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The Bioeconomic Implications of A Bycatch Reduction Device as a Stock Conservation Management Measure

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Abstract *The proposed regulation to reduce bycatch and discarding of finfish in the southeastern region is a gear modification that excludes finfish from shrimp trawls. This regulation is analyzed using a simple theoretical model of a multispecies fishery whose bycatch is harvested in a directed fishery consisting of commercial and recreational fishermen. The costless reduction in bycatch fishing mortality imposed on the multispecies fishery does not result in an increased stock size for the bycatch fish species or a substantial increase in its level of harvest. Instead, the fish stock is reallocated from the multispecies fishery to the fishery directed at the bycatch species causing fishing effort to expand in the bycatch species fishery that drives the stock size down to the previously existing equilibrium level. Recreational harvest and effort levels remain unchanged since the model is linear in effort and the commercial fishery is given access to the fishery first.*

Keywords Bycatch, policy analysis, bioeconomic model.

While it is true that a great deal (perhaps the greater part) of what has been done in the name of "conservation policy" turns out, upon subjection to economic analysis to be worthless, or worse, it is nevertheless also true that economic theory can offer a formulation of the conservation objective sufficiently clear and precise to permit the derivation of rational policies in the future. Such a formulation, like the application of economic theory in other fields of policy, can be no match for the passionate romanticism with which the question has been invested in political platforms and public discussion, but some of the policies of the past and present are sufficiently egregious to convince even dedicated conservationists of their error or, at least, insufficiency. Perhaps it is too much to hope that in their hour of confusion and despair, the protectors of nature might turn to economics for succor, but even idealistic hopes have the quality of springing eternal. (Gordon 1958)

Introduction

The harvesting of finfish in shrimp fishing operations, known as incidental take or bycatch, is a complex multidisciplinary and international fisheries management problem. Countries around the world have been or are addressing this problem in their commercial shrimp fisheries. Annual estimates of finfish bycatch range from 64 thousand tons for Guyana to 1 million tons in the United States with potential benefits from utilization ranging from $28 million to $1.273 billion (FAO and IDRC, 1982). Less emphasis has been placed on bycatch utilization since the Sheridan *et al.* (1984) study found that bycatch utilization could reduce shrimp biomass by 25%. This change in attitude is seen in the Executive Committee of the American Fisheries Society policy statement concerning the unnecessary take and waste of marine resources that supports gear modification regulations (Perra, 1992). The elimination of bycatch from shrimp trawl operations by gear modification was the focus of the International Bycatch Conference (Jones, Doolin, Gravlee, Jones, and Stewart, 1992). Also indicative of this change in approach is the Office of Management and Budget and the House Appropriations Committee requirement to evaluate the impacts of turtle excluder/trawl efficiency devices (TEDs) on shrimp and finfish catch rates in the Gulf of Mexico and South Atlantic (Renaud *et al.,* 1990).

The reason for the change in attitude is that finfish bycatch is a significant domestic fishery management problem. Objective 5 of the Gulf of Mexico shrimp fishery management plan proposes that finfish bycatch be minimized through gear development (GMFMC, 1981b). The groundfish fishery management plan cites the discarding of finfish bycatch in shrimp harvesting operations as a significant problem to be solved through the development of economically feasible excluder gear (GMFMC, 1981). The reef fish scientific assessment panel recommended in March, 1990 that the directed red snapper fishery be closed because the allowable biological catch was being harvested as a bycatch in the shrimp trawl fishery (GMFMC, 1992). Finally, an amendment to the 1990 reauthorization of the Magnuson Fishery Conservation and Management Act (MFCMA), section 304(g) Incidental Harvest Research, requires a three year research program prior to implementation of finfish bycatch regulations in the shrimp fishery, effectively blocking regulations until 1994. To satisfy the requirements under this amendment, the "Shrimp Trawl Bycatch Research Requirements" states that the long run, economic impacts of alternative bycatch reduction measures be determined (National Marine Fisheries Service, 1991).

Adding to the complexity of the bycatch problem is the incidental take and subsequent mortality of endangered and threatened marine turtles estimated at between 11,000 (Henwood and Stuntz, 1987) and 44,000 (National Research Council, 1990) turtles per year in the Gulf of Mexico shrimp fishery with an estimated net loss to the fishery of between $4.5 and $33.3 million depending on the regulatory scenario employed (Griffin *et al.,* 1988). Also, any increase in domestic shrimp prices caused by Section 609(b) of Public Law (P.L.) 101-162, which bans the importation of shrimp unless harvesting nations implement incidental harvest regulations comparable to U.S. standards and rates, would encourage the entry of vessels into the domestic shrimp fleet and further exacerbate existing finfish and marine turtle bycatch problems as well as increasing shrimp harvesting costs (Keithly *et al.,* 1993).

Given the national concern expressed by the amendment of the MFCMA, the expressed need by the National Marine Fisheries Service (NMFS) to determine the economic impacts on the domestic fishery, the recognition of nontarget species bycatch in three fishery management plans, and the American Fisheries Society bycatch policy as well as the international scope of this problem, the bioeconomic implications of bycatch reduction regulations need to be determined. The envisaged solution to this problem is to modify the existing gear using knowledge of fish behavior so that bycatch is reduced and then to persuade fishermen to adopt the gear modifications. This solution implicitly assumes that finfish escaping from shrimp trawls will survive to recruit into other commercial and recreational finfish fisheries resulting in increased stock abundance. However, this technological approach does not consider the impact of this increased abundance on fishing effort. This critical stock–effort effect is qualitatively examined using a simple bioeconomic model of a stylized fishery that generates and discards a bycatch species that is the focus of another directed fishery with commercial and recreational components. The model is then used to investigate the impact of a bycatch reduction device on commercial and recreational fishing effort levels in the fishery for the bycatch species.

The next section of the paper will review the literature on nontarget species bycatch with the intent of indicating the magnitude of the problem. The bioeconomic simulation model is described next. This section is followed by a discussion of the implications of management regulations designed to reduce bycatch in fish harvesting operations. The paper concludes with a summary of the general results derived from this qualitative discussion of the fishery management problem and the bioeconomic model.

Literature Review

The numerous studies conducted on bycatch since Lindner (1936) and Gunter (1936) first commented on the bycatch problem can be divided into two categories. First are the studies that estimated the amount of protein discarded annually by the shrimp fleet and the potential for its utilization. The second category consists of research that concentrates on the species composition of the discards and the biological impacts of bycatch discards on finfish stock size.

Various estimates from both study categories indicate that a significant level of finfish bycatch is taken by the fishing effort directed at the Gulf of Mexico shrimp resource. Blomo and Nichols (1974) found a range of one pound of finfish to a pound of shrimp in the winter to seven pounds of finfish to a pound of shrimp landed in the summer and suggested an average of four pounds of finfish for every pound of shrimp landed. A ten to one ratio of finfish to shrimp was found in a study conducted by Chittendon and McEachran (1976). Bryan's (1980) finfish to shrimp ratio was three to one. In 1985, Pellegrin *et al.* found finfish to shrimp ratios that ranged from 2 to 1 to as high as 21.1 to 1. Usually, the bycatch is not in a form that has market value to the fishermen. This portion of the bycatch is discarded and is not available for recruitment into the commercial or recreational finfish fishery (Pellegrin *et al.*, 1985).

The effect of bycatch on finfish stocks was initially addressed by Nichols *et al.* (1987). The estimated bycatch of red snapper, king mackerel, and Spanish mackerel was found to be comparable to or exceed the average recreational catch. In an analysis based on Nichols *et al.* (1987), Powers *et al.* (1987) concluded that the elimination of red snapper from the shrimp bycatch would result in a ninety percent increase in this fish stock available to recreational and commercial finfish fishermen. In updated (Nichols *et al.*, 1990) and revised (Nichols and Pellegrin, 1992) analyses, annual finfish bycatch in the shrimp fishery has been estimated at between 700 million and 1.7 billion pounds.

Studies have been conducted to determine the economic impacts of discarded bycatch. Blomo and Nichols (1974) found that if the finfish resources were utilized instead of discarded, then the total bycatch of trawl fish (368 million pounds in the western Gulf of Mexico) could move through the fish meal and oil reduction market with a negligible price affect. Although Anderson (1993) and Arnason (1993) conclusions differ, their respective analyses suggest that the costs of discarding bycatch can significantly affect the equilibrium stock size under different initial assumptions. Since the shrimp fishery has historically landed commercially valuable species of finfish, determining the conditions under which incentives exist to discard marketable finfish is important. That is, management regulations designed to reduce bycatch discards should avoid creating incentives to discard commercially or recreationally valuable finfish.

Bioeconomic Model

A stylized bioeconomic model is developed to determine the magnitude and direction of change in the affected fisheries from proposed bycatch reduction regulations. Discarding in commercial fishing operations occurs because the retention of the discarded species is prohibited by regulation, the discarded species has a nonmarket value or has no commercial value, or a valuable species is discarded to make room for a more valuable species. Finfish species that have no commercial value, such as juveniles, or a nonmarket value, derived from the recreational fishery for the adult species, are discarded immediately by the commercial fishermen as are species whose retention is prohibited by regulation. Less valued species are discarded to make room for more valued species primarily as a function of trip length and the vessel's hold capacity (Clark, 1985). The discarding of the juvenile finfish bycatch or incidental catch is essentially a problem of a multispecies fishery in which only one species has value to the fisherman. The analysis is complicated by the existence of a directed fishery that exploits the adult stock of the discarded juvenile species. This adult finfish has market value in the commercial finfish fishery and a nonmarket value in the recreational finfish fishery.

Multispecies Fishery Model

The fishery economics literature normally assumes a generic gear that harvests a mix of species where the population dynamics can be expressed in the simple two species case as

$$\dot{X} = F(X) - q_x E_x X$$
$$\dot{Y} = G(Y) - q_{yx} E_x Y \tag{1}$$

where $F(X)$ is the growth function of species X,
$G(Y)$ is the growth function of the bycatch species Y,
$q_x E_x X$ is the harvest level h_x of species X in the fishery for species X,
$q_{yx} E_x Y$ is the harvest level h_{yx} of species Y in the fishery for species X,
X is the biomass of species X,

Y is the biomass of the bycatch species Y,
q_x is the catchability coefficient of the gear for species X in the fishery for species X.
q_{yx} is the catchability coefficient of the gear for species Y in the fishery for species X, and
E_x is the level of total fishing effort for both species in the fishery for species X.

Equation (1) assumes that the two species are ecologically independent and that the growth functions are positive, increase at a decreasing rate with respect to stock size, and are equal to zero when stock size is zero or at its maximum environmental carrying capacity (K), *i.e*.

$$F(X) > 0,\ F''(X) < 0,\ \text{and } F'(0) = F(K) = 0 \text{ for } 0 \leqslant X \leqslant K,$$

$$G(Y) > 0,\ G''(Y) < 0,\ \text{and } G'(0) = G(K) = 0 \text{ for } 0 \leqslant Y \leqslant K.$$

More realistic, but complex, models allow for species interdependence through competition and predation in the population dynamics (Larkin, 1966 and Clark, 1979), but this model is sufficient to present the basics of the problem.

Bioeconomic equilibrium under open access conditions can be characterized by setting net revenue π equal to zero;

$$\pi = P_x h_x + P_y h_{yx} - c_x E_x = 0 \tag{2}$$

where P_x is the exvessel price for species X,
P_y is the exvessel price for species Y and is set equal to zero when the bycatch species Y is discarded in the fishery for species X, and
c_x is the unit cost of fishing effort.

Assuming a logistic growth function for species X and Y and that the total fishing effort level is determined solely by the high valued species X, then the total landings of the target species is:

$$h_x = \frac{r_x c_x}{P_x q_x}\left[1 - \frac{c_x}{P_x q_x K_x}\right] \tag{3}$$

where r_i is the intrinsic growth rate and
K_i is the environmental carrying capacity (i = x, y, and yx).

The discard level is given by:

$$h_{yx} = \left[\frac{q_{yx}K_{yx}r_x}{q_x} - \frac{q_{yx}K_{yx}r_x c_x}{P_x {q_x}^2 K_x}\right]\left[1 - \frac{q_{yx}r_x}{r_{yx}q_x} + \frac{q_{yx}r_x c_x}{r_{yx}P_x {q_x}^2 K_x}\right] \tag{4}$$

where an increase in the exvessel price P_x for species X, ceteris paribus, will initially increase the bycatch h_{yx} of species Y and then cause it to decline as the stock of species Y is depleted.[1]

[1] A percentage of the discarded bycatch could be assumed to survive. That is, instead of 100 percent mortality, some fixed mortality less than 100 percent could be assumed. When factored into the computer model, this reduced bycatch mortality caused fishing effort in

Commercial Bycatch Fishery

A directed fishery for the bycatch species Y that employs a fishing gear that is species specific or operates in areas that do not support populations of species X is incorporated into the model. The population dynamics of species Y for this alternative directed fishery can be represented by

$$\dot{Y} = G_y(Y, h_{yx}) - q_{yc}E_{yc}Y - q_{yr}E_{yr}Y \tag{5}$$

where $G_y(Y)$ is the growth function of species Y,
E_{yc} is the level of commercial fishing effort directed at species Y,
E_{yr} is the level of recreational fishing effort directed at species Y,
q_{yc} is the catchability coefficient for the directed commercial fishery for species Y,
q_{yr} is the catchability coefficient for the directed recreational fishery
h_{yx} is the level of bycatch of species Y in the fishery for species X,
$h_{yc} = q_{yc}E_{yc}Y$ is the level of harvest for the directed commercial fishery for species Y.
$h_{yr} = q_{yr}E_{yr}Y$ is the level of harvest for the directed recreational fishery for species Y.

Equation (5) incorporates a stock effect, caused by the bycatch (h_{yx}) of species Y in the fishery for species X, in the population dynamics for species Y. In addition, the directed fishery for species Y is assumed to have a recreational component as is common in many finfish fisheries in the southeastern region.

Assuming a logistic growth function for species Y, that the bioeconomic equilibrium for the commercial fishery can be represented as in equation (2), and for expositional purposes that the recreational fishery does not exist ($E_{yr} = 0$), then the equilibrium fishing effort level, harvest level, and stock size associated with the directed commercial fishery for species Y can be represented by:

$$E_{yc} = \frac{r_y}{q_{yc}}\left[1 - \frac{q_{yx}r_x}{r_yq_x}\left[1 - \frac{c_x}{P_xq_xK_x}\right] - \frac{c_{yc}}{P_yq_{yc}K_y}\right] \tag{6}$$

the directed fishery for species Y to increase by a smaller amount than under the 100% bycatch mortality scenario when a bycatch reduction device is adopted by the fishery that generates the bycatch. However, equilibrium stock size for species Y was unaffected. A positive price for the landed bycatch would require explicitly modelling adult and juvenile growth functions for the bycatch species. Equation (4) implies that fishing effort for species X would increase with a positive price for species Y. The result would be that fishing effort in the multispecies fishery that generates the bycatch would be higher than in the model presented in this paper. The adoption of a bycatch reduction device would eliminate this landed bycatch as well as the discarded bycatch, the finfish would recruit into the directed commercial and recreational fishery for the bycatch species, and effort for species Y would increase leading to the same equilibrium stock size for species Y before and after the introduction of the management regulation. This suggested modification would introduce some interesting effects for the path to the new equilibrium since the recruitment of adult finfish would occur immediately while juvenile finfish would recruit into the commercial and recreational finfish fishery for the bycatch species at a slower rate. However, this dynamic problem is beyond the scope of this paper.

$$h_{yc} = \frac{c_{yc}r_y}{P_y q_{yc}}\left[1 - \frac{q_{yx}r_x}{r_y q_x}\left[1 - \frac{c_x}{P_x q_x K_x}\right] - \frac{c_{yc}}{P_y q_{yc} K_y}\right] \tag{7}$$

$$Y_c = \frac{c_{yc}}{P_y q_{yc}} \tag{8}$$

where C_{yc} is the unit cost of commerical fishing effort in the fishery for species Y.

Under the conditions of a relatively elastic demand (Emerson, 1988) for the fish species Y and an open access resource, equation (8) indicates that the elimination of bycatch in the multispecies fishery does not directly affect the population equilibrium stock size of species Y. Equations (6) and (7) indicate that both the fishing effort E_{yc} and harvest h_{yc} levels in the directed commercial fishery for species Y are directly affected by the level of bycatch in the multispecies fishery for species X.

Recreational Bycatch Fishery

Recreational fisherman obtain utility (U) from harvesting the finfish resource. Following McConnell and Sutinen (1979), the bioeconomic equilibrium for the recreational fishery in this simple model can be expressed as

$$U = V_y h_{yr} - c_{yr}E_{yr} = 0 \tag{9}$$

where V_y is the marginal value derived from the recreationally caught fish (i.e. the willingness to pay for the last fish caught) and

c_{yr} is the unit cost of recreational fishing effort.

As in the case for the commercial fishery,total recreational fishing effort (E_{yr}), the level of recreational harvest (h_{yr}), and equilibrium stock size (Y) can be derived by assuming that no commercial fishery for species Y exists ($E_{yc} = 0$).

$$E_{yr} = \frac{r_y}{q_{yr}}\left[1 - \frac{q_{yx}r_x}{r_y q_x}\left[1 - \frac{c_x}{P_x q_x K_x}\right] - \frac{c_{yr}}{P_y q_{yr} K_y}\right] \tag{10}$$

$$h_{yr} = \frac{c_{yr}r_y}{V_y q_{yr}}\left[1 - \frac{q_{yx}r_x}{r_y q_x}\left[1 - \frac{c_x}{P_x q_x K_x}\right] - \frac{c_{yr}}{V_y q_{yr} K_y}\right] \tag{11}$$

$$Y_r = \frac{c_{yr}}{V_y q_{yr}} \tag{12}$$

Under these conditions of a relatively elastic recreational demand for the fish species Y and a common property resource, the elimination of bycatch in the multispecies fishery does not directly affect the population equilibrium stock size of species Y in equation (12). However, the level of fishing effort, equation (10), and the level of harvest, equation (12), in the directed recreational fishery for species Y are affected by the level of bycatch in the multispecies fishery for species X.

Recreational-Commercial Allocation

In an open access fishery directed at the bycatch species Y, the resource is allocated between the commercial and recreational user groups where profits from commercial fishing are equal to the utility derived from recreational fishing.[2]

$$\pi = P_y h_{yc} - c_{yc} E_{yc} = 0 = V_r h_{yr} - c_{sr} E_{yr} = U$$

Solving this expression for the equilibrium stock size results in

$$\frac{c_{yc}}{P_y q_{yc}} = \frac{c_{yr}}{V_y q_{yr}} \tag{13}$$

Equation (13) implicitly defines the allocation of the stock according to equations (8) and (12), fishing effort levels according to equations (6) and (10), and harvest levels according to equations (7) and (11).[3] Equation (13) indicates that the resource will be allocated between the commercial and recreational fishermen when their relative cost/value ratios are equal. Since the relative values of these two uses of the fishery resource are exogenously determined in this analysis, a reduction in bycatch will not affect the equilibrium stock size of species Y or the allocation between the commercial and recreational fisheries.

Discussion

The static equilibrium relationships derived in the previous section are used to generate the graphs in Figures 1 to 4.[4] Quadrant I in each of the figures represents the open access supply curve S_{oa} and the market demand curve D that determine the equilibrium market price P and the harvest level H and, in Figures 1 and 2, the bycatch level H_y for the fishery. Quadrant II is the price–population size curve SS that relates price P to stock size X or Y. Quadrant III presents the population equilibrium curve PE that relates fishing effort levels E to stock size X or Y. Quadrant IV contains the sustainable yield curve SY(E) that relates fishing effort levels E to harvest levels H and, in Figures 1 and 2, to bycatch levels H_y. Using these graphs, the impacts on the directed commercial and recreational fishery for the bycatch species Y caused by a regulation imposing a bycatch reduction device on the species X fishery can be determined.

[2] This is a static version of the dynamic model developed by McConnell and Sutinen (1979) for allocating a fishery resource between recreational and commercial user groups.

[3] These static results correspond to the dynamic results of McConnell and Sutinen (1979) and Bishop and Samples (1980) for commercial and recreational allocations of a fishery resource, except that they now incorporate the influence of the discarded juvenile bycatch in a multispecies fishery.

[4] The mathematical notation used earlier in the paper has been simplified to improve the readability of the graphs.

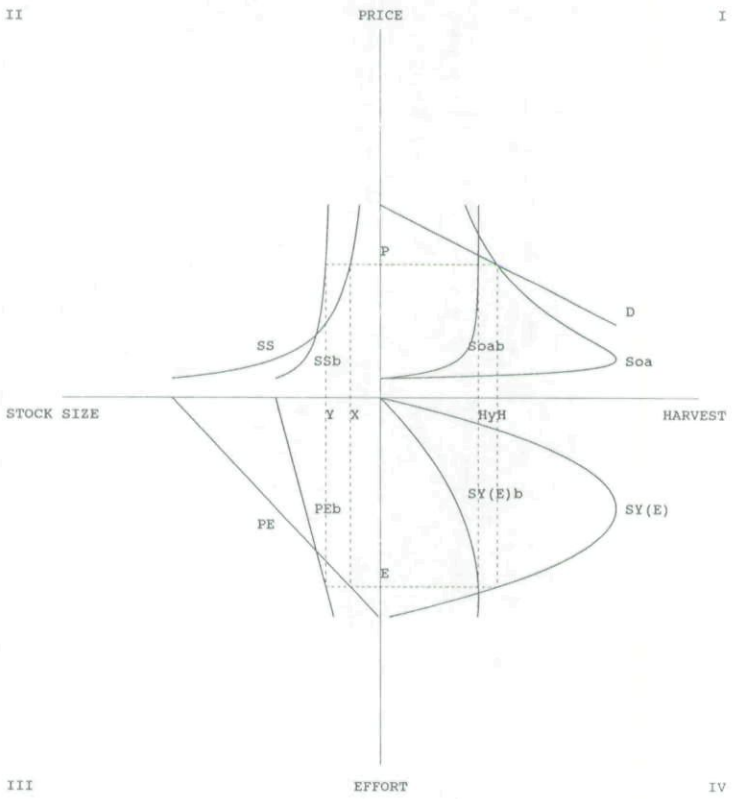

Figure 1. Multispecies Fishery Before Gear Modification

Before the bycatch reduction device gear modification, the multispecies fishery in Figure 1 produces a level of fishing effort E that is determined by exvessel price P, harvesting cost c_x, and abundance of species X. In quadrant I, the intersection of market demand D and the open access supply curve S_{oa} determine an equilibrium price P for the equilibrium harvest level H in the species X directed fishery. Since the bycatch species Y has no value to the fisherman, the equilibrium bycatch level H_y is determined by the open access bycatch supply curve S_{oab} at exvessel price P for species X. In quadrant IV, the sustainable yield curve SY(E) determines the harvest level H produced by the fishing effort level E that corresponds to the equilibrium exvessel price P. Similarly, the bycatch level H_y is determined by the intersection of fishing effort E on the sustainable yield curve for the bycatch species $SY(E)_b$. Since the bycatch species Y is assumed to have no market value, it is discarded and does not affect the fishing effort level E in the fishery for species X. However, the equilibrium stock size of the bycatch species Y is determined by the fishing effort level E for species X in quadrant III on the population equilibrium curve PE_b. The equilibrium stock size for species X is also determined by the fishing effort level E for species X on the population equilibrium curve PE in quadrant III.

In Figure 2, a bycatch reduction device is installed in the fishing gear of the multispecies fishery for species X that generates the bycatch of species Y. This device reduces bycatch mortality for species Y by sixty percent without affecting

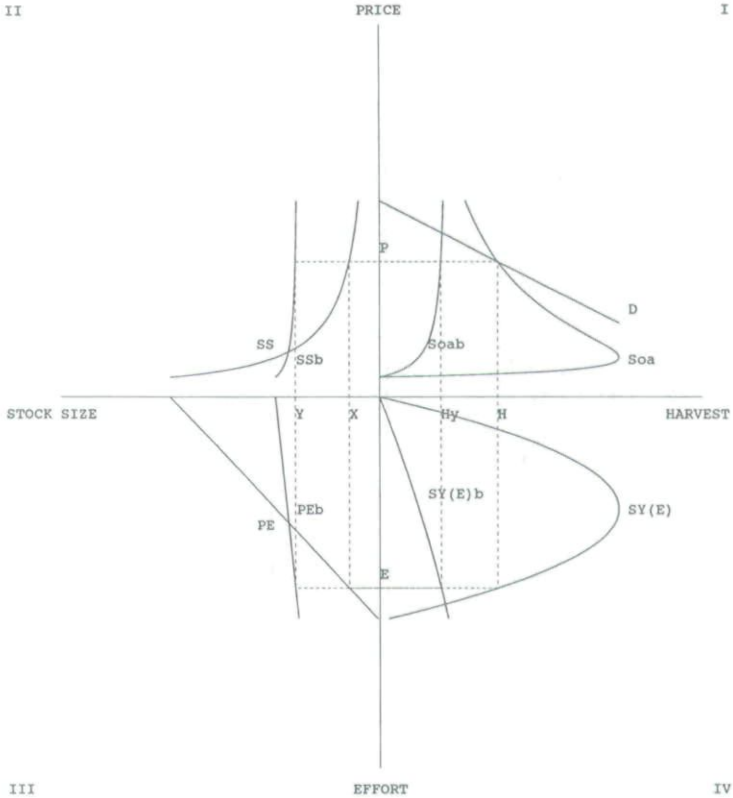

Figure 2. Multispecies Fishery After Gear Modification

fishing mortality or harvesting costs for species X.[5] As a result, the harvest level of species X remains unchanged at H, but the level of bycatch declines substantially as depicted by a comparison of H_y in quadrant I of Figures 1 and 2. The equilibrium stock size X is unchanged for the multispecies fishery, but the bycatch species stock size level Y increases in quadrant III of Figure 2 relative to its level in Figure 1.

In Figure 3, the impact of the bycatch reduction device on the commercial sector of the species Y fishery is illustrated. Prior to the adoption of the bycatch reduction device in the multispecies fishery, the equilibrium level of harvest is H, the equilibrium fishing effort level is E, and the equilibrium stock size is Y in quadrants I, IV, and III of Figure 3, respectively. With the mandated adoption of the bycatch reduction device in the multispecies fishery, bycatch levels decline in Figure 2, and recruitment into the bycatch species fishery increases. As a result, the fishing effort levels in quadrant IV of Figure 3 increases from E to E′ due to the outward shift in the sustainable yield curve from SY(E) to SY(E′). A corresponding increase in the open access supply curve from S_{oa} to S_{oa}' in quadrant I causes harvest levels to increase from H to H′. However, the stock conservation goal for the bycatch species Y is not achieved since the increased fishing effort maintains the stock at its original equilibrium level in quadrant III. Since the

[5] The 60 percent reduction in the parameter value of the catchability coefficient q_{yx} in the computer program that generates Figure 2 corresponds to the bycatch reductions desired by fishery managers.

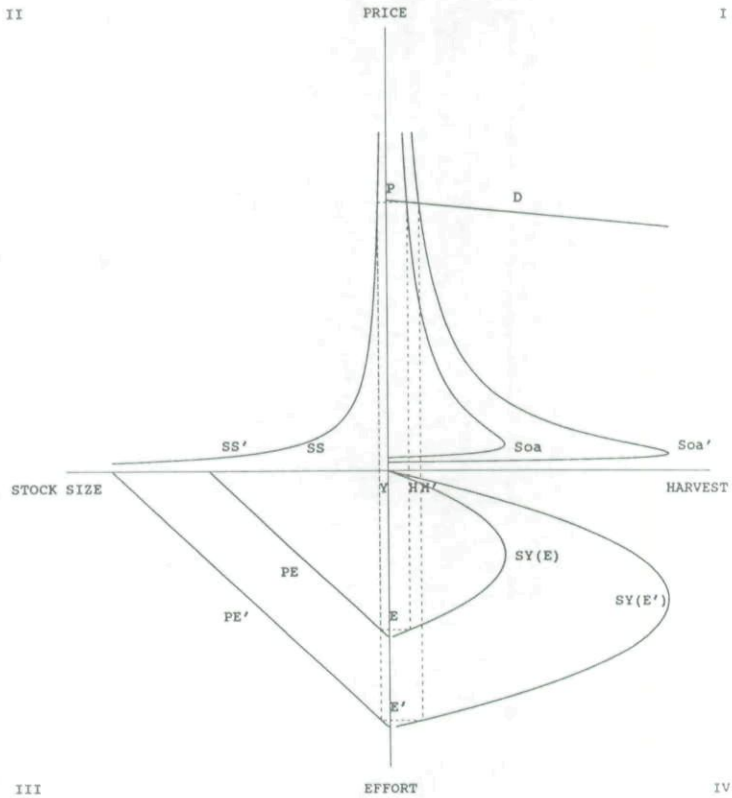

Figure 3. Commercial Fishery for Bycatch Species

bycatch reduction device does not affect prices, costs, or gear catchability in the commercial fishery for bycatch species Y according to equation (8), the equilibrium stock size is unchanged at point Y in quadrant III of Figure 3.

In Figure 4, the impact of the bycatch reduction device on the recreational fishery is illustrated. In this case, the result is hardly noticeable when compared to the commercial fishery in Figure 3. This occurs because the commercial fishery for species Y harvests the increased abundance of fish before the recreational fishery has an opportunity to exploit the resource. Had the recreational fishery been given access to the resource first, the commercial fishery would have remained relatively unchanged.

Conclusions

Future research will incorporate a number of the caveats that accompany this qualitative analysis of the bycatch problem. First, these results are based on a logistic growth function. Direction of change is probably the same for any growth function that satisfies the second order conditions of the logistic function, but the magnitude of the change could be different. Second, stock recruitment effects are ignored in this analysis. Third, the results presented and discussed in this paper depend on a fishery facing relatively elastic demand for the fish species (Emerson, 1988). Relatively inelastic demand functions would result in reductions in fishing effort and increases in stock size as bycatch is reduced in the multispecies fishery

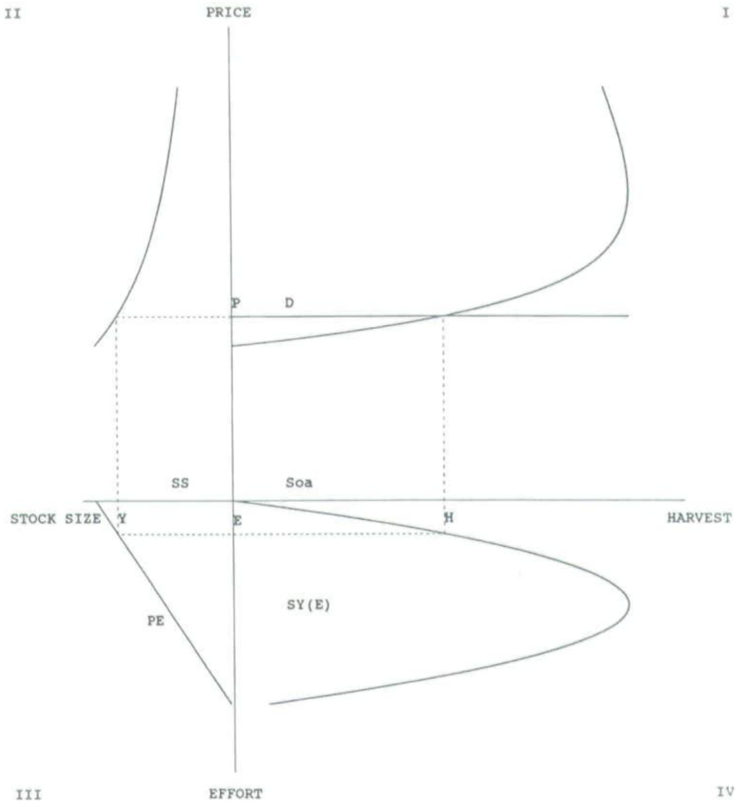

Figure 4. Recreational Fishery for Bycatch Species

(Blomo and Nichols, 1974). Fourth, the treatment of fishing effort as a linear variable in the model generates some unrealistic results for the reallocation of the fish stock between recreational and commercial fishermen. An indirect cost function, that is nearing completion for the shrimp and reef fish fisheries, could be used to correct this shortcoming of the model. Fifth, the model representing the recreational fishery for the bycatch species could be modified to account for kept versus released catch. Sixth, fishing gear catchability could be modeled as a function of stock size. Finally, optimal control techniques could be employed to determine the long run paths from equilibrium point to equilibrium point so that the discounted present value of net benefits can be calculated for each proposed management scenario, such as total allowable catches for the recreational and commercial bycatch species fishery, individual transferable quotas, or closed fishing seasons or areas.

However, the essence of the bycatch problem is clarified by using this simple modelling approach. Management regulations that attempt to reduce bycatch levels in one fishery may have unexpected effects in other fisheries. Reducing the bycatch fishing mortality in the multispecies fishery does not result in increased stock size of the bycatch fish species or substantial increases in its level of harvest as has been suggested in Powers *et al.* (1987). Instead, it reallocates the fish stock from the multispecies fishery to the fishery for the bycatch species. This increase in abundance expands fishing effort in the fishery for the bycatch species. This expansion of fishing effort drives the stock size down to the equilibrium level that existed prior to the reduction in bycatch in the multispecies fishery with modest increases in harvest levels. Obviously, if the level of harvest in the directed fishery for the bycatch species increases slightly with a substantial increase in fishing effort, then the costs associated with this harvest level are higher than they would be under an exclusive property rights management scenario. That is, the same level of harvest can be produced in Figure 3 with a lower effort level resulting in a lower harvesting cost and a higher stock size.

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