Ecosystems (2005) 8: 125–132
DOI: 10.1007/s10021-004-0078-y

ECOSYSTEMS




# Looking to the Future of Ecosystem Services

E. M. Bennett,[1]* G. D. Peterson,[2] and E. A. Levitt[1]

[1]*Center for Limnology, University of Wisconsin, 680 N. Park St., Madison, Wisconsin 53706, USA;* [2]*Department of Geography and McGill School of the Environment, McGill University, 805 Sherbrooke St. W., Montréal, Québec, Canada H3A2K6*

## ABSTRACT

Ecosystem services—the benefits that people obtain from ecosystems—are essential to human existence, but demands for services often surpass the capacity of ecosystems to provide them. Lack of ecological information often precludes informed decision making about ecosystem services. The Millennium Ecosystem Assessment (MA) was conceived in part to provide the necessary ecological information to decision makers. To this end, the MA set out to address the stated needs and concerns of decision makers and examine the ecological dynamics and uncertainties underlying these concerns. To improve our understanding of their information needs and concerns, we interviewed 59 decision makers from five continents. The respondents indicated that although most people generally agree about the ideal state of the planet—free of poverty and extreme inequality, replete with cultural and biological diversity—they often disagree about the best way to achieve these goals. Further, although nonspecialists are generally concerned about the environment and may have a good understanding of some of issues, they often have a more limited grasp of the ecological dynamics that drive the issues of concern. We identify some of the principal uncertainties about ecosystem dynamics and feedbacks that underlie the concerns of decision makers. Each of the papers in this special feature addresses these ecological feedbacks from the perspective of a specific discipline, suggesting ways in which knowledge of ecological dynamics can be incorporated into the MA's assessment and scenario-building process.

**Key words:** ecosystem services; scenarios; Millennium Ecosystem Assessment; ecological dynamics; management dilemmas.

## INTRODUCTION

Ecosystem services—that is, the benefits that people obtain from ecosystems—are essential to human existence (Daily 1997). Demand for ecosystem services often surpasses current capacity, and experts predict that these demands will continue to increase in the near future (Vitousek and others 1997; MA 2003). For example, by 2020, demand for rice, wheat, and maize is projected to increase by 40% over 1993 values (Pinstrup-Andersen and others 1997). Similarly, over the past century, withdrawals from baseflow of the world's rivers have grown twice as fast as the global population (Schiklomanov 1997), reducing the amount of water left in rivers for other ecosystem functions. If current trends continue, human demand for ecosystem services may exceed the Earth's ability to provide them.

Growing demands for ecosystem services can no longer be met by tapping unexploited resources (Watson and others 1998; Ayensu and others 1999). As the demand for services increases, people often respond by modifying ecosystems to increase their provisioning capacity. This anthropogenic transformation of ecosystems often enhances the

Received 15 May 2003; accepted 17 March 2004; published online 28 February 2005.
**Corresponding author; e-mail:* embennett@wisc.edu

production of some services at the expense of others (Jackson and others 2001). Increases in agricultural production, for example, may come at the expense of the provision of clean water. Technological or institutional advances sometimes help to generate win–win solutions to these types of tradeoffs. For example, some tillage strategies improve agricultural production even as they reduce runoff to surface water. Ultimately, to ensure the continued supply of ecosystem services, we will be compelled to manage ecosystems actively, with a view to the long-term, sustained production of a bundle of goods and services. The long-term management of ecosystem services will require difficult decisions involving tradeoffs between the production of various ecosystem services and the benefits and risks of using technology to provide them.

The Millennium Ecosystem Assessment (MA) was conceived in part to respond to this concern by synthesizing the latest scientific information about ecosystem change and presenting it in a format that is useful for decision makers. The MA is a multiscale integrated assessment of the current and future state of ecosystem services and will provide scientific information for many formal and informal user groups, including the Convention on Biological Diversity, the Convention to Combat Desertification, the RAMSAR Wetlands Convention, nongovernmental organizations, national ministries involved in environmental planning, the private sector, and civil society.

Decision makers are now facing a wide variety of impending crises that will require informed ecosystem management decisions. The growing demand for services is putting pressure on managers to provide more services without overstressing ecosystems. Yet the ways that these systems produce the services that we require are complex and poorly understood, often causing management decisions to be made under conditions of great uncertainty.

One way of coping with high levels of uncertainty about the future is to use scenario planning (Peterson and others 2003); therefore, the MA is now developing scenarios that explore the provision of ecosystem services. Scenarios—sets of narratives about the future—have been used by decision makers in the business community and elsewhere for several decades as an alternative to predictions, forecasts, and other single-future strategic planning processes (Davis 1998). Scenario planning involves thinking about a wide range of plausible futures, including both well-known trends and key uncertainties, and using this information to generate a set of storylines that can guide decision making. Scenarios can be quantitative or qualitative and can look forward from the present or backward from an imagined ideal future.

To develop alternative visions of the future of ecosystem services in a way that will supply usefull information to decision makers, the MA scenarios must first address the specific concerns of policy makers and then capture key aspects of the ecosystem dynamics that drive those concerns. We interviewed a broad range of policy makers to learn which issues are of greatest concern to them. At the same time, ecologists have identified a number of situations in which major management decisions must be made in the absence of a sound ecological understanding of the results of those decisions. The MA is using the concerns of decision makers and an ecologically informed understanding of the management dilemmas that they face to develop a set of scenarios that illuminate the future of ecosystems in a way that is relevant to policy decisions. In this paper, we present the outcome of the interviews, describe the ecological management dilemmas, and suggest how the MA might tackle these concerns in one set of scenarios. We then provide a brief overview of the papers collected in this special feature, each of which addresses a different aspect of the development of global scenarios for ecosystem management.

## Insights from Interviews with Decision Makers

What are the main concerns of decision makers about the future of the world's ecosystems? Insights from leaders about their concerns can help to focus the MA scenarios directly on the most pressing interests of decision makers and other users of the scenarios. We interviewed 59 leaders drawn from nongovernmental organizations, governments, and the business world across five continents (Figure 1). The leaders were chosen based on recommendations from the MA board (themselves selected from MA users to guide the MA process) and from other interviewees, and were not intended to be a random selection; however, we intentionally chose leaders from across many sectors and continents to access a broad range of concerns and responses. Based on previous scenario work (Van der Heijden 1996), we designed open-ended, general questions that would elicit a wide variety of rich conversations about issues that the interviewees thought were critical determinants of the current and future states of the world (Table 1). These interviews were conducted by

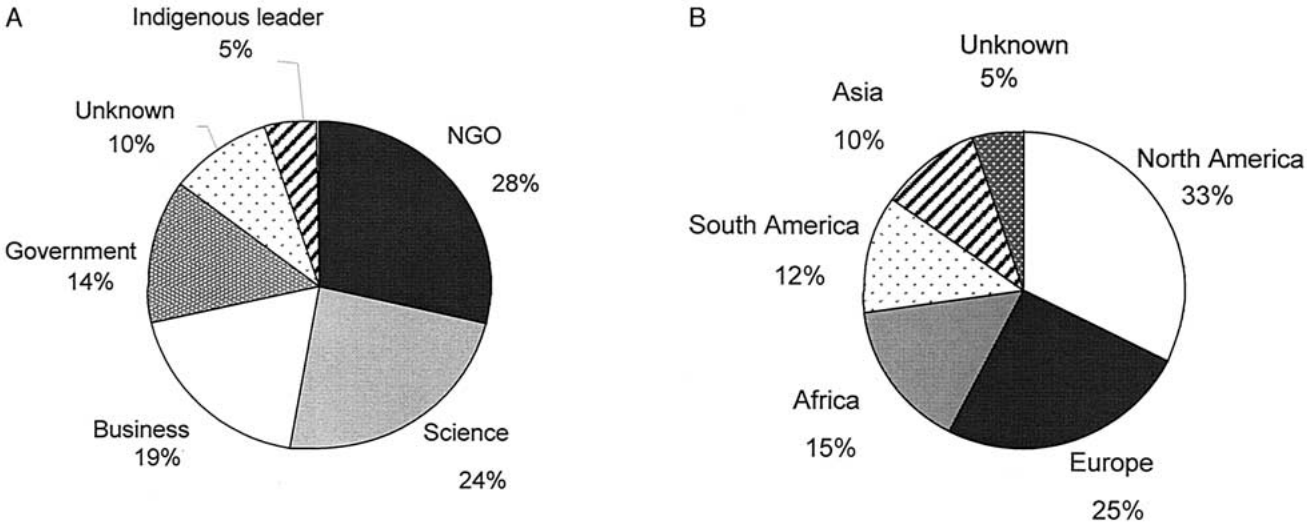


**Figure 1.** Percentage breakdown of interviewees by **A** sector and **B** region. NGO, nongovernmental organization.

**Table 1.** Interview Questions

| |
|---|
| What words would you use to describe the current state of the Earth's natural and human systems? |
| What words would you use to describe the ideal state of the Earth's natural and human systems in 2050? |
| What obstacles do you envision to achieving this ideal world? |
| If you could talk to someone who visited the world in 2050, what would you need to know to understand what the world really looks like in 2050? |
| Who or what will be most influential in determining the pathway of change into the future? |
| What is the biggest change you expect between 2003 and 2050? |
| What surprises might you envision between now and 2050? |
| What gives you the most hope for the future? |

e-mail and telephone between spring 2002 and spring 2003.

The decision makers we interviewed agreed that many of the key aspects of ecosystem services, such as biodiversity and water quality, were declining in a perilous fashion, and that this degradation was, at least in part, unnecessary. They were concerned about the negative consequences of invasive species and the effects of trade and transportation on the invasability of ecosystems. Although most of them were concerned about what they saw as negative trends in the state of ecosystems, they disagreed about which aspects of global society were the main drivers of ecological degradation. The most frequently mentioned drivers were poverty, inequality, overpopulation, overconsumption, and the mismanagement of resources.

Although there was broad agreement among the decision makers that we should strive to create a culturally and biologically diverse planet where people lead rich, fulfilling lives, there was a great deal of disagreement about exactly what was meant by this goal, as well as which policies and actions would best achieve it. Some of them thought that attempting to create an ideal state in a world that is always changing was futile and potentially dangerous. Although these decision makers generally agreed on the essential elements necessary to creating a better world—such as the alleviation of poverty, wise ecosystem management, stemming the loss of biodiversity—there was wide disagreement about which of these tasks was the most important and which should be tackled first.

Changes related to social and economic inequality, globalization, urbanization, civil society, and technology were widely cited as principal forces that will shape the future. Again, the specific role and result of each of these factors was disputed. Many interviewees thought that the tension between people's attachment to local places and the simultaneous desire for a cosmopolitan global culture would play a major role in shaping the future as it is manifested in the growth of religious fundamentalism, global cultural homogeneity, and creolization. Positive elements of increasing global connectedness that were mentioned included increases in communication, knowledge, and opportunities for a greater range of people. Interviewees believed that the growth and expansion of global civil society is critical to producing a desirable future. At the same time, many of them thought that traditional knowledge and values could play an important role as alternatives to one-size-fits-all global policies. While civil society was seen as playing a key role in positive change, human greed and overconsumption were cited as limiting factors.

Urbanization was also considered to be a critical factor in determining human stress on ecosystems. On one hand, diverse, well-organized cities could enhance the provision of ecosystem services, but rapid, chaotic growth might catalyze ecological crises. For example, carefully planned urban growth that includes green space can enhance the provision of recreation within a city. However, chaotic sprawl with little or no storm sewer planning could lead to increased flooding in urban areas. Technology was seen as both a problem and solution. There was general agreement that new technologies would continue to emerge, but their impact on society and the environment was questioned. Many people were concerned about our reliance on fossil fuel and wondered how future societies would be affected by the consequences of its use. Shifts in the global political economy of these resources were considered to be an important determinant of the world's future.

There was widespread consensus that there are many aspects of today's world that offer hope for the future. Some people saw the resilience of ecosystems and humans as key sources of hope. Others placed great confidence in technology and the idea that new discoveries might reduce the unintended costs of previous technological changes. Most respondents saw the increasing opportunities for their children as a promising sign of a desirable future.

These interviews with potential users of the MA provide information about factors that should be incorporated into scenarios designed for their use. The primary concerns of these decision makers arose from their desire to understand how different modes of social–ecological interaction might affect the provision of ecosystem services. One aspect of particular concern was the nature of cross-scale connections between social-ecological systems. Can ecosystem services be maintained solely through global or large scale-environmental policies without regard to regional or local-scale policy making? Another lesson to be gained from the interviews was the need to address the decision maker's concerns about the impact of different approaches to managing social-ecological systems. Are responsive approaches to environmental problems good enough? or are safe-fail intervention strategies better?

## Insights from Ecology: Ecological Management Dilemmas

Each of the concerns expressed by the decision makers is rooted in ecological dynamics that affect the outcome of management actions. Although ecologists are increasingly able to forecast future ecological conditions, it is extremely difficult to control the underlying dynamics of ecosystems. For this reason, many management decisions must be made in the absence of a complete ecological understanding of the results they will engender. We call these situations, in which decision makers must use beliefs and values to help choose between competing alternatives, ''ecological management dilemmas''. In general, these dilemmas revolve around the general situation in which we choose to transform an ecosystem with the aim of obtaining a set of desired ecosystem services; however, when these transformations are only partially understood, they may undercut other desired services.

Good decisions under these conditions need to be robust to uncertainty and surprise where possible, and should be made with the awareness that they may prove to be wrong as the future unfolds. Flexibility and learning mechanisms to cope with the fact that many decisions will have to be reconsidered, altered, or even neutralized by consequent decisions and realities are a critical part of the decision-making process.

Here we present two ecological management dilemmas that are especially critical to the concerns of the interviewees. Each describes a modification of ecosystems that were of concern to the interviewees and where we have incomplete ecological information about the total impact of the modification. The MA needs to develop scenarios that address these dilemmas in a useful way with respect to the concerns that were expressed in the interviews. As human domination of the Earth increases in extent and intensity, two general ecological uncertainties, which lead to many management dilemmas, are critically important: (a) What degree of ecological complexity is needed to provide reliable ecological services? (b) To what degree can people use technology to substitute for the role played by relatively undisturbed ecosystems in the provision of services?

### How Much Ecological Complexity Is Enough?

Many interviewees were concerned about the loss of biodiversity, invasive species, and other issues related to managing ecosystem complexity. Humans are simplifying the earth's ecosystems (Vitousek and others 1997), but the consequences of simplification on the provision of ecosystem services are uncertain. Some ecological research suggests that a relatively small number of species that perform different ecological functions can provide many ecosystem services (Ewe 1999; Loreau and others 2001). However, other studies suggest that although this may be true over small areas and short time periods, the loss of species increases the variability of ecosystem services and decreases the resilience to disturbance of ecosystems (Peterson and others 1998; McCann 2000).

If ecosystems can be simplified with only a minimal loss of ecosystem services, then ecological simplification is an ethical issue and is peripheral to sustainable development. However, if the ongoing provision of ecosystem services is susceptible to ecological simplification, then maintaining complex ecosystems should be at the center of our efforts to maintain sustainable development. How much diversity is needed to maintain the consistent provision of ecosystem services and what are the costs or foregone benefits of maintaining this diversity? This issue is related to the question of how much diversity (of landscapes, ecosystems, and species, as well as within species) is needed to effectively and sustainably produce desired ecosystem services—and the answer to this question is unknown ecologically (Deutsch and others 2003).

Dilemmas may arise from this ecological uncertainty whenever a manager must choose between simplifying a system (usually for some immediate gain in the provision of a particular ecosystem service) and maintaining complexity (often sacrificing the gain in the immediate provision of ecosystem services in favor of future provision or the provision of another service). For example, a farmer may be able to improve provision of food by converting a complex savannah ecosystem into an agricultural field; however, this change may cause the loss of some nutrient cycling benefit that had been provided by the savannah. To decide how to develop the field, the decision maker must use beliefs about the value of increased food production in comparison to the value of the savannah's nutrient cycling benefits. These decision may become even more complicated if we assume that the decision maker is not aware of all of the services provided by each of the potential ecosystems.

## Can Technology Substitute for the Role of Ecosystems in the Provision of Ecosystem Services?

Many interviewees voiced concerns about using technology to provide ecosystem services that would otherwise only be available through long-term maintenance of the ecosystem in its current state. In many cases, the human demand for services has grown so great that it cannot be met by tapping unexploited resources. However, it is difficult to anticipate the full impact of technology on the provision of ecosystem services. Although applying a technology may provide a particular ecosystem service or services, the use of this technology might have unforeseen negative impacts on the provision of other services or the provision of the same service at some time in the future.

Ecological engineering offers the possibility of increasing the quality and amount of available services while maintaining the capacity of ecosystems to produce other ecological services (McDonough and Braungart 2002). To meet this goal we need to find reliable means of engineering ecosystems to produce the desired services in a sustainable fashion without unwanted side effects. Although there have been some successes, many such efforts have yielded surprising consequences (Holling 1986; Holling and Meffe 1996; EEA 2001), suggesting that we do not have the sophistication or understanding to engineer ecosystems effectively without creating unforeseen problems.

Our lack of complete knowledge about how ecosystems work and the impacts that technology might have on them, coupled with our need to use technology to meet the rising demand for ecosystem services, leads to a dilemma in deciding when the use of technology is an appropriate way to meet that demand. An example of this type of dilemma is provided by water management. Over the past century, societies have altered rivers to regulate water levels. Although these systems were often successful in providing the intended services, such as hydroelectric power or drinking water, changes in rivers and their floodplains caused unanticipated declines in the ability of rivers to provide other ecosystem services, such as floodplain habitat or flood control.

Sometimes, these changes resulted in negative consequences, such as water contamination and floods, in addition to providing the desired service (World Commission on Dams 2000).

In some cases, it has been recognized that it is cheaper to enhance some services via ecosystem protection rather than technological replacement.

For example, New York City offers subsidies to farmers in the watershed from which it gets water to encourage them to manage their land in a way that improves the quality of the city's drinking water. This system of ecological management improved the quality of the drinking water at a far lower cost than would have been incurred by building a water treatment plant (Chichilnisky and Heal 1998; Heal 2000; Dudley and Stolton 2003). However, as Sagoff (2002) remarks, such examples by themselves do not imply that preservation is always the best way to meet our demands for ecosystem services.

In fact, there are a number of examples of land management by local people that suggest that the provision of ecosystem services can be improved in a relatively sustainable way that does not hamper the capacity of surrounding ecosystems to provide nonagricultural ecological services. For example, research over the past decades has indicated that approximately 10% of the land area in the Amazon (Balee 1989) has anthropogenically produced fertile soil (Glaser and other 2001) that is more resilient to disturbance than nonanthropogenic soil. Similarly, recent work has suggested that pre-Columbian societies practiced productive mixed aquaculture/agriculture systems in relatively unproductive parts of Bolivia (Erickson 2000; Heckenberger and others 2003). Consequently, there is some evidence that ecosystems can be engineered to reliably provide certain types of services. However, the ability to engineer ecosystems to produce many other types of services is largely untested.

The desire to find solutions to these ecological management dilemmas is complicated by our inability to foresee the future. Future technologies may enable feats that are still impossible or are prohibitively expensive today. Similarly, ecosystem services that have thus far gone unrecognized or been regarded as inessential may be discovered to be important to human society or the maintenance of other ecological services in the future. Experience with managing complex systems such as ecosystems indicates that surprises are to be expected. Understanding the role of technology in providing adequate substitutes for ecosystem services—categorizing when substituting human-created services for ecosystem services is a good idea — will be an important step toward knowing when it is better to seek technological solutions and when preservation of the ecosystem in question is a more sustainable path.

These areas of incomplete ecological knowledge that lead to management dilemmas provide examples of unknowns about ecological dynamics, and it is these unknowns that underlie decision makers' concerns and disagreements about the best route to a desirable future. Research aimed at expanding out understanding of ecological dynamics, including ecological feedbacks, will be critical for resolving management dilemmas on the path to sustainable development. All of the dilemmas relate to how well we can control ecosystems and a critical element of ecosystem control is how well we understand these complex systems versus and how well we *think* we understand them. Ecological complexities such as cross-scale feedbacks and other interactions across services and scales require an approach that leads to decisions that are robust to uncertainty, surprise, and the possibility that the decision will lead to unwanted consequences.

## Future Directions for the Millennium Ecosystem Assessment

Ecosystems are complex dynamic systems that can amplify some problems and mitigate others. To aid in management efforts, ecological information about the dynamics of these systems must be made available to decision makers in a usable format and in a timely fashion. Yet ecosystem dynamics are rarely given full consideration when environmental policy decisions are made. In some cases, there is a lack of timely, pertinent information. The information may exist but not be available because it is in an unusable format or has not reached the right person at the right time. Or the information may exist but not be used because it is not valued. At other times, the information is simply not available because the situation truly represents a research frontier. One aim of the MA is to provide pertinent information in a usable format to decision makers when they need it, and one of its four working groups has been charged with exploring flows of ecosystem services between 2000 and 2050 via the use of scenarios.

How can the MA scenarios use the information collected from the interviews and the synthesis of current ecological dilemmas to fulfill its goal of providing such information? The interviews serve to identify the central concerns of leaders who might use the MA scenarios to help make far-reaching decisions on policy and environmental management. The review of ecological dilemmas shows how management quandaries are rooted in uncertainties and our incomplete ecological understanding of the world. That is, the dilemmas point to current frontiers in ecological research that intersect with the information needs of decision makers. For the MA to build scenarios that are of real value to decision makers, it will need to address the concerns expressed by the interviewees about current ecological dilemmas.

We can imagine an infinite number of possible futures that could be examined through scenario development. However, scenarios are most effective when they are presented in small sets with clear, strong differences across the scenarios. Therefore, the MA must choose only a few storylines from the large set of possible futures. The results of our interviews and our review of ecological management dilemmas suggest several topics that the MA scenarios should address. One is the use of technology to substitute for the ecosystem-based provision of ecosystem services with attention to the risks and benefits of this approach. Another relevant topic is the level of attention to underlying processes and cross-scale feedbacks that is necessary to successfully manage the provision of ecosystem services. Can we make good decisions if we are only concerned about the immediate production of a given service, or must we also consider the underlying processes that play a role in the provision of ecosystem services? Another salient issue is the impact of the level of global connectedness on the provision and distribution of ecosystem services. To be effective, the scenarios need to be designed so that a decision maker can understand the consequences, both direct and indirect, of a given decision. In addition, the decision maker should also be able to understand the potential benefits and risks inherent in each possible decision.

## Overview of the Special Feature

Several groups have already developed global environmental scenarios (Gallopín and others 1997; UNEP 2002; Nakićenović and others 2000; WBCSD 1997; WWV 2000) that provide an excellent framework for construction of the MA scenarios. These scenarios and their strengths are examined in this issue by Raskin. In this synthesis of the literature, Raskin finds many strengths in the existing scenarios that can be built upon by the MA.

Also in this issue, Cumming and others ask if the existing scenarios are consistent with current ecological knowledge. They conclude that these scenarios are often inconsistent with our understanding of slow variables and cross-scale feedbacks. That is, ecosystem dynamics—which we have argued are critical but often ignored in decision-making processes—have beeen underexamined in those exercises. A fuller consideration of ecosystem dynamics would help decision makers to tackle the concerns expressed in our interviews. Cumming and others propose that assumptions about ecosystem function should be made explicit in fixture scenario exercises, and recommend that a more intensive study be made of the complex interrelationships between social and ecological systems.

In the final paper, Butler and others examine feedbacks between human health and ecosystem services in detail. They conclude that not only do ecosystem services have important impacts on human health, but that changes in the state of human health affect important feedback mechanisms and may sometimes lead to changes in ecosystems.

The overall goal of the papers collected in this special feature was to examine the ways that ecological dynamics—and ecological feedbacks, in particular—are understood across several fields of research and to suggest someways that these dynamics can be incorporated into scenario development and other global research projects. Each of the papers focuses on a different aspect of ecosystem dynamics to explore how the dynamics relate to user concerns and how they could be built into scenario development. But perhaps the most important outcome of putting together these papers has been the realization that, although we have a wealth of information at hand about indicators of ecosystem services and their current status (for example, see the Pilot Analysis of Global Ecosystems reports, including: Matthews and others 2000; Revenga and others 2000; White and others 2000; Wood and others 2000), there is very little synthetic understanding available to help leaders make good decisions in an uncertain world.

## ACKNOWLEDGMENTS

Pieter Johnson, Graeme Cumming, and Colin Butler provided useful reviews of draft versions of the manuscript. Discussions with the Scenarios Working Group of the Millennum Ecosystem Assessment (MA) and other members of the MA community have been very helpful in developing the ideas presented in this special feature. We especially thank the many decision makers who gave freely of their time to participate in the interviews. Their wisdom and insights are greatly appreciated.

## REFERENCES

Alcamo J. 2001. Scenarios as tools for international environmental assessments. Environmental issue report no. 24.

Luxembourg: Office for Official Publications of the European Communities, European Environment Agency.

Ayensu E, Classen DR, Collins M, Dearing A, Fresco L, Gadgil M, Gitay H, and others . 1999. International ecosystem assessment. Science 286:685–6.

Balee W. 1989. The culture of Amazon forests. In: Posey D, Balee W, editors. Resource management in Amazonia: indigenous and folk strategies. Advance in Economic Botany.

Chichilnisky G, Heal G. 1998. Economic returns from the biosphere. Nature 39:629–30.

Daily GC, editor. 1997. Nature's services: societal dependence on natural ecosystems Island Press.

Davis G. 1998. Creating scenarios for your company's future. Corporate environmental, health, and safety excellence: bringing sustainable development down to earth. New York.

Deutsch L, Folke C, Skanberg K. 2003. The critical natural capital of ecosystem performance as insurance for human well-being. Ecol Econ 44:205–17.

Dudley N, Stolton S. 2003. Running pure: the importance of forest protected areas to drinking water. World Bank/WWF Alliance for Forest Conservation and Sustainable Use.

Erickson CL. 2000. An artificial landscape-scale fishery in the Bolivian Amazon. Nature 408:190–93.

[EEA] European Environment Agency. 2001. Late lessons from early warnings: the precautionary principle 1896–2000. Environmental issue report no. 22. Luxembourg: Office for Official Publications of the European Communities.

Ewel JJ. 1999. Natural systems as models for the design of sustainable systems of land use. Agrofor Syst 45:1–21.

Gallopín G, Hammond A, Raskin P, Swart R. 1997. Branch points: global scenarios and human choice. Stockholm: Stockholm Environment Institute. Available online at: http://www.gsg.org.

Glaser B, Haumaier L, Guggenberger G, Zech W. 2001. The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics. Naturwissenschaften 88:37–41.

Hawken P, Lovins A, Lovins H. 2000. Natural capitalism: creating the next industrial revolution. Boston: Back Bay Books.

Heal G. 2000. Valuing ecosystem services. Ecosystems 3:24–30.

Heckenberger MJ, Kuikuro A, Kuikuro UT, Russell JC, Schmidt M, Fausto C, Franchetto B. 2003. Amazonia 1492: pristine forest or cultural parkland? Science 301:1710–14.

Holling CS. 1986. The resilience of terrestrial ecosystems: local surprise and global change. In: Clark WC, Munn RE, editors. Sustainable development of the biosphere. Cambridge (UK): Cambridge University Press. p 292–317.

Holling CS, Meffe GK. 1996. Command and control and the pathology of natural resource management. Conserv Biol 10:328–37.

Jackson RB, Carpenter SR, Dahm CN, McKnight DM, Naiman RJ, Postel SL, Running SW. 2001. Water in a changing world. Ecol Appl 11:1027–45.

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime JP, Hector A, Hooper DU, others. 2001. Ecology—biodiversity and ecosystem functioning: current knowledge and future challenges. Science 294:804–8.

Matthews E, Payne R, Rohweder M, Murray S. 2000. Pilot analysis of global ecosystems: foreset ecosystems. Washington (DC): World Resources Institute. 90 p.

McCann KS. 2000. The diversity–stability debate. Nature 405:228–33.

McDonough W, Braungart M. 2002. cradle to cradle: remaking the way we make things. North Point Press.

[MA] Millennium Ecosystem Assessment. 2003. People and ecosystems: a framework for assessment. Washington (DC): Island Press.

Nakićenović N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, and others. 2000. Special Report on Emissions Scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge (UK): Cambridge University Press. Available online at: http://www.ipcc.ch/.

Peterson G, Allen CR, Holling CS. 1998. Ecological resilience, biodiversity, and scale. ecosystems 1:6–18.

Peterson G, Cumming G, Carpenter SR. 2003. Scenario planning: a tool for conservation in an uncertain world. Conserv Biol 17:1–10.

Pinstrup-Andersen P, Pandya-Lorch P, Rosegrant MW. 1997. The world food situation: recent developments, emerging issues, and long term prospects. Washington (DC): International Food Policy Research Institute.

Revenga C, Brunner J, Henninger N, Kassem K, Payne R. 2000. Pilot analysis of global ecosystems: freshwater ecosystems. Washington (DC): World Resources Institute. 83 p.

Sagoff M. 2002. On the value of natural ecosystems: the Catskills parable. Politics Life Sci 21:16–21.

Schiklomanov IA. 1997. Comprehensive assessment of the freshwater resources of the world: assessment of water resources and water availability in the world. Stockholm: World Meteorological Organization and Stockholm Environment Institute.

[UNEP] United Nations Environment Programme. 2002. Global Environmental Outlook 3. London: Earthscan. Available online at: http://www.unep.org/geo/geo3/.

Van der Heijden K. 1996. Scenarios: the art of strategic conversation New York: Wiley.

Vitousek PM, Monney HA, Lubchenco J, Melilo J. 1997. Human domination of earth's ecosystems. Science 277:494–9.

Watson RT, and others. 1998. Protecting our planet—securing our future. Washington (DC): United Nations Environment Programme, US National Aeronautics and Space Administration, World Bank.

[WBCSD] World Business Council for Sustainable Development 1997. Exploring sustainable development. Summary brochure. Geneva: WBCSD. Available online at: http://www.wbcsd.org/newscenter/reports/1997/exploringscenarios.pdf.

White RP, Murray S, Rohweder M. 2000. Pilot analysis of global ecosystems: grassland ecosystems Washington (DC): World Resources Institute, 89 p.

Wood SK, Sebastian K, Scherr SJ. 2000. Agroecosystems Washington (DC): International Food Policy Research Institute and World Resources Institute. 110 p.

World Commission on Dams. 2000. Dams and development: a new framework for decision-making London: Earthscan.

[WWV] World Water Vision Commission Report. 2000. A water secure world. Vision for water, life and the environment. London: Earthscan. Available online at: http://www.worldwatercouncil.org/Vision/Documents/CommissionReport.pdf.