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THE PRODUCTIVITY OF THE SEA AND MALTHUSIAN SCARCITY

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ABSTRACT

The increasing pressure of world population on natural resources has once again given rise to the spectre of Malthusian stagnation. The purpose of this Article is to examine the Malthusian doctrine of diminishing returns to natural resources using the fisheries as a case study. For the ten stocks of fish studied, it was found that Malthusian scarcity is quite prevalent. That is, fishing productivity significantly declined with expansion in effort. This hypothesis was verified for both the steady state and stock adjustment models. Without major discoveries in controlling ocean environment, it is quite apparent that the sea will be subject to Malthusian scarcity as the pressure of population increases.

The Productivity of the Sea and Malthusian Scarcity

by Frederick W. Bell
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Introduction

The increasing pressure of world population on natural resources has once again given rise to the spectre of Malthusian stagnation. The doctrine of diminishing returns to natural resources has been supported by such conservationists as Osborn [9] and Vogt [16] and denied by such economists as Barnett and Morse [1]. In the wake of increasing difficulties with producing enough food from land areas throughout the world [3] [4] [7] [10] increasing attention is being given to the sea as a source of food. Presently, only one percent of the world's food supply is obtained from the sea which occupies 70 percent of the earth's surface. Turvey [15]; Smith [14]; and Plourde [11] have recently written articles on marine economics, a subject that is getting increasing attention from economists. The purpose of this article is to examine the production economics pertaining to the fishery resources of the sea. Does the doctrine of increasing

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scarcity or diminishing returns apply to marine life which has often been suggested as a panacea for the world's food needs? The answer to this question will put into sharp focus the potentialities of the sea and also help to lend empirical validity to some of the common assumptions used in the area of marine economics.

The Production Function for the Sea: Ecology and Man

The taking of marine life from the ocean represents a direct intervention of man in the natural ecological system of the oceans. In effect, man creates an initial disequilibrium to which the ecological system must adjust (i.e., return to a new equilibrium). Schaefer and Beverton [13] have observed that the stock of marine life (i.e., fish, etc.) is increased by addition of recruits (from reproduction) and by the growth of the individuals in the stock. The stock is diminished by natural deaths. When man intervenes, the stock is further diminished by man-made mortality in the form of fishing effort. A general mathematical expression for the dynamics of this ecological system is the following (including man as a predator):[1]

$$(1)\quad \frac{1dP}{Pdt} = \alpha P + \beta P - \gamma P - F(E) + U$$

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1. Of course, this is a narrowly defined ecological system expressing a relation between man and the one species he is exploiting. The total ecological system extends to other species, the physical environment, etc.

where,

- P = stock of marine life (fish) of harvestable size (biomass);
- α = rate of recruitment;
- β = rate of growth of stock;
- γ = rate of natural mortality;
- $F(E)$ = rate of loss due to fishing effort;
- U = stochastic term to designate random environmental changes where Cov (PU) = 0.

α, β, and γ are each a general function of the biomass of the population. Let us assume that the rate of loss to fishing is proportional to fishing effort, E. "E" represents the combined inputs of capital and labor to the fishery:

(2) $F(E) = gE$

We may combine α, β, and γ

(3) $\delta = (\alpha + \beta - \gamma)$

Substituting (2) and (3) into (1), we have,

(4) $\frac{1dP}{Pdt} = \delta P - gE + U$

If the population or stock were in a steady state (i.e., ecological balance) we would have

(5) $\frac{1dP}{Pdt} = 0$

In effect, (5) represents an equilibrium between natural growth and death on the one hand and man-made mortality on the other. Under the steady state assumption, (4) becomes,

(6) $gE = \delta P + U$

Also, the catch, Q, from fishing effort may be expressed as

(7) $Q = PF(E) = P\ (gE)$

The question remains as to the behavior of δP. It is hypothesized that δP is a single valued, monotonically decreasing function of P, that should be zero at the environment-limited upper value of P. That is, the fishery is constrained either by food supply or other environmental factors to an upper limit. The behavior of δP may be approximated by the Verhulst-Pearl population growth law (i.e., logistic growth)[2];

(8) $\delta P = \psi (P_u - P)$

P_u is the upper limit of the population while ψ is a parameter. When $P_u = P$, δ equals zero. Thus, growth discontinues. Substituting (8) into (4) we have

(9) $\frac{1dP}{Pdt} = \psi (P_u - P) - gE + U$

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2. Since $dP/_{Pdt} = \psi (P_u - P)$, we may multiply through by P and obtain a quadratic function or $dP/_{dt} = \psi P_u P - \psi P^2$. Hence, the change in the population is a parabolic function of the population size. This automatically implies that the population grows in a logistic manner.

We may define catch per unit of effort by dividing (7) by E

(10) $\frac{Q}{E} = gP$

Equation (10) may also be solved in terms of P

(11) $P = \frac{Q}{gE}$

Setting (9) equal to zero (i.e., steady state assumption) and substituting (11) for P, we have

(12) $\psi \left(P_u - \frac{Q}{gE}\right) - gE + U = 0$

Solving in terms of Q, we have

(13) $Q = aE - bE^2 + \varepsilon$

where $a = gP_u$ and $b = (g^2/\psi)$ and $\varepsilon = \frac{gUE}{\psi}$

Therefore, under the above assumptions, we have reached the hypothesis that man's intervention in the ecological system follows a parabolic relation between catch and inputs of capital and labor or E.[3] As "E" is increased,

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3. Within a wide range of observation, this conclusion does not apply to Gulf of Mexico shrimp. Shrimp found in the Gulf of Mexico have a one year life cycle. That is, this year's shrimp lay a large quantity of eggs and then die. Therefore, this year's catch has no effect on the size of the population which is based upon the number of eggs layed. The relation between catch and effort is likely to be log-linear or $Q=AE^{\alpha}$ where $0 < \alpha < 1$. For this relationship, it is not possible to actually reduce physical yields by further fishing effort.

   In addition, it should be pointed out that the hypothesis developed in (13) is usually called the Schaefer mode [12]. An alternative to the Schaefer model has been developed by Beverton and Holt [2]. The latter model requires that we know many individual parameters such as α, β and γ. Given the available data, we can only approximate the aggregate effects of α, β and γ.

the biomass, P, is reduced. Dividing (13) by E, we have the average productivity of effort or

$$(14) \quad \frac{Q}{E} = a - bE + \frac{\varepsilon}{E}$$

Also, differentiating (13) with respect to E we have the marginal productivity of effort or

$$(15) \quad \frac{\partial Q}{\partial E} = a - 2bE + \varepsilon$$

Setting (15) equal to zero, we find that there is a specific quantity of capital and labor (i.e., effort) associated with the maximum sustainable yield or production (MSY)

$$(16) \quad E_{MAX} = \frac{a}{2b} \quad \text{(Effort needed to achieve MSY)}$$

$$(17) \quad Q_{MAX} = \frac{a^2}{4b} \quad \text{(Maximum sustainable yield(MSY))}$$

It should be recognized that (13) represents a steady state condition. If the steady state assumption does not hold, we shall have a change in the population or

$$(18) \quad \Delta P = (Q_E)_t - Q_t = aE_t - bE^2 + \varepsilon_t - Q_t$$

Therefore, if the actual (observed) catch, Q_t, is not equal to the equilibrium catch, $(Q_E)_t$, some changes in the stock or population will occur. Let us specify the degree of stock adjustment by the following relation:

$$(19) \quad Q_t - Q_{t-1} = \pi\,[(Q_E)_t - Q_{t-1}]$$

If we assume the stock to be in equilibrium at Q_{t-1}, then actual catch Q_t, will approach equilibrium catch $(Q_E)_t$ by Π . If $\Pi = 1$, the adjustment will be complete and the steady state assumption will hold. Substituting (13) into (19) we have

$$(20) \quad Q_t - Q_{t-1} = \pi[aE_t - bE_t^2 + \varepsilon_t - Q_{t-1}]$$

or

$$(21) \quad Q_t = \pi aE_t - \pi bE_t^2 + (1 - \pi)Q_{t-1} + \pi\varepsilon_t$$

Dividing through by E_t, we have

$$(22) \quad \frac{Q_t}{E_t} = \pi a - \pi bE_t + (1 - \pi)\frac{Q_{t-1}}{E_t} + \frac{\pi\varepsilon_t}{E_t}$$

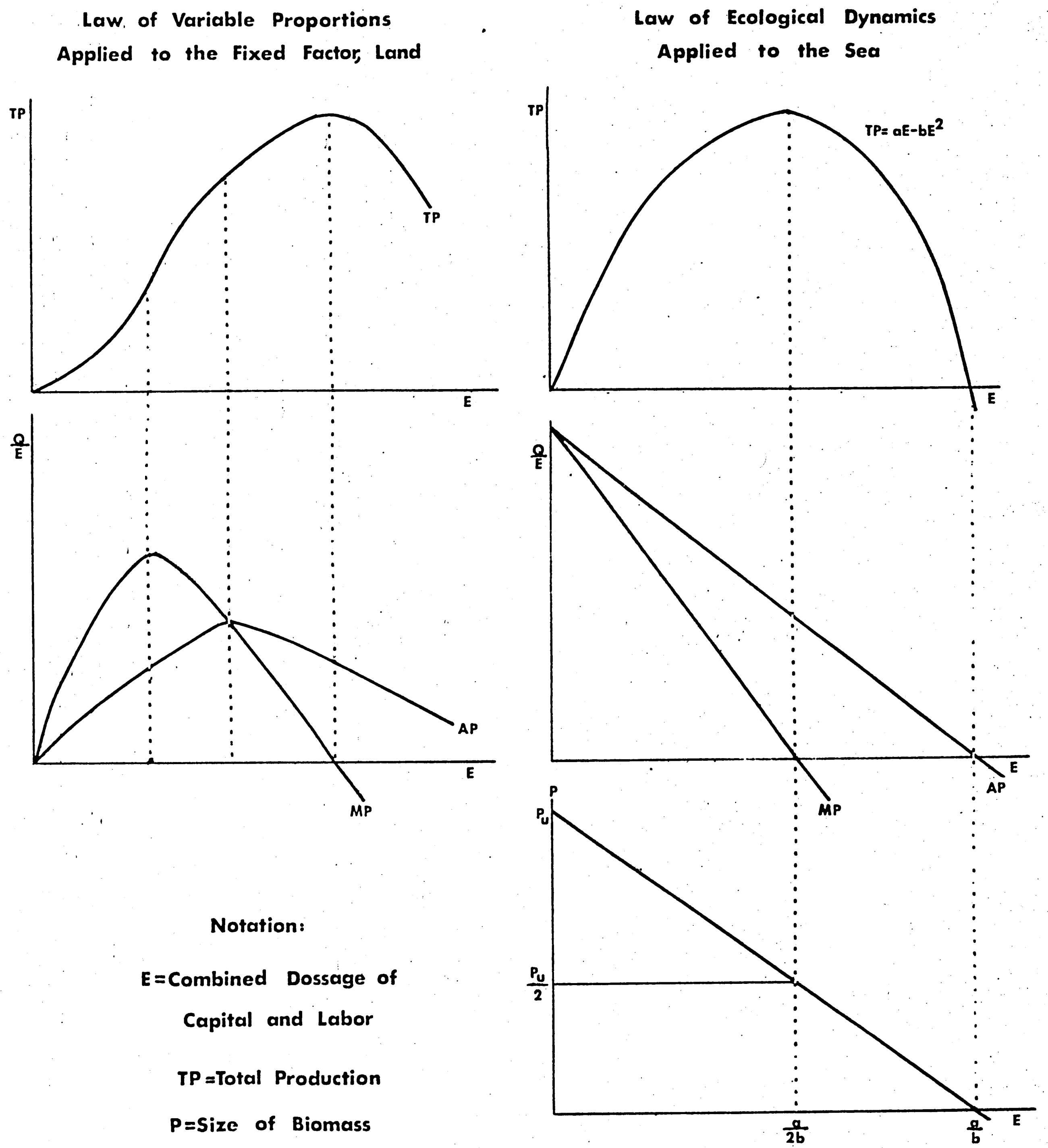
Thus, we have two models that can be tested. They are specified in (15) and (22) and represent alternative tests of this Malthusian scarcity hypothesis. Before subjecting the model to empirical testing, let us first consider just how the production economics for the sea differ from that of the land.

Malthusian Scarcity: Land Versus Sea

Figure 1 contrasts the famous "law of variable proportions" [5] with what we shall call the "law of ecological dynamics" as they are applied to the land and sea respectively. The classical economists such as Malthus were convinced that diminishing returns and stagnation were the logical result of the expansion in capital and labor applied to land and

Figure 1

Production Functions
for Land and Sea



Notation:

E = Combined Dossage of Capital and Labor

TP = Total Production

P = Size of Biomass

MP = Marginal Product

AP = Average Product

other fixed resources. Barnett and Morse [1, p. 172] have shown that this hypothesis is not verified by examination of the data. Except for a brief reference to commercial fishing, Barnett and Morse did not test this hypothesis for production from the sea.[4] In contrast to the law of variable proportions, the law of ecological dynamics indicates that both marginal and average output per unit of effort (i.e., dosages of capital and labor) will decline throughout. That is, there is no phase of increasing returns. Also the biomass which is analogous to the fixed factor, land, will vary in size depending on the level of exploitation. Theoretically we would expect that the sea would obey the classic Malthusian law of scarcity.

The conclusion reached by Barnett and Morse which rejects the Malthusian doctrine of increasing scarcity may not apply in the case of the sea since man has no way of controlling the environment or the parameters, α, β and γ and P_u as yet. That is, man has not learned to alter the quality of the fixed factor itself in the case of the sea. This is

4. The authors show some data for commercial fishing that tend to contradict the scarcity hypothesis. However, the data are too aggregative and of poor quality for the early years. Also, no data on capital inputs were available.

in contrast to the qualitative improvement of the land through fertilization and hybrid seed. For agriculture, the total product function has shifted upward over time. The chances of altering environmental parameters affecting the biomass in the sea are remote, but theoretically possible. For example, an increase in the growth rate of the biomass, δ, or the upper limit of the population, P_u, would shift the total product function upward and raise the maximum potential production, (see equation 17).

<u>Empirical Test of the Malthusian Law of Increasing Scarcity Applied to the Sea</u>

The hypotheses expressed in (14) and (22) regarding the declining productivity of fishing effort were tested for a number of species in the Atlantic Ocean, Pacific Ocean, Berring Sea, Gulf of Mexico, Caribbean area and Chesapeake Bay. Based on available data, we selected 10 fishery stocks shown in Table 1. These stocks represent a fair sample of marine life: (1)Pelagic (i.e., swim in open sea) - tuna, sardines, menhaden; (2) Demersal (i.e., bottom swimming) - haddock, halibut and (3) Crustacean (i.e., shellfish) - shrimp, lobsters and crabs. Except for northern lobsters, menhaden and sardines, all these species were fished by many nations of the world.

Table 1

Least-Squares Estimates of the Relation Between Catch Per Unit of Effort and Aggregate Effort for Selected Fisheries (Steady State Assumption)*

(catch per unit of effort is dependent variable)

	Species	Constant a	Effort (E) b	Mean Annual Seawater Temperature	Period of Observation	R^2	DW	Q_{MAX} (thousands of metric tons)	Measure of Effort
1.	Yellowfin Tuna-E. Pacific	.111 (23.5)	-.016 (-9.04)	--	1935-67	.73	.89	87.3	Boat days
2.	Haddock-N.W. Atlantic	2.92 (11.58)	-.020 (-5.48)	--	1934-61	.55	1.22	48.4	Boat days
3.	Sardine-E. Pacific	1002.6 (5.54)	-.476 (-3.13)	--	1932-50	.38	.75	526.3	Boat months
4.	Halibut-N.E. Pacific	165.4 (17.15)	-2.45 (-8.49)	--	1930-68	.66	.48	12.7	Skates
5.	Yellowfin Tuna-Caribbean	2.86 (5.76)	-.00011 (-2.62)	--	1956-65	.49	1.53	8.4	Hooks
6.	Northern Lobster-N.W. Atlantic [1]	-48.4 (-1.43)	-.000024 (-3.37)	2.13 (3.58)	1950-66	.96	2.05	11.6	Traps
7.	Shrimp-W. Atlantic and Gulf of Mexico [2]	2.55 (8.50)	-.488 (6.94)	--	1951-66	.76	1.46	N.A.	Vessel tons
8.	King Crab-Berring Sea	13.65 (13.83)	-.00063 (-6.28)	--	1959-67	.83	1.85	16.0	Tan days
9.	Menhaden-Gulf of Mexico	2.01 (9.99)	-.0000017 (-1.94)	--	1946-68	.16	1.99	270.0	Vessel weeks
10.	Menhaden Atlantic	3.84 (15.74)	-.0017 (-8.19)	--	1946-68	.77	1.44	98.6	Vessel weeks

*parentheses indicate t-values

1. Q_{MAX} computed while holding seawater temperature constant at 46.0°F.
2. Shrimp is an annual crop hence the model developed doesn't appear applicable. Instead the following equation was estimated: $Q = AE^{\alpha}$ where $0 < \alpha < 1$. See footnote 2.

Source: Division of Economic Research
Bureau of Commercial Fisheries

Table 1 shows the least-squares estimates of (14) fitted to the date on ten fishery stocks throughout the world. The estimate of "b" was negative in every case and statistically significant at the five percent level for nine stocks. However, yellowfin tuna, sardines and halibut showed evidence of strong positive autocorrelation which somewhat detracts from the statistical significance of the results. For the steady state model, the data overwhelmingly indicate that the productivity of each fishery (Q/E) significantly declines with expansion in effort (i.e., inputs of capital and labor).

Table 2 shows the least-square estimates of the parameters of (22), the stock adjustment model. The estimate of Πb was negative for all nine stocks (i.e., shrimp was excluded because stock adjustment does not apply) and statistically significant at the five percent level for seven stocks. The derived estimate of "b" was negative for seven out of nine fishery stocks.[5] In estimation of (22), significantly positive autocorrelation was only prevalent for tuna.

Our _a priori_ expectation is that $(1-\Pi)$ or the parameter for the lagged variable would be close to zero for species that grow rapidly and have high reproduction rates and close to unity for species that grow slowly and have low reproduction rates. _In general_, the results confirmed our expectations. For

5. The derived estimate of "b" was obtained by dividing Πb by Π. Π may be derived from estimated parameters of the variable (Q_{t-1}/E). See equation 22.

Table 2

Least-Squares Estimates of the Relation Between Catch Per Unit of Effort and Aggregate Effort and Lagged Catch Per Current Unit of Effort for Selected Fisheries (Stock Adjustment Assumption)*

(catch per unit of effort is dependent variable)

	Species	Constant Π^a	Effort (E) Πb	$\frac{Q_{t-1}}{E}$ $(1-\Pi)$	Mean Annual Seawater Temperature	Period of Observation	R^2	DW	Q_{MAX} (thousands of metric tons)	Measure of Effort
1.	Yellowfin Tuna E. Pacific	.096 (6.45)	-.014 (-5.13)	.134 (1.03)	--	1935-67	.74	.96	86.3	Boat days
2.	Haddock N.E. Atlantic	1.96 (4.03)	-.012 (-2.60)	.288 (2.24)	--	1935-61	.62	1.69	51.1	Boat days
3.	Sardine E. Pacific	525.8 (3.00)	-.339 (-2.98)	.734 (4.03)	--	1933-50	.70	2.64	352.9	Boat months
4.	Halibut	50.1 (2.01)	-.063 (-1.45)	.644 (4.88)	--	1931-68	.80	1.90	12.7	Skates
5.	Yellowfin Tuna Caribbean	3.85 (6.17)	-.00015 (-3.80)	-.320 (-2.08)	--	1957-65	.71	1.74	16.5	Hooks
6.	Northern Lobster N.W. Atlantic	-.789 (-3.15)	-.000012 (-1.75)	-.019 (-3.06)	1.26 (2.85)	1951-66	.97	2.10	11.6	Traps
7.	Shrimp [2], W. Atlantic and Gulf of Mexico	N.A.	N.A.	N.A.	--	--	--	--	--	--
8.	King Crab Berring Sea	12.93 (3.13)	-.00074 (-4.45)	.278 (.425)	--	1960-67	.81	1.71	17.8	Tan days
9.	Menhaden - Gulf of Mexico	1.81 (5.65)	-.0000018 (-1.97)	.146 (.809)	--	1947-68	.19	2.30	242.1	Vessel weeks
10.	Menhaden-Atlantic	2.73 (2.55)	-.0012 (-2.47)	.309 (1.06)	--	1947-68	.78	1.90	102.1	Vessel weeks

*parentheses indicates t-values

1. Q_{MAX} computed on the basis that $\Pi = 0$ since $(1 = \Pi)$ is negative and conflicts with theoretical model. Also seawater temperature was held constant at 46.0°F.
2. Stock adjustment technique is not applicable since shrimp has an annual life cycle. See text for fuller description.

Source: Division of Economic Research
Bureau of Commercial Fisheries

example, Eastern Pacific yellowfin tuna and menhaden grow very rapidly and $(1-\Pi)$ is close to zero (i.e., not statistically different from zero). Sardines and halibut grow slowly and for them $(1-\Pi)$ is closer to unityand statistically significant. Haddock grows slowly but reproduces at high levels hence we observe intermediate levels of $(1-\Pi)$. The sign for $(1-\Pi)$ conflicts with the theoretical model for northern lobster and yellowfin tuna - Caribbean. It was hypothesized that the sign of $(1-\Pi)$ for northern lobsters would be close to unity given the slow growth of the species.

For both of the alternative specifications [i.e., (14) and (22)] it would appear that Malthusian scarcity is quite prevalent in the case of the sea based upon our sample. The results also verify the logistic growth models employed by Turvey [15]; Smith [14] and Plourde [11] in formulating marine production economics. Finally, Tables 1 and 2 show the maximum sustainable yield for each fishery stock using equation (17).

Prognosis: Food from the Sea

Food supplies can certainly be increased by more intensive development of the world's fisheries. However, we have shown that for the species analyzed more intensive exploitation of the sea will result in diminishing returns to both capital and labor unless accompanied by changes in the ecological environment itself. Diminishing returns imply a rising cost industry with, as we have shown, a maximum production potential. Contrary to wide belief, the quantities of food available from the sea are not "unlimited."

It has been estimated by the Food and Agricultural Organization that the world is now consuming approximately 50 percent of the maximum sustainable yield from the sea which is about 120 million metric tons [6]. This food is at the higher levels of the food chain and does not include plankton, nor a whole range of small fishes which are widely dispersed and uneconomical to harvest. For example, the expense of filtering or centrifuging plant plankton from seawater makes its recovery uneconomical nor is the raw material obtained a particularly good one [8]. If the world's population doubles by the year 2000, we will have exhausted the total potential of the sea (i.e., reached MSY for fish presently consumed in various quantities) assuming a constant per capita fish consumption. Substantial income effects will, of course, hasten the day we reach a maximum utilization of the sea. Without major discoveries in controlling ocean environment, it is quite apparent that the sea will be subject to Malthusian scarcity as the pressure of population increases.[6] It is doubtful that the same breakthroughs in agriculture can be easily duplicated for the sea because of the difficulty of controlling environmental variables.

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6. Our general conclusions should be qualified to include potential advances in aquaculture. The possible transformation of the fishing industry from hunting wild stocks to farming may ease the Malthusian problems associated with the sea.

Finally, because production from the sea is a parabolic function of effort and the resource is common property in nature, the danger of overexploitation is a distinct possibility. That is, further increases in effort may actually reduce physical production. Therefore, in order to exploit the maximum potential of the oceans, it is necessary that proper fishery management be instituted.

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52. Basic Economic Indicators - Halibut. April 1970

53. Basic Economic Indicators - Northern Lobsters. April 1970

54. Basic Economic Indicators - Sea Scallops. April 1970

55. Basic Economic Indicators - Clams. April 1970

56. Basic Economic Indicators - Oysters. May 1970

57. Basic Economic Indicators - Shrimp. May 1970

58. Basic Economic Indicators - Blue Crabs. May 1970

59. Basic Economic Indicators - King and Dungeness Crabs. May 1970

60. Basic Economic Indicators - Menhaden. May 1970

61. Basic Economic Indicators - Tuna. May 1970

* 62. Basic Economic Indicators - Salmon. May 1970

71. Economic Projections of the U.S. and World Demand for Major Fishery Products by F. Bell, D. Nash and F. Waugh. June 1970

72. The Fundmental Theory of the Economics of Commercial Fishing by E. Carlson. June 1970

* 63 through 70 are presently in process and cover basic economic indicators for 16 other master plan fisheries.

The goal of the Division of Economic Research is to engage in economic studies which will provide industry and government with costs, production and earnings analyses; furnish projections and forecasts of food fish and industrial fish needs for the U.S.; develop an overall plan to develop each U.S. fishery to its maximum economic potential and serve as an advisory service in evaluating alternative programs within the Bureau of Commercial Fisheries.

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