Market Interactions Between Aquaculture and the Common-Property Commercial Fishery

James L. Anderson

Department of Resource Economics
University of Rhode Island
Kingston, Rhode Island

Abstract Market interactions between the common-property commercial fishery and (1) competitive aquaculturists and (2) a dominant-firm aquaculturist are modeled. It is found that the entry of a competitive aquaculturist increases natural fish stocks, reduces price, and increases total supply. If initially the natural fish stock is at a level below maximum sustainable yield, entry of the aquaculturist results in an increase in supply from the commercial fishery. In the second part, the aquaculturist is modeled as a dominant firm. In some situations, the aquaculturist behaves in a manner similar to the competitive case, but impacts on price, fish stock, and efficiency will not be as large. It is shown that there also exist cases where the dominant aquaculturist will desire to promote overexploitation of the natural fish stock.

Introduction

Commercial aquaculture in the United States is in its initial development stages. In the past two decades, interest in and growth of aquaculture have increased significantly.

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The potential growth in aquaculture production can be more fully appreciated by considering cases where aquaculture is already an important factor. For example, Norway has made great strides in pen-reared Atlantic salmon aquaculture. Norway first initiated pen rearing of Atlantic salmon and rainbow trout in the early 1960s; however, production of salmon became important only after 1970. Production of salmon between 1974 and 1983 increased from 600 metric tons to approximately 16,500 metric tons (Nordness 1984). Production is expected to continue to increase at a rapid pace.

In Japan the production of cultured marine fish, mussels, and seaweeds increased from 48,000 metric tons in 1950 to 917,000 metric tons in 1978. In 1978 total cultured output represented 9% of the total supply but approximately 80% of the yellowtail production and 94% of the eel production (Brown and Nishimura 1983). Another example of aquaculture's rapid growth is Ecuador's pond-grown shrimp industry. In 1976 only 13% of Ecuador's shrimp production came from aquaculture, but by 1981 farmed shrimp represented 75%. Imports of Ecuadorian shrimp to the United States (second largest after Mexico) have steadily increased in recent years and in 1982 were 24.74 million pounds, 44% of which came from shrimp farms (U.S. Department of Commerce 1982). It is expected that by 1990 annual production may reach 100 million pounds (Shipley 1984).

In the United States production of catfish from aquaculture was only a few thousand pounds in 1963. By 1969 it was about 60 million pounds, and in 1983 it was about 137 million pounds, liveweight (Bardach et al. 1972; U.S. Department of Agriculture 1984). In Oregon private salmon-ranching operations had returns of coho which were insignificant in 1975. However, by 1982, privately aquacultured coho represented 122,100 (14.5%) of the 844,100 ocean catch (troll and sport) off of Oregon and California, plus 165,000 adult and 19,300 jack coho returned to private salmon ranchers (Pacific Fisheries Management Council 1983), indicating that approximately 30% of the coho salmon harvested in Oregon were derived from private aquaculture activity.

Most of the private salmon aquaculture in the United States is done by three companies: Oregon Aqua-Foods, Inc., a subsidiary of Weyerhaeuser; Andromous, Inc., a subsidiary of British Petroleum; and Domsea, a subsidiary of Campbell's Soup. Other aquaculture projects have also attracted significant investment from such companies as Southern California Edison (lobster, abalone), American Trust Corporation of Maryland (oyster), General Mills (shrimp), Ralston Purina (catfish, shrimp), International Paper (crawfish), and Hormel (catfish). Such expenditures indicate the potential for changes in the market structure for certain species.

The first objective of this paper is to explore the interactive effects between open-access common-property commercial fishery and competitive aquaculturists. The equilibrium and resulting dynamics caused by entry of commercial aquaculturists are evaluated. The second section of the paper focuses on possible interactions that may result when the aquaculturist is modeled as a dominant firm and the common-property fishery is characterized as perfectly competitive. The presentation is restricted to a discussion of bioeconomic efficiency and industry dynamics. A complete analysis of the social welfare implications of aquaculture is beyond the scope of this work.

Competitive Model

This section contains an analysis of an open-access fishery faced with a linear demand and a linear supply from the aquaculture sector. All participants are assumed to be pricetakers.

Consider the model of the open-access fishery as presented in Clark (1976, pp. 153–157). Briefly summarized, the growth equation is

$$\dot{X} = rX(1 - X/k) - EX \tag{1}$$

where E is fishing effort, X is fish stock, r is intrinsic growth rate, k is environmental carrying capacity, and EX is yield (Y_F). Profit π is given by

$$\pi = (pX - c)E \tag{2}$$

where p is price/biomass and c is cost per unit of fishing effort (constant).

In equilibrium, the open-access supply is

$$Y_F = \frac{rc}{p}(1 - c/pk) \tag{3}$$

Now assume that equilibrium total demand is

$$Y = \beta_1 - \beta_2 p \tag{4}$$

and that the supply from the aquaculture sector is given by

$$Y_A = \gamma_1 + \gamma_2 p \tag{5}$$

where β_1, β_2, and γ_2 are nonnegative constants and γ_1 is a nonpositive constant. It is further assumed that aquaculture has no direct impacts on the biology of the natural fishery and that the aquaculture product is a perfect substitute for the natural product. Examples where this appears to be the case are lobster and shrimp culture, pen-reared yellowtail, Atlantic salmon, and several other species of finfish. The fishery sector now faces an equilibrium net demand—total demand (equation 4) minus aquaculture supply (equation 5)—which takes into account the supply from aquaculture, expressed by

$$Y_F = \beta_1 - \gamma_1 - (\beta_2 + \gamma_2)p \qquad \text{for } p \geq -\gamma_1/\gamma_2 \tag{6a}$$

$$Y_F = \beta_1 - \beta_2 p \qquad \text{for } p < -\gamma_1/\gamma_2 \tag{6b}$$

The equilibrium net demand for aquaculturists is simply the total demand (equation 4) minus fishery supply (equation 3).

The equilibrium natural fishery supply under two different net demand situations is found in Figure 1*a*, and the corresponding equilibrium net aquaculture demand with two different aquaculture supply situations is found in Figure 1*b*. The initial equilibrium in both figures is e_0 with price p_0, natural fishery supply is Y_{F0}, and there is no aquaculture supply. If technology existed such that the competitive aquaculture supply was given by S'_A (Figure 1*b*), the resulting net demand facing the fishery is $D'D'D$ (Figure 1*a*). The presence of aquaculture will lead to reduced consumer price (P'), increased total supply ($Y'_A + Y'_F$), increased natural fish stock, and reduced fishing effort. The efficiency of the competitive fishery is improved as more fish are landed with less effort. The biological basis of the natural fishery industry causes the nonconventional response of increased catch. When the fishery is initially exploited beyond maximum sustainable yield, the biological growth characteristics of the natural fish stock may create an equilibrium net demand which is positively sloped for a portion.

If the technology is present such that aquaculture supply is given by S''_A (Figure 1*b*), then the net demand the competitive fishery is given by $D''D''D$. (Figure 1*a*). Under these conditions equilibrium price is reduced to p'', which results in a natural fish stock that exceeds the maximum sustainable yield level. In the range where the fish stock exceeds maximum sustainable yield, the equilibrium fishery supply has the normal positive slope; therefore, the net demand facing the aquaculturists is always negatively sloped. Other equilibrium results under these conditions are that total supply is increased ($Y''_F + Y''_A$) and fishing effort is reduced.

The special case where multiple equilibria initially exist in the competitive fishery is shown in Figure 1*c*. This situation results in a perverse net demand for the aquaculturist that is nonnegative for some prices when the fish stock is below maximum sustainable yield levels, zero for some range around maximum sustainable yield, and nonnegative again for fish stocks above maximum sustainable yield (Figure 1*d*).

In this case if initial equilibrium is e_0 with p_0 (Figure 1*c*) and supply from the fishery of Y_{F0}, the presence of aquaculture supply, S'_A, (Figure 1*d*) will shift the demand facing the fishery of $D'D'D$, resulting in a new equilibrium e'_A, with lower price p', increased natural fishery supply Y'_F, and aquaculture fish supply Y'_A. The presence of aquaculture will lead to reduced consumer price, increased total supply, increased natural fish stock, and

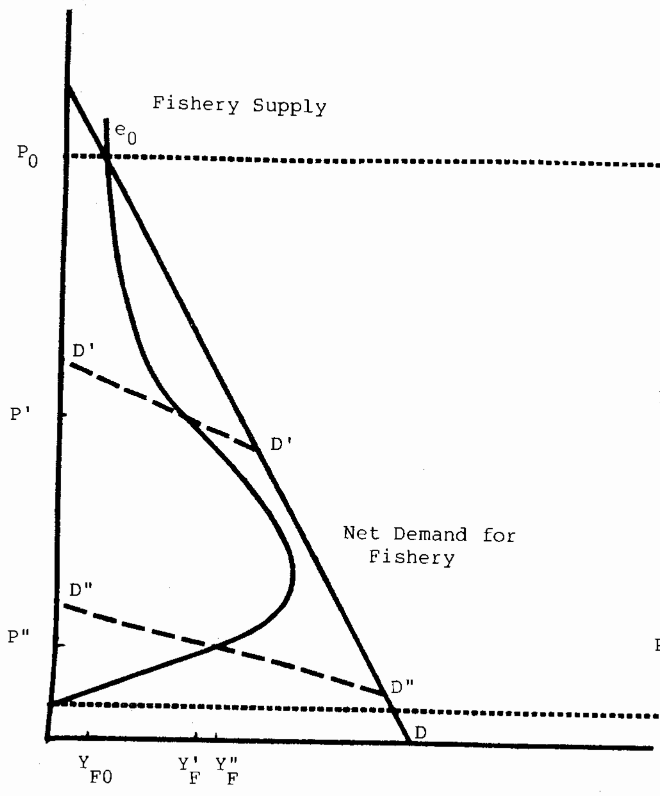

FIGURE 1*a*. Equilibrium common-property fishery.

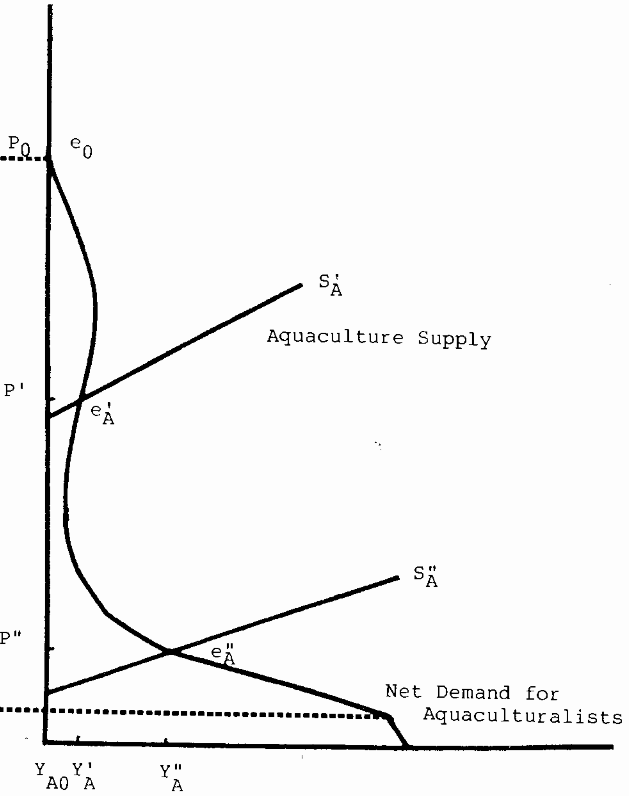

FIGURE 1*b*. Equilibrium competitive aquaculturists.

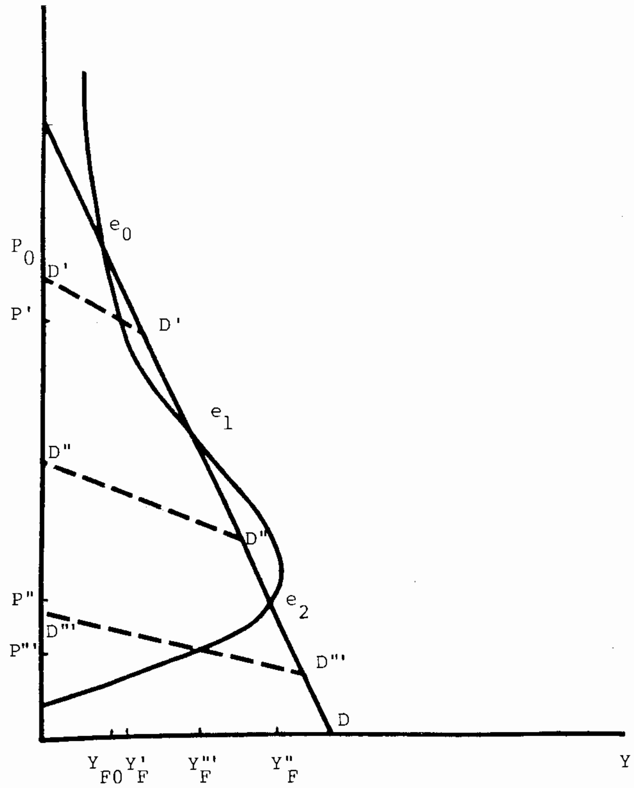

FIGURE 1*c*. Equilibrium common-property fishery.

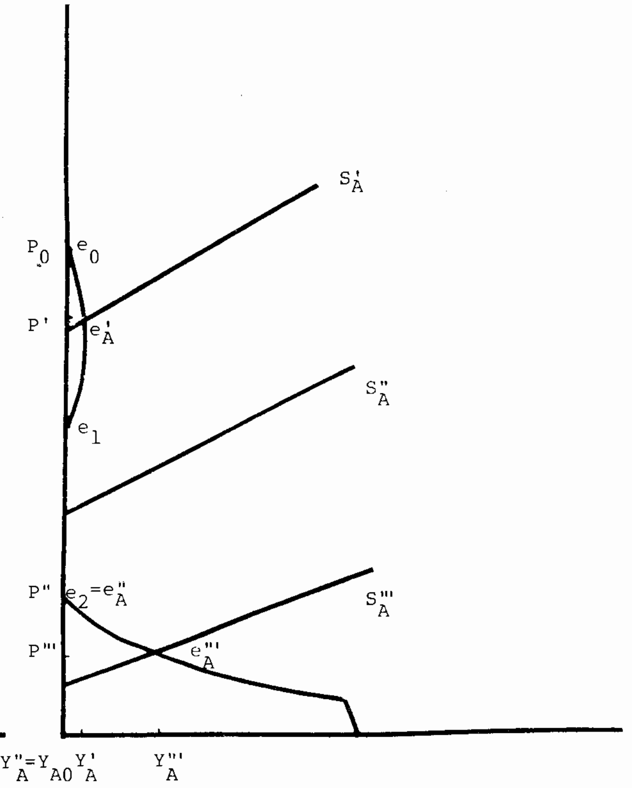

FIGURE 1*d*. Equilibrium competitive aquaculturists.

reduced fishing effort. If the initial equilibrium was e_2 in Figure 1c, the aquaculturists would not enter.

Aquaculture supply of S''_A in Figure 1d, resulting in net demand $D''D''D$ in Figure 1c, would lead to further fishing effort reduction. Fishermen will reduce effort, and fish stock will increase; aquaculturists are consequently driven down their supply curve until they are eliminated. The existence of aquaculture is only temporary because of the resulting increase in fishery efficiency.

If the aquaculturists' supply were S'''_A (Figure 1d), net demand $D'''D''D$ (Figure 1c) would result. If this occurred, equilibrium price would be still lower (p'''), fishing effort would decrease further, and supply from the common-property fishery (Y'''_F) would decline, since fish stock now exceeds maximum sustainable yield. The aquaculturists will produce at level Y'''_A.

It can be concluded that the underlying population dynamics of the biologically overexploited, open-access commercial fishery acts as an additional factor to curtail the entry of commercial aquaculturists. However, when commercial aquaculturists do enter, the result is more efficiency in the commercial fishery. When the fish stock is below maximum sustainable yield at the initial equilibrium, the presence of commercial aquaculture causes fishing effort to decrease, fish stock to increase, prices to decline, and yield from the fishery to increase. The presence of commercial aquaculture decreases the slope of the net demand curve for the commercial fishery. This reduces the range where multiple equilibria can occur and decreases the risk of catastrophic shifts in the fishery.

Although the issues of economic efficiency and system stability under aquacultural development can be dealt with in this analysis, questions of social welfare cannot adequately be addressed. However, in general, consumers will be better off in all cases. Fishermen will be worse off in the short run. The long-run impact on fishermen is indeterminate. As for aquaculturists, there are short-run gains from aquacultural production, but it is evident from this analysis that these gains may or may not be retained in the long run. The intertemporal nature of the social gains and losses must also be considered. The net present value of net social benefit will depend on how social-welfare gains and losses are distributed over time and on the magnitude of the discount rate.

The dynamics of the equilibria just discussed can be evaluated by the addition of a capital adjustment equation (using effort as a proxy for capital) where it is assumed that effort adjustment is a function of profit. (See Smith 1969, for a more general treatment.) The effort adjustment equation is

$$\dot{E} = \alpha(\pi) = \alpha E(px - c) \tag{7}$$

The inverse net demand derived from equations (6a and 6b) is

$$p = \frac{\beta_1 - \gamma_1}{\beta_2 + \gamma_2} - \frac{Y}{\beta_2 + \gamma_2} \qquad \text{for } p \geq -\frac{\gamma_1}{\gamma_2} \tag{8a}$$

and

$$p = \frac{\beta_1}{\beta_2} - \frac{Y}{\beta_2} \qquad \text{for } p < -\frac{\gamma_1}{\gamma_2} \tag{8b}$$

Substituting equations 8a and 8b and $Y = EX$ into equation 7 gives

$$\dot{E} = \alpha E\left[\frac{(\beta_1 - \gamma_1)X}{\beta_2 + \gamma_2} - \frac{EX^2}{\beta_2 + \gamma_2} - c\right] \qquad \text{for } p \geq -\frac{\gamma_1}{\gamma_2} \tag{9a}$$

$$\dot{E} = \alpha E\left[\frac{\beta_1 X}{\beta_2} - \frac{EX^2}{\beta_2} - c\right] \qquad \text{for } p < -\frac{\gamma_1}{\gamma_2} \tag{9b}$$

When $\dot{E}$ and $\dot{X}$ (equation 1) equal zero,

$$E = \frac{\beta_1 - \gamma_1}{X} - \frac{c(\beta_2 + \gamma_2)}{X^2} \qquad \text{for } p \geq -\frac{\gamma_1}{\gamma_2} \tag{10a}$$

$$E = \frac{\beta_1}{X} - \frac{c\beta_2}{X^2} \qquad \text{for } p < -\frac{\gamma_1}{\gamma_2} \tag{10b}$$

and

$$E = r - \frac{rX}{k} \tag{11}$$

Evaluating the derivatives around the equilibria of $\dot{X} = 0$ and $\dot{Y} = 0$ results in the phase diagram in Figure 2*a*, which corresponds to the initial conditions in Figure 1*c*. Point e_0 corresponds to the overfishing case and is a stable node. Point e_1 is an unstable saddle point. Point e_2 is a stable spiral. The entry of the aquaculturists reduces the first term and increases the second. This shifts the curve for the equilibrium equations (10*a* and 10*b*) downward.

The net demand relationship with the aquaculturists present and phase diagrams are illustrated in Figures 2*a* and 2*b*. The phase diagram assumes that the aquaculturists are on their supply curve at all times and fishing effort and fish stock adjust. If the initial equilibrium is e_2, the aquaculturists will not enter. The dashed curve labeled $EX = \beta_1 + \beta_2\gamma_1/\gamma_2$ in Figures 2*a* and 2*b* is defined by setting Y_A equal to zero and substituting into the aquaculturist net demand equation. This gives the locus of points to the left of which the aquaculturists are in the positive portion of their supply relationship; all points to the right have no aquaculturists. To the right of the dashed line, the common-property supply results in a price $(-\gamma_1/\gamma_2)$ which is less than the minimum cost for aquaculture.

Figure 2*a* illustrates the phase diagram corresponding to the case where aquaculture supply is given by S'_A (Figure 1*c*). The approach to the equilibrium e'_A previously discussed in price/quantity space in Figure 1*c* is reached by fishing effort and fish stock adjusting away from e_0 along a path defined by the stable spiral in Figure 2*a* with aquacultural production moving along its supply curve. Fishing effort, fish stock, fish price, and aquaculture supply will all cycle toward the long-run equilibrium e_1.

In Figure 2*b* is a phase diagram corresponding to the situation presented in Figure 1*c* where aquaculture supply is given by S''_A. In this case, the equilibrium conditions result in the eventual elimination of the aquaculturists. The approach to this long-run position from initial equilibrium e_0 is given by a stable node. Therefore, fishing effort and fish price will monotonically decrease, and fish stock and aquaculture supply will monotonically increase until the new equilibrium is reached. It can be seen that although the aquaculture supply goes to zero before the equilib-

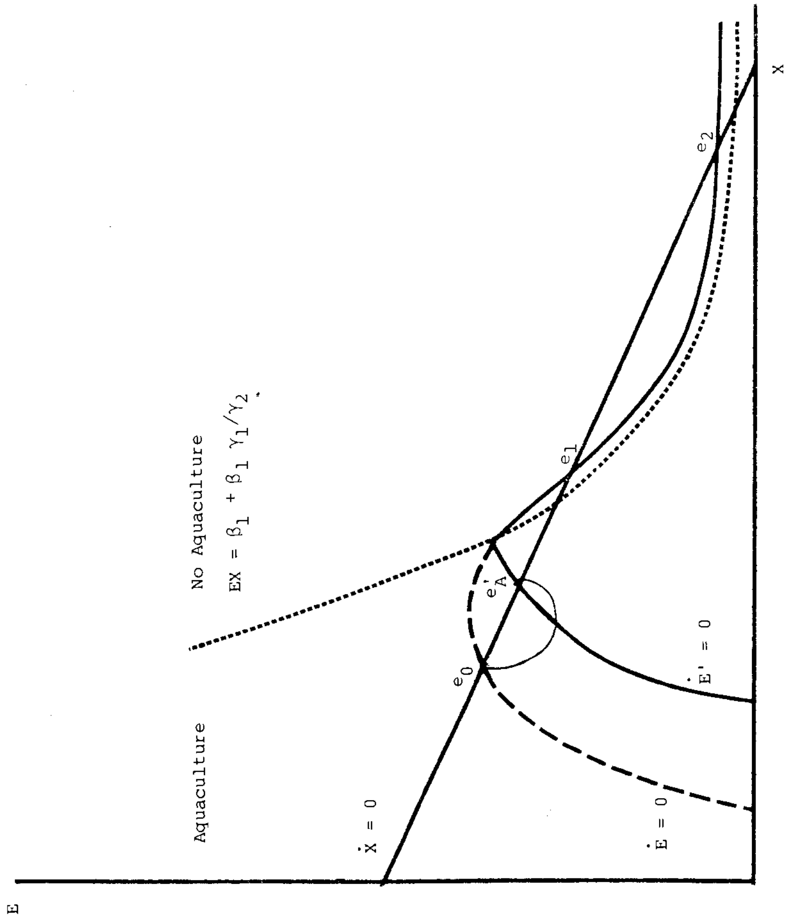

FIGURE 2*a*. Phase diagram corresponding to the situation where aquaculture supply is S'_A in Figure 1*c*.

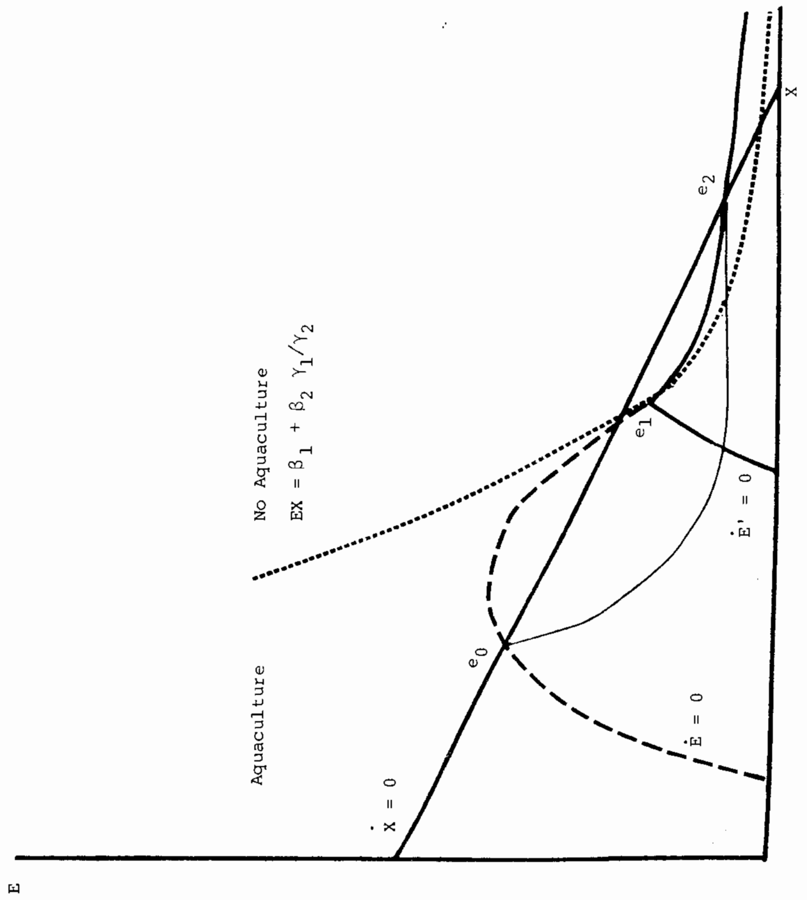

FIGURE 2b. Phase diagram corresponding to the situation where aquaculture supply is S''_A in Figure 1c.

rium is obtained, the common-property fishery continues to move toward the new stable equilibrium e_2.

Dominant Aquaculturist

As was noted in the introduction, several large corporations have taken a serious interest in aquaculture production. The supply of fish could become characterized by a dominant aquacultural firm or cartel facing a competitive open-access natural fishery. The dominant firm is assumed to be aware of its net demand, which takes into account the supply from the fishery. Once the aquaculturist chooses his output level, the open-access fishery fills in the slack demand.

The dynamic profit maximization problem for the dominant aquaculturist is

$$\max_{Y} \int e^{-\delta t} \left\{ \left[\frac{\beta_1}{\beta_2} - \frac{1}{\beta_2}(Y + EX) \right] Y - c(Y) \right\} dt \qquad (12)$$

$$\text{subject to} \qquad \dot{X} = rX\left(1 - \frac{X}{k}\right) - EX \qquad (13)$$

$$\dot{E} = \alpha E \left\{ \left[\frac{\beta_1}{\beta_2} - \frac{1}{\beta_2}(Y + EX) \right] X - c \right\} \qquad (14)$$

$$0 \le X, E, Y$$

where δ is the discount rate. This problem can be stated more generally by substituting the function $\pi(Y, E, X)$ for the aquaculturist's profit and $\overline{\pi}(Y, E, X)$ for the open-access fishery's profit. Making these substitutions gives

$$\max_{Y} e^{-\delta t}\pi(Y, E, X)\, dt \qquad (15)$$

$$\text{s.t. } \dot{X} = f(X) - EX \qquad (16)$$

$$\dot{E} = \alpha\overline{\pi}(Y, E, X) \qquad (17)$$

The Hamiltonian is

$$\begin{aligned} H = {} & e^{-\delta t}\pi(Y, E, X) + \lambda_1[f(X) - EX] \\ & + \lambda_2\alpha\overline{\pi}(Y, E, X) \end{aligned} \qquad (18)$$

The first-order conditions are

$$\frac{\partial H}{\partial Y} = e^{-\delta t}\pi_Y + \lambda_2\alpha\overline{\pi}_Y \tag{19}$$

$$\frac{\partial H}{\partial X} = e^{-\delta t}\pi_X + \lambda_1(f_X - E) + \lambda_2\alpha\overline{\pi}_X = -\dot{\lambda}_1 \tag{20}$$

$$\frac{\partial H}{\partial E} = e^{-\delta t}\pi_E - \lambda_1 X + \lambda_2\alpha\overline{\pi}_E = -\dot{\lambda}_2 \tag{21}$$

on the singular arc:

$$-\frac{e^{-\delta t}\pi_Y}{\alpha\overline{\pi}_Y} = \lambda_2 \tag{22}$$

and

$$-\dot{\lambda}_2 = -\frac{\delta e^{-\delta t}\pi_Y}{\alpha\overline{\pi}_Y} + \frac{e^{-\delta t}((\pi_{YX}\dot{X} + \pi_{YY}\dot{Y} + \pi_{YE}\dot{E})\overline{\pi} - (\overline{\pi}_{YX}\dot{X} + \overline{\pi}_{YY}\dot{Y} + \overline{\pi}_{YE}\dot{E})\pi_Y)}{\alpha(\overline{\pi}_Y)^2} \tag{23}$$

Substituting equations 22 and 23 into equation 21 yields

$$\frac{e^{-\delta t}\pi_E}{X} - \frac{e^{-\delta t}\pi_Y\overline{\pi}_E}{X\overline{\pi}_Y} + \frac{\dot{\lambda}_2}{X} = \lambda_1 \tag{24}$$

Since there are no endpoint restrictions on X and E, the transversality condition implies that the terminal costates, $\lambda_1(\infty)$ and $\lambda_2(\infty)$, must approach zero. This condition will result if in long-run equilibrium X, E, and Y are constant (i.e., $\dot{X} = 0, \dot{E} = 0$). Then, substituting equation 23 into 24 and equation 22 into 20 yields the long-run equilibrium expression

$$\alpha\overline{\pi}_Y\pi_X X - \alpha\pi_Y\overline{\pi}_X X + (f_X - E - \delta) \times (\alpha\overline{\pi}_Y\pi_E - \alpha\overline{\pi}_E\pi_Y + \delta\pi_Y) = 0 \tag{25}$$

Solving for π_Y gives

$$\frac{\alpha\overline{\pi}_Y[X\pi_X + (f_X - E - \delta)\pi_E]}{\alpha X\overline{\pi}_X + (f_X - E - \delta)(\alpha\overline{\pi}_E - \delta)} = \pi_Y \tag{26}$$

The term π_Y can be broken into the components of marginal revenue of a change in aquacultural output R_Y and marginal cost c_Y. Substituting for π_Y in equation 26 and rearranging yields

$$R_Y - \frac{\alpha\overline{\pi}_Y[X\pi_X + (f_X - E - \delta)\pi_E]}{\alpha X\overline{\pi}_X + (f_X - E - \delta)(\alpha\overline{\pi}_E - \delta)} = c_Y \tag{27}$$

As the discount rate δ goes to zero or as the adjustment in effort becomes instantaneous (α approaches infinity), equation 27 simplifies:

$$R_Y - \frac{\overline{\pi}_Y[X\pi_X - (f_X - E)\pi_E]}{X\overline{\pi}_X - (f_X - E)\overline{\pi}_E} = c_Y \tag{28}$$

The long-run equilibrium condition of equation 28 is identical to a profit maximization for a static case when the fishery is constrained to the equilibrium supply curve. Equation 28 requires that the marginal revenue from net aquacultural demand, which includes effort and fish stock effects, must equal the marginal cost of aquaculture. Because of the backward-bending nature of equilibrium supply EX, the profit function may be nonconvex in the positive orthant. The second-order conditions and nonnegativity constraints must be checked. There may be several local maxima. The profits from these points must be compared to find the global maximum.

Three possible net demands, the relevant portions of their marginal revenue curves, and price levels resulting from these curves are shown in Figures 3*a*, 3*b*, and 3*c* for the case where c_Y is increasing. Figure 3*a* illustrates a simple comparison of long-run equilibrium resulting from a dominant firm and from competitive aquaculturists, both with high marginal costs. Assume an initial

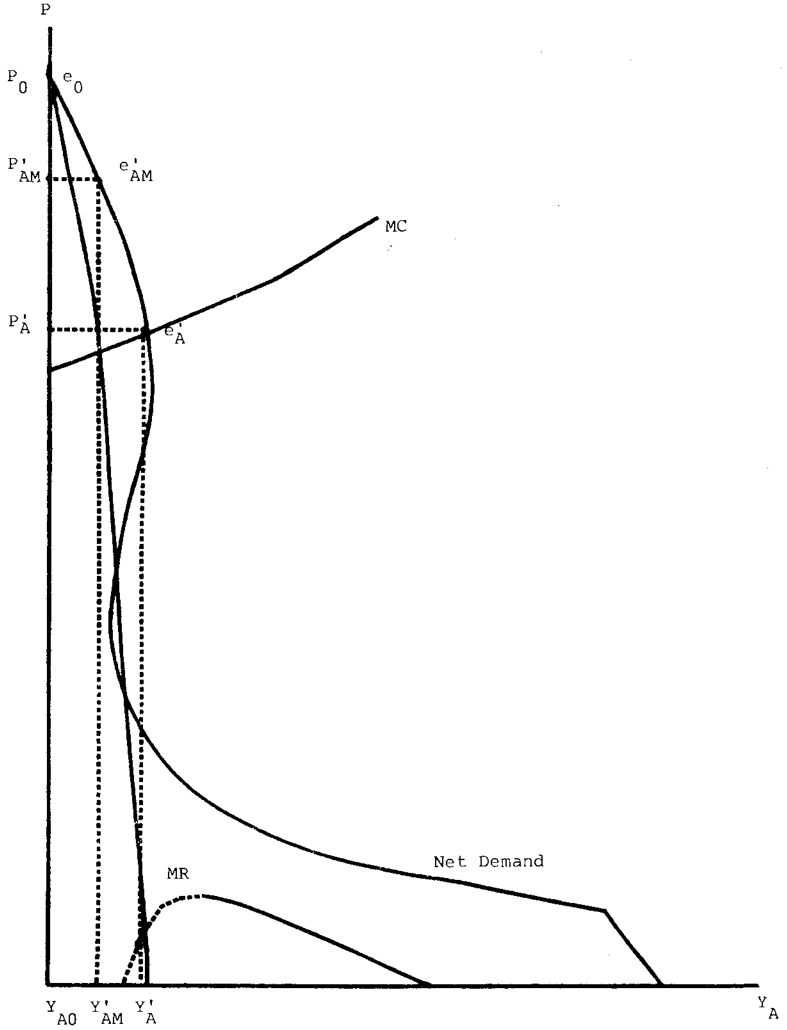

FIGURE 3*a*. Dominant firm aquaculturist, *a*.

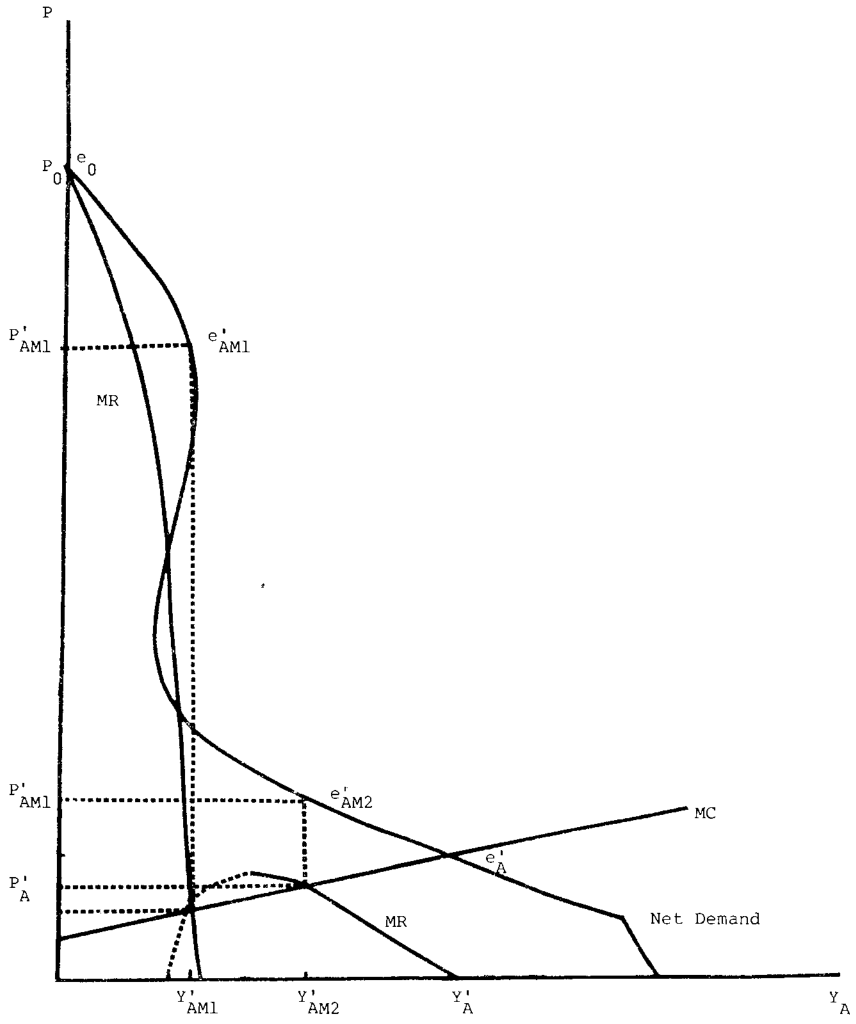

FIGURE 3*b*. Dominant firm aquaculturist, *b*.

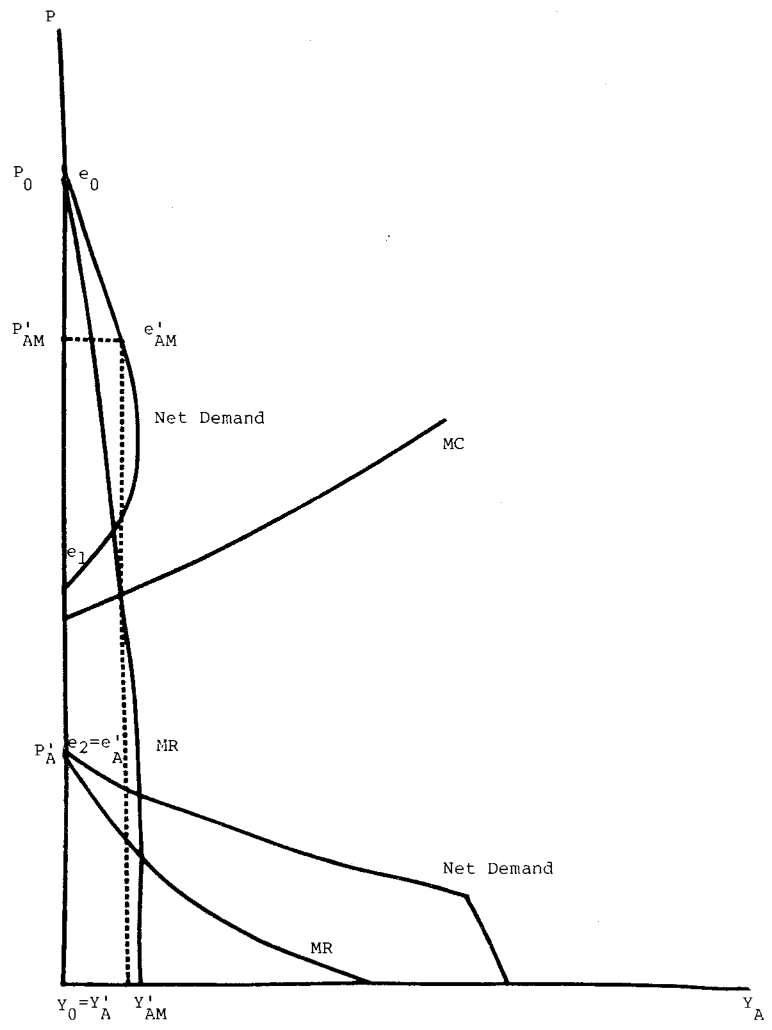

FIGURE 3*c*. Dominant firm aquaculturist, *c*.

common-property equilibrium of e_0. The dominant aquaculturist will shift the equilibrium to e'_{AM} while a competitive aquaculturist will shift the equilibrium to e'_A. The presence of the competitive aquaculturist results in lower prices, higher output, and greater natural fish stocks relative to the dominant firm case.

Figure 3*b* illustrates a case where there are two local profit maxima. In this case, the aquaculturist must compare the two discounted profits from attaining the local maxima to determine the global maximum. Assuming that initially the common-property fishery is at stable equilibrium e_0, the dominant aquaculturist has a local profit maximum at equilibrium e'_{AM1} with price p'_{AM1} and output Y'_{AM1} and another at e'_{AM2} with price p'_{AM2} and output Y'_{AM2}. The first equilibrium e'_{AM1} results in little change in fishing effort and natural fish stock from the initial equilibrium e_0. If the aquaculturist decides that discounted profits are greater from moving the system to the equilibrium e'_{AM2}, there will be significant reductions in fishing effort, increased natural fish stock, and lower consumer prices. The competitive aquaculturist equilibrium e'_A would, however, result in even greater aquacultural production, lower fishing effort, higher natural fish stock, and lower consumer prices, assuming identical marginal cost curves.

It was shown that if a competitive aquacultural supply were S''_A shown in Figure 1*d* and in the phase diagram of Figure 2*b*, and if the fishery were initially overfished (point e_0), entry of a competitive aquaculturist would result in a new equilibrium e'_A, at which the aquaculturist is eliminated. However, the dominant aquaculturist could prevent this result by controlling the price through his output decisions. If the initial equilibrium is e_0 in Figure 3*c*, the entry of the price leader aquaculturist will cause a shift to e'_{AM}. When the initial equilibrium is e_2, the dominant aquaculturist would still want the system to move to e'_{AM}. However, the competitive aquaculturist would not enter. Whether or not the aquaculturist could move to e'_{AM} depends on the dynamics of fishing effort and fish population. This will be discussed later. The important point is that the aquaculturist may desire to drive the system from a point below maximum sustainable yield to one characterized by overfishing, higher price, and reduction of both fishery and total fish supply. This contrasts with the competitive aquaculturist case where all stable equilibria result in reduced fishing effort, lower prices, and greater total supply.

It should be reemphasized that it is always assumed when comparing dominant and competitive aquaculturists that they have identical marginal cost curves. In general, one would expect the competitive aquaculturist to have higher marginal cost because the dominant aquaculturist can benefit from economies of scale. If the marginal cost curves are not identical, the comparisons do not apply.

The impact of a positive discount rate δ and an effort adjustment coefficient (α less than infinity) on the long-run equilibrium can be evaluated from equation 28. An increase in the discount rate δ decreases the denominator relative to the numerator, resulting in an increase in the second term. When the coefficient of effort adjustment α is less than infinity, the second term decreases; the net effect is indeterminate. From the aquaculturist's point of view, a positive discount rate requires an increase in the growth rate of profit. This is achieved by reducing equilibrium aquacultural output, which raises price, increases fishing effort, and reduces fish stock relative to the zero-discount-rate case. The adjustment of fishing effort has an opposite effect on equation 28 compared to the discount rate.

Dynamic analysis has the additional complication of controllability. It was previously observed that the dominant firm may desire to move the open-access fishery from a fish stock less than maximum sustainable yield to an overfishing equilibrium. When the dynamics of fishing effort and fish population are considered, this may not be possible to do using the control Y_A. Consider the equilibrium e_2 in Figure 3*c*. If the aquaculturist's desired optimal long-run equilibrium was e'_A, the aquaculturist could only get there if he could force the fishery to drive fish stock down. In the phase diagram, this occurs when E and X are attracted to the equilibria at which overfishing occurs. The aquaculturist would have to incur a negative output to raise price to a level which shifts the $\dot{E} = 0$ condition to result in increasing effort and decreasing fish stock (see Figure 4). This violates the

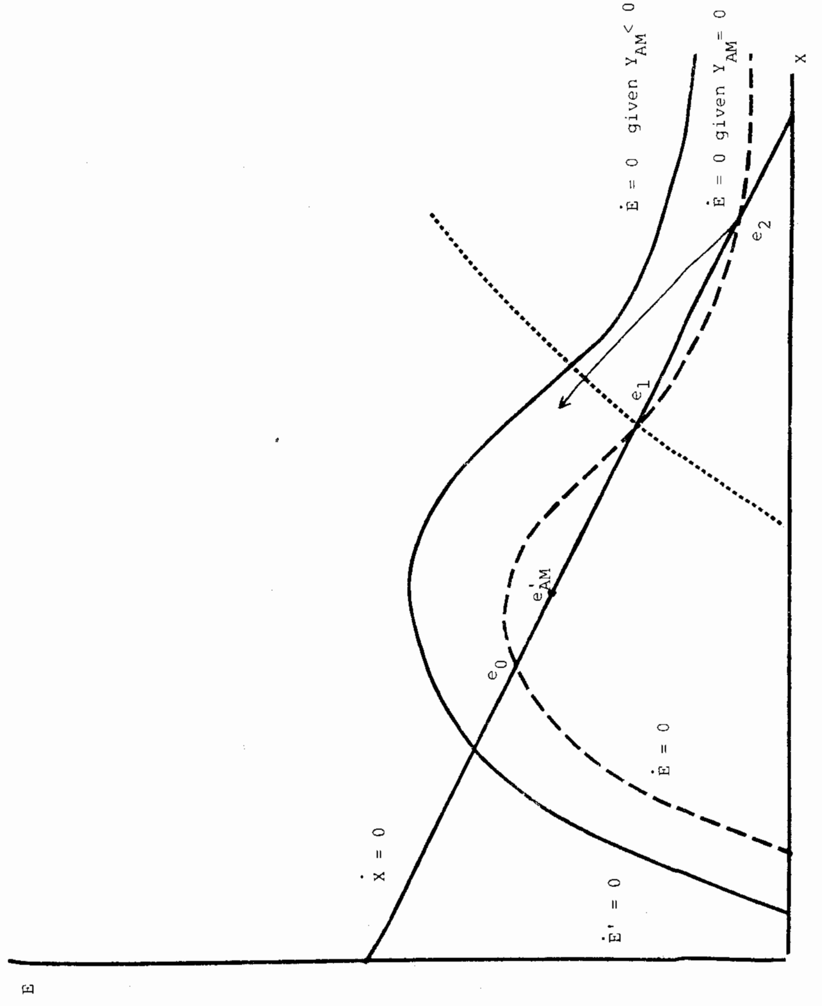

FIGURE 4. Dominant-firm-aquaculturist controllability problem.

nonnegativity constraint. Therefore, the desired optimal equilibrium solution is not possible with the control Y_A.

Conclusion

In the first part of this paper, several conclusions were reached. The stable equilibrium resulting from the entry of aquaculture will increase efficiency in the natural commercial fishery, increase natural fish stock levels, and lower consumer prices. Increased fishery efficiency results when fishermen are forced to reduce effort. The common-property nature of the fishery inhibits entry by the aquaculturist when the initial natural fish stock is less than maximum sustainable yield. It was also shown that cases exist where the presence of the aquaculturist will only be temporary. This can result when fish stock is initially less than maximum sustainable yield. When price is lowered by the aquaculturist's presence, thereby reducing fishing effort, the fish stock may recover to a sufficiently high level such that at the new equilibrium, common-property fishery production costs are less than those of the aquaculturist.

The second section presented an analysis of a dominant aquaculturist. It was found that, if marginal costs are the same as for a competitive aquaculturist, entry by a dominant aquaculturist will reduce consumer prices, reduce commercial fishing effort, or increase fish stock but not as much as in the case of the competitive aquaculturist. The competitive aquaculturist may cause a biologically overexploited fishery to move to an equilibrium where fish stocks are greater than maximum sustainable yield levels while the aquaculturist may be content with an exploitation rate where fish stock is lower than maximum sustainable yield. It was also shown that the dominant aquaculturist would never be driven out of business by the recovery of the fish stock. This is because the aquaculturist is aware of the net demand facing the firm and controls price through output decisions.

One of the common public policy goals of fishery management is to increase the stock of fisheries which public institutions consider to be overexploited. The introduction of competitive aquaculture facilitates this goal at the expense of those forced to reduce fishing effort. In cases where aquaculture is not present, public policies aimed at reducing exploitation of the stock typically force the fishery to become less efficient. The resultant inefficiency leads to an increase in consumer prices. When competitive aquaculture is present, however, overexploitation of the natural stock is reduced, total supply is increased, efficiency increases, and prices may fall. If the aquaculturist acts as a dominant firm, the promotion of aquaculture will not necessarily augment fish management objectives.

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