J. OF THE NORTHEASTERN AGR. ECON. COUNCIL VOL. VII, NO. 2, OCTOBER, 1978

AQUACULTURE'S POTENTIAL AS A FISHERY MANAGEMENT TOOL

Peter H. Greenwood

One of the redeeming virtues of the study of economics is that it enables its practitioners to discuss subjects about which they know very little. This paper represents a case in point. The premise of the paper rests on the presumption that aquaculture provides an additional source of aquatic life; this presumption is, of course, true by definition. The purpose of this paper is to investigate the potential of aquaculture to regulate the harvest from natural production, but more importantly the purpose is to consider the difficulties that even relatively simple tools pose for the fishery manager.

THE ISSUES

Consider a hypothetical fishery. The species in question is capable of being produced under artificial conditions; and, by assumption, no non-precuniary externalities exist between production by capture and by culture. A precuniary externality obviously exists since the cultured output is a substitute for the captured output. The development of aquaculture is equivalent to the entry of competitive firms in a textbook industry. Let S in Figure 1 be the short run supply of the capture industry, and let D be the demand for the species. The market clears at price P_O and quantity Q_O. The development of a culture facility will shift supply to S + A, and the market equilibrium shifts to P_1, Q_1. This development would reduce capture production from Q_O to Q_2. This same reduction would be accomplished by imposing a per unit tax of t on capture production. An increase in cultured supply would further reduce capture production and would therefore be similar in impact to an increase in the tax. Subsidizing the cultured industry would result in just such a shift and is, therefore, in many respects equivalent to a tax on the capture industry. S, it is recalled, is a short run supply, and changes in short run production should have an impact on supply in future periods.

While a tax on S and a subsidy for A may have identical impacts on capture output, they are not identical policies. In Figure 2, a per unit subsidy on culture output shifts S + A to S + A' and reduces capture production form q to q'. A tax of t in Figure 3 also results in a reduction of captured output from q to q'.

The combined production is much higher when culture is subsidized than when capture is taxed; correspondingly, the market price is much lower when culture is subsidized. It is also apparent that more real resources are used when culture is subsidized.

There are other important differences between taxes on capture and subsidies on culture. Taxes generate resentment and encourage evasion. The directness of a tax is disadvantageous to the popularity of its promulgators. It is difficult (indeed it may be impossible) to convince oneself that paying taxes is in one's own self-interest. The problems of enforcement and evasion aside, the directness of a tax is an important advantage from the economist's perspective; but this advantage may be overshadowed by the political ramifications. A subsidy, on the other hand, helps those directly affected and may be preferred politically.

THE FIRST-BEST OPTIMUM

This section begins with a discussion of the notation and functional relationships to be employed in the following two cases. The annual capture harvest H of our species is presumed to depend in a deterministic fashion on the size of the exploitable biomass X and the level of effort E. In reality, E is an index of a number of factors, but for purposes of analytic ease assume that E is equivalent to the stock of fishing capital. The stock of fishing capital depreciates at a constant rate d and is augmented by gross physical investment i. These relationships may be summarized by:

(1) $E' = i - dE$

The prime indicates a time derivative; a time subscript for i and E are assumed to be understood. The biomass is assumed to be governed by:

(2) $X' = f(X) - H$

where f(X) is interpreted as the natural increment to the stock; time subscripts on X and H are understood. The market demand for the species is given by $Q^D = Q^D(P)$ were Q^D is quantity demanded and P is the market price. The market is always presumed to clear; thus, $Q = Q^D$ where Q is simply H + A, where A is the cultured output. The market clearing equation may be written as:

(3) $P = Q^D(Q)^{-1}$

or

(3a) $P = P(Q)$

The resource cost of producing A is simply C(A), and the price per unit of physical investment is Υ.

The objective which forms the basis for comparing policies is net consumer's surplus. The theoretical problems raised by the selection of this criterion are well known; however, analytic ease justifies its use when income effects are of little importance (See Willig). The net consumer's surplus is given by:

(4) $$NCS = \int_{Q=0}^{H+A} P(Q)dQ - C(A) - \gamma$$

This expression is, of course, time specific. Our horizon extends beyond the immediate present, and we would thus be concerned with a stream of new consumer surplus. This stream would be converted to a single present value with the aid of a social rate of time preference δ. In each time period a level of A and a

---

Peter H. Greenwood is Assistant Professor of Resource Economics Institute of Natural and Environmental Resources The University of New Hampshire, Durham, N. H. The support of the U.N.H. Marine Program is gratefully acknowleged.

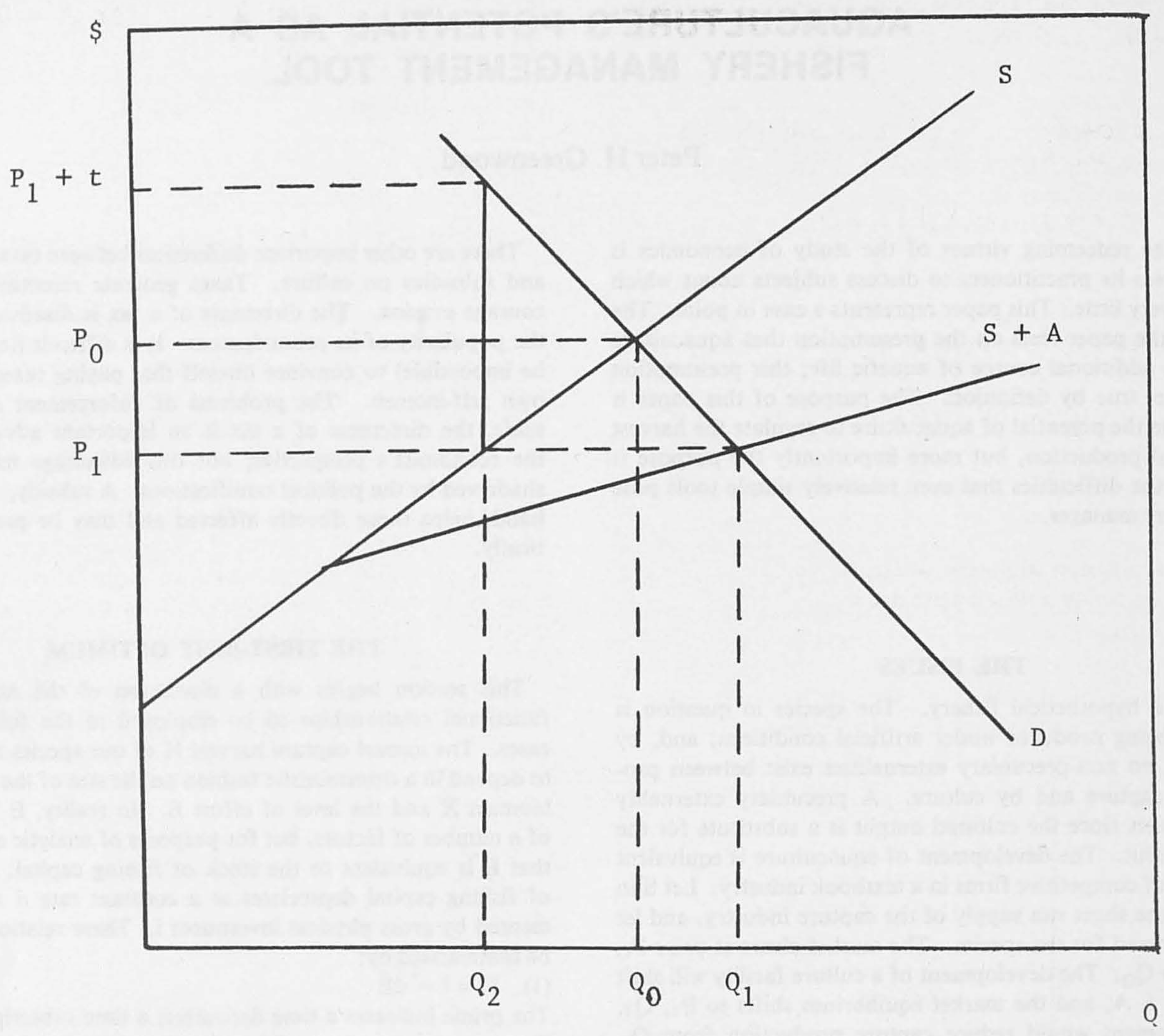

FIGURE 1.

Comparing the effects of developing aquaculture as an alternative to a capture fishery with a tax on the capture fishery.

level of i must be selected; the optimal values will solve the following problem:

$$\text{Max} \int_{t=0}^{\infty} \left[\int_{Q=0}^{H+A} P(Q)dZ - C(A) - i \right] e^{-\delta t} dt$$

$$\text{subject to } X', \; E', \; E_0, \; X_0$$

$$A \geq o, \; i \geq o$$

This is an optimal control problem. To solve this we formulate an augmented Hamiltonian:

$$(5) \quad \Psi = \int_{Q=0} P(Q)dQ - C(A) - \gamma i + q_1[f(x)-H] + q_2(i-dE)$$

In each time period i and A should be selected so as to maximize Ψ. These values will satisfy:

$$(6) \quad i = o \text{ when } -\gamma + q_2 < o$$

$$i > o \text{ when } -\gamma + q_2 = o$$

$$i = \infty \text{ when } -\gamma + q_2 > o$$

$$A = o \text{ when } P(H+A) - C' \leq o$$

$$A > o \text{ when } P(H+A) - C' = o$$

Because of the implicit assumption that this market is a small portion of total economic activity, investment has a "bang-bang" flavor. This tells us that whenever E is less than its desired level, E should be elevated to its desired level instantaneously. We recognize γ as the price of investment goods; q_2 is the value of the contribution to social welfare made by the marginal investment. If this marginal value is greater than the marginal cost, it follows that investment should continue until this value reaches the level of cost. The time paths of E, i, X, A, q_1, and q_2 are governed by:

(7) $$i = i^* \geq o, \quad A_1 = A^* \geq o$$

$$X' = f(x) - H(X,E)$$

$$E' = i - dE$$

$$q_1' = \delta q_2 - [P(H+A)H_X + q_1 f' = q_1 H_X]$$

$$q_2' = \delta q_2 - [P(H+A)H_E - q_1 H_E - q_2 d]$$

$$E_o, \ X_o$$

A steady state solution will occur where the time derivatives are zero. Thus, the steady state is determined by:

(8) (a) $$P = C' \ [\text{for } A > 0; \text{ for } A = 0, \ P < C'(0)]$$

(b) $$i = dE$$

(c) $$f(x) = H$$

(d) $$PH_E = (\delta + d)\ \gamma \ \frac{[\delta - f' + H_X]}{\delta - f'}$$

PH_E is, in economic terminology, the value of the marginal product of effort; $(\delta + \hat{d})\ \gamma$ is the private opportunity cost of physical capital. The results indicate that the private opportunity cost has to be bolstered to account for the stock externality. This can be accomplished by a tax on effort. The culture output in the steady state coincides with the output forthcoming from a competitively organized industry. There is no direct subsidy given to culture; an implicit subsidy would be given in the form of a pecuniary externality. At no time along

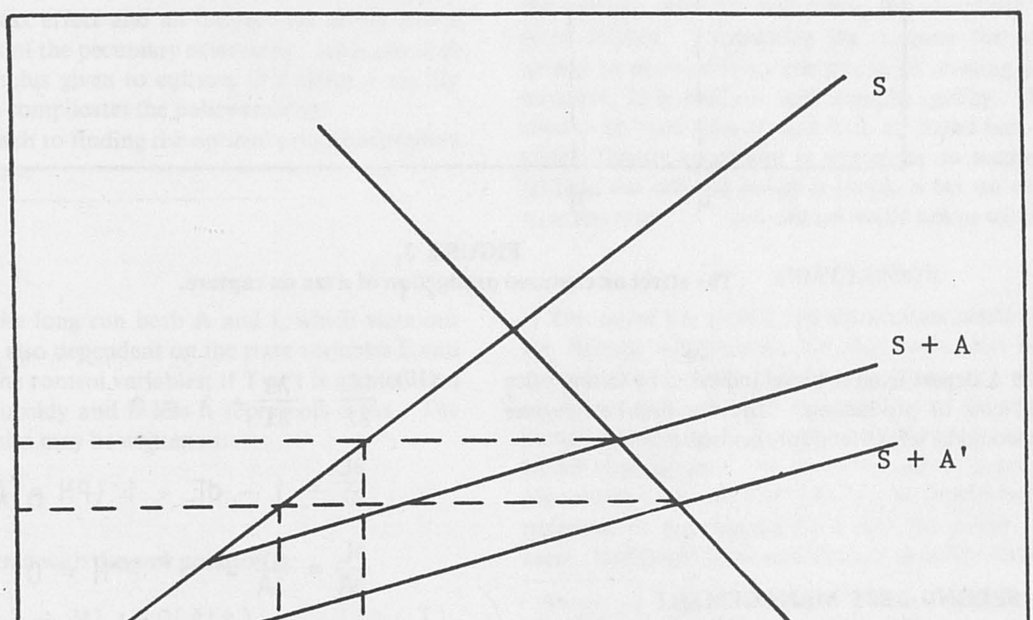

FIGURE 2.
The effect on captured production of an increase in cultured supply.

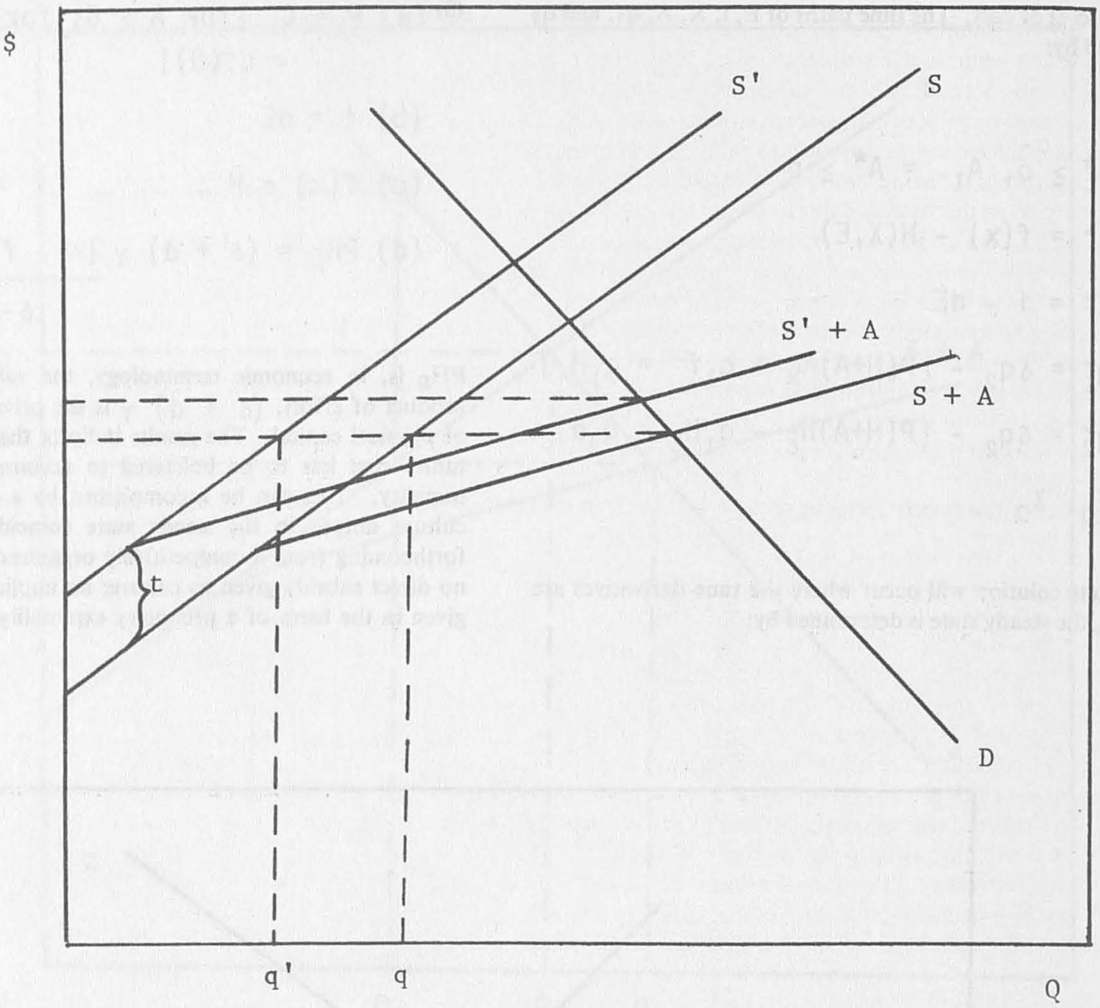

FIGURE 3.
The effect on captured production of a tax on capture.

the path should A depart from the level indicated by letting price equal marginal cost of production. Under a first-best regime aquaculturists would be left to fend for themselves.

SECOND-BEST MANAGEMENT

The previous problem is converted from a first-best to a second-best problem by the addition of a new constraint. Suppose that because of the unpopularity of a tax, we presume that fishermen may not be taxed. Subsidies, on the other hand, are permissable. The level of fishing effort is governed by the market and the individual decision makers without direct intervention. Specifically, assume that $i - dE$ is a function of industry profits which are defined by $PH - (d + \delta)$ E. To solve the new problem we have in each period to choose i, A to maximize subject to $i - dE = i^*(PH - (d + \delta)$ E). This is accomplished by writing the Lagrangian:

(9) $$L = \Psi + \lambda[i - dE - i^*(PH - (d + \delta)\gamma E)]$$

and selecting i, A, and to maximize L. The non-negativity constraints must still be satisfied. The first order conditions are:

(10) $$\frac{\partial L}{\partial i} = \frac{\partial \Psi}{\partial i} + \lambda = 0$$

$$\frac{\partial L}{\partial \lambda} = i - dE - i'(PH - (d + \delta)\gamma E) = 0$$

$$\frac{\partial L}{\partial A} = \frac{\partial \Psi}{\partial A} - i^{*\prime}P'H = 0$$

These reduce conveniently to:

(11) $$P(H+A) = C' + (q_2 - \gamma) \quad i^{*\prime}P'H = 0$$

$$i = i^*(PH - (d + \delta)\gamma E) + dE$$

Since $i^{*\prime} > 0$, $P' < 0$, these conditions require that A be subsidized whenever q_2 is less than γ. The interpretation of q_2 is the same as before; thus, whenever the social values of investment is less than its cost, aquaculture should be subsidized.

Gates, **et. al.** have evaluated a number of species on their merits as candidates for aquaculture in New England. They propose two economic criteria. A good candidate must have high per unit value, and the captured output must be large (if the captured output is not large then the price elasticity must be large).

Bloodworms, for example, have an extremely high value per pound but a small volume. Consequently, the bloodworm is not regarded as a good candidate for aquaculture on economic grounds. The subsidization of bloodworm culture could prove to be an effective (still second-best however) tool for the management of bloodworms. Taxing bloodworm capture is probably so difficult to enforce that it would not be a viable tool. Limiting entry poses difficulties of its own. A subsidy to culturists is as enforceable as IRS regulations are. My point is not that we should necessarily subsidize bloodworm culture, but rather only that with a species like bloodworms the activities of culturists would have significant leverage over the capture industry. This leverage can be seen as a handicap or it can be seen as an asset. From the point of view of the culturist it may be a handicap; from the point of view of the manager it is a potential asset.

A FURTHER COMPLICATION

We have determined that if it is possible to tax fishermen, then a first-best optimum is attainable. Someone or some institution collects the tax revenue, a fact of little consequence in a partial welfare analysis. An anonymous reviewer of an earlier draft posed an interesting question: what is the optimal policy if the revenue raised is earmarked for the subsidy of culture. If the revenue is used in this fashion it is of consequence. A tax on fishermen under this constraint has two effects on capture production, a direct tax effect and an indirect tax effect which stems from the impact of the pecuniary externality. An important side effect is the stimulus given to culture; this effect is the fly in the ointment which complicates the policy making.

The simplest approach to finding the optimal program involves some new notation. Let:

$$A = A(t) \tag{12}$$

$$i = i(t, T)$$

in the short run; in the long run both A and i, which were our control variables, are also dependent on the state variables E and X. T and t are now the control variables; if T or t is greater than zero it represents a subsidy and if less it represents a tax. The public finance constraint may be written as:

$$T\,H + t\,A = 0 \tag{13}$$

The Hamiltonian written with the new notation is:

$$\psi = CS\,[A(t) + H] - C[A(t)] - \gamma i(t, T) + q_1[f(X) - H] + q_2[i(t, T) - dE] \tag{14}$$

In each time period t and T must be chosen to maximize subject to the public finance constraint. This problem can be handled by selecting t, T, and λ to maximize the Lagrangian:

$$L = \psi + \lambda(T\,H + t\,A) \tag{15}$$

The first order conditions may be reduced readily to:

$$t = (q_2 - \gamma)\,\frac{\frac{\partial i}{\partial t} - \frac{\partial i}{\partial T}\frac{1}{H}\left(A + t\,\frac{\partial A}{\partial t}\right)}{\frac{\partial A}{\partial t}} \tag{16}$$

In elasticity form we have:

$$t = (q_2 - \gamma)\,\frac{i}{A}\,\frac{\varepsilon it + \varepsilon iT\,(1 + \varepsilon At)}{\varepsilon At} \tag{17}$$

We interpret q_2 as before as the incremental present value of investment and γ as the price of investment goods: thus if q_2 is less than γ we should intuitively feel it advisable to discourage investment. Since $E_{\iota\tau}$ is negative for positive i and t; since $E_{\iota\tau}$ is negative for positive i and negative T; since t and T have opposite signs; and since $E_{a\tau}$ is positive for positive A and t, our intuition is correct. The tax on capture will be:

$$T = -(q_2 - \gamma)\,\frac{i}{H}\,\frac{\varepsilon it + \varepsilon iT(1 + \varepsilon At)}{\varepsilon At} \tag{18}$$

While it is possible to derive relatively simple expressions for the optimal subsidies and taxes, this simplicity is largely algebraic artifact. Earmarking tax revenues for aquaculture may appeal to some as a simple means of meeting joint objectives; however, it is really a very complex policy. Furthermore, it should be remembered that it is a second-best policy. If the public finance constraint is written as an inequality, or if it is ignored the optimal policy is simply a tax on capture whenever q_2 is less than γ, and culture would not be subsidized.

CONCLUSION

This paper has shown that aquaculture could be used as a tool for fishery management, but that tools exist which are better from the economist's perspective. Moreover, we have seen that relatively simple changes in the nature of the policy may greatly complicate the optimal policy and sharply increase the informational requirements. At its easiest fishery management is complex enough. In way of conclusion we should hope that while the potential of aquaculture as a tool for fishery management is recognized it will prove unnecessary to utilize this potential.

This is an interesting subsidy. The tax makes culturists better off in each time period than they would be without one; however, in the long run their position deteriorates.

REFERENCES

1. Gates, J. M., **et al.** *Aquaculture in New England.* Marine Technical Report Series. University of Rhode Island, No. 18.
2. Willig, Robert D. "Consumer's Surplus Without Apology." *American Economic Review.* 66 (1976):589-597.