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The Economics of Endangered Species: Alternative Approaches to Public Decisions

by

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THE ECONOMICS OF ENDANGERED SPECIES: ALTERNATIVE APPROACHES TO PUBLIC DECISIONS

Potential extinction of plant and animal species and subspecies is a problem with important economic implications, yet it has not received much attention from economists. This paper has two objectives: (1) to characterize the economic issues that arise when a species is endangered[1] and (2) to compare two approaches from the economics literature which deal with extinction issues in the context of public decision-making.

The first will be termed "the benefit-cost approach" because it rests on the basic conceptual framework of benefit-cost analysis. It must be added immediately, however, that several peculiarities of the species survival problem and related issues require modifications in techniques of evaluating benefits and costs which will be described below. There, this paper will draw most heavily on work of several economists associated with the Natural Environments Program at Resources for the Future under the leadership of John V. Krutilla.

The second economic approach to public decisions affecting species survival will be termed the "safe minimum standard approach." This way of dealing with the problem is rooted conceptually in the game theory analysis of decision-making under uncertainty. The safe minimum standard of conservation was introduced into economics in Ciriacy-Wantrup's (1968) classic work on conservation economics.

To give the comparison a bit of concreteness, the California condor (Gymnogyps californianus), one of the Unived States' most endangered species, will be used repeatedly to illustrate various points. It turns out that both of the major economic forces behind man-caused extinction, overexploitation and habitat modification, have been at work in the condor case. After examining these biological dimensions of the species survival problem in the next section, various economic dimensions can be discussed. Particular emphasis will be placed on the problem of irreversibility and uncertainty. Conservation costs, some relationships analogous to joint production in the theory of the firm, and other aspects will also be introduced. Next, we shall see how the economic dimensions are treated in the benefit-cost and safe minimum standard approaches to public policy. These comparisons will lead to some conclusions for public policy and future research.

Background of the Problem

In the U.S., an estimated 46 birds, mammals, and fishes have become extinct in modern times. The federal government presently lists 188 U.S. species and subspecies of mammals, birds and reptiles as threatened (U.S. Bureau of Sport Fisheries and Wildlife). These animals run the gamut from one race of the national symbol, the bald eagle, to such obscure members of the nation's fauna as the blunt-nosed leopard lizard. It has been estimated that over 700 animal species and subspecies are presently in danger of extinction worldwide (Cox). Flora, too, are threatened. The Smithsonian Institute has recently estimated that some 2,000 U.S. plants face extinction. This is about 10 percent of the flora of the continental United States (Jenkins and Ayensu; U.S. Congress). The World Wildlife Fund's preliminary estimate of the numbers of threatened plants is 20,000 for the world as a whole.

Of course, extinction of plants and animals has been an earthly phenomenon since the beginning. Humans may have played a role in the demise of some life-forms even in pre-historic times. However, man has become the dominant force in life-form extinction. Out of roughly 20 mammals and 150 birds that have become extinct since 1600, only about one-fourth have succumbed to natural forces, while the rest have been victims of man (Cox). Furthermore, the pace of extinction is quickening. The International Union for the Conservation of Nature has estimated that an average of one species per year is becoming extinct, compared with one every 10 years between 1600 and 1950 and a natural rate of one every 1000 years during the era of the dinosaurs.

This increase in the rate at which life-forms are becoming extinct is the result of human activities that can be grouped into two general categories. Overexploitation--the elimination by humans of larger numbers than natural regeneration can replace--has often been a cause. Environmental modifications--generally through changes in the use of land and related resources, the disposal of deleterious substances, and the introduction of exotic life-forms--are the more important causes today.

The effects of both overexploitation and environmental modification can be illustrated by the condor case. The California condor is a large, mostly black vulture that inhabits southern California and possibly Baja California. A mature bird may have a wingspan of 9½ feet, the largest of any North American land bird. The condor is one of the world's most endangered species, with a remaining population of only about 50 birds. The early Europeans who came to the Pacific Coast of North America saw condors--and shot them. Since then, many condors have been shot because of curiosity, mistaken concern for livestock,[2] maliciousness, target practice, and scientific collection. In addition to their guns, Europeans brought land use changes, converting vast expanses to agriculture and urban uses, eliminating the herds of deer, elk, and later, cattle and sheep which had provided the condor with carrion. Even where native vegetation and fauna were not eliminated, various activities ranging from petroleum exploration to off-road vehicle recreation have created disturbances beyond levels that the condor can tolerate in areas where the bird once nested, roosted, fed and found sanctuary.

Proposed habitat modifications continue to put pressure on the species and it may not survive into the 21st century. In response, several governmental agencies and private groups are involved in efforts to conserve the species which include research, restrictions on mineral exploration and development on public lands, the abandonment of a proposed multi-million dollar water project, land-use controls on private lands and land acquisition projects, educational programs to inform citizens about the problem and other such measures.[3]

Can the situation of a species like the condor be considered a serious economic problem? What economic issues arise when such a situation exists? In the next two sections, the various economic dimensions of the problem will be outlined. Let us begin with the most difficult, yet potentially most important economic problem, that of irreversibility and uncertainty.

The Problem of Irreversibility and Uncertainty

There is much interest these days in genetic engineering, and it may be feasible in the future to re-create extinct species of plants and animals. However, science today is very limited in this regard and there is no alternative but to assume that extinction of species and subspecies is irreversible. Furthermore, as will be shown more fully below, there is still a great deal that is not known about the earth's life-forms. Genetic engineering, if successful, will not be able to resurrect what was never known to have existed.

Coupled with irreversibility is uncertainty of truly staggering proportions. Part of this uncertainty is related to the future directions of society itself. Recall that resources really only exist in a social context. They are highly relative, depending on a whole array of social variables including tastes and preferences, population, the institutional framework, public policies, and technology.

The changing status of the American bison illustrates this point well. Today, the bison is both an aesthetic resource of considerable value in an historical context and a genetic pool for beef animal breeding. To the Plains Indians only little more than a century ago, the bison was the basis of a whole economy, serving as a raw material for food, shelter, and clothing, as well as an object of religious significance. Even this status of the bison was apparently a relatively new phenomenon based on the introduction of horses from Europe. Prior to this technological innovation, the Plains Indians were semi-agriculturalists, possibly as an adaptation to "Pleistocene overkill" ten thousand years earlier. And Pleistocene overkill itself may have been the result of improved hunting technology and population growth (Vernon L. Smith).

The bison example illustrates well that, as someone once put it, "resources are not, they become." The earth's natural attributes including its life-forms embody a reservoir of potential resources that are only partially recognized as actual resources at any point in time.

Furthermore, there is great uncertainty about the future time paths of all the social variables that will determine which characteristics of the earth's species and other natural phenomena will "become" resources in the future. Think for a moment about the last 100 years. Who 100 years ago could have anticipated the advent of the automobile and all the impacts it has had on our definition of resources? Or, consider the affluence of certain countries, the communist revolutions, the population explosion, decolonization, the path of agricultural technology, the discovery of nuclear energy, or any of dozens of other events and trends over the last 100 years that have shaped our resource spectrum. How then are we of the present generation to anticipate what characteristics of the earth's natural attributes will be resources even 100 years hence? Yet when a species is lost, it will not be available to future generations far beyond the next 100 years.

Social uncertainty is compounded by what might be termed "natural uncertainty," uncertainty about the characteristics of the natural world that actually exist and could become resources in the future. Consider, for example, how many life-forms may yet remain to be discovered. One estimate is that there are 10 million species and subspecies on the earth (Raven, Berlin, and Breedlove).

If so, then 8.5 million species and subspecies have not even been discovered yet! Clearly, we have a great deal to learn about many that are known as well as those that may ultimately be discovered.

Another interesting example of natural uncertainty comes from pharmacological research. Certain of the earth's plants produce alkaloids which are presently the source of such compounds as morphine, quinine, and strychnine and which are considered promising in the quest for drugs to treat tumorous cancers, leukemia, cardiac disorders, hypertension, and other diseases. Yet, to date, only about 2 percent of the earth's 200,000 flowering plant species have been screened for alkaloids and the search thus far has turned up 1,000 different alkaloid compounds (Myers). One major method of searching for plants with medicinal and other useful properties is indicative of how far the sciences have yet to develop. This approach, called ethnobotany, involves long hours of talking and searching for specimens with local, often primitive people, including witch-doctors, in the hope of discovering clues to plants with useful qualities.

Irreversibility and uncertainty combine to create an economic problem when species are threatened with extinction. Once lost, a life-form cannot be regained, yet social and natural uncertainty mean that it is impossible to foresee which ones can be allowed to become extinct without large future losses and which cannot. Extinction always carries the risk that some future resource of great value is being lost.

This problem of irreversibility and uncertainty takes on new urgency in the context of the present growth debate. Humankind appears to be involved in a "great race." On the one hand are distressingly high rates of exhaustion of several nonrenewable resources that are critical to our economy under current technology as well as population growth with accompanying pressures on food resources, and cumulative destruction of natural resources which many consider important to the quality of life and perhaps even the maintenance of life itself. Racing against approaching doomsday is sociotechnical progress.

The earth's life-forms are important to this great race in at least two ways. First, as a reservoir of future resources, the earth's life-forms are among humankind's best hopes for continued technological progress through research in the natural and biological sciences. Consider cropbreeding, for example. Valuable genes have already been found in wild potatoes, tomatoes, beets, sugar cane, and the progenitors of cultivated wheat, corn, oats, and barley (Watson). The value of any particular variety, however, remains uncertain. Uncertainty in this area even extends to the very weather on which crop production depends. Despite recognition of the importance of genetic resources in crop breeding, there is growing concern that not enough is being done to conserve wild varieties and primitive cultivars which are related to present agricultural plants (Miller; Harlan). The USDA has noted that "the /genetic resource/ situation is serious, potentially dangerous to the welfare of the nation, and appears to be getting worse rather than better."[4]

Or consider medicine. Few realize that about half of the new drugs entering the market in recent years have been developed from botanic specimens (Krieg; Krutilla and Fisher). Among the better known are penicillin, cortisone, digitalis, quinine, and heparin. Many zoological specimens are of interest in medical research: the manatee for hemophilia (Vietmeyer); the armadillo for leprosy; the horseshoe crab in detecting bacterial endotoxins (Thompson); the desert pupfish for kidney disease (Bean); and so on. Again, note the role of uncertainty and irreversibility. Plants with promising medicinal properties and animals with useful physiological characteristics may not be recognized as such until new scientific discoveries are made. Who, for example, could have foreseen that a drug with the properties of penicillin would be developed from a certain lowly fungus? The horseshoe crab has been considered a pest for years and some states have even paid bounties for them. Note also that many threatened plants and animals are already of interest to medical researchers including some of the cacti of the American southwest (which contain alkaloid compound), the manatee, some species of armadillo, and several species of the desert pupfish.

Research outside the medical and agricultural fields is also active. For example, oils from various plant seeds are being investigated for possible industrial uses (Nature Conservancy).

Beyond their importance in the development of new resources through research, the earth's life-forms are related to technological progress because of their role in environmental monitoring (Jenkins and Bedford). One of the great environmental dilemmas of our times is that increasing technological dependence forces us to experiment on ourselves (Brubaker, p. 160). It is impossible to thoroughly test each new innovation for its long-run impacts before it is released for general use. Indeed, general use may be the only sure test.[5] Hence, a diverse and abundant flora and fauna may prove very useful in isolating problems in the life support system associated with new technologies before they reach man. Consider the role of the brown pelican, bald eagle, and osprey in warning that DDT was concentrating in living organisms and could interfere with avian reproduction. Again, note the existence of uncertainty. Various life-forms are sensitive to environmental changes in greatly differing degrees. Which ones will serve as indicators of environmental degradation due to technological advance cannot be foretold.

Perhaps this discussion can best be summarized by quoting Ciriacy-Wantrup's (1968, p. 252) conclusion about the hazards of irreversible depletion of critical zone flow resources.

> From a certain degree onward--for example, if more and more acres of land or species of plants and animals are affected--irreversibility in the depletion of critical zone resources limits opportunities of adaptation and narrows the potential development of a society. Both the biological and the social sciences have come to the conclusion that such a limiting and

narrowing force directs development toward specialization rather than diversification. Such a direction has been held responsible for retarded and abortive growth--in the sense of growth toward a dead end--stagnation, and death of species and civilizations.

All this has a bearing when one focuses on an individual life-form, like the condor. Beyond its value for aesthetic enjoyment, as discussed below, it is hard to see at first glance why the condor should be considered important as a future resource. Yet, S. Dillon Ripley, Secretary of the Smithsonian Institute, has said that "the condor represents, among warm-blooded vertebrates, birds and mammals, one of the very few remaining genetic reservoirs unchanged since Pleistocene times a million years ago."[6] This genetic reservoir, according to Ripley, is "waiting for ever increasing skills of scientists to interpret. What a catastrophe if the story were destroyed before its meaning could be unraveled, the code uninterpreted before it is lost."[7] If it survives, will the condor contribute to an important future scientific discovery, or in some other way become a substantially more important resource than it is today? Perhaps not, but as a society, we simply do not have the information to tell in advance. Extinction of the condor would carry the risk that something of great future value is being lost.

The discussion will move in a moment to some more conventional economic aspects of life-form conservation. This issue of irreversibility and uncertainty is discussed first for a definite reason. So often when a life-form faces extinction there is a tendency to rush about trying to establish some economic value for it as a justification for conservation. Some of the pitfalls of this approach are discussed in a recent, very interesting article by Ehrenfeld. In point of fact, life-form conservation may generate current benefits in some cases, as we shall see below. However, many life-forms make little or no economic contribution now and there appear to be few prospects on the horizon. Even life-forms with a current value are impossible to evaluate over the long run. No one can foresee what, if any, contribution a given life-form will eventually make. Uncertainty in this regard is the problem and this should be recognized clearly and without apology. In fact, given what has been said above, one suspects that from the standpoint of public policy it is more important to come to grips with the problem of irreversibility and uncertainty than to precisely measure whatever foreseeable short-run benefits accrue to society from conservation; but more on this later. First, some additional economic dimensions of the problem must be introduced.

Some Additional Economic Dimensions

In addition to the problem of irreversibility and uncertainty, the first, and perhaps most obvious, point to be made is that conservation of endangered species may entail social costs. Two types of costs are illustrated from the condor case. There are direct (out-of-pocket) costs for research and management. More important in terms of magnitude--at least for the condor--are the opportunity costs of forgoing temporarily, or perhaps permanently, the exploitation of some resources in the critical habitat. For example, the last major nesting area of the condor is also thought to be promising for oil and natural gas, yet exploration and development within this region would almost certainly be fatal to the species. Hence, efforts to conserve the condor entail the cost of oil potential which must remain unexplored.

A second additional economic dimension relates to some benefits of life-form conservation which may offset these social costs partially or completely. Some of these benefits are associated directly with the life-form itself. For example, if whales are successfully conserved, market benefits from exploitation on a sustained yield basis would become feasible. In other cases, such benefits are of an extramarket character. For example, viewing condors in the wild, photographing them, reading about them in a continuing flow of reports, and seeing them in published photographs and movies are all potential sources of social benefits from continued condor survival.

Beyond these rather direct benefits are additional ones which are generated by the complementarities between conservation efforts and certain other resource uses. For example, complementarity in costs exists between condor conservation and outdoor recreation.[8] This complementarity derives from the fact that many of the conflicting resource uses (oil and gas exploration, for example) would not only harm the condor, but also damage the natural amenities on which human recreation depends. Complementarity exists on the benefit side as well. The condor adds "color" to the area it inhabits and the prospect of seeing a condor and perhaps even getting a picture enhances general outdoor recreation in the habitat.[9]

A third additional economic dimension concerns the risk that conservation efforts will be unsuccessful. Some attempts to increase the longevity of species have been successful; e.g., the American bison, the California tule elk, the trumpeter swan, the whooping crane and the sea otter. However, the condor itself reminds us that efforts toward conservation may be unsuccessful. There is no evidence that the condor is responding to the measures taken on its behalf sufficiently to stabilize or increase the population. Technically, the condor may already have crossed its critical zone (Ciriacy-Wantrup, 1968) or its extinction threshold (Bachmura).

Finally, market failure appears likely in dealing with potential extinction in many if not all cases. Arguments based on externalities, public goods aspects, extramarket resources, and divergences between private and social rates of discount come so easily to mind that there is no need to belabor the matter.[10] Let us turn instead to alternative approaches which would combine the various economic dimensions of the problem in order to facilitate sound public choices, beginning with the benefit-cost approach.

The Benefit-Cost Approach

Bachmura and Plourde have dealt with the problem of threatened life-forms in separate articles. Furthermore, while Krutilla and others active in the Natural Environments Program at Resources for the Future have not dealt empirically with a threatened species problem, they do emphasize that maintenance of plants and wildlife is one of the advantages of preserving natural environments, and many of the concepts they have developed appear to be as applicable to the preservation of species as to other components of natural environments. Because their work is by far the most developed and detailed, the following discussion will draw most heavily on the work of the RFF group and particularly, the recent synopsis by Krutilla and Fisher.

The works by Bachmura, Plourde, and Krutilla and Fisher are developed in the context of benefit-cost analysis.[11] It must be noted at the outset, however, that none of these authors is completely satisfied with benefit-cost analysis on a practical level. In fact, much of what Krutilla and Fisher say can be interpreted as warnings against the application of benefit-cost analysis, as it is currently practiced by public agencies, to problems involving natural environments, and their discussion contains many suggestions of more appropriate techniques. Let us illustrate what is involved in the benefit-cost approach by casting the condor situation in a Krutilla-Fisher framework.

Following Krutilla and Fisher, we will deal with two alternatives, the preservation alternative and the development alternative. The preservation alternative consists of doing those things which appear to be necessary for the survival of the condor. This would include controls on the development of oil and other minerals, leaving certain water resources and critical condor feeding areas undeveloped, planning recreation to avoid excessive disturbances near important nesting and roosting sites, some artificial feeding, further research, and other such measures. The development alternative would consist of exploiting the oil, minerals, water and other land resources wherever this is economically feasible.

Let "development costs" equal the direct, non-environmental social costs associated with development. For example, in the case of oil, development costs would include the costs of finding, developing, and producing the oil and gas in the condor habitat but would exclude the value of damages to aesthetics because of land scarring, spills of oil and brine into local watershed and the like. Let B_d equal development benefits, the gross social benefits of development minus development costs, all in present value terms.

Likewise, let "preservation costs" equal the social costs directly associated with the condor conservation efforts and complementary resource uses such as recreation, but excluding the opportunity cost of forgoing, at least temporarily, the use of the resources which would be exploited under the development alternative. For example, preservation costs would include the costs of artificially feeding the condors to assure an adequate food supply. It would also include a trail that is deemed desirable to permit back-packing into an area where the resulting disturbance would not be detrimental to the condor. But the value of oil production, which would have to be forgone because of the condor and other such opportunity costs associated with development forgone, would not be included in preservation costs.

Symbolize preservation benefits by B_p. These are the gross social benefits of the preservation alternative minus preservation costs, all in present value terms. These gross benefits would include the recreation benefits associated with condor observation. At least theoretically, gross benefits would include some measure of the condor's contribution as part of the reservoir of future resources. Also included in these benefits would be the benefits generated by resource uses complementary to condor conservation efforts, like recreation, that would be lost if the development alternative is chosen.

Krutilla and Fisher foresee a number of problems with conventional approaches to estimating B_d and B_p. Let us list four:

(1) Option value and quasi-option value cannot be measured. Option value has had a controversial history since its introduction by Weisbrod.[12] Cicchetti and Freeman finally defined option value to be a risk premium as that term was originally defined by Friedman and Savage. This definition seems to have been accepted by most economists, although recent writers have demonstrated that option value may be either positive, negative, or zero, even for a risk-averse consumer (Henry). Furthermore, a new concept, which Krutilla and Fisher choose to call "quasi-option value," has emerged. Quasi-option value is not a risk premium, but rather the extra value of choosing not to take irreversible steps if new information about the outcomes of alternative decisions will become available in the future (Arrow and Fisher; Henry; Krutilla and Fisher, pp. 69-72). For the rational consumer or producer, quasi-option value would be positive, regardless of risk preferences. Given all that was said about irreversibility and uncertainty, both concepts would appear to be applicable to the problem of endangered species, yet no methods are available presently to estimate these values. Thus, it will be necessary to deal with only an approximation of true preservation benefits (B_p). Let us symbolize "<u>measurable</u> preservation benefits" by B_p'. Further, assuming that option value is positive, it is clear that $B_p' < B_p$, since option value and quasi-option value cannnot be estimated by known techniques.

Lest an important point go unnoticed, let it be explicitly stated that acknowledgement of the existence of these two option values is the principal strategy for coping with the problem of irreversibility and uncertainty within the benefit-cost approach.

(2) Another unmeasurable benefit of the preservation alternative is existence value. Existence value is not a reflection of risk preferences like option value or the prospect of new information like quasi-option value, but rather reflects the utility that people receive from simply knowing that something exists. For example, many people (the author included) would be willing to pay something to know that the blue whale will continue to exist. This willingness to pay is not attributable to any expectation of benefiting directly through eventual consumption of whale products or aesthetic enjoyment of whales, but rather to knowledge of the whale's existence (Barkley and Seckley). Clearly, however, no market exists on which to express this willingness to pay, perhaps at least partially because of the public goods nature of species existence. Here is an additional reason to argue that $B_p' < B_p$.

(3) Ambiguity in property rights raises questions about the basis for evaluating B_p. Traditional benefit estimation is based on willingness to pay. This always raises questions about the apropriate measure of consumer's surplus. In our present case, if property rights in the condor were attributed to those who may eventually benefit from its continued survival, then the correct measure of preservation benefits would be the amount that would be required to compensate them completely for the loss. "Willingness to receive compensation" as a measure of consumer's surplus would generally be greater than the amount preservation beneficiaries would be willing to pay to see the condor survive. Mishan (1971) has argued that willingness to receive ought to be the measure of benefits where natural amenities are at stake. To the extent that his

argument is accepted, conventional measures of B_p' would underestimate true benefits, and this would be another reason to suspect that $B_p' < B_p$, where measurable benefits are based on willingness to pay.

(4) Another problem with conventional benefit-cost analysis relates to the assymetric incidence of technological change. The assymetric incidence concept, which can be traced back to Ciriacy-Wantrup (1968, pp. 46-47), has received a great deal of emphasis in the work at RFF.[13] Minerals and other products of extractive industries which contribute to development benefits are generally used as raw materials in the production of consumer durables and energy. Here, technology hopefully will continue to provide substitutes in production which do not significantly affect the satisfaction of consumers. Other things being equal, for example, one does not notice whether the electricity from a wall outlet is produced from fossil fuels, solar generating facilities, or nuclear fusion. On the other hand, many of the products of natural environments, particularly enjoyment of natural amenities, enter directly into consumption. Hence, there are few, if any, opportunities for development of new technologies which can substitute inputs without affecting the qualities of natural amenities that yield satisfaction to consumers. With economic growth and technological progress (which Krutilla and Fisher expect to continue), the value of natural amenities should increase relative to the value of more conventional commodities. To the extent that conventional benefit-cost techniques do not include this assymetry, they will tend to overestimate B_d and underestimate B_p. If this argument is accepted, it would appear to be applicable to some threatened species like the condor, southern bald eagle, and whooping crane, which attract attention for their aesthetic qualities.

For all these reasons and others as well, Krutilla and Fisher suggest that benefit-cost analysis be applied to public choices between development and preservation alternatives in three steps. First, B_d should be carefully examined. If B_d is negative, clearly the development alternative is not economically justified regardless of environmental impacts. Krutilla and Fisher point to several cases where development of natural environments will not survive close scrutiny even before environmental damages are introduced. My own work in the condor case further supports this view.

Of course, there are bound to be cases where B_d is positive. The second step, then, is to evaluate B_p' as well as possible and compare this with B_d. One would expect that there are cases where measurable preservation benefits are sufficiently large to offset B_d even though $B_d > 0$. This result obtained, for example, in the very interesting and widely cited study of Hell's Canyon by the RFF group.

However, it is too much to hope that the real world will always be so simple. There are bound to be cases where $B_p' < B_d$. Here, however, caution is advocated. Because of option value, quasi-option value, existence value, ambiguity in property rights, and for other reasons, it is entirely possible that true preservation benefits (B_p) are still larger than B_d. Hence, Krutilla and Fisher (and Bachmura and Plourde as well) advocate giving the "benefit of the doubt" to preservation. Presumably, this means that the preservation alternative should be chosen unless development, after considering B_p', is still very attractive economically.

We can reinterpret this conclusion slightly in a way that will prove useful later. B_d can be thought of as part of the social costs (benefits forgone) of preservation. Offsetting these costs are B_p'. Thus, B_d minus B_p' can be thought of as the measurable social costs of preservation. The Krutilla-Fisher criterion can then be stated as: Choose the preservation alternative unless the measurable social costs of doing so are unacceptably large, so large that B_p, measured in full, is in all probability less than B_d.

For example, B_d for the condor is estimated to be around \$3 million per year. Space will not permit the details of the analysis which led to this estimate, and it will be used for illustrative purposes only. The bulk of this \$3 million is an estimate of the benefits forgone because of the conflict between oil development and the condor in the main nesting area. Actually, it is probably an overestimate of these costs, since it is based on the assumption that the price of oil will be constant at around \$10 per barrel. If one assumed, based on recent experience, that the price of oil will continue to rise, this appreciation in the value of the unexploited oil would reduce the social cost of postponing its use.[14] No attempt was made in our study to estimate B_p', for reasons that will be explained later. Suppose for purposes of illustration that $B_d - B_p'$ is \$1 million annually.[15] According to Krutilla and Fisher, development would still not necessarily be economically justified, since all the unmeasurable factors discussed above are not included. Development would be justified only if in the best judgment of the analyst, option value, quasi-option value, existence value and suitable adjustments for ambiguity in property rights and technical change probably would not add \$1 million or more to preservation benefits. Otherwise, the benefit of the doubt would be given to the preservation alternative.

The Safe Minimum Standard Approach

For a life-form, the safe minimum standard of conservation is achieved when extinction is avoided, generally through maintenance of sufficient numbers and habitat to insure survival. For the condor, choosing the safe minimum standard would be equivalent to choosing the preservation alternative as discussed above.[16]

Because potential extinction of life-forms creates the problem of irreversibility and uncertainty, Ciriacy-Wantrup (1968) has argued that the choice of whether or not to establish the safe minimum standard should be approached using the theory of decision-making under uncertainty from game theory. According to this approach, society should choose the strategy which minimizes maximum possible losses. Thus, the safe minimum standard should be chosen unless the social costs associated with it are greater than the maximum possible losses from extinction.

Two problems with this approach immediately come to mind. First, the minimax solution has often been criticized as being ultra-conservative. In the present case, for example, the safe minimum standard would be adopted if its costs were one dollar less than the social losses that would be incurred under the worst conceivable future situation. For example, if it could be foreseen that the largest possible loss from extinction of the condor would be $300 million and the cost (assumed known with certainty) of the safe minimum standard was $299,999,999, rigid adherence to the game theory solution would dictate choosing the safe minimum standard. Obviously to live is to take chances. Whether we observe human behavior under risk and uncertainty in the private sector (insurance, use of the automobile, business) or the public sector (defense, public health programs), a less conservative approach is exhibited. If the costs of avoiding uncertainty become unacceptably large, individuals and societies accept the chance of large losses rather than blindly pursuing a minimax approach.

The second problem relates to the assumption in game theory that while the probabilities of alternative outcomes are not known, the outcomes themselves and their values under alternative strategies can be foreseen. In the language of game theory, the "pay-off matrix" is assumed to be known with certainty. While this is a useful construct for differentiating theoretically between risk and uncertainty, it is not very realistic. If the problem of irreversibility and uncertainty is adequately characterized in this paper, then not only are the probabilities of alternative outcomes unknown but also the outcomes themselves and the associated payoffs. Thus, whether the safe minimum standard is in fact the minimax solution may be unclear if the social costs of the safe minimum standard are quite large.

To deal with these problems on a practical level, a decision process analogous to that of a private person buying insurance has been advocated (Ciriacy-Wantrup, 1967; Ciriacy-Wantrup and Phillips). If the costs of insuring one's house against fire are considered small, he/she will usually buy the insurance and avoid the risk. However, if the costs of insurance are unacceptably large, one might well choose to live with the risk instead. Similarly, on a practical level, the safe minimum standard is the appropriate social choice unless its costs are unacceptably large.

Ciriacy-Wantrup (1968, pp. 254-56) argues that in most cases the costs of the safe minimum standard will be small, provided that the threat of irreversible depletion is from human rather than natural processes and actions are taken to establish the safe minimum standard before the situation becomes desperate. The cost would probably be small in absolute terms for life-forms because only a remnant population must be maintained to prevent extinction. If so, these costs would be small in relative terms as well, compared to the costs of avoiding uncertainty in other areas such as defense and public health.

If costs are indeed small, both of the above problems would apparently be solved. The lower are costs, the less applicable is the criticism that the minimax is overly conservative. While the pay-off matrix is still not known, the lower are costs the more confident is the decision-maker that the safe minimum standard will indeed minimize maximum possible losses.

The safe minimum standard can be viewed from another vantage point by referring to the current literature on intergenerational equity (Rawls; Mishan, 1975; Solow; Dasgupta; Dasgupta and Heal). While this literature has tended to focus on the rate of depletion of stock resources, our discussion of the uncertain prospects of future generations and growing dependence on rapid technological progress would indicate that intergenerational equity is an issue for flow resources as well. The narrowing of the reservoir of future resources caused by extinction means that while the current generation may gain economically from using land and related resources in ways which cause extinction, this is at the expense of increased uncertainty for future generations. Thus, the social goal in implementing the safe minimum standard might be described as avoiding the imposition of uncertain but potentially large losses on future generations whenever this can be accomplished without excessive economic sacrifice to the present generation. When a species is threatened with extinction, the public decision problem is one of deciding whether it is more equitable to impose the cost of the safe minimum standard on the current generation or to impose potential losses from irreversibility on future generations. This is inherently a social decision about how much "we" are willing to give up for "their" sake.

The safe minimum standard approach has not yet been applied extensively to actual policy issues. Out of Ciriacy-Wantrup's interest in irreversibility and uncertainty have come studies involving prime agricultural land in California (Ciriacy-Wantrup, 1976), and the California tule elk, a threatened subspecies of the American elk (Ciriacy-Wantrup and Phillips; Phillips), and the present study (Bishop, 1972, 1973, 1974). Another very interesting application of the same principles is Kneese's thinking on the nuclear energy question. The introduction of substantial amounts of dangerous long-lived radioactive materials into the environment is rather like irreversibly introducing a "negative" flow resource. Kneese argues persuasively that conventional benefit-cost analysis is inappropriate in such cases. He goes on to suggest that the additional costs of coal-fired electricity generation are not sufficiently large to justify the risks associated with widespread use of nuclear power under current technology.

The condor case will further illustrate how the safe minimum standard approach works in practice. The gross costs of efforts to save the condor include the opportunity costs (benefits forgone) generated when some of the resources such as oil and water within the habitat cannot be developed. This is equal to B_d, the development benefits under the benefit-cost approach. As noted above, my estimate of B_d is about \$3 million annually and this is probably an overestimate. Offsetting this opportunity cost are the measurable benefits associated with the safe minimum standard. But this would be identical to B_p', the benefits (net of preservation costs) associated with the preservation alternative. Thus, in benefit-cost terms, the measurable social costs of the safe minimum standard for the condor is $B_d - B_p'$. Assuming that my benefit-cost analysis is correct,[17] the social costs of the safe minimum standard for the condor is clearly less than \$3 million per year.

Is this too high a cost for the present generation to bear for the sake of maintaining the condor as one link in the reservoir of future resources? As noted above, this is inherently a social decision and not one which can be addressed directly by the economist. Still, the economist may help society to view such dollar figures in perspective. We are talking here of perhaps one percent of what Americans spend on chewing gum. Or, as a further example, this is apparently around one percent of what we are spending annually for products used by cat owners for indoor sanitary purposes. Clearly, this is not a large sacrifice to our society in relative terms.[18]

One objection to this approach might well be mentioned at this point. What about the cumulative costs of trying to save the many other species as well as the condor?[19] It is true that the safe minimum standard approach as developed here for uses on a single species and this does raise important issues for future research, as we shall see below. However, it is worth noting here that the condor appears to be rather atypical in this regard. The fact that the condor chose land with potential for oil and gas as a very critical part of its remaining habitat is the primary factor responsible for this cost figure. Effort to maintain a minimum population and habitat for most threatened life-forms should entail much lower costs.

Finally, let us ask what the roles of option value and quasi-option value are within the safe minimum standard approach. I would submit that their primary role is in understanding the social costs of the safe minimum standard. This role should not be minimized, since it is important to continue to explore what we as economists can and cannot measure using benefit-cost techniques. But as tools to help society cope with the problem of irreversibility and uncertainty, the concepts of option value and quasi-option value do not appear to be particularly powerful. It is the very essence of this problem that alternative outcomes, payoffs, and probabilities are not known even to an approximation beyond the next decade or two. Thus, to attempt to make alterations in expected values for risk preferences as in option value or to evaluate the potential directions and usefulness of new knowledge does not appear to be feasible over the long time spans in question here even if techniques of quantification are successfully developed for the short run. On the other hand, to the extent that irreversibility and uncertainty are problems to the present and perhaps the next generation, the two option values are helpful in understanding that the social costs of the safe minimum standard may not be as large as they appear at first glance. Similar roles can be envisioned for existence value, issues relating to the ambiguity about property rights and assymetry in the implications of technological progress.

Conclusions

Interestingly enough, while the benefit-cost and safe minimum standard approaches are considerably different theoretically, they come to some common conclusions. First, both approaches conclude that the potential extinction of species is a problem of sufficient economic significance to warrant attention from economists and public policy-makers. Both approaches agree that to cope with the problem of irreversibility and uncertainty should be one of the major concerns of the policy-maker, although the safe minimum standard approach may place more emphasis on this aspect vis-a-vis other economic dimensions of the problem. Finally, both approaches agree that positive measurable net benefits are not sufficient economic justification for choosing development where extinction of one or more species may result. Both approaches conclude that as a practical criterion, development is economically justified only if the social costs of avoiding extinction $(B_d - B_p')$ are unacceptably large.

Despite these common conclusions, major differences exist between the two approaches in their views of the role of the economic analyst, the place of the two option values in the analysis, and the directions that future research ought to take. In the benefit-cost approach, the economic analyst is attempting within the limits of current knowledge to define for the policy-maker which alternative most closely approximates the ideal of economic efficiency. The safe minimum standard approach views the economist's role as one of helping the policy-maker to understand the economic issues that arise when a species is faced with extinction, to estimate the social costs of the safe minimum standard in specific cases, and to help the decision-maker to view these costs in perspective. In the safe minimum standard approach, the public policy issue is not so much what is efficient, but what the present generation, through established institutions for public decision-making, is willing to sacrifice in order to maintain the reservoir of future resources.

Option value and quasi-option value are the keystones of the benefit-cost approach to the problem of irreversibility and uncertainty. As explained above, the safe minimum standard approach would consider these concepts to be most useful in understanding costs of the safe minimum standard. From this difference come diverging implications for future research. The benefit-cost approach would suggest that society's best hope for better coping with this sort of uncertainty would be further research to better understand the two option values and hopefully quantify them in order to narrow the gap between measurable and actual preservation benefits. The safe minimum standard approach would suggest that while such research might prove useful for refining estimates of the social cost of the safe minimum standard, society's best hope for coping with irreversibility and uncertainty lies in research to help define better strategies for implementing the safe minimum standard of conservation. For example, the condor study and other studies like it have dealt with individual threatened species. Non-economists, on the other hand, are beginning to talk in terms of preserving examples of at least the major ecosystems of the earth (Myers; Sullivan and Shaffer; UNESCO, 1973, 1974). What would be the economic implications of such a network of ecosystems in the United States and other developed countries? Furthermore, there is growing concern about the potential impacts of rapid natural resource development in the LDC's (Myers). Tropical areas appear to have special problems in this regard compared to the temperate zone. What would the safe minimum standard approach imply in these countries? To what extent will it be economically feasible to maintain representative ecosystems there? From the point of view embodied in the safe minimum standard approach, such questions are much more pressing and deserve a higher research priority than do refinements in our ability to quantify benefits and costs over the next decade or two.

FOOTNOTES

1. This paper will follow the common practice of referring to "endangered species," but it should be recognized that when a biologist or wildlife manager uses this term, he/she is most often concerned about individual subspecies as well as the species as a whole. An endangered species or subspecies is one which is recognized by man as being sufficiently close to extinction to make its survival beyond the next few years or decades questionable. No attempt is made here to distinguish between "endangered" species on the one hand and "threatened" or "rare" species on the other.

2. The California condor, unlike its Andean cousin, eats only carrion and has never been known to kill for food.

3. More about the natural history and current status of the condor can be found in the studies by Koford; Sibley; Miller, McMillan, and McMillan; Carrier; and Wilbur.

4. Quoted by Miller, p. 1231.

5. This is not meant to imply that there are no ways to improve efforts to thoroughly test new products or that more rational procedures for testing new production could not be devised on the basis of sound uncertainty economics.

6. Quoted in U.S. Forest Service, p. 43.

7. Quoted by Atkinson, p. 72.

8. It should be noted in passing that the condor's sensitivity to disturbance would rule out certain kinds of recreation, such as off-road vehicle use and high density camping, near nests and roosts. However, there is adequate land

available for such uses away from important condor areas and, with proper controls in particularly sensitive locations, the condor and low-disturbance recreation are generally compatible.

9. Recreation is the most obvious and perhaps the most easily quantifiable activity that is complementary to efforts to save the condor, but there are other such cases. For example, the present condor habitat is one of the few places remaining where the black bear could be studied in a typical Southern California chaparral environment with minimal human impacts. Other scientific resources include two small watersheds which have had minimal contacts with pollutants found to a greater or lesser extent in virtually all other streams in Southern California. This quality, which would almost certainly be lost to development in a few years if the area were opened up, might prove useful in assessing the more subtle impact of man on the regional environment (U.S. Forest Service).

10. These aspects are treated by other authors including Amacher, Tollison, and Willet; Bachmura; Plourde; and Krutilla and Fisher.

11. A fourth economic paper on endangered species is that by Amacher, Tollison, and Willett. This paper is basically in agreement with the benefit-cost approach, but will not be discussed because the decision of whether or not to permit extinction was not explicitly dealt with. Their paper focuses on eagles as sheep predators and cites evidence that if anything the eagle population should be increased.

12. The main issue from the standpoint of benefit-cost analysis was whether option value represents a new benefit or whether it is simply the traditional concept of benefits viewed from a different direction. This question was apparently solved by Cicchetti and Freeman, who cite the previous literature.

13. See also V. Kerry Smith. An attempt to include this assymetry in an actual study was made by the RFF group in their study of Hell's Canyon. See Krutilla and Fisher, pp. 84-150 and other literature cited there.

14. The discussion is in terms of the social cost of postponement because the decision to leave the oil (if any) in the ground is reversible. The social cost is not the total value of the oil but the social cost of producing it at some future date rather than now.

15. It is assumed that this figure includes an allowance for recreational growth as in the Hell's Canyon study.

16. Note again that the prospects here are not certain. There is a risk that all these efforts will fail to insure survival. In this sense, the discussion here is a bit oversimplified.

17. As noted above, space did not permit further description of how I arrived at this figure and it is used here only for illustrative purposes.

18. One could, of course, refine the $3 million cost figure by estimating some of the preservation benefits. However, given the fact that the cost (less than $3 million) is known to be small in relative terms, this need not be done unless it is relevant to policy.

19. This question was raised in comments on an earlier paper (Bishop 1972) by O'Connell.

REFERENCES

Atkinson, Brooks. "'40 Dirty Birds' Hold Their Own but are Never Safe." Smithsonian 2(1972):72.

Amacher, Ryan C., Robert D. Tollison, and Thomas D. Willett. "The Economics of Fatal Mistakes: Fiscal Mechanisms for Preserving Endangered Predators." Public Policy 20 (1972):411-41.

Bachmura, Frank T. "The Economics of Vanishing Species." Nat. Res. J. 11 (1971):675-92.

Barkley, Paul W., and David W. Seckler. Economic Growth and Environmental Decay: The Solution Becomes the Problem. New York: Harcourt, Brace, Jovanovich, Inc., 1972.

Bean, Michael J. "The Pupfish Goes to Court." Defenders 51(1976):119-21.

Bishop, Richard C. "Conceptual Economic Issues in Conserving the California Condor." Western Agricultural Economics Proceedings 45(1972): 119-22.

______________. "Land Prices, Social Costs, and Land Use Policies." Economics of Natural Resource Development in the West 4(1973):101-122.

______________. "Uncertainty and the Evaluation of Environmental Impacts." Environmental Impact Assessment: Guidelines and Commentary ed. by Thomas Dickert with Katherine Domeny. Berkeley: University of California Extension, 1974.

Brubaker, Sterling. To Live on Earth. Baltimore: Johns Hopkins University Press for Resources for the Future, 1972.

Carrier, W. Dean. Habitat Management Plan for the California Condor. San Francisco: U.S. Forest Service, Region 5, 1971.

Cicchetti, C. J. and A. M. Freeman III. "Option Demand and Consumer Surplus: Further Comments." Q.J.E. 85(1971):529-39.

Ciriacy-Wantrup, S. V. "The 'New' Competition for Land and Some Implications for Public Policy." Nat. Res. J. 4 (1964):252-267.

_______________. Resource Conservation: Economics and Policies. 3rd Ed. Berkeley and Los Angeles: University of California Division of Agricultural Sciences, 1968.

_______________ and William E. Phillips. "Conservation of the California Tule Elk: A Socioeconomic Study of a Survival Problem." Biological Conservation. 3(1970):23-32.

Cox, James A. The Endangered Ones. New York: Crown Publishers, 1975.

Dasgupta, Partha. "On Some Alternative Criteria for Justice Between Generations." Journal of Public Economics, 3(1974): 405-423

__________, and Geoffrey Heal, "The Optimal Depletion of Exhaustible Resources." Review of Econ. Stud. Symposium, 1974, pp. 3-28.

Ehrenfeld, David W. "The Conservation of Non-Resources." American Scientist. 64(6) (1976):648-656.

Harlan, Jack R. "Our Vanishing Genetic Resources." Science 188 (1975).

Henry, Claude. "Option Values in the Economics of Irreplaceable Assets." Rev. of Econ. Stud. Symposium 1974, pp. 89-104.

International Union for the Conservation of Nature, Red Data Book, Morges: IUCN, 1974.

Jenkins, Dale W., and Edward Ayensu. "One Tenth of Our Plant Species May Not Survive." Smithsonian 5(1975):92-96.

Jenkins, Robert E., and W. Brian Bedford, "The Use of Natural Areas to Establish Environmental Baselines." Biological Conservation 5(1973):168-174.

Kneese, Allen V. "The Faustian Bargain." Resources 44(1973):1-4.

Koford, Carl B. The California Condor. National Audubon Society Research Report No. 4. New York: Dover Publications, Inc., 1953.

Kreig, M. B. Green Medicine: The Search for Plants that Heal. New York: Rand McNally, 1964.

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

Millen, Alder H., Ian I. McMillan, and Eben McMillan. The Current Status of the California Condor. National Audubon Society Research Report No. 6. New York: Dover Publications, Inc., 1965.

Miller, Judith. "Genetic Erosion: Crop Plants Threatened by Government Neglect." Science 182(1973):1231-34.

Mishan, E. J., The Postwar Literature on Externalities: An Interpretive Essay." J. of Econ. Lit. 9(1971), 1-28.

________. "The Folklore of the Market: An Inquiry into the Economic Doctrines of the Chicago School" J. of Econ. Issues 9(1975):681-752.

Myers, Norman "An Expanded Approach to the Problem of Disappearing Species." Science. 193(1976):198-202.

Nature Conservancy. The Preservation of Natural Diversity: A Survey and Recommendations. Prepared for the U.S. Department of the Interior, 1975.

O'Connell, Paul F. "Natural Resources and the Environment: Discussion." Western Agricultural Economics Association Proceedings. 45(1972):136-137.

Phillips, William E. The Conservation of the California Tule Elk: A Socio-Economic Study of a Survival. Edmonton University of Alberta Press, 1976.

Ploudre, Charles. "Conservation of Extinguishable Species." Nat. Res. J. 15 (1975):791-98.

Raven, Peter H., Brent Berlin and Dennis Breedlove. "The Origins of Taxonomy." Science. 174(1971):1210-1213.

Rawls, John. A Theory of Justice. Cambridge: The Belknap Press of Harvard University, 1971.

Sibley, Fred C. Effects of the Sespe Creek Project on the California Condor. U.S. Bureau of Sport Fisheries and Wildlife Report, 1969.

Solow, R. M. "Intergenerational Equity and Exhaustible Resources." Rev. of Econ. Studies Symposium 1974. pp. 29-45.

Smith, Vernon L. "The Primitive Hunter Culture, Pleistocene Extinction, and the Rise of Agriculture." J. of Pol. Econ. 83(1975):727-755.

Smith, V. Kerry Technical Change, Relative Prices, and Environmental Resource Evaluation. Baltimore: The Johns Hopkins Press for Resources for the Future, Inc., 1974.

Sullivan, Arthur L. and Mark L. Shaffer. "Biogeography of the Megazoo." Science. 189(1975): 13-17.

Thompson, Peggy. "Value Extracted from a Nuisance," Smithsonian 6(1975):40-45.

UNESCO Conservation of Natural Areas and of the Genetic Material They Contain. Programme on Man and the Biosphere, MAB report series No. 12, Morges, 1973.

______. Criteria and Guidelines for the Choice and Establishment of Biosphere Reserves. Programme of Man and the Biosphere, MAB report series No. 22, Pari 1974.

U.S. Bureau of Sports Fisheries and Wildlife. Threatened Wildlife of the United States, 1973 Edition. Washington: U.S. Govt. Printing Office, 1973.

U.S. Congress, House. Report on Endangered and Threatened Plant Species of the United States. Presented by Secretary, Smithsonian Institute, House Document No. 94-51, 1975.

U.S. Forest Service. "Environmental Analysis of the Moratorium on Oil and Gas Leasing in the Sespe Condor Sanctuary," Preliminary draft. San Francisco: Forest Service Region 5, 1973.

Vietmeyer, Noel. "The Endangered but Useful Manatee Could Help Solve One of the Tropic's Major Environmental Problems." Smithsonian 5(1974):60-64.

Watson, I. A. "The Utilization of Wild Species in the Breeding of Cultivated Crops Resistant to Plant Pathogens" in Genetic Resources in Plants, I.B.P. Handbook No. 11, O. H. Frankel and E. Bennett, eds. Philadelphia: F. A. Davis Co., 1970, pp. 441-457.

Wilbur, Sanford R. The Food Supply Resources of the California Condor. U.S. Bureau of Sport Fisheries and Wildlife Report, Ojai, California, 1972.

World Wildlife Fund. "20,000 Plants in Danger." Biological Conservation. 4(1972):255.