PERSPECTIVES ON BIODIVERSITY

Valuing Its Role in an Everchanging World

Committee on Noneconomic and Economic
Value of Biodiversity

Board on Biology

Commission on Life Sciences

National Research Council

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the 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. The committee thanks the following individuals for their participation in review of this report:

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While the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the authoring panel and the National Research Council.

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Preface

At the request of the Department of Defense (DOD), in 1995, the National Research Council's Board on Biology convened the 14-member Committee on Noneconomic and Economic Value of Biodiversity. The committee was charged with many tasks that are summarized as follows:

- Review how the current scientific knowledge about economic and noneconomic values could be applied to management of biological resources;
- Using case studies, assess how the various aspects of value have been or might be used by managers in development, implementation, and evaluation of management plans; and
- Suggest how managers can improve their use of information about the values of biodiversity in their management decisions

It is important to note that the charge did not require the committee to recommend which values should have high priority for consideration by managers. The committee chose, in its deliberations, to consider management of biological resources as lands owned by and managed by DOD and other federal agencies and by state and local governments. Case studies were selected to illustrate the scope of management decisions that occur when different values of biodiversity are considered.

The committee—composed of members representing disciplines of biodiversity sciences (systematics, ecology, population biology, conservation biology, and ecology), resource management, sociology, economics, and philosophy—convened its first meeting in Washington, D.C., in July 1995 and the final and sixth meeting in Keystone, Colo., in July 1996. Since 1996, there have been

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numerous working meetings of two to four committee members. During this period, as the scientific information on biodiversity and its valuation proliferated, the committee examined and reconsidered, and in a few cases rewrote, sections of the report.

I was fortunate to work with a knowledgeable, collegial, and interesting committee that engaged in lively debates and worked diligently on this report. I am extremely grateful to the committee and especially to committee members Perry Hagenstein and Robert Paine, whose generosity and attention to this report seemed boundless. The progress of the report endured several personal tragedies of committee members, and I am especially appreciative of their work during their adversity. The committee began and completed much of its work with the able assistance and professional direction of NRC Study Director Janet Joy. In 1997, Tania Williams became study director, and she was responsible for advancing the committee's efforts through careful administrative, editorial, and intellectual contributions and for contributing greatly to the final product. Personally, as well as on behalf of the committee, I thank them. Eric Fischer and Paul Gilman, formerly director of the Board on Biology and executive director of the Commission on Life Sciences, respectively, helped the committee refine its report. The committee benefited from and acknowledges with appreciation the efforts of DOD personnel who arranged the committee's visit to Camp Pendleton, Calif., and those who made presentations at committee meetings; they are listed in appendix C.

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Executive Summary

The Committee on Noneconomic and Economic Value of Biodiversity in the Board on Biology of the National Research Council's Commission on Life Sciences was charged with examining "how current scientific knowledge about the economic and noneconomic value of biodiversity can best be applied in the management of biological resources". This report reviews current understanding of the value of biodiversity and the methods that are useful in assessing that value in particular circumstances. It responds to a request to the National Research Council from the Deputy Undersecretary of Defense for Environmental Security, which recognized that many of the lands it owns or controls have potentially high value for protection and maintenance of biodiversity. The primary purposes for which these lands are managed requires that they be held in relatively large blocks and that they not be developed for commercial or residential uses. Other federal agencies and many state natural resource agencies also have lands held in large blocks where biodiversity can be protected and maintained. Taken together, the state and federal lands, including military reservations, collectively identify a developing national system of potential biodiversity reserves. Their importance aesthetically, economically, and biologically should not be undervalued.

Conservation of biodiversity does not enter into resource-management decisions in only one way. It is a vital element in sustaining natural processes. But management of natural systems involves many tradeoffs between conservation of biodiversity and other management goals. The extent of the tradeoffs and the extent of a manager's ability to effect the conservation of biodiversity are limited by the extent of the manager's authority.

Resource-management decisions in nearly all cases are incremental. A manager's decisions are limited in space by agency mandates and geographic constraints. They are usually limited in time by the ability to forecast conditions

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and human needs. But concerns with biodiversity extend beyond those boundaries. Although a manager's actions are local and immediate, the management perspective must be broad enough to recognize a range of values and the implications of decisions for survival of larger ecosystems. A series of decisions that individually do not have major effects can have major cumulative effects.

This report differs from many recent ones that have focused solely on measures of the economic value of biodiversity in that it seeks to embrace the range of values that legitimately can be used to determine the merits of alternative courses of action regarding biodiversity. Recognizing that improved methods for assigning value can enhance the process of decision-making, we also provide a summary of state-of-the-art methods for establishing value. But we focus even greater attention on methods of weighing input from stakeholders who have different systems for determining the value of different actions so as to yield sound resource-management decisions.

The intent of this report is to provide perspectives on biodiversity that resource managers can consider in making decisions. The different approaches to valuing biodiversity are discussed throughout the report. Case studies are used to show that no single list of tools can be used for management decisions on biodiversity. We suggest that managers consider in their deliberations a broad range of information on biodiversity, including differing views and values of biodiversity. We believe that managers can benefit from such information. The committee reviewed the relevant scientific literature on biodiversity, its values, concerns about its status, and its treatment in analyses of its value.

Understanding the technical meaning of biodiversity and its implications is necessary if the values of conserving biodiversity are to be incorporated appropriately into resource-management decisions. The approach to providing such understanding used in this report is three-fold.

First, we develop the basis for understanding the importance of the components of biodiversity and some of the ways in which biodiversity is measured. Recognition that diverse biological systems are essential for life on the planet is, obviously, important in managing resources. But such management requires a fuller understanding of biodiversity and its components. In chapter 2, we attempt to define these components and to describe some of the ways to measure them. Biodiversity includes not only the world's species with their unique evolutionary histories, but also genetic variability within and among populations of species and the distribution of species across local habitats, ecosystems, landscapes, and whole continents or oceans. Because biodiversity is such a broad concept, methods for its quantification are necessarily broad. Nonetheless, the available data indicate that a greater species diversity in an ecosystem tends to increase the likelihood that particular ecosystem services will be maintained in the face of changing ecological or climatic conditions. The committee concludes that, given the variation in missions of agencies, managers must consider both the mainte-

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nance of viable local populations of species of interest and the maintenance of biodiversity on larger scales as essential for the functioning of ecosystems.

Second, we discuss how people derive value from biodiversity and how it contributes to the well-being of society. It contributes to various kinds of services that depend on functioning ecosystems, to social and cultural values and to human industries. Chapter 3 discusses how the many dimensions of biodiversity and its components contribute to decisions on management of biodiversity. The individual components of biodiversity—genes, species, and ecosystems—provide society with a wide array of goods and services. The components of biodiversity are interconnected. For example, genetic diversity provides the basis of continuing adaptation to changing conditions, and continued crop productivity rests on the diversity in crop species and on the variety of soil invertebrates and microorganisms that maintain soil fertility. Similarly, a change in the composition and abundance of the species that make up an ecosystem can alter the services that can be obtained from the system. Biodiversity contributes to our knowledge in ways that are both informative and transformative. Knowledge about biodiversity is valuable in stimulating technological innovation and in learning about human biology and ecology. Experiencing and increasing our knowledge about biodiversity transforms our values and beliefs. A fairly large literature characterizes nonextractive ecosystem services that have direct benefits to society, such as water purification, flood control, pollination, and pest control.

Methods of analytically estimating economic and noneconomic values of biodiversity must be viewed in the broad context of people's different ways of thinking about values. In chapter 4, major Western philosophies of value are reviewed to provide a context for describing how the tools of economists can contribute to understanding how biodiversity values fit into the management of biological resources. The relevance of the different philosophies themselves to management decisions is also recognized. Generalized human responses to biodiversity can be grouped into three broad categories:

- *We might need it.* In this category are the claims concerning the actual or potential usefulness of biodiversity—genetic resources for medicine, pharmacy, and agriculture; ecosystem services; and, ultimately, the continuity of life on Earth.
- *We like it.* In this category are the claims that biodiversity is a direct source of pleasure and aesthetic satisfaction—its contribution to quality of life, outdoor recreation, and scenic enjoyment; to preserving a sense of place; and to preserving refuges of wildness (wildlands and wild habitats).
- *We think we ought to.* In this category are the claims that people have duties to preserve and protect biodiversity—duties based on higher moral principles or on rights that are attributed to biodiversity or its living components.

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It is reasonable for a person to hold views in all three categories simultaneously. Reasons for action must be based on both positive and normative premises, that is, on facts and on some concept of what is good. In the broad categories of reasons for caring about biodiversity, we have lumped motivations that derive from different understandings of the facts and different perceptions of the good.

Utilitarianism, which judges the effectiveness of actions by how well they contribute to satisfying people's preferences, is the basis for most mainstream economic analyses of value. Where direct evidence of values is provided by prices in market transactions, the economist's usual tools (for example, marginal analysis—examining the effects of small incremental changes in prices and quantities) provide useful information for making decisions. Where for various reasons markets do not provide such evidence of value—the usual case for decisions about biodiversity—several techniques have been developed to substitute for market evidence.

The economic value of biodiversity has its place in the policy-making process. Although biodiversity might well have substantial economic value, compared with alternative consumptive resource uses, economic value does not tell us everything we need to know about the value of biodiversity. Economic valuation is an attempt to provide an empirical account of the value of services and amenities or of the benefits and costs of proposed actions (projects or policies) that would modify the flow of services and amenities. Economic valuation provides a utilitarian account, that is, an account of contribution to the satisfaction of human preferences. Therefore, it provides a particular perspective on value—in this case, on the value of biodiversity. Utilitarians might object to some aspects of the economists' utilitarian account: to produce an economic account of contribution to preference satisfaction, a particular kind of structure has to be introduced into the analysis, and utilitarians will not always endorse the process or the results.

Chapter 5 reviews the array of tools that economists have developed for estimating values when the lack of ordinary markets precludes use of their favored measure, market-determined prices. These are powerful tools for informing decisions involving biodiversity, but they have limitations. Estimates of value based on them should be treated with careful attention to the assumptions that have been used in obtaining them. Support for their veracity can be indicated by the degree to which results obtained from various estimates converge. Particular care should be taken as the scale of the decisions for which estimates of value are made diverges from the normal scale of market processes. The economist's usual view of market decisions as being made at the margin—that is, for small changes in quantities and prices—is a key assumption for most estimates of value.

Results of both direct evidence and surrogate measures of value provide useful information for informing decisions about biodiversity. But both approaches provide only part of the needed information. Utilitarianism is only one valid way of looking at values, and the results of economic analysis are condi-

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tioned by fairly rigorous assumptions. In most cases, a process is needed to weigh the results of different approaches for valuing biodiversity and to validate the analyses used for estimating values.

This report includes several case studies that involve aspects of biodiversity to illustrate a wide spectrum of resource-management situations. All involve ways in which recognition of the values of biodiversity could or did contribute to resource management. The message of the several case studies taken as a whole is that valuing biodiversity in real decisions is constrained by decision boundaries that are not consistent with the scale on which natural systems operate; by limits in the ability to describe how biodiversity will be affected by such decisions; and by disagreements over the weights to be assigned to different measures of value.

Our intent has been to provide examples that embody an array of complications and challenges inherent in environmentally sensitive management decisions. We have purposely avoided such global issues as climate change and its potential consequences; although surely important in connection with the central themes of our report, these are beyond the capacity of local managers and decision-makers to influence significantly. Rather, we present and discuss scenarios ranging from specific local actions to regional problems that, although acknowledged, remain unsolved. These are intended to encapsulate the multiple dimensions of the management challenge; we do not intend them to be interpreted as specific instructions. Management flexibility and development of mutual trust and understanding are likely to achieve management objectives more effectively than rigid prescriptions.

The usual processes for involving the public and other interested parties in government resource management and environmental decisions have been limited in their effectiveness. Alternatives are needed that will provide for input of both scientific information and people's values and for weighing these in an iterative process that allows testing of the scientific information and clarifying values. This report discusses the merits of analytic deliberation processes as a way of bringing value- and science-based information to bear on decisions involving biodiversity.

Analytic deliberation is a class of discursive processes for dealing with conflicts that draws on the best features of both analysis and deliberation; these processes incorporate input from traditional public participation, from normal political processes, and from science in several ways. It also relies on sound analysis grounded in the best available science. It is a structured process tailored to match local circumstance and to fit the needs of managers to make decisions. Analytic deliberation processes are based on continuity and repetition involving a stable group of participants who are committed to the success of the endeavor. In a sense, they mirror the operation of ordinary markets, in which prices are set in a continuing series of negotiations among buyers and sellers. Each market decision provides additional information for agreeing on the price in the next situation.

Resource managers are faced with the unenviable but necessary task of

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weighing the various consequences of their decisions in terms that are relevant to people and their values and with doing this in the absence of unambiguous measures of human values and in the absence of unambiguous supporting information on the potential effects of their decisions on biological processes, local and global. Decisions must and will be made. The dilemma for managers and society alike is that most of the decisions will be local and have mainly local effects that can be monitored and used to guide later decisions, but some will involve broader issues, major commitments of resources, and longer periods of adjustment. At whatever level decisions involving the recognition of the importance of conserving biodiversity are made, the following findings will help to guide action.

- That a broader understanding of the implications of biodiversity conservation is needed for resource-management decisions on the various scales at which they are made.
- That the available tools for estimating both economic and noneconomic values to management alternatives are limited in their usefulness in these decisions, in part because of the wide differences in philosophies of value held by the public, but also because of the nonmarket nature of so many of the values of biodiversity. No measure or calculus adequately provides for simultaneously weighing the full range of possible values in most such decisions.
- That reaching public consensus on decisions involving biodiversity is hindered, often by the lack of facts on which agreement can be reached, but also by public processes that fail to take full advantage of opportunities to develop consensus.

The committee concludes the following:

- There is an urgent need for more information about biodiversity and its role in sustaining natural processes and for it to be gathered, organized, and presented on various scales and in ways most useful to those charged with managing natural resources.
- No simple models or approaches can adequately capture both market and nonmarket values of biodiversity in a simple, objective manner. Traditional and emerging benefit-cost approaches to valuing biodiversity can contribute important and relevant information to decision-making. But the wide ranges of values and value systems held by those affected by resource decisions and the inherent difficulties in quantifying nonmarket values place some limits on the role of models in these decisions.
- There is great power in using an analytic deliberative process, which is inherently qualitative, in making decisions about biodiversity, although the ultimate decisions themselves must be made by the managers or policy makers. This

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includes using the process to weigh the different kinds of values that are involved.

• Because most decisions affecting biodiversity will be made on a local scale, there is an urgent need for periodic regional assessments of the state of biodiversity so that managers can assess the consequences of their decisions in broader and more ecologically meaningful contexts.

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1

Introduction

"Nothing is inexhaustibale but the wealth of nature."

—R.W. Emerson

Assemblages of plants, animals, and microorganisms increasingly compete with an expanding human population and its rising economic aspirations and associated environmental demands for a broad range of resources in and products from the natural world. That simplified overview frames a pressing need to address and minimize such conflicts. Controversy is often generated by management decisions that have either beneficial or adverse consequences for biological diversity. The nationwide debate over changes in forest management in the Pacific Northwest to protect the spotted owl and its associated ecosystems and the global controversy over the costs and benefits of deforestation in the Amazon are cases in point. Such controversies often arise over differing opinions on the relative importance or value of the organisms at risk in relation to the economic value of the developmental or recreational activities in question. It is natural to believe that improving the methods of valuing the costs or benefits of changes in biodiversity can reduce disagreements over the values and enhance both the process and the results of resource-management decision-making.

Dietz and Stern (1998) identify factors that contribute to conflicts over biodiversity management. First, biodiversity is multidimensional; decisions about it will have many effects, and people will be affected in different ways. Second, decisions about biodiversity involve considerable scientific uncertainty: our general knowledge of the structure and function of ecosystems is incomplete, and we rarely have enough information on the local circumstances that will be influenced by management decisions. Third, values might be in conflict, and which values will be affected by a decision can be as uncertain as the science. Fourth, managers might not be trusted by the public or by segments of it. Fifth, there is usually considerable urgency in making decisions, because taking no action or continuing current policy is highly consequential.

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In the face of such complexity and the sometimes fierce conflict that attends it, managers need the best available information and tools. This report responds to a request to the National Research Council from the Department of Defense (DOD), which recognized that many of the lands that it owns or controls have potentially high value for the protection and maintenance of biodiversity. The primary purposes for which these DOD lands are managed requires that they be held in relatively large blocks and that they not be developed for commercial or residential uses. Although the military uses affect natural conditions, often much of the lands remain relatively free of major impacts on biodiversity. The Committee on Noneconomic and Economic Value of Biodiversity in the Board on Biology of the National Research Council's Commission on Life Sciences was charged with examining "how current scientific knowledge about the economic and noneconomic value of biodiversity can best be applied in the management of biological resources" (see appendix A, "Statement of Task"). This report reviews current understanding of the value of biodiversity and the methods that have been developed to assess that value in particular circumstances.

Although not denying that improved methods of valuation can aid decision-making, the committee and its report have focused on a more fundamental challenge. Specifically, important differences in opinion about decisions regarding biodiversity are likely to arise from differences in the ethical frameworks that people use to value biodiversity. The most precise economic analysis showing that a housing subdivision will generate greater economic benefit for society than the protection of a nature reserve will hold relatively little sway over the views of a person who believes that it is morally wrong to cause the extinction of a species that is found only in that nature reserve. As much as managers might like to simplify decision-making processes to a straightforward assessment of economic costs and benefits, the reality of the most important decisions that our society faces is far more complex. Wise decisions regarding social goods are made by weighing a variety of legitimate measures of importance or value.

This report differs from many recent ones that have focused solely on measures of the economic value of biodiversity in that it seeks to embrace the range of value frameworks that legitimately can be used to determine the merits of alternative courses of action regarding biodiversity. Recognizing that improved methods can enhance the process of decision-making within any framework for assigning value, we also provide a summary of state-of-the-art methods for establishing value. But we focus even greater attention on methods for weighing input from stakeholders with different frameworks for determining the value of different actions to yield sound resource-management decisions.

The wide range in the kinds of values that people attribute to maintaining biodiversity and in the basic philosophies that lie behind these values led to the committee's conclusion that the processes making decisions involving biodiversity are of greater importance than the techniques that assign values to any one of the philosophical postures. Choosing the appropriate decision process has two

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goals. One is to shed light on how protection of elements of biodiversity affects the various kinds of values that it affords. The other is to build the confidence not only of the resource mangers, but also of the public, in the ultimate decisions.

Resource managers have the unenviable task of weighing the value of biodiversity in the absence of any one suitable metric that encompasses the range of legitimate views. Appropriate processes thus become important for identifying how possible management choices affect biodiversity for identifying how these choices affect the various kinds of values that can be assigned to biodiversity and for gaining public acceptance of the decisions made by the resource managers.

Our intent has been to provide a spectrum of examples that embody a range of complications and challenges inherent in environmentally sensitive management decisions. We have purposely constrained our examples to illustrate more local than global issues. Thus, we avoid discussion of global warming and its potential consequences; although surely important enough in connection with the central themes of our report, these are beyond the capacity of local managers and decision-makers to influence significantly. Rather, we present and discuss scenarios ranging from specific local actions to regional problems that, although acknowledged, remain unsolved. These are intended to encapsulate the multiple dimensions of the management challenge; we do not intend them to be interpreted as specific instructions. Management flexibility and development of mutual trust and understanding are likely to achieve management objectives more effectively than the blunt application of a legal procedure.

We begin by describing in some detail two examples that approach the extremes of the management dilemma. The Camp Pendleton case study involves a spatially restricted program of environmental management sensitive to the maintenance of the local biological communities. The Western Rangelands case study embodies a nearly polar opposite; the management challenges are diverse, the spatial scale is immense, there is little evidence of problem solution, and there surely is no single solution. These examples are given to establish the biological, economic, and even philosophical issues central to our report.

CASE STUDY: CAMP PENDLETON

Camp Pendleton, a 126,000-acre Marine Corps training base along the Pacific Coast between Los Angeles and San Diego, has almost by accident become a biodiversity reserve in the midst of exploding residential development. The base has a diversity of habitat types in an area of high natural biodiversity and includes a number of species of special concern, especially threatened and endangered species, such as the California gnat-catcher, the least Bell's vireo, the orange-throated whiptail lizard, and the arroyo toad. Its amphibious-warfare training mission, which might seem to be at odds with protecting biodiversity, actually treads lightly on the natural setting, which is dominated by grassland and

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coastal sage scrub and includes extensive areas of chaparral and oak woodland and increasingly rare riparian zones.

Because it is the only amphibious military training center on the West Coast, the Department of Defense has a particular interest in keeping Camp Pendleton. But, the military is increasingly recognizing the values of biodiversity on its many relatively undeveloped bases around the country. Weighing against those interests is the potentially high development values of some bases. Land values in the Camp Pendleton area are especially high, because of its setting as one of the most rapidly urbanizing regions in North America.

One result of the high interest in Camp Pendleton was the formation of the Biodiversity Research Consortium, which involves, among other organizations, the USDA Forest Service, the Harvard University School of Design, Utah State University, the University of California, and The Nature Conservancy. The consortium's study (Steinitz and others 1996) of the Camp Pendleton region includes all of the camp and the immediately adjacent terrain, a zone of 50 by 83 miles that encompasses five river basins, two zones of coastal drainage, and parts of San Diego, Riverside, and Orange Counties. The reasons for choosing this area for the intensive study included the conflict and controversies inherent in the adjoining region; the likelihood of dramatic changes in the region resulting from rapid population increase of about 300,000 to 2 million by 2010; and the possibility that a policy study might make a difference with respect to the conservation of biodiversity in the region.

The camp and immediately adjacent areas in the inland mountains to the north and east of it, such as the San Mateo Canyon Wilderness area of the Cleveland National Forest and The Nature Conservancy's Santa Rosa Plateau Reserve, are perceived by neighbors as a regional preserve for biodiversity. Among the factors entering into the study's policy planning were hydrology (the camp is subject to infrequent but devastating floods), fire frequency and predictability, slope occupancy (many parts of the region have slopes that exceed 10 to 15%), and biodiversity conservation. Biodiversity has been examined from three perspectives: total biodiversity, measured simply by numbers of species (biodiversity in the region is the highest in California; 345 vertebrate species in the region constitute 60% of the total in the state); 11 selected vertebrates species of special concern (for example, endangered species); and the diversity of landscapes and the pattern of their distribution.

The Biodiversity Research Consortium's study (a geographic information system study involving multiple layers of analysis and more than 10 gigabytes of data) led to the development of four specific strategies for development and seven alternative patterns. The strategies have different implications for biodiversity conservation and for preservation of the main features important to military planning on Camp Pendleton.

A major outcome of the study is the recognition that efforts to concentrate regional development in specific areas would make it possible to meet military

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and biodiversity conservation goals in the long run. It is crucial that housing and commercial development avoid slopes in excess of about 10–15% and flood plains. Those two limitations in combination will, however, preserve most of the biodiversity in the region and will preserve the militarily important elements of Camp Pendleton. A fundamental assumption is that the integrity of the boundaries of the camp be maintained and that development on the Santa Rosa Plateau occur in such a manner as to maintain an effective wildlife corridor between the camp and other relatively natural areas.

The study also concluded that there is a window of opportunity of 2 years to about 10–15 years during which critical decisions must be made by Camp Pendleton, regional planning authorities in the three counties, and the Nature Conservancy. During this window, such issues as the integrity of the military mission, transferring military lands to nonfederal entities for biodiversity conservation, planning for development that recognizes the limitations imposed by steep slopes and flood plains, fire management, flood control, and appreciation of the importance of biodiversity will be central in the decision-making process. There is also a growing appreciation of the relation between natural beauty as perceived in landscapes and biodiversity conservation—a mix that is especially well exposed in coastal southern California.

The Camp Pendleton case study illuminates many of the complicated interactions involved in how different means of valuing biodiversity enter into planning processes. For the military, maintenance of the status quo is important. Accordingly, camp personnel make certain that federal laws are enforced. With respect to biodiversity, the most important laws are related to endangered species and pollution. The military also wants to be a good neighbor and understands that its open space is valued by a sizable proportion of the southern California populace, not only for the organisms that it contains but also as landscape. Important issues related to biodiversity involve fire and flood control, maintenance of riparian and upland habitat corridors for wildlife movements, and maintenance of open space.

Regional governments envision Camp Pendleton as an important component of regional planning, but the camp does not want to be viewed as a wildlife park when it has its own needs for future development. Values placed on biodiversity by the public in the form of laws and activities of interested individuals and organizations are important components of all aspects of planning and development on the base; the USDA Forest Service and The Nature Conservancy own lands that either abut or are very near Camp Pendleton boundaries. The camp is also concerned that upstream land development is contributing to increased frequency and intensity of floods and increasing the likelihood of wildland fires. In a complicated situation like the one that Camp Pendleton presents, biodiversity values play important roles in all aspects of local and regional planning and development. Chapters 2, 3, and 4 discuss how biodiversity can be valued.

In sum, this case illustrates some of the complicated interactions in matters

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that are involved in maintaining and protecting biodiversity. But it provides little guidance on how to value biodiversity in this or similar situations and on how the parties to such resource-management decisions can be involved in the valuation process. It does point to the need to make such decisions in the context of the region within which islands of biodiversity, such as Camp Pendleton, exist.

CASE STUDY: WESTERN RANGELANDS

Livestock grazing is by far the most widespread land use in the American West, and it has a major impact on the biological diversity of the region. About 70% of the land area of the 11 western states is grazed (DOI 1994), mostly on federal lands managed by the Bureau of Land Management and the USDA Forest Service (Fleischner 1994; Saab and others 1995). This case study illustrates the challenges in developing consensus about the values of biodiversity over such a large geographic area. A relatively small number of ranchers with direct commodity interests in the land are pitted against a much larger number of conservationists and recreationists with less-direct interests in the value of the native biodiversity of the same land.

The economic significance of public-lands grazing, despite its near ubiquity in the West, is relatively minor on a national scale. Nevertheless, western rural cultures and economies would be substantially affected if it were to be halted. Any conservation-based modifications of present grazing policies must be based on sound information about their actual ecological consequences if the issue is to be resolved (Fleischner 1994; Vavra and others 1994). The following points are particularly relevant:

- Grasslands in the Great Plains are relatively tolerant of ungulate grazing because of their evolutionary associations with the continent's principal native grazer, the bison (*Bison bison*) (Mack and Thompson 1982; Milchunas and others 1988). In contrast, grasses of the intermountain West and Southwest have had little association with native grazing ungulates and are relatively intolerant of livestock activities.
- Riparian habitats are scarce in the West, are very rich in biomass and biological diversity, and are strongly affected by livestock grazing (DOI 1994; Elmore and Kauffman 1994; Johnson and Jones 1977; Platts and Nelson 1985; Saab and others 1995).
- The water-holding capacity of arid lands in the West has been severely altered by heavy livestock grazing to the extent that many streams that once flowed perennially today flow only violently and sporadically (Sheridan 1981). The value of restored rangelands as watersheds might exceed their value for livestock production in purely economic terms (for example, Cox and others 1984).
- The introduction of nonnative grasses and forbs, often intended to improve livestock grazing, has had major negative effects on endemic flora and

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fauna of western rangelands (for example, Bock and others 1986; D'Antonio and Vitousek 1992; Mack 1981).

- Livestock grazing has caused soil compaction and destruction of soil microbiotic crusts, and these have drastically altered the structure and function of the rhizosphere, especially in areas lacking an association with native ungulates (Fleischner 1994).
- Control and elimination of native predators (such as wolves, *Canis lupus*) and livestock-competing herbivores (such as prairie dogs, *Cynomys ludovicianus*) have reduced the biological diversity and altered the structure and function of many western ecosystems (for example, Fleischner and others 1994; Miller and others 1994).
- In most western ecosystems, livestock grazed at economically meaningful levels probably operate as keystone species by determining which components of the endemic flora and fauna will thrive and which will not. Given the near ubiquity of livestock in much of the West, it is the plants and animals that are intolerant of the activities of large, hoofed, grazing mammals that have relatively few places left to live.

The issue of the future of the federal rangelands has been polarized by absolute statements about the positive or negative effects of livestock grazing on biological diversity (for example, Ferguson and Ferguson 1983; Jacobs 1991; Savory 1988). Scientific opinion on the livestock-grazing issue remains polarized between ecologists who argue for livestock removal (for example, Fleischner 1994) and range scientists who argue that moderate grazing is not only acceptable but often a necessary tool for maintaining healthy rangeland ecosystems (for example, Vavra and others 1994). Conservation organizations and ranchers are deeply divided on the issue, and lobbying organizations representing both groups usually exaggerate and exacerbate the division. Federal land managers are caught in the middle of the controversy.

The present conflict over the future of the western rangelands might have been inevitable, given their declining economic value for livestock grazing and the growing recognition of its effects on the ecological integrity and biological diversity of arid grasslands. But there is little likelihood that livestock grazing will cease on public rangelands in the near future (Brussard and others 1994).

Most attempts to resolve the conflict over use of the western rangelands have failed, but good ecological analysis could lead to at least partial resolution of the conflict if the results of the analysis were accepted by the parties involved. What has been lacking so far is adequate forums for reaching agreement among the parties to the conflict on the facts and values that are involved. Such forums should be constituted to recognize subregional differences in biological conditions (for example, the differences in evolutionary development of the Great Plains and intermountain rangelands relative to current livestock grazing) and in values—both the values of biodiversity and the values generated by use of the

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rangeland resources. Chapter 6 presents some examples of such forums. Resolving the conflict over use of these rangelands might require both action by Congress and management changes that are sensitive to the many relevant differences at the local level.

THE COMMITTEE AND ITS REPORT

The issues addressed in this report require bringing together a variety of value perspectives, disciplinary skills, and decision processes. Melding these at levels from broad policy decisions, such as passing legislation to protect endangered species or habitats, to on-the-ground management decisions, such as guiding development in a small wetland, will be difficult. This report offers no simple answers that will fit equally the full extent of the kinds of decisions that will be involved.

Other federal agencies and many state natural resource agencies also have lands held in large blocks where biodiversity can be protected and maintained. The federal agencies include the US Department of the Interior National Park Service, Fish and Wildlife Service, and Bureau of Land Management and the US Department of Agriculture Forest Service. Each of these agencies has resource uses mandated by law that might affect biodiversity, but each also sharply limits development other than that associated with resource use. Taken together, these federal agencies, including DOD, and the state natural-resource agencies provide a major opportunity for protection and maintenance of biodiversity. These large tracts of state and federal lands, including military reservations, collectively identify a developing national system of potential biodiversity reserves. Their importance aesthetically, economically, and biologically should not be undervalued.

The committee's conclusions are not limited in their implications for protecting and maintaining biodiversity to federal and state natural-resource agency lands, but extend as well to other resource lands and management situations. At the same time, the extent and relatively undeveloped character of the federal and state natural-resource agency lands, along with the laws and policies that guide management of these lands, have shaped the committee's perspective. Some of these laws (for example the Endangered Species Act) are related to elements of protecting biodiversity. Others concern the processes for making public decisions. But these matters affecting publicly owned lands do not reduce the opportunities for protecting and maintaining biodiversity on other lands, at which this report is also aimed.

The report is the product of a committee of specialists in relevant scientific fields. Just as the kinds of decisions involving valuation of biodiversity vary in scale and range, the disciplinary perspectives about valuing biodiversity vary.

We provide information to aid managers in understanding and responding to conflicts that arise about biodiversity as a basis for decisions when tradeoffs must be made. Even the best analytical tools cannot resolve all conflicts, but we

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believe that an understanding of the limits and benefits of analytical and other approaches will aid managers in doing their job better.

In chapter 2, we review the character of biodiversity, emphasizing the differing dimensions involved. Both because these dimensions range from genes to biologically integrated ecosystems and because management decisions must be sensitive to the differing spatial and temporal scales involved, strategies for management and conservation must be clearly defined. We have chosen only to touch on some of the more quantitative techniques available to assess the *status* of populations or habitats. We adopted this stance because the statement of task focuses on the concept of *value*: a species's status need not be linked directly to its economic value, although it might well be linked to its noneconomic value. Consideration of the challenge of applying ecological criteria, which must underlie determination of status, to the socioeconomic perspectives central to value is delayed to chapter 6. However, the complexity of their interplay is apparent in most of the case studies. Managers must be aware of the multifaceted nature of biodiversity that occurs across different spatial and temporal scales, and analyses must consider a wide range of potential alternatives and impacts.

Chapter 3 reviews some previous efforts to assign monetary values to contributions of biodiversity to society. These include instrumental values of contributions to human food, fiber, and recreation and to social and cultural well-being. The exact numbers provided cannot be transferred to contexts other than those for which they were developed. The reader must be constantly aware that many aspects of biodiversity have value and that although some values can be substantial, often they cannot be accurately captured or quantified. Managers need to be aware that values other than those specifically identified might—probably do—exist and that conflicts can arise if resource extraction is the only alternative considered.

For example, some species have long-line lineages and deserve special reverence for their long evolutionary history and what we can learn from them. Aspects of biodiversity that express our nation's history and character as distinct from our individual consumer wants do not fit easily into a formal analytical framework (such as benefit-cost analysis), but they are often of central importance to land managers. Advocates for biodiversity conservation often will be motivated by such public value concerns, which form a core part of the American social fabric that resource managers must weigh against instrumental benefits. Thus, the current political debate about values in American society is often not about prices and price shifts as much as it is about the things that Americans deem important.

The Western tradition of scholarship has offered some systematic ways of thinking about values and value conflicts. Chapter 4 describes the major systematic normative positions in philosophy. Some of these traditions offer explicit suggestions about how humans might relate to conflicts about biodiversity; in others, the application to biodiversity is less clear. This material is relevant to

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resource managers in that, although it deals with venerable traditions, they describe logical ways of thinking about value conflict. Managers must be aware that there are numerous alternative systematic and well-reasoned ways to approach the valuing of biodiversity and that each tradition suggests what should be given weight in a policy decision and how a decision should be reached. Differing policy-analysis tools implicitly or explicitly draw on those traditions and thus favor particular outcomes. Some of the conflicts faced by managers grow from the concerns of "winners" and "losers" related to different policy outcomes. But many of the conflicts result from differing traditions of thinking about value and the approaches to making decisions that follow from them. In the field of risk analysis, some literature suggests that there are shared differences between federal officials and various stakeholders in their explanations of why environmental conflicts arise (Dietz and others 1989). Obviously, differences among parties in understanding why there is conflict can impede resolution of conflict.

Given all those concerns, how is a manager to proceed? No tool or approach is likely to resolve all conflicts to the satisfaction of all parties. In chapter 5, we review some of the ways that economists assign values for improving the decision-making process, as well as their usefulness and limitations. Economic tools are generally used to estimate the effects of incremental changes, so economists tend to focus their attention on aspects of biodiversity and values in scales similar to those of markets for other goods and services. That is, economists typically direct their skills and analytical tools at decisions involving relatively small changes, such as changes in the supply and price of milk, rather than in the value of milk to the nation's overall well-being. Methods like benefit-cost analysis provide useful information, but they can rarely be the sole basis for a management decision. At the same time, by quickly identifying weaknesses, they can be helpful in eliminating some forms of undesirable options from further consideration.

Chapter 6 addresses processes that resource managers can use to determine public concerns, identify alternative management approaches, obtain information from stakeholders and the public about values related to the alternatives, and identify alternatives that best meet all needs. It provides guidance on how the valuation of biodiversity and the process of weighing values of biodiversity can be used to improve policy formulation and management decision-making.

Chapter 7 stresses that it is important for managers to have a broad perspective on how conserving biodiversity fits into their management decisions. No single suitable approach to valuing biodiversity can be recommended. As managers struggle with their difficult resource-management decisions, continued effort should be made to improve information on how management affects biodiversity, to improve the integration of the various values that are relevant to conserving biodiversity, and to improve processes for reaching consensus on management decisions.

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2

What Is Biodiversity?

Biodiversity includes not only the world's species with their unique evolutionary histories, but also genetic variability within and among populations of species and the distribution of species across local habitats, ecosystems, landscapes, and whole continents or oceans. Understanding what constitutes and defines biodiversity is essential for managers and policy-makers who must attempt to incorporate its values into their land- and water-management plans. It is only when we understand all the interacting scientific dimensions of biodiversity outlined in this chapter that we can appreciate the levels of information that must be considered. Biodiversity-management options are inevitably constrained by a combination of biological and sociopolitical realities. In this chapter, we present our biological understanding of biodiversity, which provides the basis for further chapters 3 and 4, which consider the "uses" and "value" of biodiversity.

The word *biodiversity* is used in many ways. Economists and ecologists, ranchers and gardeners, mayors and miners all view biodiversity from different perspectives. When people discuss biodiversity, they often use it as a surrogate for "wild places" or "abundance of species" or even "large, furry mammals". Yet from the viewpoint of those engaged in biodiversity-related sciences—such as population biology, ecology, systematics, evolution, and genetics—biodiversity has a specific meaning: "the variety and variability of biological organisms" (Keystone Center 1991; Noss and Cooperrider 1994; Wilson and Peter 1988). The Convention on Biological Diversity similarly defines biodiversity as the "variability among living organisms from all sources". Those definitions are so broad that they can be clearly understood only by considering particular levels of biological organization—genes, species, communities, ecosystems, and even our planet.

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Each level requires different methods of analysis, different modes of understanding, and, ultimately, different approaches to management. For managers, it is not just a matter of counting species or individuals. Managers must consider the role of biodiversity in the functioning of ecosystems and the effects of management and use of resources on ecosystem processes (chapter 3).

George Evelyn Hutchison (1965), one of the founders of modern ecology, wrote about the "evolutionary play in the ecological theater". This multilayered drama generates, sustains, shapes, and sometimes even diminishes biodiversity. Charles Darwin's reflections on species diversity underlay one of the most far-reaching theories in the history of ideas: the theory of evolution by natural selection. His travels from England to the strikingly different landscapes of the New World left him awestruck and inspired. Whatever constitutes biodiversity, Darwin recognized that Brazil had a lot of it and certainly more than he left behind in an English midwinter. No modern biologist would disagree. Like Darwin, we often equate biodiversity with the number and novelty of the species present.

SPECIES, POPULATIONS, AND GENES

There is genetic diversity within species. If each species were reduced to one small population of genetically similar individuals, we would lose much biodiversity. As we move across a region, the species change, even if the numbers of species in different places might not; a forest and an adjacent grassland might contain almost entirely different assemblages of species, for instance. Moreover, the ecosystem processes in a grassland differ from those in the forest nearby.

A population consists of individuals of the same species that live in the same place and interact in various ways, including interbreeding. Populations of the same species living in different places can exchange members, but they often are genetically differentiated to some degree and the further they are separated from each other, the more distinctive they become. Metapopulations are groups of spatially separated populations that occur in patches of habitat across a landscape. Populations can become locally extinct in different habitat patches across a landscape; they infrequently exchange members, and when they do, the passage between local populations is generally hazardous and entails movement across inhospitable habitat. Local populations that make up a metapopulation experience extinction, and habitat left open is recolonized at some finite probability by other local populations within the metapopulation.

The genetic variability among individuals within a species can result from gene recombination or mutation, genetic polymorphism (the presence of different forms of the same gene), isolation of gene pools, local selection pressures, habitat (environmental) complexity, landscape mosaics, and environmental gradients. Specific genetic combinations in populations result from natural selection acting

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on individuals in response to biotic and abiotic environments and from random, nonselective fixation of genes.

New developments in the study of molecular evolution and modern laboratory techniques make it possible to determine the degree or closeness of relationships within and between populations (Avise 1994, 1995; Hillis and others 1996). Molecular data and traditional anatomical information permit us to deduce phylogenies—the branching patterns of genealogical lineages and ancestry of sets of species (Hillis and others 1996).

GENETIC DIVERSITY AND ADAPTATION

Much genetic variation is detectable only biochemically, but some is evident as variation in anatomy, physiology, behavior, and life-history characteristics—phenotypes—of individuals in a population. Genetic variation is the basis of local adaptations and of common phenomenon of gradual change in phenotype along a geographic transect where the environment changes. Genetic variation is also the basis of coevolution, whereby species evolve adaptations in response to each other's adaptations.

There are many examples of adaptive evolution within species. Across the extensive continuous range of the common mussel off the eastern coast of North America, despite its enormous reproductive output and high rates of genetic exchange, populations are genetically differentiated over surprisingly small distances—from a few meters to several kilometers (Koehn and Hilbish 1995). The common yarrow, a composite plant from California, is able to live over a great range of habitats, from the high Sierra Nevada to the Pacific Coast, and shows distinctive, genetically determined forms in different habitats (Clausen and others 1958). *Drosophila* flies show extensive variation in genome organization according to habitat, elevation, regional geography, and seasonality (Dobzhansky 1970).

Effective environmental management includes considerations of genetic variation. For example, salmon stocks in different rivers in the same region exhibit differences in genetic makeup. These are the result of independent evolution of distinct stocks, each of which has adapted to local conditions. The differences seen reflect the histories of the stocks, some resulting from local selection pressures and others from the accumulation of random changes associated with the degree of isolation and population size.

Genetic diversity provides an economic basis for protecting and conserving biodiversity (McNeely and others 1990; Oldfield 1984; Potter and others 1993; Reid and Miller 1989; Reid and others 1993; WRI/IUCN/UNEP 1992). For example, Douglas fir trees grow abundantly across the western United States. Their success is due to their diversity despite their similar appearance (Rudolph 1990). Coastal and interior populations show genetic differences in cold hardi-

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ness, response to moisture stress, and timing of bud bursts. There are also genetic differences between populations only 3–10 km apart that are exposed to different microclimates on north-facing and south-facing slopes. Moreover, genetic variability results in the continued production of diverse phenotypes, some of which are more able than others to resist attacks by western spruce budworm, an important pest for this species. Commercial nurseries make use of local variation in reforestation programs.

Current adaptations are important, but genetic diversity is also critical for the future resilience and persistence of natural systems. Variation is important to maintain a population's ability to respond to changing environmental conditions, whether natural or anthropogenic. A notable example is the rapid adaptive evolution of plants that have colonized mine tailings that are polluted by heavy metals in Great Britain (Antonovics and others 1971). This represents natural evolutionary potential, which can be particularly important in the face of rapid global change.

For managers of biodiversity, there are practical implications in the observations that some species have many locally distinct populations but others show little geographic variation and that some species have no close relatives but others occur in genera that include hundreds of species. Biologists have recognized that current taxonomy (the classification of organisms on the basis of the evolution of species from their ancestors) is sometimes inadequate for identifying appropriate units for conservation. They have recommended counting "evolutionarily significant units" (ESUs) (Moritz 1994; NRC 1996), historically isolated parts of species that, in addition to representing divergence and diversification in the past, can have direct evolutionary potential. Focusing on ESUs has the goal of ensuring that evolutionary heritage is recognized and protected.

MEASURES OF DIVERSITY

One of the decisions that managers face is how to assess biodiversity. How do we know whether biodiversity has changed? Scientists use different methods to assess biodiversity.

Biodiversity among areas can be compared with statistical indexes of species diversity (Magurran 1988; Pielou 1975). Most indices combine two different metrics: the total number of species and the relative abundances of all species (evenness) in a sample. Such indexes have been criticized on the grounds that similar values of an index might reflect quite different sample compositions. A given index value could reflect a high species richness (a large number of species, many of them rare) or could be attributed to many fewer but commoner species (for example, high relative abundance of many species).

The simplest measure of diversity, the number of species in a given area, is called within-area diversity or, technically, alpha diversity. Ecologists generally

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call this measure species richness; they imply no economic value by using *rich* or its opposite, *poor*. Only their presence (not their abundance) is taken into consideration in counting the number of species in an area.

Species counts are the most visible and most widely known measures of biological diversity. Tourists visit Costa Rica in part because its forests are so rich in bird species and its marine reefs are so rich in corals and fishes (see Costa Rica case study below). The biodiversity of the Camp Pendleton region in southern California includes 345 vertebrate species, a high level that constitutes a large percentage of all terrestrial vertebrates in that richly diverse state (chapter 1). The preeminence of the species as the central unit of biodiversity is explicit in the Convention on Biological Diversity (Heywood 1995; UNEP 1992) and the UN Environment Program's Explanatory Guide to the Convention (Glowka and others 1994). Although simple species-per-area statistics are useful, there are caveats:

- Species counts are rarely complete.
- Counts depend in complex ways on the area surveyed and how the survey was conducted.
- Counts of individual species might need to be weighted by their abundances, percentage covered, or mass.

Surrogate measures of biodiversity, such as the numbers of genera (the taxonomic category directly above the species in the Linnean hierarchy) or even higher taxa (such as families), have been used. These can be effective when taxonomy accurately reflects underlying relationships and includes the descendants of a common ancestor, but systematists recommend that such approaches be treated with care and considered to be only interim stages in the development of a deeper understanding of biodiversity.

If phylogenetic analyses are available, it can be useful to estimate the number of lineages present to take into consideration uneven species representation. For example, 20 species of lizards might represent only three main lineages in one area, but 15 in another. Such information might be used to identify a focus of active evolutionary diversification in the first case and the survival of ancient lineages in the second. Such tentative conclusions gain force if additional instances of coexisting taxa are found.

Case Study: Costa Rica

Costa Rica, a small country with high biodiversity, has been pioneering new conservation methods and creating a new biodiversity-conservation ethic by recognizing that its wildlands and biodiversity are among its most important economic assets. The nongovernment Instituto National de Biodiversidad (INBio) has been established to inventory the biodiversity in the country; identify new

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uses of biodiversity for education, industry, and science; and contribute information (and financial resources earned from the economic development of biodiversity) to the conservation of biodiversity in established conservation areas. For decades, Costa Rica has also been the focus of considerable ecological research that has helped to create the knowledge base for the conservation and use of biodiversity.

The country's protected areas and wildlands contribute important economic benefits to the nation, including water and electricity, tourism, and scientific research. A growing economic contribution of wildlands involves trade in biochemical and genetic resources for use in the pharmaceutical and biotechnology industries (discussed further in chapter 3). Costa Rica has long been a source of material used for natural-product screening by industry, but samples were typically sold at relatively low prices with no provision for royalties. INBio is now involved in biodiversity prospecting in an effort to earn greater revenues that can be channeled back into conservation.

A typical contract between INBio and a pharmaceutical firm might involve an agreement to provide 1,000 samples with a 3% royalty if a discovery is made. In view of the small likelihood of finding a commercial product, the time required for product development, and the lifetime of the patent on the final product, the net present value of such an agreement would amount to roughly $50,000–$500,000, comparable with the traditional spot-fee up-front payments for samples of $100–$200 each) (Reid and others 1993). Pearce and Moran (1994) calculate that the value of tropical forest land for medicinal plants ranges from $0.01 to $21 per hectare. Thus, although the use of land as a source of medicinal plants might not justify conservation in its own right, medicinal values can add to the overall stream of economic benefits from the protection of wildlands.

The combined annual economic contribution of wildlands to Costa Rica's gross domestic product (GDP) for watershed protection, ecotourism, scientific research, and biodiversity prospecting is in the range of $87–200 million. Most of the contribution is attributable to tourism and protection of the electricity-generating capacity of the country. Costa Rica's wildlands might eventually contribute even more than this sum to the economy because of their carbon-sequestration potential. Under the Framework Convention on Climate Change, countries might eventually benefit economically from steps that they take to reduce rates of carbon emissions from deforestation. Costa Rica has already received "carbon offset" grants from US companies in return for actions to protect these areas from deforestation, and at $5–$10 per ton of carbon the value of the country's standing forest might be substantial. The current economic contribution of Costa Rica's wildlands can be compared with agriculture's contribution of $864 million in 1989 (GCR 1990) from twice the land area size of the country's protected areas. Even though the average contribution to GDP per unit area of agriculture exceeds that of wildlands, maintenance of wildlands is often the more economically attractive option for the specific soil and ecological conditions in

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much of the country. With growing evidence of the economic importance of wildlands and protected areas—and growing understanding that the most economically valuable use of many of these regions is as wildlands—the country is now seeking to enhance the economic benefits from the natural systems and to establish mechanisms whereby the benefits can serve as incentives for conservation.

Species Counts Might Not Be Representative

For many groups of species (such as nematode worms, mites, and aquatic fungi), what we know for certain is only that we do not know many, perhaps even most of the species. Consequently, we can measure species numbers for some but not all of the species in an area. Only for a few regions do we have even partial inventories of the species present. For example, an inventory of fungi, lichens, bryophytes, vascular plants, mollusks, arthropods, amphibians, mammals, fishes, and birds has been done for the Pacific Northwest, where controversy rages over the old-growth forests, but the effort is incomplete because of variation in our knowledge of different groups. We know all the birds and mammals, but our knowledge of insects and fungi is far from complete. Even that example is exceptional because of the large number of species and groups that were inventoried.

Measures of species numbers are usually just counts of easily observed or identified species. Costa Rican forests are rich in birds, but whether the forests are relatively rich in other species—fungi, for example—is unknown. Areas rich in one group of species are often rich in another, but not always. Remote islands might have many bird species but few or no mammals or amphibians.

Species Counts and the Area Counted

Larger areas contain more species than smaller areas; the United States has more species (of everything) than does the state of Tennessee. However, the number of species does not increase in simple proportion to the area. An area, that is half the size of another area, might have 85% of the larger area's species. Consequently, we cannot use the number of species per unit area as a biodiversity measure without understanding the biological context. Thus, equally perhaps, when we conclude that Costa Rica or riparian habitats within western US rangelands are diverse (see the western rangelands case study in chapter 1), we mean that they are richer in species than other areas of similar size.

ENDEMISM AND DIVERSITY ACROSS SPACE

As we move across a region, the species composition might change greatly even though the species numbers might not. This change in species in a region is an important measure of diversity in its own right. We call the difference in

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composition between-area diversity, or beta diversity. The various ways of measuring such diversity all arise from this insight: two adjacent environments might both contain 10 species, but the number they share could range from 0 (when beta diversity is highest) to 10 (when beta diversity is lowest—zero).

Endemics are the species that are prevalent in or peculiar to an area. The greater the fraction of endemics areas hold, the greater the between-area diversity as we cross its boundary. Endemism and between-area diversity are also related to the typical size of a species range. The smaller the typical range, the more quickly one moves from an area with one set of species to an area with another set.

Areas differ greatly in endemism. All the forests of eastern North America hold 160 species of birds, and the tropical forests of Hawaii once held about 130 species. Hawaii's breeding species were fewer than eastern North America's but were all endemic and had small ranges. Fewer than 25 of eastern North America's birds are endemic (Pimm and Askins 1995). The distinctiveness of an area's flora and fauna leads to several concerns of managers: why some areas with few species contribute greatly to biodiversity, why endemic species contribute so much to biodiversity, and why some species in some places contribute nothing to regional or global biodiversity.

An area's endemic species dominate discussions of protecting biodiversity because it is the loss of these species that causes a global loss of species diversity. Usually, endangered species are endemics with small ranges (Collar and others 1994; Pimm and others 1995). Few endangered species are rare over very large areas. However, many species with formerly wide geographical distributions—such as the grizzly bear, mountain lion, leopard, bald eagle, and peregrine falcon—have become endangered because of severe habitat loss, persecution, and widespread use of pesticides. Thus, concerns about biodiversity at Camp Pendleton (see case study in chapter 1) focus on the several species, such as the California gnatcatcher, now found only or almost only there.

The concern about endemics means that there can be conflicts between measures of local versus regional diversity. For example, across much of the eastern United States, the fragmentation of once-continuous tracts of forest has led to a local increase in species via the invasion of widespread open-area species, such as cowbirds, bobwhite quail, and white-tailed deer. Forest managers and wildlife managers (Dasmann 1964; Giles 1978; Leopold 1933), once viewed the creation of openings in continuous forest as important for increasing game-species productivity and non-game-species diversity (biodiversity). Earlier editions of the wildlife-managers handbook published by the Wildlife Society (Giles 1969; Mosby 1960, 1963; Schemnitz 1980) considered the development of forest edges to be an important management tool. Those recommendations have been deleted in the latest edition (Bookhout 1994). A forest edge might have a higher number of species per unit area, but these are generally common and widespread species. The creation of forest edges and fragmentation by logging eliminates the continuous habitat required by forest interior species, such as ovenbirds, worm-eating

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warblers, and waterthrushes. Therefore, although edges can increase local diversity, it constitutes as a loss to regional and global biodiversity. It has long been known that birds could be classified as forest interior or edge species (for example, Kendeigh 1944), but it has only recently been appreciated that edges create biological and physical environments that can be detrimental to some species. Birds have been particularly well-studied in this context, and edge habitats have been shown to contribute to increased nest predation and cowbird brood parasitism (for example, Böhning-Gaese and others 1993; Robinson and others 1995; Terborgh 1989).

Humanity has both deliberately and accidentally introduced species worldwide. Obviously, introductions of nonindigenous species—that is, plants, animals, and microorganisms in areas outside their natural geographical ranges (OTA 1993) can add nothing to global biodiversity. Replacing a region's endemic species with species that are more widespread can increase biodiversity locally, but it also reduces between-area diversity by homogenizing global flora and fauna. The mediterranean regions are an excellent example: introduced grasses and forbs can increase diversity at the local level, but they generally reduce biodiversity in western rangelands (see the case study in chapter 1).

Introduced species can also be seriously harmful. Some introduced trees have reduced large areas of the Everglades nearly to single-species stands and have correspondingly endangered native species (see the Everglades case study in chapter 3). According to the 1993 report of the Office of Technology Assessment (p 5),

> approximately 15% of the nonindigenous species in the United States cause severe harm. High-impact species—such as the zebra mussel, gypsy moth, of leafy spurge (*Euphorbia esula*) (weed)—occur throughout the country. Almost every part of the United States confronts at least one highly damaging nonindigenous species today. They affect many national interests: agriculture, industry, human health, and the protection of natural areas. . . . Harmful nonindigenous species cost millions to perhaps billions of dollars annually.

Introduced species, of course, can be beneficial. Very few of the foods we grow are endemic to the United States. Virtually all other crops are nonindigenous. Many introduced species—such as Kentucky bluegrass and wisteria—come to be perceived by some people as occurring naturally in a region. Some people believe that other nonindigenous species, such as the green crab in waters near Martha's Vineyard, detract from the integrity of the environment.

Regardless of these examples of beneficial effects of introduced nonindigenous species, the adverse effects of nonindigenous species on endemics have resulted in their being one of the leading causes of global extinctions (Nott and others 1996; Pimm and others 1995). According to Norse (1993), the other causes are overexploitation, physical alteration of habitat (including habitat destruction and degradation), pollution, and global atmospheric changes.

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LANDSCAPES AS BIODIVERSITY

In many discussions, *biodiversity* refers to “a diversity of landscapes”. We consider a region that contains both grassland and forest to be more diverse than one that contains only grassland. It is the mixture of ponderosa pine savannas, grasslands, wetlands, and riparian woodlands that gives Boulder, Colorado, its diverse environment (see the Boulder case study in chapter 3). Camp Pendleton has not only a large number of threatened and endangered species, but also a diversity of marine, estuarine, riparian, and terrestrial “habitat types” (see the Camp Pendleton case study in chapter 1). Costa Rica (see the case study this chapter) has many more life zones than an area of comparable size (for example, West Virginia) in eastern North America.

Terms like *grassland* and *forest* denote different associations of species. Grassland and forest edge have high between-area diversity. Boundaries between associations often correspond to obvious physical differences in the environment and differences in ecological processes, such as nutrient cycling. The use of landscape terms to describe biodiversity raises three questions for managers to deal with:

- How do we classify landscapes?
- How do landscapes differ with respect to ecosystems and ecosystem processes?
- What linkages exist between ecosystem processes across diverse landscapes?

The term *association of species* is deliberately vague. Ecologists apply it to areas (with the sets of species they contain) that range from a few square meters to continents. On the largest scale, we refer to tundra, coniferous forest, deciduous forest, grassland, savanna, desert, tropical rain forest and so on. Ecologists call these major regions *biomes*. On smaller scales, Noss and Peters (1995) classify and identify the endangered “ecosystems” of the United States. By ecosystem they mean distinct assemblages of plants and animals. For example, naming an ecosystem “Florida scrub” is a statement of the likelihood that we will find a set of plant and animals widely across this ecosystem. In addition, the species typically will be different from those in other ecosystems. On an even smaller scale, we have finer divisions of environments variously called habitats, associations, communities, and biotopes.

When sufficient data are available, formal statistical procedures enable a manager to recognize a biome, landscape, ecosystem, habitat, biotope, or other ecological association. The procedures group smaller areas into larger divisions according to the principle that species are similar within and different between those divisions (Hengeveld 1990; Pielou 1975). For most of the cases, the recog-

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nition of divisions is informal, often with reference to an expert or general guide; such informality does not deny the utility of the divisions.

In the 1880s, C.H. Merriam, one of the great natural historians of the West, characterized the biodiversity of northern Arizona and mapped it into seven "life zones" on the basis of altitudinal bands of temperature and the appearance of the vegetation. Merriam's classification preceded formal vegetation surveys and statistical analyses. Nonetheless, his classification retains its utility as a broad guide to where to find plants and animals and where the boundaries between their distributions will likely lie. On a much finer scale, the conspicuous zonation of intertidal rocky shores provided the initial motivation for studying near-shore marine ecosystems (Gilsen 1930).

Grassland and *forest* clearly do more than refer to the similarity of species within and the differences between associations. A grassland, like any other environment, has its own typical set of ecological processes, and these might be different qualitatively and quantitatively from those in the nearby forest. The plants in grasslands, for example, might be adapted to frequent fires; indeed, without fires, trees might invade and forest take over. In contrast, the dominant ecological processes in a lake might be related to the nature of the nutrient effects inputs from surrounding areas. Sometimes the threats to biodiversity are the human impacts on natural ecosystem processes, such as changes in the hydrology and fire regimes of the Everglades (see the case study in chapter 3).

Biodiversity on the landscape scale involves more than the mosaics that differ in composition (such as forest versus grassland). It also includes the connections and dynamics between and among patches and their implications for the functioning of ecosystems (Turner and Gardner 1991). Connections can occur through the flow of water, energy, materials, or organisms. For example, water moves through upland to riparian and wetland areas and then to streams, carrying with it dissolved nutrients. The accumulation of water in wetland or riparian areas leads to soil saturation, decomposition by anaerobic pathways, dominance by different plant and microbial species, and substantial effects on the chemistry of streams. Nitrogen fertilizer that is leached from upland agricultural systems can be taken up and retained by riparian plants or denitrified to nitrogen gas in soils (Hedin and others 1998; Peterjohn and Correll 1984, 1986). In either case, the maintenance of landscape diversity controls the overall exchange of nutrients between terrestrial and aquatic ecosystems.

On a coarser scale, the seasonal movement of migratory birds between tropical and temperate ecosystems connects these otherwise independent biomes (see Everglades case study, chapter 3). This flow of organisms requires that managers in each region consider the dynamics of the other region in their analyses. By its very nature, biotic exchange over long distances implies a lack of independence.

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SPECIES ARE HISTORIES

Each species has a unique history. Species are the result of evolution(descent with modification (Darwin 1859) or "accumulated history" (Salthe 1972, 1985). Species contain the history of the lineage that they represent, just as humans carry the history of their ancestors. The concept of lineage is central to the imagery of evolution. Equally central is the notion of relationship: some lineages are more closely related than others, in the sense that they shared an ancestor more recently. Systematists now have well worked-out concepts of affinity, methods, and techniques for assessing degree of phylogenetic relationship and for reconstructing pieces of the history of life on Earth.

Some taxa are of special interest because of their evolutionary relationships. For us, the chimpanzees, gorillas, and orangutans have special value as "kin". In the Galapagos, Darwin's finches are closely related species that serve as a living example of evolutionary diversification in action. Their special value stems from what the studies of them have contributed to intellectual history. Hawaiian honeycreepers are even more deeply differentiated, and they show a varied adaptation that makes them a special object of study. On another scale, closely related beetles remind us that South America and Africa were once the supercontinent Gondwana; their common heritage is evident despite about 100 million years of geographic separation (Pitman and others 1993).

Other taxa gain special value not as a result of their close evolutionary relationships but because they are distantly related to other groups. In the tree of life branches have different lengths. Long branches represent early divergences now lacking close relatives. Some well-known examples are the platypus and echidnas of Australia. The sole living representatives of the monotremes, a long-branch taxon that is the sister-group of all other living mammals. A sister group is the closest genealogical relative of a given taxon, exclusive of the ancestral species of both taxa (Wiley 1981). The mountain beaver of the Pacific Northwest is a long-branch taxon. It is the sister-group of all the family Sciuridae (the squirrels and relatives) or perhaps even of all rodents (the largest of the mammalian orders) and might date back 40 million years as a separate lineage.

Often several or many long-branch taxa occur in the same region (Morrone and others 1996). Biologists believe that regions with long-branch taxa have a high probability of including additional, as yet unknown or unstudied, taxa. Thus, regions where long-branch taxa occur have special significance as biodiversity-conservation areas. The forest region of the Pacific Northwest harbors the tailed frog (the single species of the endemic family Ascaphidae, about 100 million years old and the sister group of all other roughly 4,500 species of frogs), the torrent salamanders (an endemic family of four species, distantly related to all other salamander taxa), the Pacific giant salamanders (the endemic family Dicamptodontidae, the sister group of the well-known ambystomatid salamanders), and a number of insects. The torrent salamanders house a long-branch

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taxon of monogenean trematode parasites, and the mountain beaver is home to the world's largest flea, itself a long-branch taxon. The redwood and sequoia trees are sister species that form a long-branch taxon. They are distantly related to the dawn redwood of China, which is extinct in the wild but was preserved in Chinese monasteries and is itself a long-branch taxon.

BIOLOGICALLY BASED RANKING AND RATING METHODS

Biologists assess the importance of conserving biodiversity in various ways. Some are based on conserving species, others on maintaining community or ecosystem functions.

From the perspective of the field of biological systematics, species do not all have equal value when it comes to biodiversity maintenance and conservation. Several approaches have been used to assign such value. One can use a generalized hierarchical approach, working along a genealogical to phylogenetic continuum from genetically distinct sister populations to groups at various taxonomic levels. Populations of a species that vary geographically in degree of genetic distinctiveness would have greater value than populations of a species that are genetically more uniform. Similarly, with respect to a given protected species, a related species that is more distinct genetically would have greater value than one that is only slightly different. That kind of ranking can be used in a phylogenetic ranking of taxa; species that are phylogenetically increasingly remote would have increasing value because the goal is to maintain the greatest amount of biological diversity. The method can be made precise when sufficient information on relationships is available (Faith 1994). With such a scheme, long-branch taxa have the greatest value.

That scheme can be combined with habitat, community, ecosystem, and geographic (bioregion) approaches. A habitat or region that has several long-branch taxa is more valuable for biodiversity maintenance than one that has none or only one. In contrast, one might choose to focus on a region that is relatively poor in long-branch taxa because many factors go into valuation, and pragmatic concerns or special interest in a species might force decision-making. When this happens, it is wise policy to identify a rationale underlying the decision.

Another consideration in biodiversity maintenance is the geographic distribution of a species. In general, species that are widely distributed require less attention than species that are narrowly distributed, although that widely distributed species that have low population density might be of more concern than an endemic that is well protected and in good demographic condition.

The components of biodiversity are hierarchical and intricately linked. For example, the genetic variability within a species is related to their continued adaptation and evolution in the face of biological, physical, and chemical changes. A variety of species in an ecosystem might increase productivity and stability. The pattern of ecosystems on the landscape influences energy flow, nutrient

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cycling, and population movements. The value of agricultural or forest productivity is undeniable, but its intrinsic relationship to soil microbial processes, hydrological and atmospheric cycles, pollinators, and pest predators is largely unknown and unappreciated by most sectors of society. Chapter 3 discusses the values of biological components in detail.

Given that funds for conservation are limited, how should they best be allocated to ensure the most efficient conservation of biological diversity? That question confronts decision-makers in institutions as varied as government departments responsible for protected areas and nongovernment organizations, such as The Nature Conservancy. Typically, the answer involves setting priorities for habitat or ecosystem conservation; and this, in turn, requires assigning relative values to the areas under consideration for protection. Although ultimate decisions of which habitats or ecosystems will be protected might be influenced by considerations of the cost of protecting various sites or assessments of the likely threat to a site in the absence of protection, the initial ranking of sites should be based on biological criteria.

No approach to priority-setting can serve all biodiversity-conservation objectives. For example, one logical goal of conservation would be to conserve both the greatest diversity of species and the greatest diversity of natural habitats. Consider two hypothetical ecosystems, one with 1,000 endemic species and one with 10. If sufficient money were available to protect two 1,000-hectare sites, where should they be. Locating both in the species-rich site would protect far more species but would sacrifice the protection of unique habitats. Placing one conservation site in each ecosystem would protect the diversity of ecosystems but with a tremendous loss of species diversity. There is no scientifically based means of comparing the value of a “unit” of habitat protection with a “unit” of species protection, so there is no single solution to the problem.

Biological value is assessed with reference to five basic criteria:

- Richness, the number of species or habitats in a given area. A region with more species or habitats per unit area is given higher value than a region with fewer. Thus, tropical forests, with their high number of species, are often seen as having higher conservation priority than adjacent tropical dry forests which are slightly less rich in species.
- Endemism, the narrowness of the distribution of the species in an area. A region with many endemic species is given higher value than a region with fewer. Thus, Madagascar, some 80% of whose plant species are found nowhere else, has higher conservation priority than a region with a lower proportion of endemic species.
- Rarity of species or habitats in a region. A region with rare species or habitats is given higher value than a region with abundant ones. Thus, wetlands in arid regions are given higher value than wetlands in temperate regions.
- Ecosystem services, the importance of the natural habitat, or resident

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single species capable of influencing ecosystem function (see chapter 3) for various services of importance to humans. Thus, a forested watershed that is the source of public water is seen as having higher conservation value than one that is not.

• Protected status and representation, the relative protection of the species or ecosystem that already exists. Protection of an ecosystem that is not yet represented in a system of protected areas is given higher value than one that is.

Some examples of the use of biological ranking methods are discussed below.

Rare Species and Habitats

The Nature Conservancy's method for ranking "elements of natural diversity" is the best-known example of a valuation approach that is based primarily on the rarity of and threat to species and biological communities. The conservancy obtains information about the known or estimated numbers of subpopulations, the estimated numbers of individuals, the narrowness of ranges and habitats, trends in population and habitat, threats, and fragility, and then it assigns a rank of 1–5 (with 1 representing extreme vulnerability) (Johnson 1995). It then focuses its habitat-acquisition efforts on areas that have more rare and imperiled species.

In addition, a variety of quantitative tools permit a population's status or viability to be assessed or a habitat's ecological importance to be determined. Box 2-1 classifies and lists some of these techniques as a quick guide for a manager seeking widely available literature relevant to some local and pressing situation.

Representative Biological Communities

The 1982 World Conservation Union Bali Action Plan (McNeely and Miller 1984) called for the establishment of a worldwide network of national parks and protected areas covering all terrestrial biogeographic regions, and it set a target of protecting at least 10% of each bioregion. The union later conducted a series of systematic regional reviews to identify gaps in protected-area coverage, with emphasis on ensuring representative coverage of protected areas. Other international efforts, such as the UNESCO Man and the Biosphere Program, also have chosen to emphasize representative coverage of protected areas in their conservation priority-setting. By the late 1980s, about 15 of some 227 biogeographic provinces still had no protected areas, and 30 had five or fewer areas that encompassed less than 1,000 km^2 (Reid and Miller 1989).

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BOX 2-1
Quantitative Tools to Assess Biological Importance

Category	Reference
Population Status and Viability Analyses	
Minimum viable populations	Gilpen and Soulé 1986; Goodman 1987; Harris and others 1987; Soulé 1987
General	Ballou and others 1995; Boyce 1992; Ruggiero and others 1994; Shaffer 1980; Soulé 1987
Plants	Menges 1990, 1998; Schemske and others 1994
Animals	Groom and Pascual 1998; Lamberson and others 1992; Reed and others 1988
Landscape Design Issues	
Metapopulations	Gilpin and Hanski 1991; Hastings and Harrison 1994; Hanski and Gilpin 1997; McCullough 1996; Tilman and Kareiva 1997
Ecosystem fragmentation	Andrén and Anglestam 1988; Delcourt and Delcourt 1992; Forman 1995; Harris 1984; Lynch and Whigham 1984; Murcia 1995; Saunders and others 1991; Schwartz 1997; Shafer 1990; Robinson and others 1995; Turner and Gardner 1991; Wahlberg and others 1996; Wilcox and Murphy 1985; Yahner and Scott 1988
Habitat corridors (connectivity)	Adams and Dove 1989; Beier and Noss 1998; Forman 1995; Forman and Gordon 1986; Hudson 1991; Mackintosh 1989; Simberloff and others 1992
Population sources and sinks	Donovan and others 1995a, b; Howe and Davis 1991; Pulliam 1988, 1996; Pulliam and Danielson 1991; Trine 1998
Species Introductions	
Nonindigenous species	Brothers and Spingarn 1992; Drake and others 1989; Mooney and Drake 1986; Parker and Reichard 1998; Ruesink and others 1995
Harmful species	OTA 1993
Reserve Locations	
Rare species and biodiversity hot spots	Bedward and others 1992; Forey and others 1994; Gaston 1994; Groombridge 1992; Johnson 1995; Myers 1980, 1988, 1990; Prendergast and others 1993; Reid 1998; Wilson 1992
Siting decisions	Andelman and others in press

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Species Richness and Endemism

A number of priority-setting systems focus on the protection of areas that are particularly rich in species or that have many endemics. For example, Myers (1989) identified 10 "hot spots" that deserved conservation emphasis—tropical forest areas with high species richness and relatively high endemism that also faced exceptional degrees of threat from human activities. The list was expanded to include eight additional regions—four in the humid tropics and four in Mediterranean-type habitats (Myers 1990). Myers estimates the number of plant species in a region and the percentage of those species that are endemic, evaluates the threat of habitat loss for the region, and then ranks highest regions with large numbers of threatened endemics on relatively small areas.

Birdlife International has followed a similar approach, identifying regions that have relatively high numbers of bird species with restricted ranges (less than 50,000 km^2). In all, 221 "endemic bird areas" have been identified and are being emphasized as a focus for conservation action (Johnson 1995).

The Maintenance of Biodiversity and Ecosystem Services

The preceding sections have focused on the varied definitions of biodiversity, how it is related to landscape-scale patterns, its genetic basis, and its evolutionary origin and significance. Those descriptive accounts identify what biodiversity is; they do not address how it is maintained or influenced by specific interactions or what the role of species—individually or collectively—might be in ecosystem functioning. These are developed more fully in chapter 3.

The role of ecological interactions in influencing whether species can coexist locally has been recognized at least since the time of Darwin (1859), who showed that a clipped grassy plot harbored more species than an undisturbed one. Since then, an extensive literature has developed the theme that various interactions can influence the genetic structure and morphological appearance of local populations (Tollrian and Harvell 1999), the probability of species coexistence (Paine 1969), and the biological structure and function of entire freshwater assemblages (Brooks and Dodson 1965; Carpenter and Kitchell 1993; Werner 1986). Probably all known taxa, ranging from pathogens to (especially) humans, are involved in this interactive natural world. The dynamic relationships and their immediate and long-term consequences obviously influence the determination and evaluation of species diversity patterns.

The locally resident species also affect considerations of ecosystem function. For instance, these are increasingly factored into conservation priority-setting, particularly with regard to the protection of water quality.

Many countries have forest policies that require the protection of forested buffers along rivers and streams to reduce siltation and protect the rivers from changes in water temperature. In some cases, protected areas have been estab-

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lished in watersheds specifically to protect the quality of the water supply of an urban area or to protect dams from siltation. The management implications of changes on local species composition and therefore probably richness and of its capacity to alter ecosystem function are developed in chapter 3 in the Everglades case study and the section *Ecosystem Services*, and in chapter 6 in the Lake Washington case study. Nature is complex and highly interactive: management decisions increasingly consider the totality of the biological matrix; no species lives in isolation, and changes in one are certain to affect the ecological and evolutionary continuity and the performance of others and of the assemblage in which they are imbedded.

SUMMARY

Biodiversity includes not only the world's species with their unique evolutionary histories, but also genetic variability within and among populations of species and the distribution of species across local habitats, ecosystems, landscapes, and whole continents or oceans. Because biodiversity is such a broad concept, methods for its quantification are necessarily broad. In this chapter, we have attempted to define the components of biodiversity and to describe some of the ways to measure them. In the following chapters, case studies illustrate management decisions driven by various concepts of what biodiversity is or does. For instance, aesthetic considerations were influential in the preservation of open spaces in Boulder, CO (chapter 3), whereas water quality issues motivated the restoration of Lake Washington (chapter 6). The Everglades case study describes a major federal project in which biodiversity itself and habitat restoration were the primary considerations (chapter 3). Given such variation in mission, managers must consider both the maintenance of viable local populations of species of interest and the maintenance of biodiversity on larger scales, which is essential for the functioning of ecosystems. This chapter has addressed the many components of biodiversity that managers need to consider; the next chapter extends our understanding of how people value the components of biodiversity. Throughout the report, case studies illustrate management decisions that were based on the varied biodiversity components.

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3

The Values of Biodiversity

The individual components of biodiversity—genes, species, and ecosystems—provide society with a wide array of goods and services. Genes, species, and ecosystems of direct, indirect, or potential use to humanity are often referred to as "biological resources" (McNeely and others 1990; Reid and Miller 1989; Wood 1997). Examples that we use directly include the genes that plant breeders use to develop new crop varieties; the species that we use for various foods, medicines, and industrial products; and the ecosystems that provide services, such as water purification and flood control. The components of biodiversity are interconnected. For example, genetic diversity provides the basis of continuing adaptation to changing conditions, and continued crop productivity rests on the diversity in crop species and on the variety of soil invertebrates and microorganisms that maintain soil fertility. Similarly, a change in the composition and abundance of the species that make up an ecosystem can alter the services that can be obtained from the system. In this chapter, we review the types of goods and services that mankind obtains directly and indirectly from biodiversity and its components.

Biodiversity contributes to our knowledge in ways that are both informative and transformative. Knowledge about the components of biodiversity is valuable in stimulating technological innovation and in learning about human biology and ecology. Experiencing and increasing our knowledge about biodiversity transform our values and beliefs. There is a fairly large literature characterizing nonextractive ecosystem services with direct benefit to society, such as water pollution and purification, flood control, pollination, and pest control. In addition, such services in biophysical and economic terms characterize the institutional mechanisms needed to generate incentives for their preservation (Daily

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1997; Missouri Botanical Garden forthcoming). In this chapter, we review the types of social and cultural values associated with knowledge of biodiversity. We use those values in chapter 4 to discuss how they can contribute to decisions on management of biodiversity.

BIOLOGICAL VALUES

The components of biodiversity are the source of all our food and many of our medicines, fibers, fuels, and industrial products. The direct uses of the components of biodiversity contribute substantially to the economy. In 1989, US agriculture, forestry, and fisheries contributed $113 billion[1] to the US gross domestic product (GDP), equal to the contribution of the chemical and petroleum industries combined (DOC 1993). The full contribution of biodiversity-related industries to the economy is higher still, in that it includes shares of such sectors as recreation (see Everglades and Boulder, Colo., case studies in this chapter and Lake Washington case study in chapter 6), hunting (see Quabbin Reservoir case study in chapter 6), tourism (see Costa Rica case study in chapter 2), and pharmaceuticals.

The economies of most developing countries depend more heavily on natural resources, so biodiversity-related sectors contribute larger shares of their GDPs. For example, the sum of the agriculture, forestry, and forest-industry products in Costa Rica in 1987 accounted for 19% of the nation's GDP (TSC/WRI 1991), whereas these sectors accounted for only 2% of the US GDP (DOC 1993). The relatively small direct economic contribution of biological resources in the two countries illustrates the difficulty of "valuing" biodiversity. The small fraction of the value of these ecological systems that is accounted for in US economic ledgers contrasts starkly with the fact that our survival depends on functioning ecological systems. At the same time, our limited ability to value ecological systems parallels our limited appreciation of our dependence on these systems. The imperfections of our knowledge are seen in the $200 million Biosphere 2 trial—in the unsuccessful attempt to house eight people for 2 years in an ecologically closed system. Cohen and Tilman (1996) concluded that "no one yet knows how to engineer systems that provide humans with the life-supporting services that natural ecosystems produce for free."

Biodiversity in Domesticated Systems

Humans rely on a relatively small fraction of species diversity for food. Only about 150 species of plants have entered world commerce, and 103 species

[1] This measure and measures that follow in the chapter are very general indications of monetary values associated with various aspects of biodiversity. They are calculated in different ways and have different bases for calculation. Care should be taken in comparison.

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account for 90% of the supply of food plants by weight, calories, protein, and fat for most of the world's countries (Prescott-Allen and Prescott-Allen 1990). Just three crops—wheat, rice, and maize—account for roughly 60% of the calories and 56% of the protein consumed directly from plants (Wilkes 1985). Relatively few species that have not already been used as foods are likely to enter our food supply, but many species now consumed only locally are likely to be introduced into larger markets and grown in different regions. For example, the kiwi fruit was introduced into the United States as recently as 1961; within 20 years, US sales had grown to some $22 million per year (Myers 1997).

Although relatively few species are consumed for food, their productivity in both traditional and modern agricultural systems depends on genetic diversity within the species and interactions with other species found in the agroecosystem. Claims that such biodiversity "archives" can serve as substitutes for biodiversity in natural habitats are more fanciful than factual. Genetic diversity provides the raw material for plant breeding, which is responsible for much of the increases in productivity in modern agricultural systems. In the United States from 1930 to 1980, plant breeders' use of genetic diversity accounted for at least the doubling in yields of rice, barley, soybeans, wheat, cotton, and sugarcane; a threefold increase in tomato yields; and a fourfold increase in yields of maize, sorghum, and potato. An estimated $1 billion has been added to the value of US agricultural output each year by this widened genetic base (OTA 1987). Breeders rely on access to a wide range of traditional cultivars and wild relatives of crops as sources of genetic material that is used to enhance productivity or quality. Different landraces can contain genes that confer resistance to specific diseases or pests, make crops more responsive to inputs such as water or fertilizers, or confer hardiness enabling the crop to be grown in more extreme weather or soil conditions.

Much of the genetic diversity available for crop breeding is now stored in a network of national and international genebanks administered by the UN Food and Agriculture Organization, the Consultative Group on International Agricultural Research, and various national agricultural research programs, such as the US Department of Agriculture's National Seed Storage Laboratory in Fort Collins, Colorado. The value of these genebanks for agricultural improvement is substantial. For example, in a presentation to this committee,[2] Evenson and Gollin estimated the present net value of adding 1,000 cataloged accessions of rice landraces to the International Rice Research Institute's genebank at $325 million (on the basis of empirical estimates that these accessions would generate 5.8 additional new varieties, which would generate an annual $145 million income stream with a delay of 10 years). As important as they are in agriculture,

[2] Presentation to the full committee at its October 1995 workshop, "Issues in the Valuation of Biodiversity," by Robert Evenson, Yale University.

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genebanks, and other in situ collections (cyropreserved and in zoos) are viable only for a very narrow array of species.

The important contribution of genebanks to agricultural productivity has been recognized by government since the 18th century. It led to the rise of botanical gardens and expeditions in search of new plant varieties, including the fabled voyage of the HMS *Bounty* (Fowler 1994), and is growing substantially as traditional landraces continue to be replaced by modern varieties.

Genetic engineering has greatly increased the supply of genetic material available for introduction into crop varieties. Genes from any species of plant, animal, or microorganism can now be moved into a particular plant. For example, genes from the winter flounder have been transferred into the tobacco genome to increase its frost resistance, and genes from the microorganism *Bacillus thuringiensis* have been transferred into corn, wheat, and rice to give them resistance to insect pests. Genetic engineering is not without considerable risks, and its ultimate success will depend on genetic variability in natural populations. It is clear that the rapid increase in uses of genetic engineering will continue as knowledge and applications of new techniques increase.

Not only are specific genes valuable in modern agricultural systems, but the maintenance of genetic diversity is also valuable in traditional agricultural systems. The greater the genetic uniformity of a crop, the greater the risk of catastrophic losses to disease or unusual weather. In 1970, for example, the US corn harvest was reduced by 15%—for a net economic cost of $1 billion—when a leaf fungus spread quickly through a relatively uniform crop (Tatum 1971). Since then, breeders have taken greater precautions to ensure that a heterogeneous array of genetic strains are present in fields, but problems due to reduced diversity still recur. The loss of a large portion of the Soviet Union's wheat crop to cold weather in 1972 and the citrus canker outbreak in Florida in 1984 both stemmed from reductions in genetic diversity (Reid and Miller 1989).

Humans also use a relatively small number of livestock species for food and transportation: only about 50 species have been domesticated. Here, too, genetic diversity is the raw material for maintaining and increasing the productivity of species.

Biodiversity in Wild Systems

Humans still harvest considerable quantities of food, fuel, and fiber from nondomesticated ecosystems. For example, gross revenue from the world marine fisheries in 1989 amounted to $69 billion (WRI 1994). Fish contribute only 5% of the protein consumed worldwide, but the proportion can be much higher locally. In Japan, the Philippines, the Seychelles, and Ghana, for example, fish account for more than 20% of protein intake (PAI 1995). In some developing countries and among some population segments in developed countries, terrestrial wildlife also continues to be an important subsistence resource. In some

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areas of Botswana, for example, over 50 species of wild animals provide as much as 40% of the protein in the diet; and in Nigeria, game accounts for about 20% of the animal protein consumed by people in rural areas (McNeely and others 1990).

Increased diversity of livestock can sometimes improve productivity. In Africa, for example, "game ranching"—in which wild species of antelope replace domesticated livestock on particular ranches—can result in higher yields of meat than could be obtained from domesticated animals (WRI 1987). Naturally diverse ungulates can use grassland resources more efficiently than domesticated varieties in these situations.

In rural Alaska, more than 90% of the people harvest and use wild animals for both food and clothing. The cash value of wild food constitutes 49% of residents' mean income (ADFG 1994). The marine mammals of the northern Bering, Chukchi, and Beaufort seas are among the most diverse in the world; many of the species are used for subsistence purposes by Alaskan Natives, and many have important symbolic roles in cultural identity (NRC 1994).

Most of the world's timber production still comes from nondomesticated systems, although a growing share is now harvested on plantations. In tropical forests, for example, the area of plantations increased from 18 million hectares in 1980 to 40 million in 1990. Although statistics on the world value of internal and externally traded timber products are not available, the world value of forest-product exports alone in 1993 was to $100 billion (FAOSTAT 1995).

Recreational uses of biodiversity—fishing, hunting, and various nonconsumptive uses, such as bird-watching—also contribute to the economy (see Everglades and Boulder, Colo., case studies in this chapter and Lake Washington case study in chapter 6). In the United States alone, such activities involved about 77 million persons over the age of 16 in 1996 and resulted in expenditures of $101.2 billion (DOI/DOC 1997). Wildlife watchers made up the largest group (62.9 million participants in 1996); their expenditures included $16.7 billion for equipment, $9.4 billion for travel, and $3.1 billion in other expenses. Of a total of 39.7 million sportspersons, 35.2 million were adult anglers and 14.0 million were hunters; this group spent $72 billion in 1996, including $37.8 billion for fishing, $20.6 billion for hunting, and $13.5 billion in unspecified expenses (DOI/DOC 1997).

One of the most rapidly growing values of biodiversity in wild ecosystems is related to tourism. Worldwide receipts from international tourism in 1990 totaled $250 billion (WCMC 1992), and domestic tourism is believed to be as much as 10 times higher. How much of the tourist trade is attracted specifically by biodiversity is difficult to tell. Of the $55 billion in tourism revenues accruing to developing countries in 1988, an estimated 4–22% was due to "nature tourism" (Lindberg 1991). More than half of the visitors in Costa Rica, for example, state that the national parks are their "principal reason" for traveling to the country (see the case study on Costa Rica in chapter 2). Costa Rica's protected areas are estimated to account for $87 million annually in tourism revenues.

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As in domesticated agroecosystems, the diversity of genes and species undergirds the continued productivity of these components of biodiversity in nondomesticated ecosystems. The genetic diversity in a species provides the basis for the species to adapt to changing environmental conditions. Reduced genetic diversity increases the probability of species extinction or of substantial reductions in the population of a species due to changing environmental conditions (such as, a change in climate or the introduction of a new disease). For example, wild exotic trout in the western United States can be destroyed by whirling disease, which is caused by the microorganism *Myxobolus cerebralis*; the only way to restore infected populations is to find genetically resistant populations (Hoffman 1990).

The productivity of an ecosystem can be high both in systems with large numbers of species, such as tropical forests, and in systems with relatively small numbers of species, such as wetlands.

The extirpation of the California sea otter from much of its range in the 1800s resulted in substantial changes in near-shore ecosystems (Estes and Palmisano 1974). Recovery of otter populations to their original densities affects other ecosystem components of commercial or recreational value: giant kelp, sea urchins, abalone, and surf clams. The sea otter is a primary predator (top of the food chain) of mollusks and urchins, which graze on stands of algae that are primary producers (of calories consumed) in coastal regions extending from California through the Aleutian Islands. As a consequence of the extirpation of sea otters, grazing urchins became common and reduced the biomass of primary producers.

Just like the loss of specific species, the manipulation of the food chain structure can alter the productivity of direct value to humans. For example, in areas where intense gillnet fisheries have seriously depleted Nile perch stocks, many African cichlids have recovered in Lake Victoria (Kaufman 1992). Equivalently, the introduction of the Nile perch into Lake Victoria led to the extinction of many species of the native cichlid fish and substantially reduced the total harvest of this important food source (Johnson and others 1996).

Biodiversity in the Pharmaceutical and Biotechnology Industry

Wild species of plants and animals have long been the source of important pharmaceutical products. Natural products play a central role in traditional healthcare systems. The World Health Organization estimates that some 80% of people in developing countries obtain their primary health care in the form of traditional medicines (Farnsworth 1988). Systems of ayruvedic medicine (traditional Hindu medical practices) in India and the traditional systems of Chinese herbal medicine, for example, reach hundreds of millions of people. Total sales of herbal medicines in Europe, Asia, and North America were estimated at $8.4 billion in 1993 (Laird and Wynberg 1996). That total is not large on a global

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scale, but sales of herbal medicines can often be an important source of income for local communities and business.

Natural products also continue to play a central role in the pharmacopeia of industrialized nations. Of the highest-selling 150 prescription drugs sold in the United States in 1993, 18% of the 150 consisted of essentially unaltered natural products, and natural products provided essential information used to synthesize an additional 39% (Grifo and others 1997). In total, 57% owed their existence either directly or indirectly to natural products.

Natural products were once the only source of pharmaceuticals, but by the 1960s synthetic chemistry had advanced to the point where the pharmaceutical industry's interest in natural products for drug development had declined greatly and it declined further with the introduction of "rational drug design". Several technological advances led to a resurgence of interest in research in natural products in the 1980s. The development of modern techniques involving computers, robotics, and highly sensitive instrumentation for the extraction, fractionation, and chemical identification of natural products has dramatically increased the efficiency and decreased the cost of screening for natural products. Before the 1980s, a laboratory using test-tube and in vivo assays could screen 100–1,000 samples per week. Now, a laboratory using in vitro mechanism-based assays and robotics can screen 10,000 samples per week. Where the screening of 10,000 plant extracts would have cost $6 million a decade ago, it can now be accomplished for $150,000 (Reid and others 1995). In the next decade, throughput could grow by a factor of 10–100.

As the new technologies became available in the 1980s, many companies established natural-products research divisions. Of 27 companies interviewed in 1991, two-thirds had established their natural-products programs within the preceding 6 years (Reid and others 1993). In most large pharmaceutical companies, natural-products research accounts for 10% or less of overall research. But some smaller companies now focus exclusively on natural products. For example, Shaman Pharmaceuticals bases all its drug-discovery research on natural products used in traditional healing systems, and it currently has two drugs in clinical trials.

How long the interest in natural-products drug discovery will last is impossible to know. New techniques of combinatorial chemistry and other advances in drug design might reduce interest in natural-products research. Even so, many chemists feel that current synthetic chemistry is still unable to match the complexity of many of the natural compounds that have proved effective as drugs. For example, paclitaxel, known as Taxol, a compound from the Pacific yew tree (which is not considered economically important for timber or other commercial purposes), is being used in treatment for ovarian and breast cancer. The compound was discovered in the 1960s but could not be synthesized until the 1990s; and even now, the process is so time-consuming and expensive that natural precursors are used in the production of the drug.

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Drugs developed from natural products often generate large profits for drug companies, but the actual value of biodiversity as a "raw material" for drug development is much smaller (Simpson and others 1996). On the average, some $235 million and 12 years of work are required to produce a single marketable product in the drug industry. Moreover, less than 1 in 10,000 chemicals is likely to result in a potential new drug and only 1 in 4 of those candidates will make it to the pharmacy. On the basis of typical royalties paid for raw materials, the likelihood of discovering a new drug, the length of patent protection, and the discount rate, the present net value of an arrangement whereby a nation contributes 1,000 extracts for screening by industry would be only about $50,000. Moreover, there would be a 97.5% chance that no product at all would be produced. The likelihood that any particular plant or animal will yield a new drug is extremely small, but endangered species in the United States have yielded new drugs. We can to some degree aggregate the plants and animals that are most likely to lead to new drugs. These are likely to have considerable value as prospects (Rausser and Small in press).

Biotechnology

Until recently, pharmaceutical, agricultural, and industrial uses of biodiversity relied on largely different methods of research and development. Today, with the help of the new biotechnologies, individual samples of plants or microorganisms can be maintained in culture and screened for potential use in any of those industries. Companies are screening the properties of organisms to develop new antifouling compounds for ships, new glues, and to isolate new genes and proteins for use in industry. A thermophilic bacterium collected from Yellowstone hot springs provided the heat-stable enzyme Taq polymerase, which makes it possible, in a process known as polymerase chain reaction (PCR), to amplify specific DNA target sequences derived from minute quantities of DNA. PCR has provided the basis of medical diagnoses, forensic analyses, and basic research that were impossible just 10 years ago. The current world market for Taq polymerase, is $80–85 million per year (Rabinow 1996). Biodiversity is the essential "raw material" of the biotechnology industry, but the process of examining biodiversity for new applications in that industry has only begun.

Biodiversity and Bioremediation

It has become clear in recent years that the fundamental role of microorganisms in global processes can be exploited in maintaining and restoring environmental productivity and quality. Indeed, microorganisms are already playing important roles, both in the prevention of pollution (for example, through waste processing and environmental monitoring) and in environmental restoration (for example, through bioremediation of spilled oil). Modern biotechnology is pro-

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viding tools that will enhance the environmental roles of microorganisms, and this trend should accelerate as the appropriate basic and applied sciences mature (Colwell 1995; Zilinskas and others 1995). A variety of probes and diagnostics for monitoring food and environmental quality have been developed (Dooley 1994), and there is much discussion of the development of genetically engineered organisms for speeding the clean up of wastes, spills, and contaminated sediments. Furthermore, marine biotechnology is being pursued avidly and on a larger scale in Japan (Yamaguchi 1996), where one major goal is to find ways to lower global atmospheric CO_2 concentrations. Without doubt, the prediction of climate change will be much improved by a better understanding of global cycles, and the tools of marine biotechnology will be heavily involved in this endeavor.

The fundamental premise here is that chronic pollution reduces system species diversity and diminishes ecosystem function. Thus, restoring perceived environmental quality and productivity cannot easily be separated from basic biodiversity issues.

Ecosystem Services

A substantial risk of undesirable and unexpected changes in ecosystem services is posed when the abundance of any species in an ecosystem is changed greatly. Our ability to predict which species are important for particular services is limited by the absence of detailed experimental studies of the ecosystem in question. Nonetheless, the available data indicate that a higher level of species diversity in an ecosystem tends to increase the likelihood that particular ecosystem services will be maintained in the face of changing ecological or climatic conditions (below, "Species Diversity and Ecosystem Services").

Both wild and human-modified ecosystems provide humankind with a variety of services that we often take for granted (see box 3-1). The services include the provision of clean water, regulation of water flows, modification of local and regional climate and rainfall, maintenance of soil fertility, flood control, pest control, and the protection of coastal zones from storm damage. All those are "products" of ecosystems and thus a product of biodiversity. The characteristics and maintenance of these ecosystem services are linked to the diversity of species in the systems and ultimately to the genetic diversity within those species. However, the nature of this relationship between ecosystem services and biodiversity at the lower levels of species and genetic diversity is complex and only partially understood.

Biodiversity and Ecosystem Services

Humankind derives considerable benefits not only from the products of biodiversity but also from services of ecological systems, such as water purification, erosion control, and pollination. The relationship between biodiversity and

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BOX 3-1
Types of Ecosystem Services Linked to Biodiversity

Atmospheric—Climatic
- Gaseous composition of the atmosphere
- Moderation of local and regional weather, including temperature and precipitation

Hydrological
- Water quality and quantity
- Stream-bank stability
- Control of severity of floods
- Stability of coastal zones (through presence of coastal communities, such as coral reefs, mangroves, or seagrass beds)

Biological and Chemical
- Biotransformation, detoxification, and dispersal of wastes
- Cycling of elements, particularly carbon, nitrogen, oxygen, and sulfur
- Buffering and moderation of the hydrological cycle
- Nutrient cycling and decay of organic matter
- Control of parasites and disease, pest control
- Maintenance of genetic library
- Habitat and food-chain support

Agricultural
- Crop production, timber and biomass energy production, pollination
- Stabilization of soils

Economic and Social
- Support of human cultures
- Aesthetic value and ecotourism

SOURCE: Adapted from Daily 1997.

ecosystem services is complex and will be discussed in greater detail later, but in general, most ecosystem services are degraded or diminished if the biodiversity of an ecosystem is substantially diminished. Because most ecosystem services are provided freely by natural systems, we typically become aware of their value and importance only when they are lost or diminished.

Historically, ecosystem services were not generally scarce and management decisions were rarely based on their low marginal value. That is decreasingly true, particularly with regard to drinking-water quality, flood control, pollination, soil fertility, and carbon sequestration. This trend is prompting interest in developing institutional frameworks through which to restore and safeguard these services in the United States and internationally.

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The cost of the loss of various ecosystem services can be high. The US National Marine Fisheries Service estimated that the destruction of US coastal estuaries in 1954–1978 costs the nation over $200 million per year in revenues lost from commercial and sport fisheries (McNeely and others 1990). Hodgson and Dixon (1988) calculated the cost of the potential loss of the service that the forested watershed of Bacuit Bay in the Philippines provides in preventing siltation of the coastal coral ecosystem. The forest prevents siltation: if it were cut, siltation would increase, thereby reducing tourism and fisheries revenues. In a scenario in which logging is banned in the basin, the net present value of a 10-year sum of gross revenues from all three sources would be $42 million. In a scenario of continued logging, the net present value would be only $25 million. One recent and controversial set of global estimates of the value of ecosystem services is discussed in chapter 5.

The value of various ecosystem services can also be seen in the costs that must be incurred to replace them. For example, natural soil ecosystems help to maintain high crop productivity, and the productivity that is lost if soil is degraded through erosion or through changes in species composition can sometimes be restored through the introduction of relatively expensive fertilizers or irrigation. Forested watersheds slow siltation of downstream reservoirs used for hydropower; a forest is altered and sedimentation increases, the hydroelectric-power generating capacity lost could be replaced through the construction of new dams. Wetlands play important roles as "buffers", absorbing much stream runoff and preventing floods; if wetlands are filled, their flood-control role could be assumed by new flood-control dams. The US Army Corps of Engineers estimated that retaining a wetlands complex outside Boston, Massachusetts, realized an annual cost savings of $17 million in flood protection (McNeely and others 1990).

The conversion of one type of habitat to another—such as a conversion of natural forest to agriculture or of agricultural land to suburban development—can dramatically affect a wide variety of ecosystem services. Historically, the impacts of such conversions on ecosystem services have not received attention from policy-makers and managers, for two main reasons. First, the relationship between an ecosystem and a service is typically poorly understood. The conversion of a park to a parking lot will obviously change patterns of water runoff, but other effects of habitat conversions are difficult to predict. For example, the replacement of native vegetation in the western Australian wheatbelt with annual crops and pastures reduced rates of transpiration, increased runoff, and consequently raised the water table, creating waterlogged soil. Salts that had accumulated deep in the soil salinized the soil surface. The saline wet conditions altered ecosystem services by reducing farmland productivity and reducing the supply of freshwater. Restoring such degraded ecosystems can take decades and be accomplished at high cost. In addition, the changes threatened the remaining fragments of

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native communities and salinized the region's freshwater lakes. Careful research could probably have predicted many of those effects, but such research is rarely undertaken before a land-use change (Heywood 1995).

Second, ecosystem services are often public goods. Individual landowners who cut their forests bear little if any of the cost associated with the reduction of water quality experienced by downstream water-users. Similarly, the flood-control service that is lost when landowners fill their wetlands might have little direct effect on those landowners, but the private economic benefits of land conversion to agriculture will be important (see the following case study on the Everglades). Such losses are described in economic terms as "externalities"; the changes in the environment occur as a result of economic activity, such as land development or cutting forests for lumber, but the losses are external to the market transactions.

Case Study: The Everglades

This case study shows the complexity of valuing ecological resources and developing achievable scenarios for ecological and economic sustainability in a watershed system, particularly one in which human activities that change the quality or flow of water in one area affect the biological uniqueness, aesthetic value, and local economy of other areas.

The Everglades are part of the largest wetland ecosystem in the lower 48 states. Historically, water from the Kissimmee River flowed southward into Lake Okeechobee and during wet years overflowed the southern rim of the lake, spreading across the Everglades in a broad "river of grass" that slowly flowed southward to the Florida Bay estuary. The large spatial scale of the system, the highly variable seasonal and interannual patterns of water storage and sheet flow across the landscape, and the very low concentrations of nutrients in the surface waters led to a unique assemblage of wading birds, large vertebrates, and fish and plant communities in a mosaic of habitats over the region (Davis and Ogden 1994).

Since the early 1900s, the environment of Southern Florida has undergone extensive habitat degradation associated with hydrological alterations by humans. Initially, these were to drain land for agriculture and human settlements; later alterations were to protect against flooding. The resulting Central and Southern Florida Project (the C&SF Project) of the US Army Corps of Engineers is one of the most massive engineered hydrological systems in the world. The human population of Southern Florida is now 4.5 million and growing at a rate of almost 1 million per decade, mostly concentrated along the lower eastern coast.

The Everglades has been compartmentalized for a variety of land uses: agriculture in the north, where the largest accumulations of organic soils once existed; water conservation areas in the central portions; and the Everglades National Park in the south. The Everglades Agricultural Area (EAA) covers about

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27% of the historical system, the water conservation areas 33%, the park 21%, urban areas about 12%, and various nondeveloped areas about 7% (Gunderson and Loftus 1993). About half the original Everglades remains in some semblance of its natural state in the water-conservation areas and the park (Gunderson and others 1995).

The construction of canals, levees, and pumping stations has changed the hydrology of the entire system, leaving it vulnerable to a variety of influences. There have been population declines in native species; for example, during the last decade, populations of wading birds averaged less than 10% of their historical highs. Populations of a dozen animal species and 14 plant species have been so reduced that they are now endangered or threatened. Nonnative and nuisance species, such as *Melaleuca quinquinervia* (a tree introduced from Australia in the early 1900s to help drain the Everglades) and the Brazilian pepper tree (*Schinus terebinthifolius*), have invaded extensive areas, outcompeting native plants. In the converted agricultural areas, soil subsidence and water-level declines so great that they are measured in feet (Alexander and Cook 1973) have increased the susceptibility of the Everglades to drought and fires. Agriculture has introduced excessive nutrients into the system, and the decreased overland flow of freshwater has resulted in salt-water intrusion into the Everglades National Park and along areas of urban development to the east. If the present ecosystem continues to degrade, ecological sustainability cannot be achieved without fundamental changes (Davis and Ogden 1994).

Over the last several decades, state and federal programs have been created to address water-conservation problems in the Everglades. Crises resulting from a failure of existing policies have led to major reconfigurations and new institutions, structures, and policies (Gunderson and others 1995). Even among the agencies and institutions that were concerned primarily with the ecological functioning of the Everglades, there were conflicts over specific management objectives, owing in part to differences in the legal mandates governing the different management agencies. Conflicts were also generated by a lack of critical data needed to evaluate the likely effects of potential manipulations of the hydrological regimes of today's Everglades and by legal and other constraints on the options considered and evaluated by the agencies.

The agencies recognized that single-purpose interventions were unlikely to succeed and that restoration activities needed to be evaluated in a system-wide context. There was also common recognition that it was impossible to recreate precisely the original ecological conditions, because the drainage system had been altered in irreversible or very difficult-to-reverse ways. At issue were maintenance of the integrity of the watershed and water quality, preservation of biodiversity in a region of great interest, conservation of endangered species as required by law, and the sustainability of natural resources in a setting of rapid economic and population growth. Two current examples illustrate the complexity of the process.

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The US Army Corps of Engineers recently completed a reconnaissance report for the C&SF Project (COE 1994). This represented the first phase of the corps's effort to examine ways to modify the C&SF Project to restore the Everglades and Florida Bay ecosystems while providing for other water-related needs of the area. Restoration objectives included increasing the total spatial extent of wetlands, increasing habitat heterogeneity, restoring hydrologic structure and function, restoring water quality, improving availability of water, and reducing flood damage on tribal lands. Recognized constraints included protection of threatened and endangered species, minimizing loss of services provided by the C&SF Project, and minimizing regional and local social and economic disruption. The reconnaissance study was the first step in development of a restoration plan. It set the stage for feasibility studies to develop further the most promising alternatives and recommend a plan for authorization by Congress.

The second example is a 4-year US Man and the Biosphere (US MAB) study on ecosystem management for sustainability of southern Florida ecological and associated societal systems (Harwell and others in press). This project places water-management and biodiversity issues into an ecosystem-management framework that presumes that the last century's fragmented and compartmentalized approach to management must evolve to one that explicitly recognizes the mutual interdependence of society and the environment. Such an approach will require integration of theory and knowledge from the natural sciences with analyses of societal and ecological costs and benefits of ecosystem restoration.

The US MAB project defined ecological sustainability goals for each component of the landscape with a focus on core areas of maximal ecological goals and buffer areas to support the attainment of those goals, established plausible management scenarios, and examined how the scenarios were related to the desired goals for sustainability of the regional ecological and societal systems (Harwell and Long 1995).

Three management scenarios were examined. The report concluded that only one was ecologically sustainable. It involves using portions of the EAA for dynamic water storage while it remains entirely or partly under private ownership; the EAA consists of 280,000 hectares, used primarily for sugar production, with total annual economic activity of about $1.2 billion (Bottcher and Izuno 1994). A National Audubon Society report on the endangered species in the Everglades made a similar recommendation (National Audubon Society 1992). Although this scenario was considered sufficient to achieve the ecological goals for the core areas it was concluded that complete acquisition of the EAA would have too high an economic and social cost (Bottcher and Izuno 1994). However, on the other hand, the sustainability of the sugar industry in the EAA itself is at risk because of extensive soil degradation, possible changes in the subsidies that support sugar prices, political efforts to tax the sugar industry exclusively for funds to restore the Everglades, and economic pressure to acquire EAA lands for residential development. Thus, it was seen that putting part of the EAA in a

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buffer to support ecological systems might counteract some of the risks to sustainability of the agricultural system.

The US MAB report suggested possible uses for the EAA that would allow for sugar production to continue and for the water-management needs to be met, thereby linking the sustainability of the ecological system with the societal sustainability of the local community. The analysis concluded that sugar is probably the most desirable form of agriculture for the EAA, in that its nutrient demands and nutrient exports to the Everglades are considerably lower than those of vegetable crops. Sugar agriculture was seen as much preferable to the alternative of housing developments or urbanization. The study concluded that the environment of southern Florida has more than enough water, except in severe drought years, to support all expected urban, agricultural, and ecological needs but that currently the greatest fraction of the freshwater is lost directly to the sea through the engineered system of drainage canals. The critical issue, then, is not competition for resources, but the storage and wise management of this renewable resource.

Risk Management of Ecosystem Diversity and Services

From the standpoint of resource management and policy-making, the link between species diversity and ecosystem services can best be characterized in a risk-management framework. For any given service, a number of changes in the relative abundance of species in an ecosystem could often be made with relatively little impact on the service in question. But addition or removal of particular species could profoundly alter one or more services. Moreover, the presence of a diversity of species—and the genetic diversity in those species—will aid in the persistence of a particular service in the face of changing ecological and climatic conditions. We rarely have sufficient ecological knowledge of a system to allow an accurate assessment of how a change in species diversity is likely to affect one or more services, although we often can identify at least some of the species whose depletion or addition is likely to matter. Management decisions involving potential impacts of changes in species populations on ecosystem services thus typically confront the problem of analyzing and managing risk in the face of scientific uncertainty.

No two species are identical, so, in a general sense no species in any ecosystem is "redundant". Nevertheless, for any particular ecosystem service, some species could be added or removed from the ecosystem or be replaced with other, nonnative species with little detectable influence on that service. In such cases, one species functionally compensates for another (Menge and others 1994). A clear example is the service that different plant species provide in slowing soil erosion and thereby maintaining clean water and soil productivity. A natural forest is often extremely effective at minimizing soil loss from an ecosystem. However, knowledge of the plant species in a particular forest ecosystem is

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necessary before one decides what plant species might be removed without changing the efficiency of erosion control.

Although the species in an ecosystem might perform similar functions, there is insufficient knowledge to predict when removing a species from an ecosystem will have an impact. Species in each ecosystem interact—are linked—and removing them might have serious effect; a change that has little effect on one ecosystem service might affect other services profoundly. Species whose low relative abundance would not suggest their large impact on populations of other species in a community are referred to as "keystone" species (Paine 1969; Power and others 1996). The chestnut blight largely eliminated the once-dominant chestnut from eastern deciduous forests (the species is still present, but now grows only in a bushy form), but its loss seems to have had relatively little influence on patterns of water runoff or sedimentation in the region because diverse species of hardwoods growing in similar habitats with similar canopy coverage and similar patterns of evapotranspiration were present in the system. However, if a keystone species were removed or added in this example, it could profoundly affect one or more services. The loss of a keystone species is likely to influence many of the functional processes in an ecosystem, as in the sea otter example earlier in this chapter.

Few communities and virtually no regional ecosystems have been studied in sufficient detail to allow an accurate assessment of all the species that are likely to play keystone roles in relation to various ecosystem services. Often, some species can be identified as likely keystone species in the absence of careful study and experimentation, but ecological science can help little in predicting which other species will play such roles. A virus, for example, could play a keystone role in a particular ecosystem. The rinderpest virus has gradually been eliminated from wild cattle near the Serengeti, and their populations have increased spectacularly over the last 20 years, as have predator populations (Dobson 1995; Dobson and Hudson 1986). The dramatic growth in the population of grazers, however, has reduced recruitment of trees in the area. Indeed, the ages of trees growing in several areas of East Africa suggest that recruitment of trees occurs only rarely and might be strongly influenced by the patterns of disease in the ungulate populations (Dobson and Crawley 1994). Box 3-2 presents some changes in species or populations of particular species that have had substantial effects on ecosystem services.

A particular species might compensate functionally for another that is removed from an ecosystem, but a simplified ecosystem is less likely to maintain a particular ecosystem service than one with a greater diversity of species playing similar functional roles. A reduction in the diversity of species performing similar functions in an ecosystem reduces the likelihood that the related service can persist in the face of changing ecological or climatic conditions. Reduction in the population of a species due to the introduction of a pest or pathogen is less likely to disrupt a particular service if species that are unaffected by the pest or patho-

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BOX 3-2
Effects of Changes in Species Diversity or Abundance on Ecosystem Services

- The introduction of exotic species of *Myrica faya* with nitrogen fixing-symbionts into Hawaii dramatically increased productivity and nitrogen cycling and altered the species composition of the forests (Vitousek and others 1987).
- In the absence of flood pulses, the introduced salt cedar, *Tamarix*, has outcompeted the native cottonwood-willow community. Native birds that have evolved to forage in native plant communities and lizards that have adapted to microhabitat characteristics do not find the salt cedar to their liking (Krzysik 1990).
- Flying foxes (*Pteropodidae*) in isolated and faunally depauperate South Pacific island ecosystems are the primary pollinators and seed dispersers and are responsible for ecosystem structure and biodiversity in a comparable way with predators in some continental and intertidal communities (Cox and others 1991). Flying fox populations are declining, and at least 289 plant species, which not only provide ecosystem services but yield 448 economically valuable products, are in jeopardy (Fujita and Tuttle 1991).
- Desert rodents, through seed predation and soil disturbance, have keystone effects on the biodiversity and biogeochemical processes in desert ecosystems (Brown and Heske 1990). When the three resident species of kangaroo rats (*Dipodomys*) were removed from experimental plot in Chihuahuan Desert scrub, perennial and annual grasses increased 3-fold over a 12-year period, appreciably changing the vegetation structure of the desert ecosystem.

gen play similar functional roles. Similarly, climatic change is less likely to affect a particular service if a diversity of species perform similar functional roles. Each species is likely to be affected differently by a given change in climate, so the risk that all species involved in a particular service will be lost from a system is lessened.

Another way that diversity could affect ecosystem services is by increasing their stability. Again, the underlying idea is simple. In the face of year-to-year fluctuations or sustained directional changes in climate or soil fertility or other environmental conditions, productivity and nutrient cycling are more likely to be sustained at high rates if a number of species are present. Some species might be most effective under current conditions; while others might become more important unless conditions change. For example, in an 11-year field experiment based on 207 grassland plots, increased plant species diversity resulted in greater stability in the community and ecosystem process in experimental plots, especially in the face of a severe drought (Tilman 1996; Tilman and Downing 1994). Experimental studies also indicate, for example, that species diversity itself can influence some ecosystem services, particularly in species-poor systems. In their study of artificial tropical communities in which experimental plots contained 0, 1, and 100 species

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of plants, Ewel and colleagues found that the total number of species had a greater effect than species composition on a variety of biogeochemical processes (Ewel and others 1991). Artificial communities with different combinations of one to four species also differed dramatically in net primary productivity: productivity was higher with more species (Naeem and others 1994).

Those results are all consistent with the idea that one of the benefits of diversity is that it increases the likelihood that a species that is highly productive under any particular conditions will be present in the community (Hooper 1998; Hooper and Vitousek 1998). Where highly productive species have been identified in advance and conditions are managed so as to be suitable (as in agricultural monocultures), very high rates of productivity can be attained without much onsite diversity. For example, American farmers produce on average about 7 tons of corn per hectare, but when challenged, as in National Corngrowers' Association competitions, farmers have tripled those yields, producing 21 tons per hectare. Annual yields of biomass up to 550 tons/ha are theoretically possible for algal cultures; yields half as great have been achieved (Waggoner 1994).

SOCIAL AND CULTURAL VALUES

Many people develop a deep aesthetic appreciation for biodiversity and its components. This appreciation has several dimensions, including an appreciation of how biodiversity reveals the complex and intertwined history of life on Earth and a resonance with important personal experiences and familiar or special landscapes. Interest in nature is manifest in many hobby activities, including bird-watching and butterfly-watching; keeping reptiles, tropical fish, and other "exotic" species as pets; raising orchids or cacti; participating in native-plant societies; viewing nature photographs and reading nature writing; and watching nature televisions shows. Kiester (1997) has suggested that such experiences provide the basis for a connoisseur's appreciation of biodiversity. By cultivating a connoisseur's perspective, we might develop a better understanding of the aesthetic value of biodiversity just as art critics and scholars help us to appreciate art.

Information

Biodiversity holds the potential for applied knowledge through the discovery of how different species have adapted to their varied environments (Wilson 1992). That is, biodiversity holds potential insights for solutions to biological problems, both current and future. We might discover bacteria that inhabit hot springs and have evolved enzymes that function at unusually high temperatures, as in the case of PCR described earlier. We might discover novel predator defense mechanisms of plants and develop previously unimagined alternatives to pesticides for our foods. Or from indigenous peoples we learn about poison-dart frogs; study of

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the toxins of poison dart frogs is providing insight into fundamental neural mechanisms. Such new insights and tools came not from our imaginations but from observations of other peoples and other species. Even with the dazzling power of modern molecular biology, is it reasonable to expect that we can imagine all the new solutions that can be devised? The diversity of life supplies us not only with new tools and techniques, but also with the inspiration to imagine innovations. "There are more things in Heaven and Earth, Horatio, than are dreamt of in your philosophy" (Shakespeare, Hamlet, act I, scene V).

Biodiversity holds the potential for us to understand ourselves better. We have developed profound insights about our own culture and society through the study of other peoples. Likewise, we can learn about our physiology through the study of other species. Many of our insights about ourselves could only have come through the study of other species. For example, our knowledge of our development and reproduction rests on the study of many diverse species beyond the common laboratory species, such as bacteria, nematodes, rats, mice, and monkeys. It had long been presumed that testosterone is necessary for mating behavior in males—except possibly in humans—because it was the case for all animals that had been studied. However, the discovery that this was not the case in the red-sided garter snake showed that the correlation between testosterone and behavior in vertebrates was not, after all, axiomatic (Joy and Crews 1988). The zebra fish has recently proved to be an especially useful model for understanding the molecular genetics of neural development (Brown 1997). Even plants reveal important cues to our physiology. Research on the circadian clock of the mustard plant (*Arabidopsis*) has led to techniques for studying circadian clocks in animals in more detail and with greater precision than ever before possible (Kay 1996). Considerable advances in understanding of the human nervous system have come from studying nonhuman vertebrates and invertebrates. For example, the nematode *Caenorhabditis elegans* has provided insights into nervous disorders and diseases, such as Alzheimer's disease.

Biodiversity has often served as an early-warning system that has foretold threats to human health before sufficient data had been collected to detect effects directly. Rachel Carson's (1962) *Silent Spring*, for example, established a strong case against the use of pesticides primarily on the basis of threats to wildlife populations. The same pesticides have since been found to present serious public-health risks. Similarly, declines in populations of the common seal in the Wadden Sea and reproductive failure in the Beluga whale in the St. Lawrence River in Canada might stem from the ingestion of PCB-contaminated fish—if so, caution should be used to ensure the safety of marine food supplies for human consumption (Chivian 1997).

Wildlife studies have shown evidence of effects of various chlorinated organic compounds on the immune systems of animals (reviewed in Repetto and Baliga 1995) and on their reproductive physiology (Colborn and others 1993).

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The evidence is much less conclusive that these compounds have an effect on human physiology, but the accumulation of evidence from wildlife studies points to the need for more-detailed research on possible effects on humans.

Much of the study of biodiversity might have no immediate applied value, but it is valuable nonetheless. It is impossible to predict how new knowledge will be used. Knowledge about various forms of life has, as seen in the above examples, had direct effects on improving human health and has led to revolutions in science, such as our understanding of molecular genetics. Few people in Darwin's time would have imagined how his fascination with animal variation would transform the study of biology and so profoundly alter our notions. Bacterial genetics was an obscure field of research in the 1950s, but it led directly to what we now call molecular biology. Even the small cadre of bacterial geneticists could not have known how their research would revolutionize biology and medicine.

Transformation

Biodiversity can transform our values in the sense that experiences with and knowledge of biodiversity provide opportunities for self-knowledge—knowledge of our own values, attitudes, and beliefs and our place within life as a whole. Although we often regard our natural environment as either a means or a hindrance to such ends as satisfying our physical needs and accumulating material goods, our interactions with our environment also develop our sense of aesthetic pleasure, our curiosity, and our sense of where we fit in the broader scheme of things. A biologically diverse environment offers broad opportunities for developing new ways of appreciating one's place, the scope of one's enjoyments, and oneself (Kellert and Wilson 1993; Norton 1986; Wilson 1984).

Sometimes, the contributions of biodiversity are indirect: knowledge expands experience, as evident in a comment made by a recent graduate of an adult literacy program in Washington, DC: "You know, I never even cared about the trees in my neighborhood until I read about how they grow." Children who are exposed to activities and direct experiences with wildlife gain more than knowledge about wildlife. Their attitudes change (Hair and Pomerantz 1987). They become more concerned about wildlife in general; that is, about wildlife in other parts of the world. There is a small but growing literature on how experience with wildlife—and especially with wilderness and outdoor recreation—influences values, beliefs, and attitudes (Finger 1994; Hendee and Pitstick 1993; Kaplan and Talbot 1983; Orams 1996; Rossman and Ulehla 1977; Shearl 1988; Shin 1993).

One's conception of self is related to nature in highly symbolic ways. Few Americans wish to live in the kind of society that poisons the Bald Eagle, our symbol of national strength and pride. The grandeur of the symbol is enhanced by the opportunity to watch the Bald Eagle in flight. Conversely, the symbolic

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power of the eagle would inevitably be diminished if there were no eagles living in the wild.

People are motivated by more than the satisfaction of their physical needs; they are moved by the possibility of expanding their horizons—both their own experience and also knowledge "for its own sake". The experience of biodiversity provides such opportunities. The examples cited above suggest that diverse environments contribute to a self-knowledge that, although it can take a multitude of forms and is difficult to catalog, is nonetheless irreducibly valuable in its own right.

Aesthetics

> To superkill a species is to shut down a story of millennia and leave no future possibilities [Holmes Rolston III, quoted in *Natural History* 1996, p 75].

Many people develop a deep aesthetic appreciation for biodiversity and its components. This appreciation has several dimensions, including an appreciation of how biodiversity reveals the complex and intertwined history of life on Earth and a resonance with important personal experiences and familiar or special landscapes.

In addition to moral, ethical, and religious values, there also are deeply intellectual reasons for conservation of biodiversity; chapter 4 reviews these in detail. The Copernican revolution was an intellectual breakthrough that changed our view of ourselves. The self-awareness that comes from knowledge of biodiversity is only beginning to be realized. Biodiversity ultimately arises from the fact that there has been one evolutionary history of life on Earth, with vertical (through time) inheritance. It follows that the species present today have unique histories. There are many definitions of organic evolution, but two that are especially relevant in this connection are "descent with modification" (Darwin) and "accumulated history" (Salthe). Species contain the histories of their lineages. It is the concept of lineage that is central to the imagery of evolution, and the vast panoply of life through time has become part of our culture. Equally central is the notion of relationship: some pairs of lineages are more closely related than others, in the sense that they have a more recent common ancestor. There are now well worked-out methods for assessing degree of phylogenetic relationship and for reconstructing the history of life on Earth. These developments have made it possible to express values in new ways.

Sense of Place

Long-branch taxa frequently have played special cultural roles or have been recognized as having intrinsic value (Dworkin 1994). The Ginkgo tree was saved

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from extinction in Buddhist monasteries because of a concern that is moral and cultural in origin. It now has a "sense of place" value in many parts of the world. Surprisingly, this is a case in which other values also come into play, in that Ginkgo extracts now constitute one of the most widely used medicines in Europe, prescribed by German medical doctors to over 10 million patients annually.

Many writers have noted that biodiversity, especially the habitats of native and indigenous species, helps to root not only plants but also people by giving them a sense of place. As noted in chapter 2, it is a characteristic association of species that usually leads us to categorize a place. Indeed, some have suggested that the conservation of landscapes is the best remedy we might have to counter the transience, or rootlessness, that has become one of the most salient characteristics of American society. For example, Wallace Stegner (1962) wrote about American rootlessness and restlessness especially in the American West. He understood the lure of freedom in the absence of obligation. But that rootlessness, Stegner wrote, has often been a curse.

> Our migratoriness has hindered us from becoming a people of communities and traditions, especially in the West. It has robbed us of the gods who make places holy. It has cut off individuals and families and communities from memory and the continuum of time.

Gary Snyder (1996) and Carolyn Merchant (1992) have suggested that our ethics and by implication the value we place on biodiversity, must be grounded in an understanding of local habitats and the functioning of ecosystems. This work, especially Leopold's notion of a "land ethic" has inspired work in both environmental philosophy and social psychology; the latter has indicated that concern with the intrinsic value of biodiversity is widespread in the United States (Karp 1996; Stern and others 1993, 1998).

A sense of place is founded on relationships—for example, with nature, with the past, with future generations, and with those with whom one shares responsibility for maintaining the essential character of one's surroundings (Gussow 1972). To belong to or in a landscape, one must feel connected to its past, both natural and human. One is then aware of the moral obligation to cultivate the landscape in ways that maintain its identifying characteristics so that future generations can recognize it as one does now. The work of protecting native flora and fauna establishes a continuity with the future through a consistency with the past. Thus, we maintain a connection with a landscape through time (Cronon 1991; Worster 1985).

The effort that we make to protect the habitats of native species entrenches a relationship between people and places. One sees one's own activities and those of one's community as rooted in a particular place; one's experiences, in other words, depend on where one is (Gallagher 1993; Light and Smith 1998).

The protection of biodiversity is often the catalyst that turns generic locations into distinct places. The difference is that a place is a location that we have

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filled with meaning and thus have claimed with our feelings. History, natural or human, insofar as we claim it as our own, must be imbedded in places that we cherish in shared memory and whose symbols we maintain and respect. Native and indigenous species are living parts of our community history (Baily 1915). (See the case study below on Boulder, Colo., open space.)

Space is the symbol of freedom in the western world; it is a frontier to conquer; it is the potential, not the actual. It is an ever-receding horizon. Place, in contrast, involves commitment and responsibility, actuality rather than potential. It is not the realm of conquest, but the sphere of concern and conservation. The reintroduction and protection of native species, in contrast, follows Virgil's counsel:

> It is well to be informed about the winds,
> About the variations of the sky,
> The native traits and habits of the place,
> What each locale permits and what denies.

Much of what many people deplore about the human subversion of nature—and fear about the destruction of the environment—has to do with the loss of places that they keep in shared memory and cherish with collective loyalty. Many fears stem from the loss of the particular—the specific characteristics of places that make them ours—and so from the loss of the security one has when one is able to rely on the lore and the love of places and communities that one knows well.

The beauty and majesty of nature have always affected human beings: we take pleasure in perceiving nature's beauty, and we feel wonder and awe at its enormous scale (the starry skies) and its dynamic power (a hurricane). The aesthetic categories of the beautiful and the sublime, which became prominent in the writings of 18th-century philosophers, apply to our understanding of the value of biodiversity today. Plants and animals in their intricate and functional design are beautiful; we perceive that beauty with pleasure. We garden; we cut flowers for our homes; we keep birds, fish, and many other animals in our homes; we frequent zoos; and so on. Ecotourism is based largely on people's enjoyment of natural beauty. Artists celebrate that beauty in paintings and sculptures drawn from nature. Indeed, nature is the primary object of representation in art and a constant theme of poetry.

The record of evolution stretches the limits of our understanding and imagination. Those who study this record—paleontologists, zoologists, ecologists, botanists, and many others—discover in every kind of plant and animal a story worth telling, a complex tale of adaptation that exemplifies evolutionary processes. About 99% of the species that have ever existed on Earth are now extinct, and the ones that exist today are the latest descendants and deeply reward study for the historical record that they contain. No less than the artifacts of great civilizations gone by, rare species descended from organisms that lived eons ago possess a historical value and authenticity that demand attention and apprecia-

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tion. When we take pleasure in the qualities of these organisms—when we enjoy simply knowing and perceiving them with no further use or application in mind—we are engaged in the experience of the aesthetic.

Case Study: Boulder, Colo., Open Space

The city of Boulder, Colo., lies at the intersection of the eastern face of the Rocky Mountains and the western edge of the Great Plains in an area of high diversity of mountain and prairie species. The citizens of Boulder, an affluent educated community, have long valued and protected its natural setting, most recently by establishing the so-called blue line, a contour at the city's western edge above which no development is to be extended, and by approving an increase in the city sales tax of 0.4% to buy and protect land adjacent to the city as open space. Boulder now has the highest per capita acreage of municipally owned natural area of cities in the United States.

The purposes of open space, as codified in a charter amendment approved by voters in 1986, are preserving and restoring natural areas and their biota, preserving land for passive recreational use, retaining traditional agricultural land uses, limiting urban sprawl, and preserving aesthetic values (City of Boulder Open Space Department 1995). Loss of natural areas to urban sprawl is proceeding rapidly throughout most of the region around Boulder, and there have been attempts to curtail the open-space program, initiated primarily by the real-estate, development, and general business communities in the Boulder Valley. However, care has been taken to get city council and general public support and involvement during all phases of land purchase and policy implementation.

Public-opinion polls conducted in 1994 and 1995 indicate that although conservation of biodiversity is a factor in public support for open space, the primary purpose in the minds of most people is to keep urban and suburban sprawl at bay (Miller 1994; Miller and Caldwell 1995). It is clear that, to the great majority of Boulder's population, the value of open space as natural viewscape exceeds the value of the same land for possible commercial and residential development.

In recent years, the Open Space Department has begun shifting its emphasis from the purchase of new land to the development of management plans that will ensure its ecological integrity into the future. Of particular concern is the increasing use of open space for outdoor recreation (Zaslowsky 1995). Two issues illustrate the growing conflicts between the value of Boulder open space as a biodiversity reserve and its value as a template for outdoor recreation. The first involves closing a trail to protect the high biodiversity of habitats and replacing it with a nearby trail. The second involves an attempt to implement leash laws in some areas where dog owners traditionally had been permitted to walk their pets

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off-leash. In both cases, the managers in the Open Space Department recommended restricting, but not prohibiting, recreation uses. Neither the users nor those who favored protection were satisfied.

Those examples suggest three general lessons about the challenges that managers of suburban open spaces can expect to face. First, it is more difficult to impose restrictions on the use of open space after its establishment than at the time of its establishment. Second, hard data on the consequences of recreation on the biodiversity of open space will be helpful in resolving conflicts. Third, the ecological integrity of suburban open spaces will persist only if citizen users can be educated as to the consequences of their collective impacts. It is a daunting educational challenge. Public participation has long been an integral part of the planning process regarding Boulder open space. The relative success of the program is attributable largely to deliberate efforts to integrate public opinion and participation into the decision-making process.

Ethics and Religion

Very often, people value biodiversity for ethical and religious reasons. These reasons are often part of a comprehensive ethical or cosmological world view that, on the one hand, is anchored in a self-conception or identity and, on the other hand, is supported by an interpretative tradition and the communities that share it. Such values—and the worldly points of reference that support them—are held not in the form of needs or preferences, but rather as judgments that attach to identity. One does not "choose" these values; they are the deeply held values that form our identity.

SUMMARY

In this chapter, we have discussed how the many dimensions of biodiversity and its components contribute to decisions on management of biodiversity. The goods and services, present and potential, that humans derive directly or indirectly from biodiversity can be viewed from different social and cultural perspectives. The case study examples of the Everglades and Boulder illustrate why a broadened understanding is necessary for management considerations. In the next chapter, we see that information on the many philosophical and systematic approaches to valuing biodiversity can favor particular outcomes in management decisions. Knowledge of these value systems can broaden a manager's ability to resolve conflicts and to understand differences among parties involved in management decisions.

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4

Different Ways of Thinking About Value

There are many reasons why people might care about biodiversity. The previous chapter developed two broad categories. The first category comprised biological values that embraced aspects ranging from biodiversity of wild systems, a broad group of direct value to humans called ecosystem services, and contributions to biotechnology and bioremediation. The second category comprised social and cultural values, placing particular emphasis on aesthetic appreciation, a sense of place, and the deep emotions associated with ethics and religion. Generalized human responses to biodiversity can be grouped into

• *We might need it.* In this category are the claims concerning the actual or potential usefulness of biodiversity: genetic resources for medicine, pharmacy, and agriculture; ecosystem services; and, ultimately, the continuity of life on Earth.

• *We like it.* In this category are the claims that biodiversity is a direct source of pleasure and aesthetic satisfaction: its contribution to quality of life, outdoor recreation, and scenic enjoyment; to preserving a sense of place; and to preserving refuges of wildness (wildlands and wild habitats).

• *We think we ought to.* In this category are the claims that people have duties to preserve and protect biodiversity—duties based on higher moral principles or on rights that are attributed to biodiversity or its living components.

It is reasonable for any particular person to hold reasons in all three categories simultaneously. Reasons for action must be based on both positive and normative premise that is, on facts and on some concept of what is good. In the

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broad categories of reasons for caring about biodiversity, we have lumped motivations that derive from different understandings of the facts and different perceptions of the good.

Motivations rooted in claims of usefulness and satisfaction of human preferences are recognized in Western philosophical systems, but there is sharp disagreement on how much weight should be accorded to such motivations. Usefulness, especially, depends on claims of fact, and there remains much dispute about many of the pertinent facts. When it comes to motivations based on aesthetics and moral duty, alternative philosophical systems differ as to how much weight such motivations should be accorded and as to the ethical foundations on which the motivations are based.

It is no wonder that the public discussion of biodiversity issues is so extraordinarily susceptible to semantic confusion and talking at cross purposes. The objective of this chapter is to bring clarity to the discussion by characterizing the main traditions of Western ethical theory and developing briefly their implications for biodiversity.

CONSEQUENTIALISM AND UTILITARIANISM

Consequentialism holds that right action is whatever produces good consequences. For consequentialists, practical ethics involves judging the consequences by possible actions. People might be inclined to differ about which of consequences are most important. To put consequentialism into action, a single scale for evaluating quite diverse consequences would be useful.

Utilitarianism provides such a scale. Its basic premise is that whatever an individual wants is the best indicator of what is good for that individual. The consequences of different actions can be judged on a single scale: their contribution to preference satisfaction.

To modern utilitarians, preferences summarize whatever motivations lead the individual to prefer one option to another and, given the opportunity, to choose the preferred option. It is a misconception to claim that utilitarianism counts only the satisfaction of instrumental needs (food and shelter, for example) and the selfish desires of individuals. Preferences might concern the public good and community values and might be the results of a long and searching process of introspection. An individual's preferences might well be the considered plan for a thoroughly examined life, but nothing requires that they be. In deference to individual autonomy, utilitarianism does not subject preferences to interpersonal review or to substantive tests against principle or reason.

The individual's preference (or utility function) makes different options commensurable on the scale of preference satisfaction. The individual can adjust the bundle of goods and services chosen, making tradeoffs at the margin to maximize preference satisfaction. Given the budget constraint, individual willingness to

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pay—the amount of money that the individual would willingly pay to get a desired good, service, or state of the world (in total or at the margin,[1] as the case might be)—expresses the individual's value of increments in goods and services, whereas willingness to accept—the amount of money that would induce the individual to willingly give up the good, service, or state of the world—expresses value for decrements.

Utilitarians seek to provide an ethical framework for society as a whole, not just for individuals. Bentham (1986) offered the criterion of "the greatest good for the greatest number". In modern times, that has been put into use in the benefit-cost criterion: right action is whatever maximizes the excess of benefits over costs, where benefits and costs are aggregated (unweighted) across individuals.

The utilitarian criterion is related to markets in the following way: under ideal conditions, market prices are equal to marginal willingness to pay and to accept. Total willingness to pay and accept, however, includes also the consumers' surplus, which is seldom directly revealed by markets. In addition, markets often fail to reflect the full value of public goods and, for various reasons, can distort the value even of private goods. In the utilitarian system of valuation, preference satisfaction is fundamental, and market outcomes are of interest only to the extent that they provide a good account of contribution to preference satisfaction.

Two major problems with utilitarianism must be discussed. First, as Mill noted (1987), "Socrates dissatisfied should have more moral weight than a pig satisfied". That is, it is a weakness of utilitarianism that preferences are not subject to interpersonal review or substantive tests against principle or reason. It seems unreasonable to assume, as utilitarians do, that any set of preferences is as worthy as any other. Second, as Rawls (1972) noted, utilitarianism does not take seriously the distinction between persons. The criterion of the greatest good for the greatest number might be satisfied by an action that causes great harm to a few to provide relatively trivial benefit to many. Some commentators would prefer an ethical framework that evinced more concern for the effects of social choice on individuals.

LIBERTARIANISM AND CONTRACTARIANISM

Libertarianism takes the distinction between persons very seriously. Libertarians find fault with the utilitarian judgment that the welfare of society is the aggregate welfare of its members. Utilitarians might be comfortable with a policy that hurt some people while helping others even more, but libertarians

[1] Typically, willingness to pay is thought of "at the margin", that is, to preserve the next unit under threat. One could think about willingness to pay for biodiversity in total, but it would be a very large number and irrelevant for most policy purposes.

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emphasize the separateness and inviolability of the individual. From that perspective, the rights of person and property matter most.

The basic libertarian principle is that people should be free to do as they like as long as they respect the similar freedom of others. Libertarians deplore coercion of any kind and therefore tolerate only as much government as is necessary to keep people from violating the rights of others. Tyranny begins when the government coerces citizens even "for their own good".

Libertarians believe that markets are by far the best mechanisms for gathering and processing information about the value of everything—including biodiversity. Markets also secure liberty, make individuals accountable for their actions, and promote the virtues of competition. Libertarians therefore excoriate attempts by "scientific managers" to second-guess market outcomes through benefit-cost and other kinds of economic and policy analysis. There is not a dime's worth of difference, libertarians believe, between policies based on benefit-cost analysis and policies based on any other form of centralized planning. Libertarians regard pollution as a form of assault, trespass, or invasion; to impose my wastes on your person or property, libertarians believe, is to violate your personal and property rights (see boxes 4-1 and 4-2). Accordingly, libertarians approve policies that prevent, prohibit, or at least minimize pollution. They regard pollution-control law, therefore, as continuous with the common law of nuisance, which allows injunctive relief.

BOX 4-1
Property Rights

Property rights define the relationships among people with respect to the use of things. A well-specified and secure system of property rights is said to promote stability and order in society. Property rights that are exclusive wherever feasible promote markets and, as libertarians tell us, political freedom.

In light of the current property-rights movement, it is well to remember that property rights are the creation of the government that defines and secures them, that they evolve in response to changing circumstances. Just as evolution and adaptation in property rights can be virtuous, so too can stability in property rights; and there is inevitable tension between these virtues. Some proposals from the current property-rights movement are not really about stability—that is, protecting existing property rights—but are about extending them in ways quite inconsistent with recent political history: broadening the conditions under which property-owners might demand compensation for private losses due to regulation in the public interest and reversing the quarter-century-old principle of "polluter pays".

Similarly, the virtues of exclusiveness inevitably conflict with the virtue—especially powerful in the case of biodiversity—of breaking the isolation paradox. Innovative solutions are needed to resolve conflicts over biodiversity that arise from the isolation paradox.

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BOX 4-2
The Isolation Paradox

The intuition that, for an important set of economic problems, coordinated action is essential and can lead to stable solutions is hardly new. Adam Smith discussed the case of 100 farmers in the upper end of a valley, beyond the reach of the existing barge canal. All would benefit from extending the canal. None could bear the cost alone, but each would enjoy benefits larger than one one-hundredth of the cost. Acting alone, each can do nothing, but everyone could enjoy a net benefit from coordinated action. The isolation paradox is the general name given to problems of this kind. An isolation paradox is present whenever individual action fails but there exists a cost allocation (not necessarily an equal sharing of costs, as in Smith's example) such that all parties would be better off with coordinated action than with no action at all. The essential idea is that where an isolation paradox exists, there is in principle the possibility of converting a conflict into a sustainable cooperative solution, and we might benefit from exploring that possibility.

Solutions to the isolation paradox do not have to involve government or (even worse in today's political environment) big government. Individuals can act together to form and maintain clubs to get the job done. Many entities that call themselves clubs, such as the local health and fitness club, are actually private for-profit enterprises. Today, one can readily imagine a private entity resolving the canal-extension problem profitably—an option that did not occur to Adam Smith—just as "city water" is delivered to an individual home by an investor-owned corporation.

The idea of the isolation paradox suggests an openness to solutions that invoke a variety of institutional forms: private enterprises, voluntary associations, and government from the most local level to the national scale and beyond. Given the centrality of information and coordination, the array of feasible institutions is continually shifting as information, communication, and exclusion technologies develop. For a particular problem, the appropriate institutions will be consistent with the dimensions and scale of the problem itself and with the prevailing technologies and political realities. To protect biodiversity, for example, one can conceive of private for-profit genetic reserves; nature reserves operated by corporations, voluntary associations, or governments; clubs supported by members and donors operating in markets to enhance both private and government conservation efforts; and government operating as facilitator of consensual agreements among stakeholders, as well as legislator, regulator, and resource manager. Flexibility is the key in both institutional forms and the incentives those institutions transmit.

Although the libertarian defense of the individual against coercion is compatible with environmentalism in the case of pollution control, there is no such compatibility in the case of the Endangered Species Act. An endangered plant that grows on a person's land is as much his property, so libertarians reason, as are the vegetables that flourish there. The landowner is free to eat the vegetables,

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and he or she should also be free to consume the endangered plant. The idea that the plant becomes a "public good" rather than a private one just because it is endangered strikes libertarians as robbery by "slight of terms". If society wants to protect the plant by prohibiting its sale, libertarians argue, it must compensate the landowner. Anything less is a plain and clear violation of the Fifth Amendment guarantee that private property shall not be taken for public use without just compensation.

A major problem for libertarianism is how to maximize individual freedom without permitting society to degenerate into anarchy. Clearly, some restraints on individual choices are needed, but the libertarian distaste for restraints in general serves them poorly in deciding which restraints are appropriate. As we have seen, a prohibition against invasions would prevent pollution but not save biodiversity. Yet the interest that third parties, or the public at large, might have in clean air is no more obvious than their interest in biodiversity. The problem might be solved if libertarianism adopted some alternative rationale for constraints on individual prerogative, such as, the prevention of harm to others. However, as Ronald Coase (1960) argued convincingly, the concept of harm has a symmetry that renders it essentially useless for this purpose: pollution can harm the public, but prohibition of pollution would harm the polluter.

Contractarianism seeks to provide a way to maximize individual freedoms while avoiding anarchy (see box 4-3). The utilitarian position seeks to evaluate consequences, but contractarians are more concerned with process: they are skeptical that people can agree on what is good, and they seek instead agreement on a good process for making public decisions. The basic contractarian principle is Pareto safety: no change that visits uncompensated harm on anyone should be permitted; equivalently, according to the assumption that people would not consent to changes that would harm them, change should occur only with unanimous consent. This contractarian ideal is implemented in the market, where exchange is voluntary, and would be put into use by public institutions that require unanimous consent, voluntary taxation, and so on.

Because Pareto safety imposes strict criteria on proposed changes, it protects the status quo, whatever the status quo happens to be (note that the present status quo is not at all congenial to libertarians). As James Buchanan (1977) and others have shown, Pareto safety can be justified only if the status quo itself is justified. Contractarian proposals for justifying the starting point or original position include unanimous adoption of a starting constitution by real people who have real positions at risk (which would provide strong justification but seems insurmountably difficult in practice), and the Rawlsian constitution, which would be adopted behind an imaginary "veil of ignorance", where individuals who do not know their positions in society might be more inclined to come to agreement.

A complete and coherent contractarian position requires a Rawls-Buchanan two-stage process: unanimous adoption of a just constitution followed by consensual change. The constitutional stage seems elusive in practice, and Rawls'

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BOX 4-3
Welfare Economics, Utilitarianism, and Contractarianism

Welfare economics is the economics discipline's attempt to define the good life and to measure progress toward it. Individual good is defined as the satisfaction of individual preferences. The value measures are found through a process that identifies the minimal expenditure that will maintain the individual's baseline utility level. The procedure accurately reflects individual preferences, as intended, but also has the more controversial property that the preferences of the well-off count for more.

Welfare economics speaks with a clear voice about individual good, but there are distinct utilitarian and contractarian variants for addressing social good. The utilitarian approach is manifested in the benefit-cost criterion and in indexes of standard of living and cost of living. Money metrics of individual utility (for example, willingness to pay and willingness to accept) are summed across individuals to calculate social-welfare levels and changes. This interpersonal rule by aggregation has the property that it could identify a welfare improvement in a change that visited great harm on a few in the service of small gains for many.

The contractarian alternative finds it intolerable that individuals might be obliged to bear uncompensated harm in service of the public good. It emphasizes Pareto safety and consensual change: voluntary exchange of private goods and voluntary taxation for provision of public goods. Accordingly, contractarian welfare economics places great importance on property rights and compensation for individuals who would otherwise be made worse-off as the result of actions undertaken for the public good.

"veil of ignorance" process is more nearly a thought experiment than a practical prescription. Without the constitutional stage, libertarian and contractarian proposals remain seriously flawed: libertarians remain unable to deal consistently with public goods and community values, and contractarians find themselves defending a legal and economic status quo that has not itself been justified.

KANTIAN ETHICS

A tradition of ethical theory dating at least to the 18th-century writings of Immanuel Kant takes seriously the distinctions between instrumental needs, desires, tutored aesthetic taste, and matters of moral principle. Kant distinguished among three kinds of value: instrumental, subjective, and categorical. An object has instrumental value insofar as it is a means to a valued end. If you want your car to go, for example, you must fuel it. This kind of "if-then" statement, which Kant called the "hypothetical imperative", is testable and so universal and rational. Insofar as the statement "If you want your car to go, you must fuel it" is true,

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fuel has an "instrumental" although relative value (relative first to your desire to drive your car and ultimately relative to all the things you desire).

An object or outcome has subjective value insofar as people happen to like or enjoy it—although, of course, inclinations differ. As they say, there is no arguing about taste.

Kant believed that aesthetic judgments, as about beauty in nature or art, are subjective in the sense that they are not amenable to proof. Yet he also believed that these judgments make a claim to intersubjective agreement because they can be based on good reasons and shared experiences. In the case of ordinary pleasures, we value the object because we enjoy it. In the case of aesthetic pleasures, in contrast, we enjoy the object because we value it for reasons that we might expect others to grasp. Our feelings of pleasure (or pain) help us to perceive emotional and other qualities of the object; the feelings are the means by which we experience and appreciate qualities of the object and are not themselves (as pleasures) the ends we seek.

For example, a bird-watcher enjoys perceiving new avian species because he or she values these rare and wonderful animals and their qualities. That is appreciation—the enjoyment of what one values. It leads one to try to point out the valuable qualities so that others might appreciate them. It is the opposite of hedonism, which leads us to value what we enjoy rather than to enjoy what we value. Because of the difference, Kant considered aesthetic judgment to go beyond the mere satisfaction of the senses and to engage the aesthetic qualities of nature—such as its beauty, complexity, and contingency—that science cannot capture.

Finally, Kant asserted—and this is what distinguished him from utilitarian philosophy—that we can make rules that are appropriate to situations in view of our sense of who we are. By obeying these rules (Kant spoke of them as duties), we recognize the value of particular objects and outcomes as ends in themselves. Kant called the rules *categorical imperatives*. Like hypothetical imperatives, they are rational and objective, in the sense that they are public, apply to everyone, and are open to discussion, deliberation, and critical inquiry. Unlike hypothetical imperatives, however, categorical imperatives assert values that are not relative to other goals but are seen as principled responses appropriate to particular situations. To qualify as a categorical imperative, a statement must be expressed in universal terms: in situations of this kind, one should always respond in this way. The categorical imperative is not relative to any goal, such as, well-being, but is a principled response that follows from reflection on our identity as moral agents given a description of the situation to which we are to respond.

Categorical imperatives are proposed as universal moral principles. Kant insisted that a moral statement was meaningless unless it could be stated universally. The essential Kantian task is to identify a set of universal moral principles that permit one to deduce from them the proper course of action in specific cases.

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Problems arise when a situation invokes moral principles that are themselves in conflict and no single proper course of action can be deduced. Faced with disagreement about the moral principles that should guide our actions, Kant did not theorize at length about situations where principles compete. It is fair to suppose that the proper course might be to undertake a process of public deliberation leading to the enactment of legislation within constitutional constraints. By legislating and following moral rules, we determine our moral character and identity as a nation.

We are now in a position to understand the difference between utilitarian and Kantian theories of value. For utilitarians, society has no moral identity independent of the welfare of its members, who judge what benefits them. All values but welfare are instrumental or subjective. Ideally, everything but welfare itself can be assigned a value that indicates its relative worth with respect to promoting well-being. For Kantians, in contrast, value attaches to outcomes that reflect the rules or duties that we as a society accept as appropriate given our evolving identity and our understanding of the situation. Whereas utilitarians are comfortable with a scheme that values the practical and the aesthetic, and the public and the private, on the same scale, Kantians are at pains to confine relative valuation to the practical end of the continuum. Kant draws this distinction as follows: "That which is related to general human inclination and needs has a *market price*. But that which can be an end in itself does not have mere relative worth, that is, a price, but an intrinsic worth, that is, a *dignity*." Kantian ethics, however, have not resolved the problem of deciding what to do when "ends in themselves", that is, those things too important to trade off, conflict.

Kantian ethics appeals directly to the concern that preferences alone are an insufficient guide right action. In the Kantian system, aesthetic judgment, intrinsic values, and moral principle can and should trump preferences in a considerable variety of circumstances. However, several problems arise in the Kantian system. It is not clear which things have "a good of their own" independent of contribution to human welfare.

EGALITARIANISM AND ENVIRONMENTAL JUSTICE

John Rawls proposed the egalitarian criterion that inequality should be tolerated only insofar as it improves the well-being of the worst-off individual. The general problem with Rawlsian egalitarianism is that its exclusive focus on the worst-off might undermine incentives and freedom of action for everyone else. Implications of this kind of egalitarianism for environmental quality and biodiversity are unclear. If, as some suspect, environmental improvements have lower priority for the worst-off people than for the well-off, an egalitarian approach might lead to reduced provision of environmental public goods.

Environmental justice focuses directly on environmental quality for the worst-off people. The basis concern is that public policy not worsen the situation

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of the already underprivileged by visiting a disproportionate amount of society's environmental waste on them. Rather than seeking broad-based welfare improvements for the poor, as Rawls would, the environmental-justice movement seeks to improve environmental quality for the poor and to make decision-making processes and forums more inclusive of all members of society. A problem arises potentially when environmentalists place a higher priority on environmental justice than do the poor themselves.

DEEP ECOLOGY

The basic approaches of Western philosophy call for concern for welfare (utilitarianism), respect for rights (contractarianism), and respect for things that have "a good of their own" (Kantianism). The basic program of deep ecology is to take any or all of the basic ethical approaches and expand the set of entities that matter—that is, entities whose welfare counts, that have rights, and that have a good of their own—independently of human beliefs. For example, Peter Singer argues that society—in recognizing the relevance of welfare for ethnic minorities, women, children, and sentient beings—is already descending a slippery slope that must lead ultimately to respect for the welfare of all animals, plants, and even rocks. Singer is a utilitarian, but the slippery-slope argument can also be applied in ethical frameworks based on rights or intrinsic values.

The essential policy implications of deep ecology involve conscious and deliberate limitation of the impacts of human beings on the other entities that together make up the planet and life on it. Some would argue that Singer's slippery-slope argument is not entirely convincing. The hard work of legal craft and scholarship is directed to making the fine distinctions that protect society from slippery slopes, and history shows that society often has been able to stop or reverse itself. In application, deep ecology encounters two kinds of problems: the standard problems of the welfare, rights-based, and intrinsic-value approaches; and the special problems of grounding the expanded concern for nonhuman entities. What makes us think that humans are the only sentient species? And what about the welfare of nonsentient beings? Worthwhile exercise of rights would seem to require at least cognition, but some have argued that society could delegate to human specialists the responsibility of advocacy for noncognizant entities (for example, trees). Intrinsic value is something to be recognized by human beings; thus, broadening the category of things that have "a good of their own" requires that human beings see the light and so fails to provide a locus of value independent of human beliefs.

DISCURSIVE ETHICS

We have made a distinction between ethical approaches that attempt directly to value the consequences of actions and theories that seek to define valid pro-

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cesses for deciding right action. Discursive ethics offers a process-oriented approach that is less formal than contractarianism or even the Kantian approach of public deliberation.

Discursive ethics begins with the assumption that humans are social beings and ethical deliberation makes sense only in a social context. Individuals might sit in solitary contemplation of what is "just" and "good", but their definitions of those terms and the language in which they frame ethical questions result from social interaction. All moral principles will depend on human sociality, so discursive ethics assumes that the key challenge in resolving ethical conflicts is to ensure that our discussions are competent and fair.

The sociologist Jurgen Habermas, who is the principal proponent of this approach, offers some principles for competent and fair moral discussion (Habermas 1991, 1993). The discursive approach to ethics does not prescribe specific ethical principles that a community must follow. It does not make universal claims about what is right in all contexts. Rather, the advocates of discursive ethics argue that a fair and competent discussion process must be used in arriving at moral norms that will guide individual choices. The moral rules developed by a community and the specific choices that the community makes will depend on circumstances. But the choices can be considered ethically appropriate if all those affected by decisions agree to the principles on which the choices will be based and if agreement comes as a result of open and informed discussion.

Discursive ethics has several strengths. It assumes that appropriate action depends on context. It relies on a model of human decision-making that emphasizes human cognitive strengths rather than mental limitations (Dietz 1994; Dietz and Stern 1995). It emphasizes the ethical challenges that emerge when societies are faced with new problems that are not easy to analyze with existing moral principles. It assumes that our morality must evolve as we face new problems, and it offers a democratic process through which such evolution can take place.

Discursive ethics also has some serious limitations. Two seem especially relevant to the problem of valuing our natural heritage. One is a conceptual problem. As Habermas (1993:105–11) has noted, only humans can participate in debates about morality, so the interests of non humans or of the biosphere itself are represented only to the extent that humans speak for them. The second problem is a practical one. Habermas offers an ideal system for settling moral disputes, but he offers no practical machinery for implementing his ideals. Although the utilitarian view of the world can be translated into policy analysis through the machinery of benefit-cost calculations, the tools of discursive ethics have not been as well developed. But over the last 2 decades, there have been a number of experiments in using discursive processes to inform environmental policy, and the results seem promising (Cramer and others 1980; Dietz 1994; Dietz and Pfund 1988; Renn and others 1993, 1995).

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RELIGIOUS AND SACRED VIEWS

Religious beliefs influence attitudes toward nature and biodiversity. Just as there are many concepts of religion and what is considered sacred, there are many religious views of nature.

A recent ethnographic study of environmental values by anthropologists concluded that "it seems that divine creation is the closest concept American culture provides to express the sacredness of nature" (that is, Americans have a sense of nature that is linked to their ideas about the divine) (Kempton and others 1995). Survey research has also found links between religious beliefs and environmental concern (see, for example, Eckberg and Blocker 1996). But the links between religion and environmental concern take several different forms. Some find a religious basis for believing that there is order and balance in nature that deserves to be preserved; that can be extended to the idea that every species plays a role in the balance of nature. Some people's beliefs about nature derive from Genesis and its admonition that humans should make productive use of nature. Some of the writings of the transcendentalists and romantics grew out of the idea that people can find evidence in nature of a god as Creator.

The considerable range of religious views of nature (and of most other topics) points toward the difficulties in characterizing all or part of them as a single philosophy of value. But, it makes sense to recognize the possible importance of religious underpinnings of attitudes toward nature. (The committee considered including a discussion of non-Western views here, but that is beyond its expertise and probably of little relevance to most potential users of this report.)

IMPLICATIONS OF VARIOUS VIEWPOINTS FOR THE VALUE OF BIODIVERSITY

Many people naturally and intuitively distinguish instrumental and intrinsic values—assigning value to something because is serves a valued purpose and because it is valued for itself. Many people ascribe intrinsic value to some aspects of biodiversity. Although there is fairly broad agreement among philosophical traditions about what is meant by instrumental value, there is much less agreement about what is meant by intrinsic value and about how seriously to take the idea that something like biodiversity might have intrinsic value.

If we accept for the moment that intrinsic value means what is ultimately valued, a utilitarian would ascribe intrinsic value to preference satisfaction and welfare; biodiversity would then have only instrumental value. A libertarian would ascribe intrinsic value to freedom, that is, the absence of coercion; again, biodiversity could have only instrumental value. A Kantian might (or might not) determine that respect for (some aspects of) the biota is a universal principle, thereby ascribing intrinsic value to it. A deep ecologist might well ascribe intrin-

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sic value to many aspects of the biota. Clearly, the major Western philosophical traditions disagree much more than they agree about ascribing intrinsic value to biodiversity.

Ronald Dworkin (1994) argues that many claims couched in the language of rights are really claims of intrinsic value. In the controversies about abortion, for example, many people who talk of fetal rights do not mean that a fetus literally has rights that it can (or should be able to) enforce against its mother. Rather, they are claiming that the fetus has a value that should be taken seriously, even if it conflicts, say with the welfare of the mother. A similar claim could be made for some aspects of biodiversity. They are serious concerns—serious enough that people believe they should endure sacrifice up to some considerable level to preserve them. Things that have intrinsic value in this sense are important enough that they should not be sacrificed for trivial gain.

Utilitarianism, and especially its welfare-economics version, would recommend that biodiversity be preserved and enhanced insofar as the benefits exceed the costs. Benefits would be broadly defined to include market values, economic surpluses, and willingness to pay or to accept nonmarket values, including existence values. (Existence values are values that are not predicated on use, in the ordinary sense of that word; that is, people gain utility from, or have preferences concerning, states of the world, in this case with respect to biodiversity). Biodiversity would be valued and promoted insofar as society desired it and were willing to pay for it. Some individuals, however, might turn out to bear costs greater than the benefits that they enjoy, without violating utilitarian precepts.

Contractarianism would, in principle, promote biodiversity to the same extent as utilitarianism; that is, the basic concepts of value are identical—the buyer's best offer and the seller's reservation price (the lowest price at which the individual would sell voluntarily) under contractarianism and willingness to pay and to accept under the benefit-cost criterion). Nevertheless, contractarians would demand a special concern for protecting property rights, compensation of individuals harmed in service of the general public good, and incentive-compatible methods of financing the public-good aspects of biodiversity. In a world with nontrivial transaction costs, those requirements might pose impediments, in addition to those raised by ordinary costs, for biodiversity programs.

Kantianism would recognize a hierarchy of concerns about biodiversity. Instrumental reasons for preserving biodiversity would be recognized but would be ranked lower than tutored aesthetic concerns (Kiester 1996); the intrinsic values of things that have "a good of their own" would rank highest of all. A Kantian approach takes seriously the possibility that people individually and as a society might believe that we ought to protect species as "ends in themselves" and thus apart from the welfare effect of such a commitment. In other words, we might preserve species because we believe that we ought to do so; and we would accept this responsibility, as a matter of collective responsibility not individual satisfaction. That is not, of course, to say that we must sacrifice all our wealth to

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protect every species. On the contrary, Kant was clear in distinguishing the obligatory from the supererogatory, that is, actions that are morally praiseworthy but go beyond the call of duty. Kantians would be comfortable using economic analysis to structure incentives so that we can get the most species protection at the lowest cost.

Randall and Farmer (1995) have argued that utilitarianism, contractarianism, and Kantian ethics could accept, for different reasons, a safe minimum of conservation for species, habitats, and ecosystems. However, the different philosophical frameworks are likely to disagree about the subset of biodiversity that deserves such protection and about the conditions under which human society would be justified in abandoning the safe minimum because it demanded "too much" sacrifice.

Egalitarianism would insist on special concern for the welfare of the worst-off human beings; this has unclear and not necessarily favorable implications for concern for biodiversity. The environmental-justice approach might well demand protection of biodiversity in impoverished places and for impoverished people but is likely to encounter opposition from those who believe that the impoverished have more pressing concerns.

Deep ecology could take any of the basic utilitarian, contractarian, or Kantian ethical approaches and extend the category of things that matter (whose welfare is a concern, that have rights, or that have "a good of their own") to all or some of the elements of biodiversity. A major thrust would be to ground the claims of natural heritage independently of human value and belief so that humans would be obliged categorically (not just as it suited them individually) to honor these claims.

Discursive ethics is really a process—and a relatively loosely defined process at that. Its promise lies in determining and expressing genuinely social values inherent in biodiversity as opposed to the aggregation of individual values that utilitarism would promote.

SUMMARY

This chapter reviewed the main Western philosophies of value. This provides a context for the description in the next chapter of how the tools of economics contribute to understanding biodiversity values in relation to resource-management decisions. Understanding the implications of these various philosophies for valuing biodiversity is important for public-resources managers, who must deal with different value philosophies in their decisions.

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5

Economic Methods of Valuation

Chapters 3 and 4 discussed a wide array of services and amenities that biodiversity provides for people who might or might not value its individual components—individual genes, species, and ecosystems—and the diversity of components. Some aspects of biodiversity are valued directly; while others are valued for their contributions to ecosystem support and, hence, to sustainable production of things that are valued directly. The economic value of biodiversity has its place in the policy-making process. Although biodiversity might well have substantial economic value, compared with alternative consumptive resource uses, economic value does not tell us everything we need to know about the value of biodiversity.

Economic valuation is an attempt to provide an empirical account of the value of services and amenities or of the benefits and costs of proposed actions (projects or policies) that would modify the flow of services and amenities. Economic valuation provides a utilitarian account, that is, an account of contribution to the satisfaction of human preferences (see chapter 4 for a detailed discussion). Therefore, it provides a particular perspective on value—in this case, on the value of biodiversity. Utilitarians might object to some aspects of the economists' utilitarian account: to produce an economic account of contribution to preference satisfaction, a particular kind of structure has to be introduced into the analysis, and utilitarians will not always endorse the process or the results. In addition, there are many nonutilitarian perspectives on value (see chapter 4), which deserve consideration on their own merits.

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THEORETICAL FOUNDATIONS

Welfare-Change Measurement

The foundation of benefit-cost analysis (BCA) is welfare-change measurement: the benefit from some proposed action is the money-related welfare change that it generates. The concept of benefit is an increase in welfare, that is, preference satisfaction; and welfare change is measured in terms of money. Valid money measures of welfare change can be defined conceptually and can be estimated with reasonable accuracy, precision, and reliability; and individual welfare changes to arrive at social benefits and costs can be added up. Skepticism about any of those claims, in general or in the specific application to biodiversity, suggests that caveats should be applied to the interpretation of benefit-cost information or its use in policy decisions.

The conceptually valid measures of welfare change are willingness to pay (WTP) for benefits and willingness to accept (WTA) for costs. WTP is the amount of money that someone would willingly pay to get a desired good, service, or state of the world rather than go without; WTA is the amount of money that would induce someone to willingly give up the good, service, or state of the world. Those measures are readily defined in market terms—WTP is the buyer's best offer, and WTA is the seller's reservation price (the price at which the seller will hold rather than sell)—but they are by no means restricted to commodity markets. Some people are willing to pay substantial amounts of money for improvements in the quality of their life. Some would willingly accept a lower level of amenities if compensated with money; for example, some would willingly move to an undesirable location if promised a large enough pay raise.

For BCA of a policy proposal, aggregate benefits are defined as the sum of WTP figures for all those who stand to gain from the proposal. Aggregate costs are the sum of WTA figures for all who would provide goods and services or bear disamenities if the policy proceeds. Some critics object to aggregating benefits or costs that accrue to individuals, on the grounds that individuals with greater income and wealth tend to have greater WTP (or WTA) and that simple aggregation makes no attempt to correct for this or to place extra weight on things that benefit the disadvantaged.

Given that many proposals promise benefits and costs continuing well into the future, the "bottom line" of the BCA is expressed as net present value, that is, the difference between the sum of present and future benefits and the sum of present and future costs, all discounted to the present. The practice of discounting has been controversial in some circles, especially in the context of environmental projects and policies (for example, Daly and Cobb 1989), where it is claimed that discounting tends to trivialize the demands of future generations for present conservation (see box 5–1) . That argument has been winning fewer converts in recent years (Heywood 1995), as economists have been reminding us

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BOX 5-1
Does Discounting Harm the Future?

The discounting of future benefits and costs is a practice introduced from financial analysis to account for the productivity of capital. In recent years, some environmental economists have been swayed by critics who worry that discounting implies that the concerns of the future (perhaps only a few decades hence) count only trivially in the calculations of the present. Thus, we have the discounting paradox: we must discount, it is claimed, to avoid damaging the future by making wasteful commitments of capital to unproductive projects; and we must not discount, it is also claimed, to avoid trivializing future demands for present conservation.

The paradox can be resolved in the following way. We can be reasonably confident of two propositions: if the problem is simply to determine the rate of consumption from an endowment (the "cake-eating problem"), a society with a positive discount rate will choose a consumption path relatively high at the outset and declining over time (Page 1977); and if capital is productive and the young need to borrow it to produce efficiently, equilibrium interest rates will be positive and a policy of repressing the interest rate (undertaken, one imagines, to protect the future) will actually depress the trajectory of future welfare (Farmer and Randall 1997). That is, in a cake-eating economy, discounting is destructive of future welfare, but in a productive economy it is not.

This resolution of the discounting paradox directs our attention to the real question: are we, or are we not, operating in an economy that is ultimately cake-eating? If capital accumulation is sufficiently high, renewable resources are managed carefully, capital and renewable resources are adequately substitutable for exhaustible natural resources, and technological development tends to enhance the substitutability of plentiful resources for those which are most scarce, the cake-eating problem can be avoided. In that case, concerns that discounting inherently damages the future are misplaced. It can also be argued that such policy interventions as the safe minimum standard, which address directly crucial natural resources, provide a more appropriate response to conservation crises within otherwise productive economies than would repression of the discount rate.

that realistically high discount rates discourage wasteful investments that would actually harm future prospects. Current writers are skeptical about the wisdom of using low discount rates to achieve policy goals, preferring more direct approaches to the concerns of environmentalists. For example, Howarth and Norgaard (1991) argue that balancing equity among generations should be addressed by intergenerational transfers of resources, and Farmer and Randall (1997) suggest that targeted conservation policies provide the appropriate remedy to the extent that particular natural resources are both necessary for human welfare and threatened with exhaustion.

Cost-effectiveness analysis can be useful in guiding decisions toward the

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most efficient way of meeting specified goals. However, it does not provide estimates of values. If there are several ways of accomplishing a particular and well-specified goal, cost-effectiveness analysis compares the costs of the various approaches; the most cost-effective is the one that accomplishes the goal at the lowest cost. If different approaches would achieve different quantitative levels of performance, cost-effectiveness might be expressed as cost per unit of performance (for example, cost per acre preserved or cost per nesting pair saved). If the policy-maker is confident that the different approaches are otherwise equivalent in terms of the results achieved, choosing the most cost-effective approach is justified.

Categories of Value

WTP and WTA for some natural resource or amenity are equivalent to its total economic value. However, humans use and enjoy natural resources and amenities (as they do other goods and services) in a variety of ways. At one extreme, natural resources can provide commodities that are purchased and consumed directly; at the other extreme, people might enjoy satisfaction that a particular habitat is being maintained at high quality. Both kinds of use generate economic value, but it is likely to be expressed in different ways and via different institutions for commodities, in terms of quantities taken and prices paid and for habitat quality, perhaps via voluntary contributions to conservation organizations.

Total economic values include all the several kinds of economic values that have been identified by economists. Total economic value is the WTP for a change in the state of the world. To impose some order and consistency, the following relatively simple classification of economic value is gaining ground among economists.

Use value is generated when a person uses an environmental service actively, typically by consuming it directly or combining it with other goods and services and the person's own time to "produce" an activity that generates utility. Recreation experiences, for example, are produced by combining on-site amenities with travel services, recreation equipment, and the participant's time. Use value is likely to be reflected (at least in part) in behavior such as purchases and visits.

Use value, naturally, includes the expected value of future use. If uncertainty attends future availability of an amenity or future demand for it and potential users are risk-averse, *use value under uncertainty* can include *option value*, the value of assurance that things (such as biodiversity) that are available now will still be available when we need them, and *quasi-option value*, the value of waiting to decide on the disposition of an asset (such as whether to build houses on Camp Pendleton—see the case study in chapter 1) motivated by the possibility that we will be able to make a "better" decision later, perhaps because we will have more information. When institutions provide opportunities for individuals to secure options for future use, these kinds of value might be reflected in behavior.

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Passive use value captures the idea that people might enjoy satisfaction from "just knowing" (that is, enjoying the assurance) that a particular habitat is being maintained in good condition. There is no general expectation that passive-use value involves overt activities or is reflected in behavior. However, contributions to voluntary organizations that provide habitat preservation and political support for pro-habitat policies are consistent with passive-use value.

Together, use value, option value, and quasi-option value make up total economic value. It also includes bequest value, in that bequest motives assume that one's heirs will enjoy use or passive use. Total economic value includes all the kinds of economic value. There is no claim that economic value, however, constitutes the totality of value. As chapter 4 has made clear, there are many *ways of valuing*, but, total economic value then represents a comprehensive application of the economic way of valuing.

METHODS OF VALUATION

Valuation relies on detailed information from the natural sciences. We might value an environment as an asset, in which case its value would be the net present value of the services that it provides and will provide. Alternatively, we might evaluate some proposed action (a project or policy); value would then be the net present value of the change in services that the environment will provide minus the cost of implementing the proposed action. Either way, valuation requires detailed knowledge of the service flows of the environment, of the costs incurred in preparing these services for human enjoyment, and of the responsiveness of service flows and costs to human interventions (Randall 1987 and NRC 1997 provide conceptual models of the valuation process). Much of that information must originate with experts whose specialties are far from economics, for example, ecologists and hydrologists. Economic valuation depends heavily on information that is fundamentally noneconomic.

Valuation also requires evidence of WTP and WTA. Evidence of WTP and WTA varies along two dimensions of quality: consistency with the conceptual framework of welfare-change measurement and reliability of the data themselves. For example, data generated by market transactions are convincing in at least one respect—paying money is the sincerest expression of WTP and accepting money and relinquishing an amenity constitute the sincerest expression of WTA. But the data might, for a variety of reasons, fail to measure the correct value concept. Price typically indicates marginal value (literally, the value of the next unit more or less than the status quo quantity—a small change); but a proposal might involve nonmarginal (big) changes. In addition, market distortions of various kinds might distort prices, markets might be incomplete or otherwise imperfect, and the environmental service involved might be nonmarketed. Data generated by contingent valuation or contingent policy referendums often can (because a researcher controls the valuation context) be addressed to the right value mea-

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sure, but still this might raise doubts as to whether contingent payments and votes are reliable predictors of behavior. Valuation researchers are often faced with one or another form of this dilemma: "harder" data might depart from the ideal, and conceptually valid measures might be "softer". In some cases where hard data depart from the ideal value concepts, economists have developed ingenious methods of inferring the ideal values; however, there is always a risk that they will be forced to substitute assumptions for evidence and structure for information. The resulting value estimates will be to some degree artifacts of the methods used and the research decisions made.

Direct and Indirect Evidence from Markets

It is hard to imagine a market for biodiversity as a whole, but its various components are routinely marketed. Consider a biodiverse forest. Timber, fuel wood, and some nonwood products can be produced and sold. The forest can provide catchment for water that is valued by downstream farmers and urban residents. The forest ecosystem can harbor genetic resources with commercial potential, for example, rare species that might be of pharmacological interest or wild species that are precursors of modern, commercially important plant varieties. Recreationists and nature-lovers can devote resources (money and time) to visiting the forest. People can buy homes near the forest to have access to its amenities. The productivity and value of these various activities depend on how the forest is managed, so proposals that affect forest planning and management will generate costs and benefits that are reflected, to various degrees, directly or indirectly in markets. The Pacific Northwest case study in this chapter provides a detailed example.

Market Demands and Prices

For commodities that can be sold in quantities that are small relative to the total market, the economic value that can be assigned to a decision to sell or preserve is simply the product of the market price of the commodity and the quantity. For example, if 20 acres of old-growth timber is reserved from the market to protect a pair of spotted owls, one estimate of the cost of this decision is the product of the volume of the timber and the market price per unit volume. That holds as long as the quantity is so small that its removal from the market does not affect the market price of timber generally.

But consider the Pacific Northwest (see case study, this chapter), in which the area of federal forest taken off the market to protect the spotted owl and other threatened species had accounted for some 10% of the nation's softwood lumber production. The quantity of timber removed from the market was clearly large enough to affect the market price for timber in much of the country. For such a decision, an estimate of the economic cost must consider not only the change in

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the quantity of timber marketed from that area, but also the change in the market price per unit volume of the remaining marketable timber (from before the decision to after the decision). Such an estimate must also consider what economists refer to as "substitution effects". The changes in quantities and prices that result from a decision of this magnitude affect the market price of timber in other areas. Timber producers in forests other than those immediately affected by the decision (for example, the southern United States) respond to the change in timber price by changing the quantities of timber that they put on the market, thus causing further changes in the price of timber. Additional complications include the effects of the changes in timber price on the marketing of such substitute products as steel and plastics and the modifying effects of time as these various factors work through the marketplace. In sum, calculating the effects of decisions that affect market prices is not easy, but it is conceptually feasible.

The goal of valuation—measuring net present value—introduces two complications. First, "net value" requires that any costs associated with using the resources, such as, timber-harvesting costs, be subtracted from gross value. Second, "present value" requires prediction of future demands for environmental services. In the cases of timber, water supply, and genetic materials, the forest augments the supply of things that are valued as factors in production. So the demand for forest products is a derived demand, which complicates predictions of demand: the analyst needs to be concerned with demands for the final products (houses, irrigated crops, and pharmaceutical products) and with the supply of other things that might serve as substitute factors in their production.

The idea of substitutes suggests another approach to valuation: when it is hard to observe market demands for forest products directly, the analyst might look to market evidence concerning substitutes. For example, the avoidance cost method might value improved water quality by observing the household water-filtration costs avoided, and the replacement-cost method might value increased water catchment by calculating the cost of additional reservoir capacity that would serve the same purpose. In both cases, the methods provide an upper-bound value for the particular services they address: the services cannot be valued at more than the cost of avoiding the need for replacing the service with a perfect substitute, but they could be valued at less than that, in the event that effective demand would not clear the market for these services at these prices. The Quabbin Reservoir and Lake Washington case studies in chapter 6 illustrate this.

Travel-Cost Methods

Recreationists spending their money and time to visit the forest leave a trail of indirect evidence about their WTP for the services and amenities that it provides, and travel-cost methods attempt to tease out this WTP. The weak-complementarity assumption, of course, limits the travel-cost method to estimating the

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use values associated with site amenities. The simplest travel-cost models posit simply that the number of visits, at a given level of site quality, is a function of travel costs and socioeconomic variables, where travel cost is a proxy for the "price" of visits and includes costs of distance traveled and time spent in traveling. Substitute sites and activities typically are included in arbitrary fashion or assumed to be of little import (formally, this is accomplished via assumptions of separability in the utility function). A large literature attests to the difficulty that researchers have experienced in estimating the cost of travel time (Bockstael 1995), but this is symptomatic of a general difficulty: it is inherently difficult for researchers to observe the cost of a visit, that is, the value opportunities foregone to make the visit (Randall 1994). If one assumes a relationship between the quality of on-site amenities and the costs of goods and services used in traveling to the site, the value of an increment or decrement in site quality is measured as the integral between demands for visits at the with-proposal and without-proposal levels of site quality.

The random-utility model (RUM) has become the travel-cost model of choice (Bockstael 1995) because its systematic treatment of substitute sites allows it to characterize site quality more completely. RUM models are therefore more useful than basic travel-cost models for valuing changes in levels of environmental amenities. Their disadvantage arises from their substantial information needs, which in practice often lead to the use of very large data sets and simplifying analytical assumptions that impose rigidities; thus, estimates based on travel-cost models are to some degree influenced by researchers' analytical choices.

When travel-cost models are used to predict number of visits, validation is relatively simple, and several well-known models have performed well (for example, Bockstael and others 1987). However, direct validation of the value estimates obtained with travel-cost models is impossible; the best one can do is test for convergence of the results of travel-cost methods and the results of alternative approaches, such as contingent valuation, and such tests have provided some empirical evidence of convergent validity.

Hedonic Price Analysis

Hedonic-price analysis separates the factors that contribute to prices to identify the contribution of those based on environmental amenities. Imagine a good with several important or desirable features, such as a house or automobile. It is a reasonable hypothesis that the price of a particular house or car reflects its particular characteristics. If a statistical analysis succeeds in explaining the price of a house as a function of its characteristics and one of those characteristics is the level of environmental amenities, then the marginal (small) impact of a change in an amenity level (a trait that makes it attractive) on the house price should provide evidence of this amenity value. This is the intuition behind hedonic price analysis. A hedonic-price function, relating house prices to characteristics, is

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estimated. Typically, three kinds of characteristics are used: on-site characteristics, such as the number of bedrooms; neighborhood characteristics, such as school quality; and environmental amenities, such as access to a biodiverse forest. The first derivative of the hedonic-price function with respect to the environmental characteristic of interest is its hedonic price (or marginal implicit price), a measure of the marginal value of the amenity.

The literature suggests that hedonic-price analysis has succeeded, in a fairly wide range of circumstances, in generating plausible estimates of marginal hedonic prices for various housing characteristics, including environmental amenities. To value nonmarginal changes in amenity levels, however, it is necessary to estimate hedonic demands, that is, demands for amenities. The literature reports many attempts to find conceptually valid methods of identifying hedonic demands, but no method has proved generally acceptable. Hedonic-price analysis is often effective for valuing marginal changes in the levels of environmental amenities that can be accessed via, say, choice of home site but cannot generally be used for valuing nonmarginal environmental changes. The assumptions underlying the method limit its application to a subset of use values; for example, a housing-price hedonic analysis will measure use values associated with home site amenities, but not values that can be accessed regardless of exactly where one lives.

Evidence from Self-Reports

If we design and ask the questions with enough care, perhaps people can provide reliable evidence of amenity values by telling us their WTP or WTA directly or by telling us what they would do (for example, buy or not buy or vote yes or no) if given well-specified choice situations that we construct to generate data that we can analyze to infer their WTP or WTA. That is the intuition behind contingent valuation and contingent-choice experiments. The great advantage is that the researcher controls the context of choice, which makes it possible to estimate total economic value, passive-use value, and various use values that can elude the methods that use market-generated evidence, directly or indirectly. A further advantage is that information can be obtained to value amenity levels beyond the existing range; if it can be described by the researcher and comprehended by the respondent, it can be valued. The potential disadvantages lie in the self-reported nature of the data: some people might seek to answer strategically, some might answer carelessly, and some might struggle mightily (but hopelessly in the end) to provide valid responses to questions that cannot be answered meaningfully. Economists, who are weaned on the admonition to "watch what people do, not what they say", approach these methods with a well-developed skepticism; yet the results, although mixed, have been encouraging enough to stimulate a proliferation of applications.

The techniques require primary data collection in a survey or experimental

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context. With rapid advances in information and communication technologies and increasing synergism among research programs in, for example, economics, social psychology, and marketing, it is reasonable to expect vigorous innovation in research design and data collection methods. In this report, we use the standard categories of contingent valuation (in which responses to one or a few choice questions provide the basic data for valuation) and contingent-choice experiments (in which value is inferred from responses to a sometimes long sequence of pairwise choices). The basic project underlying the methods is to learn about value from people's self-reports; and as development and testing of these methods proceed, we can expect new approaches to emerge and existing categorizations to become obsolete.

Contingent Valuation

The essential elements of a contingent-valuation (CV) exercise are a description of the default and alternative situations (respectively, what you get if the proposal fails and if it passes), the institutional environment, the valuation question, and the policy-decision rule: How does the answer to the valuation question affect whether the proposal passes or fails? (See the Grand Canyon flush case study below.) The valuation question can be continuous (or open-ended); for example, What would you be willing to pay? Or it can be in the form of a dichotomous choice; for example, Given the stated cost to you and the policy-decision rule, would you vote yes or no? (Alternatives in common use are, Would you buy it or not?; Would you donate to the trust fund or not?) The different forms of the valuation question require different analyses to estimate WTP or WTA; for example, the results of the dichotomous form are usually analyzed with some kind of RUM (Hanemann 1984). With different policy-decision rules, they imply different kinds of incentives for truthful responses (Hoehn and Randall 1989).

There is already an extensive literature of CV applications, and attempts to validate CV include tests for internal consistency and tests of convergence with value estimates obtained with different methods. Encouraging results have been obtained (for example, Carson and others 1996; Smith and Osborne 1996), but critics have raised enough doubts (for example, Hausman 1993) for CV to remain controversial. A 1993 report by a prestigious panel (Arrow and others 1993) failed to settle the issues when it endorsed CV in principle, even for measuring passive-use values in environmental-damage litigation, but announced a long and demanding list of standards that a valid CV should satisfy. CV that would meet the panel's standards would be prohibitively expensive in most applications, and, as methodological innovation and the accumulation of evidence proceed, the process of rethinking the panel's recommendations is beginning.

One of the panel's recommendations deserves highlighting here. In keeping with a good deal of professional opinion, the panel concluded that CV could not

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be endorsed for estimating WTA directly—that whereas WTA is the appropriate measure of value for decrements in environmental services, considerations of reliability lead to the recommendation that, instead, self-reports of WTP to avoid loss can substantially understate WTA (Hanemann 1984). The panel's recommendation would have the effect, therefore, of undervaluing the losses from destruction of unique ecosystems.

Contingent Choice Experiments

Open-ended CV sets a rather difficult task for respondents (announcing a dollar value of some nonmarketed amenity), and dichotomous-choice CV sets a simpler task (announcing whether a proposal is accepted or rejected at a specified cost) but collects only one or two valuation data points. It might be argued that progress could be made by having respondents make a larger number of simple pairwise choices. That is the motivation for contingent-choice experiments, in which data generated by a sequence of pairwise choices are analyzed with RUMs to generate value estimates. As Adamowicz and others (1994) demonstrate, these methods have another potential advantage: contingent-choice and actual-choice data can be combined to extend the range of data points and to test for consistency between the two kinds of data. The methods also have disadvantages: a long sequence of pairwise choices can tax respondent's patience, and the RUM analytical framework imposes rigidities on the analysis.

Contingent-choice experiments are a fairly recent development, so the evidence on their performance is rather thin. Initial applications have emphasized amenity-use values, but there is no inherent reason why they could not be used to estimate passive use and total values, and (given the CV controversies) current research in environmental-damage assessment is heading in that direction.

Case Study: The Grand Canyon Flush

Dams and reservoirs on major streams affect downstream conditions by changing water flows, water temperatures, sediment loads, and the character of stream-bottoms and beaches. A large-scale test of the potential for reestablishing stream-bottom and beach characteristics in the Grand Canyon of the Colorado River was conducted in the spring of 1996. A week-long surge of water through the canyon was provided by opening the gates on the Glen Canyon Dam just upstream of the Grand Canyon. Initial results of the experiment were evident almost immediately, even while the "grand flush" was in progress.

A major purpose of the experiment was to determine whether sandbars along the river could be restored for recruitment of riparian trees and shrubs, an important element in the canyon's ecosystem; a finding before the experiment indicated that the dam-caused lack of springtime floods had reduced the energy in the river needed to lift bottom sediments onto adjacent sandbars. An additional goal was

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to improve habitat for some native species of fishes, at least one of which is endangered. To meet those goals, water storage behind the dam had to be reduced, thereby reducing potential water supplies to downstream users and power generation. The interests affected by the flush included water and power users; recreationists, especially rafters who use the sandbars; sport fishers who value the cold-water trout fishery below the dam; Indians living along the Grand Canyon; and species whose habitat is affected by river flows and the character of the canyon's ecosystem.

The Issues

The gates on the Glen Canyon Dam in northern Arizona were opened on March 26, 1996, after over 10 years of study. The dam was built primarily to control water flows to meet domestic, municipal, and irrigation needs in the downstream states of California, Arizona, New Mexico, and Nevada and the upstream states of Colorado, Utah, and Wyoming. But the dam was also an important producer of hydroelectric power. After construction of the dam and filling of the reservoir, other concerns grew in importance, including river rafting and protection of species, some of which were endangered fishes. The effects of the dam on the character of the river—the smoothing of normal seasonal variations in flows through the Grand Canyon—were also recognized. Proposals were made to open the dam's gates occasionally to allow flood-like surges of water to rebuild the sandbars along the river banks. But lowering water levels in the reservoir was also seen as a threat to meeting the needs of water users and as expensive in terms of reduced power supplies.

Lake Powell (behind the Glen Canyon Dam), Lake Mead, and a number of smaller reservoirs on the Colorado River and its tributaries, hold about 4 times the average annual flow of the Colorado River. This storage is used to even out the year-to-year and seasonal supply of water to various users, divided between the upper and lower basin states by interstate compact and court decrees. In view of the history of large variations in runoff and of periodic droughts, the Glen Canyon Dam was built upriver of Grand Canyon National Park in part to provide water to the upper basin states and in part to regulate flows into Lake Mead, which supplies much of the water to users in California.

The dam is also a major source of power, although generating income from this power has always been secondary to supplying water. Congress specified that, although power production was not to interfere with supplying water, maximal power at firm rates was an objective. Without the power production, the dam would have been seen as uneconomical and might never have been built (NRC 1996:11-3). Once the dam began to operate, the smoothing of seasonal variations in water flows had major effects on the river as it flowed through Grand Canyon National Park. The dam stored and substantially reduced the sediments carried by the river. In addition, the elimination of high flows in the spring reduced the

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ability of the river to move coarse sediments that reached the river from tributaries below the dam. The result was a loss or reduction in height of the many sandbars along the river that provided camping sites for recreationists and backwater habitat for native fish. The release of water from the pool behind the dam also lowered the average temperature of the river, especially in the stretches just downstream of the dam. This favored introduced species of trout but militated against native fishes, such as the humpback chub.

Use of the river was also changing, especially with the rapid increase in recreational river rafting. The increase in average daily flows in the summer increased the opportunities for rafting, and maintaining relatively steady flows, as opposed to the fluctuations that come with providing power on demand, is generally seen as improving the experience of whitewater rafting. The loss of sandbars on which to camp is seen by rafters as a negative factor. The river downstream of the dam also became a valued cold-water fishery for trout. Those factors assumed greater importance relative to supplying electric power in the early 1980s. The Bureau of Reclamation (BOR) and the Western Area Power Administration (WAPA), the federal agencies responsible for operation of Glen Canyon Dam and marketing power from it, however, still saw their responsibilities as meeting the goals of supplying water to users and electric-power production and marketing. But as a result of pressure from new constituencies, such as trout fishers and river rafters, and the mandates of the National Environmental Policy Act and the Endangered Species Act (ESA), BOR initiated the Grand Canyon Environmental Studies (GCES).

After initiating the GCES, the BOR decided that it needed outside help to gain credibility for the studies. The Research Council was asked to form a committee to provide scientific review of the GCES, which it did from 1986 to 1995. The committee interacted with the GCES, provided regular reviews and comments, and summarized its work in its 1996 report (NRC 1996:16-8). Early and major criticisms of the GCES effort was that it lacked a coherent ecosystem perspective and that its process for getting external advice was slanted toward the views of BOR and WAPA, even though BOR received 33,000 comments on its draft environmental impact statement (EIS) for operation of the dam. The GCES was also limited initially to considering effects only in the region immediately below the dam, although the region within which effects occurred was much broader. In part, that limited conception of the affected region was a result of law and politics, but the Research Council reviews helped to expand the region of concern to areas that could reasonably be expected to be affected by changes in the dam's operations (NRC 1996:28-33).

One result of the GCES was consideration by BOR of alternative ways of restoring some features of the downstream ecosystem through controlled releases of impounded water at the Glen Canyon Dam. A finding that the river's tributaries below the dam supplied enough sediments to rebuild sandbars but that the muted flows of water as a result of the dam did not suffice to lift the sediments

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was a key piece of information. In effect, BOR used an adaptive management strategy that recognized the need to weigh power-production costs and benefits against environmental costs and benefits. It also agreed to an experimental release, which was delayed to March 1996, to test the results of the GCES (NRC 1996:219–20).

The Valuation Problem

As the GCES process developed, the matter of weighing conflicting values grew in importance. On the one side were the revenues from hydropower generation and, of course, the necessary commitment to supplying water to users. Although electric power is sold to users who pay in ordinary dollars, the valuation issue is not simple. The economics of the electric-power industry are changing, and prices in a regulated industry are not always a good measure of real economic values. On the other side were a variety of values that are even more difficult to measure: recreation, including trout fishing and rafting; maintaining biological communities, including endangered species; maintaining riparian communities, including geomorphic formations; providing nonuse values, such as scenic and aesthetic resources; and preserving sites of cultural or archeological importance, including those related to Indian cultures. The GCES addressed the costs of reducing power generation in considerable detail. Nevertheless, the Research Council report concluded that it was difficult to resolve all the problems in the power-economics analyses.

Distributional issues across an array of affected interests, such as those involving investor-owned and municipal utilities and cooperatives, also affected the perspective used in the analyses. The Research Council committee concluded that a national perspective, as opposed to a regional or industry perspective, is appropriate because the dam is federally owned and the resources affected are of national, and perhaps even international, importance (NRC 1996:181). Economics research methods were also used in an effort to estimate the effects, in monetary terms, of water-release alternatives on river recreation and nonuse values. National and regional economic effects of the alternatives on recreation were estimated. The largest changes in economic effects were those involving commercial white water boating. Estimates of impacts on nonuse values derived with a CV method were based on household surveys in the region and nationally. These estimates were compared with estimated values of power production and recreation for the alternative levels of water flow. The results indicated that the estimated national nonuse values overwhelmed the estimated power, recreation, and regional nonuse values in evaluating river-flow alternatives (NRC 1996:118-36).

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Results—The Grand Flush

For 1 week at the end of March 1996, BOR conducted its experiment by releasing 45,000 ft^3 of water per second—about 4 times the normal flow through Glen Canyon Dam. The results were visible within a day as new sediments added 0.5-3.0 m to the height of sandbars and beaches downstream. The results were almost immediately called a success with respect to improving recreational conditions throughout the Grand Canyon area and improving habitat for the humpback chub (NY Times 1996; Shapard 1996). At the same time, officials noted that this did not necessarily mean that such releases would become the norm, either at Glen Canyon or at other dams around the country. The estimated loss of power revenues of $2.7 million was not the most important factor in the assessment. Rather, more time is needed for a complete assessment of the environmental effects. Future large releases at Glen Canyon Dam must still fit with the need to provide water and power for traditional users (NY Times 1996; Shapard 1996)

An issue to be faced in the future is the possible effects of large water releases from Glen Canyon Dam on an endangered species, the Kanab amber snail, whose habitat is some 75 km below the dam. According to a Fish and Wildlife Service official, a third population of these snails will have to be established in addition to the two existing populations before another flood of this magnitude is permitted. Thus, whatever the other costs and benefits of occasional planned flooding of the river, they can be overridden by the requirements of the Endangered Species Act.

Commentary

The experimental release of a surge of water from the Glen Canyon Dam had the expected beneficial environmental effects throughout the Grand Canyon. The costs in lost power generation appear to have been within reasonable bounds. The 10 years of studies that preceded the release, which cost about $50 million, received continuing scientific guidance from a Research Council committee, laid a solid foundation for the decision to go ahead with the experiment. Of particular importance was the finding during the course of the study that even though the Glen Canyon Dam blocked the downstream flow of sediments from above the dam, there was sufficient input of sediments from tributaries below the dam to justify the belief that sandbars and beaches could be restored. That was an important scientific consideration in the decision to go ahead with the experiment.

Although meeting biodiversity and other environmental objectives was a major goal of the experiment, it was also constrained by the legal mandates for the dam, which emphasized providing storage to regulate water flows to meet needs of users and to provide electric power at a reasonable price. The decision to go ahead with the experiment appear to have been made by responsible officials with detailed advice from scientists. Although it is clear that careful consid-

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eration was given to the wide range of interests in the results of the test, including the varied interests of the Indian tribes along the Grand Canyon, the process used in getting inputs from these interests was not clear in the reports on which this case study is based.

APPLICABILITY TO BIODIVERSITY

What is Different about Biodiversity (from the Perspective of Valuation)?

Biodiversity presents two kinds of challenges for valuation: complexity and preponderance of nonmarket benefits. Biodiversity is an especially complex good, service, or amenity; in some ways, it is all these things. It might be most appropriate to think of biodiversity as a state of the world. Biodiversity involves complex suites of environmental services and amenities, which raise difficulties of several kinds:

- Information needs concerning the productivity of the environment with and without the proposed action in terms of services and amenities, stretch the capacity of the natural sciences.
- Many of the environmental services and amenities are unfamiliar to ordinary citizens, whose WTP and WTA are the fundamental information for valuation.
- Theoretical requirements for valuation of complex policies are systematically violated by schemes that value components of biodiversity separately, each by whatever method is feasible and appropriate, and then calculate total economic value by adding the component values. Valid approaches are limited to holistic total value (for example, one-shot WTP for the proposed change in the state of the world, with respect to the particular habitat) and sequential piecewise valuation in which each successive component is valued, assuming that budgets have been adjusted for WTP for all components earlier in the sequence (Hoehn and Randall 1987). Perhaps unsurprisingly, sequential piecewise valuation has seldom been implemented, and published valuation efforts using the piecewise strategy typically are susceptible to criticism in this regard.

Although we should be mindful of the inherent complexity of biodiversity, not all valuation tasks call on us to address its full extent (see the Pacific Northwest case study, below). Often, we are asked to value not total biodiversity, but the benefits and costs of proposed actions that would make relatively modest changes in it, for example, actions addressing just a few species in a particular place or modifying a particular section of habitat. The challenge of valuing modest changes in biodiversity is not trivial, but the task is more manageable than valuing total biodiversity. We note that, according to Norton (1988), a long series of marginal decisions can collectively make nonmarginal changes; and WTP to prevent those nonmarginal changes is greater than the sum of the mar-

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ginal WTPs to make the marginal changes. So we could wake up one day to find that, through a series of small and individually rational decisions, we have "sold off" too much biodiversity too cheaply.

The second kind of challenge that biodiversity presents for valuation is the preponderance of nonmarket benefits—the combination (as befits a state of the world) of passive-use values, nonmarket-use values, and values arising from uncertain future uses of various kinds; the latter presents the greatest challenges for valuation. Accordingly, the role of market-oriented valuation methods can be relatively limited. Furthermore, if a holistic approach to total economic value is taken, that would tilt the choice of valuation method toward CV.

Some of the problems of weighing nonmarket benefits and costs are shown in the case study of the Pacific Northwest forests. A large part of the old-growth federal forests in the Pacific Northwest was reserved to protect habitat for the northern spotted owl and other species only after President Clinton intervened. The supporting analysis showed some—but only some—of the incremental costs of providing additional levels of habitat protection, but it was not possible to assign comparable estimates to the value of habitat protection. Despite the limitations of the analysis, it was helpful in weighing the alternatives considered in this presidential decision that involved aspects of biodiversity.

Case Study: Pacific Northwest Forests

This case involves a conflict between protection of species that depend on old-growth forests and long-standing use of the Pacific Northwest's forests as a major source of timber and wood products for national and international markets. Although the conflict started over protection of a single endangered species, the northern spotted owl, it grew into an issue involving protection of a suite of species, including various strains of salmon. At stake in the resolution of this conflict was not only the protection of species, but also sustaining the ecosystems that produce timber products and recreation services and support the people and communities that depend on the region's forests.

The northern spotted owl issue in the Pacific Northwest started in the late 1970s when biologists began to express concern over the loss of old-growth forests, which were believed to be the primary nesting, roosting, and foraging habitat for the owl. The reduction in area of the original old-growth forests was greatest in private forests, which had long been a major source of forest products. But the concern over loss of old-growth habitat focused on federal forests, which by the 1970s contained most of the remaining old growth and had also become an important source of forest products.

The spotted owl was listed as an endangered species under the ESA, and several reports confirmed that old-growth forests provided important habitat. Old-growth forests were also found to provide important habitat for the marbled murrelet and to help protect spawning habitat for salmon. In response to ESA

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suits brought by environmental groups, a federal court halted further harvesting of old-growth timber on federal lands in the region until a satisfactory EIS had been prepared and actions proposed that would meet the requirements of the ESA. Logging on federal forests in the region was brought to a virtual standstill.

In an effort to find a solution, President Clinton convened a 1-day conference in Portland, Oregon, that soon led to yet another report, the report of the Forest Ecosystem Management Assessment Team (FEMAT). The FEMAT report and accompanying EIS present a detailed analysis of this federal public-lands issue involving biodiversity (FEMAT 1993).

Ten alternative policy options for management of federal lands within the northern spotted owl region were defined and compared. The president chose an option that created a system of reserved late-successional forest areas, riparian reserves, and so-called adaptive-management areas. The reserves more than doubled the area that was already congressionally reserved but left some federal forest available for a mix of resource uses. The president's choice was driven by the need to provide for the future viability of listed endangered species, especially the northern spotted owl and the marbled murrelet, to meet requirements set by the court.

The options differed in estimates of the future likelihood of "habitat outcomes" related to the expected viability of various species that are believed to depend on the continued existence of old-growth forests in the northern spotted owl region and estimates of expected effects on timber harvests and associated employment and economic measures. Expected habitat outcomes for each option were estimated separately for 48 species or groups of species of fungi, 16 groups of species of lichens, 12 species and 13 groups of species of bryophytes, 131 species of vascular plants, 102 species of mollusks, 15 species groups of arthropods, 18 species of amphibians, 15 species of mammals, 11 species of bats, 7 groups of species or races of fishes, and 38 species of birds, including the northern spotted owl and the marbled murrelet. The likelihood of projected future habitat outcomes for each species or group of species for each of the policy options was estimated for four categories: well distributed; locally restricted; restricted to refugia; and extirpation. The expected outcomes were estimated by a small group of specialists for each major group of species (fungi, lichens, bryophytes, and so on) who were, in effect, required to agree on the estimates of the likelihoods for the four categories of habitat outcomes.

Other groups of specialists provided estimates of other outcomes for each policy option, including some probable annual volumes of federal timber harvests, direct timber-industry employment, and annual federal receipts from the sale of federal timber, all within the defined range of the northern spotted owl. These, of course, are only partial measures of economics-related effects. Several other kinds of economic-related impacts were discussed in the report, including the outlook for production of commodities other than timber, such as minerals; forage for range livestock; production of "special" forest products, such as floral

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greens and wild edible mushrooms; outdoor recreation; scenic, water, and air quality; and other "public goods". For all the nontimber outputs, however, the specialists found that it was not possible to provide quantitative estimates of levels of production or output for each policy option.

Results for three of the nine policy options illustrate incremental changes in estimated habitat outcomes and in estimated economics-related measures between one policy option and another. Three policy options, in increasing order of degree of protection afforded to habitat for the various groups of species identified above, are

- No action—based on the federal lands management direction in place in 1992.
- President's choice—adopted by President Clinton after the spring 1993 meeting in Portland.
- Environmental option—would have put the largest area of federal land in protected reserves.

A comparison of the three options, their effects on three economics-related measures, and their effects on the availability of "well-distributed" habitat for the northern spotted owl, the marbled murrelet and coho salmon (three of the 426 species or groups of species for which estimates of the likelihood of habitat outcomes were made) is presented in table 5-1.

The table shows the changes in the likelihood of well-distributed habitat for each of three species and the associated decreases in three economics-related measures. Obviously, the president's choice as the "best" overall alternative management regime for federal forests in the spotted owl region does not maximize favorable habitat outcomes. The choice was based on weighing the costs of mainly economics-related impacts against the benefits of added species protection.

For some species, such as the marbled murrelet and coho salmon, the estimated improvements in expected habitat conditions from adopting the president's choice are fairly dramatic relative to staying with the 1992 management regime (for example, from 26% to 80% for the marbled murrelet). But for the northern spotted owl, the improvement is less dramatic. The estimated additional improvements in habitat conditions from adopting the environmental option are not as large, and the estimated costs in terms of decreased federal timber harvests, and federal timber-sales receipts are quite large. The expected decreases in timber-related employment are not proportional to the decreases in federal timber harvests, because harvests from federal lands make up only part of the total regional timber harvest.

The decision in this case was aimed not at protecting biodiversity itself, but at resolving an issue related to protecting endangered species. But the basis of the decision was an evaluation of habitat outcomes of a long list of species and a range of alternatives. The approach for estimating habitat outcomes was to force

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TABLE 5-1 Comparison of the Three FEMAT Options

	Effect		
	No Action	President's Choice	Environmental Option
Areas, millions of acres:			
Late-successional reserves	5.913	7.053	11.496
Riparian reserves	0.619	2.231	1.870
Matrix	8.460	4.853	2.831
Economics-related measures:			
Probable annual federal timber harvests, (billion board-feet)	1.669	1.084	0.177
Timber-industry employment, thousands of jobs	123.7	119.8	112.9
Annual federal timber-sales receipts millions of dollars	524.0	355.5	62.9
Habitat outcomes, % likelihood of well-distributed habitat:			
Northern spotted owl	71	83	89
Marbled murrelet	26	80	92
Coho salmon	10	65	80

SOURCE: FEMAT 1993.

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a small group of specialists in each category of species to come to an agreement in a short time with only the currently available information. Perhaps years of additional research would lead to different estimates, but resource managers usually cannot wait that long. The approach provided reasonably adequate information for recognizing real differences in habitat outcomes among the management options that were considered.

The economics-related measures of differences in effects among the options were also reasonable, although limited. The decision was political. Effects on employment and receipts from timber sales are relevant when federal forests are involved. But they are only partial measures of the values involved in maintaining some degree of biodiversity.

Effects on communities in the region and the value of interagency and citizen collaboration in making these kinds of decisions were also recognized in the FEMAT report. And there was a short discussion of the economic effects of increased prices (due to decreased federal timber harvests) on consumers of wood products. But estimates of the various effects with the different options were not included in the report, largely because of conceptual and measurement problems. There was no single "currency" with which the value of biodiversity could be measured for this resource management decision even if there had been clear agreement on how to measure differences in biodiversity.

The size of the region was based largely on the range of the northern spotted owl, which was the subject of the original court case. That meant it was a very large area for focusing on some kinds of effects, such as human-community impacts, which vary considerably from one locale to another whose measurement can easily be lost when impacts on individual communities are melded into state or multistate regional estimates. At the same time, once the issue was defined to include the impacts of forest management on salmon, it was difficult to leave out the effects on salmon of management of ocean fisheries, which extend the scale even more. In contrast, evaluation of habitat outcomes for some of the species that have restricted ranges, such as some of the mollusks, might have lost something by being part of a bigger analysis.

This case shows of the incremental effects of a resource-management decision involving biodiversity. The FEMAT analysis provided input for the decision by showing what would be gained and lost for each additional increment of protection of old-growth forest habitat. The basic structure of the analysis was appropriate even if the analysis was limited by gaps in available information.

Roles for the Various Valuation Methods

Direct market evidence can be useful for valuing natural-resource commodities harvested from biodiverse environments, genetic resources useful (for example) in plant breeding for agriculture and forestry, pharmaceutical resources, and so on.

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The travel-cost method is useful for evaluating recreational-use benefits. The growing demand for adventure travel and ecotourism suggests that such benefits will play an increasing role, especially in habitats where charismatic megafauna are present and tourism can be managed compatibly with species and habitat preservation.

Hedonic price analysis can have a role in benefit estimation, for example, in cases where a market develops in land near habitat reserves so that land value reflects demands for amenities generated by biodiversity. Nevertheless, it is reasonable to expect the role of such analysis to be modest and occasional.

The methods relying on *direct and indirect evidence from markets* have important limitations for valuing biodiversity:

- They have some conceptual and methodological problems.
- They are limited to a subset of use values; passive-use value and holistic total economic value are beyond their reach.
- It is difficult to implement conceptually valid piecewise valuation procedures that would give these methods a role in eclectic valuation schemes that use different methods to value different components of the suite of biodiversity services and amenities.

Contingent valuation, although controversial, is the obvious method for valuing biodiversity because it is, at least in principle, capable of valuing nonmarket-use values, passive-use values, and total economic value. Nevertheless, biodiversity presents serious challenges for CV in that respondents often are asked (of necessity) to value relatively unfamiliar services and amenities.

Of the more than 2,000 publications to date involving CV, relatively few have addressed biodiversity, habitats, or endangered species. Passive-use values, because they are nonrival (that is, passive users do not compete with each other for access), can be very large in the case of environmental services that appeal to a large number of people. In a CV of viewing of elephants in Kenya, Brown and Henry (1993) elicited WTP for maintenance of elephant populations. Their results show that visitors gain about $25–30 million per year in consumer surplus (value over what they actually pay) for viewing elephants, a proportion of which is likely to represent passive use value. On wider habitat protection, Moran (1994) shows that the consumers' surplus attached to nonconsumptive use of Kenya's protected areas by foreign visitors (as a subset of all users) is about $450 million. It is safe to conjecture that those values would be overshadowed by the passive-use values of nonvisitors if these had been measured.

Given the broad applicabilty of CV to valuing biodiversity, it is important to address the criticisms that have been raised about CV:

- Validation of CV is inherently difficult. In the absence of convincing validation, and given the very large value estimates that can be expected for

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passive-use value and total economic value of prominent biodiversity resources, CV and the value estimates that it generates will remain controversial.

- CV surveys of biodiversity or species-preservation issues often generate a relatively high proportion of protest or refusal responses, and some respondents indicate an unwillingess to address these issues in terms of trades for money. Good CV design—for example, structuring the CV as a referendum about spending more or less public money for preservation projects—can minimize the occurrence of protest or refusal responses. Nevertheless, some refuse to respond to even the best CV questions, and some of these nonrespondents are thoughtful people who draw on nonutilitarian moral philosophies when trying to resolve biodiversity issues. Chapter 4 makes clear that these are legitimate reactions, and they illustrate the limits of utilitarian CV in dealing with nonutilitarian concerns.
- CV comes in a variety of forms, each with its own communication and incentive properties, so blanket claims about the validity of CV are meaningless. But one constant is that the validity of any CV effort depends on respondents' understanding of what is being valued. In the case of biodiversity, citizen knowledge of the details of any particular case is likely to be quite low, so researchers will need to provide a good deal of case-specific information. Therefore, issues of communication and comprehension are likely to be prominent in criticism of many CV efforts directed at biodiversity. It is important to recognize that this problem applies also to any other approach or process that takes citizen opinion seriously.

Contingent-choice experiments are still in their infancy, especially in contexts where passive-use values can well dominate. Nevertheless, one might expect increasing application of these methods.

EXAMPLES

Various estimates have been made of the value of aspects of biodiversity. They include in this report the estimates for ecosystem services in chapter 3, the estimates in the Pacific Northwest forests and Grand Canyon flush case studies in this chapter. In addition, the article by Costanza and others (1977) discussed in a later section, *A Tempest Over Valuing the World's Ecosystem Services*, has global estimates of average per hectare and total values of biodiversity for 17 ecosystem services and 17 biomes.

In most of the cited examples, as well as in most of the numerous other published examples, the value estimates are for some particular element of biodiversity or for services that are related to some element of biodiversity. The estimates in the paper by Costanza and others (1997) are unusual in that the sum of the values for the 17 ecosystem services represents estimates of one-time annual values or the present value of the stream of expected future values.

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BOX 5-2
Why Benefits and Costs Matter

When called on to defend the systematic use of BCA in public decision processes, economists are likely to start talking about the need to impose a market-like efficiency on the activities of government (for example, Arrow and others 1996). However, the reasons are not immediately obvious. It can be argued coherently that, although society delegates many workaday decisions to the market, government is an institution that human societies invoke when they choose, for their own reasons, not to be efficient. It is not a frivolous point: efficiency is a harsh discipline and one that in practice tends to reinforce the distributional status quo; it is by no means clear that society ought to impose that discipline on everything that it does. So we must look elsewhere for good reasons to take benefits and costs seriously in public policy.

Benefits and costs cannot count for everything. Hubin (1994) asks us to consider benefit-cost moral theory: that right action is whatever maximizes the excess of benefits over costs, as economists understand the terms benefits and costs. It is hard to imagine a single supporter of such a moral theory among philosophers or the public at large. Instead, we would find unanimity that such a moral theory is inadequate and an enormous diversity of reasons as to exactly why.

Benefits and costs must count for something. This argument comes in two parts. First, benefits and costs provide a fairly good account of contribution to preference satisfaction (Hubin 1994). Second, preference satisfaction matters morally. One cannot imagine a plausible moral theory in which the level of satisfaction of individual preferences counts for nothing at all. If we examine a broad array of contending moral theories, preference satisfaction counts for something in each of them.

Public Roles for Benefit and Cost Information

Preference satisfaction to inform decisions, rather than to decide issues. Because preference satisfaction is a consideration under any plausible moral the-

Benefit-Cost Analysis in the Federal Government

Benefit-cost analysis (BCA) is a generic term that can refer to nearly any comparison of benefits and costs as long as they are measured or estimated in comparable units. In the federal government, the term sometimes refers to protocols for comparing the "desirable and undesirable impacts of proposed policies" (see box 5-2) (Arrow and others 1996). An early use of a formal process of BCA was in the evaluation of federal water-resources development projects after enactment of the Flood Control Act of 1936. The act required that proposed projects be undertaken only "if the benefits to whomsoever they accrue exceed the costs." That, of course, is consistent with the progressive model of "scientific govern-

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ory, an account of benefits and costs might be used routinely as a component of some more comprehensive set of evidence, accounts, and moral claims to inform the decision process. This notion is congenial to many economists (for example, Arrow and others 1996, p 221). However, it leaves unanswered the question, How should an account of preference satisfaction be weighted relative to other kinds of information? And can the answer be principled, or must it always be circumstantial?

Preference satisfaction subject to constraints. One alternative way of coming to terms with the idea that preference satisfaction counts for something in any plausible moral theory but cannot count for everything is to endorse preference satisfaction as the decision rule for issues in which no overriding moral concerns are threatened. Preference satisfaction could then be decisive within some broad domain, which itself would be bounded by constraints reflecting rights that ought to be respected and moral imperatives that ought to be obeyed. That would implement the commonsense notion that preference satisfaction is fine as long as it does not threaten any concerns that are more important. The general form of such constraints might be, "don't do anything disgusting." The basic idea is that the public decision-maker should adopt—or a pluralist society would agree to be bound by—a general-form constraint to eschew actions that violate obvious limits on decent public policy. That kind of constraint is in principle broad enough to take seriously the objections to unrestrained pursuit of preference satisfaction that might be made from a wide range of coherent philosophical perspectives. Examples of such constraints might include these: Don't violate the rights that other people and perhaps other entities might reasonably be believed to hold. Be obedient to the duties that arise from or could reasonably be derived from universal moral principles. Don't sacrifice important intrinsic values in the service of mere instrumental ends. In each of those cases, the domain within which pursuit of preference satisfaction is permitted would be bounded by nonutilitarian constraints. In the context of protection of habitats, species, and ecosystems, society could decide on the basis of preference satisfaction but subject to some kind of conservation constraint.

ment", a model that achieved great influence in the first half of this century (Nelson 1987).

Guidance for analyses of federal water-resources projects grew in a series of documents (the "Green Book" of 1947, Senate Resolution 148 of 1957, Senate Document 97 of 1962, and so on) that ultimately provide for a "four accounts" model for water-resources planning: the national economic-development account (basically, a BCA); the regional economic-development account, which focuses on income and employment effects; the environmental-quality account, which overlaps with the national economic-development account to the extent that it proves feasible to determine the benefits and costs of at least some of the antici-

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pated environmental-quality changes; and the quality-of-life account. Both benefits and costs were to be measured in terms of estimated market values. The approach appears straightforward on the surface, but numerous issues arise in trying to apply the general guidelines to proposed projects, including defining the appropriate scope of the analysis, deciding how to account for regional and local effects, and especially deciding how to treat real benefits and costs for which market values do not exist.

Concerns in the last 2 decades with the presumed high costs of federal regulations has broadened the use of BCA by the federal government. Executive order 12291 of 1981 required analysis of benefits and costs of all new federal regulations with major economic and other effects. It stated that regulatory actions should maximize "net benefits to society" and should not be undertaken "unless the potential benefits to society . . . outweigh the potential costs to society." The order, taking note of the difficulty of estimating both benefits and costs in monetary terms, required that proposed rules include descriptions of benefits and costs that cannot be quantified and that the determination of net benefits include "an evaluation of the effects that cannot be quantified in monetary terms." Executive order 12866 of 1993 replaced executive order 12291. It, too, required that assessments of benefits and costs include qualitative measures of those which are difficult to quantify. A recent article by several prominent economists noted that estimates of benefits and costs of regulations should be accompanied by a description of the uncertainties surrounding the estimates and that the analyses should also identify distributional (equity) consequences (Arrow and others 1996). But the executive orders provide few clues about how these qualitative measures are to be made and used in analyses. BCA for federal regulations continues to be treated on a largely ad hoc and project-by-project basis, especially where the market provides little guidance on values.

With the fading of the progressive dream, a pluralistic, participatory process has emerged. Instead of trusting in the experts to get things right, citizens seek access to the decision-making process. BCA has a somewhat different role in such a process: it will have influence to the extent that citizens are convinced, first, that benefits and costs are relevant considerations and, second, that the particular BCA is reasonably accurate and reliable. The second of those concerns—essentially, the quality of benefit-cost information—is a serious concern in the context of biodiversity, but it has already been discussed here at some length. Here, we address the first concern: Can we give good reasons why benefits and costs are relevant considerations in policy decisions?

• A BCA is an account—not a perfect account but a fairly good account—of the prospective contribution of some proposed action to the satisfaction of human preferences. Because preference satisfaction cannot logically count for everything but also cannot logically count for nothing, benefits and costs will be

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relevant considerations in policy decisions but will not be the only relevant considerations (Hubin 1994; Randall 1999).

One appealing answer to the question of when BCA counts and how much it counts is that an ethically pluralistic society of thoughtful moral agents would have good reasons to agree to choose on the basis of benefit-cost considerations when nothing more important is at stake and to impose the most important of these "more important" considerations as constraints on what can be chosen (Randall 1999).

- In the case of biodiversity, the appropriate constraints can well include safe minimum standards of conservation for critical species and habitats (see box 5-3) (Farmer and Randall 1998).

BOX 5-3
Safe Minimum Standard of Conservation

Ciriacy-Wantrup (1968) proposed the safe minimum standard (SMS) of conservation. The stock of a renewable resource (for example, a species or ecosystem) would be maintained at a level at least high enough to protect it from potential extinction unless the costs of so doing were "immoderate" (Ciriacy-Wantrup) or "intolerably high" (Bishop 1978). The SMS is designed not to serve as a comprehensive conservation policy, but to impose a constraint on "business as usual" to protect against disasters.

Some philosophers and economists have criticized the SMS, charging that it is an ad hoc policy switch that cannot be grounded in a single, clear objective statement; in other words, whatever justifies "business as usual" cannot also justify the SMS. Farmer and Randall (1997) have responded that standard utilitarian, contractarian, and Kantian accounts of societal ethics encounter irresolvable problems when extended to conflicts between existing generations and potential future generations. In the absence of philosophies that resolve intergenerational conflicts in an internally consistent manner, such safeguards as an SMS constraint make sense.

There is disagreement among ethical systems as to the interpretation of the escape clause: How high would the cost of maintaining the SMS have to be, to be judged intolerable? In some utilitarian interpretations, the intolerable cost is quite low, so the SMS constraint becomes little more than a reminder to perform BCA carefully, to take option and existence values seriously, and to give preservation the benefit of any doubt. Kantians, however, could argue coherently that the intolerable cost should be high enough to impose genuine hardship.

Finally, to what species and ecosystems should the SMS be applied? At one extreme, there can be broad agreement that things that are essential for human welfare should be subject to the SMS. At the other extreme, the "precautionary principle" (that we should apply the SMS to every species "just in case") is supported by relatively few and is impracticable if taken literally.

Clearly, commitment to an SMS constraint in principle leaves some important issues unresolved.

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A TEMPEST OVER VALUING THE WORLD'S ECOSYSTEM SERVICES

In May 1997, Robert Costanza and a long list of coauthors published a paper titled "The Value of the World's Ecosystem Services and Natural Capital" in *Nature.* They estimate the annual value of the world's ecosystem services to be about $36 trillion, compared with an estimate of about $18 trillion for the world's annual gross product. The reaction of neoclassical economists is best typified by V. Kerry Smith's response (Mispriced Planet, Summer 1997, *Regulation*): "Their results should not be used in any form—whether as measures of the importance of changes in natural resources to human welfare; as yardsticks for future project appraisals; or as sources of a road map for future research." Although there are many technical issues for debate, the core of the argument arises because of the claim by Costanza and others (1997) that their estimate of the value of ecosystem services is based on the concept of WTP.

A thought experiment is useful. Imagine that evil aliens orbit Earth and threaten to destroy ecosystem resources one by one unless we pay blackmail in the form of an annual fee for each service. Costanza and his colleagues are quickly assembled to value each category of ecosystem services. The first resource threatened is forests, which generate $4.7 trillion per year, on the basis of the estimated WTP of the world's countries for the forests' total ecosystem services (Costanza and others 1997). On the basis of the group's recommendations, Earth agrees to pay $4.7 trillion each year. Next the aliens threaten the coastal shelves, worth $4.3 trillion. However, having already agreed to pay $4.7 trillion for forests, reducing available world gross product for human consumption from $18 to $13.3 trillion, Earth opposes the Costanza estimates because "we cannot afford $4.3 trillion more; we are much poorer now." In other words, the demand and value for coastal shelves is reduced because available gross product from which to pay is reduced. If we follow this line of argument, the world's total annual gross product ($18 trillion) is the most that could be paid as a bribe to save the world's ecosystem services without reducing the accumulated value of the the world's capital.

The value estimates of Costanza and others (1997) are based on separate studies of the values of individual components, each of which assumes that people's incomes remain at current levels. The problem has been termed the independent valuation and summation problem by Hoehn and Randall (1989), who argue that it is inappropriate to simply add the values obtained from independent studies, because aggregate values will be overstated. It is clear from the way that Costanza and others construct their estimates that their work does, in fact, suffer from the independent valuation and summation problem. However, the story is not over.

Costanza and others (1997) respond to Smith with a substantive counterargument of their own. Because ecosystem services are, for the most part,

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unpriced, the sum of the world's gross product underestimates world income. Furthermore, the actual value of the world's ecosystem services would increase through proper management if the resources were properly priced. A simple example will illustrate their argument: Because of overfishing, the North Atlantic fishery is now capable of contributing little to the world's gross product. With proper management (which might include putting a price or tax on each fish taken from the sea to discourage overfishing), the fishery would be restored, the sum of the world's gross product would go up, and our ability to pay a bribe to protect coastal shelves from alien destruction would increase.

The utility of the paper by Costanza and others (1997) is not in its estimates of the value of the world's ecosystem services, but rather that it initiated a visible discussion of the difficulties of estimating such values, whether on a global or on a more localized basis. As was pointed out in chapter 2, biological systems are complex. The debates over the Costanza paper point to the complexity and interactions of economic systems. These debates have contributed to a better public understanding of the difficulties in estimating economic values, especially in the absence of market-price information. As long as the value of most ecosystem services is not subjected to a market test, such debates will continue, and in the end they will advance understanding not only of the issues, but also of the values that are involved.

SUMMARY

Economists have developed an array of tools for estimating values when the lack of ordinary markets precludes use of their favored measure, market-determined prices. These are powerful tools for informing decisions involving biodiversity. But they have limitations. Estimates of value based on them should be treated with careful attention to the assumptions that have been made in obtaining them. Support for their veracity can be indicated by the degree to which results obtained from various estimates converge. Particular care should be taken as the scale of the decisions for which estimates of value are made diverges from the normal scale of market processes. The economist's usual view of market decisions as being made at the margin—that is, for small changes in quantities and prices—is a key assumption for most estimates of value.

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6

Management and Decision-Making

This report is concerned with situations in which policy-makers and resource managers must make decisions that will affect biodiversity and in which there is conflict about the appropriate course of action. The previous chapters identify some of the problems facing policy-makers and managers who must deal with such matters. They also describe the various kinds of information about biodiversity that must be considered and synthesized in policy and management decisions.

The very ideas of biodiversity and its role in sustaining natural processes are complex and diffuse over various spatial and temporal scales. The implications of the meanings of biodiversity for managing natural resources are varied and require bringing technical expertise to bear on such matters (chapter 2). Biodiversity and the processes of which it is a vital part generate a wide range of economic and social and cultural values (chapter 3). Identifying these and specifying them in scales appropriate to the kinds of decisions that confront managers are crucial parts of the decision-making process.

People view and value natural systems and processes from various perspectives, each of which has legitimacy in public discourse (chapter 4). Those perspectives add complexity to the management of natural systems, and recognizing that they exist will help managers to understand the issues that they face. The relative simplicity and appeal of any set of analytical tools is not likely to fit easily with the conflicting views of interests involved in even relatively straightforward issues involving biodiversity. The economists' set of tools is the most complete and internally consistent available for addressing matters of value (chapter 5). Variations on the basic utilitarian accounting of value have been developed by economists to address some of the complications of dealing with natural

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processes. Although these are often helpful, decisions involving biodiversity must still be made with attention to matters that cannot be readily encompassed in a market-economics framework.

The line of reasoning developed in the previous chapters suggests the need for a discursive process that can build confidence in decisions in the face of incomplete information and differing basic values. Such decision processes will not by themselves eliminate the need for better information or the differences in philosophies. They offer some hope, however, of gaining the support of decision-makers and the public for decisions involving natural systems.

Policy and management decisions that concern biological resources commonly involve competing resource uses and conflicting value systems. Uses of land to provide goods and services with well-defined markets (for example, timber for wood products and space for development) and uses that lack well-developed markets (for example, habitat for wildlife, and maintenance of ecological functions) often compete and conflict. Those making decisions concerning biodiversity are expected to resolve the conflicts and to do so in a way that appears legitimate to the various interests affected by the decisions.

Decision-makers almost never have perfect ability to resolve conflicts and satisfy their customers. One reason is that the scope of their responsibilities might not fit comfortably with the scope of the resources affected by their decisions. For example, on-the-ground managers are limited by the geographical scope of their jobs, which often does not coincide with the range of the biological resources for which they are in part responsible, as in the Camp Pendleton case study (chapter 1), where maintaining the valuable wildlife habitat on the military base was affected by what happened on the upstream portion of the watershed that fed the river flowing through the base.

Policy-makers and resource managers also face limitations of knowledge and time—time for making important decisions, time for acquiring the knowledge needed for good decisions, and the knowledge to weigh short-term results against long-term effects. Like many decisions involving constraints of knowledge and time, decisions that concern biodiversity often must, and should, be made tentatively and incrementally. Resource managers often face pressures that seem to require immediate answers when none are certain, but the nature of decisions involving biodiversity suggests the need for a kind of management that expects changes in knowledge and readily accepts and adapts to them as they become available. Such changes in knowledge are almost sure to occur in the realms of both biology and the social sciences. And the values that society chooses to pursue will change over time as well. That makes biodiversity decisions especially challenging, and the task of assessing values, formidable.

In this complex world, the incompleteness of information is not a valid reason for not using all the information that is available. Nor is the need for simplifying decisions to accommodate pluralistic views a reason for not considering moral values. In addition to the tools from the biological and social sci-

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ences discussed in previous chapters, there are processes that help managers to make the best possible decisions even in the face of difficult constraints (Dietz and Stern 1998). Most of the processes discussed in the literature are concerned with public decisions. These vary in scale and include legislative processes (such as, congressional hearings leading to legislation), to federal or state decision that have major effects (such as those requiring environmental impact statements), to decisions that are judged to have more limited impacts (such as decisions that require only environmental assessments). The specifics of the decision processes vary, but all have generally the same elements: definition of the problem and problem focus, analysis of the alternatives based on available facts, fair representation of the range of viewpoints concerned, and a structure for deliberation.

Congress has decreed that decisions regarding publicly owned resources must be open to public review and comment. Under the National Environmental Policy Act (NEPA), federal resource managers are required first to identify the kind of decision to be made and its potential ramifications. On the basis of the range of alternatives available, all germane issues must be presented to the public in a "scoping process" wherein key issues are identified and public input is recorded to ensure that relevant topics that concern participants are addressed. The record of public input and resulting analysis of potential effects must be made available in a draft document for a second round of public review before preparation of a final document that identifies the decision to be made, potential effects, and a range of reasonable alternatives (including an alternative of "no action") for review before the decision.

Most of the laws and regulations that shape the actions of managers of public and natural resources call for some form of public involvement in decision-making. Nearly all decisions about federal public lands fall under the requirements of NEPA or other broad laws (such as the Administrative Procedures Act) that mandate public input into decisions. But most researchers and practitioners acknowledge that the standard methods for public participation to meet these requirements (for example, hearings and letters commenting on draft plans or environmental impact statements) yield a great deal of heat and perhaps not much light (Chess and Purcell 1997; Cvetkovich and Earle 1994; Proctor 1998; Shannon 1991; Tuler 1995; Tuler and Webler 1995)

In the discussion that follows, a generic process known as analytic deliberation is discussed in some detail. It has grown out of frustration with the standard methods for public involvement and an awareness that the public trust is essential to good public policy and management decisions. That trust can come only when the public believes that it is engaged in the decision-making process in a meaningful, rather than pro forma, way. The point of analytic deliberation processes is that there are mechanisms to engage the public, respect the best available scientific analysis, find better solutions, build understanding, and nurture trust among all involved parties.

An analytic deliberative process is iterative. Analysis informs deliberation

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which in turn, directs further analysis as the basis for additional deliberation. Thus, science, in the form of analysis, is brought into full play in the deliberation process, which also informs the science.

THE PROBLEMS FACING MANAGERS

Scientific Uncertainty

Managing ecosystems to preserve or enhance biodiversity is a complex task. Complexity is added when a manager must consider competing goals, such as recreation or resource extraction. The basic science, while providing essential guidance to ecosystem managers, usually provides results that include some uncertainty. And, the research needed to provide contextual data that allow the application of general scientific principles to local situations is generally weak. As a result, managers must proceed with a limited and uncertain scientific basis for their decisions. In practical terms, although the accessible science can give managers some understanding of the likely consequences of alternative policies and management regimes, they will also be aware that the consequences are not known with certainty. Indeed, managers are often faced with "meta-uncertainty" (Dietz and others 1993) in that they do not know how much uncertainty exists—they are uncertain about the extent of the uncertainty.

Uncertainty about the biological and physical consequences of management alternatives affects benefit-cost analysis (BCA) and other policy-analysis tools. The results of those analyses are at least as uncertain as the ecological analyses on which they are based. Because BCA and related tools are still developing and because the amount of context-specific information is sparse for most decisions, uncertainty is added. As noted in chapter 5, there is still some controversy about the use of methods intended to estimate the nonmarket value of biodiversity, which increases uncertainty still further. In the face of scientific uncertainty, BCA and related valuation tools can sometimes eliminate some options as unrealistic or inferior. But rarely will there be enough information to pick a course of action that is unambiguously superior to all other options.

The limited amount of information needed for such analyses constitutes one measure of the need for research. For example, improvements in the techniques of contingent valuation (CV) in recent years have occurred as a result of research. Additional research on CV techniques, as well as on BCA, are likely to improve future estimates of the values of natural systems.

Value Complexity and Uncertainty

Even if the science involved no uncertainty, there would be value-based sources of conflict. Different members of the public assign different values to biodiversity, to the benefits to be gained when biodiversity is preserved or lost,

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and to the costs required to preserve biodiversity. Indeed, the problem is not simply that people assign different weights to the various outcomes of biodiversity-related policies. As noted in chapter 4, people also think in different ways about how to consider biodiversity: some are willing to accept tradeoffs of the sort examined in a BCA, and others that some threats to biodiversity invoke moral imperatives that outweigh efficiency calculations and preclude tradeoffs. Even with perfect scientific information, managers would face controversy because of different values and different ways of thinking about them.

Better science and better policy analysis might help to reduce controversy by clarifying options, and social-science research can improve the understanding of the diversity of value positions held by stakeholders. But research and analysis will not make conflict disappear.

WHY DELIBERATE?

We believe that the best strategy for managers of biodiversity faced with difficult decisions, scientific uncertainty, and public conflict is to make use of deliberation with interested parties (Dietz and Stern 1998). Ultimately, decisions in the public realm must be made by managers who hold statutory responsibility for the resources that they manage. But their decisions can be informed by skillful use of deliberation. Deliberation cannot eliminate conflict, but it can clarify the bases of conflict, build trust among those who disagree, and provide for a learning process that leads to better and more-informed decisions.

Fiorino (1990) has suggested three reasons for involving the public in environmental policy: normative, substantive, and instrumental. The normative reason is based on US democratic traditions. A manager must act in a way consistent with public intent as expressed in both statutory mandates and in public expressions of concern over policy and management decisions. Structured and focused deliberation grounds valuation of biodiversity and policy decisions about biodiversity in democratic process and scientific analysis.

The substantive reason for public participation is that citizens carry knowledge that is a critical supplement to scientific analysis. This rationale is especially important for valuation problems because even the best available valuation tools are limited and uncertain and might rest on philosophical assumptions that some stakeholders reject. A structured discussion is an effective way to allow people to express their preferences, to reflect on their own values and those of others, to weigh evidence from biological and social-science analyses, to modify their views, and ultimately to provide decision-makers with information on values and value tradeoffs that supplements information from other methods.

The instrumental reason for public participation is that, in the face of conflict, participation allows for the development of compromise, trust, and engagement by those who might otherwise prove implacable foes of a proposed policy. Conventional public participation processes, however, usually do not

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produce this desirable outcome; they often, lead to hostility, mistrust, and entrenchment.

Processes that allow deliberation over time can gradually build the kind of public trust that provides a solid basis of public actions. Concern over and resulting responses to deteriorating conditions in Seattle's Lake Washington are a case in point (see case study below). Deliberation, debate, and a role for scientific understanding were common themes at all stages, from recognition that a problem existed through taking action to monitoring to ensure that lake conditions do not again deteriorate. Although it was not a concern for enhancing biodiversity that initially led to action, the results have done just that. The lake is now managed by a number of agencies, and numerous municipalities are involved.

CASE STUDY: LAKE WASHINGTON

Community reaction to ameliorate perceived environmental change has a long history, beginning at least in the 1600s, long before the general term biodiversity had been coined. We encapsulate here details on Lake Washington as an example with generalizable implications for many urban lakes. Intervention (management) was motivated by developing health issues and a state of the lake that was increasingly intolerable to the public (the stakeholders). Scientific information played a major role in guiding the management decisions, in diverting first untreated sewage (a health issue) and eventually the treated waste fluids (a plant-nutrient issue). The lake is now scientifically managed at an acceptable water quality for the combined benefit of many categories of users.

The development of Seattle, from its founding in 1851 as a small coastal village to its current status as a major West Coast port and metropolitan area, has been accompanied by typical growing pains and associated costs. The city is essentially squeezed between two major bodies of water: Puget Sound to the west and Lake Washington to the east. The latter is a relatively young post-Pleistocene lake, formed about 12,000 years ago; it is 28 km long and 65 m deep at its deepest and has a surface area of 86.5 km^2. By 1860, lake-side land development and deforestation had begun; by 1900, the lowland conifer forest had been cut, and raw sewage had begun to enter the lake (Edmondson 1991). In its pristine form, the lake was connected to Puget Sound and in its deeper portions was mildly brackish, as indicated by diatom remains in the lake's sediments. The diatom assemblage suggests little effect by a small American Indian population on the lake's biota before to the arrival of European settlers (Bagley 1916). Seattle's increasing importance as a port prompted major changes in the lake's architecture in 1916. The level was lowered by 3 m, and the lake was connected to Puget Sound through a new, locked ship canal, which both increased commercial ship traffic to and from the lake and, by reducing the influx of seawater, influenced lake water chemistry. Furthermore, a major river, the Cedar, was

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redirected to flush ships through the locks. By 1922, 30 storm drains and sewage outfalls served about 50,000 people discharging into the lake.

During the period of unrestricted growth, there was no dearth of concern about public-health issues. Between 1889 and 1948, numerous reports recommended control of pollutants, including human sewage, because the lake was a drinking-water source. In 1907, an outbreak of typhoid resulted in 570 cases. By 1936, raw sewage, but not the treated effluent, was being directed into Puget Sound. In 1958, residents of Seattle approved a $125 million bond issue to divert all the secondary effluent to Puget Sound and thus eliminate the major source of nutrient contamination (predominantly phosphorus) and its undesirable effects on lake chemistry and biological structure. Edmondson (1991) estimated the cost at $2.80/month per household, to be financed by revenue bonds. Diversion was completed by 1965; by the summer of 1971, the lake's transparency, one measure of phytoplankton density, was comparable with that of 1950, and recovery was deemed to be well under way.

The Decision-Making Process

Three natural features visibly dominate Seattle's geographic setting: Puget Sound, snow-capped mountains, and Lake Washington. Actions focused on deterioration of the lake date to 1889 and a series of reports commissioned by state and city agencies. In 1956, the mayor of Seattle empowered the Metropolitan Problems Advisory Committee; by 1958, it had generated a detailed assessment of the expanding water-quality problems and their potential solutions. Because remedial action would extend well beyond the political boundaries of Seattle—that is, require a regional response involving cooperation with adjacent municipalities—the Metro Enabling Act was drafted, calling for public involvement by the affected communities. The act eventually received legislative approval despite the objection that "Metro" was a disguised form of socialistic, "big brother" government (Edmondson 1991).

The pros and cons were broadly aired in the mass media and civic clubs. Basic science played an essential role, both in identifying the causes of lake deterioration and in predicting (successfully) the benefits of an expensive remediation to be underwritten by increased local taxation. The initial vote, in March 1958, failed to pass the bond issue. A simplified version was submitted 6 months later and passed, receiving 59% of the vote. Restriction of the basic issues, increased public awareness and education, and a sense of ecological urgency all seem to have contributed. Edmondson (1991:54) has discussed the ingredients of aggressive public action: "In general the pro-Metro propaganda was accurate. The leaflets issued by state agencies presented clear, concise descriptions of the problems, and were objective, even when urging a vote for Metro. The debate gave a good chance for arguments against Metro to be pre-

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sented to a wide audience. . . . The important thing is that the voters were provided with information as well as informed opinion to use in making their decision."

Results

Benefits began to accrue almost immediately. At the peak of eutrophication in 1964, the lake was a "nuisance lake": it smelled because entangled masses of the cyanobacterium *Oscillatoria* were rotting on the shore (local newspapers renamed it "Lake Stinko"), and public swimming was discouraged by advertising the presence of pollution. The lake is now clean, and the odor is gone. Although data on Lake Washington itself are unavailable, studies on 543 lakefront properties in Maine showed that average value increased by $7,395 for each 1-m increase in water transparency. Perceived water quality clearly translates into enhanced property values (EOS 1996 77:102). The 1916 lowering of the lake's level exposed about 5 km^2 or 8% of the lake's bottom area. About 64% of the 115-km shoreline is occupied by residential property of enhanced value, so both owners and the city, through property tax increases, benefited. The locks themselves permitted commercial barge and recreational boat traffic to commute between Lake Washington and Puget Sound. Seattle has long boasted that it is the small-boat capital of the world. The economic benefit is unknown but must be substantial.

In 1935, sockeye salmon were stocked in the Cedar River; but they attracted little public interest before 1960. Regular abundance estimates, beginning in 1967, suggested a population of 189,400 fish, and the economic benefit is unknown but must be substantial in 1970. Edmondson (1991) suggests a minimal annual value of the fishing, both recreational and commercial, in excess of $6 million since 1964. Benefits will continue to accrue as long as sockeye salmon return in adequate numbers. Accelerated urbanization of the lake's east side and associated land development activities in portions of the lake's watershed have also generated subtle effects. The data support the obvious fact that effective lake management requires understanding of substantially greater spatial domains, including entire watersheds, farmlands, and even aquifers. To control flooding and associated massive landslides in the Cedar River, large rocks were piled along the banks. This "rip-rap", or revetment, controlled erosion successfully and enhanced spawning conditions for at least two fish species. Edmondson (1991) suggests that the $3.5 million expense would be substantially less than the combined value of an enhanced fishery and the cost, if revetment had not been constructed, of flood damage and reduced property values. Taxpayers in metropolitan Seattle appear knowledgeable about water-quality issues, are increasingly active through habitat-restoration projects (such as adopt-a-stream initiatives), and willing to commit effort and public funds.

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Biodiversity Changes

Lake Washington before 1851 was a largish lake of low productivity surrounded by a dense conifer forest. Its biota was probably little different from that of many other such lakes, except that the riverine connection to Puget Sound allowed anadromous salmon, sea-run trout, and sturgeon to enter. All that began to change when people of European ancestry populated the region, and their ensuing increase in numbers, alteration of the watershed through deforestation, and sewage-based phosphorus enrichment of the lake induced pronounced ecological shifts.

Most, if not all, species that are present have probably always been present, even if only represented by spores or resting stages buried in the sediment (for example, Hairston and others 1996). There probably have been few local extinctions, and certainly the eutrophication of Lake Washington contributed to no global ones. The avifauna has been modified: breeding loons and dippers have disappeared, and hybrid ducks, "urban" Canada geese, and coot now abound. Changes in fish diversity are perhaps more relevant. Sturgeon are potentially long-lived; the occasional Lake Washington corpse might well be a relic from days (1916) when there was unrestricted passage to Puget Sound. They could well be locally extinct. But rainbow trout have been stocked annually since 1977, and sockeye salmon were introduced in 1935. Eric Warner (Muckelshoot Indian Nation, pers. comm.) has assembled records dating to the late 1800s: of 30 native fishes, only two species of salmon (pink and chum) are confirmed as extinct; 22 exotic or introduced species have been added, of which only four have disappeared. The rooted aquatic plants bordering the lake have also changed. A European invader, *Myriophyllum* (milfoil), was found in the eastern United States before 1900, in Minnesota by 1970, and in Lake Washington in 1973. By 1976, it had become a nuisance species, clogging waterways and fouling swimmers and sailboat hulls. The invader has displaced stands of native pond weeds in these shallow waters, not eliminated them. On the positive side, it provides food for fish and birds and habitat and shelter for lake organisms, and, in Edmondson's words (1991:48), the extensive marsh and wetlands "are a most unusual amenity for a densely populated city area."

The greatest biological shifts characterized the phytoplankton and zooplankton assemblages. Excessive nutrient in the form of phosphorus led to eutrophication beginning about 1900 and substantial blooms of the cyanobacterium *Oscillatoria* by the early 1960s. Public action led to reduced phosphorus input, the associated general disappearance of *Oscillatoria*, and eventually the reappearance of the zooplankter *Daphnia*. *Daphnia* reduced the density of "normal" lake phytoplankton still further, and as a consequence lake transparency doubled. All those species are normal inhabitants of lakes: *Oscillatoria* was identified in 1933. However, lake alkalinity has been increasing gradually since 1960, perhaps because of changes in water chemistry in streams and rivers flowing through

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agricultural or urbanized lands, and this in turn is linked to increases in another cyanobacterium, *Aphanizomenon*. The latter genus had been present sporadically; in August 1988, it accounted for about 80% of the lake's phytoplankton volume (Edmondson 1997).

Conclusions

Visible changes in urban lakes have a proven ability to alter public perception of water quality, to underlie health issues (swimmer's itch and typhoid in severe situations), and to be expensive to remedy. In the Lake Washington case, scientific understanding focused on medical issues and water chemistry played the major role in a publicly funded restoration project that had uncertain, although surely positive, biodiversity consequences. Public and scientific appreciation of regional ecological linkages has generated concern about watershed use, land-use practices, (including clear-cutting and increasing urbanization), and subsurface hydrology. Stakeholders and users include the National Oceanic and Atmospheric Administration, the forest industry, commercial and recreational fishes, a wide range of water-sports enthusiasts, and float plane operators. Lakeside property owners enjoy special benefits and pay higher taxes. Management decisions involving primarily state agencies and a regional metropolitan council appear committed to maintenance of "system" quality above some threshold. Biodiversity issues play a minor role in this multiuser lake governance, but regular monitoring of lake chemistry and biology, concern about the ecological consequences of species introductions, and maintenance of water quality probably ensure that this large urban lake will retain most of its original biota in the presence of intense and varied human use.

ANALYTIC DELIBERATION PROCESSES: A USEFUL TOOL

Analytic deliberation is a class of discursive processes for dealing with conflicts that draws on the best features of both analysis and deliberation. These processes incorporate input from traditional public participation, from normal political processes, and from science in several ways. It also relies on sound analysis grounded in the best available science. It is a structured process tailored to match local circumstance and to fit the needs of managers to make decisions. Analytic deliberation processes are based on continuity and repetition involving a stable group of participants who are committed to the success of the endeavor. In a sense, this mirrors the operation of ordinary markets, in which prices are set in a continuing series of negotiations among buyers and sellers. Each market decision provides additional information for agreeing on the price in the next situation.

Analysis and deliberation are complementary processes. Sound analysis grounded in the best available science is essential for making good decisions

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about biodiversity. But science alone will not be sufficient to assess value tradeoffs and indicate the best decision. Scientific uncertainty, value uncertainty, and conflict about values will always accompany decisions about biodiversity. To help to overcome those problems, managers will benefit from carefully structured, scientifically informed deliberation among interested parties. Such deliberation can clarify value positions, identify points of agreement and disagreement, suggest lines of compromise, and build mutual understanding among potentially antagonistic groups. Analytic deliberation processes aid managers in understanding the positions of interested parties and in formulating a position that integrates information about values with scientific analysis.

Problem Focus

The analytic deliberative process is focused on a problem. It is an aid to decision-making, just as are BCA, impact assessment, risk analysis, and other tools. The process is not an open-ended discussion. Rather, it is intended to provide guidance to managers about specific problems and decisions.

Grounding in Facts and Values

Analytic deliberation processes are grounded in careful consideration of both available scientific understanding and the diversity of value positions relevant to a decision. A recent Research Council report (NRC 1996:214) defines analysis as "the systematic application of specific theories and methods, including those from natural science, social science, engineering, decision science, logic, mathematics and law, for the purpose of collecting and interpreting data and drawing conclusions about phenomena. It might be qualitative or quantitative. Its competence is typically judged by criteria developed within the fields of expertise from which the theories and methods come."

The discursive analytic deliberation processes test the biological, economic, and social information brought to bear on issues involving "systems". The continuity of these discursive processes provides the opportunity to obtain new information, to replace or add to what is questionable, and to legitimize what is used in decisions. The information relevant to such decisions informs analytic deliberation processes, and the processes bring to light uncertainties about the information and provide a forum for reaching agreement.

Structure and Fair Representation

Analytic deliberation processes are structured. Although much like a committee meeting, it usually involves a gathering of interested individuals, the process must be carefully structured to achieve its goals. The design must be tailored to match local circumstances, the problem being considered, the nature of interested

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parties, and the time and resource constraints on making the decision. Concentrating on specific questions provides a basis for reminding participants of the intent of the deliberation, and the structure of the process ensures that participants stay on target during discussions. The discussion can be structured so that there is continuing emphasis on linking deliberation to available scientific analysis.

Care must be taken to ensure that voices representing all relevant positions are heard. The process should not be dominated by the side that turns out the most supporters or that has the most aggressive advocates, as can happen with public hearings and unstructured group processes. In cases involving federal agencies, special care must be taken to satisfy the requirements of the Federal Advisory Committee Act, which spells out procedures for meetings that solicit advice from members of the public.

A critical problem in analytic deliberation processes is identifying the parties that should participate. Chess and Hance suggest that managers can identify stakeholders by asking the following questions (Chess and Hance 1994):

- Who has information and expertise that might be helpful?
- Who has been involved in similar decisions before?
- Who has wanted to be involved in similar decisions before?
- Who might be affected by the decision?
- Who might be affected but not know it?
- Who might reasonably be angered if not included?

Managers must keep in mind at least two dimensions of concern about biodiversity decisions. One dimension reflects the difference between concern about use value of biodiversity resources and concern about existence values. Some parties will be concerned about the management of a tract of land (or water) to produce income, jobs, and other immediate goods. Others will value the biodiversity of a tract of land for its very existence or for its actual or potential role as habitat for threatened or endangered species. Another dimension reflects the distinction between local interests of those who live and work on or near the habitat being managed and the interests of those who are distant from it but as citizens have an interest in it; this is a local or national dimension.

Conflicts about biodiversity management are often conflicts between people at different places along these dimensions. A successful deliberative process must involve people from distant points along both the use-existence dimension and the local-national continuum. If attention is not paid to both dimensions in selecting participants, key interested parties will not be represented.

The Deliberative Process

The National Research Council (1996:215) defined deliberation as "Any process for communication and for raising and collectively considering issues. . . .

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In deliberation, people discuss, ponder, exchange observations and views, reflect upon information and judgments concerning matters of mutual interest, and attempt to persuade each other." After careful scientific analysis and the application of tools to inform valuation, such as BCA, a manager still faces considerable uncertainty about what will happen and incomplete information about benefits and costs. In addition, some stakeholders will not agree with the valuations produced by formal methods of analysis, nor even with the idea that such analyses are the appropriate way to make decisions. It is then an appropriate time to deliberate.

Questions that a manager might ask of the deliberative process include

- Given the available information, resource constraints, and multiple goals that must be considered, what are the advantages and disadvantages of various options?
- What are the tradeoffs among options, and how do interested parties differ in their views of those tradeoffs?
- Is there a way to craft a strategy that is broadly acceptable to most affected parties?
- Are there conflicts that might be resolved with more information or more resources?

The goal of such deliberation is not primarily to pick an option; that is the manager's responsibility. The goal of the deliberation is to ensure that the views of affected parties are known and that managers are aware of the diversity of views among those parties. But successful deliberation goes further and allows participants to educate each other about both facts and values, develop a better understanding of each other's concerns, and sometimes find compromises. Even if some parties remain unsatisfied with any option except the one that they most prefer, the manager and other participants will have a better understanding of the sources of conflict. It is best that such deliberation begin early in the decision process, before all analyses are completed or even identified. That gives the participants a sense that their input is of consequence. It also might identify for the managers the key issues around which conflict arises so that special attention can be paid to them in analysis.

The rules of a deliberation are designed to ensure that all participants have a fair opportunity to express their views and be heard, that discussion remains focused on the questions at hand, that relevant analyses can inform the deliberation, and that agreements and disagreements can be identified. The exact process to be used must be designed with attention to the problem under consideration. Varied group processes can be used with success, including those suggested by Dietz and Pfund (1988), Renn and others (1993), and NRC (1996:199-206). Each method uses the social-science literature on small-group processes and on

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communication to design a set of rules that maximize the benefits and minimize the difficulties of small-group interactions.

Norton and others (1998) have suggested a two-tiered process for environmental policy analysis that is consistent with our analysis. The two-tiered process notes that preferences for environmental goods and services cannot be taken as static except in the very short term. They propose that some analysis must proceed in a "reflective" tier that is highly deliberative and in which values are juxtaposed with scientific understanding of long-term processes. In this tier, one would expect some evolution of public preferences. More routine analysis lies in a second, "action" tier that attempts to prescribe specific actions and makes use of both conventional economic analysis and dispute-resolution methods, with both conditioned on understandings and consensus developed in the "reflective" tier.

We do not specifically advocate a two-tiered process, because of our emphasis on linking analysis to the circumstances of the manager. A two-tiered process can be useful if the manager, or the larger agency for which the manager works can find the time and resources for periodic reflective analysis regarding goals and vision. Analytic deliberation processes are grounded in an understanding that values and preferences for environmental goods and services change over time, in part as a response to public conversation. Indeed, this is one theoretical justification for the deliberative approach (Dietz 1987). Valuation methods must be attentive to the emergent character of environmental values (Dietz and Stern 1995; Fischhoff 1991; Fischhoff and others 1980), and analytic deliberation is one way to take account of this fact. Thus, the process that we advocate captures the key insights of the proposal by Norton but also attends to the limited resources that most managers can allocate to analysis.

Several of the case studies in this report provide some guidance for analytic deliberation approaches involving biodiversity issues, although none of them was specifically designed as an analytic deliberation approach. The case study in the next section, "Deer and the Quabbin Reservoir", is an example of a successful deliberative process. It provided multiple opportunities for the public, including hunters and other interested groups, to interact with land managers and scientists over some period to develop a consensus on actions to reduce the deer herd at the reservoir. It also relied to a degree on analysis of likely results of alternative ways of reducing the deer herd.

The Pacific Northwest forests case study (chapter 5) and the Grand Canyon flush case study (chapter 4) were much more elaborate; each stretched over several years. Both used analyses of some possible economic effects of alternative approaches to inform deliberations. Over the life of the two cases, the deliberation processes fed on the analyses and provided new insights that led to further analyses. It is clear that the analyses and the deliberations both improved the ultimate decisions in both cases.

The Camp Pendleton case study (chapter 1) also relied on both analyses and

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deliberations. Although biodiversity values were of great importance, no explicit attempts were made to estimate economic values of aspects of biodiversity or of the costs of implementing various strategies for protecting biodiversity. The Everglades case study (chapter 2) was not structured as an analytic deliberative process, but, like the Camp Pendleton case study, it involved both analyses and deliberation.

The western rangelands case study (chapter 1), at first glance and because of its far-flung nature, seems to offer little opportunity for a structured analytic deliberative process. However, such approaches are being tried at the local level throughout much of the West. It remains to be determined just how much common ground exists between environmentalists and livestock growers; given the history of acrimony among the constituencies, these efforts clearly are worthy.

The various analyses that have been made of the federal rangelands issues have been piecemeal and have not played a major role in the legislative debates over rangelands policies. But the failure to accommodate the historical federal range policies to more recent environmental concerns begs for a new approach. The elements of a structured analytic deliberative process carried out over the broad geographic scope of the federal rangelands issue might offer some hope of success.

Case Study: Deer and The Quabbin Reservoir

The Quabbin Reservoir, an impoundment about 100 mi west of Boston, is the main source of municipal drinking water for the Boston metropolitan area. It provides pure potable water that requires no treatment other than disinfection to some 40% of the Massachusetts population. Construction of the 39.4-mi^2 reservoir during the 1930s and early 1940s required the physical and legal elimination of four towns with long settled village centers. The state-owned reserve surrounding the reservoir includes 60% of the 186 mi^2 (about 120,000 acres) of largely forested watershed of the reservoir (Platt 1995). Farmland was allowed to revert to forest, and fields were planted to trees. Access to the reservation around the reservoir was closely regulated and hunting was prohibited, both to protect the purity of the water.

With a mosaic of former fields and young vegetation, the deer herd grew rapidly. It peaked in the 1950s at about 60 deer/mi^2, much higher than in the surrounding area and well above what wildlife managers consider optimal (Dizard 1994). The increase in the size of the deer herd in the absence of hunting and major nonhuman predators destroyed much of the vegetation that protected the watershed, and this led to a drop in the deer population.

A long drought in the 1960s led the reservoir's managers to try clear-cutting some of the forest and thinning other parts to increase runoff into the reservoir. One effect of that strategy was to improve browse, the lack of which was becoming a problem because of the high deer population. The number of deer, which

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had fallen to about 20–30/mi^2 in the early 1970s, again started to rise (Dizard 1994). By the late 1980s, it was evident that the deer were eliminating practically all vegetation below the browse line.

Although seen as a problem by some people, the growing deer population was valued by others as a visible sign of some remaining degree of wildness in the environment and by hunters. Taking action to reduce deer herds and their effects on their habitat was a frustrating experience for the state agency that manages the watershed and is charged with providing clean water. The conflicts were over understandings of the biological facts of deer, their relationships to their habitat, and the effects of management, but mostly over personal differences in values.

Those differences were identified in a series of meetings with the public. Alternatives for controlling the number of deer, some suggested by the public and others by the management agency, were considered. In the end, it was decided that shooting deer was the only practical way to reduce the herd to levels that would allow ordinary vegetation to do its job in protecting the watershed. Once the decision was made, the problem was to decide whether public hunting would be allowed as a management technique and how the part of the public that liked the idea of the reservoir as a no-hunting reservation could be convinced that shooting deer was the appropriate approach (Dizard 1994).

The state agency responsible for management of the reservoir initially favored using sharpshooters instead of sport hunters to do the shooting, but the hunter lobby and the state Division of Fisheries and Wildlife objected. After many meetings with the public, the managers decided that a strictly controlled hunt by hunters chosen by lottery and given special instructions would work. The managers wanted to use the hunt as a management device, not to give hunters a chance to satisfy "primal urges" or to embody "some abstract notion of a sporting ethos" (Dizard 1994). The "hunt" was carried out in 1991 and, with careful orientation sessions for the selected hunters, appears to have been successful; and the provisions that had been made to maintain the purity of the water supply seem to have been effective.

It was not easy to carry out this kind of a management program in the face of conflicts over values involving nature. The issues over management of the deer herd around the reservoir are fairly typical of the issues of how to manage the growing deer population in the eastern United States generally. The human population is increasingly suburban and semirural in its location, but is increasingly removed from rural agricultural America in its views. The deer compete with gardeners and landscapers for space and vegetation. Sporthunters compete with animal-rights activists and nature lovers. To the extent that management agencies are involved, they compete with each other and seek to maintain influence by responding to the competing interests of those who support them in their quest for power and funds. Resolving these conflicts does not rest on a clearly defined and agreed-on set of values. In most cases, the processes for bringing

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parties together in attempts to resolve such conflicts are not nearly as well developed as in the Quabbin Reservoir case. As Stout and others (1994) observe, agencies with responsibility for deer management "need to be inquisitive, consensus building, and proactive by including multiple stakeholders" in their decisions. In doing this, they must also avoid blurring distinctions between values and scientific judgments and must make clear to the public that its input in management decisions must be balanced with biological and technical information.

Other Uses

Guiding a decision will be the most common application of deliberation, but it can be useful in other ways. Chess and others (1998) provide further guidance on when and how managers can use deliberative processes. Generally, managers and scientists are in the best position to identify research that will assist decision-making. But in some cases, broader deliberation with interested parties is helpful because it can identify the kinds of information that will reduce conflict and build consensus. Such a deliberative process can help to reduce conflicts that are based in differing understandings among stakeholders of what will happen under various options and to suggest lines of research that will reduce differences about the facts. And deliberation at the start of a research effort will help interested parties to become stakeholders in the research and thus aid in making the research results influential with those who might otherwise be skeptical. In these circumstances, the analytic base for deliberation comes from scientists and other experts who can outline what kinds of questions might be answered by research and with what degree of certainty. We do not suggest such deliberation when the resources for analysis are inadequate and the studies to be conducted are routine, because there might be little to gain in such circumstances. But when a substantial and novel research effort is to be undertaken and it is necessary to decide what analyses to conduct, consultation with interested parties can be helpful.

Determining the value of aspects of biodiversity that are not reflected in market prices is a central problem in biodiversity policy, as we have noted in chapter 5. One common but controversial approach to this problem is the CV method. But the CV method is based on surveys, and responses are given rather quickly, without the deliberation, reflection, and conversation that occur in market transactions that produce market prices (Dietz and Stern 1997). That has led to the suggestion that the value of biodiversity might be assessed better through a deliberative social process than through a process based on individual survey responses. It is an intriguing argument, but too little work has been done in exploring this approach to recommend it as a substitute for CV methods. We suggest that further effort be devoted to examining ways of improving CV and developing complements to it, including deliberative methods.

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DELIBERATION, LEARNING, AND THE DECISION PROCESS

As a society, we are learning how to value and manage biodiversity. The tools we use in valuation and management must reflect and facilitate the continuing learning process. We urge that managers view their efforts as experiments. This requires humility because outcomes are uncertain. And it requires flexibility because policies might have to altered midstream as science develops better understanding, as societal values evolve, and as the biophysical environment changes. It requires mechanisms for monitoring and evaluating. Analytic deliberation processes are a flexible tool that can aid in such learning. They allow for reflection on what has been done, on what has resulted, on how values and science have changed, and on courses for the future.

As though the scientific complexities were not daunting enough, managers' work is further taxed because it is clear that there is no single "public interest" when it comes to biodiversity. In chapter 4, we note the diversity of philosophical positions that can be used to understand the value of biodiversity. The public partakes of all these views and others as well. Thus, some conflict and diversity of opinion are inevitable. The variety and conflict that result will always arise in public management of biodiversity. Nor can managers ignore the conflict. Biodiversity management takes place under public scrutiny. Government decision-makers are required by such laws as NEPA to allow the public to participate in the decision-making process concerning publicly owned resources. How can information on the values of resources effectively inform decision-makers in a way that allows them to incorporate the wide range of public viewpoints expressed?

The nation's legal system imposes additional constraints on proposals: they must comply with federal and state laws, they must objectively present socially ethical proposals, access to opportunities or resources must be equitable, and decisions must fall within the missions and legal mandates of the agencies charged with implementing them. A decision that fails to comply with any of those requirements, no matter how positive the social benefits, can be quickly overturned on appeal to the legal system. That leaves a relatively small decision space within which decision-makers must operate, and it is within this decision-space that one must try to draw conclusions that are fair, competent, and efficient. Analytical techniques, such as those described in chapter 5, can be a great aid in making decisions. But ultimately such techniques are not sufficient. The analytic deliberative process described here is an important aid to understanding conflicts, resolving them when possible, and building trust. But it too is not a panacea. The analytic deliberative approach is justified on normative, substantive, and instrumental grounds (Fiorino 1990). It is normatively appropriate in that it allows all parties affected by a decision to have a say in it. It is substan-

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tively appropriate in that it provides a broader range of expertise than would be available if decisions were made with input only from scientists and managers. The perspectives of scientists and managers are essential, but other interested parties can offer additional information needed for good decisions, particularly about values. Finally, analytic deliberation processes are instrumentally appropriate in that such a process can help to build trust and understanding and, even when disagreement persists, clarifies the basis of disagreement.

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Broadening the Biodiversity Manager's Perspective

Resource managers are faced with trying to satisfy a wide range of human needs—food, fiber, recreation, cultural and aesthetic satisfaction, national security—that depend on natural processes, all within the constraints imposed by diverse agency and other landowner mandates. They must be sensitive to the effects of management on current and long-term resource production and on the many values that people find are satisfied by these processes. The job is difficult because of the complexities of both the natural world and human society and because of the inevitable conflicts.

An important consideration in resource management has been biodiversity and its conservation. At one end of the management spectrum, that means maintaining intact native biological communities and ecosystems. At the other end, it means simply adapting management to recognize the role of biodiversity in maintaining productivity of managed landscapes. In most cases, it means recognizing how managing and conserving biodiversity fit into broad landscapes—probably a mix of public and private lands—only part of which can be managed with biodiversity concerns in mind. These concerns are important at all scales of decisions, from local to global.

But just how important is biodiversity conservation relative to the other concerns that resource managers must address? This report does not answer that question directly. Rather, it looks at processes that will be helpful to managers in comparing various biodiversity concerns or values with other values related to resources.

Conservation of biodiversity does not enter into resource-management decisions in only one way. It is a vital element in sustaining natural processes. But management of natural systems involves many tradeoffs between conservation of

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biodiversity and other management goals. The extent of the tradeoffs and the extent of a manager's ability to effect the conservation of biodiversity are limited by the extent of the manager's authority or decision space.

Resource-management decisions in nearly all cases are incremental. A manager's decisions are limited in space by agency mandates and geographical constraints. They are usually limited in time by the ability to forecast conditions and human needs. But concerns extend beyond those boundaries. Although a manager's actions are local and immediate, the management perspective must be broad enough to recognize a range of values, as well as the implications of decisions for survival of larger ecosystems. A series of decisions, no one of which has major effects, can have major cumulative effects.

This report contains several case studies that are intended to show how a variety of management situations involving biodiversity conservation were or might be resolved. They include President Clinton's decision to reserve some 7 million acres of Pacific Northwest forests to protect the northern spotted owl and a local decision to protect open space in the city of Boulder, Colorado. Somewhere on that scale is the situation at Camp Pendleton, a military base along the coast of southern California that contains habitat for several endangered species but also has potentially high residential values if it were to be decommissioned by the Department of Defense. The latter case is representative of the potential for biodiversity conservation on the 25 million acres of Department of Defense lands, some of which are scheduled for decommissioning.

The conflicts over biodiversity and competing values in the case studies are substantial. Some are driven by the strictures of the Endangered Species Act, which includes only some of the values of biodiversity. The cases also show the limits placed on solving the broader problems of biodiversity conservation by the limits on the manager's decision space. In the face of those limits on a resource manager's ability to deal with the issues surrounding conservation of biodiversity, what help can this report provide?

A limitation of the case studies is that they illustrate decisions that were or are to be made in the absence of an overall strategy for conserving biodiversity. The Pacific Northwest forests case study led to a balanced regional decision to protect some species that depend on old-growth forests. Although important regionally and in itself, the impact of the decision neither extends beyond the boundaries of the Pacific Northwest nor fits into a broader national strategy for conserving biodiversity.

The intent of this report is to consider the many approaches to valuing biodiversity for broadening the resource manager's perspective. The task assigned to the committee that wrote this report was to examine "how current scientific knowledge about the economic and noneconomic value of biodiversity can best be applied in the management of biological resources." To do that, the committee reviewed the relevant scientific literature on biodiversity, its values, concerns about its status, and its treatment in analyses of its value.

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The committee found

- That a broader understanding of the implications of biodiversity conservation is needed for resource management decisions on the various scales at which they are made.
- That the available tools for estimating both economic and noneconomic values to management alternatives are limited in their usefulness in these decisions, in part because of the wide differences in philosophies of value held by the public, but also because of the nonmarket nature of so many of the values of biodiversity. No measure or calculus adequately provides for simultaneously weighing the full range of possible values in most such decisions.
- That reaching public consensus on decisions involving biodiversity is hindered, often by the lack of facts on which agreement can be reached, but also by public processes that fail to take full advantage of opportunities to develop consensus.

Managers are faced with the unenviable, but necessary, task of weighing the various consequences of their actions in the absence of unambiguous supporting information on their effects on biological processes, local and global. They are faced with weighing the effects in terms that are relevant to people and their values and with doing this in the absence of unambiguous measures of human values. The dilemma for managers and society alike is that decisions must and will be made.

The committee found a need for better understanding of current conditions and trends related to biodiversity on the scales of typical resource-management decisions. This is a high-priority need. Applying scientific knowledge about values and biological processes generally requires relatively fine-grained information about both biological and value effects of management actions, including information on the potential cumulative effects of management and of use of resources on the basic elements of biodiversity. Despite the growing recognition of the importance of biodiversity in sustaining biological processes, major gaps still exist in our understanding. The case studies show the limits of existing knowledge of biodiversity and its implications, as well as the limits of the tools and processes for estimating values to be used in management decisions.

Managers need ways to evaluate the effects of decisions within their decision space in the broader regional or even global context of biodiversity conservation. A step in this direction is the relatively recent development of regional assessments of biological resources and the biological, economic, and social consequences in some regions of the United States (for example, the Interior Columbia River Basin and the southern Appalachians). Having this kind of information available would help resource managers of subregional areas to assess the possible cumulative effects of management and resource use, as well as biodiversity conservation, in their areas on the broader regional ecosystem.

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The main regional assessments that have been done in this country have focused on areas with extensive federal ownership, in large part because the regional assessments are intended to help in federal resource management. Other areas of the country, however, also face biodiversity issues, many of which might be important for federally funded projects that are subject to regulations under the National Environmental Protection Act (NEPA). In addition, the assessments themselves note the paucity of information on major groupings of species and uncertainties about the kind of biological information that would be most useful for managing ecosystems.

A concerted effort involving the full range of federal resources management and research agencies is needed to develop the kind of biological information required for appropriate management of biodiversity on all spatial scales and across jurisdictional boundaries. Recommending an appropriate organization and assigning of responsibilities for such an effort are beyond the scope of this committee. But it seems clear that a multiagency effort is required and that the information should not be collected only for federal lands. Other owners of resource lands also need this kind of information. Despite the growing recognition of the importance of biodiversity in sustaining biological processes, major gaps still exist in our understanding of the systematics of species in the United States, and knowledge of species diversity globally is readily available only for mammals and birds.

No single means of establishing economic and noneconomic values allows decision-makers to weigh the full range of people's values in biodiversity simultaneously. The committee examined range of value systems and how they might apply to decisions involving biodiversity. Each of the value systems discussed in chapter 4 of this report—contractarianism, Kantian ethics, egalitarianism, deep ecology, and so on—has legitimacy, but none by itself adequately represents the range of public concerns in biodiversity conservation. Decision-makers must be aware of the wide range of possible value systems and to consider them fairly in their decisions.

Economic valuation is grounded in utilitarianism, a value system that would recommend that biodiversity be protected and promoted to the extent that society wants it and is willing to pay for it. Other value systems focus attention on other concerns: property rights, intrinsic values that have "a good of their own", ensuring that impoverished people have access to their needs, assigning rights to "nature and so on". None is necessarily inconsistent with a belief in a "safe minimum standard" for conserving biodiversity. That does not mean, however, that the different value systems would lead to the same results in conserving biodiversity.

Economic valuation adds information that is objective to the extent that there are well-established standards for critiquing it (chapter 5). Discursive processes provide a means for deciding what weight should be assigned to valuations based on economics and other standards (chapter 6).

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Valuing biodiversity in an economic context poses challenging problems because of the many benefits provided by diverse biological systems, the lack of markets for most of the benefits, and the relatively uncompromising requirements of economic analysis. Chapter 3 has provided many examples of how biodiversity contributes to economic values. Although based generally on market-determined values, benefits as measured in an economic valuation of biodiversity conservation can also include the willingness to pay for or accept non-market-determined values (chapter 6). When applied in this broad sense, economic valuation should have an important, although not singular, role in resource-management decisions.

In the absence of widespread agreement on a philosophical approach and measurable results that describe the values of natural systems in such an approach, resource managers have turned to public participation in their decisions in an effort to reach some sort of public consensus. Partly because of requirements for public participation in NEPA decisions, there is now a substantial literature on ways to improve this participation. Much of it is concerned with ways to incorporate information on resources and values in decisions. Some is concerned with improving ways to explore and reach agreement on different approaches to valuation.

For resource managers, public participation processes can be contentious. The range of value perspectives that deserve a place at the table is wide and not necessarily amenable to compromise. The managers usually have little basis for choosing or weighting one perspective over the others. Nevertheless, using the best methods of economic valuation and the best available information will reap substantial benefits. Analysis of alternatives, including economic valuations, might help to reduce the gap between contrary perspectives. Structured deliberation that involves stakeholders in these decisions and is supported by analysis will be useful in defining boundaries and directions.

Although economic valuations often understate the value of natural processes and systems, when economic values are unambiguously greater than expected costs, questions of value and choices are clarified. Especially in the context of utilitarian values, market prices provide a relatively unambiguous measure of some benefits and costs.

In the face of constraints of knowledge, time, and understanding of people's basic values, it is still appropriate that decisions involving the conservation of biodiversity be made. Most of the decisions will be local and have mainly local effects that can be monitored and used to guide later decisions. But some will involve broader issues, major commitments of resources, and longer periods of adjustment. At whatever level decisions are made that involve the recognition of the importance of conserving biodiversity, the following conclusions will help to guide action.

- There is an urgent need for more information about biodiversity and its role in sustaining natural processes and for it to be gathered, organized, and

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presented on various scales and in ways most useful to those charged with managing natural resources.

- No simple models or approaches can adequately capture both market and nonmarket values of biodiversity in a simple, objective manner. Traditional and emerging benefit-cost approaches to valuing biodiversity can contribute important and relevant information to decision-making. But the wide ranges of values and value systems held by those affected by resource decisions and the inherent difficulties in quantifying nonmarket values place some limits on the role of models in these decisions.
- There is great power in using an analytic deliberative process, which is inherently qualitative, in making decisions about biodiversity, although the ultimate decisions themselves must be made by the managers or policy makers. This includes using the process to weigh the different kinds of values that are involved.
- Most decisions affecting biodiversity will be made on a local scale, but the aggregate of these decisions will affect biodiversity on regional and even global scales. Therefore, there is an urgent need for periodic regional assessments of the state of biodiversity so that managers can assess the consequences of their decisions in broader and more ecologically meaningful contexts.

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A

Statement of Task

The committee will perform a study to examine how current scientific knowledge about the economic and noneconomic value of biodiversity can best be applied to the management of biological resources. The committee will include the following areas of expertise: the biodiversity sciences (ecology, population biology, conservation biology, and systematics), resource management, economics, sociology, and philosophy). The report of the committee will

- Review the current state of scientific knowledge about the noneconomic and economic values and benefits of biodiversity, including the relative utility of economic cost-benefit analyses and noneconomic approaches; included in the review should be a characterization of the various kinds, aspects, and dimensions of value and benefits that need to be taken into account by managers and decisionmakers, an evaluation of the tools available to assess them, and an examination of the ways in which such assessments are currently used in helping to make decisions about the management of biological resources.
- Examine, with the aid of case studies involving Department of Defense and other lands as appropriate, how this knowledge can be synthesized and applied to protection, use, and management of ecosystems and biodiversity—especially, taking into account that much of the value may be noneconomic in nature, how the various aspects of value can and should be weighed in making management decisions, and the limits to such comparisons.
- Identify weaknesses in the current understanding of economic and noneconomic value and limits to its utility as it relates to management of biodiversity, questions that must be addressed to enhance its utility for managers, and research and development needed to address the needs identified.

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• Based on current knowledge and taking into account risks and uncertainties, make recommendations on how managers can improve how they use information about the value of biodiversity in the process of developing, implementing, and evaluating management plans.

Related questions that the committee may usefully address include: How can managers use knowledge about the value of biodiversity to help guide them in determining the most appropriate level of protection for an area (e.g., preservation versus conservation)? To what degree are different kinds of value affected by different levels and kinds of use? How should managers weigh the degree to which current actions that affect the biodiversity of an area might influence future value and costs—e.g., is current heavy use of an area for training likely to result in serious degradation of ecosystem services, cultural or aesthetic value, or potential for biodiversity prospecting in the future?

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B

Biographical Sketches

Diana H. Wall is the director of the Natural Resource Ecology Laboratory and associate dean for research in the College of Natural Resources and professor of rangeland ecosystem sciences at Colorado State University. Her research interests span hot and cold deserts and managed agroecosystems, with emphasis on nematode biodiversity, ecology and survival in the Antarctic Dry Valleys, and biodiversity of nematodes. Her focus is on the impact of disturbance on soil invertebrate communities and ecosystem processes. Dr. Wall was president of the American Institute of Biological Sciences, president of the Intersociety Consortium for Plant Protection, president of the Society of Nematologists, and president of the Sigma Xi chapter at the University of California, Riverside. She is president-elect of the Ecological Society of America. She was a member of the National Research Council Board on Environmental Studies and Toxicology and chairs the National Research Council SCOPE Committee on Soil and Sediment Biodiversity and Ecosystem Functioning. She is a member of the Scientific Advisory Board of the National Science Foundation National Center for Ecological Analysis and Synthesis and a member of the DIVERSITAS Scientific Steering Committee.

Carl E. Bock is professor of environmental, population, and organismic biology at the University of Colorado in Boulder. He is an ornithologist and animal ecologist with particular interest in the ecology and conservation biology of grasslands in the American West. From 1980 to 1991, he and his wife and colleague, Jane Bock, were directors of the Appleton-Whittell Research Ranch, a sanctuary of the National Audubon Society in the grasslands of southeastern Arizona. Dr. Bock is a fellow of the American Ornithologists' Union, former

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president of the Council of the Cooper Ornithological Society, a 30-year member of the Ecological Society of America, and a trustee of the Colorado Nature Conservancy.

Thomas Dietz is professor of sociology and environmental science and public policy at George Mason University. He received a PhD in Ecology from the University of California, Davis in 1979 and a bachelor's degree in general studies from Kent State University in 1972. He is past president of the Society for Human Ecology, a fellow of the American Association for the Advancement of Science, a Danforth Fellow (Class of 1972), and the 1997 recipient of the Distinguished Contribution Award by the American Sociological Association's Section on Environment, Science and Technology; he has been a Fellow at the Swedish Collegium for Advanced Study in the Social Sciences. He has been coeditor or coauthor of *The Handbook for Environmental Planning* (Wiley, 1972), *The Risk Professionals* (Russell Sage Foundation, 1987), *Human Ecology: Crossing Boundaries* (Society for Human Ecology, 1993), *Environmentally Significant Consumption: Research Directions* (National Academy Press, 1997), and over 60 refereed papers and book chapters. His current research interests include environmental values and valuation, human driving forces of environmental change, and cultural dynamics. He has served on the National Research Council's Committee on Human Dimensions of Global Change.

Perry R. Hagenstein has been an independent consultant on natural-resources economics and policy since 1976 in Wayland, MA. He is president of the Institute for Forest Analysis, Planning, and Policy, a nonprofit research and education organization, and chairman of the Board of Trustees of the New England Natural Resources Center, a nonprofit trust that works with other organizations on interstate natural-resources issues in New England. He was research forester, Fordyce Lumber Company, Arkansas; principal economist, Northeastern Forest Experiment Station, USDA Forest Service; senior policy analyst, US Public Land Law Review Commission; research fellow, Harvard University; and executive director, New England Natural Resources Center. He has served on numerous committees and boards of the National Research Council that concern natural resources and is now a member of four such committees. He is a former president and long-time board member of American Forests, the nation's oldest national citizens conservation organization.

Anthony J. Krzysik is senior research ecologist at US Army Construction Engineering Research Laboratories. He received a BS in chemistry from Carnegie Mellon University, and an MS in physical chemistry and a PhD in biology-ecology from the University of Pittsburgh. His research focuses on practical applications of quantitative and theoretical ecology to a broad range of natural-resource management problems. His current research includes statistical sam-

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pling designs and field methods for quantifying biodiversity and environmental determinants on landscape and regional scales and ecological assessments and monitoring. His long-term research continues on the ecological effects of landscape-scale military training activities in the Mojave Desert and multivariate modeling of species-habitat relationships. He was the field and statistical ecologist for an international interdisciplinary team of scientists that assessed ecosystem impacts of a megaproduction urea-phosphate plant on the Black Sea in Ukraine, and he has been a peer reviewer for the Environmental Protection Agency's Environmental Monitoring and Assessment Program.

Robert T. Paine is a professor of zoology at the University of Washington. He is a member of the National Academy of Sciences and has served on numerous National Research Council panels. Dr. Paine is also a member of the Ecological Society of America (of which he was president in 1979-1980), the American Society of Naturalists, and the American Association for the Advancement of Science. His research is on the interactive forces organizing complex assemblages that inhabit marine rocky shores.

Stuart L. Pimm is a professor in the Department of Ecology and Evolutionary Biology at the University of Tennessee, Knoxville. Dr. Pimm's major interest is in conservation biology. The problems associated with endangered and introduced species have been the subject of his long-term and continuing theoretical and empirical studies. He has spent much of his field time in Hawaii and elsewhere in the Pacific. Dr. Pimm has headed a team to return the Guam Rail to the wild; this species was exterminated from its only known range in Guam by an introduced snake. In southern Florida, he leads a project on the endangered Cape Sable Sparrow. He contends that conservation biology provides questions of the greatest challenge for ecological theory while better theories are essential tools for conserving biodiversity. In 1993, he was awarded a prestigious Pew Scholarship in Conservation and the Environment.

Walter Reid is an independent consultant on environment and development, and a visiting fellow at the World Resources Institute, a policy-research institute based in Washington, DC. Dr. Reid has conducted policy research in biodiversity conservation, climate change, energy policy, sustainable agriculture, and biotechnology. He is the author or co-author of numerous reports and articles, including *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity* (WRI 1989), *Conserving the World's Biodiversity* (IUCN, WRI, Conservation Intl, WWF, and World Bank, 1990), *Biodiversity Prospecting: Using Genetic Resources for Sustainable Development* (WRI 1993), *Frontiers of Sustainability* (Island Press 1996), and *Are Developing Countries Already Doing as Much as Industrialized Countries to Slow Climate Change?* (Energy Policy 1997). For 6 years, Dr. Reid was vice president for program at the World Resources Institute

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(WRI). Earlier, he was a senior associate in the Biological Resources Program at WRI and a Gilbert White Fellow with Resources for the Future, in Washington, DC. Dr. Reid earned a PhD in zoology with specialization in population and community ecology from the University of Washington in 1987. He received his BA in zoology from the University of California at Berkeley in 1978.

Mark Sagoff is senior research scholar at the Institute for Philosophy and Public Policy in the School of Public Affairs, University of Maryland. He is the author of *The Economy of the Earth* (Cambridge University Press, 1988), was named a Pew Scholar in Conservation and the Environment in 1991, and from 1994 to 1997 served as president of the International Society for Environmental Ethics. He has taught at Princeton University, the University of Pennsylvania, the University of Wisconsin (Madison), and Cornell University.

William D. Schulze is senior fellow in the Center for the Environment, Cornell University. His professional interests and research include environmental, public, experiential, and behavioral economics. A major research area subject of his has been the development and exploration of survey methods in contingent valuation and their application to environmental policy. Related research interests include economic decision-making, especially with respect to the provision of public goods, and the effects of risk communication and assessment on valuation of environmental goods.

Dale E. Toweill is wildlife program coordinator for the Idaho Department of Fish and Game in Boise, where he has been involved in wildlife management and land-use policy decisions over the last 15 years. He received a BS and an MS in wildlife management from Oregon State University and Texas A&M University, respectively; and a PhD featuring emphasis on microeconomics and natural-resources policy from Oregon State University. He has written books and articles on wildlife management and is interested in the allocation of public resources and public lands and the resulting economic impacts on society.

Peter M. Vitousek is Clifford Morrison Professor of Population and Resource Studies in the Department of Biological Sciences, Stanford University. He received a PhD in biological sciences from Dartmouth College and taught at Indiana University and the University of North Carolina before going to Stanford. His research has focused on ecosystem structure and function and on land-water and land-atmosphere interactions as they are influenced by natural processes and human activities. He is a member of the National Academy of Sciences and a fellow of the American Academy of Arts and Sciences.

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David B. Wake is Professor of Integrative Biology at the University of California at Berkeley, where he is also Curator of Herpetology and Director of the Museum of Vertebrate Zoology. He is a member of the National Academy of Sciences and has served on the Board on Biology and panels of the National Research Council. As an evolutionary biologist and systematist he is concerned with the description and preservation of biodiversity, and has been especially active in Middle America, where he has focused on salamanders. In recent years he has led efforts to document and gain an understanding of factors involved in the decline and disappearance of amphibians in many parts of the world. He is a former President of the Society for the Study of Evolution, the American Society of Naturalists, and the American Society of Zoologists.

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C

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