Ecosystems (2000) 3: 11–15
DOI: 10.1007/s100210000003

ECOSYSTEMS

Ecosystem Valuation under Uncertainty and Irreversibility

Jean-Paul Chavas

Department of Agricultural and Applied Economics, University of Wisconsin, Madison, Wisconsin 53706, USA

Key words: environment; valuation; uncertainty; irreversibility.

INTRODUCTION

The valuation of ecosystems has attracted much interest from economists (for example, Freeman 1993; Bingham and others 1995; Norton 1995; Suter 1995; Faber and others 1996; Acutt and Mason 1998). Clearly, ecosystems are valuable: they directly or indirectly support human life. Yet, while human activities historically have led to economic development, they also have created environmental problems and threatened the health of ecosystems. These negative impacts include species extinction, exhaustible resource depletion, global warming, ozone layer destruction, acid rain, water and air pollution, soil erosion, and deforestation.

Ecosystem functions are quite complex and often poorly understood. Although progress has been made in understanding ecosystem dynamics, great uncertainties concerning their long-term evolution remain. This uncertainty makes it difficult to decide the best way to manage ecosystems. Lack of consensus on environmental decisions among citizens (for example, conservationists vs business firms) and scientific disciplines (for example, ecologists vs economists), as well as experts, is common. Imprecise knowledge about ecosystems contributes to this situation because different individuals often have different information about the state of the environment. Without common information, it is difficult for different parties to agree on particular environmental decisions.

This disagreement creates significant challenges for environmental management. In this article, I focus on the effects of uncertainty and irreversibility, and their role in natural resource valuation. I examine the interactions between uncertainty and ecosystem dynamics and discuss their implications for environmental management.

Received 8 June 1999; accepted 22 July 1999.
e-mail: chavas@aae.wisc.edu

DYNAMICS AND UNCERTAINTY

Ecosystems change over time in complex ways. First, ecosystems involve many ecological variables that interact with each other. These interactions can take place within local ecological arenas (for example, predator–prey relationships) as well as in a more global context (for instance, the case of ozone depletion).

Second, ecosystem dynamics can be highly nonlinear, meaning that knowing the path of a system in some particular situation may not tell us much about its behavior under alternative scenarios. This contrasts sharply with linear dynamics, where investigating changes in a system generates understanding of its dynamic properties in any situation. As a result, learning about an ecosystem is difficult, especially if one is interested in its long-term trajectory. For example, nonlinear systems can be chaotic, where the long-term path of a deterministic system is unpredictable as arbitrarily small changes in initial conditions translate into large changes in long-term trajectory. Whereas a better understanding of short-term properties of an ecosystem is always useful, it may not provide precise information about longer-term dynamics. The "fast-moving" variables that underlie short-term dynamics may differ from the "slow-moving" variables that characterize long-term evolution. In this case, anticipating the long-term trajectory of a particular ecosystem can be challenging, both in identifying the relevant variables and in measuring them. This is particularly true in the common situation where the number of interacting variables is large.

Third, ecosystems are subject to unpredictable effects of variables that are not anticipated by decision makers. These unpredictable effects generate uncertainty due to lack of knowledge and/or lack of information. Lack of knowledge covers the situation where no individual in society has objective information about relevant effects. Scientific progress consists of producing new knowledge that reduces uncertainty and the extent of unpredictability. Lack of information occurs when decision makers lack knowledge of the effects associated with particular variables. Examples include unpredictable weather patterns (for instance, drought) and unanticipated effects of environmental changes (health effects due to contaminated water, nonpoint source pollution) as well as the case of asymmetric information, where some individuals may not be aware of what others (for instance, experts) know. Both the complexity of our environment and the cost of obtaining and processing information limit the quantity as well as the quality of information used by any decision maker. As a result, the best available scientific information typically is incomplete and uncertain for most decision makers. In this context, improving ecosystem management decisions is directly linked with decision makers' ability to obtain improved information.

Improving Ecosystem Management

Economists view ecosystem management as the process of choosing decision rules relating available information to particular actions affecting the ecosystem. How are those decisions made? They can vary from simple rules of thumb to complicated rules reflecting the complexity of the situation. An important issue is the impact of current decision rules on the future, which requires assessing the effects of decisions on the dynamic trajectory of the ecosystem.

This assessment typically involves alternative scenarios representing the effects of both current decisions and future uncertainty. Under learning in a dynamic context, this means developing decision trees, where each branch of the tree represents new information and/or new decisions. The ends of each branch reflect mutually exclusive outcomes, each obtained under a different scenario. The analyst then simulates the information available about ecosystem dynamics and its sensitivity to particular decision rules represented in the decision tree.

First, the "value" of each scenario represented in a decision tree must be assessed. This is a difficult but necessary step if we are serious about improving ecosystem management. Rejecting valuation would severely limit our ability to assess environmental decisions. Indeed, valuation provides a means of comparing alternative choices and thus of rationalizing particular management and policy choices. However, environmental services typically have no market price, meaning that there is no simple way of valuing the environment.

Alternative methods used to value environmental services have been proposed, including hedonic pricing, the travel cost method, and contingent valuation. The hedonic price method focuses on nonmarket characteristics that differentiate market goods. It uses the relationship between prices of market goods to uncover the "implicit price" of their underlying characteristics. An example is the situation when higher (lower) wages are associated with better (poorer) working conditions (Freeman 1993, chapter 12). When applied to recreational sites, the travel cost method uses the cost of a visit to each site as a proxy for the (nonobserved) price of its services. When this cost varies across individuals, this provides a basis for estimating the user demand for recreational services (Freeman 1993, chapter 13). Contingent valuation consists of surveying individuals to estimate directly their willingness to pay for specific environmental services. The reliability and credibility of this method have been questioned (for example, Diamond and Hausman 1994). Also, it is not clear that money is always an appropriate measurement unit, especially when the services valued are irreversible (for example, species extinction). In spite of shortcomings, contingent valuation remains a feasible way to measure people's value of the environment and is likely better than no measurement at all (Hanemann 1994).

Second, the uncertainty associated with each scenario in a decision tree, and its evolution, must be evaluated. This involves the information available currently as well as in the future. Uncertainty evaluation is a crucial step because a decision rule depends solely on information available to the decision maker. Only crude decision rules are possible in situations of poor information. And refined decision making requires refined information. This stresses the importance of obtaining quality information from research as well as adaptive management. Adaptive management consists in designing experiments that have the dual role of controlling the ecosystem and improving information (for example, see Walters 1997). When the cost of experimentation is low and the information generated is high quality, then adaptive management can be an important source of new information. Otherwise, the learning process typically relies heavily on research activities.

Uncertainty is assessed most commonly in terms of probabilities. Bayesian updating of probabilities then represents learning. Whether probabilities always can capture the role of uncertainty in decision making is questionable, particularly in the evaluation for nonrepeatable events. Also, the abilities and limitations of the brain in processing information underlines the complexity of the human decision-making process. Fuzzy logic, for example, has been proposed as a more realistic alternative to probabilities in representing human behavior under uncertainty (for example, see Munda 1995). At this point, probabilities will likely remain the main approach to measuring uncertainty, mostly because of their empirical convenience. However, we should keep in mind that they do not seem to capture well complete surprises, that is, events that are not part of our current knowledge base.

Third, the effect of alternative decisions on the path of the ecosystem needs to be assessed. Most human actions have some effect on the environment. But there is a more basic issue. Is it possible to make choices that can lead to *any* particular state of the ecosystem? This is the issue of system controllability. Controllability should not be taken for granted, as illustrated in situations of irreversibility. Irreversibility occurs when the ecosystem cannot escape from particular states no matter what action is taken. This means that the ecosystem may be controllable as long as it does not reach the irreversible states. But if it does, it is no longer (fully) controllable. A good example of irreversibility is the extinction of species: species that become extinct cannot feasibly be brought back into any ecosystem.

Irreversibility has significant implications for the efficiency of decision rules under uncertainty. Efficiency focuses on designing projects that generate the largest possible benefits at the smallest cost. Here, the terms benefit and cost are defined broadly: a benefit (cost) is associated with any situation that improves (decreases) the welfare of particular individuals. Economists typically measure benefit and cost by using monetary units. Whereas this seems appropriate in most situations, it may not capture well intergenerational issues or situations of irreversibility (see below). In such situations, nonmonetary measures of environmental benefit/cost may be needed (for example, using changes in environmental entitlements as welfare indicators).

Efficiency can be evaluated using optimization methods (for example, dynamic programming) that translate values and probabilities into recommended decision rules for ecosystem management. By definition, irreversibility limits future ability to change the ecosystem. It implies that staying away from irreversible states means maintaining the ability to make adjustments as new information becomes available. There is value in keeping future options open, and this is referred to as "option value" (Arrow and Fisher 1974; Fisher 1995; Chavas and Mullarkey 1999). Option value is always nonnegative (since the decision maker can always decide to ignore new information). Yet, option value can depend on current decisions. To illustrate, consider the case of choosing between a reversible decision and an irreversible one. The option value associated with the reversible choice is positive, whereas it is zero under the irreversible decision, implying that there is always some benefit in avoiding irreversible states. This argument is quite general and applies no matter what the irreversible states. The option value is an integral part of environmental benefits (Arrow and Fisher 1974; Fisher 1995; Chavas and Mullarkey 1999). By reducing option value, irreversibility adversely affects efficiency. This provides an incentive for implementing conservation strategies that improve the odds of avoiding the irreversible states. Examples include soil conservation methods that attempt to avoid irreversible soil erosion and ecological reserves that seek to increase biodiversity and reduce the chance of species extinction.

Many environmental problems also involve equity issues whenever the debate focuses on the distribution of environmental benefits among individuals and/or over time. Whereas economists are well equipped to investigate efficiency issues, they are less able to address equity issues, contributing to disagreement in the analysis of environmental problems and their solutions. The practice of "discounting" future benefits in project evaluation is one example. Economists argue that discounting is needed to reflect the opportunity cost of money over time (as measured by an interest rate). This practice reduces the benefits from learning, thus providing a disincentive to collect information. Also discounting tends to make the long-term future "irrelevant" because it undervalues the welfare of future generations. Such a treatment of future generations can be considered unacceptable on equity grounds. This disagreement has motivated the concept of "sustainable development," with a focus on the preservation of environmental services for future generations. Because future generations are not present, assessing their environmental benefits can be difficult. In the analysis of current ecosystem management, benefits can be evaluated only on the basis of current information, taking into consideration both current and future resource users.

It is our responsibility to incorporate the welfare of future generations in project evaluation on both efficiency and equity grounds. Unfortunately, at this point, there is no consensus on how to implement such an approach in ecosystem management. Going beyond efficiency, there is a need to incorporate equity in ecosystem analysis. One promising possibility is to rely on a fairness criterion. A situation is said to be fair if any individual prefers his/her own situation to the situation of any other individual. Fairness is a concept that has the advantage of being both intuitive and empirically tractable. When applied to intergenerational equity based on current information, fairness would be satisfied if any individual is indifferent between living in the present generation versus some future generation.

There are close connections between irreversibility, sustainability, and intergenerational equity. Indeed, unsustainable policies are commonly associated with both irreversible effects and adverse influences on the welfare of future generations. Such policies typically have two characteristics. First, they generate current benefits at the expense of future generations, thus contributing to a more unequal distribution of environmental benefits across generations. Second, their irreversible effects limit the ability of future generations to respond to new information, thus reducing the option value. These two characteristics reinforce each other in their adverse effects on intergenerational equity. When strong, such effects are the main factors characterizing the absence of sustainability.

This analysis has two implications related to sustainability problems. First, it stresses the need to identify circumstances leading to irreversible states that have significant adverse effects on human welfare in the long term. Scientists can make important contributions to knowledge by uncovering unsustainable situations as early as possible. This involves a better understanding of irreversible situations in ecosystem dynamics, as well as a better assessment of the values associated with irreversible states. Second, appropriate policies can be implemented to avoid such irreversible situations. One effective way to improve sustainability involves the use of "safe minimum standards" designed to reduce the odds of facing the irreversible states. Note that safe minimum standards may not be appropriate in the absence of irreversibility (in which case many options exist to react to new information). However, when irreversibility combines with adverse effects, then there is a need to develop cautious strategies for preserving future options and protecting the welfare of future generations. Then, designing and implementing cost-effective safe minimum standards is a way to avoid both irreversible states and their long-term negative effects on ecosystem health and human welfare.

CONCLUSION

Good ecosystem management requires good information. When refined information is available, one might prefer policies that allow for flexible strategies in response to new information at all levels (that is, local, regional, national, and international). Such an approach appears appropriate as long as it does not threaten to introduce significant irreversibilities. However, in situations where irreversibility occurs, a different management strategy is needed. This is particularly true when the irreversible states have significant adverse effects on future human welfare.

Interdisciplinary research can make significant contributions to ecosystem management. Ecologists, in particular, can identify scenarios where irreversible states may occur. Economists can help assess the welfare implications of such states, with a focus on measuring option value. This process can give useful insights into both the efficiency and intergenerational equity implications of current ecosystem management decisions. When significant irreversibilities arise, it is important to know about them as early as possible. Then, the design and implementation of safe minimum standards can help reduce the odds of facing the irreversible states, thus preserving the ability to manage ecosystems such that they continue to provide environmental services to future generations.

The extent of uncertainty involved in ecosystem dynamics implies a need for vigilance about moves toward irreversible states. Much information is needed to support good environmental management. At this point, case studies are likely the best framework to refine our research tools. They can help develop better linkages between ecological and economic models and strengthen the usefulness of ecological research in environmental management. These challenges offer great opportunities for ecologists, economists, and policy makers to work together for improving ecosystem management.

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