Working Paper Series

Working Paper No. 388

ASPECTS OF SPECIES EXTINCTION: HABITAT LOSS AND OVEREXPLOITATION

Anthony C. Fisher

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS

BERKELEY

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

University of California

Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

Working Paper No. 388

ASPECTS OF SPECIES EXTINCTION: HABITAT LOSS AND OVEREXPLOITATION

Anthony C. Fisher

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics

March 1987

ASPECTS OF SPECIES EXTINCTION: HABITAT LOSS AND OVEREXPLOITATION

Anthony C. Fisher

1. Introduction

This paper explores the uses of economic theory in understanding what many noneconomists regard as the major environmental problem of our time--the coming mass extinction of species. Among economists, it is John Krutilla who recognized the problem, along with the closely related one of wilderness preservation, and engaged the interest and talents of the profession. His seminal work, "Conservation Reconsidered," which appeared in the American Economic Review, now nearly 20 years ago, not only drew our attention to the problem but first (to my knowledge) showed how concepts of economic theory could help to explain it and even offer solutions. This brilliant and profound work marked the beginning of a research program, originally at Resources for the Future under Krutilla's direction and now represented by a variety of efforts there and elsewhere. It was my privilege about halfway through in 1975 to participate with him in a summing up of what might be regarded as the first phase of the program. In the present paper, I wish to offer a couple of models, drawing on more recent work by myself and others, to describe key aspects of the problem of species extinction: habitat loss and overexploitation.[1]

Although some part of the problem is surely due to the harvesting or overharvesting of particular species, most knowledgable people believe loss of habitat is more important. As the well-known biologist, Edward O. Wilson has stated: "The one process ongoing in the 1980's that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats" (my italics). This can take several forms: Direct conversion as in drainage of wetlands or development of drylands for agriculture, housing, and transportation; chemical pollution as from acid rain; and "biological pollution"--the introduction of exotic species. Of these, the most important currently appears to be direct conversion for agricultural and other development. Prevention of widespread extinctions is thus intimately related to preservation of the natural environment.

The difficulty is that wildlands and the natural populations they support are the results of geomorphologic and biologic processes taking place over millions of years. If destroyed, they cannot be replaced or restored. In other words, the loss is irreversible. This is enough to suggest care in decisions that will lead to loss of habitat. But there is another complicating factor at work here: uncertainty about the value of what will be lost. It is simply not true that every disputed tract is home to a plant or animal species that will prove to be of value to humans. On the other hand, we can be fairly sure--though only in a statistical sense--that the loss of large tracts, especially tropical moist forests that support a rich variety of species (many as yet undiscovered and, therefore, untested for useful properties), will result in some loss of value. Further, information in this respect is likely to improve over time as research activities uncover new species, screen them for medicinal properties, explore their uses in industrial processes, crossbreed key characteristics into domesticated crops and livestock, etc.

The question I wish to explore here is how to think about developing a natural environment, taking account of both the irreversibility of development and the accumulation over time of information about the values (if any) that development would preclude. In the next section, I present a model to describe the development decision.

2. A Model of Habitat Loss

The decision is whether or not to develop a tract of wildland. I assume the decision will be made on the basis of an evaluation of benefits and costs, with the decision rule: Develop if the net present value of benefits exceeds that of costs, including the opportunity costs, the foregone benefits of preservation. I assume further that development is irreversible: If the tract is developed in the first of two periods considered, it cannot be preserved in the second period. Finally, I assume that second-period benefits of development and preservation are uncertain, but information will improve and the uncertainty will be resolved by the start of the second period.[2]

A useful way of approaching this problem is to consider what occurs when the decision-maker deals with the uncertainty about second-period benefits by simply replacing random variables with their expected values, a common practice in applied analysis. The resulting assessment of the development project and the corresponding decision will then be contrasted to those that would follow a proper accounting for the prospect of new information. The implicit assumption of risk neutrality in both cases will also be further discussed.

Suppose, then, the decision-maker chooses to preserve or develop in the first period on the basis of known first-period and expected second-period benefits. Net present value over both periods, as a function of the first-period decision (0 or 1, where 0 = preservation and 1 = development), is:

$$V^*(0) = B_1(0) + \delta \max \{E[B_2(0, \theta)], E[\hat{B}_2(1, \theta)]\} \qquad (1)$$

or

$$V^*(1) = B_1(1) + \delta E[B_2(1, \theta)] \qquad (2)$$

where B_1 = first-period benefit, B_2 = second-period benefit, δ = a discount factor, and θ = a random variable. Note that, as a consequence of the irreversibility assumption, first-period development is locked in (equation 2).

The development decision rule is:

$$d_1^* = \begin{cases} 0 & \text{if} \quad V^*(0) - V^*(1) \geq 0 \\ 1 & \text{if} \quad V^*(0) - V^*(1) < 0 \end{cases} \tag{3}$$

where d_1 = first-period development. Observe that, if $E[B_2(1, \theta)] \geq E[B_2(0, \theta)]$, the current development decision is based solely on a comparison of current preservation and development benefits, $B_1(0)$ and $B_1(1)$.

Now suppose the first-period decision allows for new information that will resolve the uncertainty about second-period benefits by the start of the second period. Net present value in this scenario is given by:

$$\hat{V}(0) = B_1(0) + \delta\ E\{\max\ [B_2(0, \theta),\ B_2(1, \theta)]\} \tag{4}$$

or

$$\hat{V}(1) = B_1(1) + \delta\ E[B_2(1, \theta)]. \tag{5}$$

Note that second-period benefits are not replaced by their expected values. Instead, the decision-maker is assumed to learn which second-period option, $d_2 = 0$ or $d_2 = 1$, will yield greater benefits and to choose that one. Of course, at the start of the first period, when d_1 must be chosen, he has only an expectation as to which will prove greater.

The development decision rule is:

$$\hat{d}_1 = \begin{cases} 0 & \text{if} \quad \hat{V}(0) - \hat{V}(1) \geq 0 \\ 1 & \text{if} \quad \hat{V}(0) - \hat{V}(1) < 0. \end{cases} \tag{6}$$

What can we say about value-maximizing or optimal development in the first period in each case? Clearly, since $V^*(d_1)$ and $\hat{V}(d_1)$ are different, d_1^* and $\hat{d}_1$ will be different. A natural hypothesis is that $\hat{d}_1 \leq d_1^*$ since it would seem to make sense to put off development, which is irreversible, if there is a prospect of better information about the benefits it will preclude. Stated differently, if the decision-maker ignores the prospect of better information and simply replaces random variables with their expected values, first-period development will be too great. This is precisely the result we obtain. From the convexity of the maximum operator and Jensen's inequality,

$$\hat{V}(0) - V^*(0) = \delta E \{\max [B_2(0, \theta), B_2(1, \theta)]\} - \delta \max \{E[B_2(0, \theta)], E[B_2(1, \theta)]\} \geq 0. \tag{7}$$

Since $\hat{V}(1) = V^*(1)$, it follows from (7) that $\hat{d}_1 \leq d_1^*$. This means that optimal first-period use of the tract is <u>less</u> likely to be full development ($d_1 = 1$) when the decision takes proper account of the prospect of new information. Conversely, ignoring this prospect and replacing random variables with their expected values (an easy trap to fall into) will bias the decision in favor of development.

Qualifications and Extensions

A couple of implicit assumptions lie behind the result as stated. These merit some discussion here. One involves treatment of the decision-maker's attitude toward risk. In working with expected values, I have implicitly assumed a risk-neutral attitude. Following the arguments of Arrow and Lind (1970) and others, this may be appropriate in a social decision. But even if it is not, note that the result is independent of any assumption about risk preferences. Although benefits, in the setting of an applied analysis, might normally be measured in money units, there is nothing in our formulation that requires this. Benefits could just as well be measured in utility units, in which case the decision-maker is maximizing expected utility and displays risk aversion. The result--a traditional bias in favor of development or habitat loss--continues to hold. Of course, the numbers in an actual application would be different depending on whether or not a risk premium of some sort is added to the quantity $\hat{V}(0) - V^*(0)$ in equation (7). This might represent a difference between private and social benefit evaluation if the private evaluation cannot properly adopt a neutral attitude toward risk. There may be other differences as well. For example, some information may not have private value. But, in any case (risk neutral or risk averse, public or private) the qualitative result in equation (7) holds.

A second assumption that may be troubling to some is that the decision-maker obtains perfect information, as opposed to merely better information, about second-period benefits. This assumption is made solely to simplify the notation. Elsewhere, Michael Hanemann and I show that an analogous kind of result goes through in a more standard Bayesian setting, in which information is updated from period to period, but does not completely resolve uncertainty [Fisher and Hanemann (1986)].

Finally, an explicit assumption: Resolution (in the present model) is independent of the first-period development decision. This is clearly an empirical matter. One can imagine a situation in which undertaking some development now yields information about future benefits. But where the uncertainty is largely about future benefits of habitat preservation--what will be found, what might it be good for, etc.--resolution will come (if it does) not from destruction of habitat but from research into the nature and properties of the indigenous species. The research may be stimulated by consideration of a tract for development, but the information flows from the research and not the act of development. Also, note that, in the development-dependent learning scenario, it must be possible to develop a part of the tract in such a way that information is provided about the rest without, at the same time, affecting it. Here, one faces a problem. If the development is not to foreclose substantial potential future benefits by locking in a choice that may prove mistaken, it must be "small." But, then, it can be shown that a result much like the present one--a bias in favor of full development over small development--follows if the prospect of information from the small development is neglected [Fisher and Hanemann (1987)]. In the present case, where the choice is one of whether or not to develop the tract in the first period, the concept of dependent learning is simply not relevant unless one accepts as a rational argument something analogous to the celebrated Vietnam-era explanation: "It was necessary to destroy the village in order to save it."

3. A Model of Overexploitation

Much of the economic literature on the possibility of extinction of a renewable resource, such as a fishery, has focused not on habitat destruction but on the rate of harvest [see, for example, Clark (1976) and Berck (1979)]. In this respect, it is well known that the common-property nature of some of these resources, again exemplified by the fishery, leads to overexploitation in the sense that more of the resource is harvested sooner than would be the case under sole ownership. Consequently, extinction is more likely. But the work of Clark, Berck, and others goes deeper. It suggests that, even under sole ownership, a resource can be optimally exploited to the point of extinction. In this section I present a simple model of renewable resource harvest that confirms this result. I then show how less orthodox notions of resource value, introduced and emphasized by Krutilla, affect the result.

Since the notion of a steady state is crucial to the analysis, we shall need a multiperiod decision framework instead of the simple two-period one of the preceding section. I continue to assume, however, that the problem faced by the decision-maker is one of allocating a resource efficiently over time.

I also continue to assume that the decision in question is a public one. This is appropriate for two reasons. First, I wish to abstract from the common property problem which would seem to be more of a problem in a situation involving many private harvesters. Second, in a sequel, I introduce an element of public good benefit from the unharvested stock. To put the matter a bit differently, the resulting (efficient) allocation would not ordinarily be achieved by the private sector both because it would be more subject to common property conflicts, and because it would not capture any public good benefits.

One other assumption is made which differs from that in the preceding section: Uncertainty is not explicitly considered. Clearly the benefits of harvesting or of not harvesting are uncertain. However, the arguments I wish to put forward in this section do not depend on uncertainty. Let me emphasize that the model in this section is accordingly not an extension of the one in the preceding section. It is instead simply a different approach featuring different analytical elements to deal with a different concern: overexploitation as opposed to habitat loss.

The decision problem can be stated as one of maximizing the present value of benefits from the resource where benefits can be given the standard interpretation of combined consumer and producer surplus. In symbols, the problem is

(8) $$\max_{y_0, y_1, \ldots, y_{T-1}} \sum_{t=0}^{T} \frac{\int_0^{y_t} p(z)\, dz - c(y_t)}{(1 + r)^t}$$

subject to

(9) $$X_{t+1} - X_t = g(X_t) - y_t$$

where y_t = extraction in period t, X_t = the resource stock in t, $p(\cdot)$ = demand for the resource, $c(\cdot)$ = (total) extraction cost, r = (social) discount rate, z = variable of integration, and $g(\cdot)$ = growth of the stock.

Solution of the problem yields

(10) $$\frac{\lambda_t - \lambda_{t-1}}{\lambda_{t-1}} = r - \left(\frac{\lambda_t}{\lambda_{t-1}}\right)\frac{dg}{dX_t}$$

where λ is a Lagrange multiplier, interpreted as the shadow price of a unit of the resource in the stock. In a steady state the shadow price is not changing, so equation (10) becomes simply

(11) $$\frac{dg}{dX_t} = r$$

which can be represented as in Figure 1. But note that another outcome is possible in which the steady-state stock is not $X = X^*$ but $X = 0$. If the

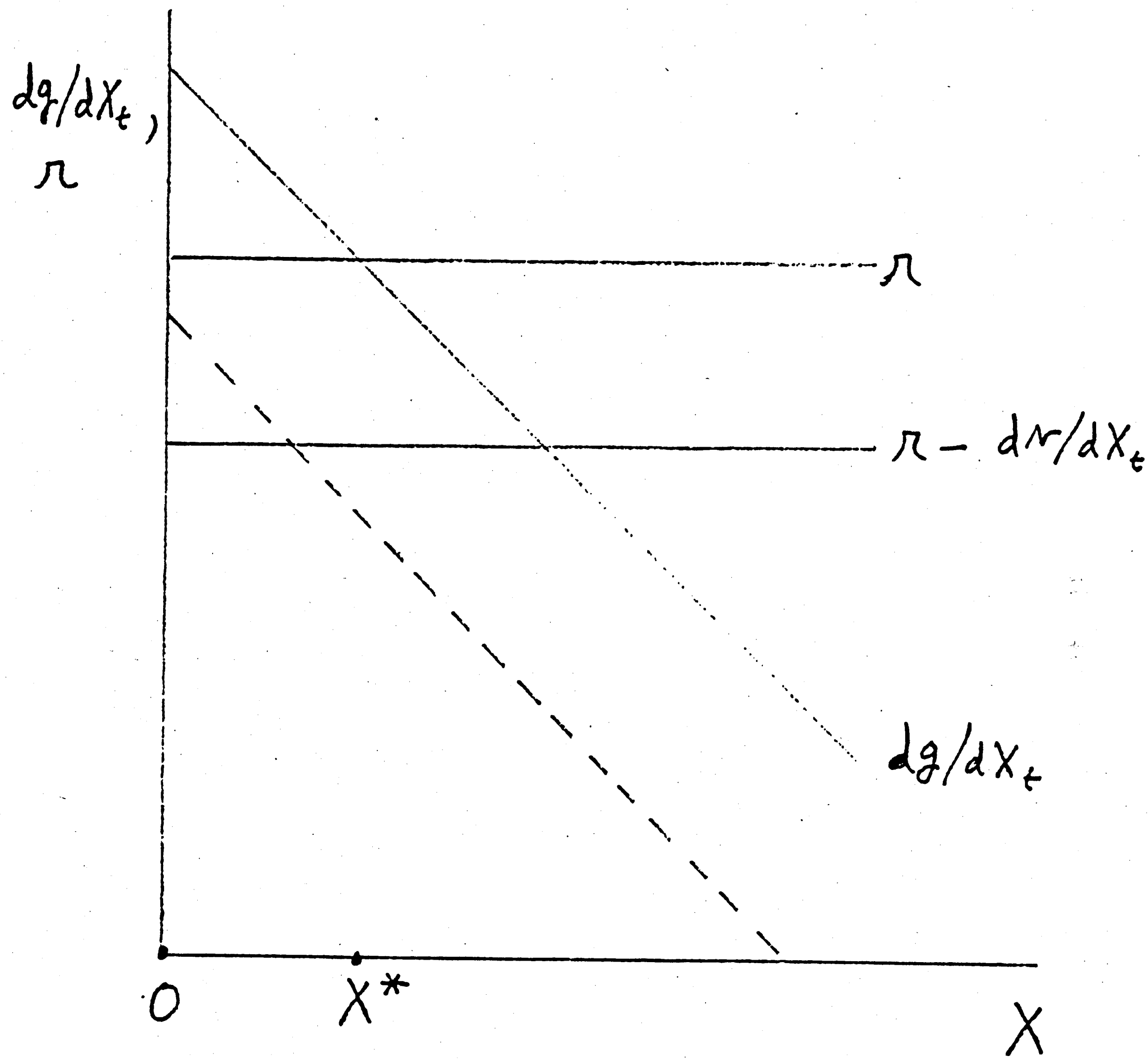

Figure 1. Bio-Economic Equilibria

natural productivity of the species, dg/dX, remains below the productivity of capital in the economy, r, even as the stock dwindles, the two curves can fail to intersect at any positive X. This possibility is represented by the dotted-line curve in Figure 1.

Thus, extinction of the resource can occur even in the absence of common property externalities. It can be rational if the objective is to maximize the net present value of the harvested resource product. Given a positive rate of discount, it does not pay to wait for a slowly growing natural population to regenerate itself.

However, as suggested elsewhere in the context of multiple-use forest resources [Hartman (1976), Bowes and Krutilla (1985)], the unharvested stock can be regarded as a store of value: genetic information that can lead to applications in medicine, agriculture, etc. If it is further assumed that this nonextractive value depends (positively) on the size of the stock, the result quickly follows (as I shall show) that the optimal steady-state stock is increased. This assumption can be questioned. Might it not, instead, be true that, as long as a number of individuals remain, sufficient to reproduce, merely adding to the number provides no benefit? It turns out that this is not true. Variability among different populations of the same species and within populations is crucial to the ability of species to successfully evolve in response to changes in their environment and, more to the point, to be useful in a variety of applications--and variety depends on the size of the stock. For example, wheat in the American Northwest loses its resistance to rust within about five years. New strains must be developed from infusions of wild varieties [Ehrlich, Ehrlich, and Holdren (1977)]. As another example, a recently discovered wild-grass relative of corn is a perennial. If this characteristic can be introduced to the domestic corn crop, the savings from elimination of annual plowing and seeding (and consequent soil erosion) will be very substantial [Vietmyer (1979)].

Let us then change the objective function in equation (8) by introducing a term for value as a function of stock size, $v(X_t)$. The solution, equation (11), becomes

$$(11') \qquad \frac{dg}{dX_t} = r - \frac{dv/dX_t}{\lambda_t}.$$

Since $dv/dX_t > 0$, the second term on the right-hand side is negative, and the optimal stock is increased as indicated in Figure 1. Extinction is less likely, though it is still possible.

4. Conclusions

Plant and animal species--renewable resource of great value--are facing extinction from the activities of "economic man." I have explained the inconsistency with the aid of models of habitat conversion and resource exploitation. I have also tried to show how the models are appropriately modified, in ways suggested by the work of Krutilla, to produce a different outcome--one in which extinction is less likely to appear as rational economic behavior.

Even this may be unsatisfying to one who takes an explicitly noneconomic approach to the problem of extinction. It is certainly possible to argue, for example, on religious or ethical grounds that all species are "sacred" or, at least, have a right to exist apart from any value (agricultural, industrial, medicinal, and even aesthetic) they may yield to humans. This paper does not directly take issue with such a view. It is, instead, simply an exploration of some implications of the economic approach. Yet, in the hard choices that confront us, such as how much tropical rainforest to reserve from development that would be destructive of habitat, where to set up the reserves, how to finance them, etc., it may not be possible to avoid the economic approach. Some balancing of benefits and costs, some tradeoffs, are likely to be required, not by some obscure economist but by the realities of decision making in the national and international political arenas. What I find interesting is the large measure of support given those concerned about extinction by the economic approach pioneered by John Krutilla.

Footnotes

[1]For a somewhat different approach and a comment that clarifies the difference between it and the original Krutilla-Fisher formulation, see Bishop (1978) and Smith and Krutilla (1979), respectively .

[2]The model is based on the original formulations by Arrow and Fisher (1974) and Henry (1974) but adopts the more transparent notation of Hanemann (1983). For extensions to many periods and partial instead of perfect information, see Fisher and Hanemann (1986).

References

Arrow, K. J., and Fisher, A. C. "Environmental Preservation, Uncertainty, and Irreversibility," Quarterly Journal of Economics, 88 (May, 1974), pp. 312-319.

Arrow, K. J., and Lind, R. C. "Uncertainty and the Evaluation of Public Investment Decisions," American Economic Review, 60 (June, 1970), pp. 364-378.

Berck, P. "Open Access and Extinction," Econometrica, 47 (July, 1979), pp. 877-882.

Bishop, R. C. "Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard," American Journal of Agricultural Economics, 57 (1978), pp.10-18.

Bowes, M. D. and Krutilla, J. V. "Multiple Use Management of Public Forestlands," in A. V. Kneese and J. L. Sweeney eds., Handbook of Natural Resource and Energy Economics, Volume II. Amsterdam: North Holland, 1985.

Clark, C. W. Mathematical Bioeconomics. New York: John Wiley & Sons, 1976.

Ehrlich, P. R., Ehrlich, A. H., and Holdren, J. P. Ecoscience: Population, Resources, Environment. San Francisco: W. H. Freeman, 1977.

Fisher, A. C., and Hanemann, W. M. "Quasi-Option Value: Some Misconceptions Dispelled," Journal of Environmental Economics and Management, 14 (1987), forthcoming.

Fisher, A. C., and Hanemann, W. M. "Information and the Dynamics of Environmental Protection: The Concept of the Critical Period," University of California, Department of Agricultural and Resource Economics, Working Paper No. 420. Berkeley, June, 1986.

Hanemann, W. M. "Information and the Concept of Option Value," University of California, Department of Agricultural and Resource Economics, Working Paper No. 228 (Berkeley, November, 1983).

Hartman, R. "The Harvesting Decision When a Standing Forest Has Value," Economic Inquiry, 14 (1976), pp. 52-58.

Henry, C. "Investment Decisions Under Uncertainty: The Irreversibility Effect," America Economic Review, 64 (December, 1974), pp. 1006-1012.

Krutilla, J. V. "Conservation Reconsidered," American Economic Review, 57 (June, 1967), pp. 777-786.

Krutilla, J. V., and Fisher, A. C. The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources. Baltimore: Johns Hopkins University Press, 1975 (for Resources for the Future).

Smith, V. K. and Krutilla, J. V. "Endangered Species, Irreversibility, and Uncertainty: A Comment," American Journal of Agricultural Economics, 61 (May, 1979), pp. 371-375.

Vietmyer, N. D. "A Wild Relative May Give Corn Perennial Genes," Smithsonian, 10 (1979), pp. 68-76.

Wilson, E. D. In Harvard Magazine (January-February, 1980).