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Analysis

Issues in ecosystem valuation: improving information for decision making

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Abstract

In Spring 1991, the U.S. Environmental Protection Agency convened an expert group of ecologists, economists and other social scientists for the purpose of advancing the state of the art of ecosystem valuation methods. This Ecosystem Valuation Forum was organized as a dialogue because it has been clear from the outset that agreement even on the meaning of the term "ecosystem valuation" could not be taken for granted. Individuals from diverse disciplines, and from industry, environmental groups and government agencies disagree about what information about ecosystem services is needed, how it should be used and, therefore, what would constitute an advance in the methods that analysts should employ. The Forum discussed the varied ways in which experts from different disciplines approach valuation, what ecosystem attributes or services are important to value, and the factors that complicate the task of assigning values to ecosystem attributes. The Forum placed particular importance on approaching the problem of ecosystem valuation from the perspective of decision makers. Therefore, members discussed the variety of decision makers who might need valuation information, the controversy over where balancing decisions about costs and benefits should be made, and the implications for what information is needed

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within different institutional constraints. In addition, agency decision makers operate under real time and resource constraints. Thus, the Forum discussed the need to develop protocols that would guide analysts in a search for decisive information. The Forum concluded that the time is ripe for making new progress in solving some of these problems, while acknowledging that it may not be possible to develop a single unifying definition of value. Instead, the goal would be to understand how various concepts of value are structured, how they relate to each other, and how they can guide us toward a more integrated valuation process. The Forum recommended that next steps in addressing these issues be organized around case studies, particularly those that would enable researchers to improve linkages between ecological and economic methods and to develop improved protocols for valuation studies.

Keywords: Ecosystem valuation; Decision makers

1. The problem

Public and private decision makers want and need better information about the values of ecosystems in weighing the advantages and disadvantages of human actions that may affect ecosystems. The level of public interest in environmental protection has never been higher, nor has the investment of public and private dollars. Although environmental and business interests disagree about when and how information about the economic costs of achieving environmental objectives should be weighed, all sides are concerned about improving the availability and use of information about ecosystem values in making policy decisions.

However, information often is lacking about: (1) the physical changes to ecosystems and the socio-economic consequences that might result from alternative courses of action; and (2) the "value" of those changes. Information is inadequate because the capacity to value alterations in ecosystem attributes is not well developed, particularly for ecosystem functions and processes. While some progress has been made in valuing certain aspects of ecosystems as commodities—recreation, for instance—much work remains before satisfactory methods for valuing all the services and attributes of ecosystems will be available.

One of the limits to providing sufficient ecosystem valuation information to decision makers is that it is extremely difficult to measure fully the functions and processes of an ecological system or to predict the ecological impacts of disturbances to those complex systems. Furthermore, even where relatively simple ecosystems are fairly well defined, it is difficult to determine the causal relationships between human actions and ecosystem functions and processes. Much needs to be done before the consequences of human alterations to ecosystems will be well understood or predictable.

Early in the first meeting of the Forum, it became clear that even the phrase "ecosystem valuation" presumed a level of agreement among the individuals and disciplines that could not be taken for granted. Because experts from within and across disciplines currently approach the question of ecosystem valuation from such very different perspectives, it has been critical to explore the problem in valuing ecosystem services and attributes and to construct an interdisciplinary agenda for discussion.

It is desirable to place this effort to value ecosystem services within some historical context that describes how concerns about valuing the services of the natural environment become a part of the information set used in policy decisions. In 1958, a subcommittee of the Inter-agency Committee on Water Resources issued a report on Proposed Practices for Economic Analysis of River Basin Projects [2] (known to many as the "green book") which had a profound and lasting effect on the principles and practice of economic analysis of public projects. Many of the problems in fully valuing ecosystem attributes still faced today were anticipated in that report:

[2] U.S. Federal Inter-agency River Basin Committee. Subcommittee on Standards and Evaluation. "Proposed Practices for Economic Analysis of River Basin Projects" a report to the Inter-Agency Committee on Water Resources, Washington DC, 1958 (revised).

"The public policies governing the development of the Nation's water and related land resources are not necessarily determined solely on the basis of economic considerations." (p. 3)

"... from the standpoint of society as a whole there may be beneficial or adverse effects that would escape consideration in a summation of individual evaluations, as for example,... value of resource conservation to future generations..." (p. 6)

"The problem of evaluating, from a public viewpoint, the extent to which a project [policy] accomplishes the aim of satisfying human needs and desires presents a major difficulty at the outset, because there are no common terms in which all effects of a project [policy] are normally expressed." (p. 6)

The members of the Forum are conscious of the pertinence of these observations today, some three decades later. However, it is important to recognize the evolutionary nature of our knowledge base, and the need to be aware that the ability to characterize and estimate the economic values of environmental services, (available largely outside organized markets) changes with the advance of the scientific and the economic disciplines involved. Perhaps natural and social sciences have advanced sufficiently that needed progress can now be made.

The need to be aware that the ability to characterize and estimate monetary values of environmental services has grown tremendously since the "Green Book" appeared. Of course, a great many problems remain unresolved, and further progress on tools to establish monetary values is needed. Beyond that, three problem areas persist that have been less well recognized.

First, to a considerable degree, ecosystem valuation could be improved if currently available tools for monetary valuation could be competently applied more often. Additional resources for economic studies would help, but resources, even if augmented, will likely always be inadequate to assess every situation in which ecosystems are damaged or at risk. Such studies could well be a waste of resources as well. The challenge is to define what sorts of valuation information is likely to be decisive: i.e., that is really needed to make decisions. Ways to build on existing information rather than to rely on expensive primary data gathering need to be developed.

Second, the fact that good valuation studies depend on sound ecological results is not adequately appreciated. Ecosystem services can be valued in dollars only after those services are well understood, yet predicting how ecosystem service flows will change as a result of human intervention is often difficult or impossible. As ecology itself evolves to better understand the services ecosystems provide and to better predict how they will change as a result of human actions, existing economic tools can be applied to better evaluate ecosystems. In the meantime, decision criteria to adequately address ecological uncertainties need to be devised, and such criteria are likely to involve human values beyond monetary values.

Third, it would be a mistake to think that if ecosystem services were perfectly understood and evaluated in monetary units according to accepted economic precepts, the problems of ecosystem valuation would be completely solved. Many would question whether monetary valuation alone adequately captures what decision makers need to know to confront irreversible ecosystem modifications that could have serious long-term economic and social repercussions. Perhaps the most important task is to clarify where conventional economic values are sufficient for decisions and where broader human values—including non-monetary values—and criteria for decision making are more appropriate.

1.1. How do we value ecosystems?

A discussion of what one means by "value" is inescapable if people from diverse disciplines and perspectives are to find a common language for dialogue. Value to the average citizen is not a confusing word. It means the general importance or desirability of something. As often happens with words, more precise definitions of value have evolved in different disciplines to meet different needs, but that greater precision sometimes limits interdisciplinary inquiry.

We acknowledge that the Forum may not be able to develop a single unifying definition of value. Instead, our goal is to understand how various concepts of value are structured, how they relate to each other, and how they can guide us toward a more integrated valuation process.

Ecosystems have important attributes, both structural and functional, which influence an ecologist's perspective about how the value of ecosystems should be understood. To some economists, ecosystem values correspond to what people will pay to maintain or restore that system or some of its attributes; to others, it may mean societal value as determined through the political process; to still others it means valuing the consequences to the community. To philosophers the term "value" is a verb encompassing utilitarian, aesthetic and moral assessments. To social-psychologists, ecosystem values may mean characterizing the reasons, feelings and beliefs people express for preferring some ecosystem attributes over others.

Values are by definition anthropogenic (a forest cannot tell us whether it prefers to be old growth or young and vigorously growing), however, ecosystem values need not derive from human use of the systems or their components. That is, ecosystems may be valuable to people as ecosystems as well as producers of timber and clean water.

The Forum recognizes the need to separate issues of semantics from issues central to improving ecosystem valuation. Thus, although public discussions often include references to "intrinsic" values for species and ecosystems as opposed to their instrumental values to humans, the Forum will not employ this dichotomy, in part because its current use obscures important distinctions. The broad variety of values derived from ecosystems fall upon a continuum ranging from easily priced tangible benefits (such as food and pharmaceuticals); through the values associated with less easily priced services, aesthetic experiences and bequest values; all the way to moral and spiritual values.

Separating these many different ways in which ecosystems are valuable to people is a significant first step, particularly because the methods for measurement will vary. Our goal, therefore, is not to classify these by locating them within or outside the process of human valuation, nor is it to separate goals from the means by which they are achieved. Instead, we intend to recognize the entire range of human values and to seek ways to integrate these multiple values in an improved decision framework.

It also is important to understand the various roles that individuals play and how these roles affect the notion of "valuing" something. It can be observed empirically that the same individual, whether lay citizen or expert, will value ecosystem attributes differently when expressing personal values and when serving in some advisory or decision-making role for a public institution. People also reason differently when acting as decision makers or advisors (for example, when they vote to institute strict land-use regulations) than they do as private agents (when they might, by contrast, use their own land to the maximum intensity allowed by current law). Similarly, people seem to emphasize quite different issues and decision criteria when their concern shifts from short-term considerations relevant over months or years to concerns about sustaining processes over several generations.

Thus, some ecosystem valuation experts question which of these valuation contexts should be used to determine people's "real" values. To many economists, the answer is to use the values people express as individual households or consumers, because the generally accepted norm is to attempt to act (and therefore to value outcomes) based on the perceived preferences or goals of the group being represented. Thus, these multiple concepts of value may be distinct and not necessarily contradictory.

However, as the science of ecology has matured, mankind's knowledge about the interconnectedness of ecosystem processes and structures has grown. As a result, individual citizens have shown increasing concern about the effects of human actions on ecosystems. An important attribute of this concern, though, is the awareness of many citizens that they do not understand all of the attributes of ecosystems that are necessary to support the ability of the natural environment to produce those services that they benefit from directly, and that much more remains to be learned. This lack of information affects people's abilities to place a value on ecosystem attributes.

This raises new questions about whether there is a prior step to choosing whose values to count. Might people be willing to allow scientific advisors—and the ways of valuing inherent to their disciplines—to play a role in shaping the valuation information used in collective decision-making processes? This could take various forms. People might want experts to inform them about the interconnectedness of ecosystem processes and structures and let them, as citizens, express their values through democratic processes. Or, people might want experts to develop other kinds of methods for valuing certain ecosystem attributes determined by scientists to be crucial to the viability of ecosystems, but which are not directly useful to people.

We cannot calculate ultimate values for ecosystems. But, by emphasizing the varied ways in which ecosystems are valued, we propose to offer a variety of guides to improved decision making with an accompanying set of criteria or "rules of thumb" indicating which guides to emphasize in particular contexts.

1.2. What is to be valued?

Ecosystems are dynamic—populations of species rise and fall, one species may substitute for another species, physical processes change. Although such changes occur naturally, human actions often cause more rapid or unanticipated changes. The effects of such changes are not necessarily ecosystem collapse; alternate ecological states are possible. However, some ecosystems are more desirable to people than others. Some ecosystems provide more habitat for threatened or endangered species than others; some ecosystems provide more water purification services than others; and some ecosystems provide more recreation opportunities than others.

Experts continue to struggle with the fundamental question of what services to value. The choice of which ecosystem attributes to value is itself a valuation decision, and a challenging one. The very term "ecosystem" is a multi-scale concept, referring to such widely different circumstances as a rotting log, a prairie, and the earth itself. Even individual attributes of concern occur at widely different temporal and spatial scales. One needs to know what is important to measure, and why.

The notion of importance is central to any coherent approach to valuation. After all, if there is no agreement regarding the ends, there can be no agreement regarding valuation. Put somewhat differently, "values" in ecosystem valuation are derived from criteria whereby particular courses of action are regarded as good or bad. Ecologists may think in terms of ensuring the resilience of a particular ecosystem, or of maintaining its productivity. Economists may think in terms of a monetary expression of the goals derived from preferences. Other social scientists will think in terms of other expressions of human preferences. Regardless of the form taken, valuation of ecosystems cannot logically proceed in isolation from a clear idea about what ends are being sought.

An identification and categorization of various ecosystem attributes also is necessary in organizing an inquiry to improve methods for valuing those attributes.

Ecosystems have many different attributes and offer many different services, the value of some or all of which decision makers may wish to consider in weighing the advantages and disadvantages of a course of action. A partial list could include, among many others:

- food (e.g., oceans)
- sources of wild medicinal plants (e.g., forests)
- water purification (e.g., wetlands)
- flood control (e.g., wetlands)
- erosion control (e.g., forests, wetlands)
- carbon sequestration (e.g., forests, oceans)
- habitat for wildlife (most ecosystems)
- reservoir of biological diversity
- nutrient recycling
- detoxification of chemicals
- recreation and outdoor adventure
- aesthetic enjoyment, solitude, and spiritual fulfillment

Several factors complicate the task of assigning values to ecosystem attributes. For example, many important structures or functions of ecosystems do not directly benefit people, but are necessary for the ecosystem as a whole to provide the services that people do use. For example, attributes that are more directly useful to humans include food, medicine, recreation and aesthetics, while those that help sustain viable ecosystems include such attributes as habitat, nutrient recycling and genetic diversity. Changes in these latter services could, in theory, be translated into effects on valued goods and services more directly useful to people. In practice, however, the time, data, or methods for that translation often are not available. Although the task presents a difficult set of conceptual problems, progress in improving the valuation information available to decision makers must begin to consider the value of those ecosystem attributes that help sustain the ecosystem itself. [3]

Ecosystem services also have present and future dimensions. The patterns in which they are used today will affect their ability to continue to "produce" the outputs that people care about and, thus, people's "option" to use such goods and services in the future.

In addition, human knowledge about ecosystems is very incomplete. Thus, we may not anticipate all the goods and services that an ecosystem does or could provide. For example, the Pacific Yew—previously considered a "weed" species—has recently been found to have medicinal value in the treatment of certain cancers. There also may be unknown future values in ecosystem goods and services other than those that have commodity value. For example, 30 years ago, neutralizing acid deposition and sequestering carbon were not recognized to be valuable ecosystem services.

Furthermore, ecological impairment may not just be a matter of damage to various life-support and ecosystem functions, but also to some very important notions of a meaningful quality of life. Often the environmental harm of concern to people is more a matter of a less satisfying, uglier and diminished existence that, despite increased material benefits, people describe as less beneficial in intangible terms than the nurturing landscape that has been lost.

Categorizing the services that ecosystems provide may help in deciding what to measure or in selecting among different valuation methods for different services. Also, different methods may be based on different categorizations. If more than one valuation method is determined to be useful in making a decision, then an understanding of the categories assumed will allow an assessment of whether certain attributes or services are being double counted.

As an example, the following categories were modified from a list developed by Steven Kellert (Kellert and Clark, 1991):

Naturalistic / outdoor recreational services e.g., observation of wildlife in a natural environment or fishing on a secluded lake.

Ecological services e.g., nutrient cycling.

Existence services e.g., knowing a species or ecosystem (e.g., Yellowstone) exists even though you never intend to see it.

Scientific services e.g., the potential of species and systems to increase human knowledge about the natural world.

Aesthetic services e.g., the beauty of natural systems and individual species.

Utilitarian goods or services e.g., direct resource commodities such as fish production, medicines, agricultural products, etc.

Cultural, symbolic, moral and historic services e.g., the role a species can play in a particular society, such as the bald eagle in some American Indian cultures.

[3] There is another type of characterization that arises frequently in economic modeling. This one is defined from the perspective of whether the good or service once "produced" by the ecosystem enters preferences directly or if it requires some type of transformations before it is of direct value. Some goods and services of an ecosystem may be recognized by people, but they may or may not have direct value to such individuals. For example, timber is harvested from forests because it is useful to people, but in meeting these needs individuals generally do not purchase trees. Instead, they buy milled lumber, furniture or houses made from wood products. Similarly, it may be the case that some people do not value ground water other than as a water supply. In this situation the ground water may be a final output of the aquifer, but an intermediate input to the production activities required to extract it, assure it is safe drinking water, and deliver it to the people wishing to use it. The ultimate drinking water available for consumption at each person's house is the final product.

The Forum plans to emphasize the values resulting from ecosystem functions. This does not imply that ecosystem structures are unimportant. Rather, the commodity values of fish and timber, the recreational values of lakes and forests, and other values of ecosystem structures are relatively well understood. In contrast, the services provided by ecosystem functions, such as climate moderation and water purification, are poorly appreciated by decision makers and the public, poorly estimated by environmental scientists, and incompletely valued by current valuation methods. The values of these poorly characterized services are potentially quite large. Also, in contrast to some other poorly characterized services, such as aesthetics or existence services, those provided by ecosystem functions may be more amenable to assessment and quantitative valuation.

The development of a categorization system is identified in (see Section 5) as a topic for future work.

2. Information needs

2.1. The choice problem

The debate about how choices should be made, and by whom, forms the backdrop to any effort to improve valuation methods. At the most basic level, choice implies value. Whether the decision maker chooses to do something or not, the act of choice implicitly reveals a threshold for the value the decision maker has assigned to what is at stake.

In the United States, decisions are made by individuals, executive branch agencies, legislative bodies, or the courts within limits set by existing law and the constitution. People differ, however, about which decisions are appropriately made by individuals and which by collective processes. Within the category of collective processes for social choice, the relationship between legislative, executive and judicial bodies becomes important in shaping different views about where balancing decisions should be made and how.

A key factor is the degree of specificity of desired outcomes set in the legislative process. In

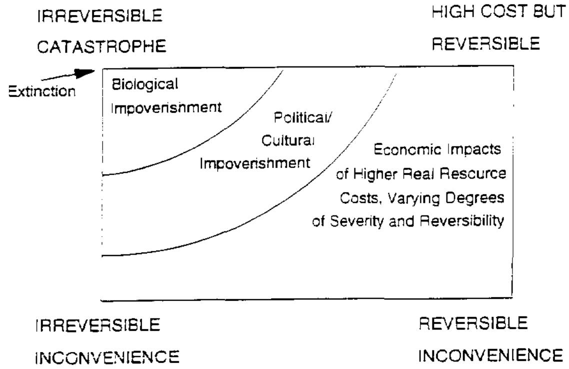

Fig. 1. Potential impacts on the natural environment: severity and reversibility.

some statutes, Congress establishes general goals. Under these circumstances, agencies weigh costs and benefits in the rulemaking process to specify desired outcomes. In other cases, Congress establishes the desired outcome more specifically, weighing costs and benefits in the legislative process, and asks the Executive Branch to determine the best means to achieve these pre-established ends. In actual practice, of course, these distinctions are blurred, particularly because ends set by Congress usually can be achieved to different degrees. [4]

These general scenarios play a significant role in determining the place of cost-effectiveness and benefit-cost analysis in particular (see Section 2.2 for examples). The specific directives set by Congress also have implications for what types of information will be most useful (see Section 2.3 distinguishing information about ecosystem effects and values). Different methods for providing information also may be useful depending on whether the information is needed to describe, predict or value alterations to ecosystem attributes, and on how easily or accurately the ecosystem attribute being assessed can be measured in monetary terms (see Section 4.2 on methods and Section 4.3.4 on units of measure and the question of how to deal with incommensurate terms.)

[4] Disagreements about the limits of discretion of the executive branch are frequently decided through judicial action.

The perceived social cost of a "wrong" decision is important in understanding the debate over whether to make particular decisions in one "locus" or another. There are several ways to consider the costs of a wrong decision, which need to be explored further. As one example, Fig. 1 presents two dimensions for mapping the outcomes of decisions facing society—the severity of effect and the degree of irreversibility. (Other dimensions of concern might also be appropriate, and more work is needed in defining the scale for any of these measures: e.g., "severity" could be measured by recovery time, spatial scale, numbers of species, etc.).

Decisions about the "locus" of choice can be overlaid on this map. Decisions in the lower right corner involving low severity and complete reversibility in the ecosystem from the perspective of the collective society—are often made by individuals. Decisions in the upper left corner—involving potentially catastrophic and irreversible effects—are often made through some collective choice process, often set or constrained by legislative decision. For these latter decisions, it may be necessary to organize information differently and focus on a "safe minimum standard" and cost-effective ways of realizing it. The decisions in the middle also are often made collectively in executive branch agencies where conventional benefit-cost analysis may be used. Then the question for debate is where to draw the lines between these groups and what information is most useful for decision makers particularly at these important boundary areas.

The use of benefit-cost analysis for making collective decisions is strongly supported by some and strongly questioned by others. The appropriate, and broadly accepted use of this and other economic tools is a matter worth continuing consideration.

It is important to recognize the limits of monetary valuation in making decisions. According to conventional economic theory, monetary terms can be used to analyze the efficiency of resource use. However, depending on the assignment of rights, economies can operate efficiently in very different ways. Many environmental problems routinely involve equity issues as well as efficiency considerations, not only in assigning rights to resource use between present and future generations, but also between those having disparate power or resources within present populations.

Bromley (1976) states the point as follows:

"As the empirical vehicle for welfare economics, benefit-cost analysis ostensibly guides society toward [a] Pareto optimal point. Unfortunately, this move is often confused—by virtually all 'policy makers' and not a few economists—with being analogous to socially optimal. We seem to require constant reminding that a move to a Pareto optimal point may not involve a Pareto improvement, since some individuals will be made worse off, and others better off. The essence of public choice is the shifting of comparative advantages; it is the restructuring of rights and the exposure to the rights of others."

Thus, redistributing rights to natural resources and environmental services is a collective choice which, in turn, determines a new efficient allocation of resources and services. Such a shift in how resources and services are allocated results in new prices, including new implicit values for the resources and services themselves (Norgaard, 1991). These collective choices must be made before valuation can occur. For example, determining the efficient use of child labor in the United States was made moot by the collective decision that child labor—irrespective of potential economic benefits—is morally unacceptable.

2.2. Implications for economic analysis

As stated previously, the choice to weigh costs and benefits in legislative versus executive bodies determines the context in which ecosystem valuation methods will be used—in particular, whether valuation information will contribute to a cost-effectiveness or a benefit-cost analysis when the decision reaches an executive branch agency.

A fundamental difference exists between those decisions in which a complete, monetary benefit-cost analysis, as an economist might understand that concept, is employed and a decision in which a different balancing of advantages and disadvantages is employed. We do not take a position on which approach is the more correct, but rather argue that both approaches must be understood as equally legitimate processes for choice depending on the context.

Although this section will focus on distinctions between these two contexts for applying monetary methods for resource valuation, we recognize that additionally relevant valuation strategies might involve assessments based upon ecological and/or social-psychological methods. This would certainly be the case for many resource values, such as existence or aesthetic values, which are not expressed or measured well monetarily.

Cost-effectiveness analysis

Under some circumstances, decision makers analyze the relative costs of alternative means of achieving previously set objectives. This is an analysis of how to accomplish what one has already decided to do. For environmental regulations, often the first step is to set "safe minimum standards" which can help ensure that only alternatives that achieve stated objectives are compared.

For example, states set water quality standards using EPA criteria. If surface water downstream from a permitted outfall, say from a municipal wastewater treatment plant, fails to meet state water quality standards, the treatment plant will be required to take action. A benefit-cost analysis of whether to improve the water quality downstream is not undertaken, but an analysis of the cost effectiveness of various options for correcting the problem might still be very appropriate for minimizing both economic and environmental costs of corrective actions.

Similarly, the Endangered Species Act, although it does allow for exceptions under rare circumstances, embodies the objective that no species should become extinct as a result of human actions. Once a species is listed as threatened or endangered, a plan is developed to protect the species. This plan may include an analysis of the economic impact of different options. Though not a formal cost-effectiveness analysis, such an impact assessment may serve the same functions.

Superfund requires that hazardous sites be cleaned up. Sites are added to the National Priority List on the basis of a hazard ranking system, not whether the monetary benefits of clean-up exceed the monetary costs. After a site is placed on the National Priority List, a remedial investigation and feasibility study is conducted, which includes a risk assessment to determine if the degree of risk warrants remedy. After options that provide an acceptable level of clean-up are developed, costs are compared.

Benefit-cost analysis

Under other circumstances, decision makers let prices, or other indicators of relative worth, determine choices. This calls for a comparison of benefits and costs to determine whether to do something.

To comply with Executive Order 12291, EPA must demonstrate that the benefits outweigh the economic costs of new controls before promulgating many, if not most of its regulations dealing with ecological effects. [5]

For example, if EPA were to promulgate additional regulations under Subtitle D of the Resource Conservation and Recovery Act to prevent adverse environmental effects from gold or other metals mining wastes, decision makers would conduct a benefit-cost analysis.

Benefits of regulation might include reducing on-site bird and mammal mortality from exposure to cyanide leaching solution, or reducing the loss of fish production caused by increased acidity or heavy metals on freshwater streams, but methods for quantifying these benefits are insufficient. Although current valuation methods can measure changes in the recreation value of affected areas, more work is needed to more fully value ecosystem attributes that are affected, before ecologists and economists can agree that information about ecosystem values is adequate for decision making. Crucial to this goal will be the determination of

[5] In most instances, Congress has precluded consideration of the costs of controls to protect human health. Although the use of benefit-cost analysis and regulatory impact assessments as part of the process for defining standards to protect human health is debated, the emphasis is on obtaining information to define thresholds where no significant health effect will occur.

production functions—defined broadly to include structures and processes that transform matter and energy inputs into ecosystem services—that are either directly valued by people or are important in supporting features of those ecological systems that are valued.

2.3. Ecosystem effects and ecosystem values

In addition to the choices about where and how costs and benefits will be weighed in making decisions, it also is useful to distinguish between two different types of information—environmental effects and value. [6] Information about effects and information about value needs to be better linked, however. Quantitative information about the increase or decrease in an ecosystem service can be a necessary. prerequisite to valuation, but values may also determine (implicitly or explicitly) which effects one chooses to measure.

Decision makers need information about the effects of human actions on ecosystems. Often this requires the ability to make predictions. In the case of deposition of hazardous air pollutants EPA has not yet decided which environmental effects (often called "endpoints") are significant to assess and, therefore, does not yet have information about either the nature or magnitude of the effects.

In another example, EPA is required periodically to review its ambient air quality standards for ground level ozone. To conduct such a review, decision makers need information about what changes in ecosystems, including forest ecosystems, would occur at different concentrations of ozone under different climatic conditions. Effects can be physical, chemical or biological. Improving information about environmental effects requires a systems perspective, a focus on appropriate models, and clear thinking about relevant measurement endpoints as well as appropriate temporal and spatial scales.

The identification of ecosystem values has clear and important implications for ecological risk assessment. The endpoints of risk assessments are the important ecosystem attributes that are believed to be potentially susceptible to the hazardous agent. Therefore, risk assessors must develop methods to estimate the likelihood of changes in those attributes that are to be valued. For example, if detoxification of chemicals is deemed to be a valued service of wetlands, then the capacity for detoxification is an assessment endpoint, and methods should be developed to estimate changes in detoxification rates in response to increased toxicant loading, dredging, filling, or changes in the hydrologic regime.

Decision makers also need information to determine the value to society of avoiding adverse environmental effects in at least two broad categories of decisions.

Executive Order 12291 requires that agency decision makers conduct a benefit-cost analysis for all new, and for any revisions to, major regulations, except where legislation or judicial decisions expressly forbid it. EPA has issued guidelines for conducting such analysis, which acknowledge that "estimating the benefits (or damages averted) of environmental regulations that affect ecosystems is perhaps the most complex problem in benefits analysis" (USEPA, 1983).

Executive branch agencies also have the responsibility under several statutes to assess damages for certain actions that have caused harm to natural resources. Liability for natural resource damages can be traced to the Trans-Alaska Pipeline Act, but it has gained much greater influence with CERCLA (and its re-authorizing amendments SARA) and the Oil Pollution Act of 1990. This legislation acknowledges that natural resources are assets and that the consumptive and nonconsumption services they provide must be considered in determining their value for the

[6] Decision makers also need information about the sources of stress to ecosystems in order to design effective environmental protection strategies. For example, Congress in its recent amendments to the Clean Air Act directed EPA to assess and perhaps control deposition of hazardous air pollutants on the Great Lakes and other large water bodies. EPA is currently measuring the total loading of pollutants to the Great Lakes and assessing how much of it comes from the air. Sources can be of different types, from point and non-point locations, directly from human actions or indirectly from other parts of the environment. However, the need for information about sources is not directly applicable to the questions of valuation before the Forum.

purpose of assessing damages. Regulations setting guidelines for placing a value on natural resources for the purpose of damage assessment have been repromulgated by the Department of the Interior after litigation over an earlier version. The National Oceanographic and Atmospheric Administration also is preparing its own regulations under different statutory authority.

Clearly, more needs to be done to improve the information available to decision makers about the nature and magnitude of environmental effects (particularly predictive information) and about the value of those effects. For specific decision points, decision makers may only need ecological data or only need economic analysis, but the point here is that, for broad advancement in ecosystem valuation methods, improvements in both are needed. Progress in understanding how ecosystems function and how they are affected by human activities provides a necessary but not sufficient basis for most choices. Conversely, improving our ability to value ecosystem functions and services will have limited utility unless we also improve our understanding of how ecological systems respond to perturbations.

3. The search for decisive information

We are reminded of two other aspects of choice. First, there is the problem of structuring the choice process so that related phenomena with possibly similar implications are regarded similarly. Deriving reasonably standardized decision protocols can be useful in achieving consistency across choices. Such decision protocols can also be very practical in economizing on decision costs. After all, choices require information acquisition, processing, interpretation, and synthesis. These actions require staff time, and hence imply considerable expense.

The second aspect of choice regards what we shall call decisive information. By decisive information we mean that information which is necessary and just sufficient to allow choice. This concept of decisive information, as well as the concept of decision protocols, warrant further clarification.

3.1. On decision protocols

As suggested above, decision protocols economize on decision costs by offering systematic rules for describing how information should be made available for each of the decisions involved in any action. Indeed, one may regard a decision tree as a decision protocol. Such maps guide the decision process in a logical and consistent search for the point at which enough is known about ecosystem effects to stop studying the problem and make a decision.

Determining the critical pathway of physical effects or exposure routes may be a useful step in developing a decision tree for valuation protocols. For example, the procedures for conducting valuation studies might suggest the circumstances under which physical data about possible exposures should be collected first.

It might be useful periodically to review mandated valuation information tasks, such as those under E.O. 12291, to determine whether the information that must be generated on a routine basis is normally relevant to the decision. In addition, protocols for conducting valuation studies ought also to provide rules of thumb for when a full study should be undertaken, de novo, and when extrapolation from previous studies is valid. This would require clear criteria for determining which classes of decisions or problems are similar.

As an example, the DOI natural resource damage regulations begin to describe valuation protocols. While crude, their Type A computation model for marine environments illustrates one approach for defining systematic procedures for developing these estimates. Often labeled as benefit transfers, most valuation estimates must re-organize existing information (often for a different resource or at best the same resource under different conditions) to the needs of a particular policy analysis. This Forum's development of a consistent framework for integrating ecological and economic "values" will not change this feature of the problem. So we must consider the implications of that resolution for the existing practices of benefit transfer and how the usually implicit protocols should be re-written.

3.2. On decisive information

Information is costly to obtain, and decision makers have limited amounts of time and money. Thus, it is important to identify in advance what information is relevant. One test is to ask what information, if known, has the potential to affect the decision one way or another. Identifying "decisive" information in advance could substantially reduce information costs of public decisions.

Perfect information will never be available on the systems affected by human decisions—private or collective. Thus, uncertainty will be an inherent feature of all important decisions. The uncertainty can be treated as part of the system, a randomness in outcomes, and/or our ability to observe it. Based on those observations, we must characterize what we know about these systems and use summaries of those observations to inform decisions. The value structure adopted influences how we collect information to inform decisions. Learning from that information is likely to change aspects of the value structure. Decisive information is that information that would permit this implicit question to be answered.

The collection of decisive information about ecosystems is especially difficult. The Environmental Protection Agency is striving to incorporate more holistic ways of understanding complex ecosystems to respond to the rising public consciousness of ecosystems as a whole. However, existing data and ways of knowing reflect already well-established values and disciplines. This creates two problems. First, disciplinary ways of knowing and their associated data inherently value those things they consider and dismiss those things they do not. Second, it is frequently impossible to synthesize or weight the incongruent data and disparate, conventional ways of knowing with new ways of knowing and recently collected data. A more holistic understanding quite frequently entails a difficult process of discourse as experts of different backgrounds strive to think in new ways to comprehend whole ecosystems.

The identification of decisive information is related to the estimation of uncertainty. A decision cannot be made on the basis of benefit-cost analysis if the confidence interval on the estimate of costs significantly overlaps the confidence interval on the estimate of benefits (estimated subjectively or by uncertainty analysis). From this perspective, decisive information is information that is feasible to obtain and will reduce uncertainty so that the confidence intervals no longer overlap significantly.

Finally, where only partial information about values is available, analysts may benefit from guidance about the appropriate use or conclusions to draw from such information.

For example, a decision rule for evaluating actions that involve irreversible transformations of unique natural environments could suggest that we monetize both the benefits and the costs of all aspects of the policy involving the ecosystem and consider their difference, recognizing that there may be many services that are not included. Then, we could ask how large the value of the omitted services would have to be in order for the policy maker to be indifferent between taking the action or not. Essentially, this is asking how large an unknown has to be to change a decision.

4. Agenda for future

Progress on improving methods for providing information to decision makers about the value of ecosystem attributes will require an interdisciplinary dialogue. Establishing an interdisciplinary agenda is no easy task, however.

During a significant fraction of their time together, Forum members have struggled to identify the reasons for their very different notions of what it means to value an ecological system. An understanding of the terms of that struggle will help to place in perspective this report about information needs, and the limits of current methods for producing useful information.

Some members of the Forum were comfortable from the beginning with the notion that changes in the service flows from ecological systems to human society ought to be valued in monetary terms to the extent supportable by available data and techniques. They felt that this would bring such services into policy discussions in terms commensurate with marketed goods and services. As a general matter this would, they felt, improve the efficiency with which society used its environmental resources. One reason for this view is the belief that such pricing would encourage preservation by making explicit the opportunity cost of development and other economic activities.

Other Forum members expressed serious reservations about this view. Their hesitation arose from the limited knowledge about the behavior of both large and small-scale ecological systems, the concern that current prices (or monetary values) do not and cannot reflect the tastes of and technologies available to future generations, and the possibility that irreversible ecological damage may result from large-scale, long-term human intervention in the environment.

In considering these differences, the Ecosystem Valuation Forum has formed the following preliminary conclusions.

4.1. Contextual issues

Information needs

Clarity about the uses of valuation information is crucial if efforts to improve valuation methods are to be productively focussed. Focusing on linkages is one key. It is essential to link the information produced by both ecological studies and valuation methods to the needs of policy makers. The information produced by ecological studies and the information needed to implement valuation methods also needs to be linked. Currently, none of these linkages are adequate.

In addition, time and resource constraints of decision makers must be taken into account so that the information collected will be useful in making a decision.

However, care must be taken to consider the implications of the personal, normative values that experts bring to the information-collection process. Success in providing improved information to decision makers will require frequent reminders about (1) the different patterns of thinking in different disciplines, (2) differences between the needs of users of information and the personal views of scientists attempting to provide it, (3) the complex interaction between natural and social systems, and (4) the difficulty (and potentially irreversible impacts) of environmental "experiments" (Norgaard, 1992).

Terminology

Semantic difficulties incurrent valuation terminology are a barrier to progress in developing improved ecosystem valuation methods. Some words in common usage, such as "benefit", "value" and "function" have special and different meanings across different disciplines.

In addition, the same terms sometimes are used to mean different things, and different terms are used to mean the same thing. Examples of the former include the word benefit, which in different disciplines might refer to avoided ecosystem impacts, economic development, or individual satisfaction. Examples of the use of different terms to mean the same thing, sometimes incorrectly, include existence value, option value, and intrinsic value; functions, processes, services, and attributes. Important issues will be more difficult to resolve as long as critical terms are being used differently.

It may be difficult, however, to create a simple, cross-disciplinary "glossary" that links terms from one discipline with those of another via straightforward translation rules. As is emphasized in the currently popular idea of disciplinary "paradigms", the meanings of scientific terms are suffused with the assumptions, methods, goals and values that give identity to the disciplines themselves.

4.2. Methodological issues

Ecological methods

Improving information about the value of ecosystem attributes will require more than improving valuation methods. The capability of ecological methods to describe and quantify ecosystem attributes, and to predict the consequences of human actions on those attributes, also must be improved. Better information is needed about how various services of ecosystems are affected as a result of human actions.

The place to start is with service flows—what are the services that an ecosystem provides, and how is the production of those services likely to change under alternative courses of action? With this causal nexus established we can begin to develop methods for estimating the value of those changes for the decision maker who faces choices among several options. The capacity of ecological methods to predict environmental effects is highly variable, however.

The fields of ecology and toxicology have advanced to a relatively high degree of accuracy in predicting the effect of some actions on particular ecosystem attributes. For example, toxicologists can predict what percentage of certain fish populations will remain at different levels of contamination much more accurately than they can predict levels of terrestrial wildlife populations.

In many other important areas, however, a great deal of uncertainty remains. Ecosystems are complex, and a high potential exists for non-additive and synergistic effects. Equally important, however, insufficient consensus exists regarding which features of ecosystems are essential to maintain.

In addition, some ecosystem attributes, such as primary productivity, support the overall viability of the system. These aspects are "services" to the ecosystem, but are not direct services to people. This does not make them less important. To the contrary, they are sometimes the most important attributes of the ecosystem from an ecological perspective because the loss of one or more of these attributes could result in the loss of many, if not all, of the other services the ecosystem provides. Thus, services that may be intermediate to the ecosystem will have a value because of their contribution to the "production" of the services that people do value.

The complexity of ecosystems poses enormous challenges for predicting alterations resulting from human actions. The variety of ecosystems and their attributes have not been completely catalogued, and not all causal relationships are known. Thus, the analyst is presented with difficult questions concerning the selection of relevant attributes as well as how to present data in a form that can be used for valuation purposes.

Valuation methods

Valuation methods may originate from economics, ecology, social-psychology, philosophy, or other disciplines.

Several methods already exist for assessing the monetary value of ecosystem attributes. Contingent valuation, travel cost and hedonic pricing are three examples of methods for monetary valuation given an existing system of rights and a high degree of knowledge about the ecosystem attribute by the user.

These methods fall into two categories—one relying on observable choices, and a second relying on the responses people make to proposed choices. The observable choice or revealed preference methods (travel cost and hedonic) are preferred by some economists on the grounds that an actual choice demonstrates the commodity (or service) to be valued has been selected by those whose monetary values are being measured. However, it is important to acknowledge that what is usually observed is the selection of a good or service that is linked to the environmental service, not the environmental service itself. Thus, the analyst's judgments can influence the monetary estimates that are inferred from these choices. The survey or contingent valuation approach assumes that stated preferences accurately represent what peoples' preferences would be if they had the choices proposed to them. The description or framing of what is to be valued has been found to be a central element in the reliability of the method.

Restoration cost and replacement cost approaches for valuing ecosystem attributes also provide monetary measures of ecosystem values. Restoration cost sets the value of a system as the cost of restoring it to its pre-damaged condition. One definition of replacement cost calculates the necessary expense if the naturally provided service didn't exist (e.g., for soil productivity, flood control or water purification). These methods rely on defining the set of attributes to be restored or replaced. Subtle changes in descriptions of how the acts of restoration or replacement are judged have significant implications for the criteria used to value the ecosystem. Moreover, these changes also influence the relationship between these approaches to valuation and the economic, monetary measures. For example, if restoration is defined as the act of restoring the predamaged or baseline condition of the ecosystem instead of its functions, the definition implies a very different mix of activities. The same qualification applies to replacement. What is involved is defining and measuring the elements, attributes, or services designated to comprise the important features of the ecosystem and evaluating whether different approaches to obtaining them in fact restore or replace what has been damaged or lost.

The concept of "putting the resource back the way it was" presents at least two challenges. First, it may be technically impossible to do, thus the cost of doing so may be impossible to determine. In addition, restoration cost may not be cost-effective: i.e., the full resource allocation implications may be negative.

Economic methods should be used with an understanding of their limitations. Even as we improve our ability to monetize natural resources, concerns are likely to remain because of uncertainties in scientific ability to predict the effects of human actions on ecosystems, particularly when the recovery time for environmental effects is very long. In addition, although improved economic methods can lead to improved environmental decisions, economics cannot substitute for collective political decisions about distribution issues, including rights to resource use to future generations or within the present generation. Thus, for some types of decisions, the issues of sustainability and ecosystem values ultimately will require collective choices within the political process.

Interdisciplinary approaches may overcome some limitations of existing economic methods. Ecological economic modeling constructs detailed dynamic simulation models of linked ecological economic systems which, after being calibrated to real world situations, can be exercised to determine the linkages and values of the ecological system.

Other disciplines may provide yet additional information relevant to valuation. Social psychologists have used a variety of survey methods to assess human preferences for varying environmental and ecosystem characteristics. For example, attitudinal scales have been developed to quantify aesthetic, ecological, naturalistic, scientific, and even ethical valuations of ecosystems and landscape features. Additionally, researchers in the field of landscape architecture have pioneered techniques for estimating the aesthetic value of varying ecological systems. These techniques have involved both expert estimations and public surveys. However, these methods do not yet capture all of the values that contribute to what people describe as a meaningful quality of life.

Although some ecosystem attributes can be valued using existing methods, current methods do not now value all the services of ecosystems that ecologists or the general public believe are important—each has strengths and weaknesses. Thus, an assessment of what can and can't be valued, and what problems remain after existing methods are improved, is important.

4.3. Challenges

In addition, there are issues related to the complexity of environmental decisions rather than to specific valuation techniques. These include dealing with uncertainty, accounting for irreversibility, and considering the rights of future generations.

Uncertainty

While some level of uncertainty is present in most decisions, the level of uncertainty about ecosystem effects can be extremely large. Decision makers must consider uncertainty both in the likelihood that a particular outcome might occur, and in the severity of the effects, should it occur.

For conceptual purposes, it is helpful to distinguish among and describe the various ways uncertainty can influence the information available to decision makers. In both the natural and social sciences, some processes often are described as having random components, which together with the systematic factors hypothesized to influence these processes contribute to the outcomes (or states) we observe. We might designate these components as "inherent randomness" simply to distinguish them from the variation that arises from incomplete or imperfect observation of these same processes. Imperfect observation is sometimes argued to cause uncertainty in the estimates or summaries of available information. In practice, both types of randomness are simultaneously present in the information available to decision makers because inherent randomness contributes to the randomness caused by incomplete observation. Both affect the summaries developed from data on the processes of interest.

Uncertainty has an added and important influence on the valuation process because people in their own personal decisions—and society in its collective decisions—respond differently to judgments that must be made for processes that are relatively more certain than those that are uncertain (i.e., are characterized as having more of one or both types of randomness). These responses to uncertainty depend upon what is at risk, how much is known about the processes that exhibit the randomness, and whether people can individually or collectively control the ways the outcomes might affect them. At the simplest level, economists describe these reactions as part of people's preferences and characterize as risk averse those who prefer to avoid uncertainty beyond simply acknowledging that the average (or expected values) of the outcomes should be the focus of attention. Retaining this simple mode, economic models attempt to relate individuals' personal attitudes toward uncertainty to the implications of their personal risk preferences for society as a whole.

These descriptions are most relevant to processes where the randomness is reasonably well understood, the outcomes largely monetary in character, and people have acquired experience in dealing with them. For most environmental risks (and especially those associated with ecosystems), this characterization is not appropriate. So the knowledge, risk perception, sense of control, range of outcomes, and opportunities for response to risks will influence both the individual's and society's valuation of changes in uncertainty. Developing methods for responding to these needs will be an important aspect of the Forum's activities during its second phase of work.

One approach follows from an analogy between decision making under uncertainty and purchasing insurance. If a proposed regulation having known economic costs will reduce the likelihood of unknown future environmental impacts, a decision to regulate still might be made when the known benefits are less than the known costs. Basically, the difference between the costs and benefits would be the cost of an "insurance policy" against future impacts. One reason to purchase such "insurance" (often expressed by the desire to be conservative where predictions about future effects are uncertain) is the concern about the limits of science to portray all possible effects—some people would "rather be safe than sorry". Of course, this does not answer the question of how much "insurance" people are willing to buy for unknown future benefits.

Irreversibility

Many changes to ecosystems can be reversed over varying lengths of time. In many other cases, however, changes can only partially be reversed, if at all. Decision makers do not need sophisticated benefit-cost analysis to justify actions to prevent irreversible environmental effects of large magnitude. Under such circumstances, analysis of the cost effectiveness of different policies or actions for preventing such consequences is appropriate. The question, however, remains how large is too large?

Temporal scale

Environmental effects may have a very long recovery time. Thus, the benefits of resource use may accrue to one generation while the costs are borne by multiple generations.

Issues of an intergenerational dimension—ensuring a sustainable flow of ecosystem services—and the impacts of discounting must be addressed. Discounting is commonly used to express future costs and benefits in terms of present monetary value, assuming that a value received now is worth more than the same value provided at some future date. Some critics regard discounting as inappropriately devaluing those ecosystem attributes that take a long time to be realized. Thus, discounting results in greater resource exploitation or use of natural capital now at the expense of future environmental health or availability of natural capital. Uncertainties include the inability of current generations to fully reflect the values and preferences of future generations, the inability to account for future technological change, and the applicability of discounting the value of renewable resources when exploitation would decrease sustainable yield.

Units of measure

For decisions affecting ecosystems, conventional benefit-cost analysis is incomplete because many costs and benefits are difficult to quantify and, even if quantifiable, may be difficult to measure in monetary terms. Common terms certainly make the summation of benefits and costs easier, but many worry that environmental values can never be adequately measured monetarily. Thus, some experts question whether the analysis should be done solely in monetary terms.

Clearly, decision makers often face choices involving values that are measured in incommensurate terms. For example, in deciding whether to purchase land adjacent to the Manassas Battlefield National Park, Congress weighed the monetary cost of the land against the benefit (or value) of maintaining the integrity of the historic site for visitors. In making pesticide registration decisions under FIFRA, EPA may be faced with a decision to ban a pesticide that is known to cause human health effects, for which the only practicable alternative would cause adverse ecological impacts.

In other cases, one might find common, nonmonetary units of measure. For example, in deciding whether to ban a pesticide, EPA evaluates alternative products to assess whether the replacement pesticide would cause more or less harm. Number of deaths or years of life lost are generally the common terms for health effects. Presumably, similar comparisons could be made using common terms for ecological effects.

5. Recommendations and conclusions

5.1. Case studies

The Forum recommends that the approach for addressing the research agenda outlined above should be to identify and explore the real challenges of ecosystem valuation through practical case studies, for only through the crucible of real experience will methods be found that will make a useful and realistic contribution to public decision making. In particular, such case studies should enable researchers to improve linkages between ecological and economic methods and to develop improved protocols for valuation studies. EPA staff involved in the cases selected can also expect to benefit directly in their work. Criteria for selection of case studies include:

- variety of issues,
- variety of temporal and spacial scales,
- decision-focused (a choice must be made),
- ecosystem values will/did play a significant role in the decision,
- illustrates one or more of the challenges identified in Phase I, and
- data is available.

5.2. Assumptions

That good valuation studies depend on sound ecological information is not adequately appreciated. Better linkages are needed between ecological and economic methods. For example, existing methods for valuing ecosystem services often rely on predictions about how ecosystem service flows will change as a result of human intervention. Advances in ecological methods themselves will help, as will efforts to integrate methods across disciplines. Forum members recommend joint modelling exercises to enhance the ability to apply existing valuation methods to a greater number of ecosystem attributes and to develop clearer, logical steps from ecosystem damage assessments to valuation.

Joint modelling efforts might be designated to:

- review what information existing ecological model(s) accept and in what form predictive information is generated,
- begin to explore ways the ecological model(s) need to be adapted to serve policy or valuation purposes and/or what economists could do with the information generated, and then
- organize a valuation study given previous work on linkages with the ecological model.

Ecosystem valuation could be improved if currently available tools for monetary valuation could be competently applied more often. Additional resources for economic studies would help, but resources, even if augmented, will likely always be inadequate to assess every situation in which ecosystems are damaged or at risk. Thus, guidance is needed on how to define the valuation information that is most likely to be decisive, on criteria for choosing among the available valuation methods, and on ways to build on existing information rather than to rely on expensive primary data gathering. Here, too, better linkages between ecological and economic methods may shed light on the problem, with decision trees relying on qualitative ecological information a possibility.

Forum members anticipate exploring specific decision scenarios as case studies for developing improved protocols for policy analysts. Possible candidates include the EPA regulations on the land application of sludge from pulp and paper mills or the re-registration of granular carbofuran. The latter case is ripe for a retrospective review of valuation protocols because it has a significant amount of data available in the ecological risk assessment, there is a clear effect on individual birds, and there are interesting valuation issues with respect to endangered species, but with the dilemma of not having been able to establish population or ecosystem effects.

Finally, work is needed to clarify where existing ecosystem valuation methods and monetary measures of value are sufficient for decisions and where new methods, assumptions, or criteria for decision making are needed. Even if ecosystem services were perfectly understood and evaluated in monetary units according to accepted economic percepts, the problems of ecosystem valuation would not be completely solved. The problems of uncertainty (both statistical and scientific), irreversibility, and large disparities in temporal and spatial scale remain.

For example, the policy for classifying wetlands as having high, medium or low value is just such an example; there may be other cases that would allow members to deal with varying temporal and spatial scale, with aesthetic and scientific values, and with multiple units of measure. Forum members recommend addressing these issues of the limits and appropriate use of ecosystem valuation methods in a more generic manner as well.

The challenge of improving ecosystem valuation methods presents an opportunity for partnership—partnership between ecologists, economists and other social scientists and partnership between the research and policy communities. Interdisciplinary dialogue between ecologists, economists, and other social scientists is essential to the task of developing improved methods for valuing ecosystem attributes.

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