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THE ECONOMIC THEORY OF NATURE PRESERVATION

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THE ECONOMIC THEORY OF NATURE PRESERVATION

I. Introduction

In this paper we develop some of the economic theory relevant to decisions about nature preservation. The theory is motivated by a discussion of current issues: the disposition of wilderness lands and the protection of endangered species. One may question the importance of wilderness and endangered species as "economic resources." We indicate how and why they are important--more important, perhaps, than the conventional extractive resources that economists usually worry about.

Two key concepts emerge from the discussion: uncertainty and irreversibility. Uncertainty is pervasive in economic life, of course. But more than the usual degree of uncertainty surrounds the potential future benefits from conserving ecosystems. Most endangered species, for example, remain as yet undiscovered in tropical moist forests that are at the same time undergoing rapid and (from the point of view of the indigenous species) destructive development. In these circumstances it is hard to predict what values--a cure for (some form of) cancer, a liquid hydrocarbon, a perennial corn, to name just three of the more interesting among current possibilities--will ultimately emerge if the species that may produce them are not lost.

Irreversibility is clearly central to thinking about endangered species or ecosystems because extinction or loss of wildlands is indeed irreversible. Again, other things are irreversible. But we shall argue that distinctions can be made among decisions and actions on the basis of whether their <u>consequences</u> are difficult or impossible to ameliorate. We shall further argue that wholesale loss of species or wilderness ecosystems fall in the category of consequences that are impossible to reverse and difficult to ameliorate.

In this setting we develop a model of decision making under uncertainty and irreversibility. The model is used to prove (given some further assumptions detailed in the text) that the optimal use of a natural environment is more likely to be continued preservation where the passage of time brings information about potential future benefits of preservation (and alternative uses) than where it does not. A related result is that the fraction of the area optimally preserved (where partitioning is possible) is larger.

The concept of "option value" which has played a large role in the literature on wilderness preservation--and elsewhere, for that matter--is clarified by our model. Here we define option value as the gain from being able to learn about future benefits that would be precluded by development (of an area) if one does not develop in the current period; in other words, the gain from retaining the option to preserve or develop in the future. Under the assumptions of our model, option value is nonnegative. A related concept, the value of information, is shown to differ in general from option value--contrary to recent claims in the literature. Option value is, in our analysis, a conditional value of information and is (not strictly) greater than the unconditional value of information.

The plan of the paper is as follows. In section II current conservation issues--species protection and wilderness use--are reviewed. Section III is a discussion of the nature and significance of irreversibility in economic processes. Section IV is the development of our formal model of decision making under uncertainty and irreversibility. Section V uses the model to clarify the discussion of option value and the value of information. Section VI offers some thoughts on other applications of the concepts and models presented here. Although developed for terrestrial ecosystems, they may have relevance to hydrospheric and atmospheric environments as well. In section VII we briefly review our findings.

II. Contemporary Conservation Issues

A. Wilderness and Other Unmodified Natural Areas

Some parts of the world, principally in temperate zones, have long been settled by societies that have become intensively industrialized and have populations that are large in relation to their land areas. In consequence of this, little land remains in a condition unmodified by man. In the New World, Australia, perhaps elsewhere in the subarctic and arctic regions, and in parts of the tropics, however, there still remains a significant amount of largely uninhabited or sparsely inhabited land that retains virtually all of the attributes that characterized it in pre-Columbian times. Some of this land is of remarkable scenic quality, other is notable less for scenic grandeur than for having preserved a complex ecosystem that retains a complete set of naturally evolved species of flora and fauna; and still other tracts represent repositories of remnant populations of flora or fauna that have been extirpated where their natural habitats have been destroyed to accommodate the requirements of industrial societies.

A considerable amount of the North American continent has remained in a largely undeveloped state. This has occurred in some cases because of the inaccessibility of high-elevation mountainous terrain, in others because of the excessive heat and aridity characterizing deserts which contain some of the most remarkable canyon lands, and in still others because of the general inhospitability of arctic and subarctic regions. These areas have provided in relatively recent times the wherewithal to establish the systems of national parks, national forests, national wildlife refuges and ranges, and public domain lands used for grazing domestic livestock as well as ungulate wildlife populations. These public lands, in turn, provide for functional systems established by law that ensure the preservation of wild and scenic rivers in an unmodified state as well as the national wilderness system and natural scientific research areas. The administration of wild lands in Canada is somewhat different at least partly because jurisdiction over resources resides with the provincial governments rather than the federal government of Canada.

In many countries which have established national wildlife sanctuaries and designated wilderness areas, the protection afforded these public lands varies considerably. In the United States, which appears to have pioneered the concept of national parks and protected wilderness areas, national parks are off limits to all extractive industries.[1] But in other countries, for example Australia and Canada, this protection often does not extend to exclusive use for recreation and scientific purposes. Extraction of minerals is commonly permitted, and building of hydroelectric facilities is a very common objective that contests the exclusive use of the area for activities that do not disturb the unmodified environment. Murchison's Falls, in Uganda, at the outlet to Lake Nyanza (Victoria) and the Lower Gordon in the Southwest Tasmanian Wilderness are cases in point.

In the United States, the wild rivers and wilderness systems intend to afford the most secure protection against man-made modifications. Here, generally speaking, not even the construction of roads or other facilities is permitted. Enjoyment of the natural environment, if it involves travel, must be by foot, horseback, or motorless craft (canoe, raft, etc.). This is at least the intent of the legislation providing for the establishment of such wilderness and wild rivers in the United States.

Although the unroaded and unoccupied areas of the United States (including Alaska) are very large in absolute terms, the amount of this land that has been set aside under the wilderness legislation amounts to approximately 33 million hectares as of the beginning of 1982 or about 3.5 percent of the total area of the United States. Of this amount, over 70 percent (23 million hectares) is the result of the Alaska National Interest Lands Conservation Act of 1979. This action completes, for all intents and purposes, national park and wilderness set-asides in Alaska. In the coterminous United States, not all of the roadless areas which were to be reviewed for possible inclusion in the wilderness system have been reviewed and acted upon. Some 10 million hectares of unroaded public domain lands under the administration of the Bureau of Land Management remain to be considered, and not all of the 25 million hectares of unroaded national forestlands that are recommended for inclusion into the wilderness system, or deferred pending further study, have received legislative attention. Accordingly, a large part of the unroaded and uninhabited public lands are not included in the current statutory wilderness system. In this respect, the wild lands remaining outside the system are in much the same status as the Australian or Canadian and other wild lands around the world; they have remained undeveloped for reasons of inaccessibility or inhospitability but are subject to conversion similar to that experienced by all present developed land.

The issue of development or preservation of wild lands is a lively one even in connection with the statutory National Wilderness System in the United States. This arises, in spite of the intent to protect these areas from development, because of a compromise that was needed to accommodate interests inimical to the wilderness legislation in order to secure its passage. To that end, the Wilderness Act of 1964 left open the possibility of mineral exploration for two decades following passage of the Act. Because this exemption will expire at the end of 1983, very intense interest has developed on the part of the extractive industries to enter the existing statutory wilderness areas for exploration. Removal of the time limit for exploration in wilderness areas has also been advanced vigorously. Serious attention has been given additionally to defeat the legislation required to establish each of the wilderness areas recommended by the relevant agencies from the roadless areas reviewed for this purpose. In this action, the extractive industries have been joined by the timber industry since wilderness areas, as well as national parks, are off limits to the resource commodity industries.

Although the bulk of the statutory wilderness areas, as well as the undeveloped wild land recommended for wilderness designation, do not occupy significant areas of commercial timberland or promising locations for fuel and nonfuel minerals, there are two regions where the opportunity returns that would be foregone by establishing protected wilderness areas could be nonnegligible. In the Pacific Northwest, also referred to as the Douglas Fir Region, the value of standing old-growth timber is significant. The old-growth stands, however, host old-growth-habitat-dependent species which are already endangered and thus the allocation of such land to timber production must take into account not only the recreational benefits foregone but also the potential value of the several endangered species. We shall return to the endangered species question presently.

A second area in which significant economic trade-offs are likely to arise is in the Overthrust Belt of the Rocky Mountains where, because of advances in drilling technology, it is now possible to tap promising geological formations in its "underthrust" portion, that is, the earth's mantle overlain by the overlapping formation. Here it is possible that not only some gas but also even petroleum in appreciable quantities will be discovered. It needs to be noted, however, that the portion of the existing wilderness system and recommended additions that overlap the Overthrust Belt represent only about 5 percent of the latter. The remainder, along with other prospective oil-bearing public lands, could occupy a prudent level of exploration for a very long time.

Because of the 20-year exemption from the provisions of the Wilderness Act that exclude entry into statutory wilderness[2] for extractive purposes and the ongoing process of fleshing out the statutory wilderness system, the issue of wilderness set-asides has been receiving a great deal of attention. This has occurred not only in public debate but also in legislative strategems that intend to trade off some (limited) additions to the National Wilderness System for legislation releasing other lands from the prospect of protected status. While the wilderness preservation issue has taken front stage, a similar controversy has developed over the prospect of landscape degradation that would spill over into the national parks. Indeed, under the policies of the Secretary of the Interior in the Reagan Administration, proposals are being considered to exchange national parklands with mineral potential for lands owned by the State of Alaska to permit the state to exploit these deposits.[3] But quite apart from the degradation from extractive activities on or within the boundaries of national parks, the establishment of mining and milling operations in proximity to park attractions such as Yosemite Valley or Jackson Hole in the Tetons can cast a pall, literally, over some of the most scenic and serene areas on the North American continent. In this respect then, the potential erosion of national park protection could in time change the protected status of national parks to a status of lesser protection not unlike that encountered in some other nations.

B. Endangered Species

We have noted that one of the valuable features of wild lands is the variety of natural populations they host. The conventional view of the threat to natural populations--endangered species--is that it is due to overexploitation. In some cases, this is undoubtedly correct. But the major threat to biological resources is habitat modification. 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. Thus the issue of endangered species protection is intimately related to that of wilderness preservation.

How serious is the threatened loss of species? There is a good deal of uncertainty here, but let us see what kinds of numbers serious students of the problem are using. In the United States, over 500 species are known to have become extinct since 1600 or between one and two per year. By contrast, over a 3,000-year span during the Pleistocene period, a period of glaciation when many individual organisms died, less than 100 species were lost in North America (Opler, 1971). About two-thirds of the recent losses have been in Hawaii due to the clearing of forests for cropland and the introduction of exotic species. This is significant because, despite the considerable interest in the problem in the United States, by far the greater number of species and endangered species are found in the tropical moist forests of the world.

Wholesale extinctions are threatened by the clearing of forests for cropland and fuel wood. Some biologists believe that 1,000 species are disappearing worldwide each year and that this rate may reach 10,000 annually by the end of the decade (Myers, 1981). By one estimate, as many as a million of the current 5 to 10 million species could be gone by the year 2000 (Myers, 1983). Again, these numbers are highly conjectural but extinction on anything like this scale would clearly be catastrophic for reasons we might now briefly consider.[4]

Why should anyone care if unprecedented levels of extinctions over the next few decades send uncounted species the way of the dodo and the dinosaur? Would human welfare really be much affected? The question here is, how does preservation of plant and animal populations not now harvested contribute to human welfare? There are at least two distinct ways in which they do this, more if we count "nonmaterial" welfare. Recently, a wild grass related to corn was discovered in a remote, mountainous area in Mexico slated for development. The wild grass is a perennial whereas domesticated corn must be planted annually (Vietmeyer, 1979). A successful hybrid could result in substantial savings due to elimination of the need to prepare the ground and reseed each year. Seed and preparation costs for corn run about $150 per hectare in the United States which has about 28 million hectares planted to corn. Annual savings could thus be on the order of $4 billion.[5] This number is highly conjectural, but the point is clear. Just one apparently trivial botanical discovery can result in dollar savings that even an economist would agree are not trivial. More generally, this example--and there are many others--illustrates one way a currently unharvested species contributes to human welfare: by conserving genetic information that may in the future be useful in some form of economic activity.

A second major way in which species are useful is as components of living ecosystems that provide the basic physical and biological supports for human life. These include maintenance of the quality of the atmosphere, control and amelioration of climate, regulation of freshwater supplies, generation and maintenance of soils, disposal of wastes, and cycling of nutrients.[6] Removal of any one species can cause a system to break down because each has evolved a set of characteristics that make it a unique functional part of the system. To some extent, it may be possible to substitute for ecosystem services. For example, nitrogenous fertilizers can substitute for nitrogen-fixing organisms. But even here there are environmental problems associated with heavy use. Agriculture in the United States, already a heavy user, still derives considerably more nitrogen from natural systems (Delwiche, 1970). In general, it seems fair to say that some services of ecosystems are not substitutable at all; and for those that are, the direct and indirect (or external) costs of substitution are likely to be high.

Loss of natural populations can also adversely affect human welfare in less tangible ways. People derive pleasure from the contemplation of strikingly varied life forms such as the perhaps 15,000 different species of butterflies. Surely this pleasure would be much reduced if, for example, all butterflies looked alike. And we ought to at least note, though we can do little more here, that some of the concern for endangered species is of a religious or ethical nature which does not easily fit into our utilitarian framework.

Protection of endangered species, and of the wild lands that are their native habitat, is being given increased emphasis by researchers and policymakers. In the United States, where as we have observed the potential losses are less severe than elsewhere in the world, a variety of statutes dealing with wildlife protection have been passed culminating in the Endangered Species Act of 1973. This Act contains several rather strong provisions, most importantly one that authorizes the Secretary of the Interior to designate areas of "critical habitat," and that requires all federal agencies to ensure that actions authorized, funded, or carried out by them do not jeopardize the existence of endangered species or modify their critical habitat. In addition to these key restrictions, the Act directly prohibits the taking or possession of any member of an endangered species and establishes a list of such species down to the level of subspecies and distinct populations of listed species. The restrictions on activities that affect habitat have become quite controversial as they have seemed to some a blank check for regulation. Somewhat surprisingly, in view of the controversy, the Act was reauthorized for three years with a large majority and with only minor changes by the U. S. Congress in 1982. An explanation for this anticlimactic action may be that, as suggested in a recent study, the alleged potential impacts of the Act on economic activity have been largely unrealized (Harrington and Fisher, 1982).

Much more serious are the impacts on economic activity that could result from a thoroughgoing attempt to prevent extinctions in the tropical moist forests that are home to most species and most endangered species. These forests are currently being converted--cleared for farming and fuel wood--at a rate that has been estimated as between 100,000 and 200,000 km^2, or between 1 and 2 percent of the total annually.[7] Any attempt to prevent this largely subsistence-level activity would clearly be very costly unless alternative sources of food or fuel were found for those affected. On the other hand, a continuation threatens enormous losses.

The challenge is twofold. First, ways must be found to discriminate among areas slated for conversion so that those richest in species can be afforded some measure of protection. Such an approach would recognize that some conversion will take place. The object would be to minimize the related losses.[8] Second, ways must be found to finance the desired protection. The 1975 Convention on International Trade in Endangered Species, which prohibits trade in specimens of endangered species, does not address the more serious and more difficult problem of preserving large areas of habitat for the thousands and maybe millions of plant and animal species that have yet to be listed as endangered because they have yet to be discovered and separately identified. The protection of even limited areas of habitat could be very costly, as we have noted; and the poor countries where they largely occur are not likely to want to bear these costs by themselves, especially when most of the potential benefits go to agriculture, industry, and medicine in the rich countries. Perhaps development aid could be tied to a measure of environmental protection. The World Bank is already beginning to do this, and the practice might be extended to cover habitat preservation. Aid has often been tied in the past, but it has been tied to purchase of the donor country's goods. Recipients might prefer a tie to protection of their own potentially valuable biological resources.

III. The Nature and Significance of Irreversibility in Economic Processes[9]

We have discussed in an informal way what appear to us to be the major contemporary issues in nature preservation. Why should there be more concern about disturbing scenic natural areas and endangered species' habitats than about issues involving the allocation of resources of comparable value? The reason is at least partly because wild lands and natural populations are the results of geomorphologic and biologic processes that represent a time frame measured in eons and, thus, cannot be produced by man. If these are destroyed, or otherwise adversely affected, they cannot be replaced or restored. There is thus a basic irreversibility that attends the modification of unique scenic or biological environments. These have been referred to as the "gifts of nature" since they cannot be reproduced in all of their essential features by the efforts of man.

A question will often arise as to whether this irreversibility is different from other examples of which we can conceive. It is sometimes suggested that all decisions, since they are time related, once taken cannot be "untaken" because this implies the ability to return to some prior moment in time. Although the theory of relativity suggests that moving backward through time is a theoretical possibility, it remains of little relevance to the solution of practical economic problems. Apart from this, there are differences among decisions because their effects can be ameliorated in some cases but not in others. There are several aspects to this observation.

The distinction between reversible and irreversible decisions in economic processes has sometimes been illustrated by the differences we can observe between production and investment decisions. A producer with a given plant and equipment, inventory of raw materials, and stock of finished goods faces the expected demand which he intends to meet. His decision on level of output in each product line may not be entirely consistent with the actual demand, and these discrepancies will be observed by changes in finished stock inventories. If errors as to the level of production required to meet the demand are encountered, stocks in inventory will rise (fall) to the extent of the over- (under-) estimate, and he can thus adjust output level by product line to conform to the actual demand. While his original decision may not be rescindable for any given production batch, he can alter the consequences by adjusting production on subsequent production runs. In this sense, we can consider decisions reversible; that is, if the consequences of a decision can be readily altered with negligible losses, it may be likened to a decision that is reversible.

If the decision, however, relates to the capacity of his plant so that he will be required to make decisions on the amount to be invested for its construction, the consequences of a poor decision will have longer duration. Investment in plant and equipment, unlike investment in raw materials inventory, cannot be liquidated in any short period of time. Indeed, if the capacity originally estimated to be required exceeded the market potential for his output, he would have made an irreversible commitment because capital is neither fungible nor readily liquidated. This, then, characterizes one aspect of irreversibility in economic processes--the inability to recoup investment in excess capacity.

While the overinvestment in plant and capacity represents an irreversibility and a matter of some significance to the individual investor, in most cases it will be a marginal decision considering the economy as a whole and can be dismissed as negligible. This is probably true of the bulk of investment decisions regardless of their significance to the individuals involved.

There are, however, consequences arising out of individual actions that do have consequences of long duration, the effects of which may be anything but trivial for society as a whole. Consider, for example, the allocation of resources that are a result of the accident of geological processes--the geysers in Yellowstone National Park. This remarkable phenomenon has at least two incompatible uses. It can serve as a geothermal source of energy for the production of electricity, or it can be reserved as a unique natural phenomenon providing opportunity for viewing and related recreational activities and as part of the national heritage. A decision to reserve the area for nature appreciation, related recreation, and scientific purposes is a decision that has been made but, of course, is not immutable. It is true that Yellowstone National Park represents a serious legislative commitment to preserve the natural features, but should the existence of society depend on its being rededicated to another use, no technical constraint would prevent a reversal of the original decision regarding its use.

If the geothermal resources of Yellowstone National Park were to be allocated to energy production, there would be a set of consequences stemming from this decision that would have more permanent implications. Construction of steam electric power plants, switchyards, transmission towers, etc., would result in a permanent adverse modification of the visual environment in the park. Mining of the superheated water would, in sufficient time, reduce subsurface pressures to eliminate the periodic geyser action and in time remove the reason for which the area was established as a national park. A decision to "restore" the area following depletion of the geothermal resources would not be technically capable of implementation. The adverse consequences of the decision to use the geothermal resources for energy production would be experienced in perpetuity. In the one case, we have the opportunity returns foregone from energy production that are limited by the availability of substitute prime movers for generating electrical energy, but retain the option to reverse the original decision, since legislation can be repealed if necessary. In the alternative case, the decision will involve precluded opportunity returns in perpetuity. There are no technical means of restoring the original character of a natural environment including the periodic eruption of Old Faithful.

Any investment in specialized plant and equipment will, in a sense, represent an irreversible commitment of capital to an undertaking and, from the standpoint of the individual investor, is not a decision to be taken lightly. But in a wider social setting, the irreversibility here is not unlike that which attends the death of any single member of a natural population. There does not appear to be overwhelming concern, except by the individuals directly involved, for the demise of a member of a species provided that reproductive capability is retained within the population. The risk of the loss of the last viable mating pair, hence the genetic information essential to survival of the species, is, however, a matter of much greater moment. The investment analogy here might be the loss of all of the information necessary to reproduce capital goods for the services of which there may be a future demand. This accounts also for the concern which society exhibits for the losses associated with dying arts and crafts. The extinction of these reduces cultural diversity in the same way as the loss of a species reduces biological diversity. Both represent reductions in the options available to a society and, thus, violate a central postulate of welfare economics: expansion of choice represents a welfare gain, reduction of options a welfare loss.

Not all environmental modifications need to be technically irreversible to provide a basis for more than usually deliberate societal decisions. As Weisbrod (1964) has noted, if restoration to an original state is excessively costly--whether in terms of the resources that must be allocated or the time required--a case exists for explicitly recognizing the option value associated with preservation of the original state.

The problems associated with restoration should receive explicit consideration. There are two important considerations that require attention. One involves the duration over which the adverse consequences of a decision must be suffered. The other involves the absence of authenticity in a reproduction or "restoration."

Consider the conversion of a wilderness ecosystem to meet the demands for the output of extractive industries. If the environmental modification results in the elimination of essential habitat for a given species--for example, the passenger pigeon or the grizzly bear--restoration is impossible or at least incomplete without the fauna dependent on the original plant associations. But, even if the survival of a species is not at issue, restoration is not a simple remedy for redressing the impact of an inappropriate decision that disturbed the original ecological environment. The clear-cutting of a climax species is equivalent to the removal of the results of ecological succession that represents, in many cases, centuries of ecological processes rather than a simple production cycle in the world of more typical choices.[10] The removed climax species would be succeeded by various seral species in a procession of changing plant and animal communities, culminating in the original ecological relationships only after a lapse of much time. In tropical climates, this restoration might be accomplished over a period of several generations sufficiently to bear at least a superficial resemblance to the original conditions for the less discriminating observer. But it is unlikely that even here the original faunal communities will be reestablished in their original associations. For example, the woods bison, the eastern race of elk, and the caribou, along with the predator populations that made up in part the eastern United States' wilderness ecosystems, are doubtless features of the original wilderness that are permanently lost to society in modern times. In the arid and semiarid West--and in the higher elevations in alpine settings in western mountains of the United States and in much of the Canadian and Alaskan subarctic and arctic life zones--perturbations to the ecological environment would take centuries to restore, if indeed this were possible.

Environmental modifications that affect the abiotic base are even more difficult to contend with. If the basic geological and soils conditions are adversely affected, replacement by perhaps more primitive, pioneer biotic communities might occur eventually; but restoration of the original biological environment will not be possible in anything like the time span that is meaningful for human societies. Vast open-pit mining operations, transportation facilities in ecologically fragile environments, such as in high mountain elevations or in the arctic, and some water resource developments are among the activities that have a potential for affecting the abiotic base in a manner that is irreversible by ecological processes for all practical purposes within the frame of human time spans.

Consider some of the complications that attend the development of a water storage reservoir in an ecologically fragile area. A faulty decision to construct a dam as revealed by hindsight involves more in its "restoration" than the dismantling of the structure when its existence is realized to incur environmental costs exceeding the returns from development. Supersaturation of the reservoir banks at full pool elevations may result in sloughing and landslides into the reservoir on drawdowns. An example of this condition is reflected in the experience of the Brownlee Reservoir in the upper reaches of the Hells Canyon in western United States. Moreover, to add to the reservoir-filling process, the retention of water in reservoirs impounding streams of high turbidity permits accumulation of sediment loads. To allow operation of the storage facility for its projected life requires allocation of storage space for the impoundment of sediment that settles out as the stream velocity is reduced in the slack-water pools. Dismantling of the structure at some future time will leave the impoundment area with an entirely different abiotic base from that which existed under original conditions. As a consequence, an entirely different ecological environment will be in prospect even if the dam is removed and natural restorative processes are permitted.

In arctic regions, removal of the primitive vegetal cover to expose mineral earth has long-run disruptive effects. The absorption of more solar heat may affect the very unstable soils relationships in areas of permafrost, with thawing, erosion, and gullying that leaves a condition of serious landscape disfigurement permanently and of growing severity with the passage of time.

A question can be raised, however, whether it is not possible to mobilize the knowledge that also accumulates with time, to short-circuit the time element in restoration. This is doubtlessly a possibility in many cases involving rather ordinary landscapes, particularly in the more rapid restoration areas of subhumid and humid climatic zones. But when we consider the extraordinary natural environments that are prized for their scientific research materials or their unusual scenic or natural features as part of the nation's ecological heritage, the problem takes on a different dimension. If the objective is simply to restore some type of outdoor recreational facility in place of the original, it is doubtlessly possible to replicate in some particulars the original features that would satisfy a part of the demands of those seeking outdoor recreation. On the other hand, of the 77 million hectares of national forestlands in the United States, for example, only some 25 million remain in a relatively undisturbed natural state and are suitable for reservation for the national wilderness system. The remaining 52 million hectares that have been modified in some particular, perhaps by roading, are available for the type of recreation that is serviced by facilities which restoration can provide.

But, there is a legitimate question whether undisturbed natural environments should be allocated to extractive industrial activities on the supposition that they can be restored eventually to provide replicas of the original that would satisfy the recreational interests of only the less discriminating clientele. The matter turns on the importance of authenticity as an attribute of the recreational experience, quite apart from the matter of preserving relevant research materials for advancing knowledge in the life and earth sciences. The demand for authenticity in undisturbed natural areas may be likened to the demand for authenticity in the visual arts.
For the bulk of the art museum clientele, the difference between an original work of art by one of the masters and a copy by one of his proteges, or a contemporary artist, is perhaps undetectable. But to a connoisseur of the arts, the mere suspicion of a forgery, even one so expert that art critics will differ in their opinions as to its authenticity, will result in a drastic reduction in the market value of the objet d'art--as many museum curators have been embarrassed to discover. The question then turns on what is the clientele, or market, that a particular amenity resource is to satisfy.

The outdoor recreation market is, in fact, a vast and complicated structure of submarkets. A developed campground in an attractive roadside location about the works of creative genius that the work of the most gifted imitator cannot provide. There may even be a cult comprised of those who revere the works of nature in a sense similar to that in which the Buddhists revere them, which may not be dissimilar from the reverence that primitive societies confer on nature in their religious observances. To those who number among the purists, preservation of the constituents of the biosphere in precisely the way it has evolved without disturbances from industrial man is a matter of great significance in a profound personal sense. Such feelings, in fact, have been captured in the works of Wordsworth and Emerson in very moving fashion. Whatever the reasons may be, whether mystical or religious, they are felt with great intensity. For analytical purposes, this translates into a highly inelastic demand for the "originals." This clientele represents, currently, a significant market that appears to be recruiting members rapidly as the income and educational and urban composition of American society changes. Moreover, this is a market for which refinements in restorative technology will do little by way of recreating "undisturbed" natural environments. Accordingly, the argument for irreversibility is a powerful one where the clientele group places a high value on the attribute of authenticity in the amenity services yielded by given natural environmental resources.

IV. Modeling Irreversibility

A. An Informal, Diagrammatic Approach

To economists, the important question about irreversibility is this: What are the implications for resource allocation? If the in situ resources of an environment are declining in value relative to the extractive resources, then, about the works of creative genius that the work of the most gifted imitator cannot provide. There may even be a cult comprised of those who revere the works of nature in a sense similar to that in which the Buddhists revere them, which may not be dissimilar from the reverence that primitive societies confer on nature in their religious observances. To those who number among the purists, preservation of the constituents of the biosphere in precisely the way it has evolved without disturbances from industrial man is a matter of great significance in a profound personal sense. Such feelings, in fact, have been captured in the works of Wordsworth and Emerson in very moving fashion. Whatever the reasons may be, whether mystical or religious, they are felt with great intensity. For analytical purposes, this translates into a highly inelastic demand for the "originals." This clientele represents, currently, a significant market that appears to be recruiting members rapidly as the income and educational and urban composition of American society changes. Moreover, this is a market for which refinements in restorative technology will do little by way of recreating "undisturbed" natural environments. Accordingly, the argument for irreversibility is a powerful one where the clientele group places a high value on the attribute of authenticity in the amenity services yielded by given natural environmental resources.

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To economists, the important question about irreversibility is this: What are the implications for resource allocation? If the *in situ* resources of an environment are declining in value relative to the extractive resources, then, clearly, irreversibility poses no special problem. An optimal investment program will call for conversion at a rate dictated by the changing relative values. Unfortunately, just the reverse is likely to be true, at least in the industrialized countries. Unique natural environments are in many cases likely to appreciate in value relative to goods and services they might yield if developed. Then the restriction on reversibility matters because value would be increased by going back to an earlier, less developed state.

The situation is represented in a broad aggregative fashion in Figure 1.[12] A production-possibilities curve having the usual concavity properties describes the trade-off between services of the <u>in situ</u> resources of natural environments, E, and produced goods, G, in an economy. The curve PP_1 gives this relationship for period 1, and the curve PP_2 gives it for period 2. PP_2 is flatter reflecting the increased output of G (but not E) made possible by technical progress. Curve $P'P_2$ is still flatter reflecting the economy's inability to yield the period 1 level of E because of irreversible conversion of some part of the natural environment in the process of producing period 1's G.

In order to say something about the relative values of the two goods, let us indicate I_1 and I_2 as community indifference curves for periods 1 and 2, respectively. Note that, even if tastes do not change from one period to the next, so that I_2 is roughly parallel to I_1, the slope at the new tangency point is flatter. If tastes do shift in favor of the environment, as some evidence suggests, the slope is still flatter; in other words, the relative price ratio P_G/P_E is still lower. The point is not that consumption of E is increased relative to G (in fact, just the reverse occurs) but that the relative value of E is increased.

Figure 1.

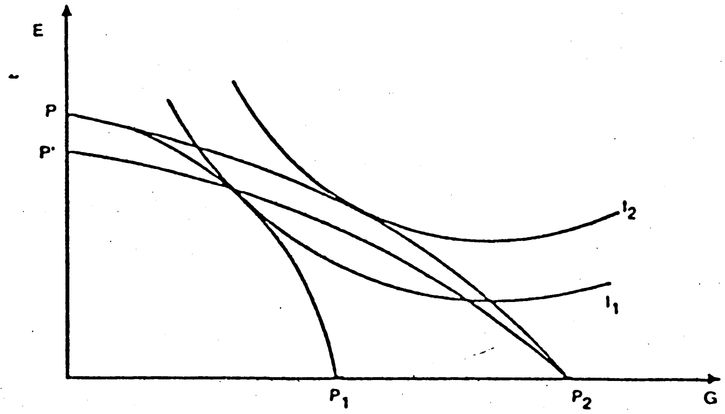

Figure 1. Production possibilities and preferences for produced goods and environmental amenities.

The argument about technical change, relative values, and irreversibility then goes something like this. Technical change is asymmetric. It results in expanded capacity to produce ordinary goods and services, but not natural environments. As long as consumer preferences do not shift sufficiently in favor of the ordinary goods (and we have evidence that they are likely to shift in the opposite direction), the supply shift implies an increase in the relative value of the <u>in situ</u> resources. This is pertinent to the assessment of any proposed conversion of the resources (the construction of a large dam, say, or an open-pit mine). Because the value of the <u>in situ</u> resources may be increasing relative to that of the water, power, or minerals produced by the development project, and development is irreversible, we might reasonably expect project investment criteria to be somewhat conservative. A rigorous theoretical exercise will establish this more precisely.

B. The Investment Decision Under Uncertainty

We have thus far not dealt formally with uncertainty about the value of <u>in situ</u> resources though it is at least implicit in all of our examples. There is a <u>chance</u> that conserving ecosystems and their component populations will lead to the discovery of a cure for cancer, a substitute for petroleum, or a perennial corn; but, obviously, this will not be known at the time a decision about a particular natural environment is taken. Less dramatically, it is quite possible, as we have suggested, that the value of <u>in situ</u> resources will rise relative to that of extractive resources; but even if this were generally true, it need not be for a particular tract of wild land. In this section we present a model of the development decision that takes account of both the irreversibility of development and uncertainty about the values development would preclude.

Our model is based on the original formulations of Arrow and Fisher (1974) and Henry (1974), but we adopt the more transparent notation and approach of Hanemann (1982). The two-period setting of section A is retained. The decision problem is: How much of a tract of wild land should be developed in each of the two periods? We choose units of measurement such that the maximum level of development (or perservation) is just unity. Then, there are three substantive assumptions. First, development in any period is irreversible. Second, the benefits of development in the first period are known, those of development in the second period are not. These assumptions capture the essential features of our problem. A third, made more for ease in obtaining unambiguous results, is that benefits are a linear function of the level of development. Later on we consider what happens when this assumption is relaxed.

Let us interpret the assumed structure a bit to indicate both its rationale and its limits. The benefits associated with a given level of development are the benefits of development <u>and</u> the benefits of preservation. Let the former be given, for the first period, as

(1) $$B_{1d}(d_1) = \alpha d_1$$

where d indicates development; d_1, the level of development in period 1; and α, a positive constant. Notice that $0 \leq d_1 \leq 1$.

Let the benefits of preservation be

(2) $$B_{1p}(d_1) = \beta - \gamma d_1$$

where p indicates preservation and β and γ are positive constants. Then, benefits in period 1 are

(3)
$$\begin{aligned} B_1(d_1) &= B_{1d}(d_1) + B_{1p}(d_1) \\ &= \beta + (\alpha - \gamma)\, d_1. \end{aligned}$$

The (linear) relationship between B_1 and d_1 is graphed in Figure 2 for the two possible cases of $\alpha > \gamma$ and $\alpha < \gamma$. Clearly, first-period benefits will be maximized by choosing either $d_1 = 0$ (if $\alpha < \gamma$) or $d_1 = 1$ (if $\alpha > \gamma$). Thus, the problem is restricted to a choice of corner solutions. The argument would be more complicated were we to consider uncertain second-period benefits as well, but this key restriction carries over.

Second-period benefits are $B_2(d_1 + d_2, \theta)$ where d_2 is the amount of land developed in period 2 and θ is a random variable.[13] Thus, second-period benefits depend on development in periods 1 and 2 and are uncertain. Notice that $d_2 \geq 0$, and $d_1 + d_2 \leq 1$. We shall assume that the problem is to maximize expected benefits over both periods. This is one particular way of dealing with the uncertainty. It is not, however, as restrictive as it may seem since we have not specified that benefits are measured in money units. If, for example, benefits are measured in utility units, then our formulation is equivalent to the quite general expected utility maximization.

The remaining structural element of the problem involves the behavior of uncertainty over time. More specifically, we consider two possible cases. In the first, nothing further is learned about the value of θ by period 2 so that d_1 and d_2 are chosen in period 1. In the second, the value of θ is

Figure 2.

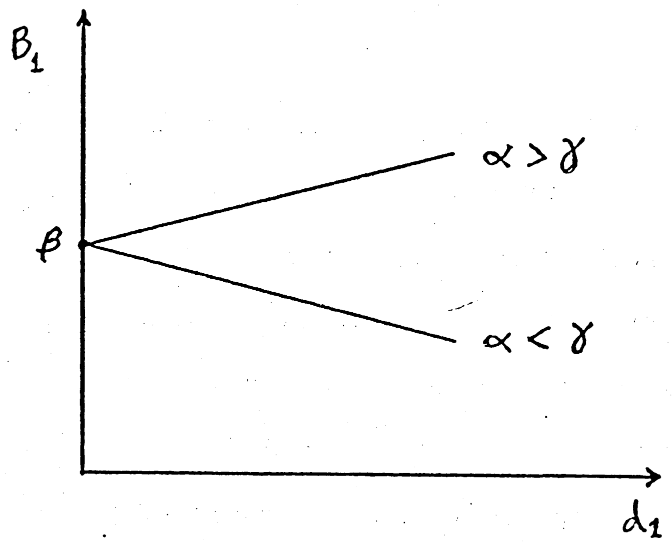

Figure 2. The linear relationship between benefits and development.

learned by period 2 so that it makes sense to defer a decision on d_2 to period 2. Now comes a very important assumption. It is that the learning, in case 2, does not depend on first-period development, d_1. For the kind of uncertainty we are trying to capture, this seems appropriate. Uncertainty is largely about the future (period 2) benefits of preservation--the value that may be discovered in some indigenous species, for example. This will be determined not by developing its habitat but by undertaking research into its medicinal or other properties. The research is not endogenous to our problem, but we do assume that the answer it yields, concerning the value of θ, does not depend on the development of the tract in question. Not surprisingly, this assumption importantly affects the results we shall obtain. At that point, we shall have more to say about the alternative assumption and its consequences.

Now let us write down expressions for the value to be maximized under each information structure. Where no new information is forthcoming by the second period, define $V^*(d_1)$ by

$$V^*(d_1) = B_1(d_1) + \max_{\substack{d_2 \\ 0 \leq d_1 + d_2 \leq 1 \\ 0 \leq d_2}} \{E[B_2(d_1 + d_2, \theta)]\}. \tag{4}$$

Then, the maximum value is $V^* = V^*(d_1^*)$, where d_1^* maximizes $V^*(d_1)$ subject to $0 \leq d_1 \leq 1$.

Where new information is forthcoming, define $\hat{V}(d_1)$ by

$$\hat{V}(d_1) = B_1(d_1) + E[\max_{\substack{d_2 \\ 0 \leq d_1 + d_2 \leq 1 \\ 0 \leq d_2}} \{B_2(d_1 + d_2, \theta)\}]. \tag{5}$$

The maximum value in this case is $\hat{V} = \hat{V}(\hat{d}_1)$ where $\hat{d}_1$ maximizes $\hat{V}(d_1)$ subject to $0 \leq d_1 \leq 1$.

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. Put differently, if the decision-maker ignores the prospect of better information, first-period development will be too great. We can prove this result, not in general, but where the choice is between no development ($d_t = 0$) and full development ($d_t = 1$). Recall that this is precisely the choice implied by our linearity assumption.

We wish, then, to compare the alternatives of developing and preserving in each information setting. Where no information is forthcoming, we have

$$V^*(0) = B_1(0) + \max\{E[B_2(0, \theta)], E[B_2(1, \theta)]\} \tag{6}$$

and

$$V^*(1) = B_1(1) + E[B_2(1, \theta)]. \tag{7}$$

Then,

(8)
$$d_1^* = \begin{cases} 0 \text{ if } V^*(0) - V^*(1) \geq 0 \\ 1 \text{ if } V^*(0) - V^*(1) < 0. \end{cases}$$

Where new information is forthcoming, we have

(9)
$$\hat{V}(0) = B_1(0) + E[\max\{B_2(0, \theta), B_2(1, \theta)\}]$$

and

(10)
$$\hat{V}(1) = B_1(1) + E[B_2(1, \theta)].$$

Then

(11)
$$\hat{d}_1 = \begin{cases} 0 \text{ if } \hat{V}(0) - \hat{V}(1) \geq 0 \\ 1 \text{ if } \hat{V}(0) - \hat{V}(1) < 0. \end{cases}$$

Notice that $V^*(1) = \hat{V}(1)$. With full development in the first period, total value over both periods must be the same since the development is locked in for the second period regardless of what is learned about the random variable θ in the first.

We have still not shown the relationship of d_1^* to $\hat{d}_1$. For this, just one more step is needed. From the convexity of the maximum operator, and Jensen's Inequality, it follows that

(12)
$$\hat{V}(0) - V^*(0) = E[\max\{B_2(0, \theta), B_2(1, \theta)\}] - \max\{E[B_2(0, \theta)], E[B_2(1, \theta)]\} \geq 0.$$

Since $\hat{V}(0) \geq V^*(0)$ and $\hat{V}(1) = V^*(1)$, $\hat{d}_1 \leq d_1^*$. In practice, what this means is that optimal first-period use of the area is less likely to be full development ($d_1 = 1$) where it is possible to learn about the benefits precluded than where it is not.

To produce this result, we made a couple of assumptions that deserve further comment. First, about the linearity of the benefit function which allowed us to compare just the two alternatives of development and preservation in each information setting. Hanemann (1982) has shown that the result ($\hat{d}_1 \leq d_1^*$) does not follow in the general case where d_1 can take any value in the interval [0, 1]. On the other hand, it may be produced in a variety of special cases.

For example, suppose we partition the area into a number of separate subareas each with its own (linear) benefit function. Then, each can be ranked by suitability for development; the one for which benefits are greatest is No. 1 and so on. Suppose further that the subarea benefit functions are independent; that is, benefits of developing subarea No. 1 do not depend on whether No. 2 is developed and so on. Now proceed exactly as before for each subarea starting with No. 1. If it pays to develop in a given information setting, move to No. 2 and ask the same question. Continue until the subarea is reached for which optimal development is zero. Since $\hat{d}_{1i} \leq d_{1i}^*$, where i indexes the subarea, the number of subareas optimally developed will be less in the new-information case than in the no-information case. In other words, the fraction of the original area developed will be less.

Of course, additional assumptions were needed to get this result. In our judgment, partitioning of an area, particularly if it is large or diverse, is plausible as is piecewise linearity. Independence of subarea benefit functions is less so. Other less restrictive assumptions about benefit functions might be devised that will yet be consistent with $\hat{d}_1 \leq d_1^*$. The judgment about all such assumptions is ultimately an empirical one.

The second key assumption we made was that resolution of the uncertainty is independent of development in the first period. We have argued that this is plausible; but, again, the judgment is an empirical one. It is fairly obvious that, if resolution depends on development, and, in particular, on a positive level of development, then (some) development may be optimal for the purpose of providing information even where this involves an irreversible commitment of resources that turns out to be a mistake. Such a result is obtained in a recent study by Miller and Lad (1982). Similarly, development for the purpose of providing information about whether the development is, in fact, irreversible may be optimal as has been shown by Viscusi and Zeckhauser (1976). The reader is free to choose among these alternative assumptions about the structure of information, but we continue to feel that ours is most plausible for our problem, i.e., relevant information about the properties of indigenous species will come not from developing their habitat but rather from research that, if anything, depends on preserving habitat.

V. Option Value and the Value of Information

In the literature on nature preservation, the concept of "option value" has played a prominent role. Beginning with the article by Weisbrod (1964), there has been a notion--advanced by some, including Weisbrod, disputed by others--that preservation carries with it a value (option value) above and beyond conventional consumer's surplus. A number of articles following Weisbrod established that option value could be identified with a risk premium: the difference between what a risk-averse consumer is willing to pay for the option of consuming (wilderness recreation, say), at a predetermined nondiscriminatory price, and his expected consumer's surplus.[14] These and other studies also exposed a difficulty; namely, that preservation, as well as development, can bring risks, e.g., floods or power failures.[15] The net option value of preserving a wilderness environment could then be negative. And, in any case, option value in this interpretation depends on risk aversion.

A different interpretation has been put forward by Arrow and Fisher (1974) and Henry (1974) and, more recently, by Conrad (1980), Hanemann (1982), and perhaps others. Unlike the first, it does not depend on risk aversion. Also, unlike the first, it is explicitly dynamic. In fact, it falls out quite naturally from the model presented in the preceding section. Option value, in this interpretation, is the gain from being able to learn about future benefits that would be precluded by development if one does not develop initially--the gain from retaining the option to preserve or develop in the future. In our terminology, this is

$$OV = \hat{V}(0) - V^*(0). \tag{13}$$

From equation (12), option value, OV, is nonnegative.

We can obtain this result in a somewhat different fashion following Arrow and Fisher's (1974) original presentation. Suppose the decision-maker ignores the prospect of new information. Then he will compare $V^*(0)$ and $V^*(1)$. A correct decision--one that takes account of this prospect--can be induced, in principle, by a subsidy to preservation. The optimal subsidy will clearly be one which leads the decision-maker to compare $\hat{V}(0)$ and $\hat{V}(1)$. To solve for the subsidy, S, write

(14) $$[V^*(0) + S] - V^*(1) = \hat{V}(0) - \hat{V}(1);$$

so that

(15) $$S = [\hat{V}(0) - \hat{V}(1)] - [V^*(0) - V^*(1)].$$

Since, from equations (7) and (10), $V^*(1) = \hat{V}(1)$, and equation (15) reduces to equation (13). The subsidy, S, is just what we mean by option value--the extra value attaching to the preservation option that would be overlooked in a conventional decision, a decision that did not take account of the prospective gains from information.

It is tempting to identify this concept of option value with another one familiar in decision theory: the value of information, or more precisely, the expected value of perfect information. However, the identification is not quite correct. Option value in this interpretation is, as Hanemann (1982) shows, a conditional value of information, conditional on $d_1 = 0$.

The unconditional value of information is $\hat{V}(\hat{d}_1) - V^*(d_1^*)$ or, in other words, the gain from being able to learn about future benefits provided d_1 is optimally chosen in each case. This may mean $\hat{d}_1 = d_1^* = 0$ or it may not. In fact, two other outcomes are possible: $\hat{d}_1 = d_1^* = 1$ and $\hat{d}_1 = 0$, $d_1^* = 1$. (Note that $\hat{d}_1 = 1$, $d_1^* = 0$ is ruled out by the result that $\hat{d}_1 \leq d_1^*$.) If $\hat{d}_1 = d_1^* = 1$, the value of information is $\hat{V}(1) - V^*(1) = 0$, whereas option value is still $\hat{V}(0) - V^*(0) \geq 0$. If $\hat{d}_1 = 0$ and $d_1^* = 1$, the value of information is $\hat{V}(0) - V^*(1)$. Notice that option value is once again greater than the value of information since $\hat{V}(0) \geq \hat{V}(1) = V^*(1) \geq V^*(0)$.

To summarize, then, option value is not identical to the value of information in the development decision problem. Option value is instead a conditional value of information, conditional on a particular choice of first-period development ($d_1 = 0$) and, moreover, is equal to or greater than the (unconditional) value of information.

VI. A Digression on Extended Applications

Our arguments and illustrations have been developed within the context of terrestrial ecosystems. But nature preservation need not be confined to this limited domain; it can be perceived to include hydrospheric and atmospheric environments as well. Viewed in this light the problem may take on additional dimensions, and the arguments addressing irreversibility and option value may require some further elaboration. But the approach taken in this paper appears to be generally applicable to the natural environment conceived in its broadest terms.

In our treatment of the terrestrial ecosystem, we considered whether or not the "real estate" in question could be partitioned into smaller parcels and whether the consequences of development, or experimentation, on a given parcel as a way to acquire information were separable and noncumulative for the remainder of the given ecosystem. In the case of the problem associated with atmospheric carbon dioxide concentrations, partitioning the atmosphere in order to carry out isolated experiments is, of course, impossible despite the likelihood that information could be gained on the relation between fossil fuel combustion and atmospheric carbon dioxide. It is not clear, however, that information of the sort sought would necessarily depend on continuing "experimentation." If suitable information can be obtained deductively from basic principles of atmospheric physics, an argument for continued combustion of fossil fuels as a way to acquire information concerning its atmospheric consequences is weakened despite whatever independent reasons can be given for their continued use.

There are likely to be cases where the adverse effects may be compounded by lags in detection and in responses to exposures (where health effects are involved) so that significant adverse irreversibilities may be set in motion by continued experimentation that are not subject to control except long after their undesirability is recognized. In the case of chlorofluorocarbons used in refrigeration, for example, the emissions do not occur significantly while the equipment is in use but only upon the escape of the gases from deteriorating containers some time after the equipment is scrapped. This delay in emissions and, hence, in observing the consequences on the ozone shield, along with the lagged response of skin cancer to reduced protection against solar radiation does not provide a proper context for a meaningful information acquisition strategy.

The introduction of lagged responses to lagged consequences of taking liberties with indivisible natural environments alters the context of the choice problem but not the general thrust of the value of retaining options where irreversibilities are encountered.

If the example of refrigerants and the ozone shield seems a bit strained, one can develop a suitable example to illustrate the point using persistent pesticides (chlorinated hydrocarbons, not detectable until after spread throughout the globe by vaporization, and concentrated through bioamplification, etc.). Other examples involve dioxin or heavy metals, again amplified by filter feeders and similar lags in detection. And where carcinoma rather than somatic illness is involved, there will be a lagged detectable response to exposure. This exacerbated condition, it seems, strengthens the argument for option value where the irreversible conditions may continue to grow even after detection because of past actions having lagged effects.

VII. Concluding Remarks

The major finding of this paper is a purely theoretical one: where economic decisions have an impact on the natural environment that is both uncertain and irreversible, there is a value to retaining an option to avoid the impact. Put differently, a development project that passes a conventional benefit-cost test might not pass a more sophisticated one that takes account of the uncertain and irreversible impact of the project on the environment. We designate the difference as option value: the gain from being able to learn about future benefits, especially those that would be precluded by the project, if one does not undertake it right away.

Option value, in this analysis, has something of the flavor of the value of information and indeed has been identified with this concept from decision theory. We show that option value is in fact a conditional value of information, conditional on a particular choice of first-period development, namely none. We further show that option value is greater than or equal to the (unconditional) value of information.

Examples of situations to which the analysis would apply are preservation of wilderness ecosystems, protection of endangered species, and maintenance of the integrity of nonterrestrial (atmospheric and hydrospheric) environments.

Footnotes

[1]In a small number of national parks where extractive activities may have occurred prior to the establishment of the park, such activities may be permitted under a grandfather clause, but typically they are prohibited.

[2]We need to distinguish between the statutory wilderness and other unroaded, uninhabited de facto wilderness areas. Only the statutory wilderness is protected from entry along with lands within the national park system.

[3]Wall Street Journal (September 1, 1982), p. 36.

[4]For a critical look at Myers' and other estimates, see Lugo and Brown (1982).

[5]The cost and acreage estimates are from Andrew Schmitz (personal communication). The savings estimate could be too high since yields of a perennial might not reach those of the leading hybrid strains, and a perennial might also require increased use of chemical herbicides and pesticides. On the other hand, elimination of the annual plowing would probably reduce soil erosion.

[6]For a detailed discussion of the role of ecosystems and individual species in these processes, see Ehrlich and Ehrlich (1981).

[7]The high estimate is due to Myers, the low one to Lugo and Brown. For further details, see Harrington and Fisher (1982).

[8]For a discussion of some promising ways to discriminate, see Harrington and Fisher (1982).

[9]This section draws heavily on Krutilla and Fisher (1975), Chapter 3.

[10]This, of course, assumes that the clear-cutting does not involve critical modifications to the abiotic base, such as soil erosion, siltation of spawning beds for salmon and trout fisheries, and other similar processes, that would permanently foreclose the restoration of original ecological relationships.

[11]Purism, as measured by Stankey (1972), was positively related to educational attainment and interestingly to urban, rather than rural origin among wilderness users.

[12]The discussion here draws on the seminal contribution of Krutilla (1967). Like the original, it is rather informal. For a more rigorous exposition that also deals with the richer and more realistic three-good case, see the work of V. K. Smith (1974).

[13]Second-period benefits can be reviewed as present values. We suppress the discount factor here because including it would not affect our results.

[14]See, for example, Zeckhauser (1969) and Cicchetti and Freeman (1971).

[15]For an argument along these lines, see Schmalensee (1972) and Henry (1974).

References

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

Cicchetti, C. J., and A. M. Freeman. "Option Demand and Consumer Surplus: Further Comment." Quarterly Journal of Economics. 85(1971).

Conrad, J. M. "Quasi-Option Value and the Expected Value of Information." Quarterly Journal of Economics. 94(1980).

Delwiche, C. C. "The Nitrogen Cycle." Scientific American. Vol. 223, No. 3 (1970).

Ehrlich, P., and A. Ehrlich. Extinction: The Causes and Consequences of the Disappearance of Species. New York: Random House, 1981.

Hanemann, W. M. "Information and the Concept of Option Value." Department of Agricultural and Resource Economics Working Paper No. 228, University of California, October, 1982.

Harrington, W., and A. C. Fisher. "Endangered Species," in Current Issues in Natural Resource Policy, edited by P. R. Portney. Washington, D. C.: Resources for the Future, 1982.

Henry, C. "Investment Decisions Under Uncertainty: The Irreversibility Effect." American Economic Review. 64(1974).

Krutilla, J. V. "Conservation Reconsidered." American Economic Review. 57(1967).

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

Lugo, A., and S. Brown. "Conversion of Tropical Moist Forests: A Critique." Interciencia. Vol. 2, No. 2 (1982).

Miller, J., and Lad, 1982.

Myers, N. "The Exhausted Earth." Foreign Policy. No. 42, Spring, 1981.

Myers, N. A Wealth of Wild Species. Boulder: Westview Press, 1983.

Opler, P. A. "The Parade of Passing Species: A Survey of Extinction in the U. S." The Science Teacher. 44(January, 1971).

Schmalensee, R. "Option Demand and Consumer's Surplus: Valuing Price Changes Under Uncertainty." American Economic Review. 62(1972).

Smith, V. K. Technical Change, Relative Prices, and Environmental Resource Evaluation. Baltimore: Johns Hopkins Univerity Press, 1974.

Stankey, G. H. "A Strategy for the Definition and Management of Wilderness Quality," in Natural Environments: Studies in Theoretical and Applied Analysis, edited by J. V. Krutilla. Baltimore: Johns Hopkins University Press, 1972.

Vietmeyer, N. D. "A Wild Relative May Give Corn Perennial Genes." Smithsonian. Vol. 10, No. 9, 1979.

Viscusi, W. K., and R. J. Zeckhauser. "Environmental Policy Choice Under Uncertainty." Journal of Environmental Economics and Management. 3(1976).

Weisbrod, B. "Collective-Consumption Services of Individual-Consumption Goods." Quarterly Journal of Economics. 78(1964).

Zeckhauser, R. J. "Resource Allocation with Probabilistic Individual Preferences." American Economic Review. 59(1969).