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The Effects of Minimum Size Limits on Recreational Fishing

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Abstract *Minimum size limits have become an increasingly popular management tool in recreational fisheries. This popularity stems from the potential of minimum size limits to accomplish the twin goals of limiting overfishing and improving fishing quality through increasing the average size of fish caught. The success of minimum size limits in achieving these objectives depends, in a complicated way, on both the behavior of anglers and the biological mechanisms that guide the growth of the fish population. This paper examines these relationships and also considers the welfare implications of size regulations.*

Key words Fisheries management, minimum size limits, recreational angling.

Introduction

Popular recreational fisheries have been beset by the same problems faced by open-access commercial fisheries, and often for the same reasons, namely that individual anglers lack incentives to conserve because of the open-access nature of recreational fishing. As recreational angling has grown in popularity, open-access effort levels have been high enough to put severe pressure on fish populations. To prevent the collapse of stocks, managers of recreational fisheries have focused their attention on limiting angler effort. Traditional means used to limit overexploitation include creel limits, enhancement, closed seasons, gear restrictions, area closures, catch and release regulations, and size limits.

While limiting overexploitation has been considered to be the primary goal of fisheries management, managers have also begun to recognize the importance of managing the quality of the angling experience. Survey research has shown that angling quality has many dimensions. Catch per unit effort is among the things important to anglers, but many also value aesthetic and social aspects of fishing, including being outdoors and being with others who share enthusiasm for the sport.[1]

Since the role of a fisheries management agency is primarily limited to managing fish populations, we may justifiably focus exclusive attention on the contribution of fishing quality to angler satisfaction. Even so, it is essential to recognize that catch per unit effort may not be the sole criterion by which fishing quality is judged.

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[1] See Fedler and Ditton (1994) and the references cited therein for survey research into angler preferences.

The focus on catch rates as a measure of quality has been a common practice in the literature on valuation of recreational fisheries.[2] However, research has shown that other dimensions of catch are important.[3] Some anglers rate the quality of a fishing experience by the numbers of fish caught and kept, while others simply seek the experience of catching fish and either keeping enough to eat or releasing all of their catch.[4] Anglers may also have preferences over the attributes of fish caught and/or kept. Some may prefer the average size of fish caught to be large, others may prefer "pan-sized" fish for consumption, and still others may want the chance to catch a trophy-sized fish.[5]

The task of managing modern recreational fishing is considerably more complex than striving to maintain a sustainable population size. Some policies may contribute to some goals, but conflict with others. For example, limiting the season in order to reduce exploitation may cause high concentrations of anglers to crowd into areas over short periods, reducing the value of the angling experience. Other policies may be able to contribute to several goals. Minimum size limits, in which all fish smaller than a particular size must be released, are one option that can contribute to both higher catch levels and better catch quality. Size limits can lead to higher population levels (and, therefore, higher catch levels) for two reasons. First, size limits are a simple means to reduce fishing pressure since more fish are released. Second, size limits increase the number of reproductive fish, leading to higher spawning rates. Minimum size limits are also attractive because more large fish survive, increasing the average size of fish caught and increasing anglers' chances of catching trophy-sized fish (Hoff 1995).

Minimum size limits are an appealing management tool, and have become more widely used across the country.[6] As fisheries managers try to tailor regulations to suit individual fisheries, it is likely that minimum size limits will be employed even more. Still, fisheries managers are uncertain about whether to impose these limits and, if so, to what degree. Research in the fisheries biology literature has addressed questions about the effectiveness of minimum size limits in alternative settings.[7] While these studies are quite detailed in their consideration of the biology of fish populations, they neglect any behavioral responses that may occur on the part of anglers to the imposition of size limits. In fact, the success of minimum size limits in achieving regulators' objectives depends, in a complicated way, on both the biological mechanisms that guide the growth of the fish population and the behavior of anglers.

To assess the potential success of a minimum size limit, it is important to consider several key questions. Will minimum size limits reduce harvest in the short-run? Will reductions in harvest lead to increases in the population, and how fast will increases occur? How will changes in the population affect harvest rates and the average size of fish caught in the long-run? How might these changes affect angler welfare? Finally, how are anglers affected by the level of the regulation?

This paper presents a simple model designed to answer these questions. Our primary focus is a predictive model of angler behavior and population dynamics, but

[2] See, for example, Samples and Bishop (1985), Johnson and Adams (1989), and Huppert (1989).
[3] Chipman and Helfrich (1988) first used principal components to group anglers into types in a study of Virginia river anglers. Fedler and Ditton (1994) examined seventeen of these studies. The studies found distinct subgroups that expressed different preferences for aspects of fishing trips.
[4] Anderson (1993) includes both landings (fish kept) and catch per day in a benefit function.
[5] For example, Petering, Isbell, and Miller (1995), in a survey of anglers, found that fish length and fish numbers both affected fishing satisfaction.
[6] Merwin (1998) writes that minimum size limits, "are by far the most common management tool and … are now the subject of wide experimentation in many states."
[7] See, for example, Maceina *et al*. (1998) for an analysis of the sauger fishery in Alabama and Colvin (1991) for a consideration of a crappie fishery in Missouri.

welfare considerations are also addressed. The model combines a behavioral model of angler participation with a simple biological model embedding a depiction of population size distributions. While purposely oversimplified, this model, nevertheless, addresses the above questions and points toward additional research issues.

In the next section, we outline a general model of angler behavior in which an angler derives utility from the number and size of fish kept. Then, we explore the problem using the Constant Elasticity of Substitution (CES) utility function. With this utility function, we investigate the effects of imposing a binding minimum size limit both in the short-run, as the regulation is imposed, and in the long-run, as the fish population responds.

General Model

We consider the choices of a representative angler in an open-access fishery once he has chosen his level of participation in the fishery.[8] In an open-access fishery, anglers cannot expect to benefit from conservation, so they make a series of static decisions rather than formulating a dynamic plan. We assume, therefore, that anglers take biomass as given. We assume also that anglers derive utility from the number of fish they catch and keep, h, and the minimum size of fish they keep, s.[9] The catch function is specified as a standard Schaefer production function, so catch is equal to qEN, where q is a catchability coefficient, E is the predetermined effort level, and N is the biomass level.[10] Total catch, then, is qEN. The number of fish kept, h, is some fraction of total catch where the fraction is determined by the "keeper," or minimum size kept. This fraction is determined by the distribution of fish in the lake as follows. The probability density function that characterizes the distribution of fish in a lake is $f(s)$. The corresponding cumulative density function, $F(s)$, is the fraction of fish below a particular size. Then, $1 - F(s)$ is the fraction of fish above a particular size, s; this is the fraction of total catch that will be kept as a function of the minimum size, s. Finally, an equation defining the production possibilities frontier between the two outputs, harvest (number kept) and minimum size, can be written:

$$h = qEN[1 - F(s)]. \tag{1}$$

The full specification of the angler's utility maximization problem is then:

$$\max_{s} U(h, s) \tag{2}$$

subject to

$$h = qEN[1 - F(s)].$$

[8] We choose this approach to highlight the angler's decision to keep or release fish. A more general model would explain the participation decision, but would obscure the keep/release decision.

[9] It may be more reasonable to think of angler utility as a function of the average size of fish kept. This average size can easily be translated into the minimum size, so the two specifications are equivalent. We use minimum size for analytical convenience.

[10] The Schaefer model is discussed in Clark (1990). It assumes that catch-per-unit-effort (h/E) is proportional to the stock level (N) through a constant proportionality factor, q. As a reviewer points out, the heterogeneity of anglers could be reflected in alternative levels of the catchability coefficient, q. The catchability coefficient could change over time as skill levels improve or could serve to differentiate serious anglers from casual ones. The introduction of a varying q might prove useful in empirical work, but would unduly complicate this theoretical model.

Notice that the choice of s determines the number of fish kept, h, through the production possibilities relationship. Substituting the production possibilities equation into the utility function and taking the derivative with respect to s yields:

$$-U_h\, qENf(s) + U_s = 0. \tag{3}$$

Rearranging this expression yields:

$$U_s/U_h = qENf(s). \tag{4}$$

This condition states that the marginal rate of substitution between h and s must be equal to the marginal rate of product transformation at the optimum.[11] We can think of the relative price of h as $1/[qENf(s)]$ so that a higher biomass level (N), a higher effort level (E), or a higher catchability coefficient (q), makes keeping fish relatively less costly than maintaining a higher minimum size.

To simplify the model, we assume that the distribution of fish is uniform (0,1).[12] Therefore, $F(s) = s$ and $f(s) = 1$. The equation describing the production possibilities frontier becomes

$$h = qEN(1 - s) \tag{5}$$

We can then characterize the optimal choices of h^* and s^* using an indifference curve diagram (figure 1). The production possibilities frontier is a linear function of s, and s takes on values between 0 and 1. As q, E, or N increase, the production possibilities frontier rotates up, pivoting around 1, the maximum value of s. Figure 1 provides one example of how h^* and s^* may change as biomass increases from N_0 (point a) to N_1 (point b), and then to N_2 (point c). In this illustration, h^* increases as biomass increases. The voluntarily chosen minimum size, s^*, falls as biomass grows from N_0 to N_1, then rises as biomass grows further to N_2.[13]

From the locus of optimal harvest levels with alternative biomass levels, we can determine $h^*(N)$ (figure 2). Points a, b, and c correspond with those in figure 1. With the introduction of a biomass growth function into this model, the equilibrium level of biomass can be characterized. The $h^*(N)$ function is upward sloping, and the biological yield function is concave, reaching a carrying capacity at K. Point b represents the equilibrium where the level of harvest $[h^*(N)]$ equals the growth in biomass. The resulting biomass level is $\hat{N}^U$, where the hat denotes equilibrium and the superscript denotes that the equilibrium is unregulated. Note that, in figure 1, the location of the production possibilities frontier is not arbitrary. If biomass is at N_0, harvest $[h^*(N_0)]$ will be less than the growth in biomass, the population will grow, and the production possibilities frontier will rotate up until the biomass reaches $N_1 = \hat{N}^U$. Similarly, if biomass is at N_2, harvest $[h^*(N_2)]$ will be higher than biomass growth. The popula-

[11] A reviewer suggests an alternative interpretation. The first order condition can be rewritten as $U_s/U_h = \lambda(s)h$, where $\lambda(s) = f(s)/[1 - F(s)]$. This $\lambda(s)$ is familiar as an inverse Mill's ratio, and it reflects the truncation in the angler's choice problem.

[12] To translate into actual sizes, multiply s by the difference between the size of the largest and smallest fish and add to the size of the smallest fish.

[13] It may be helpful to think of this model as an analog to the standard labor/leisure model in which the budget constraint pivots around the maximum amount of leisure on the horizontal axis according to the wage rate. In this case, minimum size takes the place of leisure, where the maximum minimum size is 1, and the production possibilities frontier pivots according to the values of q, E, and N. As the wage increases in the labor/leisure model, the consumption of goods always increases, but the consumption of leisure may rise or fall, depending on the relative strengths of the income and substitution effects. This model has analogous results.

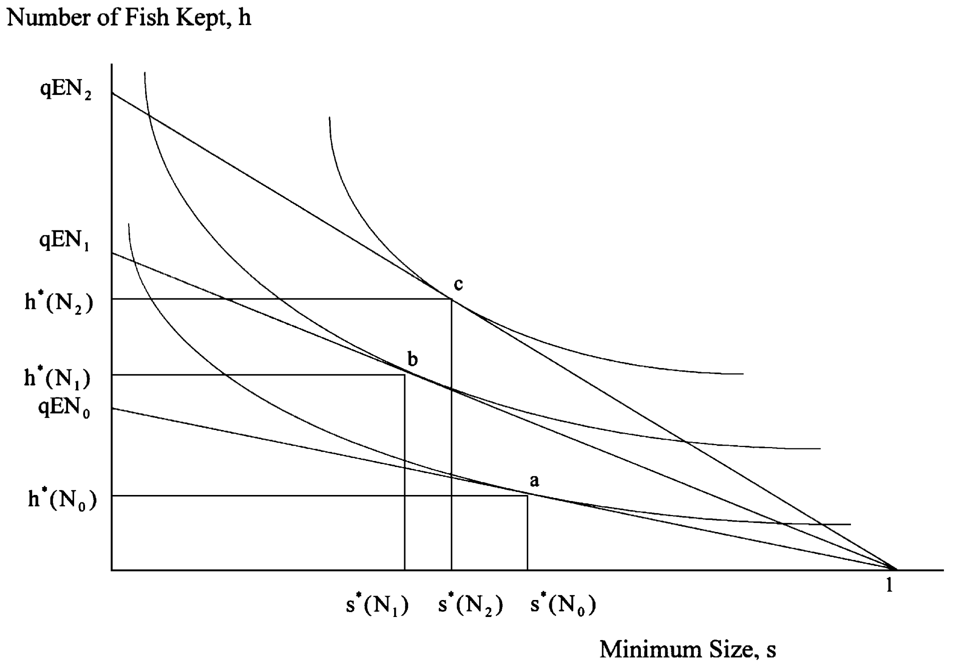

Figure 1. Optimal Choices of Minimum Size and Number of Fish Kept

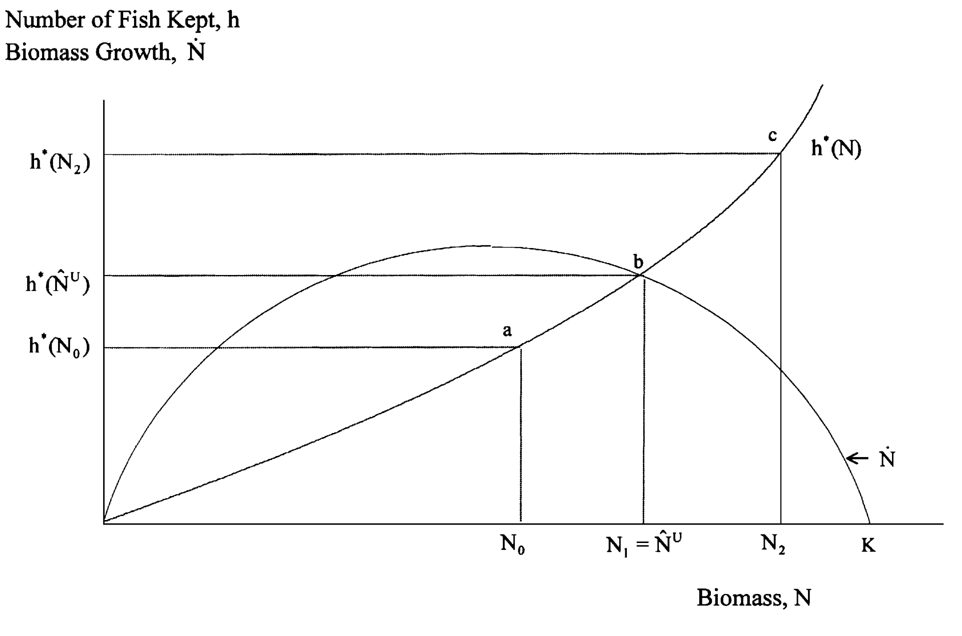

Figure 2. Determination of the Unregulated Equilibrium

tion size will fall, and the production possibilities frontier will rotate down until the biomass reaches $N_1 = \hat{N}^U$.

Now consider the introduction of a binding minimum size limit, $\bar{s}$. The size limit must be larger than the voluntarily chosen minimum size in order to be effective (figure 3). When $\bar{s}$ is imposed, the angler is constrained to harvest according to the function $\bar{h}(N) = qEN(1 - \bar{s})$. This function intersects the yield curve at a higher biomass level than does $h^*(N)$. In the short-run, biomass will be at the unregulated equilibrium level $\hat{N}^U$, and harvest will fall to $\bar{h}(\hat{N}^U)$ at point d. Then, because harvest is lower than yield, biomass will grow until a new regulated equilibrium is reached at point e, where the biomass level is $\hat{N}^R$ and harvest is $\bar{h}(\hat{N}^R)$.

We can also depict these changes on an indifference curve diagram (figure 4). Initially, the angler is at point b with the biomass at the original unregulated equilibrium level, $\hat{N}^U$. When the regulation $\bar{s}$ is imposed, the angler is constrained to be at point d, with a reduced harvest level. This constraint must lead to reduced utility; anglers could have chosen the regulated minimum size and reduced harvest level in the absence of regulation. Since they did not, the regulated combination of $\bar{h}(\hat{N}^U)$ and $\bar{s}$ must yield lower utility than h^* and s^*. However, since harvest is reduced, biomass will grow to the regulated equilibrium biomass level, $\hat{N}^R$, and the production possibilities frontier will rotate up. The angler will now be at point e. At this point, the angler achieves a higher utility level than before the regulation was imposed, even though harvest is lower, and the angler is still constrained by the regulation.

There are many possible outcomes depending on the initial equilibrium and the level at which the regulation is set. Consider, for example, an optimal harvest function that intersects the biological yield curve to the left of maximum sustainable yield (figure 5).[14] The angler is at point a with biomass level $\hat{N}^U$. The introduction

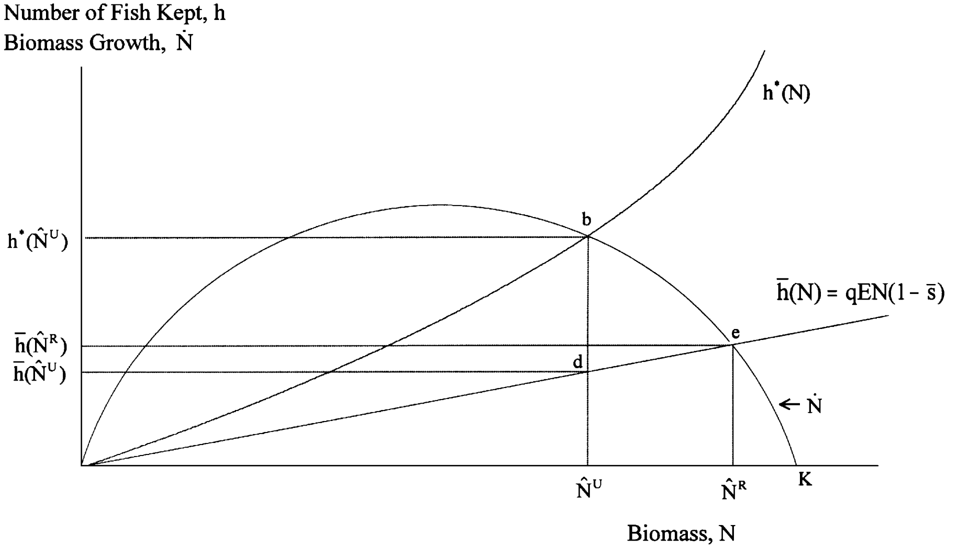

Figure 3. Determination of the Regulated Equilibrium

[14] The concept of maximum sustainable yield is discussed in Clark (1990). It is based on the assumption that, at any population level below the carrying capacity, the fishery produces some amount that can be harvested without altering the population level. The maximum sustainable yield is the maximum of all potential sustainable harvest levels. In the logistic model, maximum sustainable yield occurs at a population level that is half the carrying capacity.

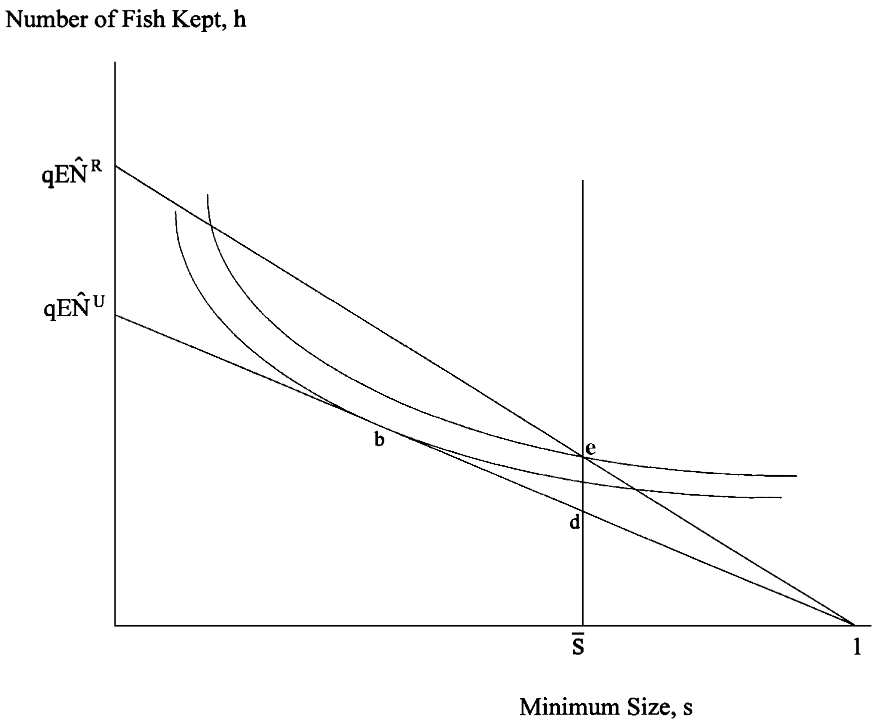

Figure 4. Effects of a Minimum Size Limit Regulation on Utility

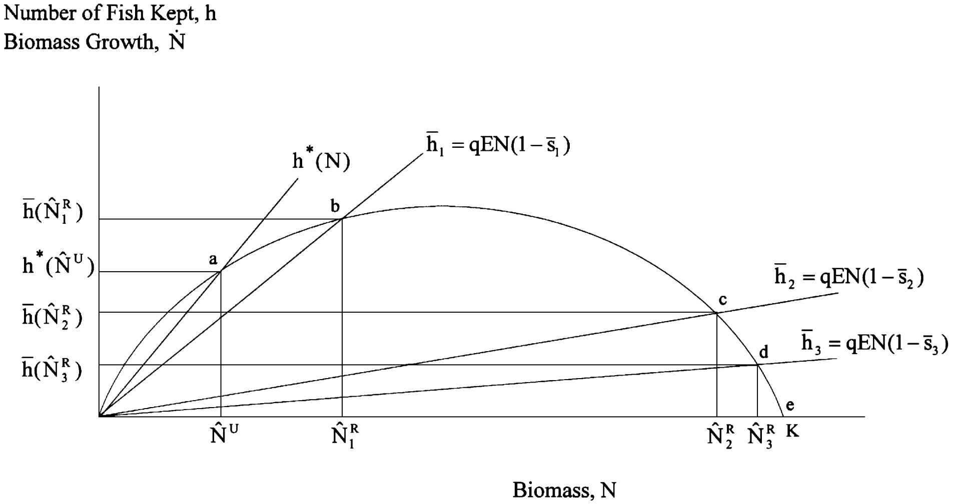

Figure 5. Alternative Minimum Size Limit Regulations

of a somewhat restrictive minimum size limit ($\bar{s}_1$) will reduce harvest initially, but will lead to increased biomass ($\hat{N}_1^R$) and increased harvest [$\bar{h}(\hat{N}_1^R)$] in the long-run (point b). In the long-run, both harvest and minimum size will be higher, leading to an unequivocal increase in utility. This outcome is represented by point b in figure 6. With a more stringent regulation, $\bar{s}_2$, where the restricted harvest function intersects to the right of maximum sustainable yield, biomass will grow even larger (to $\hat{N}_2^R$), minimum size will be higher, but harvest will fall relative to the initial harvest level [to $\bar{h}(\hat{N}_2^R)$] (see point c in figures 5 and 6). Still, utility is higher than both the initial utility and the utility level associated with $\bar{s}_1$, since the higher minimum size contributes to utility, and the reduced harvest is achieved at a lower relative cost due to the increase in biomass. If the regulation becomes very strict, it is possible that harvest falls so far that utility will also fall (see point d in figure 6). In the limit, as the regulated minimum size approaches one, harvest approaches zero, utility approaches zero, and biomass approaches its carrying capacity. This is represented by point e in both figures.

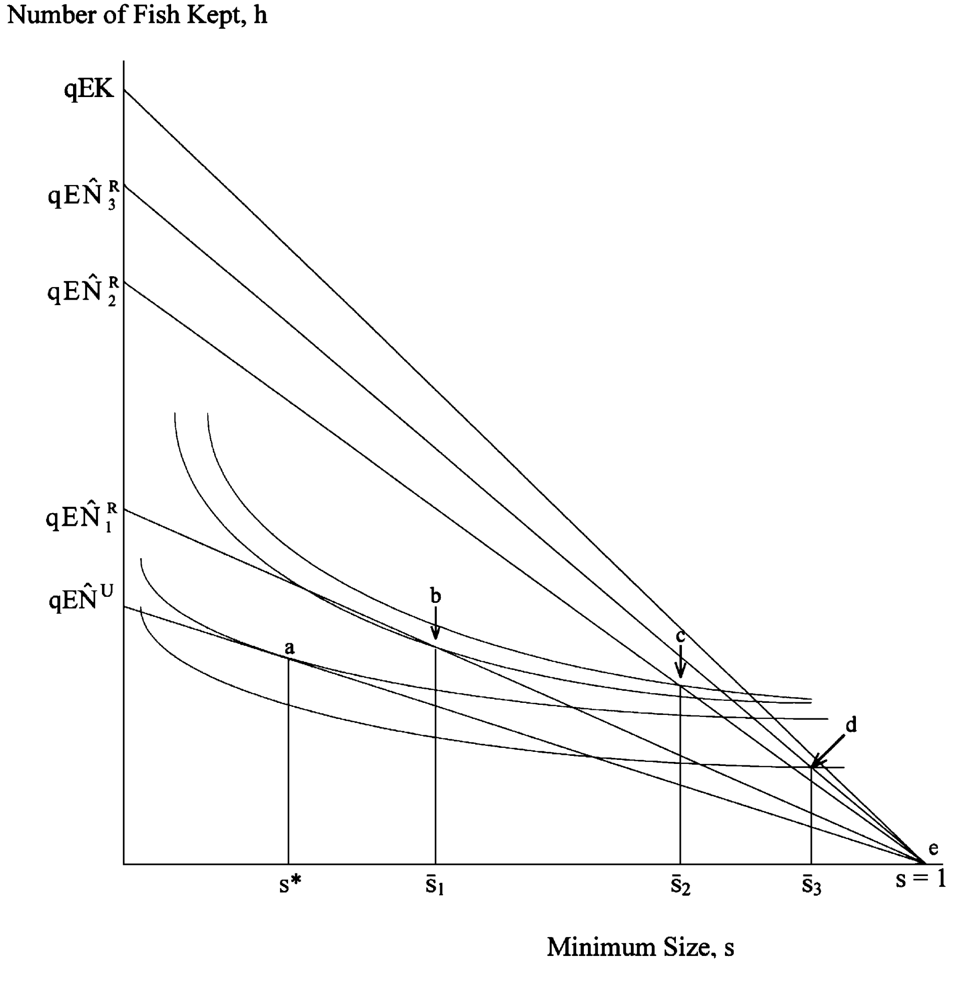

Figure 6. Effects of Alternative Minimum Size Limit Regulations on Utility

As this analysis suggests, many long-run results are possible relative to the initial position: both harvest and utility may be either higher or lower in the long-run equilibrium. Furthermore, even though increases in harvest lead to unequivocal increases in long-run utility levels, decreases in harvest do not necessarily lead to reductions in utility in the long-run. Apart from questions about welfare, it is interesting to look at how changes in biomass may change the voluntarily chosen minimum size, making the minimum size constraint either more or less binding. The implied constraint on harvest [that is, harvesting at $\bar{h}(\hat{N}^R)$ rather than at $h^*(\hat{N}^R)$] may also become more or less binding. At this level of generality, however, it is difficult to determine the outcomes that would emerge from any particular size regulation. To look at these questions in more detail, we investigate the problem using a CES utility function.

The Constant Elasticity of Substitution Utility Function

The CES utility function allows the elasticity of substitution between the number of fish kept, h, and the minimum size of fish kept, s, to range between zero and infinity. As it turns out, the nature of the solution using the CES utility function hinges on whether the elasticity of substitution between h and s is greater or less than one.

The CES utility function is specified as:

$$U(h, s) = (\alpha h^\rho + \beta s^\rho)^{1/\rho} \tag{6}$$

The solutions for h^* and s^* are:

$$s^* = \frac{1}{1 + \left(\frac{\beta}{\alpha}\right)^{\frac{1}{\rho-1}} (qEN)^{-\frac{\rho}{\rho-1}}} \tag{7}$$

and

$$h^* = \frac{qEN}{1 + \left(\frac{\alpha}{\beta}\right)^{\frac{1}{\rho-1}} (qEN)^{\frac{\rho}{\rho-1}}}. \tag{8}$$

Harvest is an increasing function of biomass, and minimum size may be either an increasing or decreasing function of biomass. The elasticity of substitution between h and s [$\sigma = 1/(1 - \rho)$] determines whether the $h^*(N)$ function is convex or concave in N, and whether $s^*(N)$ is downward or upward sloping.

By taking the second derivative of the $h^*(N)$ function, we find that h^* is convex in N if ρ is greater than zero. If ρ is greater than zero, the elasticity of substitution between h and s is greater than one. If ρ is less than zero, so that the elasticity of substitution is less than one, then h^* is concave in N. Taking the first derivative of $s^*(N)$ shows that if ρ is greater than zero, s^* is decreasing in N, but if ρ is less than zero, s^* is increasing in N. If ρ is zero (so that the elasticity of substitution between

h and s is one), the CES utility function simplifies to a Cobb-Douglas. In the Cobb-Douglas, $h^*(N)$ is linear and s^* is invariant to changes in biomass.[15]

The intuition behind these results relies on consideration of the income and substitution effects of a price change. As N increases, the relative price of h falls. The substitution effect encourages a move from minimum size (s) to the number of fish kept (h), where the income effect causes both h and s to rise. If the two goods are highly substitutable, the income effect is not large enough to counteract the strong substitution effect so that the minimum size falls. The income effect reinforces the substitution effect for the number of fish kept, so the increase in h is substantial. On the other hand, if the two goods are not highly substitutable, the substitution effect is weak. The income effect is strong enough to counteract the negative substitution effect for s so that s increases. The number of fish kept, h, also increases, but the increase is not as dramatic as with a strong substitution effect. Therefore, the $h^*(N)$ function is concave.

Minimum Size Limits

Now we consider the effects of the imposition of a minimum size limit. To be effective, the regulated minimum size, $\bar{s}$, must be larger than the voluntarily chosen minimum size, s^*. In the short-run, biomass will remain at the unregulated level, and harvest will fall to $\bar{h}(\hat{N}^U) = qE\hat{N}^U(1 - \bar{s})$. Biomass will eventually rise to $\hat{N}^R = [a - qE(1 - \bar{s})]/b$, and harvest will rise in the long-run to $\bar{h}(\hat{N}^R) = qE\hat{N}^R(1 - \bar{s})$.

In the Cobb-Douglas case, the difference between the voluntarily chosen minimum size and the regulated minimum size will not change as biomass grows. Anglers remain as constrained (in terms of minimum size) as before the regulation was imposed, regardless of changes in the biomass, since the optimally chosen minimum

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[15] The Cobb-Douglas utility function can be written:

$$U(h, s) = h^\alpha s^\beta$$

Carrying out the optimization, we get solutions for harvest and minimum size:

$$s^* = \frac{\beta}{\alpha + \beta}$$

and

$$h^* = \frac{\alpha}{\alpha + \beta}\, qEN.$$

The choice of s is a function only of the parameters α and β, and is invariant to levels of biomass and effort. Harvest is an increasing linear function of biomass, effort, and catchability. With a logistic biological growth function, $\dot{N} = g(N) = aN - bN^2$, we can solve for the equilibrium biomass and harvest levels, $\hat{N}^U$ and $h^*(\hat{N}^U)$:

$$\hat{N}^U = \frac{1}{b}\left[a - qE\left(\frac{\alpha}{\alpha + \beta}\right)\right],$$

$$h^*(\hat{N}^U) = qE\left(\frac{\alpha}{\alpha + \beta}\right)\frac{1}{b}\left[a - qE\left(\frac{\alpha}{\alpha + \beta}\right)\right].$$

These closed-form solutions are unattainable with the CES utility function.

size depends only on the parameters of the utility function. Since both $h^*(N)$ and $\bar{h}$(N) are increasing linear functions of biomass, the difference between the two grows as biomass grows. In a sense, anglers will feel more constrained (in terms of numbers of fish kept, *h*) in the long-run than immediately after the regulation is imposed, even though the long-run (constrained) harvest level, $\bar{h}(\hat{N}^R)$, is higher than the initial constrained harvest level $[\bar{h}(\hat{N}^U)]$. This is because anglers would choose a much higher *h* with the long-run biomass level than the constrained harvest level (figure 7) (The distance between A and A^1 is smaller than the distance between B and B^1).

Looking at the CES case, we see that the choice of minimum size is no longer invariant to changes in biomass. Therefore, the minimum size choice is likely to differ in the new equilibrium. A relevant question is whether the minimum size constraint remains binding. Does the choice of minimum size increase to the constrained size? First, consider the harvest function when the elasticity of substitution between *h* and *s* is greater than one. In this case, the regulation becomes even more binding. If the elasticity of substitution is greater than one, the voluntarily chosen minimum size becomes smaller with increased biomass. So, as the regulation is effective in increasing biomass, the gap between the regulated minimum size and anglers' voluntarily chosen minimum size becomes wider. In addition, since the $h^*(N)$ function is convex, the gap between the voluntarily chosen harvest level and the constrained harvest level also becomes wider. Whether the utility level rises or falls in the long-run is an open question, but the angler certainly will feel more constrained as bio-mass grows.

Recall that if the elasticity of substitution between *h* and *s* is less than one, the $s^*(N)$ function is increasing in *N*, and the $h^*(N)$ function is concave. A binding regulation will raise the biomass level, and, consequently, the voluntarily chosen minimum size. The gap between the regulated minimum size and the voluntarily chosen -inimum size is reduced, and anglers will feel less constrained as the regulation becomes effective in increasing the size of the population.

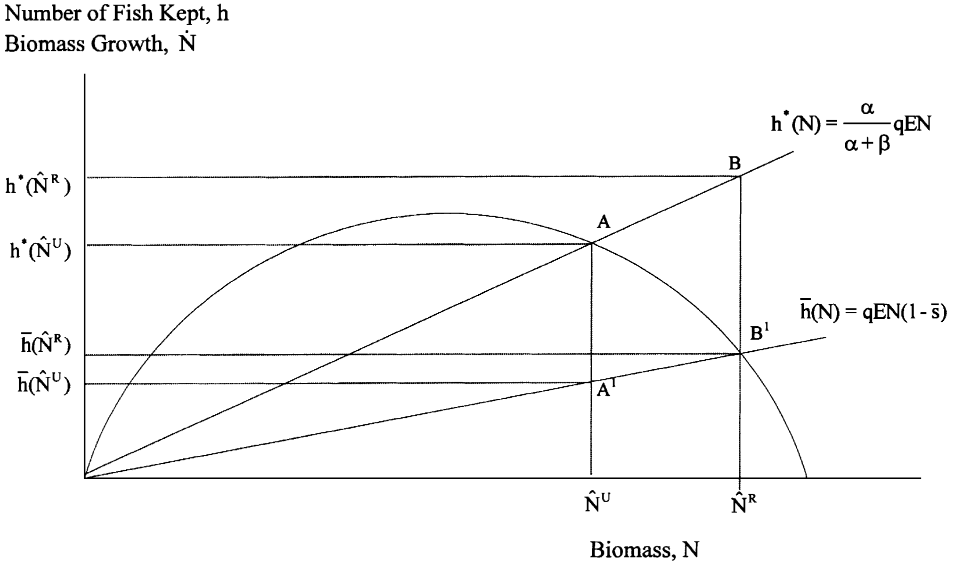

Figure 7. Regulated and Unregulated Harvest Levels in the Short- and Long-Runs

Welfare Implications of Size Limits

With a set of parameter estimates, it is a straightforward exercise to calculate the utility levels that would prevail at alternative regulated equilibria. It is only necessary to substitute the regulated harvest level at the steady state, $\bar{h}[N^R(\bar{s})]$, and the minimum size limit, $\bar{s}$, into the utility function to find the long-run utility level. In the Cobb-Douglas case, it is even possible to optimize the resulting expression with respect to minimum size to find the minimum size that would yield the highest long-run utility level. To find the size limit that would maximize long-run utility with more complex utility functions (such as the CES), numerical solution methods are required.

Of course, the long-run utility level is not achieved instantaneously. Figure 8 shows how harvest rates and minimum size change with time. Anglers first experience a sudden drop of utility levels as harvest falls in response to the implementation of the regulation. Since minimum size contributes to utility, the increase in minimum size (to $\bar{s}$) partially compensates for the loss in utility from a decrease in harvest. The immediate impact on utility is certainly negative.

As the biomass grows, the restricted harvest level also grows, implying an increase in utility along the path to a new equilibrium. Anglers continue to fish and derive utility as biomass grows. The welfare effect of a particular regulation, therefore, would be summarized in the discounted sum of utility levels that would emerge as biomass adjusts to the new equilibrium. Different regulations will lead to different adjustment paths and different long-run equilibria. It is, therefore, correct to judge alternative size limits based on the sum of discounted utility levels that would emerge from alternatives. The expression to evaluate discounted streams of utility levels would be:

$$\int_0^\infty e^{-rt} U\left\{\bar{h}[N(t,\bar{s})], \bar{s}\right\} dt. \tag{9}$$

Note that, along the path to the restricted equilibrium, anglers keep fish according to $\bar{h}$, which is a function of growing biomass and minimum size. To find the path of biomass, the differential equation describing the growth of biomass must be solved. With a logistic growth function, this solution is:

$$N(t) = \frac{\dfrac{a - qE(1-\bar{s})}{b}}{1 + \left(\dfrac{\dfrac{a - qE(1-\bar{s})}{b} - N_0}{N_0}\right) e^{[a+qE(1-\bar{s})]t}}. \tag{10}$$

Summary and Conclusions

This paper has used a comprehensive model to address questions surrounding the use of a minimum size regulation to improve fishing quality. Using simplified behavioral and biological models, both the short- and long-run implications of minimum size restrictions were investigated. In the short-run, such a regulation diminishes harvest levels and angler utility. However, as the biomass responds to the re-

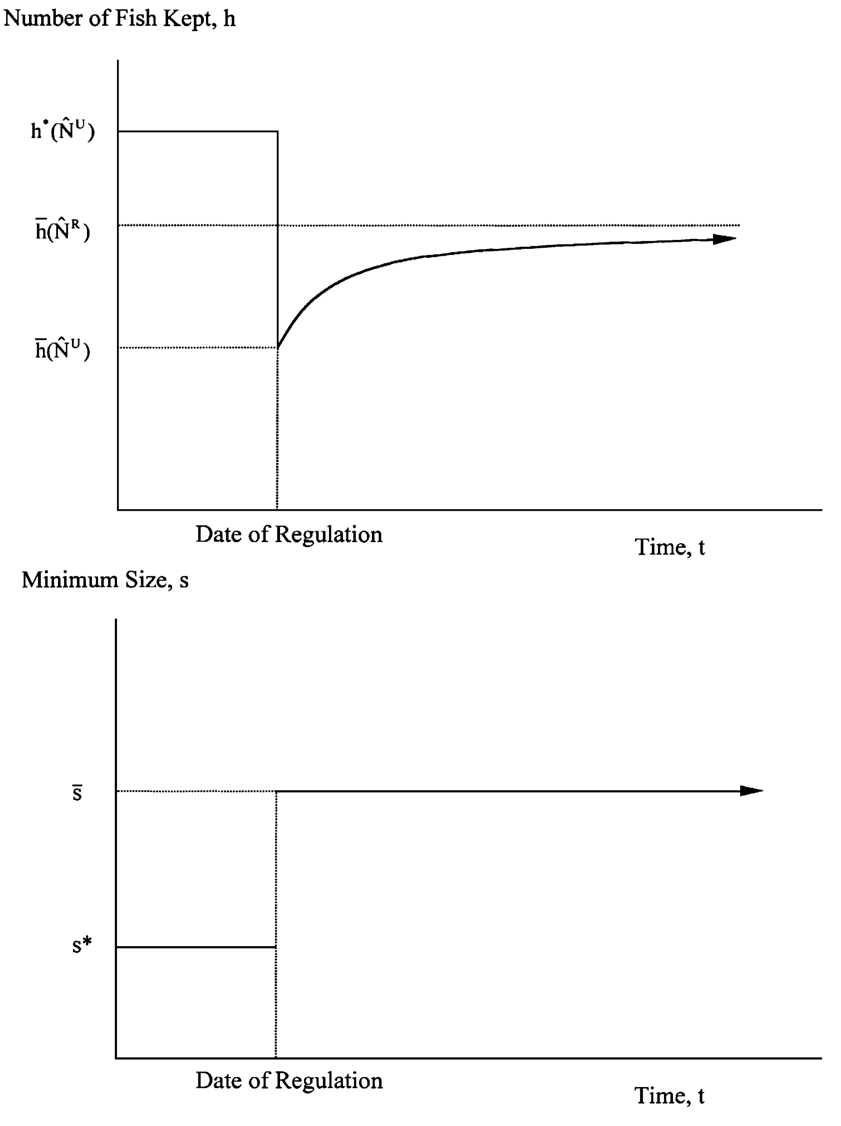

Figure 8. Adjustment to a Regulation Over Time

duced harvest, the harvest level recovers. If the fishery starts at a point to the left of maximum sustainable yield, this move unequivocally increases angler welfare. If the starting point is to the right of maximum sustainable yield, harvest declines in the long-run. Still, the increase in minimum size due to the regulation may compensate for this decreased harvest, and anglers may still be better off in the long-run.

This paper also investigated the degree to which the regulation would be binding in the long-run, depending upon the form of the utility function. If the elasticity of substitution between the number of fish kept and minimum size is greater than one, the gap between the voluntarily chosen minimum size and harvest level, and the regulated minimum size and harvest level, widens as the regulation becomes successful in increasing biomass. If the elasticity of substitution is equal to one (the

Cobb-Douglas case), the voluntarily chosen minimum size remains constant, and the gap between the voluntarily chosen and regulated minimum size remains the same. However, the gap between the voluntarily chosen harvest level and the regulated harvest level widens. Finally, if the elasticity of substitution is less than one, the minimum size constraint becomes less binding as biomass grows.

Angler behavior changes as size limits are imposed, changes in behavior affect fish populations, angler welfare is sensitive to alternative size limits, and none of these factors can be properly looked at in isolation. For these reasons, it is important to consider minimum size limits in a comprehensive bioeconomic model. This paper has done so, and the ideas here should be of interest to fisheries managers as they continue to use minimum size limits to improve fishing quality. Still, the practical applicability of this model, in its current form, should not be overstated. First, it is likely that the distribution of fish sizes will shift as a result of size limits. A more detailed model of population biology would be required to handle this possibility. Second, anglers probably have a richer choice set than specified here, including alternative levels of effort and alternative angling sites. With these extensions, this model should provide substantial guidance to managers setting size regulations.

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