DRAFT - FOR REVIEW ONLY

CROSS SECTION PRODUCTION FUNCTIONS FOR NORTH ATLANTIC GROUNDFISH AND TROPICAL TUNA SEINE FISHERIES - MEASURES OF FISHING POWER AND THEIR USE IN THE MEASUREMENT OF FISHING EFFORT

By

E. W. CARLSON

File Manuscript No. 69

September 1970

U.S. NATIONAL MARINE FISHERIES SERVICE
ECONOMIC RESEARCH Division

Abstract

Cross Section Production Functions for North Atlantic Groundfish and Tropical Tuna Seine Fisheries - Measures of Fishing Power and Their Use in the Measurement of Fishing Effort

The study of population dynamics in a fishery and the regulation of a fishery require that fishing effort be measured. This paper explores the use of cross section production functions to estimate the fishing power of individual vessels.

The problems addressed in the study are: The proper measurement of output; the measurement of fishing time; important vessel characteristics; crew size; the effect of location, and, the measurement of technological change.

Regression analysis upon data from the North Atlantic groundfish fishery and the tropical tuna seine fishery yielded highly significant results. Many of the hypothesized relationships are measureable and stable with relatively small errors. Briefly the tests indicate that: There are better measures of output than total pounds; fishing time is measured better using days absent rather than days fishing; that the use of more vessel characteristics improve explanatory power; that crew size can be an important variable; that the effects of location can be measured; and, that technological change can be measured.

The production functions measured can then be used to develop indices of fishing power that can be applied to each vessel in a fleet. The indices can then be multiplied by fishing time and aggregated into an index of total effort.

The ramifications of the study are many. It gives a simple way to build effort indices for many fleets and points the way to rationalized data collection.

Table of Contents

I. Introduction

One of the more difficult problems in the application of fishery population dynamics to the management of fisheries has been the development of a time series of effort data. If the vessels in a fleet were physically homogeneous, utilized for the same amount of time, and no learning took place, the problem of constructing an effort series would be less difficult. The problem does exist, though, because vessels are far from homogeneous. For example, a typical fleet may have vessels that are 10 or more times larger than the smallest vessels in a fleet. Obviously, under such conditions there will be serious errors introduced if corrections are not made in the effort series for the fishing power of different vessels.

Some of the important works addressed to the above problem are those of Beverton and Holt (1956), Gulland (1956), and Shimada and Schaefer (1956). Basically, their systems of estimating fishing power consisted of noting the relative catches of vessels fishing in the same area at the same time and relating these relative catches to some easily-measured vessel characteristic, such as horsepower or gross tonnage. This procedure would yield a general relationship that could be extended to all the vessels in a fleet.

Shimada and Schaefer (1956) pointed out by implication that this method only takes account of one type of efficiency; that is, differences in catching ability of vessels of different size which would occur under equal conditions of abundance. It cannot account for the ability of larger vessels to fish in distant areas with higher concentrations of fish. The larger vessels would, of course, go to the more distant grounds if the expected extra catch offset the expected extra running time.

To handle this and related problems, economists have developed techniques of measurement that fall into a general category called production functions. By measuring the production function for a fleet, it is possible to build a measure of fishing power. One of the important attributes of using a production function is that it allows the simultaneous measurement of as many parameters of fishing power as may be thought to be important in its determination.

Accordingly, production functions were estimated using data from the New England trawl fleet and the tropical tuna seine fleet. Many problems were considered in arriving at a "best" production function for these fisheries. Among the problems considered were the following: the best measures of output, the best measures of fishing time, the effect of vessel and crew size, the effect of home port, and measure of technological change.

The use of the estimated production functions to determine vessel fishing power is illustrated, using data from the two fleets. The aggregation of fishing power into total effort is also discussed.

II. The Production Function for a Fishery

The basic assumption of this paper is that a production function can adequately describe the relationship between inputs and outputs in a fishery. The production function is a technical or engineering relation between inputs and outputs and is the base upon which the economic theory of supply is built. Since it is an engineering relationship, considerations such as prices and costs are not relevant to the production function itself. The schedule of maximum output for given inputs is the production function we are trying to measure.

The classical production function for the individual firm is usually presented as follows:

$$
\begin{aligned}
x &= f(l,k,t), \text{ where} \\
x &= \text{output}, \\
l &= \text{labor}, \\
k &= \text{capital}, \\
t &= \text{natural resources.}
\end{aligned}
$$

Output (x) is measured as the flow of goods and services during an accounting period. The input variables (l, k, t) are the various kinds and qualities of labor, capital, and natural resources that go into producing the output. It is assumed that a given set of inputs produces as much as possible.

The estimation of the parameters of the production function is accomplished by running a regression upon a cross section of fishery vessels. A cross section is a sample of the vessels in a fishery for a fixed time period. The parameters estimated from the cross section will give the marginal contribution to output of each variable being used to explain output.

We will discuss the variables that will be used in the production function in the following section.

A. Output in a Fishery

Most systems for measuring relative fishing power have, ultimately, related output to some fishing vessel characteristic. The basic problem with this is that output, when using commercial landings statistics, is a very complex concept. Except in extremely simple fisheries, fishermen do not ordinarily attempt to maximize pounds of fish landed. One working hypothesis is that in all fisheries, the fishermen attempt to maximize their profits. This is not necessarily the same as maximizing total pounds of fish landed. Using total pounds as a measure of output would be an acceptable measure of output where there is (1) a single species fishery, or (2) if, in a multispecies fishery, the prices of the target species are approximately the same, and the species are equally catchable. In the general case, these conditions are not met.

How do the fishermen decide where to go and what to catch when there are multiple species in a fishery? Again, the answer to this question is difficult. Let us consider two models of behavior that might help answer this question. In the first type of fishery, the vessel captains take into account the species that are available, the grounds where they are available, the prices for which they can be sold, and the expected catch rates for their vessels on the grounds. Integrating all this information, the captain, if he is a profit maximizer, will decide to go to the grounds and fish for the species which provide the highest net profit. His decision may or may not be to fish where the catch rates are highest or for those species that bring the highest prices.

We have been discussing this as if the choice were always between species. The choice can also be made within a species, such as a decision to fish on local grounds rather than on distant grounds where the catch rates are higher. In this case, the higher catch rates may not offset the extra running time necessary.

If this abbreviated discussion is an adequate description of how fishermen behave in one type of fishery, then it follows that we may not be able to estimate relative fishing power with total pounds but must rely on some higher order measure such as the value of catch.

Value was considered by Gulland (1956) as a measure of output and rejected because of the variability of prices. A large part of the variability of fish prices is due to the seasonal availability of the fish themselves with prices moving inversely to availability. We can lessen the objections to value by only using it to estimate fishing power and by not using it to determine the catch in the catch-effort relation.

The second type of fishery is one where the location of the fish by species is generally known, but where there is considerable mixing of single species schools in the same area. If locating any school has a low probability per unit time, the fishermen will attempt to catch all that they can of those they do locate. In this case, the fish will be joint products of the fishery. If the fish are equally catchable and their prices are not too different, then total pounds could be the measure of output. If they are not equally catchable, it would take more fishing power to catch one than the other. In such a case, we might have to utilize a modified estimation scheme to arrive at a proper weighting for output. One such scheme will be discussed under the statistical section on tuna.

B. Inputs in a Fishery

1. Fishing Time

The abstract production function refers to outputs and inputs per unit of time. The unit of time is undefined. When using annual vessel data, we have to note the fact that the vessels are not utilized for the same amount of time and standardize for this.

In the biological literature, the concept of fishing day is considered to be by far the most desirable measure of vessel fishing time. There is no denying that there are very difficult conceptual problems in deciding what the proper measure should be. In the simple case, though, an economist would prefer to use days absent from port as a measure of fishing time than days fishing. This is primarily because if a fisherman is an economic maximizer, he will attempt, *ceteris paribus*, to maximize his gross revenue per day at sea and will plan his fishing strategies accordingly. Under this assumption, the fisherman may or may not fish when or where his expected catch rates are higher.

Beverton and Parrish (1954) discussed fishing time and concluded that days fishing was the more relevant variable. They justified their position by saying "....the contemporary abundance of fish may alter the relation between days absent and actual fishing time." They showed a fishery in which the ratio of hours of fishing per days absent increased secularly. The reason they observed this behavior, however, was that the vessels lacked adequate fishing power to process all the fish that they could catch in some periods.

A second objection to days at sea was the contention that the ratio of fishing time to days may differ between ports. This may be true, but it can be easily handled with available statistical techniques (this will be discussed later under Location).

Relative fishing power depends upon more parameters than just the ability to catch fish once at the grounds. It also depends upon the speed with which the vessel can get to the grounds, the types of weather it can fish in and the ease with which the catch can be handled as it is brought on board. Since time for all these activities is included in days absent but not in days fishing, the use of the latter could understate fishing power.

Another problem in fishing time pertains to those fisheries in which vessels locate specific schools of fish before shooting the gear, and hence, time is spent searching with the gear inoperative. In such a fishery, a vessel may spend most of its time in search. In the tuna fishery, the measure of effort has been search time plus actual fishing time. Beverton and Parrish speculated that the number of sets might be a better measure in such a fishery, especially where the distances between schools of fish vary greatly, holding abundance and availability constant. However, given enough observations, effect of varying distance should average out.

The difficulty with using search time is accounting for the use of spotter planes and intervessel communication regarding the presence of fish. An airplane, when it can be used, is far more effective at searching than is a vessel. Therefore, if planes are used and search is the measure of effort, the planes should be accounted for in the effort series. If vessels communicate the presence of fish to each other, then the joint probability of success at finding fish is increased. This leads one to believe that a variable such as percentage of time fished with spotter plane assistance or the number of vessels in a code group (Griffiths 1960) that helped each other, might be used as explanatory variables.

2. Capital -- The Vessel Characteristic Variables

The abstract production function has a variable called capital. This is meant to indicate the dimensions of the equipment being utilized.

In fishing, the individual firms and many of the characteristics of their capital are identifiable and measurable.

Vessel size has been recognized as a determinant of catch and is explicitly recognized in most of the effort systems in use. Beverton and Holt (1956) related gross tonnage to fishing power, and the Inter-American Tropical Tuna Commission (IATTC) focuses on the capacity of a vessel's freezers (Shimada and Schaefer 1956).

Other researchers have noted that there are other measures of vessel size that are correlated with output, among them horsepower and length. For some reason, these other variables have not been used in the analysis of output simultaneously with gross tonnage or capacity. The fact that these variables are partially correlated with gross tonnage is not sufficient reason to exclude them from the analysis. They may make an independent contribution to output. In fisheries, where the use of time series data on effort is so important, the possibility of independent contributions should not be overlooked, because there may be a tendency for vessel configurations to be changed in such a way that fishing power is increased. This happens especially with horsepower relative to gross tonnage as old engines are replaced and also as new vessels are built.

The role of horsepower in the trawl fleet appears to be that the larger the engine, the larger the net that can be dragged, the faster the net can be dragged, or the deeper the water that can be fished. In this type of fishery, the profit-maximizing skipper will adjust his net to obtain the "best" results. Although it has been noted that trawlers do not often use the full power of their engines, a larger engine increases the number of possibilities a skipper can consider when deciding where and what to fish.

In a seine fishery, the role of horsepower is less clear, except that, *ceteris paribus*, higher horsepower increases the "search power" of the vessel. A better measure of this search power than horsepower would appear to be running speed. The only way to obtain this information is by interview or sea trials.

Hull construction is an identifiable parameter of a vessel. Throughout the U. S. fisheries, there has been an increasing tendency to build new vessels of steel rather than wood, in spite of the extra cost. One would presume, then, that there are lower operating costs for steel, or that it is more "productive." It is possible to test for the effect on productivity of a wood hull by creating a dummy variable that takes on the value "one" if the hull is wood and "zero" otherwise.

The last capital input variable that was considered was age of the vessel. Most people would consider older vessels less productive, *ceteris paribus*, than newer vessels. It is rather simple to test this hypothesis by including in the tests the age of the vessels.

Hence, the dimensions of the capital input will be measured by (1) gross tonnage, (2) horsepower, (3) construction materials, and (4) age of the vessel.

3. Labor -- The Crew

Crew size could also be tested as an input variable in the production function. It seems reasonable that a larger crew would produce a higher output, and this should be tested.

One need not work in fisheries very long before he is made cognizant of the "good captain hypothesis." That is, the catch of a vessel depends as much upon the managerial skill of the captain and crew as it does upon the characteristics of the vessel. As such, there is no way to test this hypothesis.

One might attempt to test the good captain hypothesis by using the years of schooling or the years of experience of the captain to arrive at a proxy for his skill. One may suspect on economic grounds that the best captains would gravitate to the best vessels because they would be able to buy the more productive vessels or be hired away from the poorer vessels. In other words, part of the higher output of a larger vessel may not be due to its hardware but to the superior men running it. In this analysis we are restricted to crew size as one measurable variable.

4. Location

The production function makes provision for the differential productivity that could be due to location with respect to the fishing grounds through the variable called <u>land</u>. Vessels from called <u>land</u>. Vessels from some ports could have higher productivity some ports could have higher productivity than vessels from other ports be being located closer to the better grounds. Since these locations cannot be appropriated, the vessels will allocate themselves between ports so that effects on net profits will be dissipated. It is possible to test whether certain locations are more productive by creating dummy variables that correspond to home ports. If its coefficient is statistically significant, then a location may be either more or less productive than the average location.

One of the major problems encountered in the measurement of effort has been the difficulty in adjusting for technological change. Attempts have been made to adjust for technological change, but on the whole they have been less than satisfactory.

The test for the added productivity of an innovation should be done in a period when the fleet is in a period of transition from the use of the old to the new technique. This method will hold abundance and availability constant and therefore, all vessels will have the same opportunities. Bell (1966) used a dummy variable to measure the increased productivity due to stern trawling. He created a variable that was 1 if a vessel was a stern trawler and 0 if it was a side trawler. The coefficient of the dummy variable was the added productivity due to stern trawling.

This technique can be used to test the added productivity of any innovation. For example, a new electronic instrument or the use of spotter planes or maybe even the use of a radically new technique such as switching from bait boats to purse seining. The added productivity of a new technique would thus become a permanent attribute of the vessels even after it was no longer possible to measure the contribution of the technique, i.e., even after it was universally adopted.

III. The Statistical Technique

The statistical technique used to estimate the production function is regression analysis. The results are subject to all the pitfalls of interpretation usually associated with this technique.

Each regression coefficient is reported with its associated t ratio. The t ratio indicates the degree of significance of a regression. There are enough observations in the data so that t distribution approaches the normal distribution. The following table shows the meaning of different values of the t ratio.

t ratio	Prob. of occurrence is less than
1.960	5 in 100
2.576	1 in 100
3.291	1 in 1000

One word of caution: Anyone who has worked with regression analysis is aware that a researcher can choose among many different experiments and show the results that "prove" his case. As in all scientific work, the results should be checked against data not included in the experiment.

Throughout these statistical experiments, there were many dummy variables used (Johnston 1962). These dummy variables help to remove extraneous information from the equations or may provide additional information. One use of dummy variables was to remove the effects of interyear availability and abundance from the estimating equation. In the regression where 3 years of data were pooled, the following procedure was used: Two new variables were created and entries were made in the following way -- if an observation occurred in Year 1, a zero was entered in the column representing Year 2 and a one in the column representing Year 1. The opposite notation was used for observations in Year 2. If an observation occurred in the third year, zeros were entered in both columns. Thus, the dummy variables used in this fashion picked up changes in availability, abundance, and prices.

Dummy variables were entered in some experiments for construction and home port also. For example, if we wished to test whether hull construction affected productivity, we created a dummy variable that was one if the hull were wood and zero if it were steel. This technique could be extended to test the effects of different electronic gear and other non-quantifiable parameters that might significantly affect productivity.

IV. The Data

A. The New England Trawl Fishery

The Bureau of Commercial Fisheries (BCF) has collected comprehensive data on the landings of the New England trawl fleet for many years. The data consist of landings information by trip. The following information is noted for each trip:

1. Official number
2. Departure date
3. Arrival date
4. Number of days fishing
5. Grounds fished
6. Pounds landed, by species
7. Price/pound by species

The data are stored on magnetic tapes and can be manipulated with a digital computer.

The data used were for the years 1964, 1965, and 1967. The data were aggregated by vessel for the whole year. For each vessel, the following information was produced:

1. Days at sea
2. Days fishing
3. Total trips
4. Days at sea by calendar quarter
5. Days fishing by calendar quarter
6. Trips to major areas: offshore, inshore, off Canada
7. Pounds caught, by major species
8. Value, by major species
9. Total pounds caught
10. Total value

This information was augmented by the addition of information from the Merchant Vessels of the United States (1965), including:

11. Gross tons
12. Horsepower
13. Hull construction
14. Year built

Information from the BCF files was added on:

15. Crew size
16. Home port

Vessels with total landings valued at less than $10,000 were excluded from the sample; we made the assumption that these were casual fishermen. There were about 120 vessels excluded per year, accounting for three percent of New England landings. Otherwise, no editing was done; therefore, the sample contains all trips, including brokers. Thus, the estimates have built into them all conditions that vessels from this fleet experience on the North Atlantic. The total sample consisted of about 383 vessels per year or 1149 vessel years.

B. The Tropical Tuna Purse Seine Fleet

The Inter-American Tropical Tuna Commission (IATTC) kindly let us transcribe landings data from their files for the years 1966, 1967, and 1968. The data were for the whole year for the full time purse seiners. The data transcribed were as follows:

1. Official number
2. Days at sea
3. Landings by species
4. Major area fished: Atlantic or Pacific

This information was supplemented by the addition of information from the <u>Merchant Vessels of the United States</u>, including:

5. Gross tons
6. Horsepower
7. Length
8. Year built

Finally the following information was added:

9. Capacity (American Tunaboat Association)
10. Crew size (BCF files)

The total sample consisted of 89 vessels per year or 267 vessel years. The data were divided into two periods: (1) when there was unrestricted fishing for yellowfin and (2) when yellowfin was restricted to 15 percent of the total catch. The data from the restricted season were not used in the analysis because of the different conditions following the season closure.

V. The Statistical Results

A. Overall Results

The statistical results of these experiments are quite encouraging. It is possible to explain very high variations in catch with a minimum of information. In the tropical tuna fishery we can explain approximately 70 percent of the variation in the dependent variable, and in the New England trawl fishery approximately 84 percent.

Tests for heteroscaedasticity[1] showed that it existed in the linear equations. As is well known, when it is present, we have inefficient estimators. Logarithmic transformation of the variables in both fisheries removed this problem simply. Results in both forms are reported but only the logarithmic results are suitable for analytical work.

Several regression experiments were run using a single year's observations in both fisheries on the same variables. The results were very encouraging in that there was a high degree of stability in the coefficients and their t ratios. These stable results were obtained in fisheries which, if anything, are notorious for their variability in almost all aspects, biological, economic, atmospheric and oceanographic. Some results for the trawl fishery illustrating this stability are shown in Appendix 1.

1/ Heteroscaedasticity means that one of the independent variables is correlated with the error term.

B. The New England Trawl Fleet

The statistical results for the New England trawl fishery were very good. The overall "fit" of the data in the equations was very high, especially when one considers the heterogeneity of this fleet. The equations are rich in information in that many of the variables about which hypotheses were made were statistically significant with the right signs.

Because of the possible controversial nature of some of the previous discussion, the equations were run using the more traditional variables where possible. This will allow direct comparison of the results. In a sense, we shall permit the data to decide which is the better specification. We will briefly run through the results according to the topics covered in the theoretical section.

The following general production function was established for the New England trawl fleet:

$$O = f(FT, GRT, HP, CR, Age, C, PT.)$$

where O = output, either total pounds or total value

FT = fishing time, either days fished or days absent

GRT = gross registered tonnage

HP = horsepower

CR = crew size

AGE = age of the vessel

C = construction, 1 if wood, 0 otherwise

PT = homeport dummy variables

The equations providing the best results are shown in Table 1. These equations will be discussed below. A more complete set of regressions is shown in Appendix 1.

The tests of whether total value or total pounds was the better measure of output in this fishery are shown in Problems 1 through 4. The measures of overall fit (R^2) are lower in Problems 1 and 2, which use total pounds as the dependent variable (.40 and .54), than Problems 3 and 4, which use total value as the dependent variable (.83 and .83). Thus, the fishermen appear to have implicitly taken into account expected prices, expected catch rates, and steaming time to the grounds and made decisions as to where to go and what to fish. Hence, relative total revenue appears to reflect the fishing power of New England vessels. The more fishing power, the higher revenues are expected to be.

The most powerful explanatory variables for either total pounds or total value were the fishing time variables. That is, the more days fished or days absent, the higher the total value and total pounds. On the basis of contributions to the overall goodness of fit, there is no way to choose between these two variables. Our choice, therefore, will have to rest upon their effects on other variables and on the cost of gathering the information.

In Problem 3, using total value as the dependent variable and days fishing as the measure of fishing time, crew size becomes statistically nonsignificant and negative. In Problem 4, when days absent is used, crew size becomes statistically significant and a very powerful explanatory variable. Days fishing appears to be a

Table 1

New England Trawler Production Function: Alternate Specifications

Dependent var. \ Independent var.	LOG DAYS AB.	LOG DAYS FISHED	LOG G.R.T.[1]	LOG H.P.[2]	LOG CREW	LOG AGE	CONSTRUCT.[3]	DUM 65[5/]	DUM 67[5/]	Y INT	$\bar{R}^2$	F
Problem 1												
Log total lbs. (All years)												
Reg. Coef.		.649	.408	.038	-.410	-.240	-.138	-.018[4]	-.084	4.69	.405	98.70
t ratio		18.3	6.34	.525	5.16	4.54	3.78	.776	3.42			
Part. Cor. Coef.[6/]		.477	.184	.016	-.151	-.133	-.111	-.022	-.100			
Problem 2												
Log total lbs. (All years)												
Reg. Coef.	1.06		.429	.002	-.266	-.207	-.024	.011	-.059	3.39	.542	170.28
t ratio	27.8		7.58	.037	4.04	4.47	.752	.533	2.75			
Part. Cor. Coef.[6/]	.636		.219	.001	-.119	-.131	-.022	.015	-.081			
Problem 3												
Log total value (All years)												
Reg. Coef.		.886	.365	.113	-.002	-.107	-.043	-.024[4]	.0006	2.43	.834	724.34
t ratio		47.9	10.8	2.98	.062	3.86	2.28	1.92	.050			
Part Cor. Coef.[6/]		.817	.305	.088	-.001	-.113	-.067	-.057	.001			
Problem 4												
Log total value (All years)												
Reg. Coef.	1.08		.373	.074	.347	-.129	.095	.023	.010	1.44	.833	718.97
t ratio	47.6		11.0	1.94	8.83	4.66	5.00	1.79	.855			
Part Cor. Coef.[6/]	.815		.309	.058	.253	-.136	.146	.053	.025			

1/Gross Registered Tonnage
2/Horsepower
3/Construction; equals 1 if wood, 0 otherwise.
4/Dum 64
5/Dummy variables for year of observation
6/Partial correlation coefficient

less desirable measure of fishing time on four grounds: (1) It is theoretically inferior on economic grounds as discussed previously; (2) it causes other important variables to have the wrong sign; (3) it costs more money to collect this information; and (4) it is probably more subject to error.

The vessel size variables used were gross registered tonnage (GRT) and horsepower (HP). GRT was the more powerful of these variables as it was statistically significant in all equations and explained a large part of output. HP was not as powerful a variable in terms of its partial correlation coefficient. However, it was statistically significant when total value was the dependent variable, indicating that it made an independent contribution to fishing power.

The variable that indicated the age of a vessel had a negative coefficient and was statistically significant in most cases. There are at least three hypotheses why older vessels may be less productive: (1) Older vessels might tend to have more breakdowns and equipment that was not in the best working order; (2) Older vessels might have poorer working conditions and accomodations and therefore attract less able crews; (3) Older vessels may embody older technologies. If the last hypothesis is dominant, vessels do not become less productive as they get older rather, old vessels are less productive. This would have different implications than the first hypothesis when fishing power factors are computed.

The dummy variable created for hull construction took on the value 1 if the hull was wood and 0 if steel. The results using this variable were mixed. In Problem 4 using total value and days absent, it was positive and significant. This may mean that ceteris paribus wooden hulls are 25% more productive.[2] If these tests can be confirmed using other data, then it could indicate that an error is being made by the shift to steel construction unless, of course, steel has overwhelming advantages in maintenance and insurance costs.

The tests for locational differences in productivity were made by creating an array of six dummy variables, one for each of the major ports in New England. A "one" was placed in proper location in the array corresponding to a vessel's home port and a "zero" in all the others. Equations showing the results of these tests are given in Appendix 1. In the logarithmic forms of the equations, there are no consistent differences between ports when total value is the dependent variable (Problem 8). When total pounds is the dependent variable, the ports designated "Maine" appear to catch significantly more and "Boston" significantly less (Problem 10). These differences appear because Maine specializes in low value species and Boston in high. When weighted by value, these differences disappear.

On the basis of these statistical tests, we conclude that the best specification of the production function for the New England groundfish fleet is shown in Problem 4, where total value is the

2/ The antilog of 1 is 10. We have $10^{.095}$ which equals 1.25. Therefore a wooden hull is 25% more productive.

measure of output and days absent is the measure of fishing time. Good descriptions of the capital variable are given by gross registered tonnage, horsepower, vessel age, and construction materials. The contribution of labor is measurable and important.

C. The Tuna Seine Fleet

In fisheries such as the tropical tuna fishery, the species are, in the jargon of the economist, "joint products." That is, the fishermen take as much of both species (yellowfin and skipjack) as they can in an effort to fill their holds as quickly as possible. They are essentially indiscriminate between tunas in that they do not appear to pass up any that they sight solely because it is the less desirable species, although such behavior was noted up to about 1950 (Shimada and Schaefer, 1956).

According to IATTC records, the probability of a successful set on yellowfin is higher than on skipjack. This leads one to the hypothesis that a ton of skipjack represents in some way more input than a ton of yellowfin because it takes more work to catch skipjack. There are at least two techniques that might be used in this fishery to determine a weighting system for output. One technique (which is not used here) is canonical regression which was discovered by Hotelling and described by Tintner (1952).

In a sense, it is a search technique that "weights" the dependent and independent variables in such a way that the sum of the squares of the unexplained variance of all the variables is minimized. The second technique (suggested by Henri Theil) is to systematically try different weights (whose sum is one) for the dependent variable and run a series of regressions using a common set of independent variables. The regression that maximizes the coefficient of determination would have the weights, which are, in a sense, best.

The following regression was run in an attempt to arrive at the best weighting system for output:

$Q = f(D, T, CAPAC, GRT, ND, PR, CR, AGE, HP)$ where

$Q = (\alpha Y + \beta S + \gamma B)$ and $(\alpha + \beta + \gamma) = 1$ and

Y is tons of yellowfin landed

S is tons of skipjack landed

B is tons of bluefin landed

D is days at sea of each vessel

T is the number of trips of each vessel

HP is the number of horsepower of each vessel

CAPAC is the capacity of each vessel

GRT is the Gross Registered Tonnage

ND is a dummy for new design

PR is 1 for Puerto Rico homeport, zero otherwise

CR is the crew size

AGE is the age of the vessel.

The results of this experiment are shown in Table 2 , where the left hand column shows the different weights applied to each species. The column headings are for each year's observations and for pooled observations. Tests using the H statistic show that the observations are not random. Weights of .3 for yellowfin, .4 for skipjack, and .3 for bluefin are best. This in a way fits our *a priori* expectation that a vessel exhibited more fishing power when it caught a ton of skipjack than a ton of yellowfin. The statistical results indicate that a vessel does 1/3 more work to catch a ton of skipjack than a ton of yellowfin.

The above experiment presents a radically different approach to the determination of output in a fishery. Because it will be controversial, five alternative specifications of output in the tuna fishery were used in estimating the production function. Three major output specifications were as follows: total value, total pounds, and weighted total pounds using the weights determined above. In addition, yellowfin alone and skipjack alone were tested. This was done because Joseph and Calkins (1969) estimated fishing power factors for skipjack alone. Their doing this suggested that a vessel might have a species specific fishing power, so we attempted to test this hypothesis.

Selected results of the regression experiments run are shown in Table 3 and in Appendix 2. The various specifications of the dependent variable could be explained with varying degrees of

Table 2 Regression Results Using Various Weights for Tuna Species Holding Independent Variables Constant

Weights of yellowfin, skipjack and bluefin	1966 $\bar{R}^2$	1967 $\bar{R}^2$	1968 $\bar{R}^2$	All Years $\bar{R}^2$
.7,.1,.2	.559	.332	.697	.486
.6,.1,.3	.573	.351	.701	.505
.6,.2,.2	.650	.542	.731	.612
.5,.1,.4	.588	.380	.705	.531
.5,.3,.2	.730	.785	.758	.757
.5,.2,.3	.677	.622	.739	.652
.4,.1,.5	.598	.426	.711	.565
.4,.4,.2	.772	.873	.775	.779
.376,.286,.344	.756	.837	.767	.763
.4,.2,.4	.703	.711	.748	.698
.4,.4,.3	.756	.837	.767	.760
.3,.5,.2	.770	.884	.778	.776
.3,.2,.5	.707	.790	.757	.740
.3,.4,.3	.775	.883	.778	.785
.3,.3,.4	.764	.868	.774	.783
.2,.3,.5	.723	.875	.774	.775
.2,.5,.3	.744	.877	.769	.757
.2,.4,.4	.745	.879	.774	.769
.2,.2,.6	.646	.833	.762	.748
.3,.1,.6	.584	.494	.715	.603
.2,.1,.7	.523	.572	.713	.619

Table 3

Tuna Purse Seine Production Function: Alternate Specifications

Independent var. / Dependent var.	LOG CAPACITY	LOG DAYS	LOG H.P.[1]	66 DUM	67 DUM	Y INT.	$\bar{R}^2$	F
<u>Problem 1</u>								
Log tot. value								
Reg. coef.	.365	.310	.368	.067	.044	-.196	.587	76.17
t ratio	5.14	3.32	4.66	2.08	2.21			
Part Cor. Coef.	.303	.201	.277	.128	.136			
<u>Problem 2</u>								
Log total lbs.								
Reg. Coef.	.438	.373	.339	-.024	.049	.453	.680	113.84
t ratio	7.39	4.79	5.15	.914	2.94			
Part. Cor. Coef.	.416	.284	.304	-.056	.179			
<u>Problem 3</u>								
Weighted total lbs.								
Reg. Coef	.520	.416	.328	-.026	.065	.168	.704	127.07
t ratio	8.41	5.12	4.77	.946	3.71			
Part. Cor. Coef.	.462	.302	.283	-.058	.224			

1/Horsepower.

precision. As expected, weighted total pounds had the highest coefficient of determination, followed by total pounds, total value, skipjack and yellowfin, in that order.

The actual difference between coefficients of determination in the weighted total pounds equation and the total pounds equation is not statistically significant (.70 vs. .68).

The total pounds variable has, of course, almost the same weights (1/3, 1/3, 1/3) as the weighted output variable so that, ultimately, it may be of marginal significance to distinguish between them in this fishery, but we cannot know this before further experiments are conducted.

Total value as a dependent variable is inferior to total pounds. This tends to confirm our hypothesis that yellowfin and skipjack are joint products in this fishery. The weight of skipjack in total values is less than the weight for yellowfin and bluefin.[3] Therefore, it appears that the amount for which skipjack can be sold is not reflected in the extra work done catching it, at least relative to yellowfin and bluefin.

The regression results using skipjack alone as a dependent variable were surprisingly good, considering that more than half of the output in the fishery was not included in the dependent variable (see Appendix 2, Problem 2). The reason for these apparent good results is that skipjack tends to be caught by the larger vessels, hence there is a correlation between vessel size (capacity) and skipjack catch.

3/ The relative price weights are .286 for skipjack, .376 for yellowfin, and .344 for bluefin.

When the yellowfin catch alone was used as a dependent varible, the results were much poorer than for skipjack, although they were statistically significant. The probable reason for this is that the larger vessels concentrate less on yellowfin (they fish in different areas than do the smaller vessels). Hence, the total yellowfin catch of a vessel is less connected with size.

The best production functions for the tuna fishery are shown in Table 3. The only fishing time variable available for this fishery was days absent so that alternative specifications of the equations could not be run. Days absent, however, was not as important a variable in this fishery as in the trawl fishery. The reason for this may be that there is a basic difference in the way the vessels in these fisheries operate. The trawl fishery is a wet fish fishery so that the vessels are constrained by time when they go to sea, whereas the tuna boats are freezers and they stay at sea until their holds are filled; hence, there is a different connotation to the fishing time variable.

The vessel size variables used in the final equation were capacity and horsepower. Capacity was the more important of these variables. This indicates that the industry is justified in using capacity as an index of a vessel's fishing power. Several tests were run with gross tonnage in place of capacity but the results were not as good, although they were still meaningful.

Horsepower makes an important independent contribution to explanation of output. The contribution of horsepower to the increase in the coefficient of determination, though small at any point in time, may be important in the maintenance of an effort series as the compo-composition of a fleet changes.

Tests were run using crew size but results were poor, presumably because there is such small variation of crew in this fleet (12-14 men). In addition, crew size is defined by custom and union contract according to the capacity of a vessel, hence crew size does not give additional information.

The tuna fleet has two main bases: Puerto Rico and southern California. To test whether vessels located in Puerto Rico were more productive, a dummy variable was created that took the value one if a vessel's home port was Puerto Rico and was zero otherwise. The results were generally positive but not statistically significant. This indicates that the fleet's shift toward Puerto Rico is because of reasons other than catching more fish (see Appendix 2).

Tests to see if the age of the vessels could explain some of the variation in output generally showed that older vessels were less productive in the linear forms of the equations. When the logarithmic transformations were made the age variable became nonsignificant, hence it is not included in the final equations.

The original purse seine fleet consisted of vessels converted from either military craft or bait boats. There has been a major expansion of this fleet since 1963 with vessels designed specifically for purse seining. To see if these vessels were superior in a way that could not be accounted for by either horsepower or capacity, a dummy variable was created that took the value one if a vessel were built after 1962 and zero if built before 1963. It was hoped that this would pick up technological change. The results using this were generally positive and sometimes statistically significant, but the dummy variable is not included in the final equations because it was not statistically significant in them.

We conclude that for the tuna fishery the best production function and indicator of fishing power is given by Table 3, Problem 3, where weighted total pounds is the dependent variable, days absent is the measure of fishing time and capacity and horsepower are measures of the capital used.

VI. The Calculation of an Effort Index

Production functions of the type utilized in this paper make it possible to assign an index of fishing power to each vessel in a fleet based upon the physical and technological characteristics of that vessel. The assignment of relative fishing power to a vessel could proceed as follows: Using the parameters developed, calculate the expected catch of each vessel using a fixed number of days absent (or fishing). Take the antilog of this expected catch and then divide this number by the expected catch of a "standard" vessel in the fleet. This procedure will give the relative fishing power of each vessel in terms of the standard vessel.

The above procedure was followed in calculating the relative fishing power of the average vessel in each size class for the two fleets being discussed. To highlight the differences in relative fishing power that would be obtained given different assumptions about the output variable and the fishing time variable, all the equations from Tables 1 and 3 are presented. The characteristics of the average vessels in each size class for both fleets are shown in Appendix 3 and Appendix 4.

The calculation of the effort expended upon a species in the groundfish fishery would proceed as follows. The days at sea for each vessel that returned to port with more than a certain threshold percentage of the target species would be noted. The days at sea would then be multiplied by the power factor. Summing these products

Table 4

NEW ENGLAND

RELATIVE FISHING POWER: Standardized on 0 - 50 Ton Vessels

Tonnage	Relative mean Gross Tons	EQUATION (1) Tot. lbs. Days Fished	(2) Tot. lbs. Days Absent	(3) Tot. Value Days Fished	(4) Tot. Value Days Absent
0- 50	1.00	1.00	1.00	1.00	1.00
51-100	2.33	1.20	1.28	1.43	1.67
101-150	4.00	1.38	1.50	1.81	2.30
151-200	5.64	1.91	1.77	2.27	2.40
201-250	7.60	1.91	1.79	2.66	3.12
251-300	9.00	1.98	1.86	2.76	3.17
301-400	10.38	2.45	2.18	2.89	2.86
> 400	16.40	2.72	2.56	3.41	3.90

Table 5

Relative Fishing Power of Tuna Vessels - Standardized on 101-200 Capacity Tonnage Vessels, 1966-1968

		EQUATION			
Capacity tonnage	Size class	1 Log total value	2 Log total lbs.	3 Log wt. total lbs.	Tuna commission 1966-68 avg.
0- 50	1	-	-	-	
51-100	2	-	-	-	
101-200	3	1.00	1.00	1.00	1.00
201-300	4	1.31	1.33	1.37	1.03
301-400	5	1.59	1.65	1.73	1.28
401-500	6	1.89	1.98	2.13	1.57
501-600	6	2.13	2.28	2.44	1.57
601-700	6	2.50	2.66	2.93	1.57
701-800	6	2.65	2.87	3.21	1.57
801-900	6	2.68	2.90	3.25	1.57
901-1000	6	2.97	3.22	3.65	1.57
1001-1100	6	2.96	3.27	3.75	1.57

would then give the effort expended by the vessels which returned to port a significant amount of the target species. Total effort can then be calculated by extrapolation from the amount of the target species accounted by the included vessels to the total catch; i.e., by making an assumption of proportionality between them.

The calculation of a species specific effort index for the tuna fishery is a more difficult task because the species in this fishery are joint products. Total effort, not partitioned by species, is relatively easy to calculate, however. One would simply follow the procedure outlined above except that one would only exclude trips when bluefin made a significant proportion of the catch. The IATTC has not in the past partitioned effort by species, but they are attempting to do so at the present time according to a method suggested by Pella (1969).

VII. Comparison with Prior Estimates of Fishing Power

There is little information published on the relative fishing power of vessels. The only information available on the relative fishing power of trawlers is in Beverton and Holt (1956) and Gulland (1956). It would be inappropriate to use these for direct comparison. However, the above authors noted that fishing power as they measured it (using pounds and days fishing) did not increase as rapidly as did gross tonnage. In Table 4 relative vessel size was included so that a similar comparison could be made.

None of the power factors shown here increase as rapidly as vessel size. It is interesting to note relative fishing power as indicated by Equation 4 in Table 4. Here it can be seen that vessels of 301-400 gross tons have less fishing power than vessels 291-300 gross tons. Inspection of the vessel characteristic data reveals that the larger vessels are older and have smaller engines and crews. Thus, Equation 4 takes this information into account and assigns a lower fishing power.

The IATTC does calculate relative fishing power; its recent estimates are shown in the last column of Table 5. It is readily apparent from the data shown that the techniques used in this paper and at the IATTC produce radically different results. It is the opinion of this author that perhaps the IATTC should reexamine its technique, especially given the critical nature of the relation of their estimates of maximum sustainable yield to the economic and biological health of the fishery.

p. 39 missing ?
note written to publisher
7/31/73

The technique of using dummy variables to measure technological change can be a very powerful means of keeping fishing power indices up to date. Any new device, strategy, or vessel design can be tested for its ability to increase fishing power as it is being introduced and therefore can be permanently built into the vessel power factors.

One of the more important attributes of the system is that it provides a simple way to test whether information being gathered is relevant to the task at hand. For example, fishing days are collected in New England. Upon further testing it may be decided that this information is not worth its cost.

Using regression techniques, it is possible to build effort series for many trawl and seine fisheries which are simple to implement and yet are very powerful. The information needed appears to be minimal, at least for a domestic fleet.

The technique can also provide a way to handle some of the causes of secular changes in the fishing power of a fleet. For example, in both of the fleets considered, both vessel size (GRT and capacity) and horsepower made significant contributions to the determination of fishing power. Thus, as new vessels are added to a fleet, their fishing power can be estimated even though they have larger engines relative to vessel size than other vessels in their size class. It is also possible to keep estimates of fishing power current as the engines of old vessels are replaced or upgraded and changes in crew size are made.

Literature Cited

Bell, F. W. 1966. The Economics of the New England Fishing Industry: The Role of Technological Change and Government Aid, Research Report to the Federal Reserve Bank of Boston, No. 31. Federal Reserve Bank of Boston, Boston: 216 p.

Beverton, R. J. H. and Holt, S. J. 1957. On the Dynamics of Exploited Fish Populations. Ministry of Agriculture, Fish and Food (U.K.), Fishery Investigations, Ser. II, (19): 533 p.

Beverton, R. J. H. and Parrish, B. B. 1954. Commercial Statistics in Fish Populations Studies. Contributions to Special Scientific Meetings 1954, Problem and Methods of Sampling Fish Populations: Conseil Permanent International pour l'Exploration de la Mer. Denmark: 58-66.

Griffiths, R. C. 1960. A Study of Measures of Population Density and of Concentration of Fishing Effort in the Fishery for Yellowfin Tuna *Neothunnus macropterus* in the Eastern Tropical Pacific Ocean from 1951 to 1956. Inter-American Tropical Tuna Commission, Bulletin, 4(3): 39-136.

Gulland, J. A. 1956. On the Fishing Effort in English Demersal Fisheries. Ministry of Agriculture Fish and Food (U.K.), Fishery Investigations, Ser. 2, (20): 44 p.

Johnston, J. 1963. Econometric Methods. McGraw-Hill, New York.

Joseph, J. and Calkins, T. P. 1969. Population Dynamics of the Skipjack Tuna (Katsuwonus pelamis) of the Eastern Pacific Ocean. Inter-American Tropical Tuna Commission, Bulletin, 13(1): 139 p.

Klein, L. 1962. An Introduction to Econometrics. Prentice Hall, Englewood Cliffs, N. J.

Merchant Vessels of the United States. 1965. U.S. Department of the Treasury. Government Printing Office, Washington, D. C.

Pella, J. J. 1969. Stochastic Model for Purse Seining in a Two Species Fishery. Journal of Theoretical Biology, 22: 209-226.

Robson, D. S. 1967. Estimation of the Relative Fishing Power of Individual Ships. Research Bull. Int. Comm. N. W. Atl. Fish., (3):5-14.

Shimada, B. and Schaefer, M. B. 1956. A Study of Changes in Fishing Effort, Abundance, and Yield for Yellowfin and Skipjack Tuna in the Eastern Tropical Pacific Ocean. Inter-American Tropical Tuna Commission, Bulletin, 1(7): 348-469.

Tintner, G. 1952. Econometrics. John Wiley, New York.

Appendix 1.

New England Production Function

Independ. var. / Depend. var.	DAYS AB. Reg. Coef.	DAYS AB. t val.	DAYS FSH. Reg. Coef.	DAYS FSH. t val.	G.R.T.[1] Reg. Coef.	G.R.T.[1] t val.	CREW Reg. Coef.	CREW t val.	YR. BUILT Reg. Coef.	YR. BUILT t val.	H.P.[2] Reg. Coef.	H.P.[2] t val.
Problem 1												
Total lbs. 64			2677.	2.47	6334.	6.19	-33074.	1.42	10899.	2.64	1140.	2.58
Total lbs. 65			2215.	2.02	6282.	6.13	-30615.	1.31	7291.	1.75	1256.	2.79
Total lbs. 67			-150.6	.13	6198.	6.87	-33566.	2.70	11076.	2.95	607.6	1.59
Pooled Tot. lbs.			2498.	4.15	6395.	11.41	-38441.	3.83	8561.	3.73	896.8	3.67
Log Tot. lbs. 64			.4914	8.87	.9850	11.59	-.1912	1.62	.2665	2.18	.7188	12.76
Log Tot. lbs. 65			.2530	4.48	.9640	12.56	-.0500	.47	.2510	2.30	.6430	12.38
Log Tot. lbs. 67			.1032	1.85	.9800	11.84	.0206	.18	.5560	4.67	.9110	15.78
Problem 2												
Total lbs. 64	5687.	8.01			5115.	5.74	-42049.	2.26	6252.	1.62	951.6	2.31
Total lbs. 65	5455.	7.28			5375.	5.62	-41627.	2.22	3234.	.83	1081.	2.54
Total lbs. 67	5037.	6.40			5153.	5.94	-45400.	4.07	5828.	1.63	372.8	1.02
Pooled Tot. lbs.	5796.	13.87			5365.	10.18	-44789	5.24	4395.	2.05	718.9	3.15
Log Tot. lbs. 64	.8527	11.08			.7662	8.95	-.1051	.98	.2256	1.93	.4669	7.18
Log Tot. lbs. 65	.5070	6.00			.8320	10.45	-.0200	.20	.2170	2.02	.5050	8.39
Log Tot. lbs. 67	.3263	4.07			.8940	10.55	-.0330	.32	.5140	4.41	.7750	11.43
Problem 3												
Total val. 64			889.2	24.77	214.2	6.32	1939.	2.51	128.4	.94	103.7	7.08
Total val. 65			884.3	22.61	200.5	5.47	2082.	2.50	41.75	.28	117.7	7.31
Total val. 67			728.2	21.30	204.4	7.43	-380.6	1.00	82.99	.73	72.24	6.20
Pooled Tot. Val.			889.1	42.58	223.2	11.47	416.2	1.19	26.93	.34	94.88	11.19
Log Tot. val. 64			.9603	25.20	.5459	9.34	.0497	.61	.1779	2.12	.0927	2.39
Log Tot. val. 65			.7880	23.95	.4990	11.18	.1714	2.75	.2060	3.23	.0830	2.75
Log Tot. val. 67			.6848	22.52	.5530	12.22	.045	.73	.2620	4.03	.2730	8.66
Problem 4												
Total val. 64	566.1	19.78			30.36	.80	8706.	11.61	148.3	.95	89.94	5.40
Total val. 65	582.1	18.24			11.16	.27	8778.	11.00	119.1	.71	103.6	5.73
Total val. 67	538.5	21.31			154.0	5.52	1324.	3.69	90.76	.79	77.16	6.62
Pooled Tot. Val.	607.8	34.90			100.4	4.57	4476.	12.58	69.60	.78	96.03	10.03
Log Tot. val. 64	1.349	23.08			.2402	3.69	.3465	4.26	.1633	1.84	-.2122	4.29
Log Tot. val. 65	1.140	21.38			.2290	4.53	.4190	6.69	.2017	2.95	-.1560	4.08
Log Tot. val. 67	.9900	21.81			.3930	8.19	.2200	3.65	.2860	4.34	.0360	.94
Problem 5												
Total val. 64			896.5	24.43	206.7	5.95	1759.	2.21	133.1	.97	101.7	6.88
Total val. 65			894.0	22.44	190.9	5.10	1854.	2.17	48.61	.33	114.3	7.01
Total val. 67			730.7	21.13	201.1	7.04	-426.9	1.08	80.81	.71	71.4	6.06
Pooled Tot. Val.			896.1	42.24	214.3	10.69	262.3	.73	28.70	.36	92.45	10.78
Log Tot. val. 64			.9690	25.22	.5154	8.38	.0369	.45	.1855	2.21	.082	2.09
Log Tot. val. 65			.7960	23.92	.4750	10.09	.1600	2.57	.2090	3.29	.0740	2.40
Log Tot. val. 67			.6877	22.36	.5450	11.58	.0390	.63	.2600	4.00	.2710	8.54
Problem 6												
Total val. 64	563.6	19.92			61.4	1.58	9046.	12.06	114.0	.74	96.96	5.84
Total val. 65	581.0	18.35			36.43	.88	9040.	11.33	87.10	.52	111.2	6.12
Total val. 67	535.6	21.18			165.5	5.74	1460	3.96	94.66	.83	79.59	6.78
Pooled Tot. Val.	605.1	34.94			122.5	5.44	4729.	13.16	55.37	.62	101.4	10.64
Log Tot. val. 64	1.352	23.26			.2846	4.24	.3536	4.37	.1469	1.66	-.2040	4.15
Log Tot. val. 65	1.140	21.61			.2700	5.17	.4240	6.83	.1890	2.79	-.1460	3.83
Log Tot. val. 67	.9890	21.91			.4200	8.56	.2330	3.87	.2880	4.39	.0390	1.04
Problem 7												
Total val. 64			921.1	24.25	198.5	5.49	2203.	2.47	63.16	.45	102.1	6.86
Total val. 65			927.3	22.57	187.0	4.84	2102.	2.20	-21.7	.14	116.0	7.10
Total val. 67			865.3	22.92	168.0	6.05	-279.3	.72	-.4334	.003	68.96	6.15
Pooled Tot. Val.			951.57	43.00	200.8	9.92	502.3	1.33	-25.40	.32	92.60	10.92
Log Tot. val. 64			.9626	23.87	.4611	6.80	.2064	2.24	.1467	1.73	.100	2.29
Log Tot. val. 65			.8039	22.93	.4610	8.90	.2760	3.91	.1610	2.53	.09526	2.79
Log Tot. val. 67			.7550	21.93	.4660	9.35	.1969	2.95	.1749	2.73	2.557	7.24
Problem 8												
Total val. 64	561.1	19.55			63.58	1.56	8686.7	9.68	132.7	.85	100.4	5.98
Total val. 65	578.9	17.91			40.95	.93	8806.1	9.12	7642	.45	115.3	6.24
Total val. 67	554.6	21.05			162.5	5.55	1308.	3.33	143.3	1.23	79.43	6.78
Pooled Tot. Val.	606.3	34.49			130.1	5.61	4157.	10.30	96.70	1.07	103.4	10.79
Log Tot. val. 64	1.344	21.93			.2518	3.39	.3413	3.59	.1953	2.20	-.1900	3.43
Log Tot. val. 65	1.130	19.79			.2830	4.78	.4050	5.40	.2000	2.90	-.1240	2.80
Log Tot. val. 67	1.006	19.51			.3920	7.14	.2880	4.12	.2780	4.12	.0340	.75
Problem 9												
Total lbs. 64			3982.	3.53	.6973	4.44	-10062.	.38	10111	2.45	754.2	1.71
Total lbs. 65			3546.	3.09	4981.	4.62	-17193.	.65	7576.	1.80	867.6	1.90
Total lbs. 67			2983.	2.32	5251.	5.56	-25509.	2.02	8165.	2.14	512.3	1.34
Pooled Tot. lbs.			4386.	6.90	5180.6	8.92	-27597.	2.55	7471.	3.26	639.2	2.63
Log Tot. lbs. 64			.5389	9.57	.6974	7.37	.2183	1.70	.2400	2.03	.66009	10.85
Log Tot. lbs. 65			.2827	4.82	.7771	8.96	.3120	2.64	.2310	2.17	.6550	11.47
Log Tot. lbs. 67			.1420	2.21	.8430	9.06	.2820	2.27	.4879	4.08	.9330	14.17
Problem 10												
Total lbs. 64	5955.	8.47			3774.	3.78	-10501	.48	6796.	1.77	613.4	1.49
Total lbs. 65	5828.	7.80			3893.	3.84	-5828.	.71	4626.	1.18	731.9	1.71
Total lbs. 67	6698.	8.50			3959	4.52	-26853.	2.28	3868.	1.11	371.3	1.06
Pooled Tot. lbs.	6402.	15.50			4062.	7.45	-23514.	2.49	4586.	2.16	528.1	2.34
Log Tot. lbs. 64	.8643	10.94			.5303	5.53	.24291	1.98	.25445	2.22	.4233	5.93
Log Tot. lbs. 65	.4814	5.52			.6810	7.52	.3260	2.84	.2320	2.21	.5340	7.90
Log Tot. lbs. 67	.3600	4.04			.7540	7.95	.2370	1.96	.4810	4.13	.7800	9.86

1/Gross registered tonnage
2/Horse Power
3/Equals 1 if wooden vessel, 0 otherwise.
4/Equals 1 if vessel's homeport, 0 otherwise.

CONSTRUCT. 3/		MAINE 4/		GLOUCESTER 4/		BOSTON 4/		NEW BEDFORD 4/		RHODE ISLAND 4/					
Reg. Coef.	t val.	Reg. Coef.	t val.	Reg. Coef.	t val.	Reg. Coef.	t val.	Reg. Coef.	t val.	Reg. Coef.	t val.	Y Int.	R^2	$\bar{R}^2$	F
												-90900.	.368	.362	44.37
												74900.	.387	.381	46.09
												11300.	.285	.277	29.54
												38300.	.339	.337	117.5
												1.83	.650	.646	141.2
												2.35	.592	.588	105.85
												1.52	.568	.563	101.06
												-355000	.451	.445	62.48
												-222000.	.460	.453	61.91
												-209000	.354	.347	42.12
												-261000	.426	.424	169.7
												1.70	.681	.677	162.0
												2.22	.608	.604	113.29
												1.49	.578	.528	107.10
												-48000	.877	.876	543.1
												-46200	.871	.870	494.17
												-18600	.814	.813	338.33
												-35000	.846	.845	1260
												1.56	.845	.843	415.0
												1.86	.876	.878	516.19
												1.63	.845	.843	419.96
												-82900	.842	.840	404.6
												-85500	.838	.846	378.53
												-48100	.814	.812	336.77
												-70700	.808	.807	960.3
												1.28	.828	.826	365.3
												1.54	.858	.857	442.78
												1.26	.839	.838	402.3
-5419	.96											-41800	.878	.876	452.6
-7455	1.24											-37700	.872	.870	412.89
-2020	.44											-16200	.815	.812	281.3
-5982	1.81											-28000	.847	.846	1053.
-.0581	1.58											1.67	.846	.844	347.6
-.0420	1.56											1.94	.877	.875	432.17
-.0180	.66											1.67	.845	.843	349.59
19489	3.16											-105000	.846	.844	346.8
17085	2.61											-104000	.841	.839	321.68
7184	1.56											-56600	.815	.813	282.14
14256	3.95											-87100	.810	.809	813.1
.0923	2.40											1.12	.830	.828	309.3
.0780	2.74											1.40	.861	.859	376.95
.0670	2.35											1.14	.842	.840	340.43
-690.9	.12	11319.	1.55	-808.7	.12	4635	.62	1174	.17	11044	1.52	51000	.881	.878	251.3
-1323	.21	12207	1.55	-853.1	.11	8115	1.00	1470	-.20	14986	1.91	-49700.	.876	.873	232.05
-382.1	.09	3708	.61	-5542	.94	-7683	1.23	-19939	3.42	7313.1	1.19	-13300.	.839	.835	178.81
-1253	.45	8604	1.99	-2798	.67	2738	.62	-7520	1.86	11149	2.57	-34700.	.854	.852	605.9
-.0529	1.36	.1055	1.95	.0044	.02	-.0535	.97	.0251	.50	.0363	.67	1.67	.853	.849	197.7
-.0310	1.09	.0790	1.96	-.0007	.002	-.0280	.68	.0320	.87	.0820	2.02	1.88	.884	.881	248.8
-.0164	.57	.0110	.25	-.0960	.67	-.1620	3.54	-.1060	2.54	.0320	.74	1.827	.862	.858	214.64
18171	2.79	-7228	.88	-7694	.98	-6246	.75	-2402	.32	-14404	1.77	-96600.	.848	.844	190.2
18068	2.59	-5969	.68	-8943	1.04	-4459	.47	-.3492	.42	-9282	1.05	-99100.	.842	.838	174.48
7666.	1.64	-14675	2.31	-8656	1.39	-7234	1.10	-16873	2.77	-9428	1.45	-48900.	.822	.818	159.45
14241	3.78	-12459	2.56	-8300	1.75	-2039	.41	-8035	1.75	-12687	2.59	-78900.	.812	.811	449.3
.0581	1.43	-.0034	.06	.0268	.49	-.0283	.49	.0046	.09	-.1293	2.30	1.15	.838	.834	175.9
.0600	1.93	-.0160	.39	.0037	.09	-.0200	.45	.0120	.30	-.0510	1.17	1.40	.863	.859	206.2
.0634	2.08	-.0260	.57	-.0370	.81	-.0740	1.53	-.0560	1.28	-.0220	.49	1.19	.843	.839	185.77
-339024	1.96	562668	2.60	351898	1.69	59089	.27	29683	.15	358050	1.66	51500.	.408	.392	23.4
-380585	2.19	479210	2.18	332023	1.59	103437	.45	61156	.30	355627	1.62	189000.	.418	.401	23.393
-102455	.67	85775	.42	-124072	.62	-354221	1.67	-409081	2.06	215326	1.03	257000.	.330	.313	16.979
-272358	2.83	386757	3.12	181225	1.51	-52889	.42	-135014	1.16	321650	2.58	196000.	.378	.372	62.83
-.0678	1.25	.2383	3.16	.0319	.44	-.1261	1.63	-.0587	.84	.0658	.87	2.15	.694	.686	77.14
-.0280	.60	.1960	2.91	.0079	.12	-.1300	1.86	-.0190	.31	.0190	.28	2.41	.638	.628	57.558
-.0560	1.06	-.0330	.42	-.1400	1.75	-.3240	3.80	-.1670	2.13	-.1470	1.81	1.80	.598	.587	51.203
-265530.	1.66	475561.	2.37	319786.	1.65	47985.	.23	-45782.	.25	205331.	1.03	-312000.	.487	.473	32.25
-298694.	1.85	429528.	2.10	302920.	1.53	82596.	.39	-20693.	.11	230513.	1.13	-187000.	.489	.475	31.19
-106493.	.76	-52962.	..28	-314526	1.69	-532042.	2.71	-655419.	3.60	50766.	.26	105000.	.430	.415	25.934
-209963.	2.37	278594.	2.43	103667.	.93	-118571.	1.01	-250792.	2.33	159885.	1.38	-130000.	.965	.460	89.87
-.0017	.03	.1834	2.53	.0584	.82	-.0926	1.23	-.0722	1.07	-.01951	.27	1.88	.711	.704	83.81
.0050	.12	.1670	2.52	.0170	.27	-.1160	1.66	-.0290	.47	-.0240	.37	2.22	.645	.635	59.29
-.0330	.64	-.0390	.50	-.1300	1.65	-.3040	3.62	-.1910	2.50	-.1570	1.96	1.72	.610	.599	53.770

Appendix 2.

Tropical Tuna Production Function

Dependent var. \ Independent var.	CAPACITY rc [7]	CAPACITY tv [8]	DAYS AB. rc	DAYS AB. tv	H.P.[1] rc	H.P.[1] tv	G.R.T.[2] rc	G.R.T.[2] tv	CREW rc	CREW tv	PUERTO RICO[3] rc	PUERTO RICO[3] tv	YEAR BUILT rc	YEAR BUILT tv	PURSE SEINE[4] rc	PURSE SEINE[4] tv	66 DUM rc	66 DUM tv	67 DUM rc	67 DUM tv	Y - INT.	F	$\bar{R}^2$
Problem 1																							
Yellowfin - All years	1.24	5.86	.340	.248													-304.	1.62	-375.	3.45	1344.	13.07	.156
Log - All years	.244	3.42	.179	1.03													-.126	2.09	-.141	3.76	2.23	7.38	.091
Problem 2																							
Skipjack - All years	4.10	19.1	5.70	4.08													-250.	1.31	623.	5.62	-1752	110	.623
Log - All years	1.65	10.9	.684	1.84													.056	.439	.258	3.22	-3.19	34.67	.338
Problem 3																							
Tot. val. - All years	.407	7.59	.594	.285	.124	4.82											-37.3	1.35	-6.92	2.44[6]	36.89	96.28	.643
Log - All years	.365	5.14	.310	3.32	.368	4.66											.067	2.08	.044	2.21	-.196	76.17	.587
Problem 4																							
Tot. lbs. - All years	3.84	1.03	5.62	3.89	.751	4.18											582.	2.75	202	1.03	-660.4	121.2	.694
Log - All years	.438	7.39	.373	4.79	.339	5.15											-.024	.914	.049	2.94	.453	113.8	.680
Problem 5																							
Weighted tot. lbs. All years	4.81	11.8	6.74	4.27	.605	3.08											255	1.18	732.	3.50	-116.3	132.	.712
Log - All years	.520	8.41	.416	5.12	.328	4.77											-.026	.946	.065	3.71	.168	127.	.704
Problem 6																							
Tot. lbs. - All years	3.93	10.7	5.78	3.96	179	2.88[5]									414.	1.98	209.	1.06[6]	540.	2.81	-1735.	102.	.697
Problem 7																							
Log tot. lbs. - All years			.410	4.87	.061	5.86[5]	.242	3.33	1.67	2.87					.010	.304	-.037	1.29	.051	2.87	-.559	70.74	.649

Appendix 2: continued

Dependent var. \ Independent var.	CAPACITY		DAYS AB.		H.P.[1]		G.R.T.[2]		CREW		PUERTO RICO[3]		YEAR BUILT		PURSE SEINE[4]		66 DUM		67 DUM		Y-INT.	F
	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv	rc	tv		
<u>Problem 8</u>																						
Log weighted tot. lbs. - All years			.448	5.03	.065	.586[5]	.317	4.11	1.56	2.53					-.010	.287	-.039	1.30	6.58	3.53	-.762	75.87
<u>Problem 9</u>																						
Weighted tot. lbs. All years	4.44	8.03	6.30	3.94	.217	.829	1.23	1.75	-283	1.54	370	1.97	13.3	1.22	-143	.458	-668	3.29	-479	3.89	1856	69.68

1/Horsepower
2/Gross Register Tonnage
3/Equals 1 if vessel's homeport, 0 otherwise.
4/Equals 1 if vessel is built after 62, 0 otherwise.
5/Cube root of horsepower
6/68 DUM
7/Regression coefficient
8/ t value
NOTE: All variables contained in equations entitled: "Log all years" are Logs.

Appendix 3

NEW ENGLAND TRAWL FLEET: VESSEL DATA BY TONNAGE CLASS

Tonnage Class	GRT	Number Obs.	Days Absent	Days Fishing	Trips	Horse-power	Year Built	Crew	Const. % Wood	Measures of output lbs. (000)	Total Value (000)
0- 50	30	492	118	48	87	163	42	3.6	98	808	37
51-100	70	354	149	89	36	253	43	5.9	93	1086	83
101-150	120	147	162	104	24	349	44	7.9	88	1225	118
151-200	170	57	168	96	20	479	44	8.6	24	1142	114
201-250	229	33	235	155	24	604	45	14.4	0	2672	242
251-300	271	15	224	152	23	630	38	13.7	0	2591	253
301-400	313	15	235	141	17	623	36	9.0	0	4942	191
>400	495	6	221	126	24	503	44	12.7	0	3439	260

Appendix 4

TROPICAL TUNA SEINE FLEET: VESSEL DATA BY TONNAGE CLASS

							Measures of Output					
Size Class	Capacity	Number Obs.	Days at sea	GRT	Horse-power	Year Built	Pounds (000) Yellowfin	Pounds (000) Skipjack	Pounds (000) Bluefin	Total Value (000)	Total Pounds (000)	Weighted Total Pounds (000)
3	173	47	152	210	508	46	1155	115	234	236	1504	1388
4	251	83	168	370	731	48	1359	441	742	292	2542	2401
5	346	62	172	421	908	51	1847	559	142	360	2550	2461
6	453	24	182	482	1100	50	1792	928	44	389	2765	2766
6	537	19	162	619	1281	56	2511	1148	90	523	3749	3719
6	650	5	133	673	1649	59	1600	1566	0	448	3166	3319
6	793	4	180	856	1589	63	2630	3812	5	817	6447	6946
6	811	6	191	804	1600	64	2302	3547	167	781	6016	6479
6	924	12	161	793	1850	53	2038	3032	21	637	5092	5492
6	1067	5	171	855	1600	43	1490	4261	0	687	5751	6454