural mortality during the time period. If the differential increments of recruitment and growth were constants and exceeded the differential for natural mortality, also a constant, then the population would continue to grow without bound, obviously an impossibility. Conversely, if all the above increments were constants, but the increment of mortality exceeded recruitment and growth, the population would constantly decline to zero. If the population achieves a steady state equilibrium with its environment, recruitment, growth, natural mortality, and the population size must all be interrelated and one or more of the partial derivatives must also have second derivatives such that the second partial derivative of either R or G both must be negative, and/or the second partial derivative of M must be positive.

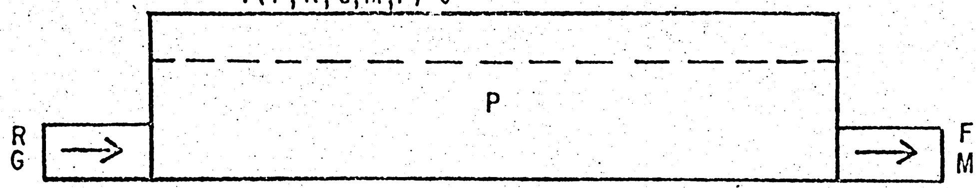
When man influences the ecosystem through his fishing effort, a new variable, fishing mortality (F) is introduced into the fishery sub-system and an entirely new system of differential equations will characterize the fishery sub-system.

Fishing mortality: The bio-mass weight removed from the fishery by man's fishing effort.

The fishery population will now be defined as the bio-mass weight of fish of an age and size, subject to capture by the fishing gear used, and recruitment can be defined as the bio-mass weight of fish reaching an age and size subject to capture within the time period.

The fishery now is described by the implicit function:

$$f(P, R, G, M, F) = 0$$



and $P_t = P_{t-1} + R + G \quad M - F$

Because fishing mortality represents an additional drain on the population during each time period, unless the rates of recruitment, growth, and/or natural mortality change from their values when the fishery was in a natural steady state equilibrium, fishing mortality would tend to pull the population steadily downward towards zero.

Two hypotheses can be formulated about the impact of fishing mortality. First recruitment, growth, and natural mortality can be assumed independent of fishing mortality. Thus, a given level of fishing mortality would reduce the population to the point where the rate of natural increase just offset fishing mortality. The population would then be in a steady state equilibrium as follows:

$$\frac{dP}{dt} = R + G - M - F = 0 \qquad \text{and} \qquad \frac{d^2P}{dt^2} < 0$$

The second hypothesis would hold recruitment, growth, and natural mortality as all being interrelated with fishing mortality such that

$$\frac{\partial R}{\partial F} \gtrless 0, \quad \frac{\partial G}{\partial F} > 0, \quad \frac{\partial M}{\partial F} < 0$$

Again, the population would come into a steady state equilibrium with its environment but the rate of natural increase to be cropped off by fishing effort would be greater because of the impact of fishing mortality on recruitment, growth, and natural mortality.

In either case, for any given population size, fishing mortality can just offset the natural rate of increase without causing population to decline. Therefore, for each possible level of population of fish, there will be a corresponding level of sustainable fishing mortality that can be achieved through fishing effort. If fishing mortality is less than the increment of natural rate of increase, some net addition to the population will take place.

Even though the partial derivatives of this complex system may not be subject to measurement, a relationship can be derived which is not only subject to empirical approximation but at the same time gives knowledge necessary to analyze economic aspects of utilization of fishery resources. Schaefer has developed the logic as follows:[1]

> "For each size population, there is a certain rate of <u>natural increase</u>, which is, under average environmental conditions, <u>some single</u> valued function of population size. In mathematical notation

$$\frac{dP}{dt} = f(p) \tag{1}$$

> "The catch, or landings, L, during a year is some function of the size of population and the amount of the other factors of production, which we collectively term 'fishing effort', E.

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

> "In the equilibrium state, which we are here discussing,

the catch is exactly equal to the rate of natural increase. This has been called the equilibrium catch by Schaefer (1954a). This equilibrium catch is the long-term annual production of the fishery for a given level of population (and effort).

"It immediately follows, of course, from (1) and (2) that under equilibrium conditions population size is some function

$$P = I\ (E) \tag{3}$$

"Data from experimental animal populations and from the commercial fisheries (Muchmann 1938, Graham 1935, 1939, Schaefer 1954a) indicate that f(P) is a single valued positive function, falling to zero at P = 0 and at P = M, the maximum population which the environment will support under average conditions, with no fishing, and having a maximum at some intermediate value of P. It further appears that a reasonably good first approximation is the quadratic

$$f(P) = k_1 P(M-P) \tag{4}$$

where k_1 and M are constants.

"It also appears that, to a good degree of approximation,

$$L = k_2 EP \tag{5}$$

where k_1 is a constant so that, under equilibrium conditions,

$$k_2 EP = k_1 P(M-P) \tag{6}$$

and consequently

$$P = M - \frac{k_2}{k_1} E \tag{7}$$

"That is, for equilibrium conditions population size is a linear function of fishing effort; and, from (5) and (7)

$$L=k\ E(M- \frac{k_2}{k_1}\ E) \tag{8}$$"

Schaefer's last equation can be written as follows:

$$L = KE - gE^2$$

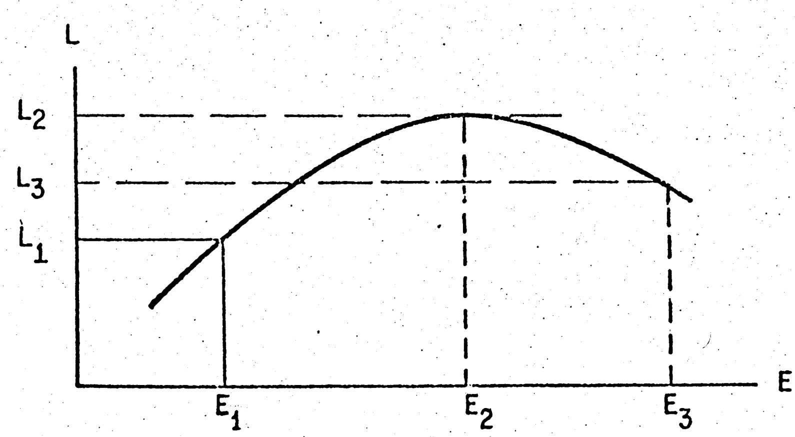
where L = Total landings of fish per year

E = Total standard days of fishing effort per year

K and g are constants.

A standard day of fishing effort for this fishery is defined as 24 hours of actual trawling time. For example, if a vessel were at sea for 10 days, and during this time it made 90 tows of 2 hours each, it would have accomplished 7.5 standard days of fishing effort $(90 \times 2 \div 24 = 7.5)$.

The above equation will be of the standard form of a second degree parabola opening in the negative direction of the landings axis:



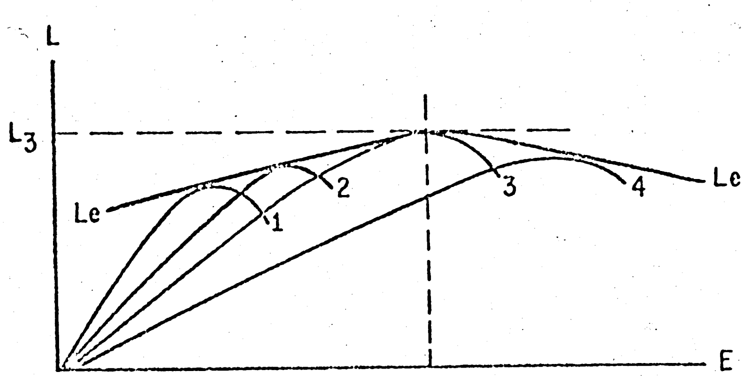
Each point on the parabola would be considered the "expected value" or sustainable yield of the fishery after the population had adjusted to its steady state equilibrium for the amount of fishing mortality represented by the corresponding level of fishing effort. For example, if the level of fishing effort were held constant at E_1 for a period of years, then, after population adjustment, landings could be expected to average L_1, and similarly for E_2 and E_3. Some level of fishing effort would enable landings to be a maximum for the fishery sub-system. This level of fishing intensity will be at the level of fishing effort where the first derivative of landings-effort function is zero:

If: $L=KE-gE^2$
Then: $dL/dE=K-2gE$
And: $dL/dE=0$ when $E=K/2g$.

This point is illustrated at the level of E_2 and L_2 in the above graph. A level of fishing effort greater than this, for example E_3, would actually produce a smaller sustainable yield of fish from the fishery.

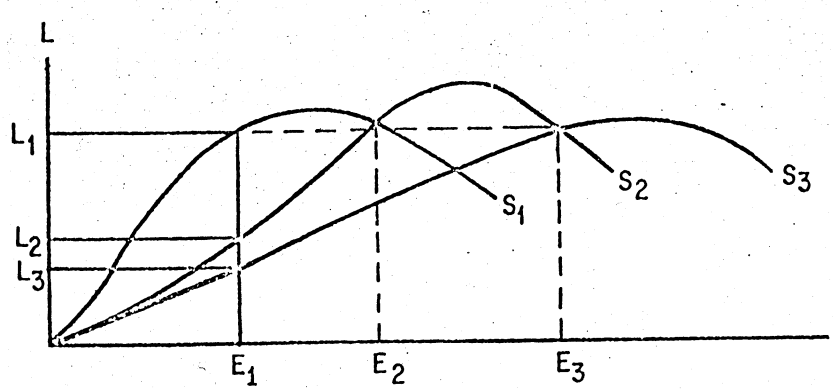
A distinction must be kept in mind as to fishing mortality in a pure biological model for a fishery, and the landing effort function for a fishery. Although the landings of fish (accounting for small fish discarded) is a measure of the fishing mortality introduced into the fishery system, the landings function also is a technical relationship between inputs of fishing gear, knowledge, and expertise for catching fish, and the output of pounds of fish. Thus, technical catching aspects of the fishing gear, and their method of use, are also reflected in an empirically determined landings effort function.

One of the most important considerations in the use of fishing gear and its impact on the fishery is the selection of the mesh size for the cod end of the trawl. As the size of the mesh opening is increased, larger fish can escape through the mesh so that the minimum age and size of fish taken in the trawl is increased. This action of the mesh size must be considered in a couple of respects. On one hand, an increase in mesh size will affect recruitment. The larger the mesh size, the larger and thus older, fish will be before they are actually recruited to the fishery population (i.e., the population of fish subject to fishing mortality by the fishing gear). At the same time, it is possible that, if fishing effort is held constant and the mesh size is increased through a range of values, the actual landings will drop, not because of a decrease in the population of fish, but rather because of the limitation on catching ability posed by the large mesh used. Therefore, the landings function will be affected by mesh size as well as the biological interrelationships within the fishery. If the mesh size is small, very young fish will be taken in the fishing process. If these fish were left in the ecosystem for a longer period of time, the weight added per fish as they matured in age would be greater than the loss of weight due to natural mortality. Thus, an increase in mesh size, (through a certain range of values) will tend to increase recruitment and permit a higher level of sustainable yield for some levels of fishing effort. However, after a point has been reached, a further increase in mesh size will result in a drop in the landing effort function due to the limited ability of the gear to take fish (i.e., because the bio-mass of fish subject to the catching character of the gear is greatly reduced). Introduction of mesh size can be illustrated graphically as follows:



For each given mesh size, a separate landings-effort function will obtain. Thus, the curve labeled 1 in the above graph illustrates one mesh size, whereas, the curve marked 2, represents the use of a larger mesh size. Throughout a range of fishing effort, the larger mesh size produces a smaller catch than the smaller mesh size. However, after the landings function for the smaller mesh size has reached its peak and turned downward (due to biological factors) landings continue to increase as effort is increased with the larger mesh size. Furthermore, the maximum sustainable yield for the fishery is greater with the larger mesh size. This impact of mesh size has a limitation on sustainable yield as indicated in landings-effort function 3. With the adoption of the mesh size commensurate with this landings function, the sustainable yield for the fishery is a maximum at L. An increase in mesh size beyond this, for example, landings function 4, results in all points on the respective landings function being lower. An envelope curve (Le) can be fit tangent to all such landings curves, or passed through the maxima of all such landings curves. In the development of biological population dynamics, such an envelope curve has been termed the eumetric yield curve. The eumetric yield curve has been illustrated as becoming asymptotic to some value on the basis that fishing mortality in the population could not exceed some maximum value. However, where the relationship reflects the combined considerations of technical interplay between landings and effort, and landings and the biological relationships in a fishery, it is logical to include the possibility of a loss in catching ability due to increase in mesh size.

The economic significance of this possibility depends on the effect of mesh size on the average size of fish landed and the tendency of the market to discriminate in terms of price for different size of fish. If the market prefers large fish to small fish, and this is reflected in a substantial price differential, the landings/effort function that will produce the maximum sustainable physical yield, is not necessarily the landings/effort function that will produce the maximum market value of fish landed. Furthermore, for relatively unexploited fisheries, the mesh size that will maximize sustainable yield will not necessarily represent a social optimum. This latter point can be illustrated as follows:



In the above situation, E_1 of fishing effort will produce landings of L_1, L_2, or L_3, respectively, for mesh sizes S_1, S_2, or S_3. Costs likely will decrease somewhat as mesh size is increased. The smaller mesh size will require higher initial cost, higher maintenance costs, greater fuel utilization, and more culling.

However, this last item will only add to costs if the increase in culling requires a larger crew, an unlikely situation. The change in cost due to mesh size will be small in relation to the total costs of fishing. In fact, for most fisheries, no great error would be introduced if it were assumed that costs did not change with mesh size. On the other hand, fishing effort of E_2 and E_3, respectively, would be needed to produce L_1 of fish with mesh sizes S_2 or S_3. Thus, with the larger mesh sizes, the total cost of producing L_1 quantity of fish would be substantially greater.

The problem of mesh size is far more complicated than this simple illustration. Obviously, as the industry approached the maximum sustainable yield for mesh size S_1, costs would be rising rapidly. Furthermore, the maximum sustainable yield would be less than possible outputs of the fishery for larger mesh sizes. Thus, a small mesh size would provide fish to society at the lowest cost in the initial stages of development of the fishery but would be a limiting factor on the growth of the fishery. Therefore, one mesh size may be justified in the initial stages of development of a fishery, and a larger mesh size would be more advantageous as the industry developed.

In summary, the industry faces a biological parameter of the form:

$$L = \alpha_1 KE - \alpha_2 gE^2$$

Where: L = Total landings of fish by the industry
E = Total fishing effort applied to the fishery
K and g are constants
α_1 and α_2 are functions of mesh size and operate on K and g, respectively.

That is, for the industry to be in equilibrium, the landings achieved from the fishing effort applied by the industry must be related by K and g as indicated above for the specific mesh size in use. If L exceeded the sustainable yield, the fishery population and landings reached an equilibrium state for that level of fishing effort. Conversely, if landings were less than the sustainable yield, the population would increase, thus increasing catch rates until again the population and yield were in equilibrium for the amount of fishing effort being applied.

The Economic Model

In order to evaluate the four policy alternatives proposed in chapter II, certain market factors affecting the decisions and outcome of the fishing firm must be added. The decision criteria and variables involved in the individual firm will be the same for each of the policy alternatives. A change from one policy alternative to another will, in effect, be a change in certain parameters affecting the specific decision of the firms and thus the outcome of the industry. Therefore, a generalized model incorporating the variables subject to control by the firm, and the parameters that will be altered under the various management policies, will permit evaluation of all four policy alternatives. The model for equilibrium of an unregulated competitive fishery will serve this purpose. Such a fishery is defined by the following conditions:

1. The industry is comprised of a large number of independent firms (one firm operates a single vessel).

2. The industry is open to entry of new firms.

3. Capital requirements are not great so that firms are able to enter the fishery with relative ease.

4. The fishery represents only a small part of the total fishing activity of the region. Therefore, skilled labor is available without affecting the wage rate.

5. The species of fish involved is differentiated by consumers so that a specific demand relationship exists for this fishery.

6. The individual firm will seek to maximize profit from his fishing activity.

Profit maximization on the part of the firm implies that the firm seeks the output of fish which will yield the maximum difference between the revenue he receives from the sale of the fish and the cost of producing fish. This is illustrated as follows:

$$\pi = Ph - C(h)$$

where:

π	=	Profit to the firm
P	=	Price received for fish
h	=	Quantity of fish landed by the firm
$C(h)$	=	Total cost as a function of landings

π is a maximum when:

$$\frac{d\pi}{dh} = o; \ \frac{d^2\pi}{dh^2} < o$$

or:

$$\frac{d\pi}{dh} = Pdh - \frac{dc(h)}{dh} = o$$

$$\frac{d^2\pi}{dh^2} = \frac{d^2c(h)}{dh^2} < o$$

Thus the firm maximizes its profit at the output where its marginal cost equals marginal revenue (which is the same as price in a competitive industry) and any further increase in output will increase costs more than revenue.

Given the competitive structure assumed for the industry, the individual firm has control over two variables which will affect its revenue and cost; namely, fishing effort, e; and mesh size, S. However, because of the biological parameter faced by the industry, the actual landings of the individual firm will depend on the number of firms in the industry as well as the firms' choice of fishing effort and mesh size. This can be illustrated as follows:

$$\sum_{i=1}^{N} ei = E = Ne \qquad (i = 1,\ldots, N)$$

$$\sum_{i=1}^{N} hi = L = Nh \qquad (i = 1,\ldots, N)$$

where: ei = Standard days of fishing effort of the $i^{\underline{th}}$ vessel.
hi = Total pounds of fish landed by the $i^{\underline{th}}$ vessel.
N = Number of vessels in the fishery.

At equilibrium:

$$L = c_1KE - \alpha_2gE^2$$

or:

$$Nh = \alpha_1 KNe - \alpha_2 g(Ne)^2$$

$$h = \alpha_1 Ke - \alpha_2 gNe^2$$

$$\alpha_1 = f(s)$$

$$\alpha_2 = f(s)$$

$$h = h(e,S,N)$$

$$e \leq \bar{e}$$

$$S \geq \underline{S}$$

Thus, the production function of the individual firm will be a function of two variables controllable by the firm, days of fishing effort expended and mesh size selected, and a parameter beyond control of the firm, the number of vessels in the fishery. An upper constraint, $\bar{e}$, must be placed on e, for there will be a maximum number of days of fishing effort that a vessel can achieve within a year. Similarly, the market will place a minimum constraint, $\underline{S}$, on mesh size. There will be some minimum size fish that the market will accept. Therefore, the firm will not consider mesh size smaller than that which will assure the taking of minimum size fish acceptable in the market.

The exvessel price for fish also is interrelated with mesh size. Large fish sell at a premium over small fish. Inasmuch as an increase in mesh size will tend to increase the proportion of large fish in landings, it will also tend to increase the average exvessel price for fish. The decision of the firm relative to mesh size now can be analyzed in terms of the firm's profit maximization criteria:

$$\pi = P(S) x h(S) - C(h,S,N)$$

$$\frac{\partial \pi}{\partial S} = o = P \frac{\partial h}{\partial S} + h \frac{\partial P}{\partial S} - \frac{\partial C}{\partial S} = o$$

$$\frac{\partial h}{\partial S} < o; \frac{\partial P}{\partial S} > o; \frac{\partial C}{\partial S} < o$$

Thus, the firm's decision as to mesh size will depend on the magnitude of the changes involved. If the relative change in price is less than the relative change in landings (the general case), the firm's revenue would decrease with an increase in mesh size. In this case, the firm would increase mesh size only if the decrease in cost were greater than the decline in revenue. However, the decrease in cost likely would be small. Therefore, the firm probably would adopt the minimum mesh size. Moreover, the firm is not likely to be cognizant of the external effects of a change in mesh size on the biological parameter. Thus the fishery, left entirely to market forces, would tend to come into equilibrium with K and g as functions of the minimum mesh size. The profit maximizing function for the individual firm then would be:

$$\pi = R(P,h) - C(h,N)$$

$$\frac{\partial \pi}{\partial h} = o = \frac{\partial R}{\partial h} P - \frac{\partial C(h,N)}{\partial h} = o$$

$$\frac{\partial^2 \pi}{\partial h^2} < o = - \frac{\partial^2 C(h,N)}{\partial h^2} < o; \text{ true if } \frac{\partial^2 C}{\partial h^2} > o$$

The model for the entire industry now can be completed with this knowledge of the behavior of the individual firm established. If the firm is going to produce where its marginal cost is equal to price, the marginal cost function for the firm becomes the supply response of the firm, and the supply response for the industry is

N times the respective quantities that the individual firm will offer (under the assumption of homogeneity of cost structure for the firms). If the marginal cost curve of the individual firm is of the general form $b_2h^2 - b_1h + b_o$, then the individual firm supply curve can be expressed as $b_2h^2 - b_1h + b_o - P = o$, and the supply curve for the industry would be :

$$\frac{b_2L_s^2}{N^2} - \frac{b_1 L_s}{N} + b_o - P = o$$

In addition to the supply relationship, given consumer tastes, income, and prices of competing goods, there will be some demand function $L_d = D(p)$ for this fish. Assume this demand function to be of the general form $a_1L_d + P - a_o = o$.

Given the demand and supply relationships for the fishery, equilibrium of the industry must satisfy three identities. First, the total revenue earned in the industry must just equal the total cost of the industry so that firms will not enter or leave the industry; second, the quantity supplied at equilibrium must be equal to the quantity that buyers will purchase at the equilibrium price; and third, the combined output of the industry must be a sustainable yield for the resource for the amount of fishing effort being applied to the fishery at equilibrium. Thus, the industry equilibrium will be:

$$a_1L_d+P - a_o = o \qquad (1)$$

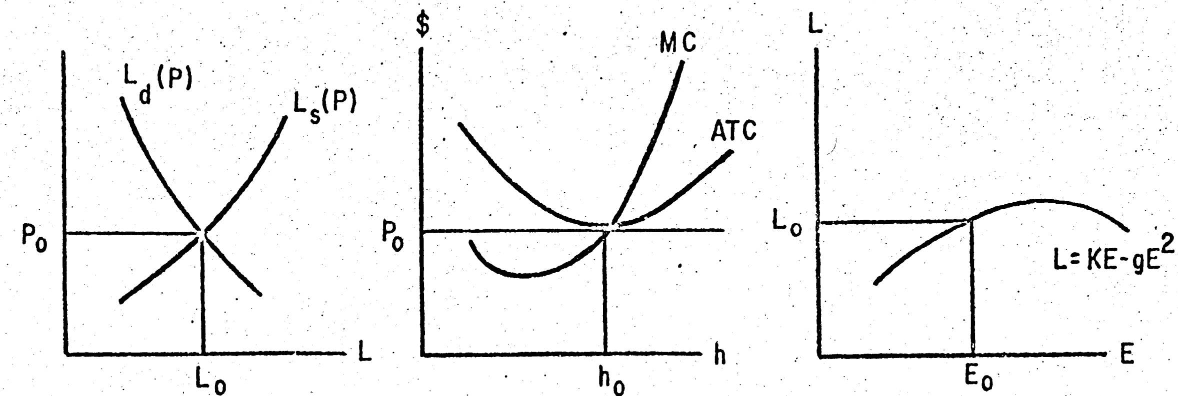
$$\frac{b_2L_s^2}{N^2} - \frac{b_1L_s}{N} + b_o - P = o \qquad (2)$$

$$TC = TR \qquad (3)$$

$$L_d = L_s = L_o \qquad (4)$$

$$L_o = KE - gE^2 \qquad (5)$$

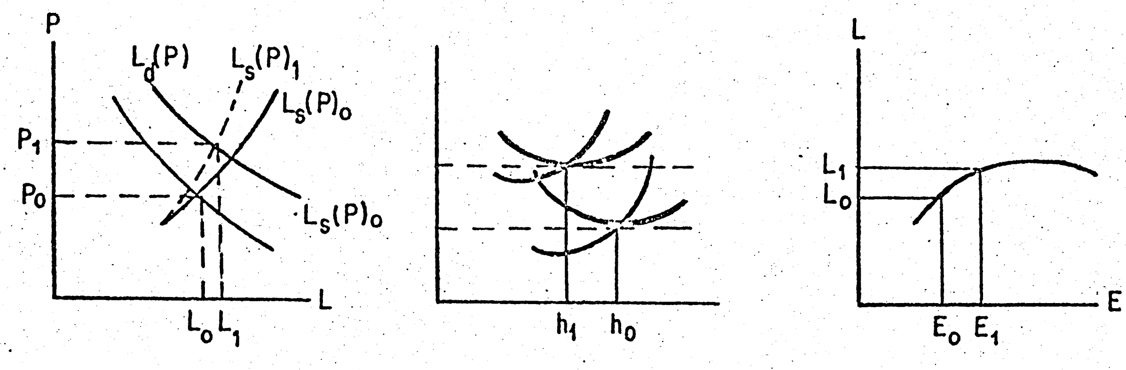
Equilibrium for the above industry can be illustrated graphically as follows:



$$N_o h_o = L_o;\ N_o e_o = E_o$$

Thus, demand and supply determine the equilibrium price, P_o, and quantity L_o. The individual firm equates its marginal cost to price at an output of h_o, and the sum of the production of the individual firms (n x h_o) just equals L_o, the quantity that buyers are willing to purchase at the equilibrium price. At output h_o, the firm is just covering its average total cost of production per pound of fish produced, so that it will be willing to continue in production, but at the same time economic profits are not being earned so there will be no incentive for additional firms to enter the industry. Furthermore, the industry output, L_o, is the sustainable yield of the resource for the amount of fishing effort, E_o, being applied to the resource.

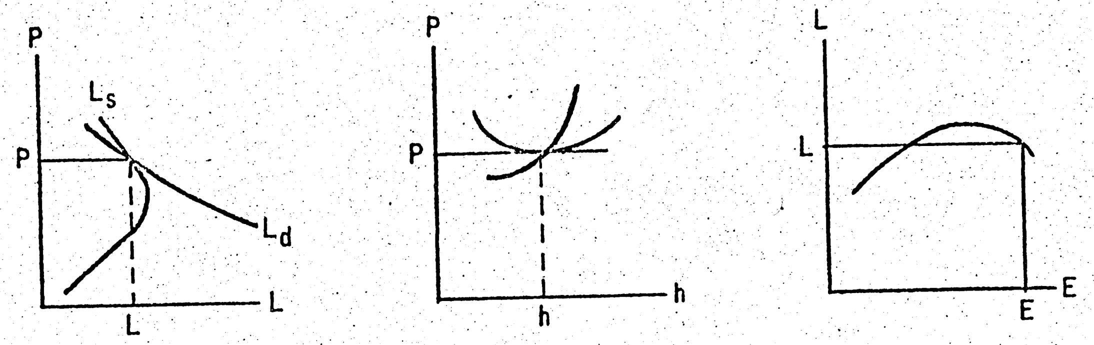
Now suppose a shift in a parameter of the demand curve resulted in an increase in demand for this product. The new equilibrium would be:



$$N_1h_1 = L_1;\ N_1e_1;\ N_1 > N_o$$

Thus, because of the external diseconomies arising from the common property status of the resource, the industry is a rising cost industry. An expansion of the industry (entry of new firms) results in a rise in the costs of producing fish for the individual vessel, and therefore, a decrease in supply (i.e., the firm will be willing to supply the same quantity only at a higher price).

Even though the industry is an increasing cost industry (supply tends to decrease as the industry expands), the total output of the industry will tend to increase with an increase in demand up to the maximum sustainable yield of the resource. However, because the firm does not pay an economic rent for the right to exploit the resource, it is possible for the exploitation of the resource to be carried beyond the point of diminishing total physical returns.



The net result of the above condition would be less fish available, a higher price for fish, and a great redundancy of economic inputs being utilized in the fishery.

Obviously, everybody would be better off to reduce fishing effort in this case. However, given the economic conditions in an open entry competitive fishery, the industry itself cannot correct this situation. Therefore, steps will have to be taken from without the industry to limit the fishing effort.

This brings the problem back to the question of fishery management policy. The various policy objectives outlined in chapter II can now be viewed in terms of the implied equilibrium conditions for the industry. The demand and supply behavioral relationships will be the same in each case. The difference in the respective models will be the industry equilibrium identity added to the model.

A competitive fishery

The identifying feature of a competitive fishery model is the requirement that TC = TR at equilibrium. Equations 1 and 2 can be solved for P and the results substituted in equation 3 to obtain the following results:

1. $P = a_o - a_1 L_d$

2. $P = b_o - \frac{b_1}{N} L_s + \frac{b_2}{N} L_s^2$

From the above, the model can be reduced to:

3. $N \int b_2 h^2 - b_1 h + b_o \, dh = a_o L - a_1 L^2$

The identity equations:

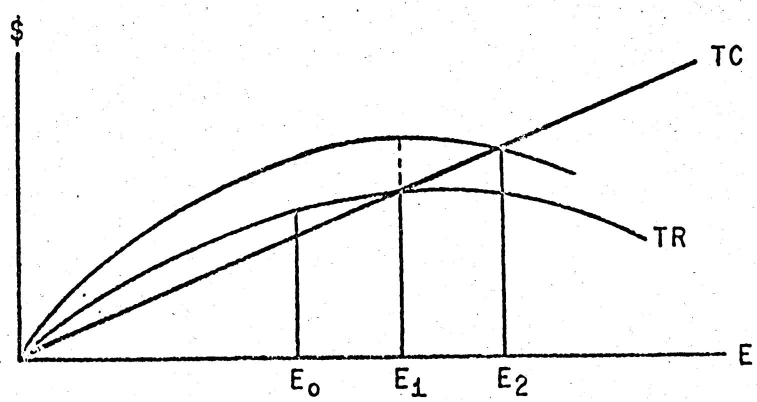
4. $L_d = L_s = L_o$

5. $L_o = KE - gE^2$

can be incorporated into equation 3' to yield the following equation for equilibrium in a competitive fishery:

$$N \int b_2 (Ke - gNe^2)^2 - b_1 (Ke - gNe^2) + b_o \, dh = a_o (KE - gE^2) - a_1 (KE - gE^2)^2$$

The graphic illustration of the above equilibrium condition is:



Thus, under one demand condition, the fishery may be in equilibrium at a level of fishing effort E_o, to the left of E_1, the level of fishing effort that would produce the maximum sustainable yield. However, given a shift in demand, the industry could come into a new equilibrium at E_2, a level of fishing effort to the right of maximum sustainable yield. A necessary condition for the total revenue function to be rising as E increases up to the maximum sustainable yield is that the price elasticity of demand be greater than 1, i.e., that the demand curve is relatively elastic.

Maximum Net Yield Above Cost

The objective posed by Gordon, and Christy and Scott can now be depicted in the same manner. The behavioral equations in the model will be the same as before but the equilibrium equation for the industry must be such as to maximize the monopoly profits from the fishery. Therefore, equation 3 of the model now would become

$$3.\quad MC = MR$$

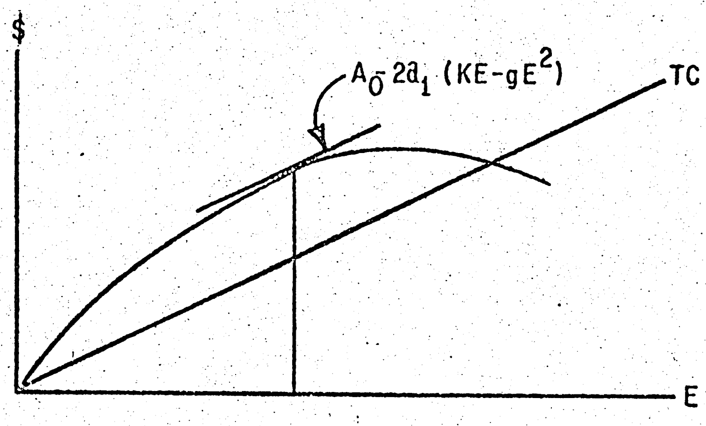
and by solving equations 1 and 2 for P and substituting into equation 3 the following results are obtained:

$$3'.\quad \frac{b_2}{N} L^2 - \frac{b_1}{N} L + b_o = a_o - 2a_1 L$$

Again, identity equations 4 and 5 can be substituted into 3' to form the single equation equilibrium condition to maximize monopoly profits as follows:

$$b_2 \, (KE-gE^2)^2 - b_1 \, (KE-gE^2) + b_o = a_o - 2 \, (KE-gE^2)$$

Graphically this solution is:



An increase in demand now would shift the revenue function upward, and therefore, at the former level of E, the slope of the cost curve would be less than the slope of the revenue curve thus permitting an expansion of the fishing effort until the slope of the revenue curve again were equal to the slope of the cost curve. The vertical distance between the cost function and the revenue function would be the monopoly profits which could either be left to be divided among the economic inputs used in the fishery or could be taxed away. In no case would the fishery ever expand to the point of maximum sustainable yield.

In order for the net return above cost to be a maximum, the industry would have to be on the highest possible revenue curve, and the lowest possible cost curve. Therefore, the management program would have to be concerned with selecting the mesh size and number of firms along with the overall level of effort allowable in the fishery to achieve the desired goal. A mesh size larger than the mesh size which would place the industry on the landings/effort function commensurate with the maximum sustainable yield would be adopted only if the increase in price more than offset the decrease in landings for each respective output of the industry.

Maximization of Economic Rent

The Crutchfield-Zellner proposal to maximize economic rent would require the maximization of $R = PxL - C(L)$. Economic rent, R, would be a maximum when $\frac{dR}{dL} = o$, or, when $P - \frac{dC}{dL} = o$. Thus, equation e would become:

$$3. \quad P - \frac{dC}{dL} = o$$

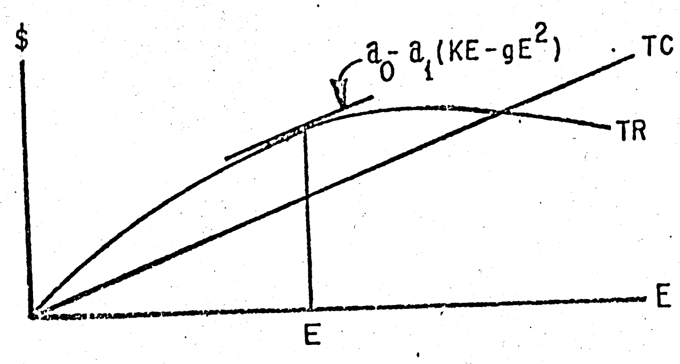
and substituting from equations 1 and 2

$$3'. \quad a_o - a_1 L = b_2 L^2 - b_1 L + b_o$$

and substituting from equations 4 and 5

$$a_o - a_1 (KE-gE^2) = \frac{b_2}{N} (KE-gE)^2 - \frac{b_1}{N} (KE-gE^2) + b_o$$

Graphically the equilibrium is:



Again, to assure that economic rent from the resource was a maximum, mesh size and the number of vessels would have to be determined as a part of the management program to assure that the industry was on the highest revenue function, and lowest cost function.

The Turvey Solution

Turvey proposed that a quantity, G, be maximized for a fishery where G = (TR + S) - (TC - R):

TR = Total Revenue from fish produced

S = Consumer Surplus

TC = Total Cost of producing the fish

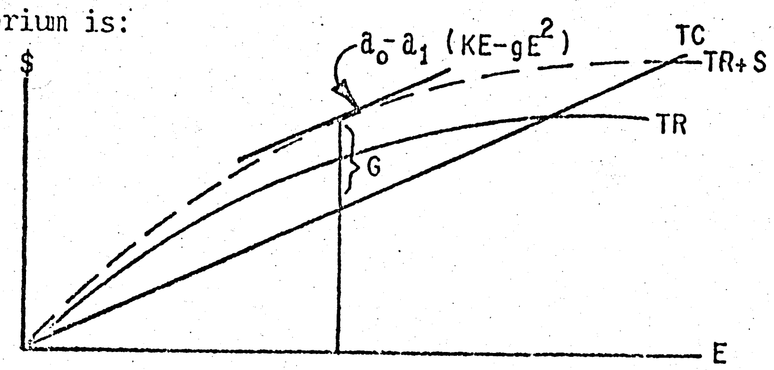
R = Intramarginal Rents

For simplification, it will be assumed that the labor supply is homogeneous in its skills and willingness to go to sea. Therefore, no fishermen are earning a quasi-rent so that intramarginal rent is zero. The Turvey maximum therefore would be:

$$G = \int_o^L a_o - a_1 L - N\int^h b_2 h^2 - b_1 h + b_o$$

$$\frac{dG}{db} = o = a_o - a_1 L = \frac{dC}{db}$$

The biological parameter, $L = KE - gE^2$ can then be used to replace L in the identity equation to reduce the Turvey equilibrium to one equation in terms of fishing effort. The graphical illustration of this equilibrium is:



If no intramarginal rents were accruing to capital and labor, the only source of rent would be the economic rent implicit in the natural resource. Therefore, the Turvey proposal would justify increased fishing effort as long as consumer surplus increased by an amount greater than the decrease in economic rent resulting from the increased effort.

1. Milner B. Schaefer, "Some Considerations of Population Dynamics and Economics in Relation to the Management of the Commercial Marine Fisheries," J. Fish. Res. Bd., Canada, 141(5) 1957, p. 673.

CHAPTER IV

THE GEORGES BANK HADDOCK FISHERY

Georges bank is a plateau rising from the ocean floor to produce an area of relatively shallow water - 2 to 50 fathoms in depth. This plateau lies to the east of Nantucket and Cape Cod, falling between 40 degrees and 42 degrees north latitude and 66 degrees and 69 degrees west longitude. The Bank is oblong in shape angling from southwest to northeast. Although the Bank extends about 150 miles from southwest to northeast, and 98 miles from south to north, the total area of the fishing bank is only approximately 8,000 square miles.

The bottom is sand intermingled with patches of gravel and rock. Various shoal areas are found on the Bank where water depths are reduced to 2 to 15 fathoms. The gulf stream, passing to the east of Georges Bank, produces a rapid tide across the Bank. However, because of the shoal areas, the tide is not a smooth flow but rather a series of swirls, eddies, and rapid currents.

The fisheries of the Northwest Atlantic Ocean have a commercial history extending back to pre-colonial days. Growing recognition of the combined problems of reduced abundance and potential depletion of the fishery resources of the Northwest Atlantic led to the convening of a conference of 11 nations (Canada, Denmark, France, Iceland, Italy, Newfoundland, Norway, Portugal, Spain, United Kingdom, and the United States) fishing the Northwest Atlantic in Washington, D.C., in January 1949. The representatives of these governments drafted the text for an International Commission of the Northwest Atlantic Fisheries (ICNAF). The Commission entered into force July 3, 1950, with the deposit of documents of ratification by Canada, including Newfoundland, Iceland, the United Kingdom, and the United States. By 1967, membership in ICNAF had expanded to 14 nations composed of Canada, Denmark, France, Federal Republic of Germany, Iceland, Italy, Norway, Poland, Portugal, Romania, Spain, Union ofSoviet Socialist Republic, United Kingdom, and the United States of America.

The objective of ICNAF is stated in the introduction of the Convention as follows:

> "The Governments whose duly authorized representatives have subscribed hereto, sharing a substantial interest in the conservation of the fishery resources of the Northwest Atlantic Ocean, have resolved to conclude a convention for the investigation, protection and conservation of the fisheries of the Northwest Atlantic Ocean, in order to make possible the maintenance of a maximum sustained catch from those fisheries..."[1]

The Convention area is defined in Article I of the Convention:

> "The area to which this Convention applies, hereinafter referred to as "the Convention Area," shall be all waters, except territorial waters, bounded by a line beginning at a point on the coast of Rhode Island in 71°40' west longitude; thence due south to 39°00' north latitude; thence due east to 42°00' west longitude; thence due north to 59°00' latitude; thence due west to 44°00' west longitude; thence due north to the coast of Greenland; thence along the west coast of Greenland

to 78°10' north latitude; thence southward to a point in 75°00' north latitude and 73°30' west longitude; thence along a rhumb line to a point in 69°00' north latitude and 59°00' west longitude; thence due south to 61°00' north latitude; thence due west to 64°30' west longitude; thence due south to the coast of Labrador; thence in a southerly direction along the coast of Labrador to the southern direction along the coast of Labrador to the southern terminus of its boundary with Quebec; thence in a westerly direction along the coast of Quebec, and in an easterly and southerly direction along the coast of New Brunswick, Nova Scotia, and Cape Breton Island to Cabot Strait; thence along the coasts of Cape Breton Island, Nova Scotia, New Brunswick, Maine, New Hampshire, Massachusetts, and Rhode Island to the point of beginning."[2]

The Northwest Atlantic includes a wide range of fishing grounds and species of commercially valuable fish. To facilitate studies and discussion of problems of the individual fisheries, the Convention area was divided into five sub-areas and smaller divisions within each sub-area. Division 5Z of sub-area 5 is comprised of Georges Bank (figure 1).

The combination of temperature, depth of water, and nature of bottom result in Georges Bank being one of the most productive fishery areas of the Northwest Atlantic and perhaps the world. In 1966, 741,766 metric tons of fish and shellfish were taken from Division 5Z (Georges Bank) of the ICNAF Convention area. This represents 23 percent of the total catch for the entire Convention area in that year.

Haddock (melanogrammus aeglefinus) is a member of the Gadidae family of fishes. Other commercial species of this family are cod, pollock, and cusk. The haddock is not a large fish on the average. The bulk of commercial landings of haddock range between 14 and 23 inches in length and 1-1/8 to 4-3/4 pounds in weight.

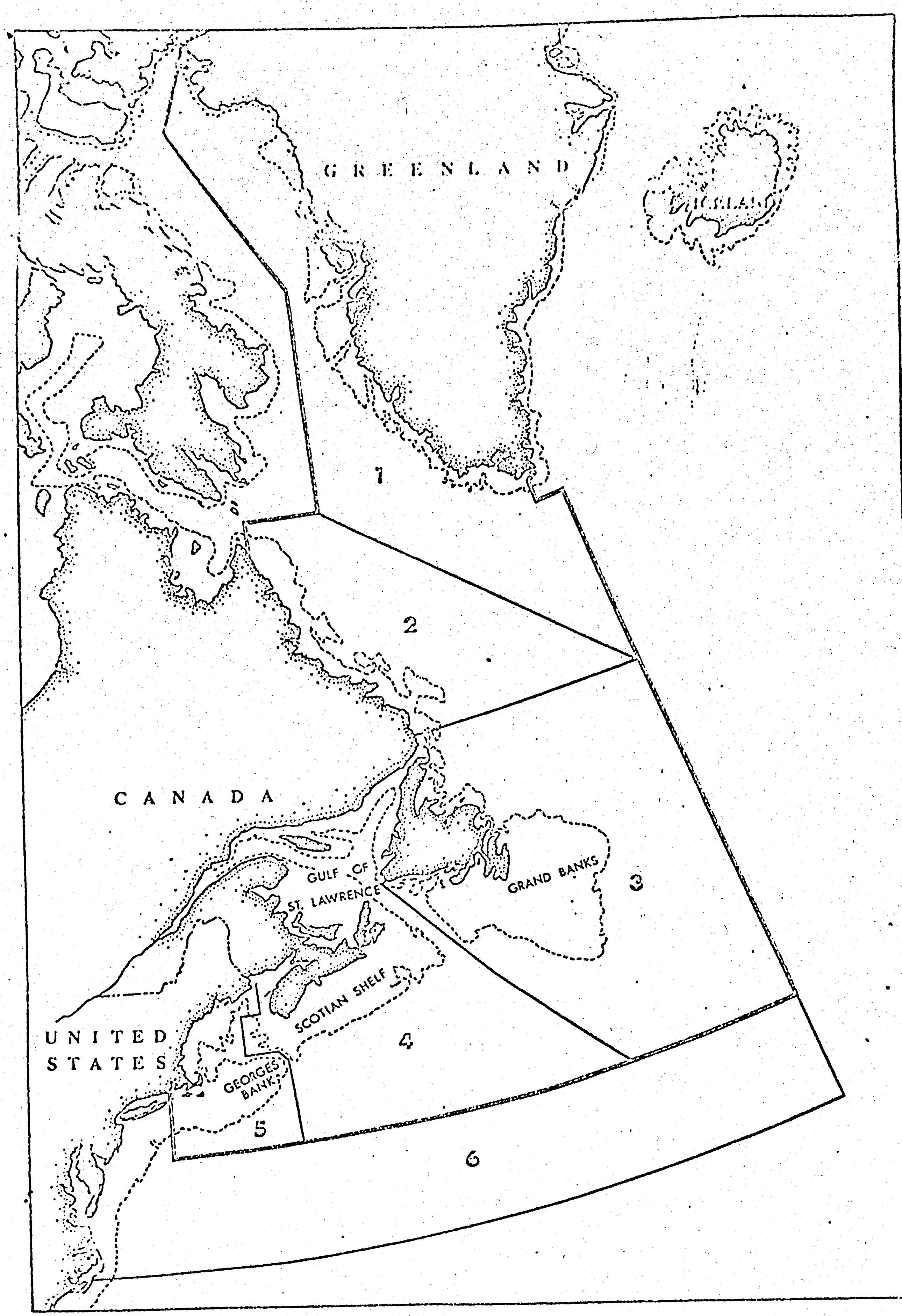


Figure 1. ICNAF Area.

The haddock is a bottom-living-and-feeding fish prefering water depths of 25-75 fathoms and a temperature range of 35 degrees to 52 degrees Fahrenheit. They tend to inhabit gravel, pebbly, clay or sandy bottoms, and feed on a wide range of invertebrates that live on these bottoms.

Haddock mature sexually at a weight of 2-3 pounds or at an age of 3-4 years. The females of the species are quite prolific, producing as many as 169,000 eggs in their first year of spawning and over 1-1/2 million eggs when they are 7-8 years of age. The main spawning season is from late February to May. The eggs are spawned on the bottom but are buoyant and rise to the surface after spawning. The incubation period of the egg tends to vary with water temperature and may be as short as 13 days with temperature in the vicinity of 41 degrees, or 15 days or more for temperatures of 37 degrees or colder. After hatching, the young persist as pelagic creatures for a period of approximately 3 months during which time they complete a larval stage and mature into young fish. During the pelagic stage, the eggs and larvae are at the mercy of the currents and a substantial number may drift out of the area.

When the young fry reach a size of 3-4 inches, they settle to the bottom and complete their life cycle in their preferred habitat of 25-75 fathoms of water. Therefore, due to the fact the Georges Bank is bordered on the west by shallow water, and on the south, east, and north by deep water, the haddock population is a good example of a closed fishery, i.e., the bottom-dwelling population neither gains nor loses members by migration.

Between the age 2-3, the young haddock reach a size of 13-14 inches in length and 1-1/4 - 1-1/2 pounds in weight. At this size, the fish are subject to capture by the 4-1/2 inch mesh used in the commercial trawl fishery. Therefore, the haddock are considered to be recruited to the population at 2+ years of age. The oldest haddock caught of record was 14 years of age. However, only about 15 percent of the commercial catch on the average is comprised of fish 7 years old or older. Therefore, for practical purposes, the fishery population is comprised of 6 age groups, 2+ years of age through 7+, with the 2+ and 3+ age groups accounting for approximately 50 percent of the commercial catch in recent years.

Temperature, bottom conditions, water depths, and food supply on Georges Bank are particularly favorable for haddock and result in this area being the most productive haddock fishery in the world. Georges Bank generally has accounted for 25 to 30 percent of the entire catch of haddock for the ICNAF Convention area, and from 65 to 80 percent of the entire United States catch of haddock (table 1). Haddock generally average higher in price than most species of fish taken in the Northwest Atlantic so that if a comparison could be made of the ICNAF production on a value basis, the Georges Bank haddock fishery would appear even more important in the total Northwest Atlantic fishery picture.

Table 1. Contribution of Georges Bank to the Haddock Catch of the Convention Area and the United States, 1955-1966

	Haddock Catch in Convention Area				Haddock Catch for U.S.	
Year	Total Convention Area	On Georges Bank	Georges Bank As Percentage Of Total	Total U.S. Landings	From Georges Bank Total	Georges Bank Percentage Of U.S.
			(000 Metric Tons)			
1955	198	43	22	64	43	67
1956	194	51	26	73	51	70
1957	171	49	29	64	49	77
1958	138	37	27	57	37	65
1959	129	36	28	51	36	71
1960	159	41	26	54	41	76
1961	179	46	26	61	46	75
1962	138	54	39	61	49	80
1963	136	55	44	56	44	79
1964	142	64	45	60	47	78
1965	249	150	60	61	53	87

Source: ICNAF Statistical Bulletin, Vols. 5-15, Dartmouth, Nova Scotia, Canada.

The Georges Bank haddock fishery was exclusively a United States fishery until 1962. Since 1962, increasing amounts of haddock have been taken by Canada and Russia. In the case of Canada, the haddock taken from this area represent fishing trips made to Georges primarily for haddock fishing. In the case of Russia, the catch during 1962-64 was largely in the form of incidental catch while fishing for other species. Russian vessels fished Georges Bank for the first time in 1961. In that year, they reported taking a total of 68,521 metric tons of fish from sub-area 5Z of which 67,550 metric tons were herring and only 55 tons were haddock. In 1962, the Russian fleet reported a catch of 209,370 metric tons on Georges of which 151,144 metric tons were herring and 1,134 metric tons were haddock.

The catch for 1965 and 1966 represents a significant change in Russian fishing. The hatch of haddock eggs and retention of fry on Georges Bank were unusually high in 1963. As a result, recruitment in 1965 was of record proportions. The entrance of this enormous year class into the fishery in 1965 resulted in greatly improved catch rates on the part of all vessels in the fishery in both 1965 and 1966. The Russian fleet was aware of the large year class entering the fishery in 1965 and took advantage of this abundance to fish specifically for haddock. Thus in 1965 and 1966 the Russian fleet landed 82,000 and 48,000 metric tons of haddock respectively. Since 1965, all year classes recruited to the fishery have been average or below. Therefore, due to the fact that the enormous abundance of the 1965 recruitment was harvested in 1965 and 1966, the catch rate, as well as total catch have fallen sharply since 1966.

Data on total landings of haddock from sub-area 5 date back to 1873. However, measurement of effort and catch per unit of effort based on observations of a sample study fleet were not started until 1932.

Prior to 1925, the fishery was being fished at a low level of effort and the standing stock could almost be considered a virgin stock of fish. From 1925 on, fishing effort increased rapidly. The 3-year period, 1929-31, was a particularly heavy period of fishing. Based on the number of vessel trips to Georges Bank during this period, it is estimated that fishing effort may have averaged over 13,000 days per year during these 3 years. This fishing effort reduced the standing stock and catch rates fell sharply. Following the peak level of effort in 1930, fishing effort declined steadily to a low of 4,800 standard days in 1934. The level of fishing activity then increased and stabilized between 7,000 and 8,000 days through the 1937-41 period.

Limitations on manpower, materials, and funds resulted in a decline of fishing activity again during World War II. Fishing effort on Georges Bank averaged only 5,300 days per year during the four war years compared with an average of 7,700 days for the previous 5 years. Following the cessation of hostilities, fishing effort surged to a peak of 8,200 days in 1947 and then dropped back and stabilized at a level of about 6,000 days for the period 1950-56. Fishing effort then increased again and reached a peak of 9,400 standard days in 1959, the highest level of fishing effort since accurate records were started for the study fleet in 1932.

Fishing activity had appeared to stabilize around 8,000 days of effort during the turn of the decade. However, improved catch rates and prices resulted in a further increase in domestic fishing in 1963 and 1964. The total level of fishing effort also increased as a result of Canadian and Russian catches during the 1962-64 period. The various periods of fishing effort, catch per unit of effort, and total harvest are summarized in table 2.

Table 2. Fishing Effort, Catch Per Unit of Effort, and Total Catch of Haddock on Georges Bank for Selected Periods, 1934-1964

Time Period	Average Days of Effort x 10^{-3}	Catch Per Day of Effort x 10^{-3}	Total Catch x 10^{-6}
1934-36	5.8	12.0	71.0
1937-41	7.7	12.3	101.3
1942-45	5.3	17.5	92.8
1946-49	7.6	12.6	96.1
1950-56	6.0	13.8	83.9
1957-62	8.1	10.4	83.5
1963-64	12.3	9.4	114.9

Source: Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts

The catch per day of fishing effort is subject to substantial fluctuations due to annual variation of recruitment. Furthermore, the recruitment may, by chance, happen to coincide with a change in fishing effort, i.e., a larger year class may be recruited to the fishery in the year that fishing effort increased. Thus, the full impact of fishing effort on catch rates does not show up in the data. Nevertheless, the averages for catch rate and days of fishing effort in the above table do show an inverse relationship between the level of fishing effort and catch rate.

Two factors can be cited as having some impact on catch rates during the 1950's. First, one of the initial projects taken into consideration by the newly-formed ICNAF was the subject of a minimum mesh size for trawl gear used for haddock. The normal industry practice was to use trawls with a mesh opening of 2-7/8 inches in the cod end. This mesh size resulted in the taking of a large number of fish too small for market acceptance. These small fish were culled out of the catch and discarded overboard. However, this resulted in the destruction of these fish and thus had an impact on recruitment to the fishery.

Based on biological studies of growth rates and the effect of mesh size on escapement, a minimum mesh size of 4-1/2 inches was proposed for haddock fishing in sub-area 5. This proposal was approved by Canada and the United States (the only two countries affected) in February 1953 and was put into effect on June 13, 1953. This increase in mesh size tended to decrease the loss of young fish and should have had a positive impact on recruitment from 1953 on. A second factor that is significant in the post World War II fishing effort is the wide scale adoption and use of echo sounders as fish locating devices. Echo sounders were introduced into the New England fisheries in the early 1950's and had come into general use by the end of the decade. Although no objective measurement has been made of the effect of echo sounders on the fishing efficiency of New England vessels, the fact that the echo sounder is now standard equipment on all groundfish trawlers indicates that industry considers the cost justifiable. It would seem logical that with echo sounders the vessel would be able to increase the proportion of standard days fished per trip at sea and perhaps increase the catch per day.

The measurement of catch per unit of effort for the sample study fleet has enabled fishery biologists to draw tentative conclusions about the population dynamics of the Georges Bank haddock population. The relationship between catch per standard day of fishing effort (24 hours of actual trawling) and the total number of standard days of fishing effort is illustrated in figure 2. The catch per day of effort is plotted against the terminal year of a 3-year moving average for total fishing effort. The use of a 3-year moving average introduces an adjustment for the impact of previous years' fishing effort on the standing stock.

The equation for the least squares regression line is:

$$(1) \quad \frac{L}{\frac{E}{1000}} = 22.6 - 1.357 \frac{E}{1000}$$

Where: L = Annual landings of haddock from Georges Bank
E = Standard days of fishing effort

The coefficient of correlation was .618. With 20 degrees of freedom, a value of .456 is significant at the 1 percent level.

If the equation (1) is multiplied through successively by 1,000 and by E, the following equation is derived:

$$(2) \quad L = 22{,}600E - 1.357E^2$$

This equation would represent an estimate of the equilibrium yield/effort relationship for the Georges Bank haddock resource (see line A in figure 2).

Additional considerations indicate that the true catch/effort relationship may have a somewhat steeper slope and peak sooner and at a slightly higher point than the equation derived empirically. The empirical observations of catch per unit of effort are likely biased on the high side for increases in fishing effort and on the low side for decreases in fishing effort. In the case of a decrease in fishing effort, the catch rate would reflect a smaller standing stock than would be true at equilibrium for the lower catch rate. The reverse would be true in cases of increases in fishing effort. Thus, it would be reasonable to shift the catch/effort relationship to the left and increase the slope slightly. Based on estimates of total mortality derived from age classification of the catch, the Beverton-Holt yield-per-recruit model turns out a catch/effort relationship as follows:

$$(3) \quad L = 28{,}340E - 2.0243E^2$$

$$(4) \quad L' = 28{,}340 - 4.0486E$$

Solving for E in equation (4) the maximum sustainable yield would occur at about 7,000 days of fishing effort. Substituting this value into equation (3) yields an estimate of 99,190,000 pounds of haddock for the maximum sustainable yield. In view of the stronger supporting biological evidence for the last equation, it is used as the best estimate of the yield/effort relationship for the Georges Bank haddock population (see line B in figure 2).

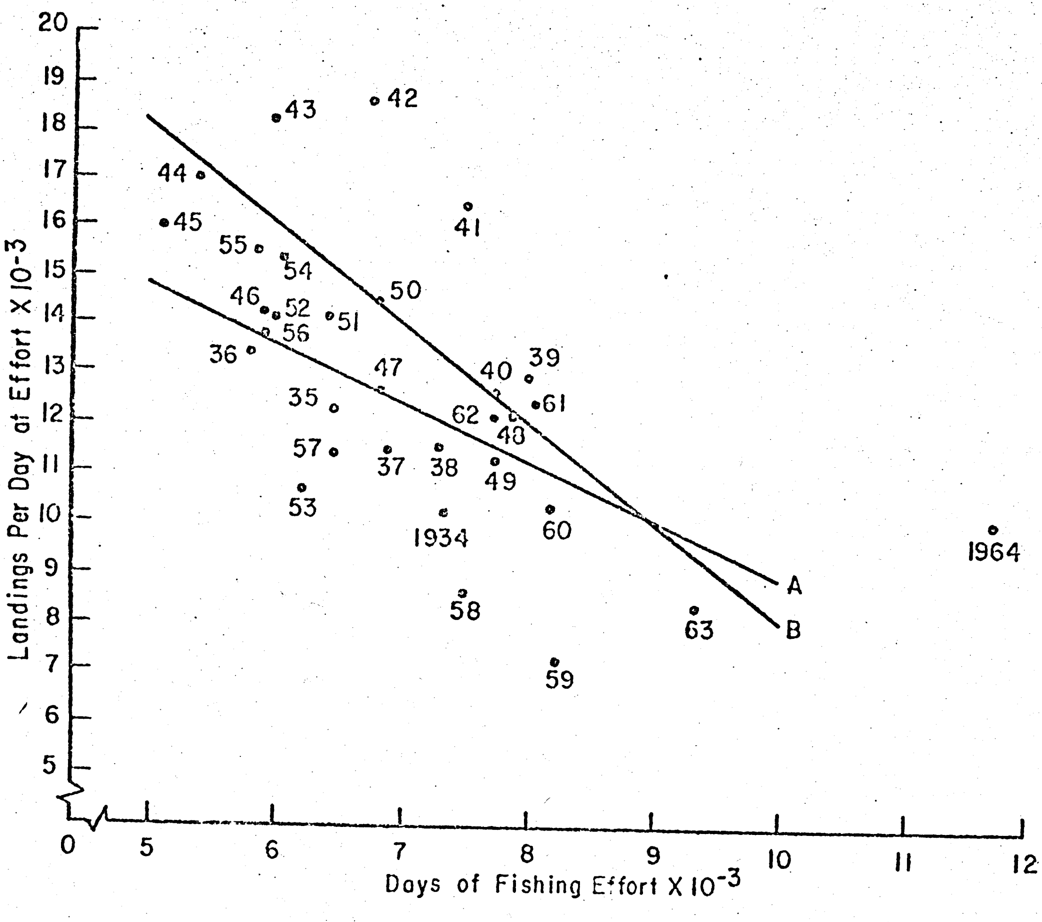


Figure 2. Relationship Between Catch Per Day of Effort and Total Effort

Georges Bank is fished by vessels operating out of ports from Rockland, Maine, to Newport, Rhode Island. However, the bulk of the haddock is landed at Boston, Massachusetts. A tabulation of 16,622 vessel trips to Georges Bank by 480 vessels accounting for

96 percent of the haddock caught by the United States on the Bank in 1964 showed that 68.9 percent of haddock produced from the Bank was landed at Boston. Gloucester and New Bedford, Massachusetts, were the next two most important ports in terms of a market for haddock from Georges. These three ports accounted for 97.7 percent of the 86.1 million pounds of haddock landed by these 480 vessels (see table 3).

Table 3. Landings of Haddock Caught on Georges Bank by Port for 1964

Port	Haddock Landings	Percentage of Total
Boston, Mass.	59,300,038	68.9
Gloucester, Mass.	14,482,359	16.8
New Bedford, Mass.	10,323,842	12.0
Chatham, Mass.	978,738	1.1
Provincetown, Mass.	737,875	.9
Other Ports	287,166	.3
Total	86,110,018	100

Source: Bureau of Commercial Fisheries, Division of Data Collection, Washington, D.C.

The landings by port do not tell the full story of the importance of Boston as the center of the fishing activity for the Georges Bank haddock resource. Although 480 vessels were involved in the 16,622 vessel trips to Georges Bank, a significant amount of haddock landings from Georges is in the form of incidental catch while fishing for other species. The criterion for designating vessels as primarily haddock vessels was that their catch had to be composed of at least 50 percent haddock. Based on this criterion, 70.9 million pounds of haddock--82.3 percent of the landings--were landed by 93 vessels (see table 4). The bulk of these landings was made by medium and large side-trawlers fishing out of Boston.

Table 4. Landings of Haddock from Georges Bank by Vessel Size for 1964

Vessel Size (Full time haddock vessels)	Number of Vessels	Pounds of Haddock Landed	Percentage of Total	Pounds of Other Species Landed
50 tons and under	5	530,545	.6	75,412
50-150 tons	52	33,972,486	39.4	14,409,879
150 tons and over	36	36,382,362	42.3	14,564,837
Sub-total	93	70,885,383	82.3	29,050,128
Incidental Catch of Other Vessels				
50 tons and under	190	2,915,624	3.4	89,884,135
50-150 tons	183	11,360,362	13.2	112,827,424
150 tons and over	14	948,639	1.1	2,696,213
Sub-total	385	15,224,625	17.7	205,407,772
Total	480	86,110,018	100	234,457,900

Source: Bureau of Commercial Fisheries, Division of Data Collection, Washington, D.C.

Of the 93 vessels whose landings contained 50 percent or more of haddock, 61 vessels landed their catches primarily at Boston (table 5). These 61 vessels accounted for 56.7 million pounds of haddock in 1964 - 95.6 percent of total landings at Boston and 71.3 percent of total landings from Georges Bank.

Table 5. Landings of Haddock from Georges at Boston by Full-time Haddock Vessels in 1964

Vessel Size	No. of Vessels	Pounds of Haddock Landed
50 tons and under	5	530,545
50-150 tons	32	23,937,670
150 tons and over	24	32,215,950
Total	61	56,684,145

Sourco: Bureau of Commercial Fisheries, Division of Data Collection, Washington, D.C.

Large trawlers accounted for 56.8 percent of the landings at Boston of the vessels primarily engaged in haddock fishing. However, the trip duration for most of the medium trawlers varied from 1 to 5 days. Therefore, these vessels were fishing the channel and western edge of the Bank. Consequently, the major fishing effort of the central and eastern portions of the Bank had to be carried out by the large trawlers whose trips averaged about 10 days.

The commercial fishing industry is somewhat unique among United States industry in that labor is not paid a predetermined wage but rather the value of the catch is split among the vessel owner and crew as per an agreed upon "lay system."

The "lay system" and earnings for average crewman and average vessel of the study fleet in 1964 are presented in table 6. Certain costs are paid out of the crew share and the net is then divided by the number of men in the crew to determine the share per man. The present agreement between vessel operators and fishermen specifies that the minimum payment will be $12 per day for deckhands and $13 per day for the other crewmen (i.e., cook, 2nd engineer, mate, 1st engineer, and captain). Therefore, a 10-day trip for a 17-man vessel would have to yield a minimum net crew share of $2,090 ($13x10x5+ $12x10x12=$2,090). If the net crew share is less than this amount, the trip is termed a "broker trip" and the vessel operator must make up the difference between the actual net crew share and the minimum guarantee. Some vessels are so well managed that they have no broker trips within a year. However, for 1964, the average annual "broker payment" for the 13 vessels in the sample fleet was $3,690 per vessel.

As indicated in the discussion of the population dynamics of the Georges Bank haddock resource, a study fleet is used to gather the

Table 6. Average Costs and Earnings of Study Fleet Vessels in the Georges Bank Haddock Fishery in 1968

Item		Amount	
Gross			$234,677
Less:	Wharfage	$ 1,224	
	Scale fee	233	
	Exchange fee	2,347	
	Welfare fund	2,347	
	1st engineer bonus	644	
	Mate bonus	515	
	2d engineer bonus	387	
	Echo sounder	627	
	Watching	742	
	Radar	1,277	
	Ice	1,870	
	Lumpers	450	
	Total		12,663
Net Stock			222,014
Crew Share (60 percent)			133,208
Less:	Fuel and oil	21,453	
	Ice	3,794	
	Icing	824	
	Groceries	14,166	
	Cook bonus	387	
	Water	206	
	Lumpers	2,109	
	Miscellaneous	84	
	Total		43,024
Net Crew			90,184
+Broker Payments			3,690
Total Crew Earnings			93,874
Share Per Man			5,904
Vessel Share (40 percent)			88,805
Less:	10 percent captain bonus	8,881	
	Broker payments	3,690	
	Gear	15,000	
	Insurance, repair & maintenance	32,000	
	Payroll taxes	3,665	
	Office expenses	10,000	
	Total		77,236
Net for Interest, Depreciation, Management, and Risk			11,570

Source: Unpublished data from Atlantic Fishermen's Union and vessel records at Boston, Massachusetts.

data on catch per standard day of effort. The study fleet in 1964 included 13 vessels. The composite and average characteristics of the study fleet are given in table 7.

Table 7. Composite and Average Characteristics of 13 Vessels in Georges Bank Snudy Fleet in 1964

Item	Total for Study Fleet	Average per Vessel
Vessel Characteristics		
Age	332	26
Length (ft)	1,439	111
Gross registered tonnage	2,996	230
Horsepower	7,030	541
Crew size	207	15.9
Fishing Characteristics		
No. of trips	335	25.8
No. of days at sea	3,510	270
Standard days of fishing effort	2,297	176.7
Total catch (lbs.)	31,824,000	2,448,000

Source: Atlantic Fishermen's Union, Boston, Mass.

Thus, from the average characteristics of the study fleet it can be seen that the fleet is largely comprised of older boats. However, age of the vessel is not the sole determinant of fishing success if the vessel has been kept in good repair. Some of the older vessels in the study fleet are "highliners" in the fishery. The average success of the study fleet compares quite closely with the average of all vessels.

A gross return of $11,570 might be considered alright by a vessel owner if the vessel were completely depreciated out and if the owner has no indebtedness on which he was paying interest and principal. However, if the vessel owner had just gone into debt $70,000 for a new engine and had to pay 6 percent interest plus 1/10 of the principal each year on this debt, he would have nothing left for management and risk until after after most of the loan had been repaid.

The return to management posed here certainly would not be attractive from the viewpoint of reinvesting in this industry. If a new vessel cost of $500,000 in 1964, and 40 percent of the vessel cost would be paid for under the vessel construction subsidy bill, the owner would have to consider investing $300,000 of his own money in this vessel. In this case, he should charge interest and depreciation against the vessel construction.

At 6 percent interest and 20 years for depreciating the hull, his annual interest and depreciation charge would be $36,000. Therefore, if he could not expect to gross more than $11,570 per year the venture obviously would be a losing proposition. Therefore, for the average vessel in 1964, the Georges Bank fishery could not be considered a particularly lucrative venture.

The financial conditions of the industry are equally as discouraging when considered from the viewpoint of the average fisherman. The average annual share per man of $5,904 cannot be considered a good wage for a full time occupation and particularly so considering the number of hours on duty and the hazardous conditions necessary to earn this annual income. The share of $5,904 was based on a vessel spending 270 days at sea a year. The crewman stands a 12-hour watch each day at sea. Therefore, if a fisherman made all trips, which would be necessary to earn the full $5,904, he would be standing watch, i.e., on duty work 3,240 hours a year. On this basis, his earning per hour would be $1.82 if he were not allowed overtime pay for time on duty beyond 40 hours per week. If, however, he were to be paid on the basis of straight time for 40 hours, and time and one-half for over 40 hours, his base hourly wage would be only $1.55 per hour. This hourly rate cannot be viewed as attractive when compared to hourly rates in alternative occupations in the Boston area (table 8).

Table 8. Average Hourly Earnings for Production Workers in Selected Occupations in Boston, 1964

Industry	Average hourly rate
Durable goods manufacturing	$2.68
Primary metal industries	2.64
Textile mill products	2.05
Food and kindred products	2.40
Carpenters, maintenance	3.13
Electricians, maintenance	3.24
Engineers, stationary	3.06
Firemen, stationary or boiler	2.66
Helpers, maintenance trades	2.62
Mechanics, maintenance	2.97
Oilers	2.48
Painters, maintenance	2.88
Pipefitter, maintenance	3.19
Tool and diemakers	3.40
Janitors, porters, and cleaners	1.86
Laborers, material handling	2.25
Packers, shipping	2.32
Shipping and receiving clerks	2.50
Truck drivers	2.91
Elevator operators	1.55
Guards and watchmen	1.74

Source: Virgil J. Norton and Morton M. Miller, An Economic Study of the Boston Large-Trawler Labor Force, U.S. Department of the Interior, Bureau of Commercial Fisheries, Circular 248, May 1966, p. 15.

The unattractive level of earnings to labor in this industry is substantiated by the age characteristics of the fishing labor force. In the same publication cited in the above table, Norton and Miller reported that 62 percent of the labor force making trips on trawlers out of Boston were 55 years of age or older and only 12 percent were under 35. Therefore, this industry has not been able to attract young workers at any appreciable rate during the past decade. These statistics imply a trapped, relatively immobile labor force.

1. International Commission for the Northwest Atlantic Fisheries, Report No. 1, U.S. Department of State, 1951, p. 13.

2. IBID, pp. 13-14.

CHAPTER V

OUTCOME OF ALTERNATIVE MANAGEMENT OBJECTIVES

ON THE

GEORGES BANK HADDOCK FISHERY

The purpose here is to illustrate the level of fishing effort on the Georges Bank haddock fishery necessary to achieve each of the policy alternatives outlined in Chapter III and to demonstrate the returns to capital and labor in each case. This means that solutions must be found for the level of fishing effort, volume of fish, and price for fish given the biological and economic parameters for the resource and industry. Ideally, the parameters should be estimated simultaneously from a common set of empirical data. Unfortunately, this cannot be done for the Georges Bank fishery.

The biological parameters are based on study fleet data from 1933 through 1964. However, cost data on the vessels are available only since 1960. The observations for 1965 and 1966 have been eliminated because of the obvious departure from normal conditions due to the entrance of an enormous year class in 1965 and the simultaneous entrance of Russian vessels on a large scale in the haddock fishery. If a simultaneous equation model were fit to the common data, i.e., costs and returns, and catch per day of effort of the study fleet for 1960-64, the observations would apply only to a small arc of the overall yield/effort function. Furthermore, the observations would encompass a period of time during which fish harvest was not only beyond the maximum sustainable yield but fishing effort was increasing. Thus, the data would not give reliable estimates of all the parameters in the bio-economic model.

In view of these data problems, a static model assuming complete certainty is employed. The biological data developed by the Woods Hole Biological Laboratory and discussed in the previous chapter are used as the basis for the biological parameters. A study by Farrell and Lampe on the demand for haddock was used as a basis for the price elasticity for haddock. Vessel performance and cost data for a selected sample of six Boston offshore trawlers were used as the basis for determining the cost of fishing. Inasmuch as the purpose of this analysis is to compare the outcome of alternative equilibrium positions and not to study the dynamics of the industry, the model used here is applicable.

The Biological and Economic Parameters

As developed in the preceding chapter, the equilibrium landings/effort function and the catch per day of effort are:

(1) $L = 28,340\ E - 2.024\ E^2$

(2) $L/E = 28,340 - 2.024\ E$

Thus, at long-run equilibrium, the combined catch of all of the vessels in the fishery must coincide with the corresponding yield value for that level of effort as per equation (1).

Farrell and Lampe estimated the elasticity of demand for haddock at the vessel level to be 2.22.[1] This estimate was based on monthly data for the period 1954-1962 using a limited information maximum likelihood simultaneous equation model in logs. Therefore, they had a constant elasticity throughout the demand curve.

For 1964, haddock landings from all grounds totaled 133,498,000 pounds and the exvessel price for haddock averaged 10.4 cents a pound at Boston. However, the landings and measure of price elasticity are based on round weight of haddock, whereas the exvessel price is for dressed weight. The conversion factor from dressed weight to round weight is 1.14. Therefore, a price of 10.4 cents a pound dressed weight would be equivalent to a 9.1 cents per pound price for round weight fish. A straight line demand curve with an arc price elasticity of 2.22 over the range of landings from 100 to 133.5 million pounds, was passed through the point representing landings and price for 1964, adjusted to round weight basis. The equation for this demand curve is:

$$P + \frac{4.18}{10^8} L - 14.7 = 0$$

One adjustment must be made to this demand curve in order to make it applicable to the Georges Bank model. The above equation represents the demand for total landings of haddock in New England.

However, Georges Bank only provides about 77 percent of total New England haddock production. Production of haddock from other fishing grounds averaged 28.7 million pounds during the 1960-64 5-year period. Production from these fishing banks tends to remain relatively constant and exhibits no significant correlation with production from Georges Bank. The demand curve can be adjusted by setting the point of origin at 28.7 million pounds and thus using a demand equation as follows:

$$(3) \quad P + \frac{4.18}{10^8} L - 13.5 = 0$$

Vessel Costs

As indicated earlier, the bulk of Georges Bank haddock is harvested by medium and large trawlers fishing out of Boston, with the large trawlers accounting for the largest proportion of the landings. Cost data for the medium trawlers were quite limited but rather complete cost and effort data are available for the large trawlers. Although the study fleet used for measuring catch per unit of effort is comprised of 13 vessels, a sub-sample of the 6 most efficiently operated vessels is used for the determination of costs of fishing. The justification for using a sample of only 6 vessels is, that if a fishery management program is going to achieve some economic objective involving efficient use of resources, then such a management program should provide for the fishing effort to be applied by the most efficiently managed vessels over time. Therefore, the cost and effort observations for the 6 most efficient vessels are more meaningful than the data for the entire study fleet of 13 vessels.

Table 1. Composite and Average Characteristics of the Six Vessels Used for Determination of Cost of Fishing Georges Bank in 1964

Item	Total	Per Vessel
Vessel Characteristics		
Age	112	18.9
Length	714	119
Gross Registered Tonnage	1548	258
Horsepower	4120	686.7
Crew Size	102	17
Fishing Characteristics		
No. of Trips	181	30
No. of Days at Sea	1868	311
Standard DAys of Fishing Effort	1212	202
Total Catch	20,560,000	3,426,667

Source: Atlantic Fishermen's Union, Boston, Massachusetts

The "lay system" for these six vessels is the same as described in the preceding chapter. The lay system represents somewhat of an economic irrationality. The vessel owner decides whether or not the vessel goes to sea. However, the bulk of the variable costs of fishing do not enter into his decision.

The vessel owner's decision would be made as follows:

Vessel Gross (40 percent of net stock)
- Less out-of-pocket costs
  - Bonus to captain (10 percent of vessel share)
  - Payroll taxes
  - Maintenance and repair of vessel and gear
  - Insurance (hull and P&I)
  - Broker payments
  - Office and accounting expenses
  - Interest on indebtedness and debt retirement
    - Sub-total

Net for fixed cost and management
- Less depreciation and interest on equity

Net for management and risk (before corporate income tax).

Within this framework, the bulk of labor costs and most other variable costs of fishing would not enter into the entrepreneurial decision of whether a vessel was going to contribute to the total amount of fishing effort in the haddock fishery. For the purpose of analyzing national policy for management of a fishery, all costs attendant to applying fishing pressure to the resource should enter into the fishery management program. Thus, for the purpose of this analysis a hypothetical example is developed in which the vessel owner is made completely responsible for all costs as is the case in most industries. Labor is charged to the vessel on the basis of a wage rate that will yield an annual income to the deckhand equal to the average earings of $8,240 earned on the six sample vessels in 1964. The standard bonuses for officers were converted into wage rate differentials for each respective position. The wage rate for the captain will produce an annual income equal to the average captain's earnings in 1964 including the 10 percent bonus to the captain out of the vessel owner's share. Because the standard watch on a fishing vessel is 12 hours, 311 days at sea represents 3,732 hours of paid time per year. The variable cost per day of effort and annual fixed cost for this simulated fishing firm is given in table 2.

Table 2. Fishing Performance and Costs for 12 Months' Operation of Hypothetical Firm Fishing Georges Bank Haddock Fishery

Item	Rate	
Vessel Operation		
No. of trips	30	
Days at sea	311	
Standard days of fishing effort	202	
Cost of Fishing		
Trip expenses per day of fishing effort		
Wharfage	8.50	
Scale fee	1.34	
Exchange fee	16.74	
Echo sounder	3.45	
Radar	7.43	
Ice	35.94	
Icing up	4.75	
Fuel and oil	135.00	
Groceries	89.95	
Water	1.20	
Miscellaneous	.75	
Gear expenses	74.25	
Repair and maintenance	84.15	
Sub-total		$ 463.45
Labor costs		
Captain @ $5.70 per hr	105.00	
1st engineer @ $2.45 per hr	45.20	
Mate @ $2.37 per hr	43.72	
2nd engineer @ $2.33 per hr	43.00	
Cook @ $2.33 per hr	43.00	
Deckhands (12) @ $2.21 per hr	489.24	
Lumpers	13.10	
Watching	4.10	
Welfare fund	16.75	
Social Security taxes	35.61	
Sub-total		838.72
Total trip-related costs per day of effort		1,302.17
Fixed Costs		
Insurance	16,000.00	
Accounting, legal & office	8,000.00	
Other onshore expenses	4,000.00	
Interest & depreciation	46,200.00	
Return to management (before taxes)	28,000.00	
	102,200.00	

Source: Unpublished data from Atlantic Fishermen's Union and vessel records at Boston, Massachusetts.

Therefore, the cost of fishing of the individual firm in terms of days of fishing effort would be:

(4) TC = \$102,200 + \$1,302.17c

A complicating factor enters in developing a decision model for haddock fishing in that, a day of fishing effort produces not only a catch of haddock, but also an incidental catch of other fish, mainly cod, pollock, cusk, and flounder. These incidental catches fluctuate from year to year but bear no statistical relationship to the catch rate for haddock. For the period 1960-64, the incidental catch for large offshore haddock trawlers average 4,800 pounds per standard day of fishing effort with a standard deviation of 330 pounds.

The weighted average price for this incidental catch in 1964 was 6.4 cents a pound. Therefore, the incidental catch can be considered as a byproduct with a mean value of \$307.20 per day of effort, or \$62,054.40 per year for the average vessel used in this study. One alternative would be to apply the entire byproduct value to variable costs. However, this would bias downward the marginal costs of fishing for haddock. Therefore, the byproduct value was split among fixed and variable costs in the same proprotion as each represents of total cost. Fixed costs account for 28 percent of total costs when fishing 202 standard days a year. Thus, \$17,375 of the byproduct value was applied to fixed costs leaving a fixed cost of \$84,825 to be applied against haddock fishing. The remaining \$44,679.40 byproduct value of incidental catch provides a credit of \$221.19 per day.

against the variable costs of fishing. The cost function adjusted for incidental catch can then be expressed as:

(5) Total Cost = $84,825 + $1080.98e

According to the biological model, the catch rate will be proportional to the size of the standing stock of fish. The equilibrium catch rate can be determined from equation (2) for any level of fishing effort. This catch rate represents the annual average catch rate. Because of the schooling habits of haddock, the actual catch rate fluctuates seasonally. In order to consider this in the model, a seasonal index of catch rates was computed from monthly catch rate data for the period July 1956 through June 1964 by a percent of a 12-month moving average method. The seasonal index was arranged in descending order of magnitude and used to generate a series of monthly catch rates from the equilibrium catch rate for each 1,000 days of effort from 1,000 through 10,000 days of effort.

The 202 standard days of effort also was distributed among the 12 months. By multiplying the standard days of effort per month times the respective seasonal catch rate, a series of landings per month was generated. Similarly, the variable cost of $1,080.98 per day of effort multiplied by the days of effort per month plus the $84,825 fixed cost provided a series of total cost corresponding to the respective total catch. Marginal cost was calculated by dividing $1,080.98 by the monthly catch rates (see appendix I, table 2).

The average total cost and marginal cost for 4,000; 7,000; and 9,000 days of effort are illustrated in figure 1. These levels of effort are roughly comparable to 20, 35, and 45 vessels respectively. The effect of the externality due to the common property status of the natural resource is quite evident in the shift upward and to the left of the cost curves as the days of fishing effort increase by the entry of more vessels. The slope of the marginal cost curve particularly becomes steep as effort approaches and goes beyond the level for maximum sustainable yield.

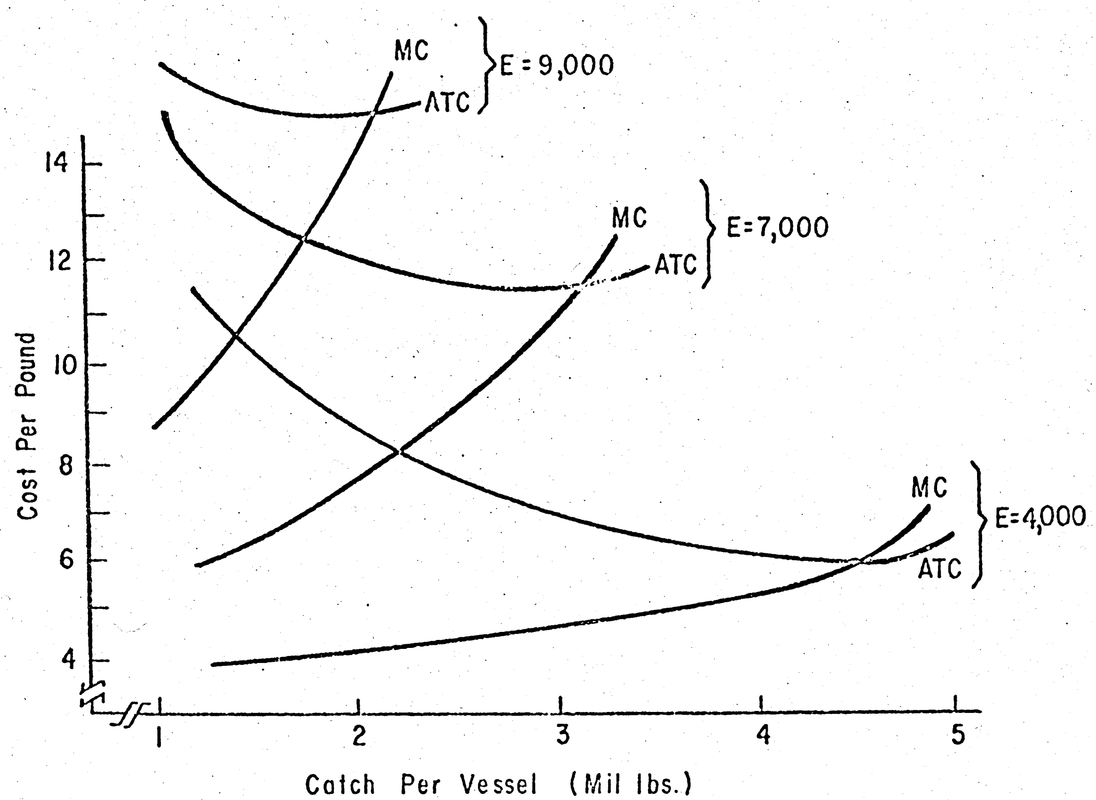


Figure 1. Effect of Fishing Effort on Cost

Another striking feature of the average total cost is that the fixed costs are such that "spreading the overhead" results in declining average total cost almost throughout the range of possible output for the entire year's fishing activity. The marginal cost does not exceed the average total cost until the last increment of effort is added. This generally agrees with actual observations that most haddock vessels tend to fish year round except for required periods of lay-up for maintenance. This also indicates that for a vessel to be maximizing its own profit position in such a way that it will be covering all long-run costs, it will have to fish a full year.

As indicated in chapter III, the system of equations describing equilibrium can be reduced to a single equation in terms of fishing effort. In this form, the model is solved in terms of marginal revenue product and marginal revenue cost rather than marginal revenue and marginal cost. If the revenue function is developed by substituting the landings/effort equation ($L = 28{,}340E - 2.024E^2$) in the demand equation, extraneous roots are introduced into the revenue equation. Therefore, a series of values for total revenue was generated from the demand curve for the equilibrium yield of the fishery for each 1,000 days of fishing effort from 1,000 through 10,000. A second degree parabola was then fit to these revenues as a function of fishing effort. The ensuing equation is:

(6) $TR=1,501,808 + 2273.45E - .1624E^2$ $\quad 1,000 \leq E \leq 10,000$

and

(7) $MRP=2273.45 - .3248E$

Under the assumption that all vessels in the fishery have identical costs, the total cost for the industry can be expressed as:

$$T.C. = \$84,825N + \$1,080.98E$$

where

T.C. = Total cost of fishing
N = Number of vessels in the fishery
E = Days fished by all vessels

Inasmuch as a well-managed vessel can fish 202 standard days of effort a year, and the marginal cost does not rise through the average total cost curve until the vessel is in the vicinity of 200 days of effort, the substitution $N=\frac{E}{202}$ can be made in the cost curve. Thus the industry total cost curve can be written:

$$T.C. = \$84,825 \frac{E}{202} + \$1080.98E$$

or

(8) $T.C. = \$1500.91E$

and

(9) $MRC = \$1500.91$

Maximum Net Return Above Cost

The equilibrium position for the fishery that will produce the greatest net return above total costs is where the rate of increase in revenue and cost are the same, or where MRP=MRC.

Thus, the single equation solution is achieved by setting equation (7) to equation (9):

$$(10) \quad 2273.45 - .3248E = \$1500.91$$

Solving equation (10) for E yields a solution of 2,379 days of fishing effort. At the rate of 202 days per vessel per year, approximately 12 vessels would be sufficient to fish 2,379 days a year. These 12 vessels would land approximately 56,804,016 pounds of haddock a year for an exvessel value of $6,305,246. Thus, the fishery would be exploited at about 57.3 percent of MSY but would capture 68.4 percent of the maximum value of the resource. Each vessel would gross approximately $587,491 per year and would have total cost of $337,238.

Table 3. Revenue, Cost and Net Return Per Vessel at Maximum Net Return Above Costs

Item	Landings	Value
Haddock	4,733,668	525,437
Incidental catch	969,600	62,054
Total	5,703,268	587,491
Cost (excluding return to management)		337,238
Net return above cost per vessel		250,253

At this rate of return, the entrepreneur could net the cost of a new vessel in less than 3 years of fishing, even given the high vessel construction costs of the United States. This model, because labor inputs were priced at a fixed wage rate, automatically shows the monopoly profits and economic rent as accruing to the vessel owner. However, these results now can be simulated through the standard "lay" system of the offshore trawlers. In this case, the vessel net before taxes would be reduced to $97,180 but the share per crewman would increase to $16,484, almost double the $8,247 annual earnings per deckhand built into the labor cost of the simulated vessel. Under actual conditions, the split of returns above costs would depend on the relative bargaining power between the union and the vessel owner and the amount taxed away as an economic rent for the privilege of the right to exploit the resource.

Table 4. Simulated Return to Labor and Capital Under Conditions That Maximize Net Return Above Cost

Item		Amount
Gross Stock		$587,491
Less "off the top costs"		22,547
Net Stock		564,944
Crew Share (60%)		338,966
Less costs		58,733
Net Crew Share		280,233
Share per man		16,484
Vessel Share (40%)		225,978
Less "out of pocket" costs	$82,598	
Less interest and depreciation	46,200	
Sub-total		128,798
Net Before Taxes		97,180

If open access to the haddock resource is continued, additional vessels could be expected to enter the fishery as long as revenue exceeded cost for the individual vessel. On the other hand, for vessels to continue in the fishery in the long run, the vessel must at least cover all costs. Therefore, the equilibrium condition would obtain when total cost equalled total revenue for the fishery. The single equation equilibrium condition for this objective is achieved by setting equation (8) equal to equation (6).

$$(11) \quad \$1,500.91E = 1,501,808 + 2273.45E - 1624E^2$$

Solving equation (11) for E yields an estimate of 6,239 days of effort or about 31 vessels. The landings for the fleet would total about 98,100,492 pounds for an exvessel value of $9,221,446. Thus, the industry would capture 99 percent of MSY and 99.96 percent of the maximum value of the resource.

The question might be raised, if free entry equilibrium is 6,239 days of effort, why did the U.S. fleet fish 8,800 days in 1964? The answer obviously is that the fishery was not in long-run equilibrium. The average age of the New England medium and large otter trawler in 1964 was 23 years. Thus, over half the fleet was either completely depreciated out or near so. If the capital value of the vessel is near zero, the fixed costs are also low. Thus, if the vessel can cover variable costs and yield any positive return to the owners, it is likely to be kept in the fishery. This is one of the most basic problems to a healthy viable fishery if the common property status is maintained. A number of factors may result in vessels entering a fishery and driving up the cost of harvesting fish under the common property status. Some of these factors may result in a short-run equilibrium in which price does not cover average total cost for the individual firm.

An increase in demand or a reduction in costs as a result of technological development may produce a stable long-run equilibrium at a level of fishing effort far beyond the level of effort that will produce the MSY. This can be demonstrated by changing equation (11) to reflect either of these conditions.

Assume that demand shifted upward by 20 percent but that the slope of the demand curve remained constant. The new demand equation would be:

$$P + \frac{4.18L}{10^8} - 16.2 = 0$$

and

$$TR = 1{,}501{,}315 + 3038.26E - .217E^2$$

Now, under free access to the resource, equilibrium in the industry would result when:

$$(12) \quad \$1500.91E = 1{,}501{,}315 + 3038.26E - .217E^2$$

Solving equation (12) for E gives an estimate of 7,958 days of effort in the fishery under the new demand status. Effort would be carried 14 percent beyond MSY and the annual harvest would drop about 1.7 million pounds below the annual harvest that could be achieved with only 7,000 days of fishing. Therefore, market conditions can result in a stable equilibrium at a level of effort considerably beyond MSY under open access to the resource.

Similar results can be produced as a result of an innovation in vessels and gear. Assume a new type vessel is developed which lowered the cost of the vessel by $70,000 and reduced the size of the crew by 4. The total cost function for the individual vessel would now be $67,385 + 888.38E and total cost for the industry could be expressed as:

(13) $TC = \$1221.97E$

Assuming the original demand curve, long-run equilibrium for the industry as a result of the innovation would become:

(14) $\$1221.97E = 1,501,808 + 2273.45 - .1624E^2$

Solving equation (14) for E yields an estimate of 7,679 days of effort for long-run equilibrium. Therefore, no lasting benefits can be gained as a result of innovation. The decrease in costs per ton of fish harvested resulting from the innovation will eventually be completely eliminated by expansion of fishing effort.

Maximum Economic Rent

The unique situation with regard to the point at which marginal cost passes through the average total cost curve suggests a simplified statement of the equilibrium condition for generating the pure economic rent from the natural resource. In order for economic rent to be realized, the marginal cost of the firm must equal the price of fish and marginal cost must exceed average total cost. The only occasion in which marginal cost exceeds total cost is when the vessel is fishing the full 202 standard days a year. Therefore, if functional relationships are determined between the final increment of MC and effort and price and effort, the level of effort can be solved for the maximum economic rent. Thus the following regression equations were fit to the data:

$$(15)\quad M.C. = 6.57 - \frac{5.5E}{10^4} + \frac{16.88E^2}{10^8}$$

$$(16)\quad P = 13.5 - \frac{12E}{10^4} + \frac{8.598E^2}{10^8}$$

The equilibrium position for maximizing economic rent can then be expressed by setting equation (15) equal to equation (16).

$$(17)\quad 6.57 - \frac{5.5E}{10^4} + \frac{16.88E^2}{19^8} = 13.5 - \frac{12E}{10^4} + \frac{8.598E^2}{10^8}$$

Solving for E yields an estimate of 6,029 days of effort necessary to maximize economic rent. At 201 days per year, 30 vessels would fish 6,030 days. With the fishery in equilibrium at 6,030 days of effort per year, the daily catch rate would be 16,135 pounds and the entire fleet would land 97,294,050 pounds of haddock per year with an exvessel value of $9,145,641. Thus, given the demand and cost functions assumed here, the economic rent would be maximized when landing about 98 percent of the MSY and 99 percent of the maximum value of the resource. The individual vessel would have gross annual sales of approximately $366,909 and a total cost of $363,936. The economic rent earned per vessel would be $2,973, or $89,190 for the entire fishery.

The amount of return above cost that can be generated per vessel in the fishery suggests an additional management objective for the United States. Because of a law passed by the First Congress of the United States, all fish landed at U.S. ports must be landed by vessels constructed in the United States. Vessel construction costs in the United States have increased substantially over construction costs in many other nations. Thus, because of this landing law, the capital investment required for a vessel is almost double what it would be if the entrepreneur were free to purchase his vessel wherever he could buy it at the lowest cost. In order to ameliorate this inequity to the fishing industry resulting from a subsidy to the shipbuilding industry, a law has been passed (78Stat.714) providing for a fishing vessel construction differential payment of up to 50 percent by the Federal Government. Thus, if a vessel cost $800,000 in the United States, that could be constructed for $400,000 in a foreign shipyard, the Federal Government will pay $400,000 of the construction costs. It would be possible to do the same thing through generating profit in the fishery and taxing the profit away but in turn giving a tax credit to the vessel owner towards construction cost of a new vessel.

For example, if the construction differential were $400,000, and the allowed period for depreciating the hull were 20 years, a vessel would have to deposit $12,916 annually at 4 percent to have accumulated $400,000 at the end of 20 years. Thus, entry could be licensed to produce an annual profit of $12,916 per vessel and a tax in this amount levied against the vessel. The tax would be deposited with the Federal Government annually but the actual tax liability would be deferred. Interest would accumulate annually on the account at the prime interest rate to the Federal Government. At such time that the vessel owner decided to build a new vessel, the tax liability would be cancelled and the tax and accrued interest returned to cover the construction differential. In this manner, profit generated from the natural resource could bear the subsidy to the shipbuilding industry.

Turvey proposed that, an increase in fishing effort beyond the level that maximized economic rent would be justified if consumer surplus increased more than economic rent decreased. In this example, the rate of increase in consumer surplus is rather small because the total landings at the point that maximizes economic rent is close to the maximum sustainable yield of the resource. On the other hand, because of the sharp rise in cost as output approaches maximum sustainable yield, the economic rent is dissipated rapidly as output is increased. Thus, consumer surplus plus rent is a maximum at the output which maximizes economic rent.

Conservation and Common Property

The model used above can also be used to depict the result of a program to protect the maximum sustainable yield of the resource but at the same time to maintain the common property status (open access) of the resource. Such a program can be implemented merely by placing a quota on the fishery and closing the fishery for the remainder of the year when this quota is realized. Such a program is now employed in conserving the North Pacific halibut stock and the eastern tropical Pacific tuna stock.

The initial demand equation resulted in a free market equilibrium at a level of effort less than MSY. In this case, a quota would be redundant. However, assume the 20 percent increase in demand which resulted in fishing effort being carried beyond the level for MSY. The results of the quota under open access to the fishery would be:

$$(18) \quad 84,825\ N + 1080.98 \times 7000 = \$11,902,800$$

Solving equation (18) for N indicates that approximately 51 vessels would enter the fishery. With 51 vessels fishing, each vessel would only be able to fish about 137 (7000 ÷ 51) standard days a year, or, the fishery would be closed about the last week of August. Conceivably, the vessels would be idle the remainder of the year. Thus, the value of the resource would be dissipated over 21 more vessels and crews than would be necessary to harvest the same volume of fish.

International Fisheries

In a domestic fishery, i.e., a resource wholly contained in U.S. waters, (3 miles territorial sea plus 9 miles fishery jurisdiction), the U.S. can adopt and implement any objective for fishery management it deems in the best interest of the country. However, in international fisheries, where the resource is common property to the world, additional problems arise. Turvey's observation that, "...fishery regulation is one of those spheres of economic policy where what is the best thing to do depends on what can be done" is particularly appropriate in regard to international fisheries.[2]

An international fishery involves a number of nations with differing goals, cost, and demand situations. Under such conditions, perhaps the most in terms of common agreement can be, that regulations be adopted to protect the MSY and prevent biological overfishing. Within this general premise, suboptimization can still be achieved if some system can be worked out for "splitting the pie," i.e., dividing the quota among the participating nations, in which case, each nation could seek to optimize its own fishing within its quota limit. A near optimum in terms of use of the resource could be achieved under such a country quota system if a market were allowed to develop for such quotas. Conceivably, under such a market arrangement, nations with the greatest comparative advantage or least comparative disadvantage could afford to lease quotas from other nations. However, such a market system opens the possibility of nations playing a game of strategy in which they seek a monopoly of the resource through indirect subsidies to their fishing fleets.

Summary and Conclusions

Because of the common property status of most fishery resources, the structure of industry does not include delegation of responsibility for determining the optimum amount of capital and labor to be combined with the natural resource. The consequences of this situation has quite often resulted in an overexploitation of the natural resource in the physical sense, and a redundant amount of labor and capital employed in a fishery. Biologists have long recognized overfishing in the physical sense and proposed management measures to prevent destruction of the basic productivity of the resource, i.e., mesh regulation and catch quotas. However, such measures did not take into account the basic question of optimum combination of factors of production.

More recently, a limited number of economists have become interested in fishery problems and a literature is beginning to take shape proposing economic objectives for fishery management. The major divergence to date is whether fisheries should be managed so as to produce the maximum net return above costs or to produce the pure economic rent implicit in the natural resource. A modification of the latter was proposed by Turvey in terms of giving credit to consumer surplus against decreases in economic rent as a justification for allowing the exploitation of a fishery to go beyond the level that will maximize economic rent. Beyond the economist camp, some individuals feel that freedom of enterprise when applied to fisheries means that no interference with the common property status must be permitted regardless of the consequences. And some biologists still hold the view that because a fishery resource exists, and this resource can yield some maximum annual harvest, we should take this annual maximum regardless of the cost.

This study has developed a bio-economic model to evaluate the outcome of all policy alternatives in terms of fish landed, price of fish, volume of inputs and returns to management, capital, and labor. This model is a static model devised for comparing the results of equilibrium that would result from alternative policy proposals. This model was then applied to the Georges Bank haddock fishery as a case study to demonstrate the results of the policy alternative.

The objective of maximum net return above costs produced dramatic returns above cost for the individual vessel, or would permit substantial returns above costs to be split between capital, labor, and the entrepreneur or be taxed away. At the same time, it is the most limiting objective in terms of the use of the resource. In the Georges Bank haddock fishery, it would limit catch to approximately 57 percent of the MSY.

The maximization of economic rent carried utilization of the resource to approximately 98.9 percent of the maximum sustainable yield. This policy objective turned out to be the most liberal approach to utilization of the resource still in keeping with efficiency in use of limited economic resources.

Turvey's proposal for maximizing the sum of consumer surplus and rents was inconclusive for the Georges Bank haddock fishery. The level of fishing effort that maximized economic rent was also the level that would maximize the sum of consumers surplus and economic rent.

If open access to the resource must be maintained, as some would argue, little hope can be held for a positive contribution from fishery resources to economic welfare over time. At best, the industry would work toward an economic equilibrium that would achieve a competitive return to capital and labor. However, before such a long-run equilibrium were ever realized, a series of short-run equilibriums (a short run that could persist for many years in fishing) could keep returns to labor and capital far below competitive earnings in other industries. No lasting benefit could be expected from innovation for increased efficiency would soon be dissipated among a redundant number of firms. Biological overfishing in the physical sense could be prevented by catch quotas, but unless some limitation of effort were included in the management program, prevention of physical overexploitation is the only accomplishment that would be achieved.

In conclusion, managing a fishery to realize the economic rent from the natural resource seems most compatible with Pareto optimality criteria for economic welfare. To limit effort to a level that would produce the maximum net return above cost (the monopoly result) forces some labor and capital into alternative uses at earnings below what they could realize in fishing. Thus, earnings to inputs in fishing are enhanced only by forcing someone into a less desirable position.

On the other hand, if open access to a fishery leads to entry of some labor and capital that would in effect produce greater social value in other occupations, restricted entry also would result in a net social gain.

The Turvey solution would permit an expansion of fishing beyond the level that would maximize economic rent if the increase in consumer surplus more than offset the decrease in rent. However, this would appear to involve inter-personal transfers within the economy and thus could not be evaluated on the basis of Pareto optimality criteria.

Additional legislation as well as clarification between State and Federal responsibilities likely will be needed in order to implement fishery management programs for economic objectives. Equally as important will be adequate data and estimates of biological and economic parameters for each fishery. Thus, of immediate concern is the further development of bio-economic models for management on a fishery-by-fishery basis. Such models become the basis for data collection, and data now available is inadequate for many fisheries. Only in this manner can reasonably accurate estimates be developed for optimal fishing effort for each fishery.

Although economic models are generally built around output, it is believed that the model employed here demonstrates that a model based on fishing effort can serve equally as well for the purposes of fishery management. The measure of fishing effort is a logical link between the population dynamics model of the biologist and the market model of the economist. The biologist needs a measure of effort to develop an index of fishing mortality. As long as the economist can relate the unit measure of effort to cost of economic inputs and market returns, the market model and biological model can be linked with the measure of fishing effort. In this respect, much remains to be done in defining the base unit of fishing effort and developing means to quantify units of vessel and gear in terms of such base units for measuring fishing effort. Hopefully, joint discussions of the biologist and economist could carry this area of research methodology ahead quite rapidly.

Much remains to be done in economic model building for fisheries. One aspect not touched on in this study is the question of dynamics of change. A dynamic model that traced out the recursive relationships between exogenous fluctuations in recruitment, growth, and natural mortality and yield per unit of effort; and thus, to returns from fishing and investment decisions in vessels and gear; and thus, back to the impact on the natural resource must be developed. Pelagic fisheries contain different problems of specification than closed demersal fisheries. Thus, the model developed here is not directly applicable to pelagic fisheries. Fisheries that are almost completely dependent on 1 or 2-year classes (shrimp, menhaden) present unique problems. Thus, much interesting work remains in developing bio-economic models necessary for sound resource development and use.

1. J. F. Farrell and H. C. Lampe, "The Revenue Implication of Changes in Selected Variables Examined in the Context of a Model of the Haddock Market," Recent Developments and Research in Fisheries Economics, ed. by F. W. Bell and J. E. Hazelton, Oceana Publications, Inc., Dobbs Ferry, N.Y., 1967, p. 48.

2. Ralph Turvey, "Optimization and Suboptimization in Fishery Regulation," The American Economic Review, Vol. LIV, Number 2, Part I, March 1964, p. 64.

Table 1. Landings Per Day of Effort, Days of Effort, and 3-Year Moving Average of Days of Effort for Georges Bank Haddock, 1932-64

Year	Landings Per Day/Effort 10^{-3}	Days of Effort 10^{-3}	3-Year Moving Average Day/Effort 10^{-3}
1932	11.6	9.1	-
1933	9.8	8.4	-
1934	10.3	4.8	7.4
1935	12.3	6.4	6.5
1936	13.5	6.2	5.8
1937	11.6	8.2	6.9
1938	11.7	7.9	7.4
1939	13.0	8.0	8.0
1940	12.8	7.2	7.7
1941	16.6	7.3	7.5
1942	18.7	5.7	6.7
1943	18.3	4.9	6.0
1944	17.0	5.6	5.4
1945	16.0	4.9	5.1
1946	14.3	7.3	5.9
1947	12.8	8.2	6.8
1948	12.1	7.7	7.7
1949	11.4	7.1	7.7
1950	14.5	5.5	6.8
1951	14.1	6.5	6.4
1952	14.1	5.9	6.0
1953	10.7	6.5	6.3
1954	15.4	5.8	6.1
1955	15.6	5.0	5.8
1956	13.9	6.8	5.9
1957	11.4	7.8	6.5
1958	8.8	7.8	7.5
1959	7.3	9.4	8.3
1960	10.4	7.7	8.3
1961	12.6	7.2	8.1
1962	12.2	8.6	7.8
1963	8.4	12.5	9.4
1964	10.2	12.1	11.7

Source: Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts

Table 2. Seasonal Index for Catch Rates, Monthly Distribution of Effort, Landings and Costs for Successive Levels of Fishing on Georges Bank Haddock

	Aug.	Mar.	Apr.	Sept.	July	Feb.	Oct.	May	June	Dec.	Jan.	Nov.
Seasonal Index	126.1	120.8	115.2	109.4	107.1	100.0	99.8	95.7	95.0	81.9	77.4	71.6
Days of Effort	18	18	18	18	18	16	17	17	17	16	15	14
Total Cost	104,283	123,740	143,198	162,656	182,113	199,409	217,786	236,162	254,539	271,835	288,049	303,183
Landings & Costs												
1,000 days effort												
Catch rate (lbs)	33,184	31,790	30,316	28,790	28,184	26,316	26,263	25,184	25,000	21,553	20,639	18,842
Landings (000's)	597.3	1,169.5	1,715.2	2,233.4	2,740.7	3,161.8	3,608.2	4,036.4	4,461.4	4,806.2	5,115.8	5,379.6
ATC (¢/lb)	17.46	10.58	8.35	7.28	6.64	6.31	6.04	5.85	5.71	5.66	5.65	5.64
MC (¢/lb)	3.26	3.40	3.57	3.75	3.84	4.11	4.12	4.29	4.32	5.02	5.24	5.74
2,000 days effort												
Catch rate (lbs)	30,632	29,345	27,984	26,575	26,017	24,292	24,243	23,247	23,077	19,895	18,802	17,393
Landings (000's)	551.3	1,079.5	1,583.2	2,061.6	2,529.9	2,918.6	3,330.7	3,725.9	4,118.2	4,436.5	4,718.6	4,962.1
ATC (¢/lb)	18.91	11.46	9.04	7.39	7.20	6.83	6.54	6.34	6.18	6.13	6.10	6.11
MC (¢/lb)	3.53	3.68	3.86	4.07	4.15	4.45	4.46	4.65	4.68	5.43	5.75	6.22
3,000 days effort												
Catch rate (lbs)	28,080	26,900	25,653	24,361	23,849	22,268	22,223	21,310	21,155	18,237	17,235	15,944
Landings (000's)	505.4	989.6	1,451.3	1,889.8	2,319.1	2,675.4	3,053.2	3,415.5	3,775.1	4,066.9	4,325.4	4,548.6
ATC (¢/lb)	20.63	12.50	9.87	8.61	7.85	7.45	7.13	6.91	6.74	6.68	6.66	6.67
MC (¢/lb)	3.85	4.02	4.21	4.44	4.53	4.85	4.86	5.07	5.11	5.93	6.27	6.78
4,000 days effort												
Catch rate (lbs)	25,528	24,455	23,321	22,147	21,681	20,244	20,204	19,374	19,232	16,580	15,669	14,495
Landings (000's)	459.5	899.6	1,319.4	1,718.1	2,108.3	2,432.2	2,775.7	3,105.1	3,432.0	3,697.3	3,932.3	4,135.2
ATC (¢/lb)	22.69	13.75	10.85	9.47	8.64	8.20	7.85	7.61	7.42	7.35	7.32	7.33
MC (¢/lb)	4.23	4.42	4.64	4.88	4.99	5.34	5.35	5.58	5.62	6.52	6.90	7.46

Table 2. Seasonal Index for Catch Rates, Monthly Distribution of Effort, Landings and Costs for Successive Levels of Fishing on Georges Bank Haddock (continued)

	Aug.	Mar.	Apr.	Sept.	July	Feb.	Oct.	May	June	Dec.	Jan.	Nov.
5,000 days effort												
Catch rate(lbs)	22,975	22,010	20,989	19,933	19,514	18,220	18,184	17,437	17,309	14,922	14,102	13,046
Landings(000's)	413.5	809.7	1,187.5	1,546.3	1,897.5	2,189.0	2,498.2	2,794.6	3,088.9	3,327.6	3,539.1	3,721.8
ATC (¢/lb)	25.22	15.28	12.06	10.52	9.59	9.11	8.71	8.45	8.24	8.17	8.14	8.15
MC (¢/lb)	4.71	4.91	5.15	5.42	5.54	5.93	5.94	6.20	6.25	7.24	7.67	8.29
6,000 days effort												
Catch rate(lbs)	20,423	19,565	18,658	17,718	17,346	16,196	16,164	15,500	15,386	13,265	12,536	11,596
Landings(000's)	367.6	719.7	1,055.6	1,374.5	1,686.7	1,945.9	2,220.7	2,484.2	2,745.7	2,958.0	3,146.0	3,308.3
ATC (¢/lb)	28.37	17.19	13.57	11.83	10.80	10.25	9.81	9.51	9.27	9.19	9.16	9.16
MC (¢/lb)	5.29	5.53	5.79	6.10	6.23	6.67	6.69	6.97	7.03	8.15	8.62	9.32
7,000 days effort												
Catch rate(lbs)	17,868	17,117	16,324	15,502	15,176	14,170	14,142	13,561	13,462	11,605	10,968	10,146
Landings(000's)	321.6	629.7	923.5	1,202.5	1,475.7	1,702.4	1,942.9	2,173.4	2,402.2	2,587.9	2,752.4	2,894.5
ATC (¢/lb)	32.42	19.65	15.50	13.53	12.34	11.71	11.21	10.87	10.60	10.50	10.47	10.47
MC (¢/lb)	6.05	6.32	6.62	6.97	7.12	7.63	7.64	7.97	8.03	9.31	9.86	10.65
8,000 days effort												
Catch rate(lbs)	15,319	14,675	13,994	13,290	13,011	12,148	12,124	11,626	11,541	9,949	9,403	8,698
Landings(000's)	275.7	539.8	791.7	1,031.0	1,265.2	1,459.5	1,665.6	1,863.3	2,059.5	2,218.7	2,359.7	2,481.5
ATC (¢/lb)	37.82	22.92	18.09	15.78	14.39	13.66	13.07	12.67	12.36	12.25	12.21	12.22
MC (¢/lb)	7.06	7.37	7.72	8.13	8.31	8.90	8.92	9.30	9.37	10.87	11.50	12.43
9,000 days effort												
Catch rate(lbs)	12,766	12,230	11,663	11,076	10,843	10,124	10,104	9,689	9,618	8,292	7,836	7,249
Landings(000's)	229.7	449.9	659.8	859.3	1,054.4	1,216.3	1,388.1	1,552.8	1,716.3	1,849.0	1,966.5	2,068.0
ATC (¢/lb)	45.38	27.50	21.70	18.93	17.27	16.39	15.69	15.21	14.83	14.70	14.65	14.66
MC (¢/lb)	8.47	8.84	9.27	9.76	9.97	10.68	10.70	11.16	11.24	13.04	13.80	14.91

Table 2. Seasonal Index for Catch Rates, Monthly Distribution of Effort, Landings and Costs for Successive Levels of Fishing on Georges Bank Haddock (continued)

	Aug.	Mar.	Apr.	Sept.	July	Feb.	Oct.	May	June	Dec.	Jan.	Nov.
10,000 days effort												
Catch Rate(lbs)	10,214	9,784	9,331	8,861	8,675	8,100	8,084	7,752	7,695	6,634	6,269	5,800
Landings(000's)	183.8	359.9	527.9	687.4	843.5	973.1	1,110.6	1,242.4	1,373.2	1,479.3	1,575.3	1,654.5
ATC (¢/lb)	56.72	34.37	27.12	23.66	21.59	20.49	19.61	19.01	18.54	18.38	18.31	18.32
MC (¢/lb)	10.58	11.05	11.58	12.20	12.46	13.35	13.37	13.94	14.05	16.29	17.24	18.64

Table 3. Equilibrium Catch Rate, Total Landings, Price, and Total Revenue for Each 1,000 Days of Effort on Georges Bank Haddock Fishery

			Regular Demand		20% Increase in Demand	
Days of Effort	Catch Per Day	Total Landings x10^{-3}	Estimated Price	Total Revenue x10^{-3}	Estimated Price	Total Revenue x10^{-3}
1,000	26,316	26,316	12.4	3,263	15.1	3,974
2,000	24,292	48,584	11.5	5,587	14.2	6,899
3,000	22,268	66,864	10.7	7,154	13.4	8,952
4,000	20,244	80,976	10.1	8,179	12.8	10,365
5,000	18,220	91,100	9.7	8,837	12.4	11,296
6,000	16,196	97,176	9.4	9,135	12.1	11,758
7,000	14,170	99,190	9.3	9,225	12.0	11,903
8,000	12,148	97,184	9.4	9,135	12.1	11,759
9,000	10,124	91,116	9.7	8,838	12.4	11,298
10,000	8,100	81,000	10.1	8,181	12.8	10,368

Source: Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts

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