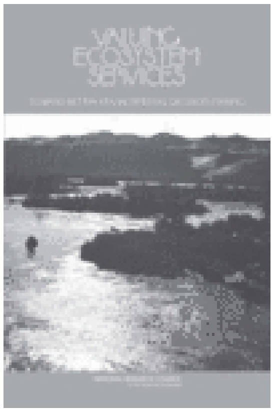
Free Executive Summary



Valuing Ecosystem Services: Toward Better Environmental Decision-Making

Committee on Assessing and Valuing the the Services of Aquatic and Related Terrestrial Ecosystems, National Research Council

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Nutrient recycling, habitat for plants and animals, flood control, and water supply are among the many beneficial services provided by aquatic ecosystems. In making decisions about human activities, such as draining a wetland for a housing development, it is essential to consider both the value of the development and the value of the ecosystem services that could be lost. Despite a growing recognition of the importance of ecosystem services, their value is often overlooked in environmental decision-making. This report identifies methods for assigning economic value to ecosystem services—even intangible ones—and calls for greater collaboration between ecologists and economists in such efforts.

Executive Summary

OVERVIEW

Ecosystems provide a wide variety of marketable goods, fish and lumber being two familiar examples. However, society is increasingly recognizing the myriad functions—the observable manifestations of ecosystem processes such as nutrient recycling, regulation of climate, and maintenance of biodiversity—that they provide, without which human civilizations could not thrive. Derived from the physical, biological, and chemical processes at work in natural ecosystems, these functions are seldom experienced directly by users of the resource. Rather, it is the services provided by ecosystems, such as flood risk reduction and water supply, together with ecosystem goods, that create value for human users and are the subject of this report.[1]

Aquatic ecosystems include freshwater, marine, and estuarine surface waterbodies. These incorporate lakes, rivers, streams, coastal waters, estuaries, and wetlands, together with their associated flora and fauna. Each of these entities is connected to a greater ecological and hydrological landscape that includes adjacent riparian areas, upland terrestrial ecosystems, and underlying groundwater aquifers. Thus, the term "aquatic ecosystems" in this report includes these related terrestrial ecosystems and underlying aquifers. Aquatic ecosystems perform numerous interrelated environmental functions and provide a wide range of important goods and services. Many aquatic ecosystems enhance the economic livelihood of local communities by supporting commercial fishing and agriculture and by serving the recreational sector. The continuance or growth of these types of economic activities is directly related to the extent and health of these natural ecosystems.

However, human activities, rapid population growth, and industrial, commercial, and residential development have all led to increased pollution, adverse modification, and destruction of remaining (especially pristine) aquatic ecosys-

[1] *Ecosystem structure* refers to both the composition of the ecosystem (i.e., its various parts) and the physical and biological organization defining how those parts are organized. A leopard frog or a marsh plant such as a cattail, for example, would be considered a component of an aquatic ecosystem and hence part of its structure. *Ecosystem function* describes a process that takes place in an ecosystem as a result of the interactions of the plants, animals, and other organisms in the ecosystem with each other or their environment. Primary production (the process of converting inorganic compounds into organic compounds by plants, algae, and chemoautotrophs) is an example of an ecosystem function. Ecosystem structure and function provide various *ecosystem goods* and *services* of value to humans such as fish for recreational or commercial use, clean water to swim in or drink, and various esthetic qualities (e.g., pristine mountain streams or wilderness areas) (see Box 3-1 for further information).

tems—despite an increase in federal, state, and local regulations intended to protect, conserve, and restore these natural resources. Increased human demand for water has simultaneously reduced the amount available to support these ecosystems. Notwithstanding the large losses and changes in these systems, aquatic ecosystems remain broadly and heterogeneously distributed across the nation. For example, there are almost 4 million miles of rivers and streams, 59,000 miles of ocean shoreline waters, and 5,500 miles of Great Lakes shoreline in the United States; there are 87,000 square miles of estuaries, while lakes, reservoirs, and ponds account for more than 40 million acres.

Despite growing recognition of the importance of ecosystem functions and services, they are often taken for granted and overlooked in environmental decision-making. Thus, choices between the conservation and restoration of some ecosystems and the continuation and expansion of human activities in others have to be made with an enhanced recognition of this potential for conflict and of the value of ecosystem services. In making these choices, the economic values of the ecosystem goods and services must be known so that they can be compared with the economic values of activities that may compromise them and so that improvements to one ecosystem can be compared to those in another.

This report was prepared by the National Research Council (NRC) Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems, overseen by the NRC's Water Science and Technology Board, and supported by the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and the U.S. Department of Agriculture (see Box ES-1). The committee consisted of 11 volunteer experts drawn from the fields of ecology, economics, and philosophy who have professional expertise relating to aquatic ecosystems and to the valuation of ecosystem services. This report's contents, conclusions, and recommendations are based on a review of relevant technical literature, information gathered at five committee meetings, and the collective expertise of committee members. Because of space limitations, this Executive Summary includes only the major conclusions and related recommendations of the committee in the general order of their appearance in the report. More detailed conclusions and recommendations can be found throughout the report.

Valuing ecosystem services requires the successful integration of ecology and economics and presents several challenges that are discussed throughout this report. The fundamental challenge of valuing ecosystem services lies in providing an explicit description and adequate assessment of the links between the structures and functions of natural systems, the benefits (i.e., goods and services) derived by humanity, and their subsequent values (see Figure ES-1).

Ecosystems are complex however, making the translation from ecosystem structure and function to ecosystem goods and services (i.e., the ecological production function) is even more difficult. Similarly, in many cases the lack of markets and market prices and of other direct behavioral links to underlying values makes the translation from quantities of goods and services to value (and the direct translation from ecosystem structure to value) quite difficult, though

BOX ES-1
Statement of Task

The committee will evaluate methods for assessing services and the associated economic values of aquatic and related terrestrial ecosystems. The committee's work will focus on identifying and assessing existing economic methods to quantitatively determine the intrinsic value of these ecosystems in support of improved environmental decision-making, including situations where ecosystem services can be only partially valued. The committee will also address several key questions, including:

- What is the relationship between ecosystem services and the more widely studied ecosystem functions?
- For a broad array of ecosystem types, what services can be defined, how can they be measured, and is the knowledge of these services sufficient to support an assessment of their value to society?
- What lessons can be learned from a comparative review of past attempts to value ecosystem services—particularly, are there significant differences between eastern and western U.S. perspectives on these issues?
- What kinds of research or syntheses would most rapidly advance the ability of natural resource managers and decision makers to recognize, measure, and value ecosystem services?
- Considering existing limitations, error, and bias in the understanding and measurement of ecosystem values, how can available information best be used to improve the quality of natural resource planning, management, and regulation?

both are given by an economic valuation function. Probably the greatest challenge for successful valuation of ecosystem services is to integrate studies of the ecological production function with studies of the economic valuation function. To do this, the definitions of ecosystem goods and services must match across studies. Failure to do so means that the results of ecological studies cannot be carried over into economic valuation studies. Attempts to value ecosystem services without this key link will either fail to have ecological underpinnings or fail to be relevant as valuation studies.

Where an ecosystem's services and goods can be identified and measured, it will often be possible to assign values to them by employing existing economic valuation methods. The emerging desire to measure the environmental costs of human activities, or to assess the benefits of environmental protection and restoration, has challenged the state of the art in environmental evaluation in both the ecological and the social sciences. Some ecosystem goods and services cannot be valued because they are not quantifiable or because available methods are not

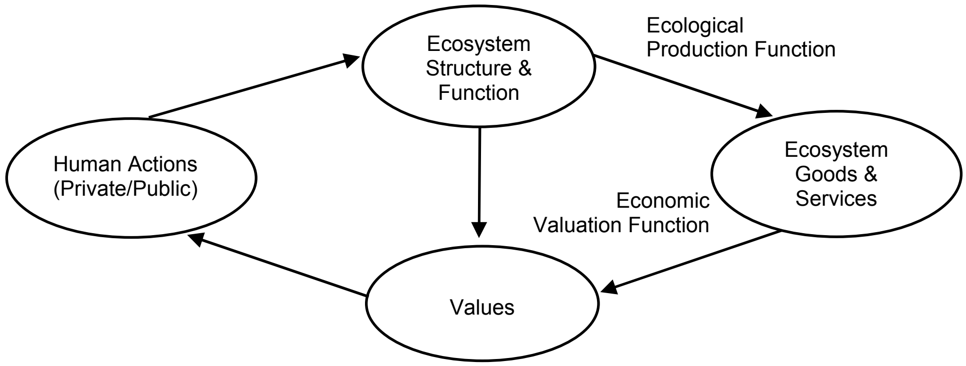

FIGURE ES-1 Components of ecosystem valuation: ecosystem structure and function, goods and services, human actions, and values. (See Figure 7-1 for an expanded version of this figure.)

appropriate or reliable. Economic valuation methods can be complex and demanding, and the results of applying these methods may be subject to judgment, uncertainty, and bias. However, based on an assessment of a very large literature on the development and application of various economic valuation methods, the committee concludes that they are mature and capable of providing useful information in support of improved environmental decision-making.

From an ecological perspective, the challenge is to interpret basic research on ecosystem functions so that service-level information can be communicated to economists. For economic and related social sciences, the challenge is to identify the values of both tangible and intangible goods and services associated with ecosystems and to address the problem of decision-making in the presence of partial valuation. The combined challenge is to develop and apply methods to assess the values of human-induced changes in ecosystem functions and services.

Finally, this report concerns valuing the goods and services that ecosystems provide to human societies, with principal focus on those provided by aquatic and related terrestrial ecosystems. However, because the principles and practices of valuing ecosystem goods and services are rarely sensitive to whether the underlying ecosystem is strictly aquatic or terrestrial, many of the report's conclusions and recommendations are likely to be directly or at least indirectly applicable to the valuation of goods and services provided by any ecosystem.

THE MEANING OF VALUE AND USE OF ECONOMIC VALUATION IN THE ENVIRONMENTAL POLICY DECISION-MAKING PROCESS

In order to develop a perspective on valuing aquatic ecosystems, it is necessary to first provide a clear discussion and statement of what it means to value something and of the role of "valuation" in environmental policymaking. In this regard, environmental issues and ecosystems have been at the core of many recent philosophical discussions regarding value (see Chapter 2). Fundamentally, these debates about the value of ecosystems derive from two points of view. The first is that the values of ecosystems and their services are non-anthropocentric and that nonhuman species have moral interests or rights unto themselves. The other, which includes the economic approach to valuation, is that all values are anthropocentric. This report focuses on the sources of value that can be captured through economic valuation.[2] However, the committee recognizes that all forms of value may ultimately contribute to decisions regarding ecosystem use, preservation, or restoration.

Although economic valuation does not capture all sources or types of value (e.g., intrinsic values on which the notion of rights is founded), it is much broader than usually presumed. It recognizes that economic value can stem from the use of an environmental resource (use values), including both commercial and noncommercial uses, or from its existence even in the absence of use (nonuse value). The broad array of values included under this approach is captured by using the total economic value (TEV) framework to identify potential sources of this value. Use of the TEV framework helps to provide a checklist of potential impacts and effects that need to be considered in valuing ecosystem services as comprehensively as possible. By its nature, economic valuation involves the quantification of values based on a common metric, normally a monetary metric. The use of a dollar metric for quantifying values is based on the assumption that individuals are willing to trade the ecological service being valued for more of other goods and services represented by the metric (more dollars). Use of a monetary metric allows measurement of the costs or benefits associated with changes in ecosystem services.

The role of economic valuation in environmental decision-making depends on the specific criteria used to choose among policy alternatives. If policy choices are based primarily on intrinsic values, there is little need for the quantification of values through economic valuation. However, if policymakers consider trade-offs and benefits and costs when making policy decisions, then quantification of the value of ecosystem services is essential. Failure to include some measure of the value of ecosystem services in benefit-cost calculations will implicitly assign them a value of zero. The committee believes that considering

[2] Unless otherwise noted, use of the terms "value," "valuing," or "valuation" refers to economic valuation, more specifically, the economic valuation of ecosystem goods and services.

the best available and most reliable information about the benefits of improvements in ecosystem services or the costs of ecosystem degradation will lead to improved environmental decision-making. The committee recognizes, however, that this information is likely to be only one of many possible considerations that influence policy choice.

The benefit and cost estimates that emerge from an economic valuation exercise will be influenced by the way in which the valuation question is framed. In particular, the estimates will depend on the delineation of changes in ecosystem goods or services to be valued, the scope of the analysis (in terms of both the geographical boundaries and the inclusion of relevant stakeholders), and the temporal scale. In addition, the valuation question can be framed in terms of two alternative measures of value, willingness to pay (WTP) and willingness to accept (compensation) (WTA). These two approaches imply different presumptions about the distribution of property rights and can differ substantially, depending on the availability of substitutes and income limitations. In many contexts, methodological limitations necessitate the use of WTP rather than WTA.

Finally, because ecosystem changes are likely to have long-term impacts, some accounting of the timing of impacts is necessary. This can be done through discounting future costs and benefits. It is essential, however, to recognize that consumption discounting is distinct from the discounting of utility, which reflects the weights put on the well-being of different generations.

Based on these conclusions, the committee makes the following recommendations (Chapter 2):

- Policymakers should use economic valuation as a means of evaluating the trade-offs involved in environmental policy choices; that is, an assessment of benefits and costs should be part of the information set available to policymakers in choosing among alternatives.
- If the benefits and costs of a policy are evaluated, the benefits and costs associated with changes in ecosystem services should be included along with other impacts to ensure that ecosystem effects are adequately considered in policy evaluation.
- Economic valuation of changes in ecosystem services should be based on the comprehensive definition embodied in the TEV framework; both use and nonuse values should be included.
- The valuation exercise should be framed properly. In particular, it should value the *changes* in ecosystem good or services attributable to a policy change.
- In the aggregation of benefits and/or costs over time, the consumption discount rate, reflecting changes in scarcity over time, should be used instead of the utility discount rate.

AQUATIC AND RELATED TERRESTRIAL ECOSYSTEMS

An ecosystem is generally accepted to be an interacting system of biota and its associated physical environment; ecologists tend to think of these systems as identifiable at many different scales with boundaries selected to highlight internal and external interactions. The phrase "aquatic and related terrestrial ecosystems" recognizes the impossibility of analyzing aquatic systems absent consideration of the linkages to adjacent terrestrial environments. For many of the ecosystem functions and derived services considered in this report, it is not possible, necessary, or appropriate to delineate clear spatial boundaries between aquatic and related terrestrial systems (see also Box 3-1). Indeed, to the extent there is an identifiable boundary, it is often dynamic in both space and time.

The conceptual challenges of valuing ecosystem services are explicit description and adequate assessment of the link between the structure and function of natural systems and the goods or services derived by humanity (see Figure ES-1). Describing structure is a relatively straightforward process, even in highly diverse ecosystems. However, ecosystem functions are often difficult to infer from observed structure in natural systems. Furthermore, the relationship between structure and function, as well as how these attributes respond to disturbance, are not often well understood. Without comprehensive understanding of the behavior of aquatic systems, it is clearly difficult to describe thoroughly all of the services these systems provide society. Although valuing ecosystem services that are not completely understood is possible (see more below), when valuation becomes an important input in environmental decision-making, there is the risk that it may be incomplete.

There have only been a few attempts to develop explicit maps of the linkage between aquatic ecosystem structure/function and value. There are, however, a multitude of efforts to separately identify ecosystem functions, goods, services, values, and/or other elements in the linkage, without developing a comprehensive argument. One consequence of this disconnect is a diverse literature that suffers somewhat from indistinct terminology, highly variable perspectives, and considerable, divergent convictions. However, the development of an interdisciplinary terminology and a universally applicable protocol for valuing aquatic ecosystems was ultimately identified by the committee as unnecessary. From an ecological perspective, the value of specific ecosystem functions/services is entirely relative. The spatial and temporal scales of analysis are critical determinants of potential value. Ecologists have described the structure and function of most types of aquatic ecosystems qualitatively, and general concepts regarding the linkages between ecosystem function and services have been developed. Although precise quantification of these relationships remains elusive, the general concepts seem to offer sufficient guidance for valuation to proceed with careful attention to the limitations of any ecosystem assessment. Further integration of economics and ecology at both intellectual and practical scales will improve ecologists' ability to provide useful information for assessing and valuing aquatic ecosystems.

There remains a need for a significant amount of research in the ongoing effort to codify the linkage between ecosystem structure and function and the provision of goods and services for subsequent valuation. The complexity, variability, and dynamic nature of aquatic ecosystems make it likely that a comprehensive identification of all functions and derived services may never be achieved. Nevertheless, comprehensive information is not generally necessary to inform management decisions. Despite this unresolved state, future ecosystem valuation efforts can be improved through use of several general guidelines and by research in the following areas (Chapter 3):

- Aquatic ecosystems generally have some capacity to provide consumable resources, habitat for plants and animals, regulation of the environment, and support for nonconsumptive uses, and considerable work remains to be done in documentation of the potential of various aquatic ecosystems for contribution in each of these broad areas.
- Because delivery of ecosystem goods and services occurs in both space and time, investigation of the spatial and temporal thresholds of significance for various ecosystem services is necessary to inform valuation efforts.
- Natural systems are dynamic and frequently exhibit nonlinear behavior, and caution should be used in extrapolation of measurements in both space and time. Although it is not possible to avoid all mistakes in extrapolation, the uncertainty warrants explicit acknowledgment. Methods are needed to assess and articulate this uncertainty as part of system valuations.

METHODS OF NONMARKET VALUATION

In response to the committee's statement of task (see Box ES-1), this report outlines the major nonmarket methods currently available for estimating monetary values of aquatic and related terrestrial ecosystem services. This includes a review of the economic approach to valuation, which is based on the aforementioned TEV framework. In addition to presenting valuation approaches, the applicability of each method to valuing ecosystem services is discussed. All of this is provided within the context of the committees' implicit objective of assessing the literature in order to facilitate original studies that will develop a closer link between aquatic ecosystem functions, services, and value estimates. It is important to note however, that the report does not provide instructions on how to apply each of the methods, but rather provides a rich listing of references that can be used to develop a greater understanding of any of the methods.

There is a variety of nonmarket valuation approaches that are currently available to be applied in valuing aquatic and related terrestrial ecosystem services. Revealed-preference methods (e.g., averting behavior, travel cost, hedonics) can be applied only to a limited number of ecosystem services. However, both the range and the number of services that can potentially be valued are increasing with the development of new methods, such as dynamic production function approaches, general equilibrium modeling of integrated ecological-economic systems, and combined revealed- and stated-preference approaches.

Stated-preference methods, including contingent valuation and conjoint analysis, can be more widely applied, and certain values can be estimated only through the application of such techniques. On the other hand, the credibility of estimated values for ecosystem services derived from stated-preference methods has often been criticized. For example, contingent valuation methods have come under such scrutiny that it led to National Oceanic and Atmospheric Administration guidelines of "good practice" for these methods in the early 1990s.

Benefit transfers and replacement cost and cost of treatment methods are increasingly being used in environmental valuation, although their application to aquatic ecosystem services is still limited. Economists generally consider benefit transfers as to be a "second-best" valuation method and have devised guidelines governing their use. In contrast, replacement cost and cost of treatment methods should be used with great caution if at all. Although economists have attempted to design strict guidelines for using replacement cost as a last resort "proxy" valuation estimation for an ecological service, in practice estimates employing the replacement cost or cost of treatment approach rarely conform to the conditions outlined by such guidelines.

At least three basic questions arise for any method that is chosen to value aquatic ecosystem services. First, are the services that have been valued those that are the most important for supporting environmental decision-making and policy analyses involving benefit-cost analysis, regulatory impact analysis, legal judgments, and so on? Second, can the services of the aquatic ecosystem that are valued be linked in some substantial way to changes in the functioning of the system? Last, are there important services provided by aquatic ecosystems that have not yet been valued so that they are not being given full consideration in policy decisions that affect the quantity and quality of these systems? In many ways, the answers to these questions are the most important criteria for judging the overall validity of the valuation method chosen.

Only a limited number of ecosystem services have been valued to date, and effective treatment of aquatic ecosystem services in benefit-cost analyses requires that more services be valued. Nonuse values require special consideration; these may be the largest component of total economic value for aquatic ecosystem services. Unfortunately, nonuse values can be estimated only with stated-preference methods, and this is the application in which these methods have been soundly criticized.

Although a variety of valuation methods are currently available, no single method can be considered best at all times and for all types of aquatic ecosystem applications. In each application it is necessary to consider what method(s) is the most appropriate. Based on its assessment of the current literature and the preceding conclusions, the committee makes the following recommendations (Chapter 4):

- Specific attention should be given to funding research at the "cutting edge" of the valuation field, such as dynamic production function approaches, general equilibrium modeling of integrated ecological-economic systems, conjoint analysis, and combined stated-preference and revealed-preference methods.
- Specific attention should be given to funding research on improved valuation study designs and validity tests for stated-preference methods applied to determine the nonuse values associated with aquatic and related terrestrial ecosystem services.
- Benefit transfers should be considered a "second-best" method of ecosystem services valuation and should be used with caution and only if appropriate guidelines are followed.
- The replacement cost method and estimates of the cost of treatment are not valid approaches to determining benefits and should not be employed to value aquatic ecosystem services. In the absence of any information on benefits, and under strict guidelines, treatment costs could help determine cost-effective policy action.

TRANSLATING ECOSYSTEM FUNCTIONS TO THE VALUE OF ECOSYSTEM SERVICES: CASE STUDIES AND LESSONS LEARNED

Although there has been great progress in ecology in understanding ecosystem processes and functions, and in economics in developing and applying nonmarket valuation techniques for their subsequent valuation, at present there often remains a gap between the two. There has been mutual recognition among at least some ecologists and economists that addressing issues such as conserving ecosystems and biodiversity requires the input of both disciplines to be successful. Yet there are few examples of studies that have successfully translated knowledge of ecosystems into a form in which economic valuation can be applied in a meaningful way. Several factors contribute to this ongoing lack of integration. First, ecology and economics are separate disciplines—one in the natural sciences, the other in the social sciences. Traditionally, academic organization and the reward structures for scientists make collaboration across disciplinary boundaries difficult even when the desire to do so exists. Second, the concept of ecosystem services and attempts to value them are still relatively recent; building the necessary working relationships and integrating methods across disciplines will take time.

Nevertheless, some useful integrated studies on the value of aquatic and related terrestrial ecosystem goods and services are starting to emerge. Chapter 5 of this report provides a series of case studies of the integration of ecology and economics necessary for valuing the services of aquatic and related terrestrial ecosystems (including those from both the eastern and the western United States; see Box ES-1). More specifically, this review begins with situations in which the focus is on valuing a single ecosystem service. Typically these are cases in which the service is well defined, there is reasonably good ecological understanding of how the service is produced, and there is reasonably good economic understanding of how to value it. Even when valuing a single ecosystem service however, there can be significant uncertainty either about the production of the ecosystem service, the value of the ecosystem service, or both. Next, attempts to value multiple ecosystem services are reviewed. Since ecosystems produce a range of services, and these services are frequently closely connected, it is often hard to discuss valuation of a single service in isolation. However, valuing multiple ecosystem services typically multiplies the difficulty of evaluation. Last to be reviewed are analyses that attempt to encompass all services produced by an ecosystem. Such cases can arise with natural resource damage assessment, where a dollar value estimate of total damages is required, or with ecosystem restoration efforts, and will typically face large gaps in understanding and information in both ecology and economics.

Proceeding from single services to entire ecosystems illustrates the range of circumstances and methods for valuing ecosystem goods and services. In some cases, it may be possible to generate relatively precise estimates of value. In other cases, all that may be possible is a rough categorization (e.g., "a lot" versus "a little"). Whether there is sufficient information for the valuation of ecosystem services to be of use in environmental decision-making depends on the circumstances and the policy question or decision at hand (see Chapters 2 and 6 for further information). In a few instances, a rough estimate may be sufficient to decide that one option is preferable to another. Tougher decisions will typically require more refined understanding of the issues at stake. This progression from situations with relatively complete to relatively incomplete information also demonstrates what gaps in knowledge may exist and the consequences of those gaps. Of course, part of the value of going through an ecosystem services evaluation is to identify the gaps in existing information to show what types of research are needed.

Chapter 5 includes an extensive discussion of various implications and lessons learned from the case studies that are reviewed. These examples show that the ability to generate useful information about the value of ecosystem services varies widely across cases and circumstances. For some policy questions, enough is known about ecosystem service valuation to help in decision-making. As other examples make clear, knowledge and information may not yet be sufficient to estimate the value of ecosystem services with enough precision to answer policy-relevant questions. In general, the inability to generate relatively precise and reliable estimates of ecosystem values may arise from any combination of the following three reasons: (1) insufficient ecological knowledge or information to estimate the quantity of ecosystem services produced or to estimate how ecosystem service production would change under alternative scenarios, (2) an inability of existing economic methods to generate precise estimates of value for the provision of various levels of ecosystem services, and (3) a lack of integration of ecological and economic analysis.

Studies that focus on valuing a single ecosystem service show promise of delivering results that can inform important policy decisions. In no instance, however, should the value of a single ecosystem service be confused with the value of the entire ecosystem. Unless it is clearly understood that valuing a single ecosystem service represents only a partial valuation of the natural processes in an ecosystem, such single service valuation exercises may provide a false signal of total value. Even when the goal of a valuation exercise is focused on a single ecosystem service, a workable understanding of the functioning of large parts or possibly the entire ecosystem may be required. Although the valuation of multiple ecosystem services is more difficult than the valuation of a single service, interconnections among services may make it necessary to expand the scope of the analysis. As noted previously, ecosystem processes are often spatially linked, especially in aquatic ecosystems. Full accounting of the consequences of actions on the value of ecosystem services requires understanding these spatial links and undertaking integrated studies at suitably large spatial scales to fully cover important effects. In generating estimates of the value of ecosystem services across larger spatial scales, extrapolation may be unavoidable, but it should be applied with careful scrutiny. Lastly, the value of ecosystem services depends upon underlying conditions. Ecosystem valuation studies should clearly present assumptions about underlying ecosystem and market conditions and how estimates of value could change with changes in these underlying conditions.

Building on the implications and lessons learned and on these preceding conclusions, the committee provides the following recommendations (Chapter 5):

- There is no perfect answer to questions about the proper scale and scope of analysis in ecosystem services valuation. One way to accomplish the integration of ecology and economics to value ecosystem services is to design the study to answer a particular policy question. The policy question then serves as the unifying frame that directs both ecological and economic analysis.
- Estimates of ecosystem value need to be placed in context. Assumptions about conditions in ecosystems outside the target ecosystem and assumptions about human behavior and institutions should be clearly specified.
- Concerted efforts should be made to overcome existing institutional barriers that prevent ready and effective collaboration among ecologists and economists regarding the valuation of ecosystem services. Furthermore, existing and future interdisciplinary programs aimed at integrated environmental analysis should be encouraged and supported.

JUDGMENT, UNCERTAINTY, AND VALUATION

The valuation of aquatic and related terrestrial ecosystem services inevitably involves investigator judgments and some amount of uncertainty. Although unavoidable, uncertainty and the need to exercise professional judgment are not debilitating to ecosystem valuation. However, when such judgments are made it is important to explain why they are needed and to indicate the alternative ways in which judgment could have been exercised. It is also important that the sources of uncertainty be acknowledged, minimized, and accounted for in ways that ensure that a study's results and related decisions regarding ecosystem valuation are not systematically biased and do not convey a false sense of precision.

There are several cases in which investigators must use professional judgment in ecosystem valuation regarding how to frame a valuation study, how to address the methodological judgments that must be made during the study, and how to use peer review to identify and evaluate these judgments. Of these, perhaps the most important choice in any ecosystem valuation study is the selection of the question to be asked and addressed (i.e., "framing" the study). The case studies discussed in Chapter 6 illustrate the fact that the policy context unavoidably affects the framing of an ecosystem valuation study and therefore the type and level of analysis needed to answer it. Framing also affects the way in which people respond to any given issue. Analysts need to be aware of this and sensitive to the different ways of presenting data and issues, and should make a serious attempt to address all perspectives in their presentations because failure to do so could undermine the legitimacy of an ecosystem valuation study.

In most ecosystem valuation studies, an analyst will be called on to make various methodological judgments about how the study should be designed and conducted. Typically, these judgments will address issues such as whether, and at what rate, future benefits and costs should be discounted; whether to value goods and services by what people are willing to pay or what they would be willing to accept if these goods and services were reduced or lost; and how to account for and present distributional issues arising from possible policy measures. In many cases, different choices regarding some of these issues will make a substantial difference in the final valuation. The unavoidable need to make professional judgments in ecosystem valuation through choices of framing and methods suggests that there is a strong case for peer review to provide input on these issues before study design is complete and relatively unchangeable.

There are several major sources of uncertainty in the valuation of aquatic ecosystem services and several options for policymakers and analysts to respond. Model uncertainty arises for the obvious reason that in many cases the relationships between certain key variables are not known with certainty (i.e., the "true model" will not be known). Parameter uncertainty is one level below model uncertainty in the logical hierarchy of uncertainty in the valuation of ecosystem services. The almost inevitable uncertainty facing analysts involved in ecosystem valuation can be more or less severe depending on the availability of good probabilistic information or lack thereof (i.e., the amount of ambiguity). A favorable case would be one in which although there is uncertainty about some key magnitudes of various parameters, the analyst nevertheless has good probabilistic information. An alternative and common scenario in ecosystem valuation is one in which there is really no good probabilistic information about the likely magnitude of some variables, and what is available is based only on expert judgment. However, just as there are different types of uncertainty in ecosystem valuation, there are also different ways and decision criteria that an analyst can use to allow for uncertainty in the support of environmental decision-making; these are reviewed in Chapters 2 and 6. One of these is the use of Monte Carlo simulations as a method of estimating the range of possible outcomes and the parameters of its probability distribution. The outcome of an environmental policy choice under uncertainty is necessarily unpredictable, and risk aversion is a measure of what a person is willing to pay to avoid an uncertain outcome. In a heterogeneous population, the analyst will have to make an assumption about the level of risk aversion that is appropriate for the group as a whole.

Although considerable uncertainty exists about the value of ecosystem services, there is often the possibility of reducing this uncertainty over time through passive and/or active learning. Regardless of its source, the possibility of reducing uncertainty in the future through learning can affect current decisions, particularly when the impacts of those decisions are (effectively) irreversible (e.g., the construction or removal of a dam). With learning, there is an "option value" that needs to be incorporated into the analysis as part of the expected net benefits that reflects the value of the additional flexibility. This flexibility allows future decisions to respond to new information as it becomes available. It follows that in a cost-benefit analysis, measurement of the benefits of ecosystem protection through ecosystem valuation should consider the possibility of learning (i.e., should incorporate the option value). At present, only a limited amount of empirical work has been done on estimating the magnitude of option value. A natural extension of the observation that better decisions can be made if one waits for additional information is through the use of adaptive management. Adaptive management is a relatively new but increasingly used paradigm for confronting the inevitable uncertainty arising among management policy alternatives for large complex ecosystems or ecosystems in which functional relationships are poorly known. It provides a mechanism for learning systematically about the links between human societies and ecosystems, although it is not a tool for ecosystem valuation or a method of valuation per se.

Based on these conclusions, the committee makes the following recommendations regarding judgment and uncertainty in ecosystem valuation activities and methods and approaches to effectively and proactively respond to them (Chapter 6):

- Analysts must be aware of the importance of framing in designing and conducting ecosystem valuation studies so that the study is tailored to address the major questions at issue. Analysts should also be sensitive to the different ways of presenting study data, issues, and results and make a concerted attempt to address all relevant perspectives in their presentations.
- The decision to use WTP or WTA as a measure of the value of an eco-

system good or service is a choice about how an issue is framed. If the good or service being valued is unique and not easily substitutable with other goods or services, then these two measures are likely to result in very different valuation estimates. In such cases, the committee cannot reasonably recommend that the analyst report both sets of estimates in a form of sensitivity analysis because this may effectively double the work. Rather, the analyst should document carefully the ultimate choice made and clearly state that the answer would probably have been higher or lower had the alternative measure been selected and used.

- Because even small differences in a discount rate for a long-term environmental restoration project can result in order-of-magnitude differences in the present value of net benefits, in such cases the analyst should present figures on the sensitivity of the results to alternative choices for discount rates.
- Ecosystem valuation studies should undergo external review by peers and stakeholders early in their development when there remains a legitimate opportunity for revision of the study's key judgments.
- Analysts should establish a range for the major sources of uncertainty in an ecosystem valuation study whenever possible.
- Analysts will often have to make an assumption about the level of risk aversion that is appropriate for use in an ecosystem valuation study. In such cases, the best solution is to state clearly that the assumption about risk aversion will affect the outcome and to conduct sensitivity analyses to indicate how this assumption impacts the outcome of the study.
- There is a need for further research about the relative importance of and estimating the magnitude of option values in ecosystem valuation.
- Under conditions of uncertainty, irreversibility, and learning, there should be a clear preference for environmental policy measures that are flexible and minimize the commitment of fixed capital or that can be implemented on a small scale on a pilot or trial basis.

ECOSYSTEM VALUATION: SYNTHESIS AND FUTURE DIRECTIONS

The final chapter of this report seeks to synthesize the current knowledge regarding ecosystem valuation in a way that will be useful to resource managers and policymakers as they incorporate the value of ecosystem services into their decisions. A synthesis of the report's general premises and major conclusions regarding ecosystem valuation suggests that a number of issues or factors enter into the appropriate design of a study of the value of aquatic ecosystem services. The context of the study and the way in which the resulting values will be used play a key role in determining the type of value estimate that is needed. In addition, the type of information that is required to answer the valuation question and the amount of information that is available about key economic and ecological relationships are important considerations. This strongly suggests that the valuation exercise will be very context specific and that a single, "one-size-fitsall" or "cookbook" approach cannot be used. Instead, the resource manager or decision maker who is conducting a study or evaluating the results of a valuation study must assess how well the study is designed in the context of the specific problem it seeks to address. In this regard, Chapter 7 provides a checklist to aid in this assessment that identifies questions that should be openly discussed and satisfactorily resolved in the course of the valuation exercise.

Finally, Chapter 7 identifies what the committee feels are the most pressing recommendations for improving the estimation of ecosystem values and their use in decisions regarding ecosystem protection, preservation, or restoration. These overarching recommendations are based on, and in some cases build on, the more specific recommendations presented at the ends of the previous chapters; they include (1) overarching recommendations for conducting ecosystem valuation and (2) overarching research needs, which imply recommendations regarding future research funding.

VALUING ECOSYSTEM SERVICES

TOWARD BETTER ENVIRONMENTAL DECISION-MAKING

Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems

Water Science and Technology Board

Division on Earth and Life Studies

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Preface

The development of the ecosystem services paradigm has enhanced our understanding of how the natural environment matters to human societies. We now think of the natural environment, and the ecosystems of which it consists, as natural capital—a form of capital asset that, along with physical, human, social, and intellectual capital, is one of society's important assets. As President Theodore Roosevelt presciently said in 1907,

> *The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value.*[1]

Economists normally value assets by the value of services that they provide: Can we apply this approach to ecological assets by valuing the services provided by ecosystems?

An ecosystem is generally accepted to be an interacting system of biota and its associated physical environment. Aquatic and related terrestrial ecosystems are among the most important ecosystems in the United States, and Congress through the Clean Water Act has recognized the importance of the services they provide and has shown a concern that these services be restored and maintained. Such systems intuitively include streams, rivers, ponds, lakes, estuaries, and oceans. However, most ecologists and environmental regulators include vegetated wetlands as aquatic ecosystems, and many also think of underlying groundwater aquifers as potential members of the set. Thus, the inclusion of "related terrestrial ecosystems" for consideration in this study is a reflection of the state of the science that recognizes the multitude of processes linking terrestrial and aquatic systems.

Many of the policies implemented by various federal, state, and local regulatory agencies can profoundly affect the nation's aquatic and related terrestrial ecosystems, and in consequence, these bodies have an interest in better understanding the nature of their services, how their own actions may affect them, and what value society places on their services. The need for this study was recognized in 1997 at a strategic planning session of Water Science and Technology Board (WSTB) of the National Research Council (NRC). The Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems was established by the NRC in early 2002 with support from the U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers

[1] Inscribed on the wall of the entrance hall of the American Museum of Natural History, Washington, D.C.

(USACE), and U.S. Department of Agriculture (USDA). Its members are drawn from the ranks of economists, ecologists, and philosophers who have professional expertise relating to aquatic ecosystems and the valuation of ecosystem services.

In drafting this report the committee members have sought to understand and integrate the disciplines, primarily ecology and economics, that cover the field of ecosystem service valuation. In fact, the committee quickly discovered that this is not an established field—ecologists have only recently begun to think in terms of ecosystem services and their determinants, while economists have likewise only very recently begun to incorporate the factors affecting ecosystem services into their valuations of these services. If we as a society are to understand properly the value of our natural capital, which is a prerequisite for sensible conservation decisions, then this growing field must be developed further and this report provides detailed recommendations for facilitating that development. Although the field is relatively new, a great deal is understood, and consequently the committee makes many positive conclusions and recommendations concerning the methods that can be applied in valuing the services of aquatic and related terrestrial ecosystems. Furthermore, because the principles and practices of valuing ecosystem services are rarely sensitive to whether the underlying ecosystem is aquatic or terrestrial, the report's various conclusions and recommendations are likely to be directly, or at least indirectly applicable to valuation of the goods and services provided by any ecosystem.

The study benefited greatly from the knowledge and expertise of those who made presentations at our meetings, including Richard Carson, University of California, San Diego; Harry Kitch, USACE; John McShane, EPA; Angela Nugent, EPA; Michael O'Neill, USDA; Mahesh Podar, EPA (retired); John Powers, EPA; Stephen Schneider, Stanford University; and Eugene Stakhiv, USACE Institute for Water Resources. The success of the report also depended on the support of the NRC staff working with the committee, and it is a particular pleasure to acknowledge the immense assistance of study director Mark Gibson and WSTB research associate Ellen de Guzman. Finally, of course, the committee members worked extraordinarily hard and with great dedication, expertise, and good humor in pulling together what was initially a rather disparate set of issues and methods into the coherent whole that follows.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Mark Brinson, East Carolina University, Greenville, North Carolina; J. Baird Callicott, University of North Texas, Denton; Nancy Grimm, Arizona State University, Tempe;

Michael Hanemann, University of California, Berkeley; Peter Kareiva, The Nature Conservancy, Seattle, Washington; Raymond Knopp, Resources for the Future, Washington, D.C.; Sandra Postel, Global Water Policy Project, Amherst, Massachusetts; and Robert Stavins, Harvard University, Cambridge.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by John Boland, Johns Hopkins University, Baltimore. Appointed by the National Research Council, he was responsible for making certain that an independent examination of the report was carefully carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Geoffrey M. Heal, *Chair*

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