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Open-access Fishery Performance When Vessels Use Goal Achievement Behavior

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Abstract *While most bioeconomic models assume that vessel operators use profit maximizing behavior, it is sometimes argued that participants use other operational goals. The purpose of this paper is to compare how vessel behavior, the bioeconomic equilibrium, and the path to achieve it are changed if participants use goal achievement behavior. It is shown that, depending on the operational rule used to achieve the goal, there can be significant differences in the amount of individual vessel effort at different stock sizes, and this can affect the location and the stability of the bioeconomic equilibrium. In addition, goal achievement behavior will generally lead to a larger open-access overshoot in terms of fleet size.*

Key words Profit maximizing behavior, goal achievement behavior, open-access fishery behavior.

JEL Classification Code Q22.

Introduction

This paper is motivated by a series of discussions I have had over the years, principally with non-economists, about the behavior of fishing firms as the stock becomes overfished. It was often contended that individual operators would compensate for stock reductions by increasing effort. This phenomenon is sometimes said to be especially prevalent in artisinal fisheries. For example, Parks and Bonifaz (1994, p. 13) in a study of Ecuadorian fisheries state, "Diminished (fish) stocks lead producers to compete for smaller and smaller (harvests), while at the same time, artesonos must continue to increase their effort to support their families from a dwindling stock." The implication was what appeared to be a rational individual response, in the aggregate only made a bad situation worse. The stock would fall even further, perhaps making it difficult to achieve stable bioeconomic equilibrium even when there is vessel exit due to negative long-term profits. I would make the counter argument that if vessel profitability decreases with stock size, then if operators use profit maximizing behavior (PMB), they would reduce effort as stock size decreased. This reduction would reinforce the effect of reduced fleet size, thus speeding stock recovery and increasing the probability of achieving a stable bioeconomic equilibrium. Indeed, it is easy to construct a formal model based on PMB that demonstrates that this will be the case. See below.

But as the reference to the Ecuadorian fishery illustrates, in some cases participants may base their behavior on goal achievement rather than profit maximization.

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The goal could be to achieve a specific profit level or to maintain a target effort or harvest level. As a contrast to PMB, this will be called goal achievement behavior, or GAB. As will be demonstrated below, in certain instances individual vessel effort will increase with decreases in stock size if operators act in this manner.

There has been some research on how things other than simple profit maximizing behavior can influence decision making in fisheries. For example, Anderson (1980) discusses how the effects of non-pecuniary benefits of fishing activity can affect fishing behavior; Bockstael and Opaluch (1983) discuss how firms determine which fishery to operate in; Charles (1988) discusses a range of non-economic issues that affect behavior; and Holland and Sutinen (2000) show how habit can be as important as relative profits in determining fishing location. However, as far as the author has been able to determine, there has been no analogous work on alternative hypotheses to explain the "intensity" of fishing once a decision has been made to enter a particular fishery or to fish in a particular area or with a particular gear.

The purpose of this paper is to provide a preliminary analysis that compares the operation of a fishery where participants maximize profits with an otherwise identical fishery where participants use GAB. The items to be compared are individual vessel behavior, stock and fleet size at the bioeconomic equilibrium, and the likely nature of the time path of stock and fleet size as the fishery approaches the equilibrium. The analysis adds new insights into the operation of an open-access fishery and lays the groundwork for expanding the analysis of the effects of regulation on individual behavior.

The paper will proceed as follows. The first main section introduces a standard bioeconomic model that can be used to make the proposed comparisons. Because the discussion can be facilitated by a graphical analysis, explicit functions with hypothetical parameter values will be used. The next section describes different operational rules that will allow vessels to achieve a specified profit level or maintain a target level of output or effort. A discussion of how the functional relationships of the bioeconomic model are altered for each of the operational rules is also included. The fourth section compares and contrasts vessel behavior, the bioeconomic equilibrium, and the time path of the fishery for profit maximization and different types of goal achievement. The next section introduces other issues that arise given the possibility of GAB. The final section provides a summary and offers suggestions for further research.

The Bioeconomic Fishery Model

The relevant issues can be captured in a Vernon Smith type model (Smith 1969), where the vessel operator can choose both the amount of effort produced per day, e, and the number of days fished per season, d. Assume homogeneous vessels with the following daily profit function:

$$\pi(e, X) = PqXe - v_1 e - v_2 e^2, \tag{1}$$

where P is price of fish, qXe is the vessel daily production function (q is the catchability coefficient and X is the stock size), and $v_1 e + v_2 e^2$ is the quadratic daily cost function. Let e_{max} be the maximum e that can be produced in a day. The seasonal profit function is:

$$\Pi(e, d, X) = d\pi(e, X) - FC, \tag{2}$$

where FC is the annual fixed cost. Let D_{max} be the maximum possible number of days fished. Further, assume that stock growth is represented by the Schaefer (1954) function:

$$G(X) = rX(1 - X/K), \tag{3}$$

where K is the maximum stock size, and r is the intrinsic growth rate. The following parameter values will be used in the graphical analysis: P = \$17, q = 0.00005, v_1 = 5, v_2 = 5, e_{max} = 3.2, D_{max} = 150, FC = \$3000, r = 0.3, and K = 100,000.

Vessel Activity

Subject to technical constraints, daily profits are maximized where the first derivative of equation (1) equals zero. Therefore, the operational level of e will be:

$$\begin{aligned} e^*(X) &= e_{max} && \text{if } (PqX - v_1)/2v_2 \geq e_{max} \\ e^*(X) &= (PqX - v_1)/2v_2 && \text{if } 0 < (PqX - v_1)/2v_2 < e_{max} \\ e^*(X) &= 0 && \text{if } (PqX - v_1)/2v_2 \leq 0. \end{aligned} \tag{4}$$

The stock size at which $e^*(X)$ falls to zero is important because it is the upper limit on a range of stock sizes where commercial activity will cease. Call this stock size the cushion stock size, X_{cush}, because it is a cushion that bounces the fishery time path back up when the stock falls into this range. See below:

$$X_{cush} = v_1/Pq. \tag{5}$$

The profit-maximizing vessel will always choose to operate the maximum number of days possible as long as daily profit is positive. Therefore:

$$\begin{aligned} d &= D_{max} && \text{if } X > X_{cush} \\ d &= 0 && \text{if } X \leq X_{cush}. \end{aligned} \tag{6}$$

Given the functions for e and d, total annual vessel effort, E, is:[1]

$$E(X) = de^*(X). \tag{7}$$

The stock size where long-run vessel profits equal zero when $d = D_{max}$ is the economic equilibrium stock size, X_{be}. It will occur at the combination of X and e where both $\partial B/\partial e$ and $\Pi(X, e, D_{max})$ equal zero.

$$PqX - v_1 - 2v_2e = 0 \tag{8}$$

$$PqXe - v_1e - v_2e^2 - FC/D_{max} = 0 \tag{9}$$

[1] Actually, since stock size will vary over the period, this is an approximation, but unless there are large changes in stock size over the season, the differences are quite small. This approximation will be used to simplify the graphical analysis.

Dividing equation (9) by e, subtracting it from equation (8), and solving for e obtains:

$$e_{be} = [FC/(v_2 D_{max})]^{1/2}. \tag{10}$$

Substituting this back into equation (9) and solving for X obtains:

$$X_{be} = [v_1 + v_2\, e_{be} + FC/(e_{be} D_{max})]/Pq. \tag{11}$$

Vessel activity can be summarized in the relationships between X and the variables e, d, and E as pictured in figures 1a, 1b, and 1c, respectively. As stated above, after a point both daily and total annual vessel effort will decrease with stock size and will fall to zero at a positive stock size. It is shown below that these patterns will differ with GAB, and this will have interesting effects on fishery operation.

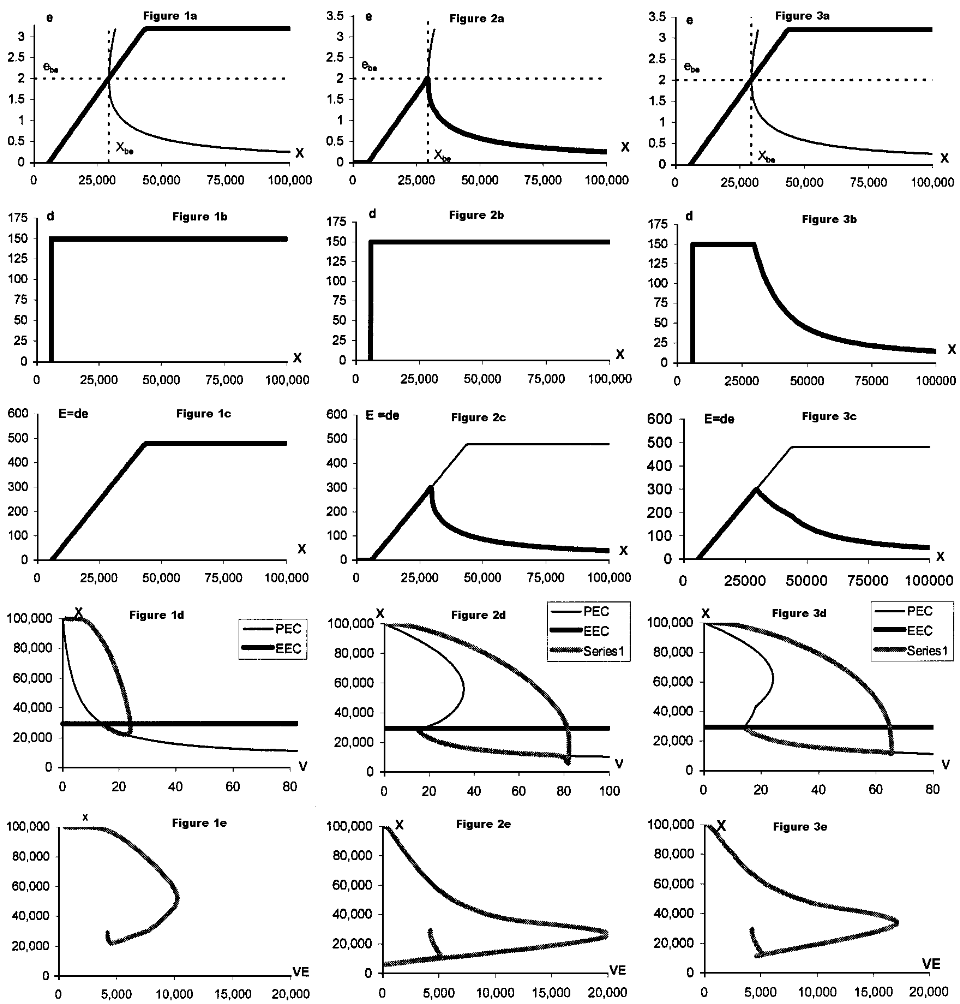
For purposes of the discussion below, consider a geometric interpretation of the simultaneous solution of equations (8) and (9) for the equilibrium values of e_{be} and X_{be} in figure 1a.[2] The solid thick curve follows from equation (8) and shows how the operational level of e will vary with stock size. The solid thin line which follows from equation (9) shows the levels of e which will generate a zero profit for different levels of X assuming that d equals D_{max}. It is impossible to cover fixed costs if X is less than X_{be}, but there are two levels of effort where this will occur when X is larger than X_{be}. Only the portion below e_{max} is pictured. Call it the Zero Profit Curve (ZPC). Because it will be part of the analysis of the operational rules for GAB below, call the smaller of the two solutions $e_{min}(X)$. The ZPC shows the relevant combinations of X and e where daily net returns will exactly cover fixed costs if $d = D_{max}$. All combinations of X and e on, above, and to the right of the curve will produce net returns equal to or greater than fixed costs. These represent the combinations where it is theoretically possible to cover fixed costs. All combinations to the left and below the curve will produce net returns less than fixed costs even when $d = D_{max}$.

The operational e curve represents the level of e where daily profits are maximized for various levels of X. The point where it intersects the ZPC represents the combination of X and e where the highest possible daily profit will just cover fixed cost when $d = D_{max}$. This is the economic equilibrium stock size, X_{be}. Two things that follow from this graph will be useful in interpreting analogous graphs with GAB. First, anytime the operational e curve, which can be different than $e^*(X)$ with GAB, is above and to the right of the ZPC, it is possible to cover fixed costs. Second, the point of intersection between the operational e curve and the ZPC will determine the economic equilibrium stock size, which can be different than X_{be}.

Bioeconomic Equilibrium

A fishery will be in a bioeconomic equilibrium when catch is equal to growth, so stock size will not change. Simultaneously, long-run profits are equal to zero, so there will be no tendency for vessel entry or exit. This point can be identified in (fleet, stock) space by plotting the economic equilibrium curve (EEC) and the population equilibrium curve (PEC). See Smith (1969), Anderson (1986, chapter 4), and Hannesson (1993, chapter 2). The EEC is the collection of fleet and stock combina-

[2] All figures and time paths were derived using Microsoft EXCEL. While the exact shapes of the curves follow from the given parameter values, the basic results are general.



Figures 1, 2, and 3. Vessel and Fishery Behavior under PMB and PGB with Cases 1 and 2

tions where long-run profit is equal to zero. All points above the EEC represent combinations of X and V where long-run profits are positive and fleet size will increase. The reverse holds true for all points below the curve. In this particular case, since there is only one stock size where long-run profits will equal zero, the EEC will be a horizontal line at X_{be} (see equation 11). The population equilibrium curve shows the combinations of stock and fleet sizes where catch will equal growth. An equation for this curve can be obtained by equating stock growth and total fleet catch and solving for V, the number of vessels is the fleet.

$$G(X) = VdeqX \tag{12}$$

$$V = G(X)/deqX$$

Substituting in equations (3), (6), and (7) and simplifying obtains:

$$V = [r(1 - X/K)]/[D_{max} q e^{*}(X)]. \tag{12a}$$

As X decreases from K to X_{cush}, the numerator will increase and the denominator will decrease, which means that V will vary inversely with stock size and will approach infinity as X approaches X_{cush} from above. Because effort per boat decreases with stock size, it takes more vessels to harvest the growth even as stock size falls. All points to the left and below the PEC represent combinations of X and V where growth is greater than catch and stock size will increase. The reverse holds true for all points to the right or above it. The intersection of the EEC and the PEC determines the bioeconomic equilibrium. The particular EEC and PEC for the set of parameters given above are depicted in figure 1d.

The Time Path of the Fishery

The phase plane diagram of the fishery is found by tracing the annual changes in stock and fleet size. Stock size changes according to the difference between growth and catch. The stock size difference equation is:

$$X_{t+1} = X_t + G(X_t) - V_t d_t e_t q X_t. \tag{13}$$

Substituting in equations (3), (6), and (7) obtains:

$$X_{t+1} = X_t + rX_t(1 - X_t/K) - V_t D_{max} q X_t e^{*}(X_t). \tag{13a}$$

Following Smith (1969), the change in fleet size will be proportional to long-run vessel profits. The vessel difference equation is:

$$V_{t+1} = V_t + \phi\{D_{max}\Pi[e^{*}(X_t), X_t] - \mathrm{FC}\}. \tag{14}$$

The parameter ϕ is the entry/exit coefficient.

One purpose of this paper is to show how GAB will change the dynamics of an otherwise identical fishery as compared to PMB. Therefore, it is necessary to set up an initial case as a basis of comparison. The time path (or phase diagram) of fleet and stock size for PMB, pictured in figure 1d, will serve that purpose. It is drawn using the above parameters and a baseline entry/exit coefficient of 0.003. After an "open-access overshoot," the path makes a non-cyclical approach to the equilibrium. In fact, once the time path approaches the PEC, it follows it very closely to the equilibrium point. It is slightly below it and growth is greater than catch, so stock size is growing. This is sometimes called a stable focus equilibrium (see Ferguson and Lim 1998). For purposes of later discussion, note that the (X,V) space is divided into four quadrants by the PEC and the EEC. The time path in this case passes through three of them.

For a given set of economic and biological parameters, the shape of the time path is related to the absolute size of the entry/exit coefficient. At low levels, the time path moves directly to the equilibrium point and remains in the same quadrant from which it begins. This is called a stable node equilibrium. As the coefficient is increased over some intermediate range, the path changes to a focus equilibrium which can go through all quadrants, sometimes more than once, in a decreasing cycle on the way to equilibrium. The higher the Φ, the more cycles it takes to reach equilibrium. Eventually, if Φ gets high enough, the path goes into a non-decreasing cycle around the equilibrium.

The baseline Φ used in figure 1 has been selected so that the time path for PMB is firmly in the range of a stable focus equilibrium. See row 1 of table 1, which describes how the time path changes as Φ changes relative to the baseline level. If it is reduced to 10% of the baseline value, the path changes to a stable node. From that level up to a point four times the baseline value, the time path remains a stable focus. The coefficient has to increase by a factor of 10 before the time path changes to a non-decreasing cycle. The remaining rows in the table describe the relative stability of the fishery system with different GAB scenarios and will be discussed further.

Introducing Goal Achievement Behavior into the Bioeconomic Model

Consider first the case where the goal is to achieve a specific level of profit. For purposes here, it will be assumed that participants shoot for a level of annual net returns that will exactly cover fixed costs. This can be justified on the notion that, properly defined, *FC* includes the full opportunity cost of alternative uses of human and physical capital. A lower profit goal will not allow for a viable operation. While a higher goal is possible, it will only affect the stock size at which the profit goal cannot be met (see the discussion below), and it will not affect the qualitative nature of the results.

Since for any X there are many combinations of e and d that cause net returns to equal *FC*, what operational rules can vessel operators use to choose a particular combination? The following will be considered here.

- Case 1 Set d equal to D_{max} and use e as a control variable to cause net returns to equal *FC*.
- Case 2 Set e equal to $e^*(X)$ and use d as a control variable to cause net returns to equal *FC*.
- Case 3 Set e to a fixed level and use d as a control variable to cause net returns to equal *FC*.
- Case 4 Set daily catch, y, to a fixed level, then set e to obtain it and use d as a control variable to cause net returns to equal *FC*.

Case 1 might be selected if there were a desire to spread the harvest throughout the season, while Case 2 might be chosen if increasing leisure time were a secondary goal. Cases 1 and 2 are similar in that they each choose one of the two control variables according to PMB. As a result, the economic equilibrium stock size, and ultimately the bioeconomic equilibrium, will be the same as with PMB. Cases 3 or 4 would apply if daily trips are defined in terms of effort or catch because of custom or vessel characteristics. Except for a special case, there will be a different bioeconomic equilibrium. The cushion stock size will also be different.

As mentioned above, the ZPC divides the (e, X) space in figure 1a into areas where fixed costs can (and cannot) be covered. Essentially this means that when stock size is below X_{be}, the profit goal cannot be met even when $d = D_{max}$. This raises the question of how vessel operation under PGB will change in this range. It is logical that operators will choose their control variable (e or d) such that they come as close as possible to meeting the profit goal. Therefore, in Case 1 where e is the control variable, when X is less than X_{be}, it can be assumed that operators will set e equal to $e^*(X)$. This will provide the largest contribution toward covering fixed

Table 1
Results of Sensitivty Analysis

	Ratio of Entry/Exit Coefficient Base Case Level														
	0.10	0.50	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
PMB	ooo	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
Case 1	OOO	OOO	OOO	OOO	OOO	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Case 2	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	xxx	xxx	XXX
Case 3 low e	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	xxx	xxx	XXX	XXX	XXX	XXX	XXX
Case 4 low y	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Case 4 high y	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Case 5 low e	ooo	ooo	ooo	ooo	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
Case 5 high e	ooo	OOO	OOO	xxx	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Case 6 low y	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Case 6 high y	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX

Node	ooo	
Focus	OOO	
Decreasing Cycle	xxx	(Focus with many cycles)
Non-decreasing Cycle	XXX	

costs. They will stop fishing when $e^*(X)$ falls to zero at X_{cush}. In cases 2, 3, and 4, where d is the control variable, the operators will set d equal to D_{max} because given their fixed level of e or y, this will provide the largest contribution towards FC. In all cases, they will stop fishing when daily net returns fall to zero. For case 2, the stock size where this occurs will be the same as with PMB, but in cases 3 and 4, it will vary with the selected constant level of e or y.

A final, unresolved issue is the entry and exit of vessels with this type of GAB. From the previous discussion, it can be seen that net returns will be less than FC when X is less than X_{be}, so the assumption concerning exit behavior in the PMB model can still apply. However, because profit will equal zero by assumption as long as X is greater than X_{be}, it cannot be assumed that entry is proportional to profit. But, it is reasonable to assume that entry is directly related to the ease with which the profit goal can be achieved as measured by the difference between the operational level of the control variable and the level where profits would be maximized. To be explicit:

Entry

$$V_{t+1} = V_t + \Phi' [e^*(X) - e_{ci}(X)] \text{ when } X > X_{be(ci)} \quad \text{Case 1} \tag{15a}$$

$$V_{t+1} = V_t + \Phi' [D_{max} - d_{ci}(X)] \text{ when } X > X_{be(ci)} \quad \text{Case 2,3,4} \tag{15b}$$

Exit

$$V_{t+1} = V_t + \Phi \, [d_{ci} \, \pi(e_{ci}, X_t) - \text{FC}] \text{ when } X \leq X_{be(ci)}. \tag{15c}$$

The terms d_{ci} and e_{ci} are the operational levels of e and d for the various cases which, depending on the circumstances, can depend on X. $X_{be(ci)}$ is the actual bioeconomic equilibrium stock size of the particular case. As noted above, it can be different under PGB depending on the exact assumptions.

Note that equations (15a) and (15b) are strictly analogous to the profit related formulation because the terms that are multiplied by the entry coefficient are equal to zero at $X_{be(ci)}$ and are monotonically increasing in X above $X_{be(ci)}$. Therefore, the general nature of entry with change in stock size will be the same. However, the actual number of entering vessels will depend upon the absolute size of the terms in parentheses and of the entry coefficient.

Because the values of Π in equation (14) and of $[e^*(X) - e_{ci}(X)]$ and $[D_{max} - d_{ci}(X)]$ in equations (15a) and (15b) will differ at the same values of X, it is necessary to calibrate the value of Φ' to maintain comparability. In all the profit goal achievement cases, the baseline Φ' was set such that it generated the same amount of entry at a stock size of 75*K, which was generated in the PMB model with Φ of 0.003 at the same stock size.

The second type of GAB is to attempt to maintain a constant effort or catch level on a daily basis, for the reasons discussed above, but then to operate their boats every day. Vessel entry/exit is proportional to profits. While fundamentally different in principle, these turn out to be slight modifications of Cases 3 and 4 as follows:

Case 5. Set e to a fixed level and then operate so that $d = D_{max}$.
Case 6. Set y to a fixed level, then set e to obtain it and operate so that $d = D_{max}$.

Consider now how these six cases can be incorporated into the bioeconomic model. Recall that the model consists of equations (4), (6), and (7), the operational levels of e, d, and E; equations (5) and (11), the economic equilibrium and the cushion stock sizes; equation (12), the PEC; and equations (13) and (14), the difference equations for stock and fleet size. Given the extra assumptions concerning how the e and d functions change when the profit goal cannot be met, it is a simple matter to apply the basic bioeconomic model to each of the cases. Once the operational rule for e_{ci} is specified, where the subscript refers to the case number, it is possible to calculate the values of $X_{be(ci)}$ and $X_{cush(ci)}$. It is then possible to construct the other equations by substituting e_{ci}, $X_{be(ci)}$, and $X_{cush(ci)}$ in the appropriate places. The basic form of the other equations will be the same in all cases. Table 2 describes how this is done for Cases 1 through 4. Cases 5 and 6 will be the same as Cases 3 and 4, respectively, except that d will always equal D_{max}, and the V difference equation will be given by equation (14).

Except in a few cases, the results should be obvious by inspection. First, there are constraints on the levels of e and y that can be chosen in Cases 3 and 4. The lowest e must be greater than $e_{min}(K)$, the effort level where the profit goal is achieved given the boat operates full time when stock size is at its maximum. It may not be higher than $e_{max.}$ The constraints in Case 4 are analogous but in terms of output. Second, the solutions for $X_{be(ci)}$ and $X_{cush(ci)}$ are found by setting equations (2) and (1) equal to zero, respectively, when $e = e_{ci}$ and $d = D_{max}$ and solving for X. In Case 4, the equations will be quadratic and the appropriate solutions are the positive value provided by the general equation. These solutions will not apply when the amount of e necessary to catch the fixed y at the solution level of X is greater than e_{max}. Finally,

Table 2
The Bioeconomic Model Equations for the Different Operational Rules

	Case 1	Case 2	Case 3	Case 4
Daily Effort	$e_{c1}(X) = e_{min}(X)$ if $X > X_{be}$ $e_{c1}(X) = e^*(X)$ if $X \leq X_{be}$	$e_{c2}(X) = e^*(X)$	$e_{c3} = e_{fixed}$ $e_{min}(K) < e_{fixed} \leq e_{max}$	$e_{c4}(X) = \text{Min}[y_{fixed}/qX, e_{max}]$ $e_{min}(K)qKy_{fixed} \leq e_{max}qK$
Equilibrium X (EEC)	$X_{be(c1)} = X_{be}$	$X_{be(c2)} = X_{be}$	$X_{be(c3)} = [v_1 + v_2e_{c3} + FC/e_{c3}D_{max}]/Pq$	$X_{be(c4)} = [-b + (b^2 - 4ac)^{1/2}]/2a$ $a = Py_{c4} - FC/D_{max}$ $b = v_1(y_{c4}/q)$ $c = v_2(y_{c4}/q)^2$
Cushion X	$X_{cush(c1)} = X_{cush}$	$X_{cush(c2)} = X_{cush}$	$X_{cush(c3)} = [v_1 + v_2e_{c3}]/Pq$	$X_{cush(c4)} = [-b + (b^2 - 4ac)^{1/2}]/2a$ $a = Py_{c4} - FC/D_{max}$ $b = v_1(y_{c4}/q)$ $c = v_2(y_{c4}/q)^2$
Days Fished		$d_{ci} = \text{Min}\{FC/B[e_{ci},X],D_{max}\}$ $d_{ci} = 0$		if $X > X_{cush(ci)}$ if $X \leq X_{cush(ci)}$
E		$E_{ci} = d_{ci}e_{ci}$		
PEC		$V = G(X)/d_{ci}e_{ci}qX$		
X Difference Equation		$X_{t+1} = X_t + \text{G}(X) - V_t d_{ci(t)} e_{ci(t)} qX_t$		
V Difference Equation		See Equations 15a, 15b, and 15c		

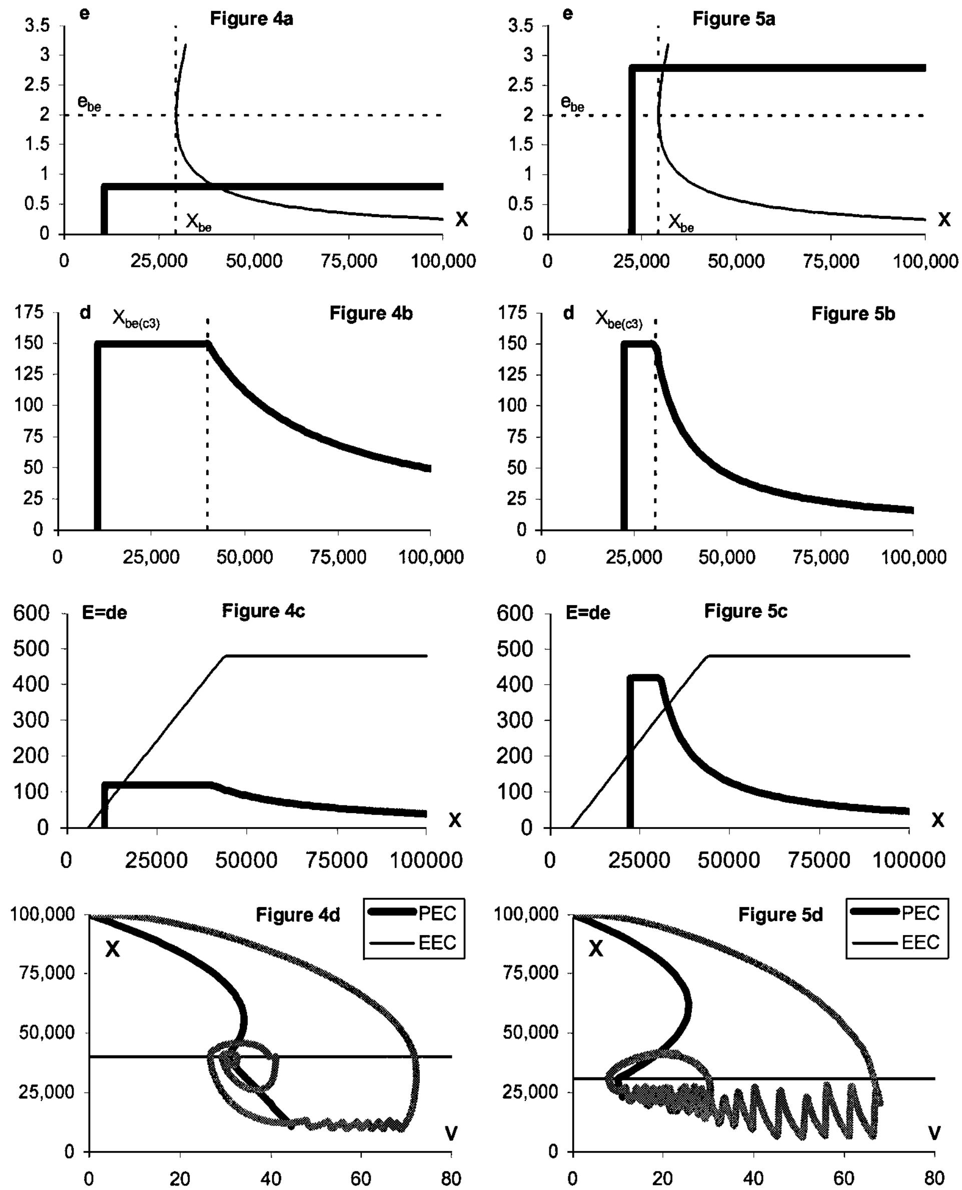
the general equation for d_{ci} applies in case 1 because, by definition, $FC/\pi[e_{c1},X]$ will equal D_{max}.

Comparisons of Open Access with Profit Maximization and Profit Goal Achievement Behavior

Comparing and contrasting the operation of the fishery when participants use the various operational rules can be accomplished by constructing a set of graphs analogous to figure 1. Cases 1 and 2 are pictured in figures 2 and 3. The analysis of Cases 3, 4, 5, and 6 can differ depending upon the size of the fixed level of e or y. These situations are pictured in figures 4–11. To save space, the graph for the time path in terms of aggregate effort is omitted from these latter figures because the results are analogous to figures 2e and 3e (see below). As a reference point, the ZPC is pictured as a thin line in all "a" graphs, and the operational e function for PMB is pictured as a thin line in all "c" graphs.

Consider first Cases 1 and 2 in figures 2 and 3. As X decreases from K to X_{be}, the operational e function in Case 1 is the lower half of the ZPC, which has been defined as $e_{min}(X)$. Below X_{be}, the operational e function is $e^*(X)$. The number of days fished, d, is equal to D_{max} at all stock sizes. In Case 2, $e^*(X)$ is the operational e function for all levels of X. The number of days fished will increase as X decreases because profit per day decreases, so it takes more days to cover fixed costs. The operational d will reach D_{max} at X_{be}. In both cases, boats will produce less total effort than with PMB for all stock size above X_{be}. Further, annual vessel effort increases as stock size decreases in this range (see figures 2c and 3c). Given the way in which vessels must be operated to come as close to achieving the profit goal as possible, when X is less than X_{be} boats will produce the same as with PMB. Also note that at stock sizes above X_{be}, e will be greater in Case 2. This means that with identical stock and fleet sizes, catch will be higher in Case 2, which will have obvious biological effects on the operation of the fishery. This is an artifact of the daily cost function. As daily effort decreases, the average cost of effort approaches v_1 and is independent of the total number of days fished. Therefore, since Case 1 will always have a lower daily effort than Case 2, [$e_{min}(X)$ is less than $e^*(X)$], its cost of effort will be lower, and it will take a smaller annual catch to cover fixed costs. This would not necessarily be the case if there were a fixed set-up cost included in the daily cost function. Although these are hypothetical examples, the point (which is confirmed in Cases 3 and 4) is that different operational rules for achieving the same profit goal will have different effects on annual harvest levels.

Given the differences in the operational E functions in these two cases, the PECs are different as well (see figures 2d and 3d). Over the range from K to X_{be}, the PEC is concave to the stock size axis. When stock size is less than X_{be}, in both cases the PEC is identical to the PEC for the PMB case because vessels effectively change over to PMB in this range. The reason for the backward bending portion of the PEC (where fewer boats are necessary to harvest the growth as stock size decreases) is that each boat will be producing more effort. Depending on the parameter values, this can occur whether growth is increasing or decreasing as stock size decreases. As noted by Hannesson (1993), if the EEC intersects the PEC in a backward bending region, it will produce an unstable equilibrium. When participants seek to achieve a given profit goal, the EEC intersects the PEC at the cusp point where it switches from a backward bending curve to a negatively sloped curve. It is important to note it is not happenstance that equilibrium occurs at the cusp in the PEC. It is the direct result of the nature of profit achievement goal, which requires that individual behav-



Figures 4 and 5. Vessel and Fishing Behavior with "Low" and "High" Fixed Values of *e* for Case 3 ior must change when the stock reaches the economic equilibrium size. Below that stock size, it is not possible to meet the profit goals and cover fixed cost. This change in behavior as the stock fluctuates around the equilibrium size is an important difference between the two types of behavior.

The time paths for these cases are also presented in figures 2d and 3d. Given the baseline level of Φ, the only difference is that there is a larger open-access overshoot than with PMB. The reason for this is that with otherwise identical vessels producing smaller amounts of effort, the stock will be able to support more of them for a longer period of time before it is reduced to X_{be}. The biological effects of the increased overshoot in terms of vessels is accentuated by the fact that as the larger fleet drives the stock down, the effort per boat of the larger fleet increases. Even when the stock gets so low that vessels leave the fishery, as long as stock size is still decreasing, effort per boat continues to increase which will partially offset the decrease in fleet size.

Figures 2e and 3e show the time path in terms of aggregate effort. At higher stock sizes, aggregate effort is lower than with PMB. Compare figure 1e. However, as the stock continues to decrease, the inequality is reversed. Also, aggregate effort continues to increase until stock fall to X_{be}, while aggregate effort can begin to decrease at higher stock sizes with PMB. If the comparative values for stock size were plotted against time, it would show that while PMB results in a faster decline in X, it does not fall as far, and it returns to the equilibrium stock size faster than with profit goal achievement. Note also that in figure 2e, aggregate effort falls to zero at one point because the stock falls below X_{cush} and the fleet temporarily ceases to operate. The results with respect to total effort were similar in the remaining cases, so this curve will not be displayed in the following figures.

Rows 2 and 3 of table 1 describe how sensitive the shape of the time path and the stability of the system are to changes in the entry/exit coefficient. Case 1 becomes non-stable at a Φ' that is 1.75 times the baseline, and Case 2 at one that is four times the baseline. In general, the greater proclivity to non-stability is due to the fact that instead of having decreases in vessel annual effort complement the decrease in fleet as stock decreases, there is an increase which at least partially offsets reduction in the fleet. The reason that Case 1 is more sensitive to changes in the coefficient is that the rate of increase in vessel annual effort is higher. See the slopes of the curves in figures 2c and 3c.

In summary, while bioeconomic equilibrium will occur at the same combination of fleet and stock size in Cases 1 and 2 as with PMB, there are important differences. First, the systems are much more sensitive to increases in Φ' with respect to achieving a stable equilibrium. Second, the open-access overshoot extends to higher fleet level, and this occurs even with the lower entrance rates.

Consider Case 3 where vessels set a constant e and modify the number of days fished in order to achieve the profit goal. Figures 4 and 5 depict cases where the fixed e is below and above e_{be}, the level of daily effort at the bioeconomic equilibrium with PMB. As noted above, the economic equilibrium stock size, $X_{be(c3)}$ in this case, occurs where the operational e curve intersects the zero profit line. In both of these cases, this occurs at a stock size greater than X_{be}, the economic equilibrium stock size with PMB. See the top two graphs in each figure. It follows, that as the fixed e is increased, $X_{be(c3)}$ will initially decrease but after e reaches e_{be} further increases will cause $X_{be(c3)}$ to increase. However, the size of $X_{cush(c3)}$ will fall continuously with increases in the level of fixed e (see table 2).

Again, d will increase with decreases in X and will reach D_{max} at $X_{be(c3)}$. Given that e is already fixed, this means that total effort per boat, E, will initially increase with decreases in X, but will remain constant over the range between $X_{be(c3)}$ and $X_{cush(c3)}$. See figures 4c and 5c. There are some interesting aspects of the operational *d* curves that have significant effects on fishery operation. First, while *e* will be less than the comparable PMB amount at higher stock sizes, at lower stock sizes when vessels try to achieve a profit goal, there is a range where they will produce more effort although they will stop operating at a higher stock size. Second, at higher levels of the fixed *e*, the constant amount of *E* will be higher, but it will be produced over a smaller range of stock sizes. That is, the difference between $X_{cush(c3)}$ and $X_{be(c3)}$ will decrease.

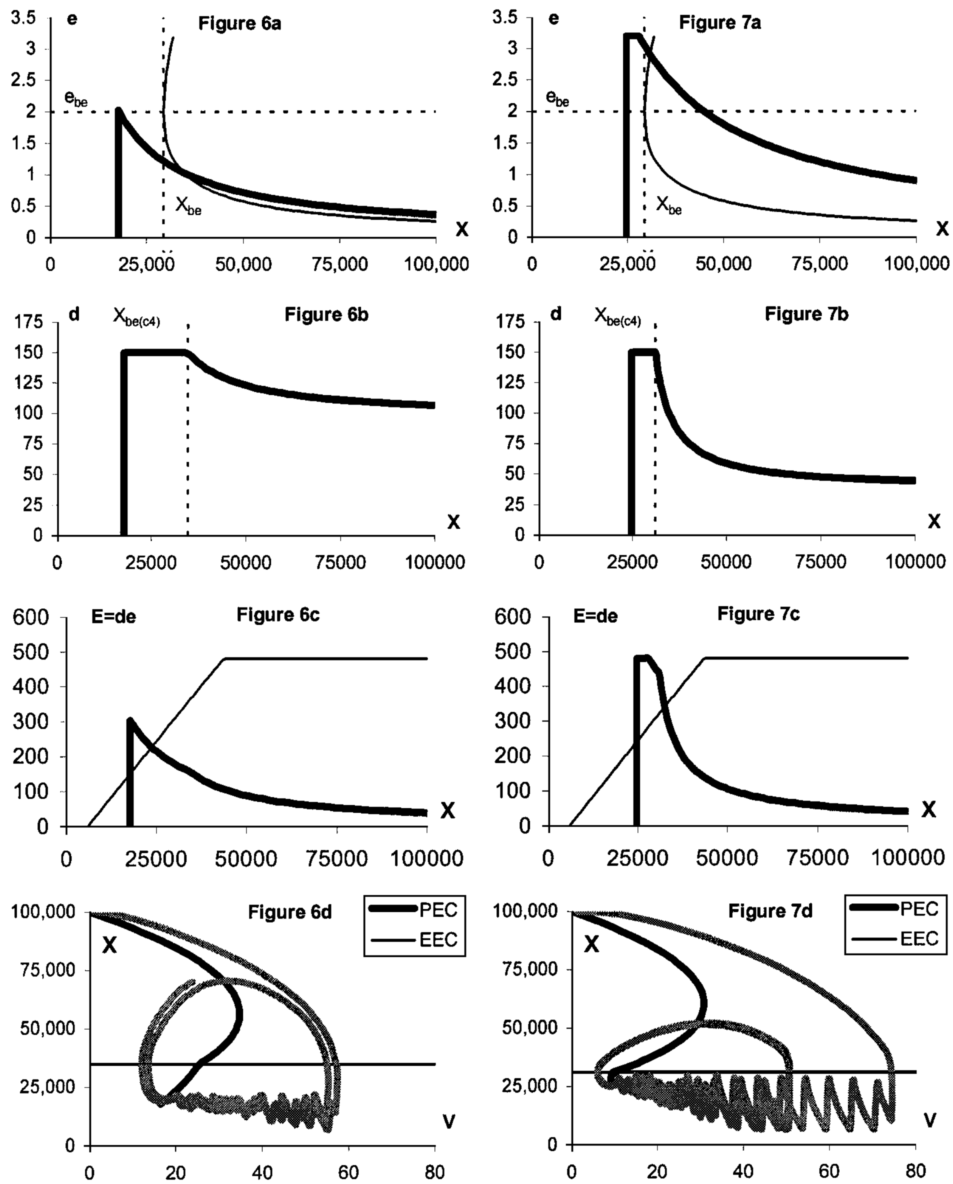
Because of these two points, there are important differences in the shape of the PEC (see figures 4d and 5d). In both situations, the PEC will be concave to the stock size axis over the range between *K* and $X_{be(c3)}$. Below $X_{be(c3)}$ it will be linear and negatively sloped (see equation (12a), where the denominator is a constant over this range of *X*). It is important to further note the explicit differences in the PEC. In PMB and Cases 1 and 2, the PEC asymptotically approaches X_{cush} from above. However, in Cases 3 and 4, the PEC is linear and abruptly stops at X_{cush}. Vessels will not operate below X_{cush}.

By comparing the two graphs, it can be seen that while the EEC intersects the PEC at its cusp, with a higher fixed *e*, the concavity of the PEC is more pronounced and the length of the linear portion is reduced (and partially hidden by the time path). Given the parameter values used in this example, this has an effect on the time path and the stability of equilibrium. Note that regardless of the level of fixed *e*, the open-access overshoot is larger than with PMB. In addition, with the lower *e*, and hence a lower X_{cush}, the time path, for the most part, stays above $X_{cush(c3)}$. Also, at the baseline Φ', the time path achieves an equilibrium. In fact, it would have to increase to four times the baseline before the system becomes nonstable (see table 1).

The time path for the higher level of fixed *e* is much different. First, given the smaller difference between $X_{cush(c3)}$ and $X_{be(c3)}$, the time path falls below $X_{cush(c3)}$ much more frequently, which explains its saw-tooth shape. While the cushion prevents the stock from falling further, the fishing industry is affected by periodic shutdowns. Also, the system does not reach an equilibrium at the baseline Φ'. The fishery will go into a cycle, and while the stock is protected by $X_{cush(c3)}$, there will be a continuous pattern of boom and bust. During the bust, not only will the fleet size be falling, but periodically it will not be profitable to fish at all. The likely reason for the nonstability is the short length of the PEC below $X_{be(c3)}$. The system remains nonstable even if the coefficient is reduced to 10% of the baseline level (see table 1).

A key issue with this case is that due to the constraint on days fished, there will be a range of stock sizes where effort per boat does not change. This is important because if effort per boat increases as stock size decreases, the PEC will have a backward bending portion. But when effort per boat stays the same or decreases with declines in stock size, the PEC has a negative slope. It is forward falling. To go one step further, the higher the fixed level of *e*, the shorter the range of stock sizes over which vessel effort will not change with stock size. And the shorter that range, the shorter will be the forward falling portion of the PEC below the cusp and the more difficult it is to obtain an equilibrium. This explains the difference between the time paths in figures 4d and 5d at the baseline level of Φ.

The results of Case 4, where vessels set a fixed daily catch and then vary *d* to obtain the profit goal, are depicted in figures 6 and 7. The operational *e* curve increases with decreases in *X* because it takes more effort to maintain the fixed *y* with lower stock sizes. Again, the economic equilibrium stock size ($X_{be(c4)}$ in this case), will occur where the operational *e* curve intersects the ZPC. Figure 6 depicts a case where *y* is "low" such that *e* is less than e_{be} at X_{be} and it never reaches e_{max}. In contrast, in figure 7 *y* is "high" and *e* is greater than e_{be} at X_{be} and it does get as high as e_{max}. Note that it does so to the left of the point where it intersects the ZPC. It can be seen that as the fixed *y* is increased, $X_{be(c4)}$ will initially fall until it reaches X_{be}, and



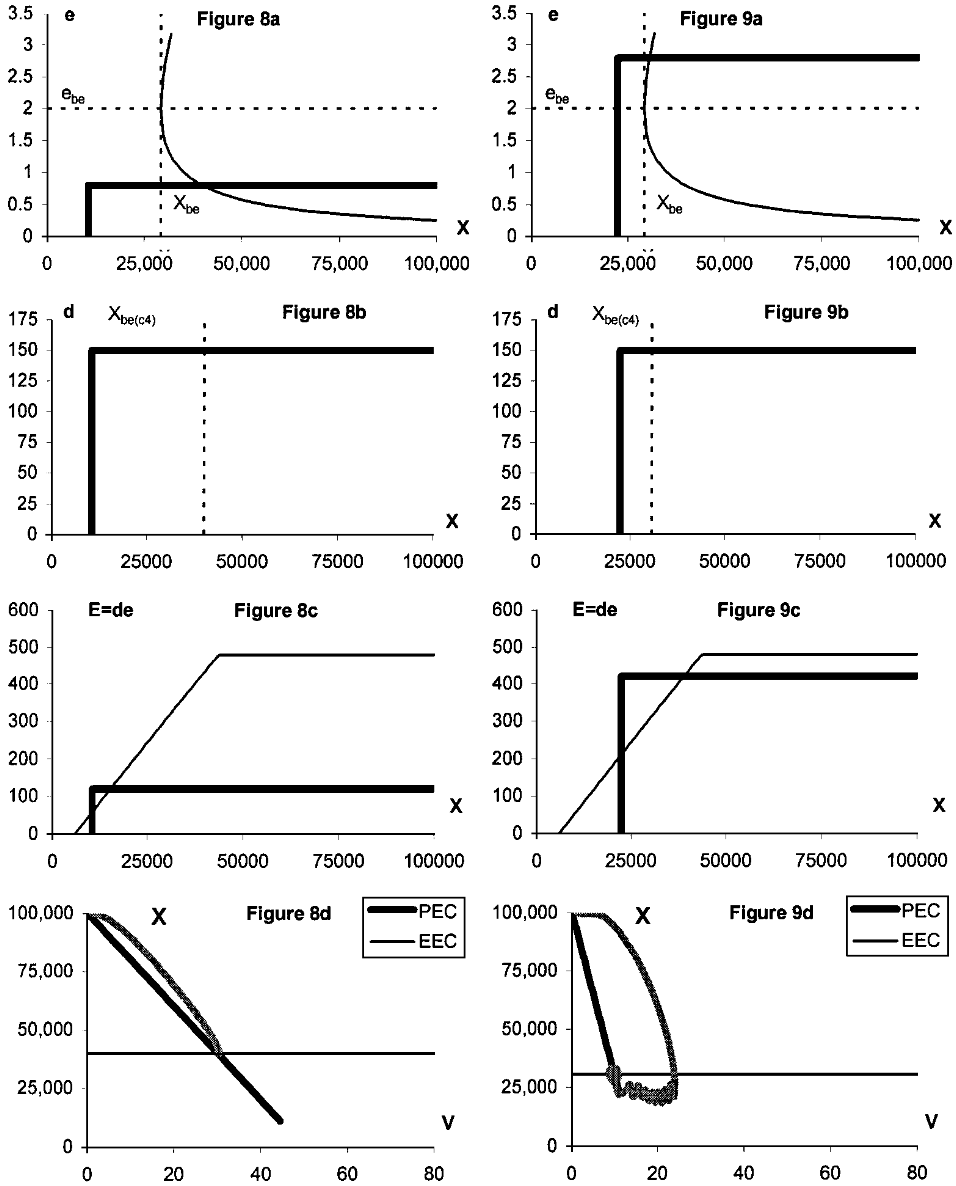
Figures 6 and 7. Vessel and Fishing Behavior with "Low" and "High" Fixed Values of *y* for Case 4 then it will increase. At the fixed level of y where the operational e curve intersects the ZPC at e_{max}, the fixed y operational rule becomes equivalent to the fixed e rule with e equal to e_{max}, and further increases in y will no longer affect $X_{be(c4).}$ Note that the operational e curve in figure 7a increases monotonically until the cushion stock size is reached and production activity will cease. If the fixed level of y were to increase by a small amount, the curve would shift up and the cushion stock size would increase. The highest possible cushion stock size occurs at that level of y where the operational level of e equals e_{max} at $X_{cush(c4)}$. Further increases in y will no longer affect the size of $X_{cush(c4)}$.

Figures 6c and 7c provide a comparison with the e curves for Case 4 with PMB. As in Case 3, boats will produce less total effort at higher stock sizes, but over a certain range of low stock sizes they will produce more. At low levels of fixed y, the effort per boat curve will not have a flat portion. More importantly, effort per boat will continue to increase with decreases in stock size at stock sizes below the bioeconomic equilibrium level. Effort per boat will increase with decreases in stock size until the cushion stock size is reached. In those cases, the PEC will be backward bending below the cusp, which means that it will be impossible to obtain equilibrium (see figure 6d). At higher levels of fixed y, it is possible for the effort per boat curve to have a flat portion and for the PEC to be forward falling below the cusp, which means that it is technically possible to have a stable equilibrium. At the same time as the fixed y increases, the flat portion on the operational E curve and the forward falling portion of the PEC below the cusp becomes short, making it more difficult to obtain an equilibrium. In other words, if the operational e curve hits e_{max} before it intersects the ZPC, the analysis becomes the same as in figure 5 where there is a high level of fixed e. The time paths demonstrate the larger overshoot and show that the fishery will go through a continuous cycle of boom and bust at both levels of fixed y. Again, sensitivity analysis showed that when Φ' is decreased to 10% of the baseline level, there is still a significant overshoot and in the system remains nonstable (see table 1).

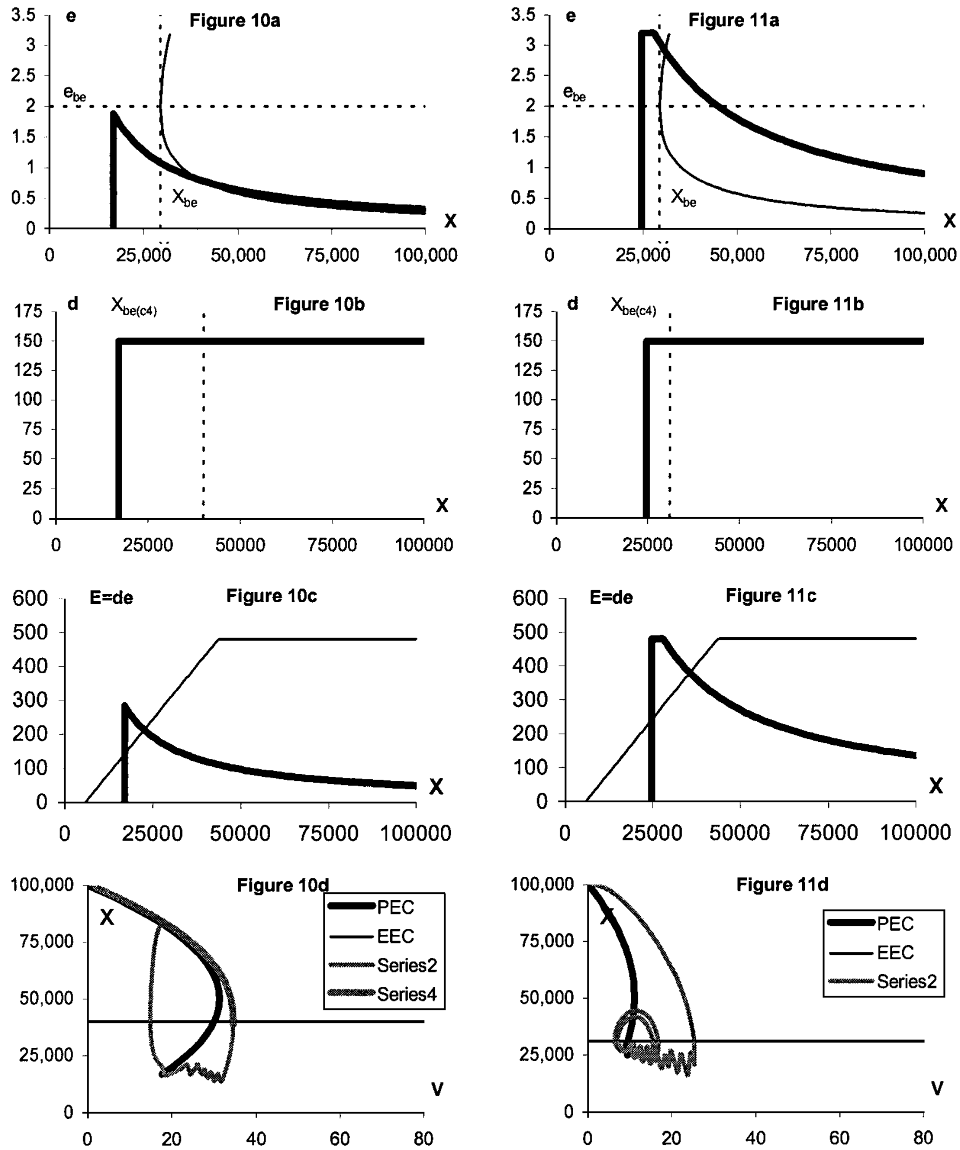
Cases 5 and 6 can be discussed in short order because of the similarity to Cases 3 and 4, respectively. The main differences will be in the b figures because d will equal D_{max} rather that the d that will cause net returns to just cover fixed costs. This difference is further reflected in the c and d figures because of the effect it will have on annual vessel effort and the PEC. In Case 5, depicted in figures 8 and 9, the annual amount of effort is constant regardless of stock size and the PEC is linear and negative throughout. The PEC is further to the right in figure 8 because boats produce less effort so the stock can sustain a larger fleet at any given size. Again, the PEC terminates at X_{cush}, the level of which decreases with increases in the fixed level of e. With a low level of fixed e, the time path is a stable node equilibrium at (and below) the baseline entry/exit coefficient. The time path becomes a stable focus when the coefficient reaches 1.5 times the baseline level and remains there over the range of comparison.

With a higher level of fixed e, the time path is different partly due to the higher level of X_{cush} (see the discussion of figure 5). At the baseline coefficient, it does fall below X_{cush} on the way to achieving a stable equilibrium. However, a relatively small increase in Φ' to 1.5 times the baseline will cause the system to become nonstable.

Case 6 is operationally the same as Case 4; there is a difference of degree rather than kind. The daily effort function is the same in both cases, the difference is that d is constant in Case 6; it does not increase with decreases in X as in Case 4. Therefore, while in both cases the annual vessel effort will increase over some ranges of a declining stock size, in Case 6 it will be greater than or equal to what it will be in Case 4. As can be seen, the system is non-stable at the baseline (and lower) levels of Φ' with both low and high fixed levels of y. As in Case 4, in the low y case, this is



Figures 8 and 9. Vessel and Fishing Behavior with "Low" and "High" Fixed Values of *e* for Case 5



Figures 10 and 11. Vessel and Fishing Behavior with "Low" and "High" Fixed Values of *y* for Case 6 due to the backward bending PEC. While in the high *y* case, it is due to the truncated length of the negative sloped portion of the PEC below the EEC.

Other Issues Related to Profit Goal Achievement

Because GAB can potentially produce a larger open-access overshoot that will result in larger fleet sizes and smaller stock sizes, to the extent that it exists in the fisheries management problem may well be worse than if operators use PMB. Given the way that both types of operators will function around equilibrium, it will be necessary to remove more boats or put more strenuous controls on individual behavior with GAB. Further, the stock rebuilding program may well start at a lower stock size. There are other implications as well. One is the economic inefficiency effect. Not only will there likely be more boats during the development of the fishery, but they will be producing at less than their potential capacity. The economic wastes from open access may be higher than previously thought.

A related point has to do with the current emphasis by FAO and other fisheries organizations on obtaining measures of capacity for existing fisheries as an aid in determining long-range management objectives and plans (FAO 1998). Undertaking such studies is based on the assumption that PMB will generate incorrect results if GAB is the norm. It is also possible that both types of behavior may be present in the same fishery, which could make the problem even more difficult.

While this preliminary analysis has focused on open-access operation, the implications for the predicted effects of various types of regulation are important as well. For example, if managers try to reduce effort by implementing closed seasons, they may have no or little success if vessel owners use GAB and if their current level of d is less than D_{max}. The regulation will reduce D_{max}, but that may not affect their current choice of the number of days to fish. Similarly, a license limitation program would be less effective than anticipated if operators use GAB, because over certain ranges of stock sizes, vessel effort would increase with decreases in stock size. In both cases, there could be inequities if both types of participants were in the same fishery.

Summary and Suggestions for Further Research

The changes in the basic bioeconomic model which result from substituting GAB for PMB are as follows. Instead of vessel annual effort decreasing as stock size falls, it will do the reverse at least at stock sizes greater than economic equilibrium. Depending upon the operational rule used to achieve the profit goal, the inverse relationship between stock size and annual vessel effort can continue even at stock sizes lower than economic equilibrium. While GAB will result in lower vessel effort at higher stock sizes, depending on the operational rules, it can result in higher vessel effort at lower stock sizes. It can also result in higher economic equilibrium and cushion stock sizes. While this may appear to be biologically beneficial, the bottom line effects depend upon overall fishery operation. It is likely that there will be a larger open-access overshoot than with PMB. This means that even with a higher cushion stock size, the stock size may reach lower levels. Because of the way GAB affects the PEC and because of the relatively small differences between the economic equilibrium and cushion stock sizes, the fishery may not be able to reach a stable equilibrium, but will instead have a continuous pattern of boom and bust. There may also be periods where the fleet completely stops fishing due to low daily net returns. These results should be interpreted with care. However, from table 1 it can be seen from the example used here, compared to a baseline Φ that was well within the stable range with PMB, there is no stable equilibrium in Case 3 with a high *e*, and in Cases 4 and 6. This is true even with a Φ that is only 10% of the baseline. At the other extreme, there does not appear to be strong difference in stability patterns in Case 5 with a low *e*. The remaining cases produced a stable equilibrium at the baseline Φ, but the range over which it remained stable was much shorter than with PMB.

Among other things, future research on this topic should focus on the fundamental question of whether goal achievement behavior is used by participants and, if so, what goals are used and what sorts of operational rules are used to implement them. It will also be useful to expand the open-access analysis by considering such things as non-linear production functions, crowding externalities between vessels, a variable price of output, *etc*. Finally, it will be necessary to provide a rigorous analysis of how goal achievement behavior will affect the expected results of common regulation techniques.

References

Anderson, LG. 1980 The Necessary Components of Economic Surplus in Fisheries Economics. *Canadian Journal of Fisheries and Aquatic Sciences* 37(5):858–70.

___. 1986. *The Economics of Fisheries Management*, Revised and enlarged edition. Baltimore, MD: The Johns Hopkins University Press

Bockstael, N.E., and J.J. Opaluch. 1983. Discrete Modeling of Supply Response under Uncertainty: the Case of the Fishery. *Journal of Environmental Economics and Management* 3(3):125–37.

Charles, A.T. 1988. Fisheries Socioeconomics: A Survey. *Land Economics* 64(3): 266–95.

FAO. 1998. Technical Working Group on the Management of Fishing Capacity. *FAO Fisheries Report No. 586*, Rome, Italy.

Ferguson, B.S., and G.C. Lim. 1998. Introduction to Dynamic Economic Models. Manchester: Manchester University Press.

Hannesson, R. 1993. *Bioeconomic Analysis of Fisheries*. New York, NY: Halsted Press.

Holland, D.S., and J.G. Sutinen. 2000. Location Choice in New England Trawl Fisheries: Old Habits Die Hard. *Land Economics* 76(1):133–49.

Parks, P.J., and M. Bonifaz. 1994. Nonsustainable Use of Renewable Resources: Mangrove Deforestation and Mariculture in Ecuador. *Marine Resource Economics* 9(1):1–18.

Schaefer, M. 1954. Some Aspects of the Dynamics of Populations Important in the Management of Commercial Marine Fisheries. *Bulletin of the Inter-American Tuna Commission* 1:25–56.

Smith, V.L. 1969. On Models of Commercial Fishing. *Journal of Political Economy* 77:181–98.