ALTERNATIVE MANAGEMENT PLANS FOR YELLOWFIN TUNA IN THE EASTERN TROPICAL PACIFIC

V. G. FLAGG
Department of Economics
San Diego State University

This work is a result of research sponsored by
NOAA Office of Sea Grant
Department of Commerce
Under Grant No. US DC 04-3-158-22 Project No. R/ME-3
1977

CENTER FOR MARINE STUDIES
San Diego State University
SAN DIEGO, CA 92182

1897

ALTERNATIVE MANAGEMENT PLANS FOR YELLOWFIN TUNA IN THE EASTERN TROPICAL PACIFIC

By

V. G. Flagg
San Diego State University
Department of Economics

Special Report
Center for Marine Studies
San Diego State University

This work is a result of research sponsored by
NOAA Office of Sea Grant
Department of Commerce
Under Grant No. USDC 04-3-158-22
Project No. R/ME-3
1977

Foreword

This paper is composed of basically three parts. In the first section a simplified version of the economics of ocean fisheries is presented in general terms and as it applies to the eastern tropical Pacific yellowfin tuna fishery. In the second section, recommendations for eliminating excess capacity and overfishing in the eastern Pacific are discussed and evaluated. The Appendix contains regression results on cost and revenue estimation in the fishery. These results were used in helping to evaluate the impact of various types of management techniques upon this particular fishery.

The purpose of this paper is to present background information on the economics of the eastern tropical Pacific tuna fishery. With knowledge of the theory and operation of the fishery, it is hoped that some progress can be made in taking steps to eliminate the undesirable aspects of excess capacity.

TABLE OF CONTENTS

ALTERNATIVE MANAGEMENT PLANS FOR YELLOWFIN TUNA IN THE EASTERN TROPICAL PACIFIC

By Virginia G. Flagg

I. Introduction

The yellowfin tuna fishery of the eastern tropical Pacific (ETP) is beset with problems. This fishery is being fully exploited, but members of the industry foresee difficulties ahead as capacity continues to increase. The fact that this is an international fishery, where a far-ranging ocean species is captured by fishermen of many nations, further complicates the management of this fishery. Another management complication is that yellowfin are caught jointly with skipjack tuna, which are not yet overfished.

Biological harvesting of yellowfin that might lead to depletion of the stock is prevented through the imposition by the Inter-American Tropical Tuna Commission (IATTC) of an annual output quota. Overcapacity in the fishery necessitates the closing of unlimited fishing early in the year, usually during March in recent years. This leads to increases in production costs and economic waste. Changes must be made in the management of the fishery in order to eliminate these economic wastes. To understand what changes are necessary, the economic theory of fisheries as applied to the eastern tropical Pacific must first be explored. This will suggest possible solutions to the problem.

II. The Economic Theory of Fisheries: Application to the ETP Tuna Fishery

The tuna fishery of the ETP is a typical example of an industry operating under conditions where overexpansion results from external diseconomics.

Because property rights in the fishery are ill-defined, there is no incentive on the part of the individual fisherman to curtail fishing in the interest of greater profitability in the long run. Although the fisherman may realize that his fishing behavior will affect the profitability of other fishermen, he operates under the assumption that other firms have no influence upon his operation since he has no way of predicting the magnitude of the effect. The lowering of the stock of fish population brings about increased costs per unit of output for all fishermen as they try to maintain their previous harvest in the face of new competition. As long as profits are to be made in the fishery, new firms will enter, thus exacerbating the tendency toward overharvesting.

Vernon L. Smith[1] has analyzed a fishing industry, specifying the necessary conditions so that unperceived social costs are imposed on the industry. When these conditions are satisfied, output will be considered to be optimal.

In order to achieve this optimal output, the condition must be satisfied that marginal profitability of increasing catch, λ or $P-MC_1$, must equal the marginal external or social cost of the fleet catch, which Smith derived to be:[2]

$$\lambda = \frac{KC_2}{f'}$$; where K is the number of vessels fishing,

$$C_2 = \frac{\partial C}{\partial X}$$ (C = total firm cost, X = fish stock in tons), and

$$f' = \frac{\partial}{\partial X}\left(\frac{\partial X}{\partial t}\right)$$ (t = time)

The fee, λ, must be levied on each ton of fish landed to bring about optimal exploitation of the fish stock. This equation for a landings fee will be analyzed as it applies to the tuna fishery. Ideally, this tax should have been imposed early in the development of the fishery to regulate its expansion. In view of the fact that the yellowfin tuna of the ETP is now being heavily exploited, this formula cannot be applied directly. The behavior of the various components of the tax as a fishery develops will be explored, however,

The three components of the landings fee, λ, will be analyzed as they vary with the exploitation of a fishery. The first component, K (number of fishing vessels), will become larger as the fishery grows. As the fishery approaches full exploitation, K will be of considerable magnitude and hence the required landings tax will be large, *ceteris paribus*.

The second component of the landings fee formula needs further explanation. C_2 is the change in total cost of a fishing unit as fish stock changes. When the latter declines owing to fishing pressure, the cost to the individual fisherman of catching the same harvest will increase, as he must range farther to find fish or must fish longer to fill his storage wells. It may be reasonable to assume that for the ETP tuna fishery total cost is a linear function of fish stock. Hence, $\frac{\partial C}{\partial X}$ will be a constant over the range of possible fish stock sizes. It will thus have no effect upon the size of the landings fee.

An alternative assumption regarding the relationship between C and X for the firm is that it is in the form of a rectangular hyperbola. This means that when the fish stock is close to its maximum level, a decline in this stock will cause total cost to rise a very small amount. At the other end, when the stock is very low, cost will rise a great deal as the stock declines. When fish stocks are somewhere between the maximum and minimum, at the level where catch approaches maximum sustainable yield (MSY), C_2 may be of an intermediate size (see Fig. 1).

The third component of the landings fee formula, f', will depend upon the shape of the underlying relationship between the size of the fish stock and changes in this stock over time. A typical equation for the production function of a fishery is the parabola:

$\frac{dX}{dt} = k_1 X(X_{max} - X)$ where X is fish population (stock) and X_{max} is maximum fish population.

$f' = \frac{\partial}{\partial X} \left(\frac{dX}{dt} \right) = k_1 (X_{max} - 2X)$ (see Fig. 2).

This is a long-run relationship. For any given fish population, there is a predictable amount of population growth during the relevant time period, represented by $\frac{dX}{dt}$. If precisely this amount, $\frac{dX}{dt}$, is harvested by fishermen during the same period, the fish population will remain unchanged. If more than the growth of the population ($\frac{dX}{dt}$) associated with the given population is harvested during the period, the fish population will decline and a new equilibrium population will be reached. Conversely, if less than the normal growth of the fish population is harvested, the population will increase and again a new equilibrium will be reached in the long run.

For the relevant portion of the curve, between X_{msy} (fish population corresponding to a yield of MSY) and X_{max} (maximum population), f' will be negative. The slope, f', will be very small when the fish stock approaches that value (X_{msy}) yielding the largest amount of catch (MSY), which is where the change in the fish stock, $\frac{dX}{dt}$, is greatest. When the fish population is close to its maximum or unharvested state (X_{max}), f' will be a large negative number.

Putting the three components of the landings fee formula together, it is apparent that the required fee to yield optimal output when the fishery is just beginning to be exploited would be very small. When the fishery is more fully developed and its yield is approaching the MSY, the required landings fee will be very large in order to optimize the catch.

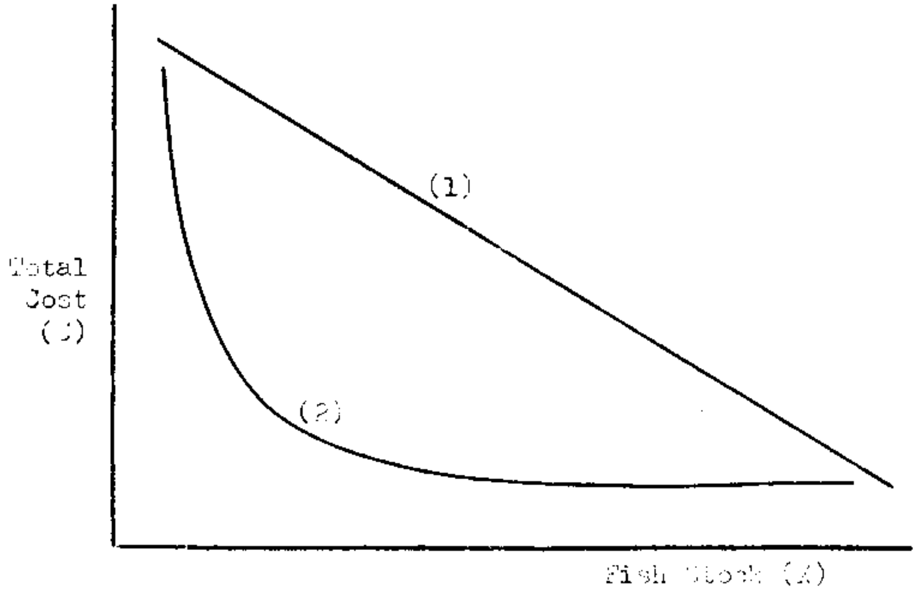

Fig. 1. Relationship between Total Cost and Fish Stock for a Firm Assuming:
(1) C is a linear function of X
(2) C is a hyperbolic function of X

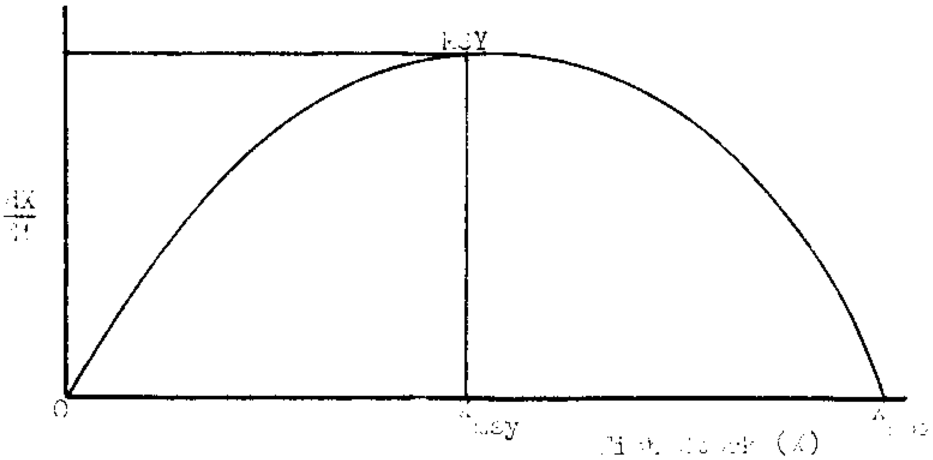

Fig. 2. Relationship between Size of Fish Stock and Changes in Fish Stock over Time

Figure 3 illustrates the same point using a conventional long run demand and supply diagram, where all vessels are assumed to have equal opportunity costs.[3]

Price is assumed constant for varying levels of output of fish. Since the annual production of yellowfin tuna from this area comprises about 6 per cent of the total world output of tuna and tuna-like fishes, this assumption is probably reasonable for this fish. The ready availability of other protein sources as substitutes for tuna increases the elasticity of demand.

Early in the development of a fishery, since no individual fisherman has control over industry output, new firms will enter and the fish stock will be reduced until average total costs are just covered by price. Let us assume the fishery expands to output ON, represented by the crossing of price line P_1 by the average total cost curve (ATC) at C_1.

If a landings fee equal to B_1A_1 were levied upon each ton of fish landed, output would expand only to quantity OM, where the marginal cost curve (MC) crosses P_1. In effect, average cost to each fisherman will be raised from MA_1 to MB_1, so that he is forced to take into consideration the social cost of his operations.

In a fully developed fishery such as ETP yellowfin, suppose that the price has risen to P_2. MC crosses P_2 at B_2, and output should expand to R. Average total cost would be A_2, but if output has been permitted to go beyond MSY so that the stock has been depleted somewhat, costs could be A_2'. Since a quota has been imposed on the ETP yellowfin fishery, it is assumed MSY has not been exceeded and hence the fishery is not operating in the backward-sloping portion of the supply curve. ES represents the ATC position of the industry at MSY. EF represents the excess amount earned on each ton of fish landed over the average total cost. This amount represents the tax that

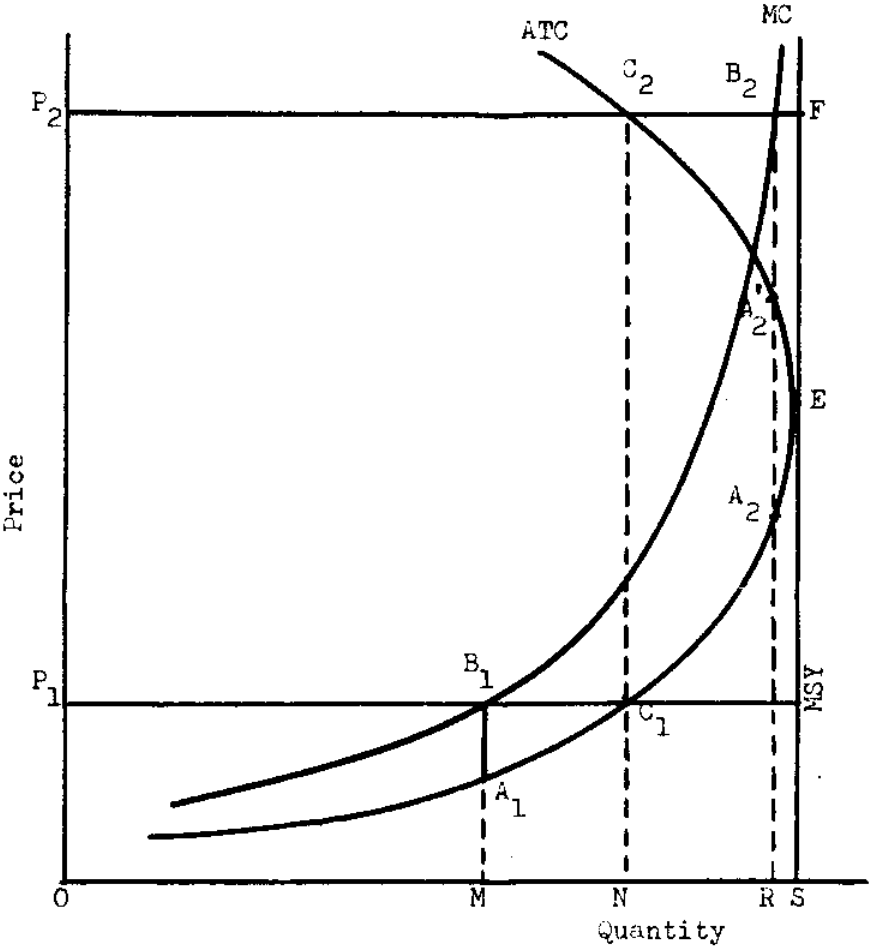

Fig. 3. Industry Demand and Supply Curves for the ETP Yellowfin Tuna Fishery

could be collected in order to capture some of the economic rent being generated in the fishery, assuming the quota is kept at MSY and also that excess capacity has not raised costs so that total revenue is absorbed by costs.

If the landings fee is set at B_2A_2 with production somewhat less than MSY, economic resource rent will be maximized. For practical considerations, however, it may be wisest to permit production to go to MSY. First, in a fishery (such as ETP tuna) characterized by increasing prices with fixed supply, the difference between optimal economic output and MSY will diminish. It may be noted that the MC curve is asympotic to the MSY line, and as P rises, the intersection of MC with P will occur closer and closer to MSY.

Second, it is unrealistic to attempt to pinpoint the precise optimal point where MC crosses P; to find that point, both biological and economic data are required. The estimates of biologists with respect to maximum sustainable yield and the production function of the fishery vary from year to year as environmental conditions change. Therefore, estimating MSY is a formidable enough task in itself; to require further the knowledge of cost and revenue functions in the fishery in order to define ideal output in terms of an economic optimum makes management of the fishery that much more difficult.

Another theoretical argument can be made for using MSY as the output goal rather than that output where MC = P. When the assumption of equal opportunity costs for each vessel is dropped, two kinds of average cost and marginal cost curves can be identified (Fig. 4).[4] The AMC curve represents Average Market Cost, or average cost including resource rent and transfer payments to intramarginal fishing units. Marginal Market Cost (MMC) is marginal to the AMC curve. ASC is the Average Social Cost curve, or average

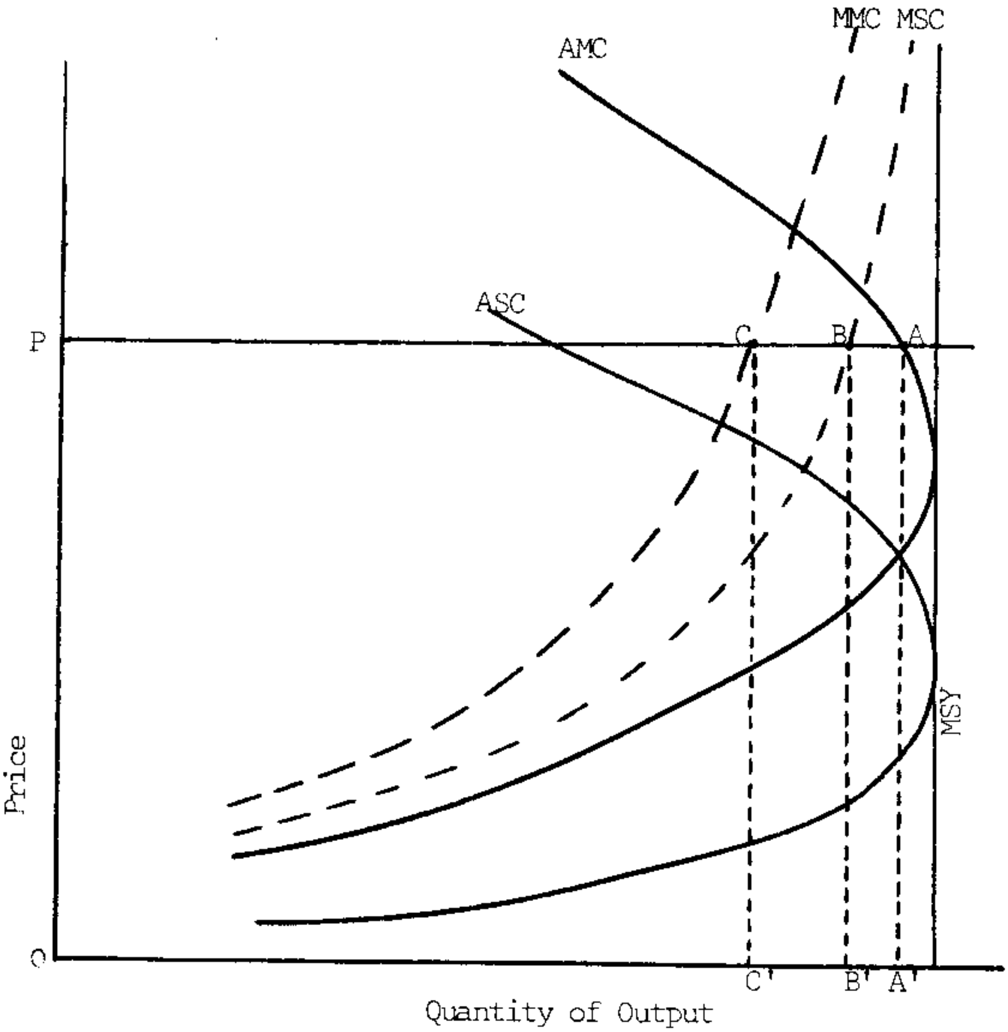

Fig. 4. Social Cost and Market Cost Curves for a Fishery

cost including resource rent but excluding transfers. Marginal Social Cost (MSC) is marginal to the ASC curve. Since the demand curve is assumed to be horizontal, with price constant, there is no consumers' surplus and the P line represents Average Market Revenue (AMR), Marginal Market Revenue (MMR), and Marginal Social Revenue (MSR).

The free entry market solution will be at A, where AMC intersects P; output will be OA'. B, where MSC intersects P, represents the solution when state control maximizes the combined total of resource rent and producers' surplus. Output is OB'. C, where MMC intersects P, determines the output OC' that maximizes resource owner's rent.[5] Output OB' optimizes output from society's point of view, since it takes into consideration the real costs to society arising from the externality but not the pecuniary costs arising from transfers to intramarginal fishing units. The case for accepting MSY as a reasonable approximation to the appropriate output goal is therefore further strengthened, since OB' is closer to MSY than the output solution OC' which maximizes resource rent alone.

An examination of the cost curves for individual vessels will clarify the dynamic processes taking place within the industry. Figure 5 demonstrates the output position of a vessel, in the short run, whether part of a monopoly owned fishery or a competitive fisherman.

OA' will be optimal output, where MC = P. Profits are MABP. In the long run, the monopolist will be able to adjust the size of the vessel to the optimal, so that profits will be maximized.

The fisherman in a competitive fishery, however, will find that more fishermen have entered, thus reducing the profits for all. As in the ETP tuna fishery, where a quota is imposed, vessels will continue to enter the fishery until excess profits for all have been eliminated and each fisherman is just

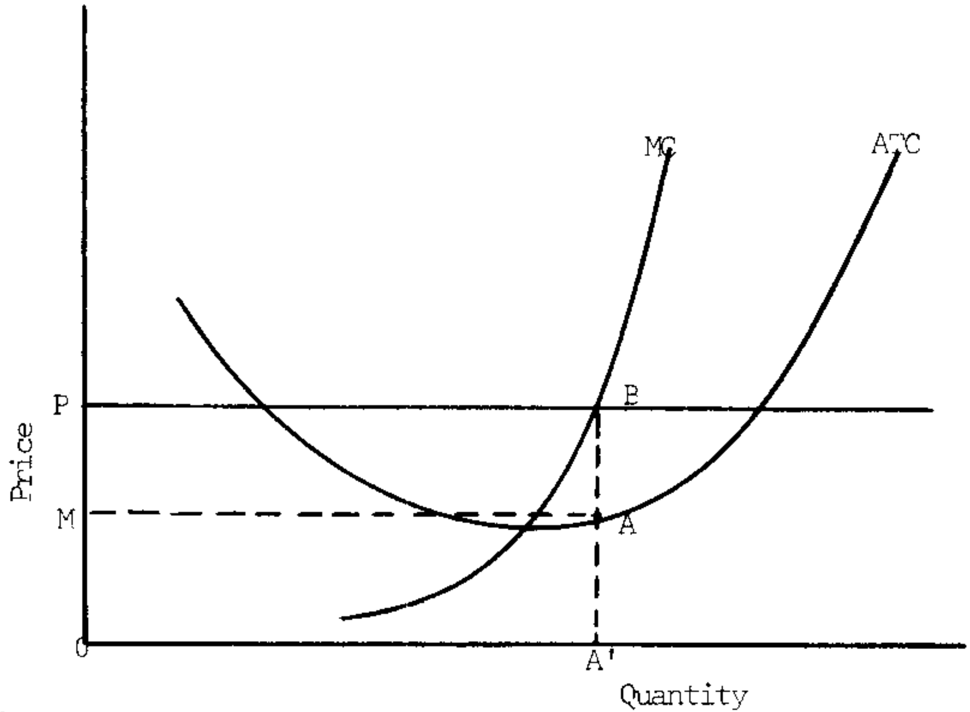

Fig. 5. Short Run Cost Curves for Fishing Vessel Under Competition or Monopoly: No Excess Capacity

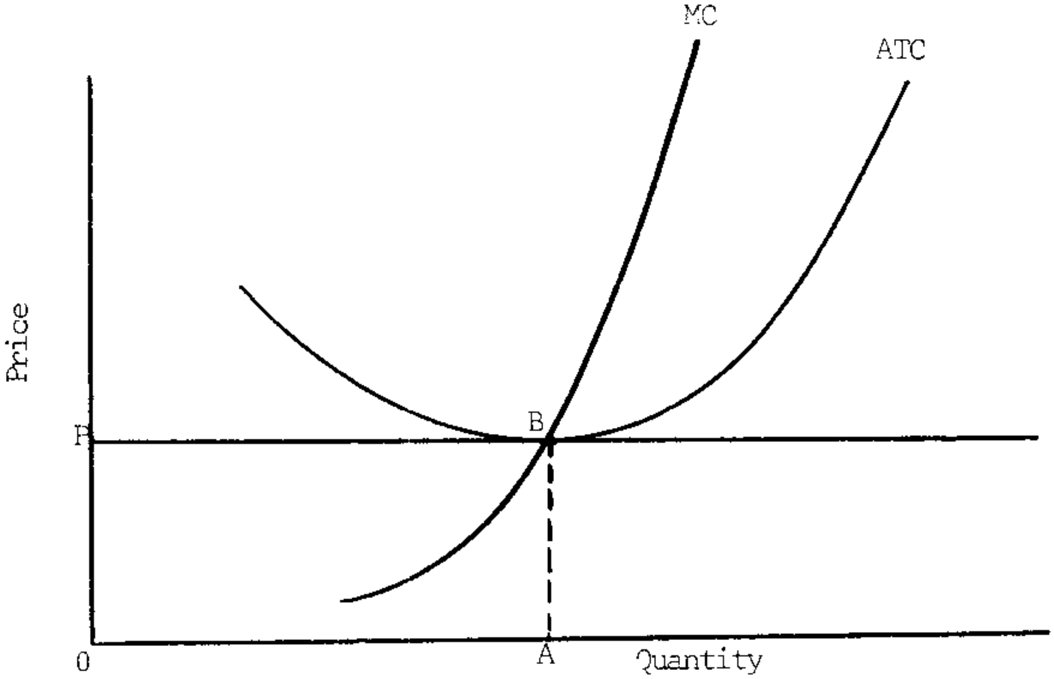

Fig. 6. Long Run Cost Curves for Fishing Vessel Under Competition

breaking even. Under competition in the long run, output for each vessel is OA (Fig. 6). This solution is similar to that for the usual firm in a competitive industry, but the reasons for the solution are different. In the typical competitive industry, new firms enter and output thus increases, causing price to slide down a sloping demand curve. When price has declined to the point where all firms are just breaking even, no more firms will enter and equilibrium will be reached.

In the case of the ETP tuna fishery, the price is assumed to be constant. The ATC curve will rise, however, as new firms enter the fishery until again the identical firms are just breaking even, as in Fig. 6. The ATC curve will shift up for two reasons. First, the externality operating upon the industry during its expansionary phase (declining stocks of fish) will cause costs to rise. Second, spreading of an overall quota over more vessels after MSY has been reached will increase the costs of each vessel, since each one will be able to operate during a smaller part of the year. Overhead must thus be spread over a smaller output, and average costs will consequently rise. Another reason costs may shift up is that the overall quota induces boat owners to build their vessels larger than optimal, so that they can capture as large a share of the quota as possible before the season closes.

III. Recommendations for Eliminating Excess Capacity

A. Landings Fee. Economic theory suggests that a landings fee is the most appropriate management tool for rationalizing a fishing industry. In attempting to levy a landings fee in order to optimize output, however, difficulties will be encountered. The chief difficulty is estimating the magnitude of the required tax. In this study, cross-section data on costs of operation for tuna seiners were analyzed in order to determine the optimal size of vessel. Ideally, a U-shaped average total cost curve would reveal the most efficient size of vessel. Calculating the difference between minimum average total cost and price would give the size of landings fee that could be collected, assuming that all vessels in the fleet are of the optimal size and the number of vessels in the fleet is just adequate to harvest the MSY, with each vessel operating fully throughout the year.

In the present study, however, the average total cost curve sloped downward to the right (see Appendix). This is caused, most likely, by the fact that the larger vessels have an advantage under the present management system in that they can bring back larger loads of fish during the unregulated season, before the quota has been filled. Thus what is the most efficient size of vessel under a different type of management system is impossible to determine. The concensus of those in the industry is that a seiner somewhere between 800 and 1200 tons carrying capacity is most efficient in operation. In a cost-of-operations study done in the early 60's, before the quota was imposed,[6] the cost curves were U-shaped, and it seems reasonable to assume that, although difficult to determine, this would be the normal shape now in the absence of quota-induced distortions.

Presently, with capacity in the ETP tuna fishery equal to about twice[7] that required to harvest the MSY, it is probable that the supply curve of the fishery is more realistically like that in Fig. 7. The point of tangency of the ATC curve to the MSY line is very close to the price line, indicating there is very little economic rent (or excess profits) being earned in the industry. With increasing entries of capital into the ETP tuna fishery, costs have reached the level where little or no rent at all is earned; that is, revenue received is totally absorbed by costs for most vessels.

The abrupt imposition of a landings fee would have drastic and painful effects.

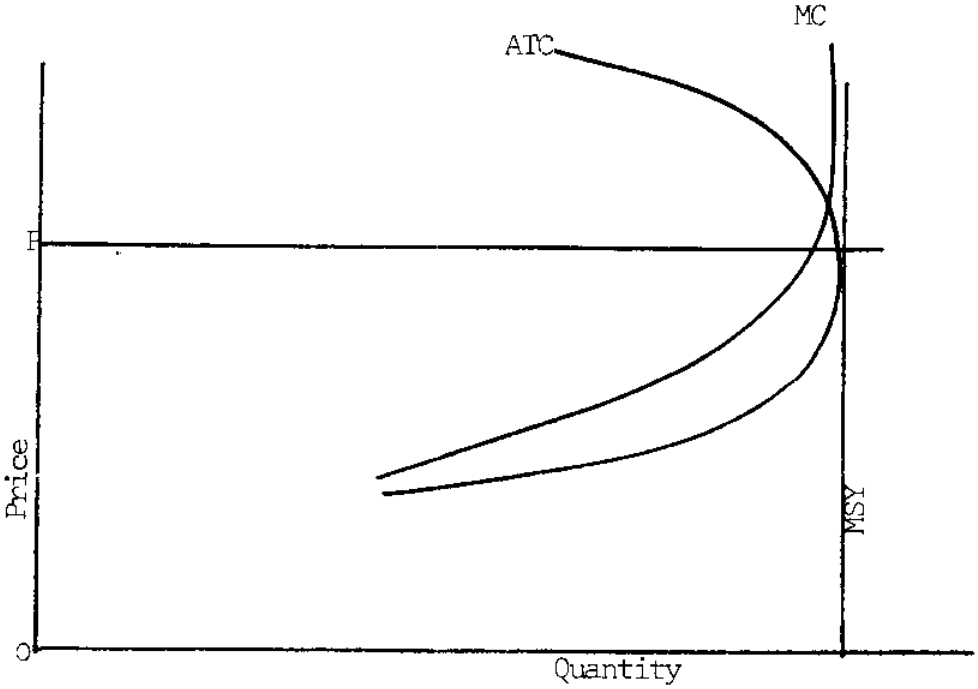

Fig. 7. Probable Relationship of Price to ATC Curve in ETP Yellowfin Tuna Fishery

Vessels with high operating costs would immediately go out of business. Since the existence of considerable excess capacity causes production to be spread over too many fishing units, costs will be so high that very few vessels (only the most highly efficient) would be able to remain in operation. The cure for overcapacity would be harsh and certain.

In view of the needs of the human beings involved in the fishing enterprise, it can hardly be recommended that this extreme policy be followed. An alternative must therefore be found in order to rationalize the ETP tuna fishery.

B. Landing Equalization Tax. A landing equalization tax is a device designed to extract the economic rent on yellowfin tuna, while at the same time stimulating the harvesting of skipjack.[8] The taxes collected from fishermen from their landings on yellowfin will be returned to them with their landings on skipjack. Biologists report that the harvest of skipjack has not yet reached the maximum sustainable yield--a fact that can help ease the transition from a management system employing solely a quota to a system utilizing a landings tax. Yellowfin and skipjack are caught principally by the same vessels in the eastern tropical Pacific. The essence of the landings equalization tax is that the harvesting of skipjack will be encouraged by the payment of a bounty. The average fisherman is thus no worse off than before the implementation of the management system.

The economic criteria the fishermen face will be different from what they were before the implementation of the plan. It will now be less profitable for the fishermen to catch yellowfin and more profitable to catch skipjack. This will benefit society in two ways: the yellowfin resource will be conserved, and skipjack will be utilized more fully.

During the initial phase of the implementation of a landing equalization tax system, if profitability of tuna vessels is high enough for fishermen to want to enter into the fishery, a moratorium on new vessel construction may be necessary. If implemented too rapidly, this type of management system may cause dislocations and hardship among the firms in the fishery. A further difficulty is that the size of tax and bounty required to rationalize the industry may be difficult to determine. Experimentation, of course, could reveal the directions in which modifications should be made. As skipjack exploitation proceeds, the subsidy may need to be eliminated. A landing equalization tax may be a useful management device, especially if it could be utilized in conjunction with another system providing for more direct control over the number of participants in the fishery.

C. License Fee. Such a fee has been used to reduce or limit capacity in certain fisheries. The Japanese have had experience with this type of management, and the Canadian government has managed the salmon fisheries of British Columbia in this way. By drawing on the experience of these two countries, we can deduce some of the effects of this type of management.[9]

If it can be assumed that vessels fishing under a licensing system will continue to fish with the same equipment and the same degree of intensity as before the licensing system was used, then there should be no difference between a landings tax system and a licensing system. Experience has shown, however, that vessel owners undertake changes to increase the share of the fish they catch. Larger, more capital-intensive vessels will be built to increase the profits of the individual vessel owner with a license, but this will subvert the intent of the licensing system, which is to reduce excess capacity. A further effect may be that new vessels, though fulfilling the purpose of the owner in increasing profits, would not fulfill the requirements of efficient harvesting. The new vessels may increase the catch of the individual vessel, but it may be at a higher unit cost. This then does not fulfill the goal of the management agency of harvesting the maximum sustainable yield at the least possible cost.

D. Fisherman Quotas. The suggestion has been made recently by Francis T. Christy, Jr. that fisheries might be managed by means of fisherman quotas, a device designed to limit entry.[10] This plan merits consideration as it might apply to the yellowfin tuna fisheries of the world.

Christy proposes that each fisherman presently engaged in a fishery be allocated a share of the total desired annual yield. The desired annual yield could be the maximum sustainable yield or the maximum economic yield, and upon the recommendation of research biologists, the desired yield may vary from year to year as the state of the fish stock fluctuates. Each fisherman holding a quota, however, will continue to have the privilege of catching his allotted percentage of the total yield. The actual tonnage he may catch will of course increase or decrease as the desired total yield increases or decreases.

Implementation in the tuna fisheries of a management scheme involving the allocation of quotas to individual fishermen may lead to efficient harvesting techniques. If the fisherman can be assured of having the privilege of catching a certain amount of fish each year, he will be motivated to catch that fish in the least costly manner.

A fisherman quota system can be compared to a typical situation of a farmer owning (or leasing) a piece of land and applying labor and capital to it in order to arrive at the optimal output. The latter will be attained when the additional cost of producing an extra unit of output exactly equals the additional revenue to be realized from the sale of the additional unit of output, or marginal cost (MC) equals marginal revenue (MR). The farmer considers his plot of land fixed in size, and he can change his output only by varying the amounts of labor and capital he applies to it.

In the case of a fisherman quota, the maximum output of the fisherman is fixed in the short run, but he can alter his cost patterns by varying the amounts or proportions of labor and capital he applies toward harvesting the resource. Again, the fisherman will wish to equate marginal cost with marginal revenue. While being permitted to harvest only a certain amount of fish, in any given season he must accept the price the market is willing to pay for the fish, since he is a small part of a large competitive industry. Since marginal revenue to him is fixed, he can improve his profit position only by changing the size or composition of his vessel, by changing the amount of labor or other variable factors (fuel) employed on the boat, or by varying the size of his quota. Experience in the ETP tuna fishery seems to indicate that a certain size of crew is most efficient for a given vessel capacity. Therefore, the only practical alternative open to the fisherman is to change the size of his vessel when it is feasible to replace the old one.

When all vessels are identical in a free-entry competitive situation with equilibrium under an overall quota (as in the present management system of the ETP), the cost curves of the individual fisherman will appear as in Fig. 6. But taking into account differences in the vessels in the fleet, some boat owners are found to reap a profit, while marginal firms are barely breaking even.

At the beginning of the imposition of a fisherman quota, many fishermen may find themselves in a position similar to that in Fig. 8, with output OA too small for efficient production. Quotas are likely to be based upon past catches, at least to some extent. The fisherman in many cases will find his vessel larger than optimal now, since he had built a larger one under the overall quota system to bring back as much catch as possible during the short open season. Now, his share of the catch is OA, with revenue being fully absorbed by costs, OABP. If he could use a smaller vessel, he could realize some extra profits.

Figure 9 shows the cost picture for vessels of three different sizes. Vessel 3 is largest and will have relatively high average costs (ATC_3). If forced to produce output OA', the firm will be just breaking even, since the ATC curve crosses the price line at this output. It is producing far below its optimal output where $MC_3 = P$. A smaller vessel with average total costs represented by ATC_2 will make a profit of $P - ATC_2$ for each ton of fish caught.

It is unlikely that a smaller vessel yet, such as that represented by ATC_1 would be given an individual quota as large as OA' based on past catches, since its probable output would typically be much smaller, where $MC_1 = P$. But if it were to produce output OA', it would not be making excess profits, since ATC_1 crosses P at output A'.

The results implied by Figure 9 have been plotted in Figure 10, showing P - ATC as a function of size of vessel (as measured by tuna-carrying capacity). Figure 10 shows that a large vessel will make little or no profit (P - ATC) on each ton of fish landed (or even negative profits), given a fixed output quota. The restriction on the size of the catch precludes the vessel operating at the point where the output is large enough so that P = MC. With a certain medium-sized vessel, the fixed quota is its optimal output, and P = MC. Profits on each ton of fish landed are a maximum. The left half of the curve is a dotted line, since it is unlikely that these smaller vessels will actually produce as much as the individual quota assumed in the example. Their profit picture could be improved, in the short run, by

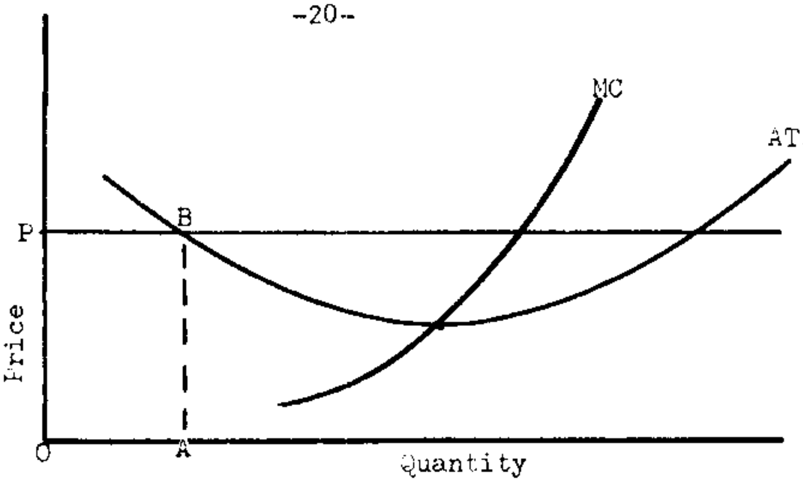

Fig. 8. Long Run Cost Curve for Large Vessels at Imposition of Fisherman Quotas

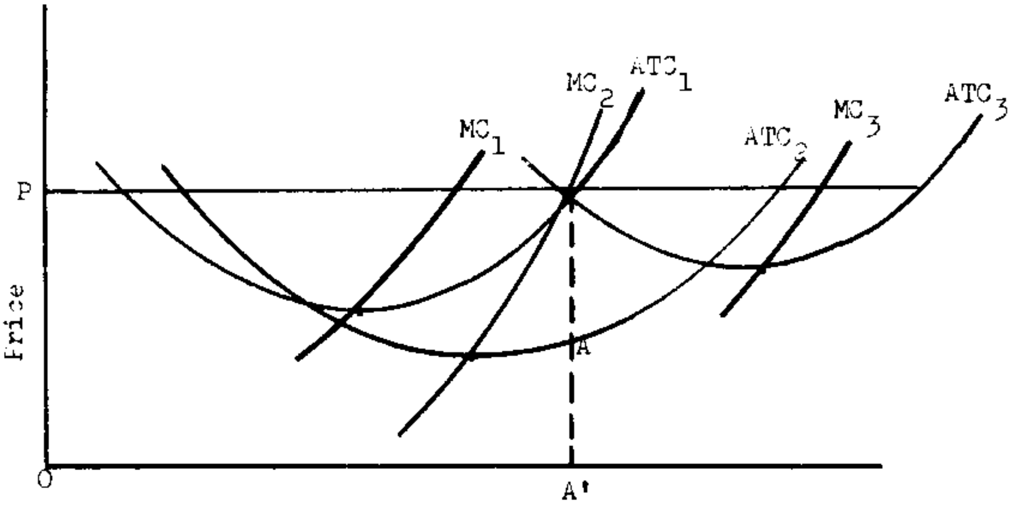

Fig. 9. Long Run Cost Curves for Three Vessels at Imposition of Fisherman Quotas

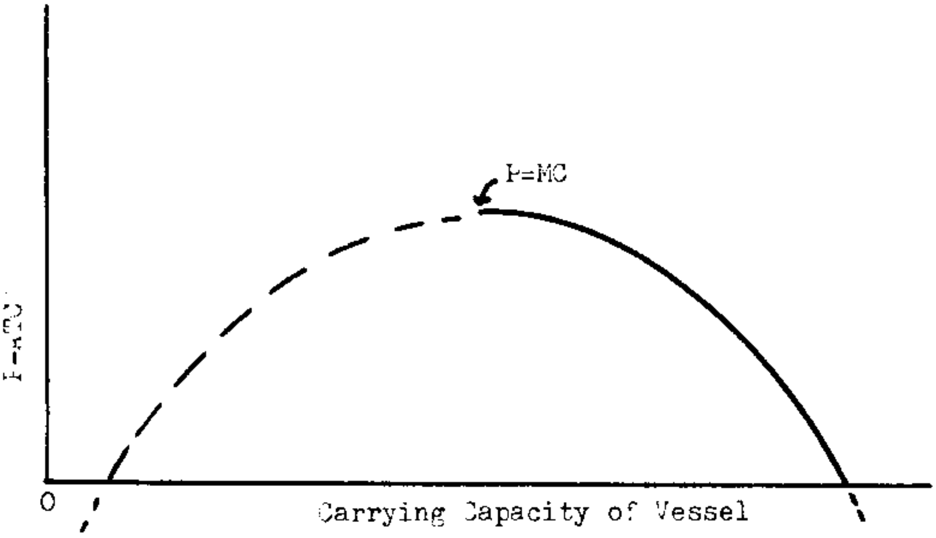

Fig. 10. P-ATC as a Function of Vessel Size After Imposition of Uniform Fisherman Quotas (Output and Price Constant)

producing less than this quota, so that their MC curve equals P. If possible, they should sell or lease any excess part of the quota that is not profitable for them to utilize. In the long run, they could earn more by investing in a larger vessel, one of optimal capacity so that P = MC at the given output level.

If fishermen could count on being permitted to land a certain amount of fish, they could fish all year or allocate their fishing effort in the most efficient manner. If portions of the individual quota could be freely bought or sold (or leased) among individual fishermen (or handled by the central management authority), it is likely that the market mechanism would operate in favor of the most efficient size of vessel. Those with smaller than optimal vessels will find that their profit picture in the long run can be improved by buying a larger quota and a larger vessel. Owners of vessels larger than optimal will attempt to buy a larger quota in the short run so that MC will equal P. In the long run, they will either continue with a small quota and build a smaller vessel, or obtain a larger quota and build two (or more) smaller, optimal-sized vessels. Thus rationality will be introduced into the industry.

One further point about the optimal-sized vessel should be made. This type of vessel will not be operating at the minimum point of the average total cost curve. The vessel size with cost curve ATC_2 (Figure 11) will be operating at minimum ATC at output OA', with profit MBCP. A somewhat smaller vessel with cost curve ATC_1 will be operating where $MC_1 = P$, and it will therefore be optimal in size (given the restrictions against free entry and exit); output OA' will be beyond minimum ATC and profits will be NACP. The assumption upon which this analysis is based is that within a certain range, a smaller vessel is more efficient than a larger vessel. This assumption is

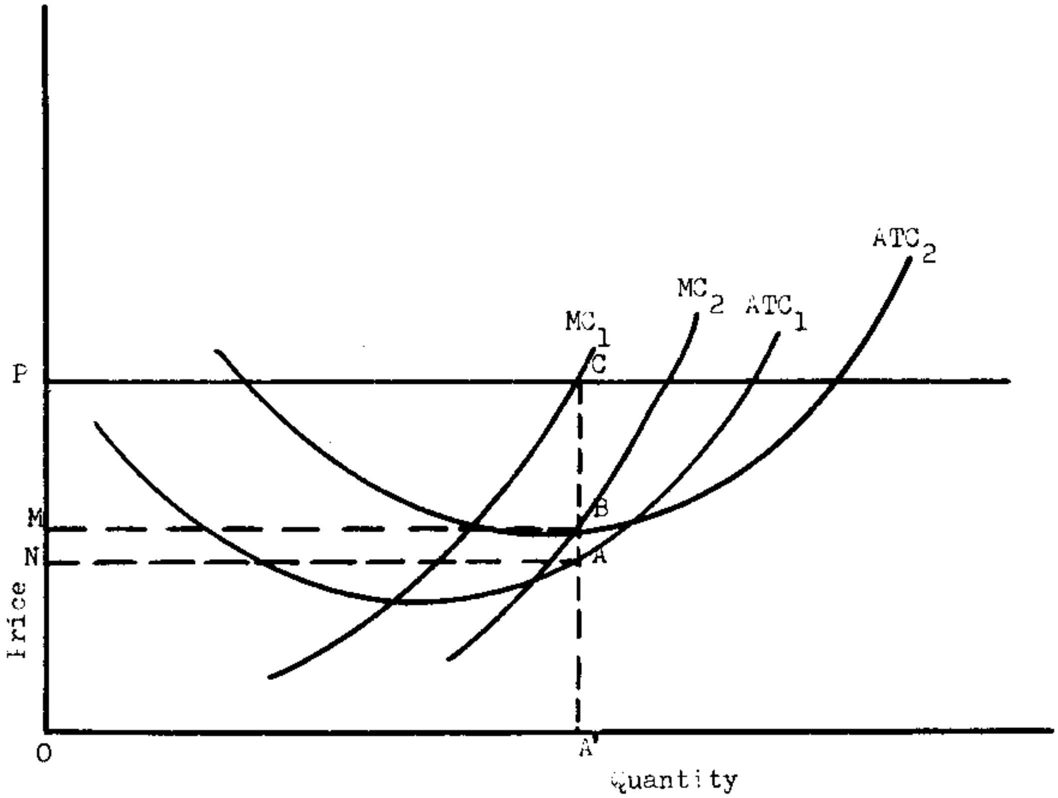

Fig. 11. Long Run Cost Curves for Two Sizes of Tuna Vessels

probably valid for the tuna fishery when comparing vessels approaching 1500-2000 tons carrying capacity. Purse seiners this large have been built in order to take advantage of the overall quota system by bringing back large loads during the open season. Indications are that the larger vessels are unwieldy in maneuvering during the catching operation, and if a boat owner could be assured of all-year fishing, a smaller vessel may be preferred, as indicated in Fig. 11.

To implement the fisherman quota system, an international commission (either Inter-American Tropical Tuna Commission with increased powers or a new international organization) could lease for a long term (initially at a nominal fee) quotas of catch to boat-owners, regardless of country of origin. Past catch would be the most useful criterion to use in allocating the quota, but other criteria may also be used, such as proximity to the fishing grounds or historical development. The international tuna commission (ITC) should retain ownership of the quota to facilitate transfer of individual quotas.

If a fisherman loses his vessel or chooses to sell it, he could sub-lease his quota to whichever fisherman will give him the highest price for using it, regardless of national origin. This will tend to make the industry efficient, because the most efficient operation will be able to pay the highest price for the privilege of catching tuna. Under a long-term lease arrangement the lessee will be able to renegotiate each year the price of sub-leasing his quota.

If the original boat owner chooses to replace his last boat, he will probably build a vessel of more optimal size for the size of his quota. Alternatively, he could build two vessels of optimal size and arrange to lease a larger quota. For example, let us suppose that the owner of a 1500 ton vessel were allowed to have a quota of 1500 tons of yellowfin. This means he could fill his quota in one trip if he caught only yellowfin, or two trips if he caught half skipjack. Let us also suppose that a 1000 ton vessel has lowest costs, when used at capacity. If the fisherman should lose his ship, he would be wise to replace it with a 1000 ton vessel, making more trips per year. He would, therefore, come out in a better financial situation.

Outright ownership of the quota, rather than a lease arrangement, is another possibility for the legal basis for the fisherman's quota system. Under this arrangement, taxes on intangible property could be collected by the tuna commission. Transfer of ownership from one party to another should be legally permitted.

At the imposition of a system of fisherman quotas,new vessels would be prohibited from entering. It would probably not be feasible for the tuna commission to collect much in the way of taxes from those vessels already in the fishery. Vast overcapacity in the fishery will mean that each vessel is operating at less than optimal output, and total revenue will probably be absorbed by total costs. It would, therefore, constitute undue hardship among boat owners to exact a tax from them.

After a few years, when attrition has caused a reduction in the number of vessels, the efficiency of the fleet will no doubt increase. A reduction in the number of vessels will permit the remaining vessels to operate during a greater portion of the year. Furthermore, those vessels that have been replaced will be of a more efficient size.

The increased efficiency of the fishing fleet will lead to the emergence of some economic rent. Fishermen would still come out as well as they did when revenue was barely covering costs under a free-entry overcapacity situation.

It is interesting to estimate the amount of taxes that could be collected if all vessels were of optimal size, and if the number of vessels were reduced so that they would all be able to fish all year, except for time needed for unloading and repairs. In 1974, the average catch per ton of carrying capacity for all species of tuna was nearly two and a half tons for California- and Puerto Rico-based seiners.[11] The high was achieved in 1967, when five tons were caught on the average per ton of carrying capacity, and the catch per ton has declined steadily since then, reflecting the effect of the quota upon vessel operations. The larger vessels were affected more adversely than the smaller vessles, since the latter had the benefit of special small boat allocations for yellowfin. If all restrictions were removed from the larger vessels, a conservative estimate is that they could make at least one more successful trip and catch an average of three and a half tons per ton of carrying capacity.

In 1974, for California- and Puerto Rico-based seiners $560 was the average price of fish caught (average gross earnings per ton of carrying capacity divided by average catch per ton of carrying capacity).[12] Assuming a 1100 ton purse seiner that was just breaking even,[13] a catch of an extra ton of fish per ton of carrying capacity would bring in $616,000 of extra profit (1100 times $560).[14] If the extra profit is spread over the total catch of 3850 tons (1100 times 3.5), the amount of extra profit earned per ton of catch is $160 ($616,000 divided by 3850).

Similar calculations could be done for vessels of another size with identical results. Although vessels of less than 1100 tons did not, on the average, break even in 1974, the profit picture probably would have been much brighter if there had been fewer boats and no quota. A vessel of somewhat less than 1100 tons may well be the most efficient size in the absence of a quota, yielding even greater profits per ton of carrying capacity. The key to profitability rests with both gross revenue <u>and</u> operating costs.

Suppose that $160 were collected on each ton of yellowfin landed by purse seiners. The maximum sustainable yield for yellowfin from the ETP is estimated to be between 148,000 tons and 178,000 tons.[15] Assuming a conservative estimate of MSY of 150,000 tons, a total of $24 million (150,000 times $160) could be collected if the purse seiners caught the entire MSY of yellowfin.[16]

This estimate should take into consideration the role of baitboats in the fishery. Since the baitboats have special allocations because of their size, they are frequently able to fish for yellowfin all year long, unlike the purse seiners. Their fishing operations may therefore be fairly efficient. Some fishermen in the industry contend, however, that if the baitboats did not catch the yellowfin, the same fish would eventually find themselves farther offshore where they would ultimately be caught by purse seiners. If there were not excess capacity among the purse seiners, it is likely that the seiners could more efficiently catch the entire MSY of yellowfin. The baitboats are needed for the albacore fleet, however, and in order to be fully occupied and to make an acceptable income, many boat owners find they must participate to some extent in the tropical tuna fishery.

For the San Diego-based baitboat fleet, minimum average total cost per ton for 1974 was calculated by Thomson to be $528.[17] That means for each ton of yellowfin landed, $46 ($574-528) could be collected from the most efficient size of baitboat (250 tons carrying capacity). Because of the nature of the fishery, being largely family-owned, and its involvement in the albacore fishery, many boats will remain smaller than the most efficient size and it would therefore be a hardship to collect a landings fee. Thus no economic rent could be realized from the baitboat fleet.

Administration of a management system would be nearly impossible if a fee were collected from purse seiners but not baitboats for the harvesting of yellowfin. If the same fee were collected however harvested, baitboats would be forced to limit their catch of yellowfin. This may mean that the MSY of yellowfin would be caught less expensively by the purse seiners, but the disruption to the baitboat owners may be severe. Their problems must be dealt with effectively.

Relying mostly upon the purse seine fleet to harvest yellowfin, economic rent of $24 million or more could probably be collected. Subtracting some of this for administrative expenses, the remaining amount would be substantial. It could be given back to those countries close to whose shores the fish swim, or to those countries claiming a historical right to some part of the fishery. The present confusion over territorial waters could be resolved through universal adherence to the tuna commission's regulations. Tuna, as a pelagic resource, should be exempted from the claims of territorial rights. Revenues to those countries successfully claiming some return from the harvest of the resource will come from disbursement of the economic rent.

As the number of tuna vessels declines, the resultant increasing efficiency can make it possible for larger lease prices to be collected. The fishermen will be equally well off. More surplus will be collected to give back to the claimants of ownership of the resource.

Christy lists four criteria for the evaluation of a management system:

1. Optimization of sustainable yield
2. Optimization of economic yield
3. Reduction of management costs
4. Acceptability of the system

Christy discusses the advantages of the fisherman quota system in general terms. It will be shown here that as applied to the ETP tuna fishery, this system would also have advantages.

With respect to the first criterion, limitation of catch to the maximum sustainable yield is already in effect in the ETP tuna fishery. Extension of this policy under a stronger management system should pose no difficult problems.

With respect to the second criterion, it was shown previously that for a fully developed fishery, such as ETP tuna, with rising demand and constant output, maximum economic yield approaches maximum sustainable yield. This criterion will therefore be approximately fulfilled. The purpose of maximizing economic yield, however, is to conserve economic resources (capital and labor) in the production of the output. Unless some method is employed to limit entry, there will be overcapacity. But free exchange of ownership (or lease) of a fisherman quota will lead to efficient production since the least cost producers will be able to bid the highest price for the privilege of fishing. Furthermore, fishermen will be motivated to adopt new technological innovations leading to a lowering of costs. Thus, progressiveness in the industry can be assured.

The third criterion, reduction of management costs, can be achieved through a fisherman quota system. Management under the present overall quota system, with an open season, consists in ensuring that yellowfin are not caught when it is not permitted. There are many complaints that the system is not being uniformly enforced. An international tuna commission with its own regulatory arm could impartially enforce the regulation that each vessel could unload only a specific amount of yellowfin. Biological research should continue to determine the maximum sustainable yield and to aid the fisherman in finding fish. Perhaps the limits of the regulatory area should be expanded, so that there would not be the difficulty of determining whether a specific catch was caught inside or outside the limits. Management costs for a fisherman quota system may be low compared to other feasible systems.

The fourth criterion, acceptability of the system, is difficult to evaluate. Buchanan and Tullock[18] have presented a theory of externality control, explaining the observed frequency of direct regulation (or quota) as opposed to penalty taxes or charges (landings fees in the fishing case). Their exposition demonstrates that producers will often prefer the above-normal returns in the short run resulting from a production quota to a tax which is clearly punitive. A landings fee in the fisherman quota management system would be levied only some time after the imposition of the system, when excess capacity had been eliminated. The above-normal returns may even be preserved in the long run if entry is restricted and if a landings fee does not fully absorb excess profits. In the case of the ETP tuna fishery, where a horizontal demand curve is assumed, there will be no above-normal returns resulting from the imposition of individual production quotas in the short run, but as in Buchanan's and Tullock's analysis, the fishermen will prefer not to have to pay punitive taxes. That analysis lends further weight to the conclusion that fisherman quotas are the appropriate management plan for the ETP tuna.

Another aspect that must be considered in evaluating any management system is the impact it will have upon the rest of the economy. Rockland[19] has found that the tuna industry in all its aspects accounts for less than one percent of employment in San Diego County. The proportion in the national economy would of course be much smaller. Limiting entry would reduce the number of crew members required, but it would not reduce the number of workers employed in the canneries since the same amount of tuna would be caught. As many of the crew members are already recruited from foreign countries, a diminution in the number of tuna boats would have very little impact upon the local economy. Since the key crew members (captain, mate, chief engineer) are usually Americans and as there is a world-wide shortage of these skilled men, employment for them will likely remain high.

The annual quota imposed by the Inter-American Tropical Tuna Commission is not being universally enforced, and as the increase in the number of tuna vessels causes increased pressure upon the resource, the present system is in danger of collapsing. An international system must be found to protect not only the resource but also those engaged in its harvest. A system of fisherman quotas is recommended as a potentially effective means of rationalizing the tuna fishery.

A management system of the fisherman quota type has never before been attempted, and there will inevitably be resistance to it through lack of understanding. However, the reasons for adopting such a system seem to be sufficiently compelling for it to be accepted eventually.

IV. Acknowledgments

This work is a result of research sponsored by NOAA, Office of Sea Grant, Department of Commerce, under grant no. USDC 04-3-158-22, project no. R/ME-3. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear herein.

The author gratefully acknowledges valuable comments on the preliminary draft by T. R. Lewis of California Institute of Technology, G. C. Broadhead of Living Marine Resources, and C. J. Orange of the Inter-American Tropical Tuna Commission. San Diego State University's Center for Public Economies and Center for Marine Studies provided helpful assistance. Numerous members of the tuna industry, who prefer to remain anonymous, were indispensable in the preparation of this report, both in providing data and in offering suggestions. Any deficiencies are the responsibility of the author. H. L. Roth, D. A. Flagg, and D. T. Flagg provided computational assistance.

APPENDIX

Cost and Revenue Data for the Eastern Tropical Pacific Purse Seine Fleet (1974)

The purpose of this analysis of costs of operation of tuna purse seiners in the eastern tropical Pacific was to determine the most efficient size of vessel, and from that information, estimate how much economic rent could be captured under the hypothetical conditions that all vessels were of optimal size and the number of vessels were optimal in the sense that the maximum sustainable yield of yellowfin could be just captured (along with the usual skipjack) if the vessels operated all year long. The usual shape of the long-run average cost curve is a U-shaped curve.

In traditional economic theory, the most efficient size of plant is the one where average total cost per unit of output is at a minimum. If Q_1 is the desired output for a plant (see Fig. 12), plant A will be operating at its minimum point, but it can lower costs by shifting to a larger size plant, plant B, even though output for the larger plant will be smaller and costs higher than they would be if operating at its minimum total cost point. Plant C has the lowest short-run average cost curve, and is therefore optimal in size, with optimal output being Q_2. (Demand curves are not considered here, since in perfect competition increased output because of new entrants will, in the long run, shift the perfectly elastic demand curve down to tangency with the minimum of the average total cost curve.)

Plants such as A, B, and C can be identified by some measure of size, such as square footage of floor space, dollar value of critical productive equipment, or, as in a fishery, by physical carrying capacity of the vessel. The analysis used here is a long-run analysis, based on a number of vessels operating at the same point in time. In an empirical analysis such as this, the situation is dynamic, and some vessels will be at the point of withdrawing from the industry

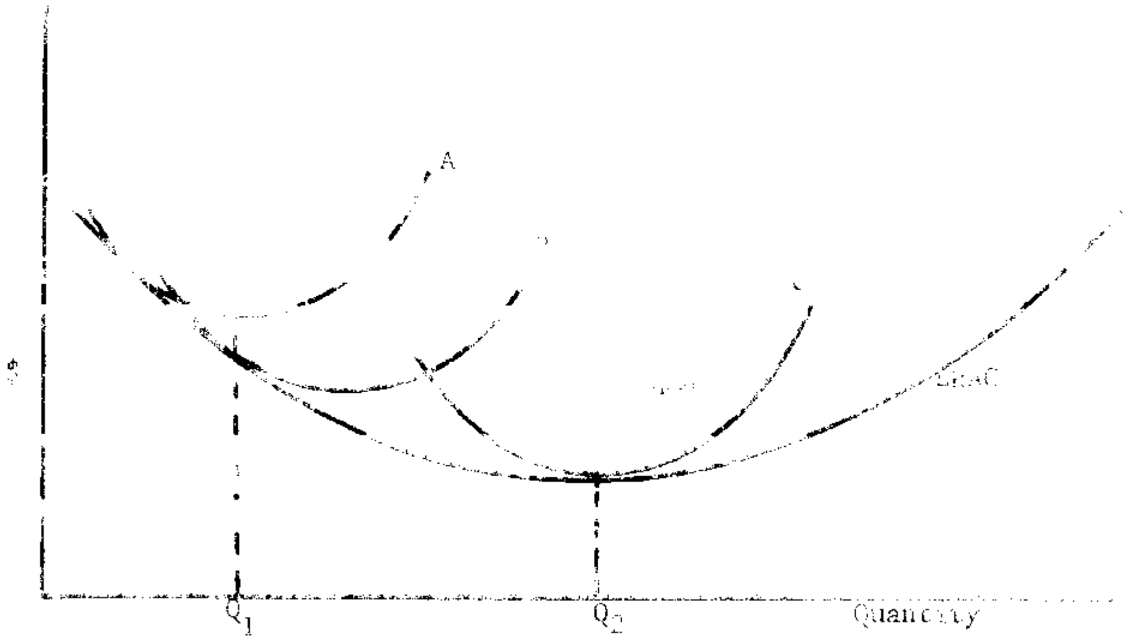

Fig. 12. Short and Long Run Average Total Cost Curves

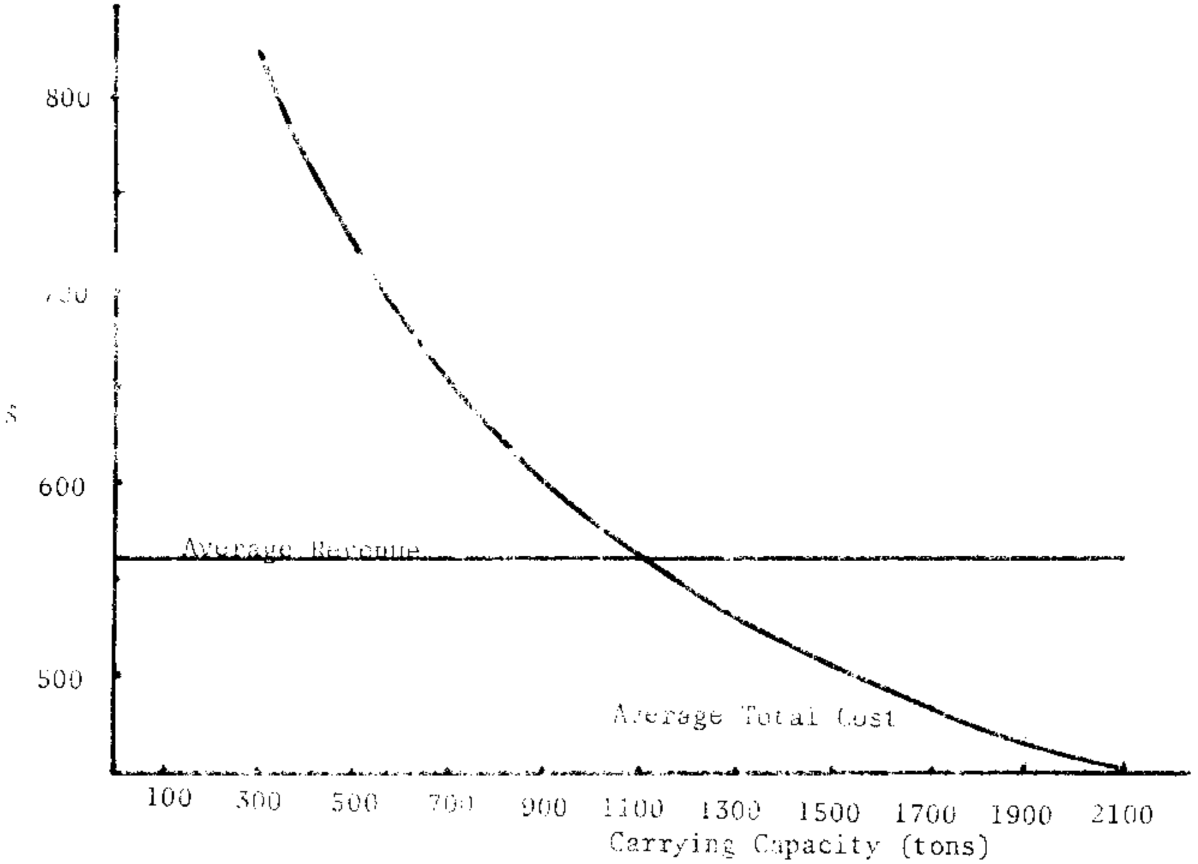

Fig. 13. Eastern Tropical Pacific Tuna Purse Seine Fleet
Average Total Cost and Average Revenue: 1974

or being shifted to a different size. Thus some of the observed average total cost points would theoretically no doubt fall above the LRAC curve of Fig. 12. But the size of vessel giving the lowest average total cost should still be some indication of the optimal size, and optimal output is that output associated with the optimal sized vessel.

Unfortunately, the empirical data did not reveal the most efficient size of vessel; other clues, such as data published by the Inter-American Tropical Tuna Commission, had to be used to estimate economic rent. The cost curve found here was downward sloping to the right (see Fig. 13). The existence of a quota gives a significant benefit to the vessels of larger capacity, since they are able to bring in large loads of yellowfin before the unregulated season closes. Therefore, it is impossible to find what the most efficient size of vessel would be in the absence of the quota system.

With the existence of a quota, the larger vessels are able to spend a major proportion of their total fishing time in the lower-cost regulatory area, because they are permitted to stay in the regulatory area on their free trip until they have filled the boat. Smaller boats fill up faster and then must go back out to more expensive areas. The yellowfin can be caught at lower cost within the regulatory area for several reasons. First, fuel, which is a very large item, is lower inside the regulatory area than outside because the fishing grounds are closer to the home port. Especially if the tunaboat goes to the Atlantic Ocean, fuel costs will be quite large. Second, the weather is better inside the line than outside, and less fuel is therefore burned up inside the line because there are fewer delays in waiting for suitable weather to fish. Third, yellowfin are more plentiful inside the line and can therefore be caught at lower cost. Less time is needed for searching.

It can be observed from the data that the critical factors in determining the profitability of a vessel are size of catch, fuel costs, and repair and maintenance expense. The latter are the largest variable costs, and it is therefore important to keep them at a minimum. A skillful skipper can not only bring in a large catch, but he can minimize fuel costs while doing so. An experienced chief engineer can anticipate needed repairs, and therefore avoid the more expensive crises.

Data from 48 vessels were analyzed. The sample of vessels selected from the international fleet of tuna seiners does not constitute a random sample; it represents those vessels whose owners were willing to share their year-end statements. The data seem to be fairly representative of the fleet as a whole, however. Included are some vessels considered high-liners (very efficient), as well as some of the least efficient vessels. There was some reluctance on the part of vessel owners to open their books, but when they were assured that the information would be presented only in summary form, many cooperated fully.

In selecting a functional form for the regression equations relating the cost components to vessel capacity, several different equations were tested. They were: linear, $Y = A + BX$; exponential, $Y = Ae^{BX}$; semilog, $Y = A + B \log X$; double log, $Y = AX^B$; reciprocal of X, $Y = A + B/X$; reciprocal of Y, $Y = 1/(A + BX)$; reciprocal of both, $Y = X/(B + AX)$; quadratic, $Y = A + B_1X + B_2X^2$; and cubic, $Y = A + B_1X + B_2X^2 + B_3X^3$. The equation selected was the one that best fit the data empirically. For the regression equations below, X = vessel carrying capacity in short tons. The numbers in parentheses are the t-values for the constants directly above. The summary data are presented in Table 1. The boats represent both U.S. and foreign registry.

Total Landings (Y_1)

The regression of landings on carrying capacity revealed a linear relationship, significant at the 1 percent level.

$$Y_1' = \underset{(1.353)}{330.193} + \underset{(7.569)}{1.943}X; \quad n = 48, \; r^2 = .555, \; \bar{R}^2 = .545$$

Table 1. Costs of Operation for the Eastern Tropical Pacific Tuna Purse Seine Fleet, 1974 (Dollars)

Vessel Carrying Capacity (tons)	Total Landings (tons)	Salt	Fuel	Labor	Crew Provisions	Repairs and Maintenance	Other Variable Costs	Total Variable Costs	Average Variable Cost
300	913	1,295	52,654	251,780	30,141	144,846	43,560	524,276	574
500	1,302	2,344	83,931	298,653	30,141	144,846	54,501	614,416	471
700	1,690	3,466	112,595	345,527	30,141	144,846	63,170	699,745	414
900	2,079	4,643	138,960	392,401	30,141	144,846	70,532	781,523	375
1,100	2,467	5,862	163,293	439,274	30,141	144,846	77,022	860,438	348
1,300	2,856	7,119	185,819	486,148	30,141	144,846	82,878	936,951	328
1,500	3,245	8,407	206,732	533,021	30,141	144,846	88,247	1,011,394	311
1,700	3,633	9,724	226,200	579,895	30,141	144,846	93,228	1,084,034	298
1,900	4,022	11,066	224,368	626,769	30,141	144,846	97,889	1,155,079	287
2,100	4,410	12,431	261,361	673,642	30,141	144,846	102,282	1,224,703	277

Vessel Carrying Capacity (tons)	Replacement Cost	Depreciation	Opportunity Cost of Investment	Insurance	Other Fixed Costs	Total Fixed Costs	Average Fixed Cost	Total Cost	Average Total Cost
300	1,637,366	109,158	81,868	27,443	12,231	230,700	253	754,976	826
500	2,242,234	149,482	112,112	37,922	26,120	325,636	250	940,052	722
700	2,758,127	183,875	137,906	46,925	32,073	400,779	237	1,100,524	651
900	3,219,484	214,632	160,974	55,017	35,380	466,003	224	1,247,526	600
1,100	3,642,690	242,846	182,134	62,470	37,484	524,934	213	1,385,372	561
1,300	4,037,131	269,142	201,857	69,439	38,941	579,379	203	1,516,330	530
1,500	4,408,809	293,921	220,440	76,024	40,009	630,394	194	1,641,788	505
1,700	4,761,846	317,456	238,092	82,293	40,826	678,667	187	1,762,701	485
1,900	5,099,223	339,948	254,961	88,297	41,471	724,677	180	1,879,756	467
2,100	5,423,188	361,546	271,159	94,072	41,993	768,770	174	1,993,473	452

Average Revenue: 560

This equation was used in estimating the amount of landings for vessels of varying sizes.

Salt (Y_2)

A regression of salt expenditure on carrying capacity revealed a relationship significant at the 1 percent level.

$$Y_2' = 1.708 \cdot X^{1.162}; \; n = 48, \; r^2 = .244, \; \bar{R}^2 = .227$$

$$(.258) \quad (3.772)$$

Fuel (Y_3)

Fuel cost for a given size of vessel is most directly dependent upon the number of days absent. Unfortunately data on days absent or days fishing for most of the boats included in this analysis are not available. Fuel cost will depend to some extent upon the amount of landings--more landings requiring more fuel. The luck of the boat and the skill of the skipper are important factors in determining how much fuel is required, however. More luck and better skill will result in a given load of fish being caught in fewer days and therefore with a smaller expenditure of fuel.

The regression of fuel cost per ton of landings with vessel carrying capacity revealed a relationship significant at the 5 percent level. The regression of total fuel cost on vessel carrying capacity revealed a more significant relationship, however (1 percent), and this was therefore used to estimate the fuel cost for vessels of varying sizes.

$$Y_3' = X/(.00531 + .00000130X), \; n = 48, \; r^2 = .686, \; \bar{R}^2 = .679$$

$$(10.032) \quad (1.547)$$

In evaluating the performance of one boat against another, fuel cost per day absent is a significant measure. Grouped data on days absent and days fishing (1974) for four size categories of boats were obtained from the Inter-American Tropical Tuna Commission.[20] Although the number of observations was small, significant relationships of these variables with vessel capacity were obtained.

Z_1 = number of days absent

$Z_2' = X/(.2888 + .00429X)$; $n = 4$, $r^2 = .945$, $\bar{R}^2 = .917$

(5.861) (20.861)

Z_2 = number of days fishing

$Z_2' = 188.017 - 11{,}941.83/X$; $n = 4$, $r^2 = .965$, $\bar{R}^2 = .947$

(27.97) (-7.416)

The regression equations (significant at the 5 percent level) were used to estimate the number of days fishing and the number of days absent for different size categories. To arrive at fuel cost per day absent, the previously estimated figures for total fuel cost were divided by the estimated days absent for each size of boat (*see* Table 2). These results must be interpreted cautiously because of the limited amount of information available.

Table 2. Estimated Days Fishing, Days Absent, and Fuel Cost Per Day Absent for Tuna Purse Seiners: 1974

Vessel Carrying Capacity (tons)	Total Fuel Cost (Dollars)	Number of Days Fishing	Number of Days Absent	Fuel Cost Per Day Absent (Dollars)
300	52,654	148	190	277
500	83,931	164	205	409
700	112,595	171	213	529
900	138,960	175	217	640
1100	163,293	177	220	742
1300	185,819	179	222	837
1500	206,732	180	223	927
1700	226,200	181	224	1010
1900	244,368	182	225	1086
2100	261,361	182	226	1156

Labor (Y_4)

Labor costs here include Social Security and unemployment insurance payments in addition to crew payments. The crew on the California-based boats are generally paid on the share system; the union negotiates directly with the owner for the share of the proceeds to be received by a crew member after trip expenses are subtracted from gross revenue. Some crew members receive less than a full share, and some of the officers receive more than a full share and perhaps a bonus. On the large, corporate-owned vessels based in Puerto Rico, most of the crew is foreign, and they are typically paid on a per-ton basis.

The relationship between labor costs and vessel capacity was linear, significant at the 1 percent level.

$$Y_4' = \underset{(2.90)}{181.469} + \underset{(3.56)}{234.368}X; \; n = 48, \; r^2 = .216, \; \bar{R}^2 = .199$$

Crew Provisions (Y_5)

The size of the crew does not vary a great deal with the size of the tuna boat. Even the smaller vessels must use a crew of about 14 at a minimum, and the larger vessels frequently use a crew of only 17.

A more significant factor affecting the cost of crew provisions is the number of days at sea. Since the larger vessels spend more days at sea than the smaller ones, the expense for crew provisions will be higher. The difference in the number of days absent for larger as compared to smaller vessels (*see* Table 2) is not very large, however. Since the quality and quantity of provisions vary substantially from one boat to another because of individual preferences, the variation due to days absent is overcome. Therefore no significant relationship was found between expense for crew provisions and carrying capacity. The mean for all vessels was used.

$$\bar{Y}_5 = 30{,}141; \text{ standard deviation} = 16{,}095, \; n = 43$$

Repairs and Maintenance (Y_6)

Informed opinion within the industry suggests that larger vessels require larger expenditures for repairs and maintenance. Because of the peculiarities of the empirical data, however, that kind of significant relationship could not be found. Repairs and maintenance expenditures increase with age of the vessel, and it is a phenomenon within the ETP tuna purse seine fleet that most of the larger vessels were built after about 1967, and the small ones were built prior to that year. In a multiple regression analysis with repairs and maintenance as the dependent variable, and age and capacity as the independent variables, no significant relationship was revealed. There was multicollinearity between age and capacity, however, which led to the difficulty. (The correlation coefficient between the independent variables was .782.)

The individual boat owner can exercise a wide degree of discretion in making repairs. The boat is typically dry-docked every 12 to 18 months, but this can be delayed during times of financial hardship. Some owners are careful about maintenance, and others delay repairs until a crisis appears.

The mean was used here for the estimate of vessel repair and maintenance expenditures.

$\overline{Y}_6 = 144{,}846$; standard deviation = 96,530, n = 46.

In comparing any individual boat to this mean, the age and carrying capacity must be considered. Boats older and larger than average can be expected to have repair and maintenance expenditures larger than average.

Other Variable Costs (Y_7)

Other variable costs include such items as fishing licenses, equipment rental, and port charges. The relationship between other variable costs and vessel capacity was significant at the 5 percent level.

$$Y_7' = 3568.5 \cdot X^{.4387};\ n = 47,\ r^2 = .107,\ \bar{R}^2 = .0875$$
$$(6.445) \quad (2.326)$$

Since tuna fishermen typically pay their trip expenses after the trip is completed and the fish unloaded, there is no loss of interest with operating capital. Therefore opportunity cost of operating expenses is not a cost in this fishery, as it is in most other fisheries.

Total Variable Costs (Y_8)

In a long-run analysis such as this, all costs are variable, including boat size. In order to distinguish categories of expenditures, however, the short-run categories of variable and fixed costs are separated. Total variable costs do not therefore include those items typically considered fixed costs.

$$Y_8' = Y_2' + Y_3' + Y_4' + \bar{Y}_5 + \bar{Y}_6 + Y_7'$$

Average Variable Cost (Y_9)

$$Y_9' = Y_8'/Y_1'$$

Replacement Cost (Y_{10})

From industry sources, data points were obtained for replacement cost and the following equation was derived:

$$Y_{10}' = 48{,}935.2X^{0.615442}$$

Depreciation (Y_{11})

In order for the fleet to be viable in the long run, depreciation must be high enough to replace worn-out vessels. Hence replacement values were used here in figuring depreciation instead of using the figures supplied by boat owners. If the boat is several years old, the original cost (and therefore depreciation) is much lower than it would be now because of inflation. Using replacement cost rather than original cost in figuring depreciation eliminates the effect of the age of the boat.

The current most prevalent method of figuring depreciation in the industry is 15-year straight line depreciation. Although the actual physical life of a modern steel-hulled vessel may be much longer, the economic life may be shorter because of rapid technological change. Thus 15 years seems a reasonable compromise.

$Y'_{11} = Y'_{10}/15$

Opportunity Cost of Investment (Y_{12})

If the boat owner had invested elsewhere, he would have had one-half the replacement cost available to him, on the average, over the life of the boat (full replacement cost the first year, zero at the end of 15 years). An interest rate of 10 percent is used here to represent forgone earnings.

$Y'_{12} = Y'_{10} \cdot 1/2 \cdot .10$

Interest costs as listed by the boat owners are typically lower than the opportunity cost of investment figures used here. If the mortgage had been acquired several years ago, it is likely that the interest rate was lower than it would have been in 1974. For this reason, the long-run analysis demonstrates less profitability in the tuna purse-seine fleet than would a short-run analysis.

Insurance (Y_{13})

All tuna boats carry hull and machinery insurance, which increases with increasing size of vessel. In addition, they carry protection and indemnity (P and I) insurance,which covers liability arising from injuries to crew members and other liabilities. Some tuna boats carry additional insurance on nets and on the catch of fish. The relationship between insurance and carrying capacity was significant at the 1 percent level.

$$Y'_{13} = 741.637X^{.633};\ n = 47,\ r^2 = .598,\ \bar{R}^2 = .589$$

$$(12.688) \quad (8.178)$$

Other Fixed Costs (Y_{14})

Other fixed costs include office overhead, attorney and accounting fees, and miscellaneous expenses. The regression of other fixed costs on carrying capacity was significant at the 5 percent level.

$$Y'_{14} = 46{,}953.9 - 10{,}416{,}959.9/X; \quad n = 47, \ r^2 = .0912, \ \bar{R}^2 = .0710$$
$$(6.304) \qquad (-2.125)$$

Total Fixed Costs (Y_{15})

It must be emphasized again that in the long run all costs are variable. But it is a useful category in this analysis.

$$Y'_{15} = Y'_{11} + Y'_{12} + Y'_{13} + Y'_{14}$$

Average Fixed Cost (Y_{16})

$$Y'_{16} = Y'_{15}/Y'_1$$

Total Cost (Y_{17})

$$Y'_{17} = Y'_8 + Y'_{15}$$

Average Total Cost (Y_{18})

$$Y'_{18} = Y'_{17}/Y'_1$$

Average Revenue

Revenue per unit of output is important in determining the profitability of a boat. The catch is a mixture of higher-priced yellowfin and lower-priced skipjack. Average revenue reveals the proportion of yellowfin and skipjack in the catch. In order to determine if larger boats caught a different proportion of yellowfin from smaller boats, total revenue for each individual observation was divided by landings and a regression run on carrying capacity. There was no significant correlation between revenue per ton of landings and vessel carrying capacity. Thus, large boats tend to catch the same proportion of yellowfin as small boats, on the average.

Average price received per ton of landings in 1974 by the United States purse seine fleet was \$560.[21] Tuna boats of under 1100 tons carrying capacity had average total cost higher than \$560; therefore they lost money, on the average, considering all long-run expenses. Boats larger than 1100 tons could realize profits, on the average.

Table 3 gives economic data for 1974 for 40 United States vessels in the eastern tropical Pacific tuna purse seine fleet. There are four or more vessels in each size class.

Accounting practices differ widely in the tuna industry, and this must be kept in mind in interpreting the table. Most boat owners keep their books on a cash basis, but some have adopted the accrual basis.

Besides fuel and oil, other trip expenses usually include salt, clearance and entry, welfare fund, pension fund, fish inspection, association fund, cargo insurance, protection and indemnity insurance, unloading and watchmen's charges, foreign port and canal charges, telephone and telegraph, drugs and medicine, plane spotting, and miscellaneous expenses. Some owners include repairs on equipment as trip expenses, and others do not.

Trip expenses are subtracted from total revenue derived from the sale of fish and the remainder is divided between the crew and the boat according to a previously negotiated formula. The crew portion is divided among the crew members, the more important members of the crew often receiving more than one share and inexperienced new members receiving only part of a share. From his earnings, a crew man pays a proportionate amount for provisions, and the rest is his income.

Some expenses not considered as trip expenses vary with the intensity of use of the boat and are therefore variable costs. Repairs and maintenance would be considerably less if the boat were kept in port and not used for fishing. Payroll taxes are usually paid out of the boat (or owner's) share of the revenue, and this clearly is a variable cost. Miscellaneous variable costs include those items that vary with the amount of fishing done but are not included with those items counted as trip expenses. Since accounting procedures vary, many of those items included by most owners as trip expenses are considered as boat expenses by other owners, even though they vary with

Table 3. Eastern Tropical Pacific Tuna Purse Seine Fleet: Economic Data for 40 United States Vessels, 1974 (Means in dollars)

	Size Class: Carrying Capacity (Tons)							
	201-400	401-600	601-800	801-1000	1001-1200	1201+	Overall Mean	Overall Standard Deviation
Landings (tons)	974	1,188	1,778	2,490	2,292	2,615	1,980	987
TOTAL REVENUE	566,536	654,588	1,011,400	1,403,880	1,217,970	1,770,482	1,090,476	541,990
Variable Costs:								
Trip Expenses:								
Fuel and oil	60,577	73,758	114,020	187,981	162,996	239,665	138,888	77,450
Other	37,722	29,980	29,295	57,106	27,190	88,167	41,408	46,588
Total trip expenses	98,299	103,738	143,315	245,087	190,186	327,832	180,296	111,825
Provisions	24,323	24,585	30,578	31,622	25,562	26,039	27,098	8,820
Crew share and commissions	213,338	263,902	359,143	436,085	422,914	449,430	366,729	178,928
Repairs and maintenance	115,072	187,401	115,422	139,318	75,864	76,016	120,868	67,822
Gear and supplies	13,082	14,652	2,903	10,502	22,355	20,293	14,687	11,998
Payroll taxes	12,163	14,335	18,951	10,985	8,345	6,685	12,328	6,389
Miscellaneous	34,280	12,224	59,655	27,247	37,604	86,989	37,825	61,924
TOTAL VARIABLE COSTS	510,557	620,837	765,967	900,846	782,830	993,284	759,831	269,848
Fixed Costs:								
Insurance	32,092	32,918	48,408	63,170	71,968	73,251	55,174	19,737
Interest	5,345	25,528	33,476	108,000	78,506	147,326	67,471	109,076
Depreciation	16,082	40,803	58,146	122,511	197,778	176,617	111,431	98,426
Other	9,265	17,997	33,151	53,195	21,825	31,795	28,662	24,571
TOTAL FIXED COSTS	62,784	117,246	173,181	346,876	370,077	428,989	262,738	210,104
TOTAL COSTS	573,341	738,083	939,148	1,247,722	1,152,907	1,422,273	1,022,569	421,757
NET RETURN BEFORE TAXES (Taxable Income)	(6,805)	(83,495)	72,252	156,158	65,063	348,209	67,907	242,499

fishing intensity.

Fixed costs include insurance, interest, depreciation, and other items such as legal and accounting fees, office rental, professional expenses, subscriptions, publications, donations, and administrative charges. Some of the figures for depreciation and interest are too low, since boat owners who have paid off the mortgage do not consider their imputed costs, as was done for Table 1. Table 3 therefore represents the profitability of the fishery as the owners themselves perceive it, with some economic costs being omitted.

The overall mean and standard deviation were calculated from the original items in the sample, not from the grouped data. Some indication of how representative this sample of 40 boats is can be found by examining Table 4. The Inter-American Tropical Tuna Commission publishes data on average gross earnings per vessel for California- and Puerto Rico-based United States tuna seiners. These figures are compared with total revenue (presumably the same as gross earnings) from this sample for five size classes. It can be seen that only the eight boats in the sample in the 801-1000 ton size class received, on the average, more than the average of all U.S. boats in this size class. The other 32 boats in the sample received, on the average, less than the amount received on the average per vessel in the entire U.S. fleet for the corresponding size classes.

Table 4. Comparison of Revenue per United States Vessel of IATTC Total Fleet Data with 40-Boat Sample ($1,000's)

Capacity (Tons)	Gross Earnings (IATTC)	Total Revenue (40-Boat Sample)
401- 600	787	655
601- 800	1,053	1,011
801-1000	1,035	1,404
1001-1200	1,543	1,218
1201+	1,806	1,770

Source: IATTC data from <u>Annual Report, 1974</u>. La Jolla, California, 1975, p. 141. Forty-boat sample data from Table 3.

FOOTNOTES

1. V. L. Smith, "Economics of Production from Natural Resources," *American Economic Review* 58:409-432, June 1968; V. L. Smith, "On Models of Commercial Fishing," *Journal of Political Economy* 77:181-198, March/April 1969. Note that the analysis presented on these pages is essentially a static or steady-state one; that is, dynamics and the nonstationary nature of the fishery are not explicitly accounted for. No attempt has been made here to analyze how the conclusions might be altered by utilizing a dynamic theory. The following references provide a dynamic treatment of fisheries: J. P. Quirk and V. L. Smith, "Dynamic Models of Fishing," in A. Scott (Ed.), *Economics of Fisheries Management: A Symposium*, University of British Columbia, Institute of Animal Resource Ecology, Vancouver, 1969, pp. 3-32; C. G. Plourde, "Exploitation of Common-Property Replenishable Natural Resources," *Western Economic Journal* 9:256-266, Sept. 1971; G. Brown, Jr., "An Optimal Program for Managing Common Property Resources with Congestion Externalities," *Journal of Political Economy* 82:163-171, Jan./Feb. 1974; C. W. Clark, "Profit Maximization and the Extinction of Animal Species," *Journal of Political Economy* 81:950-961, July/Aug. 1973; T. Lewis, "Optimal Resource Management Under Conditions of Uncertainty: The Case of an Ocean Fishery," Ph.D. Dissertation, University of California, San Diego, California, 1975.

2. V. L. Smith, *American Economic Review*, op. cit., pp. 427-429.

3. See P. Copes, "The Backward-Bending Supply Curve of the Fishing Industry," *Scottish Journal of Political Economy* 17:69-77, February 1970.

4. P. Copes, "Factor Rents, Sole Ownership, and the Optimum Level of Fisheries Exploitation," *The Manchester School of Economic and Social Studies* 40:145-163, June 1972.

5. Note that this analysis differs from Copes' inasmuch as a horizontal demand curve eliminates the possibility of consumers' surplus, and it further eliminates the distinction between the producers' monopoly solution and the state control solution.

6. R. E. Green and G. C. Broadhead, "Costs and Earnings of Tropical Tuna Vessels Based in California," *Fishery Industrial Research*, Bureau of Commerical Fisheries 3:29-45, No. 1, 1964.

7. Since fleet carrying capacity was about 153,000 tons in 1974, each vessel making one trip and catching only yellowfin could harvest close to the MSY of yellowfin. Actually, however, part of the catch consists of skipjack. Assuming that half of the catch is skipjack, it would take two trips for each vessel to catch the MSY of yellowfin plus some skipjack. Since each vessel can make about four trips per year, one-half the number of vessels operating in 1974 could harvest the MSY of yellowfin plus the same amount of skipjack. Since typically yellowfin is a larger portion of the catch than skipjack, less than half the number of vessels operating in 1974 could take the MSY plus a normal amount of skipjack. For capacity data, see Inter-American Tropical Tuna Commission, *Annual Report 1974*, La Jolla, California, 1975, p. 139.

8. This plan was proposed by F. L. Olson. Cf. "Alternative Fisheries Programs," unpublished manuscript, National Marine Fisheries Service, Washington, D.C., December 1973.

9. Cf. J. C. Mundt, Editor, "Limited Entry into the Commercial Fisheries," IMS-UW-75-1, Institute for Marine Studies, University of Washington, Seattle, 1975, p. 75.

10. F. T. Christy, Jr., "Fisherman Quotas: A Tentative Suggestion for Domestic Management," Occasional Paper #19, Law of the Sea Institute, University of Rhode Island, November 1973.

11. Inter-American Tropical Tuna Commission, op. cit., p. 141.

12. *Ibid.*

13. See Appendix.

14. Actually, the extra amount of profit would probably be considerably larger, because it is likely that the extra ton would be mostly yellowfin, bringing a price of $574 per ton. Thus, for a management system with no quota but fewer boats, this estimate of excess profits is conservative.

15. Inter-American Tropical Tuna Commission, op. cit., p. 59.

16. For 1971, the difference between optimal economic output and MSY was calculated to be about 4,000 tons, which is less than 3 percent of MSY. Environmental conditions do not permit biologists to estimate the MSY with this small a margin for error; it therefore seems reasonable to adopt MSY as the appropriate output goal. Cf. V. G. Flagg, "Optimal Output and Economic Rent of the Eastern Tropical Pacific Tuna Fishery: An Empirical Analysis," *American Journal of Economics and Sociology* 36:19-31, Jan. 1977.

17. C. Thomson, "U.S. Tuna Baitboat Fleet: Estimation of Annual Costs and Analysis of the Impact of the Yellowfin Quota on Vessel Operation," unpublished paper, Department of Economics, San Diego State University, 1977. The average price received for yellowfin tuna was $574.

18. J. M. Buchanan and G. Tullock, "Polluters' Profits and Political Response: Direct Controls Versus Taxes," *American Economic Review* 60:139-147, March 1975.

19. S. Rockland, "An Analysis of the San Diego Tuna Industry and Its Impact Upon the Local Economy," Center for Marine Studies, San Diego State University, San Diego, 1976.

20. Personal communication with C. J. Orange.

21. Gross earnings per ton of carrying capacity divided by catch per ton of carrying capacity. IATTC, op. cit. p. 141.