Fishing Power Functions in Aggregate Bioeconomic Models

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Abstract A method for estimating fishing power in the Beverton-Holt tradition in the absence of firm-level data is developed. This enables the construction of a standardized measure of fishing effort that can facilitate the analysis and implementation of various management alternatives. The methodology is applied to the Gulf of Mexico Reef Fish Fishery.

Introduction

Since the passage of the Fishery Conservation and Management Act of 1976 (P.L. 94–265) the development of fishery production models has become increasingly important. Most fishery production models are primarily biological in orientation, being based on surplus stock production concepts (Beverton and Holt 1957; Schaefer 1957; Pella and Tomlinson 1969; Schnute 1977). The main focus of these models is the construction of a functional relationship between catch (or catch per unit effort) and effort which incorporates population dynamics while recognizing that the population (biomass) is largely unobservable.

As noted by Schnute (1977), a primary goal of these models is the prediction of catch. This is perhaps partially the reason why effort is measured as a single composite variable repre-

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senting fishing activity. While accurate predictions of catch are important for fishery management, there are many economic factors which also must be considered in developing fishery models. More specifically, fishing effort is composed of economic variables for which changes in their levels can have substantial social and economic impacts beyond those directly related to catch. Thus it is apparent that economic theory may prove useful in adding more explicit economic relationships into fishery production models through the measure of fishing effort.

The incorporation of economic principles into fishery production models can be achieved by appealing to one of the main assumptions underlying these models: that fishing effort must be measured in homogeneous (standardized) units. As noted by Carlson (1973) the common measure of fishing effort, boat-days, can be very heterogeneous because boats of different construction and other characteristics have differing abilities to catch fish. By utilizing the economic notion of a production function (i.e., fishing power), economic principles may be incorporated into aggregate fishery production models as part of the standardization of fishing effort.

Ideally, both intervessel differences and intertemporal changes in the basic measure of effort must be considered in constructing a standardized measure of fishing effort. Such standardization is often achieved by utilizing qualitative and quantitative firm-level data (Robson 1966; Joseph and Calkins 1969; Griffin et al. 1977). For many fisheries, however, individual-firm data are not available to utilize these methods of standardizing effort. Consequently, in these fisheries intervessel standardization methods based on firm-level data are of little use in empirical applications. Intertemporal standardization is then often achieved by forming an effort index defined by the simple ratio of a composite of several aggregate effort measures at each point in time to the value during a predetermined base period. While these methods standardize the aggregate measure of effort to a base period, they do not incorporate any information regarding the relative importance of the individual components in the aggregate effort measure. This can result in erroneous measures of effective fishing effort.

The use of such an indexing procedure generally assumes that the contribution of each factor in the composite measure has the same effect on total effort and hence on catch. This paper presents a method of disaggregating the composite measure of fishing effort into a nominal component and a fishing power component in the absence of firm-level data.

Conceptually, the notion of nominal effort and fishing power are similar to those used by Sanders and Morgan (1976). Standardization of fishing effort is based on an index formed utilizing an aggregate fishing power function that reflects changes in the average input composition of vessels operating in the fishery. The resulting index has the property that the contribution of each factor in determining fishing effort is determined by the data rather than a priori.

A review of the basic notion of fishing effort and the development of the fishing power function is contained in the first section of this article. The second section contains an empirical formulation of these notions. The third section of the paper presents an empirical example of the use of aggregate fishing power functions in standardizing fishing effort for the Gulf of Mexico Reef Fish Fishery (GMRFF). The final section summarizes the concepts presented in the paper.

Fishing Effort

Fishing effort, like the input capital in economic theory, is well understood conceptually but difficult to measure. The correct measurement of fishing effort is extremely important when attempting to draw inferences concerning the status of a fish stock or management of a fishery. Rothchild (1977, p. 96) notes, "... errors in stock assessment are most likely to arise from a misinterpretation of the magnitude of fishing effort applied to the stock." Such a statement could also be made with respect to the management of a fishery. Since fishery management measures frequently center on fishing effort as the primary management vehicle, correct measurement of fishing effort is essential for successful management. Furthermore, it must be remembered that the variables which compose measures of fishing effort have economic and social significance. Thus changes in fishing effort may have economic and social implications beyond those directly related to changes in catch. It would then seem that economic theory can play a central role in developing standardized measures of fishing effort.

Physical measures corresponding to nominal fishing effort are generally basic measures of the magnitude of aggregate fishing activity. For example, nominal effort may be measured in terms of the total number of traps fished or the number of vessels engaged in a particular fishery. Such measures, however, are very heterogeneous with respect to their effect on the resource stock. Traps with different volume or construction or vessels of different size almost certainly differ in their ability to catch fish (Carlson 1973). Thus to assign one unit of effort to each of these nominal measures would result in erroneous measures of fishing effort. Given this heterogeneity, it becomes apparent that decisions based on utilizing nominal fishing effort alone may be incorrect.

Beverton and Holt (1957, pp. 172–173) define relative fishing power as the "ratio of the catch per unit fishing time of a vessel to that of another taken as standard and fishing on the same density of fish on the same type ground." Thus fishing power and hence total effort in a fishery at any point in time are to a certain extent dependent on the relative input composition of vessels in the fishery. This notion is the basis for the fishing power functions estimated from firm-level data by Griffin et al. (1977).

While the Beverton and Holt notion of fishing power is theoretically attractive, it is of limited use in empirical application, since the data required to estimate functions that adhere closely to their definition are seldom available. In such instances, if empirical analyses are to be conducted, either differences in relative fishing power must be assumed away (as in composite effort measures such as vessel-ton-days), or an alternative notion of fishing power with less stringent data requirements must be developed.

The notion of fishing power developed below is an abstraction of the Beverton and Holt concept. Fishing power is considered to measure the potential ability of a vessel to catch fish, with this potential being defined in terms of average vessel characteristics. A vessel with a larger crew or larger size should have the *potential* to catch more fish than a vessel smaller in both dimensions, regardless of the type of fishing ground or density of the resource stock. This is not to say that area fished or stock densities are not important in determining catch, but rather that a notion of fishing power can be devised which does not critically rely on such factors.

Consider a fishery for which the nominal measure of fishing effort is the number of vessels V. An aggregate fishing power function can be defined by

$$P_t = h(X_{1t}, \ldots, X_{nt}) \tag{1}$$

where P_t denotes average fishing power in period t and X_{it}, $i = 1, \ldots, n$ denote average measures of factors that determine the predatory capacity of vessels in the fishery. Note that the factors contained in equation 1 represent the aggregate input composition of vessels in the fishery. Total effort E_t at any point in time is then defined as the number of vessels multiplied by the average fishing power of vessels in the fishery:

$$E_t = V_t h(X_{1t}, \ldots, X_{nt}) \tag{2}$$

Formulated in this manner, firm-level data are not required. Fishing power is defined in terms of the aggregate input composition of vessels in the fishery rather than the catch rates per unit time of individual vessels. This differs considerably from Griffin et al.'s (1977) treatment of fishing power, which utilized cross-section firm-level data with proxy measures for biological factors.

The expression in equation 1 is somewhat more than an arbitrary function. More precisely it may be considered as an economic production function, where the inputs are vessel characteristics such as vessel size and crew size, and the output is fishing power. This is an extremely significant point, for it implies that standardization of fishing effort and hence changes in the factors which define fishing power are subject to the basic postulates underlying the analysis of any production technology. Thus issues involving implicit constraints in the substitution of inputs must be brought to bear in obtaining standardized measures of fishing effort.

The definition of total fishing effort as given by equation 2 offers several distinct advantages over the more conventional single-composite variable representation of fishing effort generally used when vessel data are not available. First, the fishing power function can be utilized to create a standardized measure of fishing effort, wherein the relative contribution of each factor determining fishing power and hence fishing effort is determined empirically rather than on an a priori basis. To see how this is accomplished, let $h(X)$ denote an estimated fishing power function where X denotes a vector of aggregate inputs. Fishing effort measured in standardized terms is then given by

$$E_t^* = V_t \cdot \frac{h(X_t)}{h(X_b)} \tag{3}$$

where the term in parentheses corresponds to a fishing power index relative to the base factor levels X_b. The $h(X)$ function in equation 3 merits further comment. The simple composite treatment assumes that each factor in the $h(X)$ function has the same effect on fishing power and hence on total effort. For example, if $h(X)$ contains as variables total tonnage in the fishery and total days fished, an increase in either of these variables is assumed to increase fishing power by the same amount. Further, in such cases, the form of $h(X)$ is that of a multiplicative function[1] (e.g., ton-days). Given that this equation represents a production function, this is equivalent to assuming that each input in the function has a unitary fishing power elasticity. As the firm-level work of Griffin et al. (1977) has shown, unitary fishing power elasticities for all inputs are not very plausible. The general form of the aggregate fishing power function presented in equation 1 admits the possibility of differential fishing power elasticities. Under this treatment, the effects on fishing power of changes in the input composition of vessels operating in the fishery are determined by the data, rather than a priori.

The second distinct advantage of a generalized treatment of the fishing power function relates to management considerations. Management of fisheries often centers on the nominal fishing effort measure as the primary management vehicle. However, the management of only nominal effort may be insufficient for the attainment of management goals. The explicit inclusion of a general fishing power function with no or perhaps minimal a priori restrictions can greatly improve the ability of fishery managers to *effectively* control total fishing effort if necessary. For example, if effort in a particular fishery is to be maintained at a certain level deemed optimal by the appropriate authorities, a policy may be instituted to limit the number of vessels in the fishery. If, over time, smaller vessels are replaced by larger vessels or crew sizes increase, fishing effort increases even though the number of vessels remain constant. It is of considerable importance to know how much effort changes when the aggregate input composition of vessels in the fishery is changed. In addition, the changes may be constrained to be compatible with the production technology implicitly defined by the fishing power (production) function.

Finally, the notion of fishing power as developed here has only moderate data requirements. Generally, the requisite data are available from secondary sources at little or no cost for many fisheries. This contrasts significantly with the data required to obtain a fishing power function that adheres strictly to the Beverton and Holt definition. Firm-level data are nonexistant for many fisheries and very costly to collect. Further, information on stock sizes and area fished is extremely costly and difficult to obtain with great precision.

These issues are significant in that one must question whether precise models with costly data requirements are warranted or even justified given the degree of abstraction and plethora of simplifying assumptions inherent in any empirical model.

Empirical Considerations

A general expression for a fishery catch equation can be given by

$$C_t = g(E_t, N_t) \tag{4}$$

where C_t is catch in time t, E_t denotes total fishing effort, and N_t is the resource stock size. Substitution of equation 2 into equation 4 for E_t yields

$$C_t = g[V_t \cdot h(X_{1t}, \ldots, X_{nt}), N_t] \tag{5}$$

where all terms retain their original definitions. Catch is thus expressed as a function of nominal fishing effort V_t, the factors $(X_{1t}, \ldots, X_{nt})$ that determine the average fishing power of the nominal effort measure, and the resource stock size. With the appropriate definition of the $g(\ldots)$ and $h(\ldots)$ functions in equation 5, the parameters of the fishing power function may be identified.

As an example, assume that the catch equation given in equation 4 takes the form

$$C_t = AE_t^{\beta_1}N_t^{\beta_2} \tag{6}$$

where all variables are defined as previously and A, β_1, and β_2 are parameters. In addition, let the fishing power function given in equation 1 take the form

$$P_t = X_{1_t}^{\alpha_1}X_{2_t}^{\alpha_2} \tag{7}$$

where P_t denotes the average fishing power of each nominal unit of effort and α_i, $i = 1, 2$, are parameters to be estimated. Note that in equation 7, the α_i parameters are the output elasticities corresponding to each factor. When the fishing power index (equation 3) is formed, the relative contribution to fishing power of each factor is then "weighted" by the corresponding elasticity. Thus, for the current example, it can be seen that the use of a simple composite measure of fishing power implicitly assumes that each factor in the fishing power function has a unitary output elasticity ($\alpha_i = 1$, $i = 1, 2$). Total effort is given by

$$E_t = V_t \cdot X_{1_t}^{\alpha_1}X_{2_t}^{\alpha_2} \tag{8}$$

which upon substitution into equation 6 yields

$$C_t = AV_t^{\beta_1}X_{1_t}^{\pi_1}X_{2_t}^{\pi_2}N_t^{\beta_2} \tag{9}$$

where $\pi_1 = \alpha_i\beta_1$, $i = 1, 2$, and all other terms retain their previous definitions.

The hypothesis concerning the validity of the use of a simple composite measure of total fishing effort can be tested utilizing the estimated coefficients β_1, π_1, and π_2 from equation 9. The appropriate tests are $\alpha_i \equiv \pi_i/\beta_1$, $i = 1, 2$, equal to one against the alternatives of not equal to one. A rejection of at least one of these hypotheses would imply that the use of a simple composite measure of fishing effort is not an appropriate specification.

The use of the fishing power function in equation 9 is similar in some respects to the manner in which fishing power is used by Griffin et al. (1977). However, substantial differences remain. Griffin's fishing power function is essentially a firm-level catch equation. Fishing power is defined as the expected catch per unit time of each vessel in the manner of Beverton and Holt (1957). The fishing power function contained in equation 9, while approximating the predatory capacity of a vessel, is not explicitly defined in terms of the expected catch rates per unit time of individual vessels. Also, Griffin's firm-level catch equation is based on the Schaefer (1957) notion that nonequilibrium catch is proportional to the product of total effort and stock size (i.e., $C_t = KE_tN_t$). In the present formulation this direct proportional relationship is generalized (see equation 6). Fishing power is estimated directly as statistically identifiable component of the aggregate catch equation without firm-level data.

Fishing Effort in the Gulf of Mexico Reef Fish Fishery

The GMRFF is a multispecies, multistate hook-and-line fishery. All of the Gulf of Mexico coastal states[2] participate in the fishery. The primary species taken are red snapper (*Lutjanus campechanus*), black grouper (*Mycteroperca bonaci*), and red grouper (*Epinephelus morio*).

A catch equation was estimated for each coastal state in the fishery utilizing annual data obtained from annual issues of *Fishery Statistics of the United States* (U.S. National Marine Fisheries Service 1960–78) for the years 1957–75. Nominal fishing effort was defined as the number of vessels V reported fishing out of each state. Fishing power was expressed as a function of the average crew size CS and average vessel size VS. The choice of these measures in determining fishing power are harmonious with the notion of fishing power as a measure of potential predatory capacity. Furthermore, these variables were found to be important determinations of fishing effort by Carlson (1973).

The GMRFF is a hook-and-line fishery with each crewman generally operating only one fishing line. Given this, average crew size provided a reasonable measure of "gear contact" with the resource stock. Vessel size provided an adequate measure of the area of influence over which the gear extends. The reasoning here was that larger vessels have the potential to fish a larger area than smaller vessels. Furthermore, given that weather and sea conditions can impair or prevent fishing from being undertaken, vessel size provides a rough measure of days fished. The empirical analogue of equation 9 for each state in the GMRFF is given by

$$c_{it} = \gamma_i + \beta_1 v_{it} + \pi_1 cs_{it} + \pi_2 vs_{it} + u_{it} \qquad i = 1, \ldots, 5 \tag{10}$$

where $c_{it} = \ln C_{it}$, $v_{it} = \ln V_{it}$, $cs_{it} = \ln CS_{it}$, $vs_{it} = \ln VS_{it}$, and u_{it} is a disturbance term. It is immediately evident from comparing equations 9 and 10 that the population variable has been omitted from the latter equation. This omission resulted from the absence of any direct or reasonable proxy measures for the resource stock. Thus information on changes in the stock size are contained in the disturbance term. Given this, an important consideration regarding the estimation of the state catch equation for each coastal state involves incorporating unobserved stock changes into the estimation scheme. If this can be accomplished, then even though stock is not explicitly entered into equation 10, the relevant information concerning stock changes can be incorporated through appropriate stochastic specification.

Let the stock size in time t be denoted by N_t and equilibrium and actual catch in time t by C_t^* and C_t, respectively. By assuming that changes in stock size are proportional to the difference between equilibrium catch and actual catch, the following relation is obtained:

$$N_t - N_{t-1} = \gamma(C_{t-1}^* - C_{t-1}) \qquad 0 \leq \gamma \leq 1 \tag{11}$$

The expression in equation 11 states that the stock size in time t is equal to the stock size in time $t - 1$ plus a proportion of the difference between equilibrium and actual catch. If equilibrium catch is expressed as some function of fishing effort, an autoregressive process proportional to changes in the stock size will be present. This can be seen by considering C_{t-1}^* as the predicted catch from an arbitrarily specified surplus stock production model. The expression $C_{t-1}^* - C_{t-1}$ is then the estimated regression residual in period $t - 1$, $\hat{U}_{t-1}$. We thus obtain the result that unobserved changes in biomass are proportional to the regression residuals lagged one period, $N_t - N_{t-1} = \gamma\hat{U}_{t-1}$.

The catch equation above can be considered as a first-order Taylor series approximation to an arbitrary equilibrium catch equation. Although these functions only approximate the left half of the sustainable-yield function, this presents no problem to the analysis, since it is the economic region which is approximated. Given this, the presence of autoregression and its incorporation into the estimation procedure will indirectly incorporate information on unobserved stock changes.

It should also be noticed that in equation 10 the parameters β_1 and $\pi_j \equiv \alpha_j\beta_1$, $j = 1, 2$, are constrained to be equal across Gulf states while the intercept parameters γ_i are permitted to differ. The cross-equation parameter restrictions are warranted both logically and statistically. The method of fishing and types of gear and vessels used in all Gulf states are very similar. Thus their effects on fishing power and catch should be similar. Furthermore, a statistical test of the equality of these coefficients could not be rejected. It should also be noted that these cross-

Table 1
Four-Stage Aitken's Parameter Estimates for the Gulf of Mexico Reef Fish Fishery Catch Equations

Dependent Variable[a]	Intercept	ln Vessels	ln Crew Size	ln Vessel Size[b]	$\hat{U}_{i,t-1}$
ln Florida catch	3.15533	0.740230	0.713178	0.340649	0.44048
	(0.68466)[c]	(0.067263)	(0.18169)	(0.17306)	(0.036391)
ln Alabama catch	2.374897	0.740230	0.713178	0.340649	0.85468
	(0.80167)	(0.067263)	(0.18169)	(0.17306)	(0.022373)
ln Mississippi catch	2.747624	0.740230	0.713178	0.340649	0.74216
	(0.76746)	(0.067263)	(0.18169)	(0.17306)	(0.028931)
ln Louisiana catch	0.52701	0.740230	0.713178	0.340649	0.40764
	(0.73240)	(0.067263)	(0.18169)	(0.17306)	(0.40089)
ln Texas catch	1.62417	0.740230	0.713178	0.340649	0.44820
	(0.74008)	(0.067263)	(0.18169)	(0.17306)	(0.037976)

[a] Catch is measured in thousands of pounds.
[b] Vessel size is measured in gross registered tons.
[c] Standard errors in parentheses.

equation restrictions mitigated any statistical problems arising from colinearity among regressors.

The intercept parameters were permitted to differ across states to admit the possibility that vessels originating from different states fished differing stocks. If vessels fishing out of a given Gulf coastal state fish a stock with a higher density than vessels from a different state, it appears reasonable to expect the former state's intercept parameter to be significantly greater than the latter's. However, if two or more states fish the same stock(s) their intercept parameters should not differ in a statistical sense.

Estimation of the catch equations was accomplished utilizing a four-stage Aitken's estimator (Kmenta and Gilbert 1968). This estimator permitted contemporaneous correlation of the catch equation disturbances across states and permitted the incorporation of distinct autoregressive processes for each state. Preliminary identification tests indicated significant first-order autoregression to be present for each state. These processes were then incorporated into the estimation scheme. The parameter

Table 2
Estimated Differences in Intercepts for the Gulf of Mexico Reef Fish Fishery State Catch Equations*

State	Florida	Alabama	Mississippi	Louisiana	Texas
Florida	—	—	—	—	—
Alabama	0.78044 (2.3920)	—	—	—	—
Mississippi	0.40771 (1.4729)	0.3727 (0.6542)	—	—	—
Louisiana	2.62832 (7.3294)	1.84789 (3.224)	2.22059 (3.750)	—	—
Texas	1.53116 (8.1322)	0.7507 (1.7429)	1.1234 (2.3636)	−1.09719 (2.2603)	—

* Numbers in parentheses are estimated t values.

estimates (standard errors) are presented in Table 1. For a given level of fishing power, these estimates indicated that a 10% increase in vessels in each state's fishery is estimated to increase catch by about 7.4%. Table 2 presents the estimated differences between the intercepts of the state catch equations. It is apparent that in all but two cases the intercepts are significantly different. It thus appears that to a considerable extent vessels originating in different states fish stocks of differing density. Furthermore, these differences have been successfully incorporated into the model estimation.

Total Fishing Effort and Fishing Power

Given that the parameters corresponding to vessels, vessel size, and crew size were constrained to be equal across states, the estimated expressions for total fishing effort and fishing power are the same for all states. Recalling equations 1 and 2, the estimated fishing effort function is given by

$$\ln E_{it} = \ln V_{it} + \underset{(0.2392)}{0.9365} \ln CS_{it} + \underset{(0.2697)}{0.4601} \ln VS_{it} \qquad (12)$$

and the fishing power function is estimated as

$$\ln P_{it} = \underset{(0.2392)}{0.9365} \ln CS_{it} + \underset{(0.2697)}{0.4601} \ln VS_{it} \qquad (13)$$

The estimated fishing power function given in equation 13 was utilized to test the hypothesis of unitary elasticity implicit in the composite effort measure as opposed to the generalized treatment presented above. This was accomplished by testing the hypotheses 0.9635 and 0.4601 equal or not equal to 1. Utilizing a Taylor series expansion to obtain approximate standard errors for the estimated parameters (α_i, $i = 1, 2$) the former hypothesis ($0.9635 = 1$) could not be rejected at the 0.05 level of significance. The latter hypothesis ($0.4601 = 1$) was, however, rejected at the same significance level. Thus it appears that the use of a simple composite effort measure constitutes an erroneous specification for the GMRFF.

Examination of the fishing power function indicates that a 10% increase in average crew size is estimated to bring about a 9.6% increase in the fishing power of vessels in the fishery. Given that average crew size provides a measure of "gear contact" with the resource stock, the magnitude of this elasticity appears reasonable. The elasticity corresponding to average vessel size estimates that a 10% increase in this factor will increase average fishing power by 4.6%. To the extent that average vessel size measures the ability to undertake and sustain the fishing process, this elasticity may be interpreted as the effect on fishing power of increased fishing time on an annual basis.

The effects of generalizing the fishing power function from the simple composite measure become apparent from these elasticity estimates. Under a composite treatment, vessel size and crew size would have equal (unitary) elasticities, unless some a priori elasticity restrictions were implemented. On the basis of the data utilized, it is seen that the effect on fishing power of average vessel size is slightly less than half of the effect of crew size. In this instance, the a priori assignment of a unitary elasticity for vessel size would greatly overstate the effect of changes in vessel size on fishing power and hence on catch.

Standardization of Fishing Effort and Stock Assessment

The standardization of nominal effort was accomplished by utilizing the estimated fishing power function. The index based on the estimated fishing power function is given by

$$I^*_{it} = \left(\frac{CS_{it}}{CS_b}\right)^{0.9635} \left(\frac{VS_{it}}{VS_b}\right)^{0.4601} \tag{14}$$

where I^*_{it} denotes the index number corresponding to vessels in the ith state and time period t, relative to an index base b. Once again, the effects of the elasticity estimates can be seen as "weighting" the importance of each factor in relation to its effect on fishing power. The index base for the GMRFF corresponds to west coast Florida vessels in 1960.

Table 3 presents the estimated indices for states participating in the GMRFF obtained from equation 14 and under the assumption of unitary elasticities. Inspection of the table illustrates that average fishing power varies greatly across states and, in some cases, over time within a given state. Furthermore, it is evident that the use of indices obtained under the assumption of unitary factor elasticities would result in a considerable overstatement of fishing effort. The use of these indices in standardizing nominal effort measures (in this case vessels) is accomplished by

$$E^*_{it} = I^*_{it} \cdot V_{it} \tag{15}$$

where E^*_{it} is defined to be a standardized measure of fishing effort (standardized vessels).

The effects of standardizing vessels in the GMRFF can be seen by examining Table 4. In Florida standardization serves to decrease measured effort in all years since 1960. In some years this decrease is substantial. For 1975 the number of standardized vessels is approximately 25% less than the nominal measure in Florida, indicating a decline in average vessel fishing power. At the other extreme, the number of standardized vessels in Mississippi has been more than three times the actual (nominal) num-

Table 3
A Comparison of Estimated Fishing Power Indices by State, 1957–75

	Florida West Coast		Alabama		Mississippi		Louisiana		Texas	
Year	I[a]	II[b]	I	II	I	II	I	II	I	II
1957	1.064	1.338	2.271	3.752	1.210	1.321	1.315	1.290	0.970	1.470
1958	1.176	1.415	2.361	4.085	1.297	1.650	1.281	1.391	1.154	1.776
1959	0.932	1.191	2.468	4.440	1.514	2.118	1.366	1.573	0.915	1.394
1960	1.000	1.000	2.471	4.445	1.971	2.985	1.423	2.171	1.165	2.020
1961	1.001	1.101	2.729	4.718	2.133	3.270	1.278	2.043	1.102	1.891
1962	0.984	1.001	2.785	4.943	2.487	3.962	1.604	2.555	1.153	1.970
1963	0.994	1.177	2.870	5.269	2.527	4.063	1.623	2.567	1.327	2.089
1964	0.959	1.139	2.755	5.042	2.571	4.217	1.594	2.773	1.585	2.606
1965	0.909	1.075	2.970	5.636	3.057	5.609	1.461	2.609	1.553	2.554
1966	0.937	1.089	3.251	6.293	3.148	6.112	1.554	2.970	1.836	3.063
1967	0.930	1.090	3.229	6.035	3.529	7.409	1.073	2.082	1.657	2.817
1968	0.911	1.080	2.973	5.786	3.328	6.916	1.098	2.189	1.491	2.671
1969	0.960	1.188	2.973	5.786	3.325	6.957	1.098	2.189	1.491	2.671
1970	0.875	1.088	2.404	4.725	3.268	6.915	1.268	2.406	1.377	2.446
1971	0.893	1.114	2.407	4.738	3.299	7.082	1.172	2.090	1.723	3.141
1972	0.893	0.919	2.458	4.935	3.295	7.111	0.963	1.648	1.648	2.860
1973	0.774	0.902	2.447	4.979	3.322	7.226	1.153	2.086	1.547	2.561
1974	0.860	1.110	2.612	5.505	3.309	7.260	1.250	2.365	1.504	2.474
1975	0.766	0.909	2.612	5.505	3.313	7.268	1.229	2.315	1.592	2.636

[a] Index I utilizes the estimated fishing power function given in equation 13.
[b] Index II is estimated under the assumption of unitary output elasticities.

ber of vessels since 1965. Examination of the remainder of the table indicates that in all cases the difference between fishing effort as measured by actual (nominal) vessels and fishing effort as measured by standardized vessels is substantial.

The implications regarding stock assessment are straightforward. Use of Index II (unitary elasticity index) would greatly overstate fishing effort and hence underestimate catch per unit of effort. Thus inferences based on catch per unit of effort would be misleading. Furthermore, the use of such an effort series in estimating a sustainable yield function of the Schaefer or Bev-

Table 4

Estimated Number of Standardized Vessels* and Actual Number of Vessels in the Gulf of Mexico Reef Fish Fishery by State, 1957–75

	Florida West Coast		Alabama		Mississippi		Louisiana		Texas	
Year	Vessels	Stand. Vessels	Vessels	Stand. Vessels	Vessels	Stand. Vessels	Vessels	Stand. Vessels	Vessels	Stand. Vessels
1957	108	115	11	25	5	6	2	3	129	125
1958	120	141	11	26	7	9	5	6	89	103
1959	300	280	12	30	8	12	12	16	158	145
1960	180	180	12	30	11	22	13	19	118	138
1961	219	221	13	36	12	26	30	38	151	166
1962	232	228	15	42	12	30	36	58	152	175
1963	280	278	22	63	13	33	30	49	119	158
1964	334	317	22	61	14	36	23	37	93	147
1965	337	306	20	59	14	43	23	34	85	132
1966	274	257	22	72	17	54	13	20	64	118
1967	267	248	19	59	20	71	6	6	66	109
1968	256	233	12	36	21	70	5	6	50	77
1969	242	236	12	36	20	67	5	6	46	69
1970	257	225	11	26	19	62	6	8	23	32
1971	282	252	11	27	20	66	7	8	30	52
1972	306	240	12	30	21	69	11	11	45	73
1973	331	256	11	27	19	63	13	15	41	64
1974	353	304	11	29	18	60	13	16	40	60
1975	425	326	11	29	18	60	14	17	34	54

* Standardized reef fish vessels are calculated by multiplying the actual number of vessels by the corresponding fishing power index (Table 2).

erton-Holt type would result in erroneous maximum sustainable yield (MSY) estimates. Given that management strategies are sometimes directed toward attaining MSY, the incorrect measure of fishing effort can be very significant.

Standardization of Fishing Effort and Fishery Management

The generalization of fishing effort from a single composite measure to a more generalized form as given above also has significant implications with respect to management concerns. Often fishery management measures involve attempts to maintain fishing effort at fixed levels deemed optimal on the basis of some biological or economic criterion. If the main management vehicle centers on fixing nominal effort alone, management measures may be ineffective.

The estimated fishing power function provides a method in which such changes in fishing power can be analyzed. In this regard several options are available. Consider once again a situation wherein fishing effort in a given fishery is to be held constant. In terms of the present model, this can be accomplished by restrictions of some sort on vessels, crew size, vessel size, or any combination of these.

Assume that vessels alone are limited to some level. If, as a result, larger vessels supplant smaller ones, to maintain a constant level of effort either the number of vessels must be reduced or crew sizes limited, with the number of vessels remaining constant. As regards the latter possibility, the fishing power function can be utilized to calculate contours of equal fishing power. This function indicates how much each determinant of fishing power must be changed to offset changes in other factors contained in the fishing power function.

In the present example, the iso-fishing power contours for the GMRFF are defined by the equation

$$VS = (I_0)^{1.0417}(CS)^{-0.4792} \tag{16}$$

Utilizing this expression, fishing power can be held at a fixed level. It should be noted that this type of expression can be formulated from a composite effort measure with output elasticities assumed to be unitary. However, as in the present case, when the data reject such an assumption, erroneous inferences may be drawn, with ineffective or erroneous management measures resulting.

While use of the fishing power function in this manner has theoretical appeal, its usefulness in practice may be limited in that the cost and enforceability of management measures that seek to control factors such as crew size or vessel size may be prohibitive. This may be less of a problem in the current model in that the measures defining fishing power are industry averages rather than individual-vessel statistics. Regardless of this, however, the fishing power function may be used to monitor changes in average fishing power of vessels and utilized to indicate the appropriate changes required in vessel number to keep fishing effort at the appropriate level.

Summary and Conclusions

The preponderance of theoretical and empirical models of the fishery have emphasized the attainment of an equilibrium relationship between aggregate effort and sustainable yield. When firm-level data are not present, little attention has been directed toward obtaining a measure of effective fishing effort which is standardized for individual effort components. In such circumstances, changes in the levels of these components are assumed to have the same effect on effective fishing effort and hence on catch. For the types of effort measures usually used, this is tantamount to assuming that all effort components have a unitary fishing power elasticity.

This paper has presented a means of getting at the notion of fishing power in the Beverton and Holt tradition empirically with less stringent data requirements. Fishing power was defined as an economic production function with inputs defined by aggregate measures of crew size and vessel size for vessels fishing in the GMRFF. Such data are readily available for most fisheries.

A method of incorporating unobserved stock changes into the estimation of the catch functions was also developed as a corollary to the analysis. Given that measures of stock size are generally not available and proxy measures are rough approximations at best, indirect methods of incorporating unobserved information into economic models of the fishery merit further analysis and refinement.

The economic scope of this analysis is fairly limited, dealing at some length with the specification and estimation of a fishing power function with aggregate data. However, fundamental to any empirical analysis is the specification of behavioral equations underlying the analysis. Much of fishery production analysis has been heavily oriented toward the use of biological models which focus on population dynamics. These dynamics are indeed important. However, the economic phenomena inherent in fishing effort have largely been overlooked in aggregate fishery models. The factors which define effort are important economic variables subject at least to the technological postulates underlying the economic notion of a production function. There are many possible ways in which effort can be managed or changed. Each has attendant economic and social implications beyond those directly related to catch.

For effective goal-oriented management, more explicit recognition of the factors that compose effort is necessary. The foregoing analysis is offered as a first approximation to achieving this objective. Much remains to be done.

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Notes

1. The multiplicative function as used here implies that $h(X_1, \ldots, X_n) = X_1 X_2 \cdots X_n$. Given an index such as that given in equation 6, it can be seen that each factor is implicitly assumed to have the same effect on fishing power and hence on standardized fishing effort.

2. The Gulf of Mexico coastal states include the west coast of Florida, Alabama, Mississippi, Louisiana, and Texas.

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