STOCK AND CONGESTION EXTERNALITIES IN THE FISHERY: THE CASE OF THE GEORGES BANK SCALLOP

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Estimation of U.S. and Canadian yield functions in a bioeconomic model of the Georges Bank scallop fishery indicated stock and congestion externalities. The latter resulted in nonconcavity of the combined yield function, thus generating the possibility of steady-state corner solutions where one nation would be eliminated from the fishery.

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Management of common property resources, in particular the fishery, has received considerable discussion within the economics literature. Following the path-breaking articles by Gordon [1954] and Scott [1955] the management problem was seen to involve several forms of externality having both static and dynamic implications (see Crutchfield and Zellner [1962], Turvey [1964], Smith [1968, 1969], Bell [1972] and Brown [1974].) Recent formulations have viewed management as an exercise in optimal control (see Quirk and Smith [1969], Plourde [1970] and Brown [1974]).

The purpose of this article is to report on the evidence of stock and crowding or congestion externalities within the Georges Bank scallop fishery. It is organized into four sections. The first presents some of the bio-economic relationships governing the exploitation of that fishery. These include yield functions for Canada and the U.S. and a stock adjustment (transition) equation for the scallop stock. The second section presents the estimation results of these three equations for the period 1958-1968. Stock and crowding externalities are identified. The third section examines steady state equilibrium and discusses the stability implications of these externalities. The final section summarizes the major conclusions.

I. The Georges Bank Scallop Fishery

Perhaps the most explicit discussion of the three types of externalities which might exist in a fishery is that found in Smith [1969, p. 181]:

> The recovery or harvesting process is subject to various possible external effects all of which represent external

> diseconomies to the firm: (a) Resource stock externalities result if the cost of a fishing vessel's catch decreases as the population of fish increases. (b) Mesh externalities result if the mesh size (or other kinds of gear selectivity variables) affects not only the private costs and revenues of the fisherman but also the growth behavior of the fish population. (c) Crowding externalities occur if the fish population is sufficiently concentrated to cause vessel congestion over the fishing grounds and, thus, increased vessel operating costs for any given catch.

We will be concerned with only stock and congestion externalities. While gear selectivity variables may have generated external effects within the scallop fishery, there would appear no well defined technological or institutional changes which would permit an investigation of this type of externality.

The scallop is a bivalve mollusk, harvested by dragging a dredge along the ocean bottom, periodically raising it to dump scallops and debris on board for sorting and schucking. Scallop meats are packed in plastic bags and placed on ice so that only meats are landed.

Georges Bank lies approximately 100 miles off of Cape Cod and the Georges Bank scallop is currently harvested by Canada and the U.S. While the Georges Bank scallop stock was discovered in the 1930's it did not come under intensive exploitation until the 1950's. During this period the fishery was primarily worked by U.S. vessels operating out of New Bedford, Massachusetts. In the late 1950's Canada developed a scallop fleet and rapidly entered the industry.

The fishery is currently under regulation by the International Commission for the Northwest Atlantic Fisheries (ICNAF). Data in Table I reveal two interesting features: (a) a significant shift in the relative shares of U.S. and Canadian output with the U.S. share declining from 85 percent in 1958 to 16 percent in 1966, and (b) the nearly uniform

Table I

Canadian and U.S. Effort, Estimated Scallop Stock, Landings and Catch Per Vessel Day

Year (t)	Canadian Effort ($E_{c,t}$) Vessel Days[a]	U.S. Effort ($E_{u,t}$) Vessel Days[a]	Estimated Scallop Stock (N_t) Millions of Pounds on Jan. 1[b]	Canadian Landings ($Y_{c,t}$) Millions of Pounds[a]	U.S. Landings ($Y_{u,t}$) Millions of Pounds[a]	Combined Landings ($Y_{c,t} + Y_{u,t}$) Millions of Pounds[a]	Canadian Catch Per Vessel Day $\frac{Y_{c,t}}{E_{c,t}}$ Pounds[a]	U.S. Catch Per Vessel Day $\frac{Y_{u,t}}{E_{c,t}}$ Pounds[a]
1958	1598	8775	24.1	2.6	14.4	17.0	1627	1641
1959	2098	8556	28.9	4.4	18.7	23.1	2097	2186
1960	2601	8039	37.2	7.5	21.9	29.4	2884	2724
1961	3147	8665	45.0	10.1	23.6	33.7	3209	2724
1962	4642	9070	48.4	12.5	21.9	34.4	2613	2414
1963	5905	7718	43.5	13.1	17.6	30.6	2218	2280
1964	6723	6656	36.2	13.2	14.2	27.4	1963	1834
1965	5749	2156	25.3	10.1	3.3	13.4	1757	1534
1966	5524	1001	16.3	10.7	2.0	12.7	1937	1984
1967	6785	1870	15.7	11.1	2.9	14.0	1636	1543
1968	6972	1938	15.5	10.6	2.6	13.2	1520	1323
1969	6684	2930	15.2	9.6	3.2	12.8	1436	1102

a: International Commission for the North Atlantic Fisheries

b: Estimated from data supplied by NMFS, Woods Hole, Massachusetts decline in catch/day for both countries, symptomatic of an "overfished" resource.

Smith [1969, p. 184] formulated his externalities in terms of the cost functions of a representative vessel. For the Georges Bank scallop fishery the externalities were formulated in terms of an industry production or yield function of the following form:

(I.1) $Y_{c,t} = \phi_c\ (E_{c,t},\ E_{u,t};\ N_t)$

and

(I.2) $Y_{u,t} = \phi_u\ (E_{c,t},\ E_{u,t};\ N_t)$

where

$Y_{c,t}$ = Canadian landings (yield) in time t

$Y_{u,t}$ = U.S. landings (yield) in time t

$E_{c,t}$ = Canadian effort (vessel days) in time t

$E_{u,t}$ = U.S. effort (vessel days) in time t

N_t = Scallop stock in time t

and $\phi_c\ (\cdot)$ and $\phi_u\ (\cdot)$ are Canadian and U.S. yield functions respectively.

In addition to the yield functions (I.1) and (I.2) a management program must also identify a stock adjustment or transition equation for the resource. The scallop stock was assumed to change through time according to the first order difference equation:

(I.3) $N_{t+1} - N_t = \psi(N_t;\ Y_{c,t},\ Y_{u,t})$

The assumed signs of the yield and transition functions are as follows:

$$\frac{\partial \phi_c}{\partial E_{c,t}} > 0, \quad \frac{\partial \phi_c}{\partial E_{u,t}} < 0, \quad \frac{\partial \phi_c}{\partial N_t} > 0, \quad \frac{\partial \phi_u}{\partial E_{c,t}} < 0, \quad \frac{\partial \phi_u}{\partial E_{u,t}} > 0, \quad \frac{\partial \phi_u}{\partial N_t} > 0,$$

$$\frac{\partial \psi}{\partial N_t} \gtrless 0, \quad \frac{\partial \psi}{\partial Y_{c,t}} < 0 \text{ and } \frac{\partial \psi}{\partial Y_{u,t}} < 0.$$

To estimate any specification of (I.1) - (I.3) one needs estimates of the resource stock. Accurate estimates of an open sea fishery resource have presented formidable problems which have greatly restricted applications of recent theoretical advancements. Several methods exist including capture-recapture, equilibrium catch-population, and in the case of less mobile fishery resources, stock-grid estimates via underwater television camera. The method used here is similar to that found in Schaefer [1954] and is based on an equilibrium catch-population approach.1/ From this method the scallop stock estimates in column eight of Table I were derived. The necessary data was therefore available to estimate yield and stock adjustment equations.

II. Empirical Results: Evidence of Stock and Crowding Externalities

The specific form of the yield and stock adjustment equations is given in (II.1) - (II.3) below:

(II.1) $Y_{c,t} = a\ E_{c,t} - b\ E^2_{c,t} + c\ N_t E_{c,t} - d\ E_{c,t} E_{u,t}$

(II.2) $Y_{u,t} = e\ E_{u,t} - f\ E^2_{u,t} + g\ N_t E_{u,t} - h\ E_{u,t} E_{c,t}$

(II.3) $N_{t+1} - N_t = mN_t - nN^2_t - (Y_{c,t} + Y_{u,t})$

where all coefficients a - n would be assumed, a priori, to be positive. This form was selected for several reasons. It (a) exhibited the usually assumed properties of declining marginal physical product, (for a country's own fishing effort), (b) contained the presumed externality forms, (c) permitted ordinary least square estimates of the coefficients of the linear average yield $\left(\frac{Y_{c,t}}{E_{c,t}}, \frac{Y_{u,t}}{E_{u,t}}\right)$ and (d) formulated the stock adjustment equation as a quadratic similar to that hypothesized by Volterra [1931], Lotka [1956] and others.

The regression results are contained in Table II. All coefficients

Table II
Coefficients for Yield Functions and Scallop Stock
Adjustment Equation*

Canadian Yield Function	a	b	c	d	R^2	DW
	0.021070 (4.55)	0.000002 (2.76)	0.000061 (4.63)	0.000002 (2.34)	0.8449	1.4372
U.S. Yield Function	e	f	g	h	R^2	DW
	0.020836 (4.80)	0.000001 (2.07)	0.000052 (4.22)	0.000002 (2.97)	0.8442	2.177
Scallop Stock Adjustment	m	n			R^2	DW
	0.801942 (4.96)	0.000289 (0.32)**			-	-

* t - statistics are given below coefficients in parenthesis.
** Not significant at the 5% level (one tail test)

were of the expected sign. Only one was not significant at the 5% level; that being the coefficient of the squared scallop stock term (n) in the stock adjustment equation. Approximately 84% of the variation in Canadian and U.S. landings were explained by effort and scallop stock. In estimating the stock adjustment equation the intercept was suppressed invalidating the coefficient of determination as a measure of fit and the Durbin-Watson statistic as a measure of autocorrelation. The remaining Durbin-Watson statistics are inconclusive.

Evidence of stock and congestion externalities is indicated by the significance of c, d, g, and h. The stock externality differs slightly from the Canadian (c = 0.000061) to the U.S. (g = 0.000052) industry. The crowding or congestion externality is identical for both industries (d = h = 0.000002) indicating a reciprocal negative effect of U.S. effort on Canadian yield and vice versa.

III. Steady State Equilibrium with Stock and Congestion Externalities

Consider the following discrete control problem:

$$\underset{E_{c,t},\ E_{u,t}}{\text{MAX}} \sum_{t=o}^{\infty} \rho^t \left[P^*(\phi_c(\cdot) + \phi_u(\cdot)) - k_{c,t} \ E_{c,t} - k_{u,t} \ E_{u,t} \right]$$

(III.1)

$$\text{subject to} \quad (1+m)N_t - nN_t^2 - (\phi_c(\cdot) + \phi_u(\cdot)) - N_{t+1} = 0$$

where $\rho = \frac{1}{1+r}$ is the appropriately defined discount factor, P* is a constant per pound price for scallops, $(\phi_c(\cdot) + \phi_u(\cdot))$ represents the combined yield of Canadian and U.S. industries, and $k_{c,t}$ and $k_{u,t}$ are vessel day costs for Canada and the U.S. respectively. Defining the current value Hamiltonian as:

$$\text{(III.2)} \quad H_t = \rho^t \left\{ P^*(\phi_c(\cdot) + \phi_u(\cdot)) - k_{c,t}E_{c,t} - k_{u,t}E_{u,t} + \rho\lambda_{t+1} \left[(1+m)N_t - nN_t^2 - (\phi_c(\cdot) + \phi_u(\cdot)) \right] \right\}$$

The first order necessary conditions for optimality (with positive levels of effort and scallop stock) would require:

(III.3) $$\frac{k_{c,t}}{k_{u,t}} = \frac{[a - 2bE_{c,t} + cN_t - (d+h)\,E_{u,t}]}{[e - 2fE_{u,t} + gN_t - (d+h)\,E_{c,t}]}$$

(III.4) $$P^*(cE_{c,t} + gE_{u,t}) + \rho\lambda_{t+1}\,[(1+m) - 2nN_t - (cE_{c,t} + gE_{u,t})] - \lambda_t = 0$$

and

(III.5) $$N_{t+1} - N_t = mN_t = nN_t^2 - (\phi_c(\cdot) + \phi_u(\cdot))$$

If P* is a constant per pound price for scallops then from differentiating the current value Hamiltonian with respect to combined yield we note:

(III.6) $$\rho\lambda_{t+1} = P^*$$

However, it is also the case that in steady state equilibrium $\lambda_{t+1} = \lambda_t = \lambda^*$ and $N_{t+1} = N_t = N^*$ so that (III.4) and (III.5) simplify to:

(III.7) $$\rho[(1+m) - 2nN^*] - 1 = 0$$

(III.8) $$\phi_c(\cdot) + \phi_u(\cdot) = mN^* - n(N^*)^2$$

Equation (III.7) is somewhat surprising. Solving for steady state stock one obtains:

(III.9) $$N^* = \frac{m-r}{2n}$$

which is the result usually obtained only in a simple quadratic fishery with no stock externalities.[2/]

Given the steady state scallop stock the causality in the model is relatively straightforward. Steady state stock will determine a steady state combined yield. Given stock and yield we can identify the appropriate isoyield curve in effort space and by equating the ratio of marginal physical yields to the ratio of vessel day costs (as in equation (III.3)) we may determine the optimal distribution of effort between the U.S. and Canada. This causality is portrayed in Figures 1(a) and 1(b). The locus of steady state stocks and combined yields is shown in Figure 1(a). The maximum sustained yield (MSY) of 55.6 million pounds associated with the stock $N^* = \frac{m}{2n} = 138.7$ million pounds is shown as well as the optimal yield of 54.8 million pounds associated with the stock $N^* = \frac{m-r}{2n}$ implied by equation (III.7) with $r = 0.10$ as the rate of discount.3/

The optimal stock and yield may then be substituted into the combined yield function and the resulting curve plotted in effort space. If the combined yield function were quasiconcave we would obtain a convex curve similar to that shown in Figure 1(b). Locating the tangency between this curve and a line with slope $-\frac{k_{c,t}}{k_{u,t}}$ will permit us to determine the optimal distribution of effort $(E^*_{c,t}, E^*_{u,t})$ between Canada and the U.S.

As it turns out the combined yield function (evaluated at the optimal yield and stock) is no longer a concave function in effort.4/ The segment of the isoyield contour which is in the "economic region" is approximately linear with a slope of -1.18.5/ It is shown in Figure 2. While convex, this contour causes the ratio of vessel day costs to become extremely important in the following manner:

$$\text{If } \frac{k_{c,t}}{k_{u,t}} < 1.18 \quad E_{c,t} = 7350,\ E_{u,t} = 0$$

$$\text{(III.10)} \qquad \text{If } \frac{k_{c,t}}{k_{u,t}} > 1.18 \quad E_{c,t} = 0 \quad E_{u,t} = 8700$$

$$\text{If } \frac{k_{c,t}}{k_{u,t}} = 1.18 \quad E_{c,t},\ E_{u,t} \text{ are indeterminant}$$

Figure 1(a)
Locus of Steady State Yield and Scallop Stock

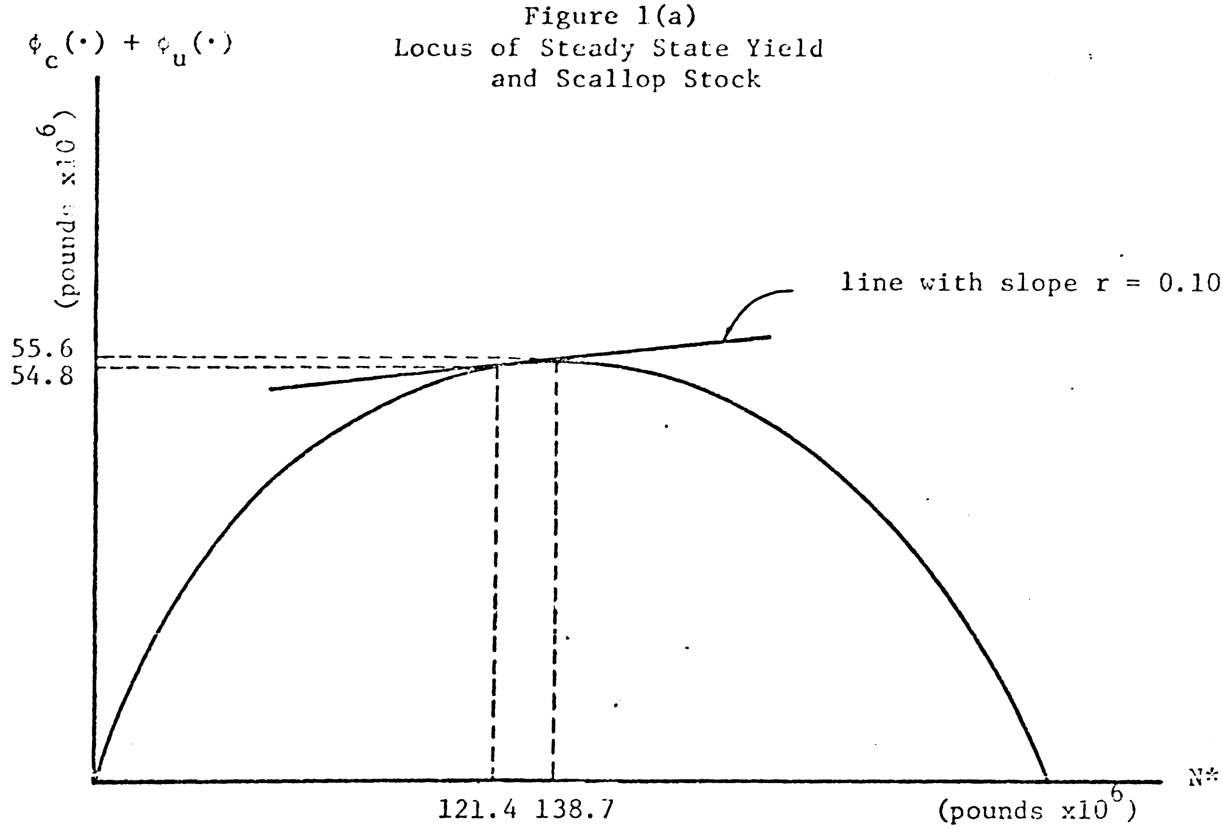


Figure 1(b)
Determination of Distribution of Effort

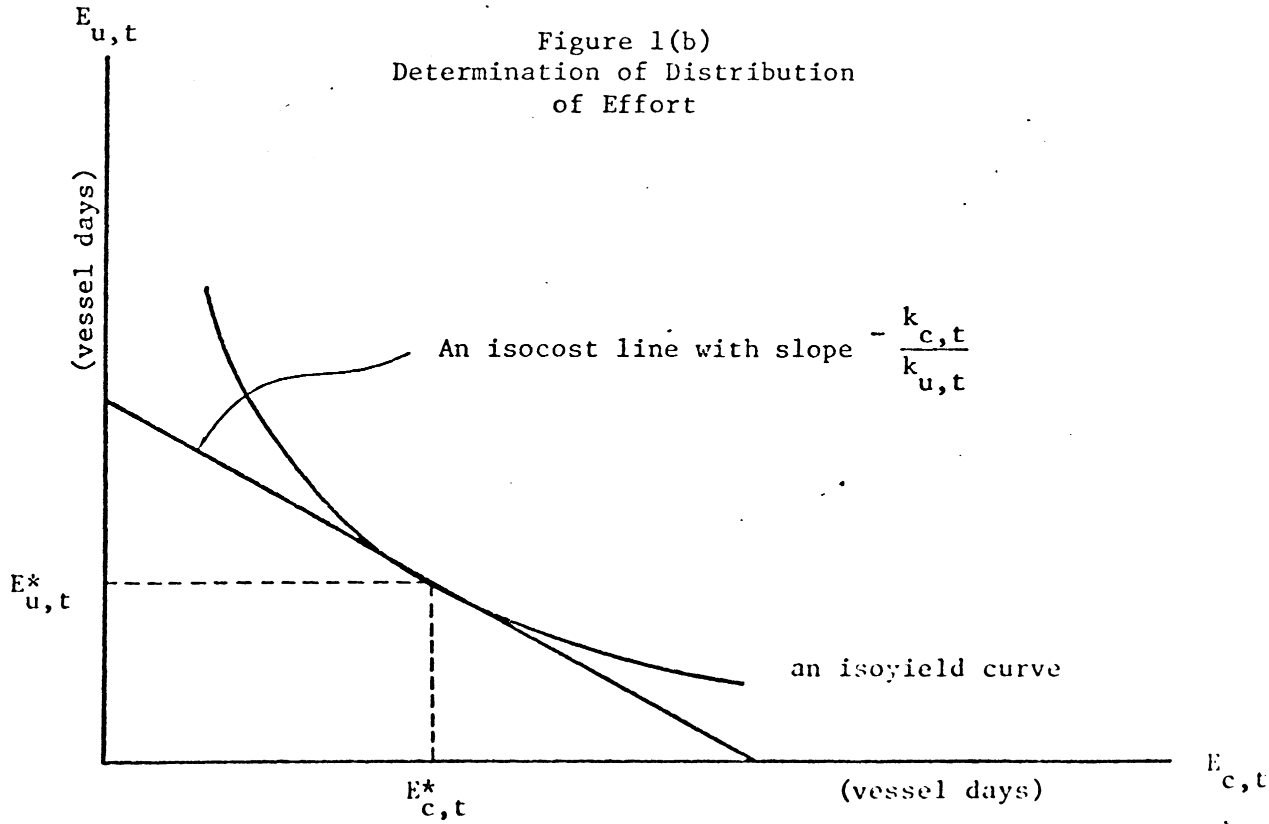
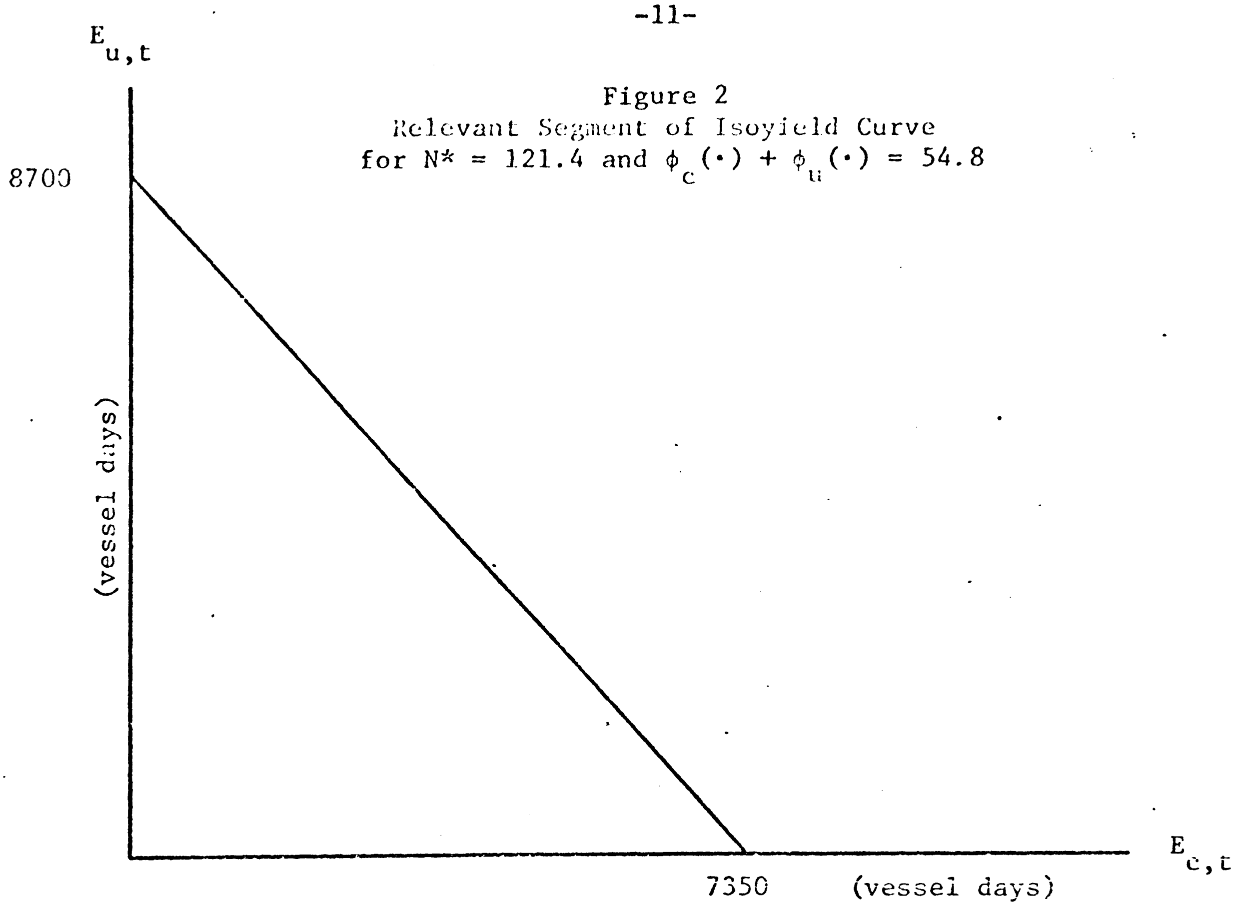


Figure 2
Relevant Segment of Isoyield Curve
for $N^* = 121.4$ and $\phi_c(\cdot) + \phi_u(\cdot) = 54.8$



Data on vessel day costs for U.S. and Canadian scallopers was difficult to obtain. Some rough calculations based on a Bureau of Commercial Fisheries Publication entitled "Basic Economic Indicators: Sea Scallops" [1970] resulted in the estimates for U.S. vessel day costs contained in Table III. These estimates were derived by adding cash expenditures for trip, repair and maintenance, fixed charges, along with wages, crew share, Captain's commission, and depreciation and dividing the resulting figure by days fished.

Data on Canadian vessel day costs was not obtainable. Canadian vessels while possibly facing higher travel expenses to and from Georges Bank were believed to have offsetting cost advantages due to a newer fleet and possible lower labor costs. If this is the case a vessel day cost ratio of $\frac{k_{c,t}}{k_{u,t}} < 1.18$ would result in elimination of U.S. vessels from the fishery.

Table III
Estimates for U.S. Vessel Day Costs $k_{u,t}$ in Dollars

t	1956	1957	1958	1959	1969	1967	1968
$k_{u,t}$	572	580	557	597	531	838	1095

The recent dominance of Canada on Georges Bank might be attributed to just this phenomenon.

IV. Conclusions and Caveats

There would appear to be strong evidence of stock and congestion externalities in the Georges Bank scallop fishery. The nature of the congestion externalities is such that the ratio of vessel day costs becomes exceedingly important in determining the distribution of effort between U.S. and Canada. Factors contributing to a Canadian - U.S. vessel day cost ratio of less than (greater than) 1.18 could result in corner solutions where U.S. (Canada) would be eliminated from the fishery.

It would appear that both Canada and the U.S. significantly overfished the resource in the late 1950's to mid 1960's and that the continued effort applied by Canada since 1965 precluded recovery of the scallop stock to where it could support higher yields. Combined effort is in excess of optimal effort even when evaluated at a ten percent rate of discount.

The numerical results would appear to be very sensitive to estimates of the scallop stock and coefficients of the stock adjustment equation. This is especially true of the coefficient of the squared scallop stock (n) in equation (II.3) which as noted earlier was <u>not</u> significant at the five percent level. This sensitivity would indicate a need for improved statistical methods to estimate scallop stock.[6/] With better methods on which to construct estimates of commercial fish stocks application of the recent advances in management theory would become more feasible.

FOOTNOTES

1/Estimates of the scallop stock were based on two assumptions: (a) that the combined yield per unit effort was proportional to the average scallop stock within the year and (b) that the factor of proportionality times aggregate effort was equal to the annual rate of fishing mortality. Within the context of the model described in Section I these assumptions imply the following two equations:

$$\text{(a)} \quad \frac{(Y_{c,t} + Y_{u,t})}{(E_{c,t} + E_{u,t})} = \gamma_t \bar{N}_t$$

$$\text{(b)} \quad \gamma_t \, (E_{c,t} + E_{u,t}) = M_t.$$

where M_t is the annual rate of fishing mortality, and γ_t is a constant of proportionality relating catch per unit effort to average fish stock within the period ($\bar{N}_t$). Independent estimates of M_t were obtained from the National Marine Fisheries Service at Woods Hole, Massachusetts such that $M_t = 0.7$ for 1957-1962; $M_t = 0.8$ for 1963-1966 and $M_t = 0.9$ for 1967-1969. From these estimates and with fishery records on $(E_{c,t} + E_{u,t})$ and $(Y_{c,t} + Y_{u,t})$ it is possible to calculate $\bar{N}_t$. Interpolation of average stock estimates gave the estimates of scallop stock on January 1 shown in column eight of Table 1.

2/Earlier formulations of stock externalities were specified in terms of a cost function with the control variable being catch rate (see Smith (1968, 1969) and Quirk and Smith (1969)). In the present formulation with effort (vessel days) as a control and the relationship between the exogenously fixed price for scallops and the costate variable determined by (III.6). The normally encountered positive effect of stock externalities on steady state stock did not appear.

An alternative formulation for maximization of the present value of net revenues might be expressed as:

$$\text{(a)} \quad \underset{Y_t}{\text{MAX}} \sum_{t=o}^{\infty} \rho^t [R(Y_t) - C(Y_t, N_t)]$$

with larger fish stocks reducing costs $(\frac{\partial C}{\partial N_t} < o)$. To solve for a cost function given the structure of the present model one would make use of the combined yield function, cost equation, and effort expansion path given as follows:

$$\text{(b)} \quad Y_t = \phi_c(\cdot) + {}_u\phi(\cdot) = aE_{c,t} - bE^2_{c,t} + eE_{u,t} - fD^2_{u,t} + (cE_{c,t} + gE_{u,t})N_t - (d+h)E_{c,t}\,E_{u,t}$$

$$\text{(c)} \quad C_t = k_{c,t}E_{c,t} + k_{u,t}E_{u,t}$$

$$\text{(d)} \quad \frac{k_{c,t}}{k_{u,t}} = \frac{(a - 2bE_{c,t} + cN_t - (d+h)\,E_{u,t})}{(e - 2fE_{u,t} + gN_t - (d+h)\,E_{c,t})}$$

By careful manipulation of (c) and (d) one can obtain expressions for effort in terms of cost (C_t) and scallop stock (N_t). However, upon substituting these expressions into the combined yield function (a) it is not possible to determine an explicit function relating cost to combined landings (Y_t) and scallop stock. But, because effort was a function of cost and scallop stock one would expect some sort of stock externality term $\left(\frac{\partial C}{\partial Nt}\right)$ modifying the steady state results expressed in (III.7).

3/The coefficients of the yield functions and stock adjustment equation were derived on scallop stock estimates entered in hundreds or thousand pounds (10^5). Therefore, solving (III.9) for r = 0.01 would yield $N^* = 1214.4 \times 10^5$ or 121.4 million pounds. Other steady state stocks would similarly have a denomination of 10^5 pounds.

4/The Hessian of the combined yield function evaluated at the optimal yield and scallop stock is:

$$\begin{bmatrix} \frac{\partial^2\phi}{\partial E^2_{c,t}} & \frac{\partial^2\phi}{\partial E_{c,t}\partial E_{u,t}} \\ \frac{\partial^2\phi}{E_{u,t}\partial E_{c,t}} & \frac{\partial^2\phi}{\partial E_{u,t}} \end{bmatrix} = \begin{bmatrix} -0.000004 & -0.000004 \\ -0.000004 & -0.000002 \end{bmatrix}$$

implying the combined yield function is neither concave nor convex. In the absence of congestion externalities the off-diagonal elements would be zero and the Hessian would be negative definite implying in a concave combined yield function.

5/A plot of the entire isoyield curve was a distorted ellipse-like quadratic with two values of $E_{u,t}$ for every $E_{c,t}$. There were two segments of this yield curve in the positive orthant ($E_{c,t}$; $E_{u,t} > 0$). The first, approximately linear segment, is shown in Figure 2. The second segment involves significantly greater levels of $E_{u,t}$ for each $E_{c,t}$ and is therefore