
Introduction to the special issue on the dynamics and value of ecosystem services: integrating economic and ecological perspectives

1. Introduction

This special issue represents the output of a 3-year working group supported by the National Center for Ecological Analysis and Synthesis (NCEAS), plus a few additional contributions. The papers cover conceptual, empirical and modeling issues concerning the dynamics and valuation of ecosystem services. They include discussions of the nature of value, the dynamics of complex adaptive systems, links between fairness and valuation, and global estimates of the value of ecosystem services using various models and databases. Taken together they represent a unique set of perspectives and a unique synthesis of the valuation issue. They provide fresh answers to some long-standing questions, and in the process raise new and interesting questions about valuing ecosystem services.

2. Background

Human activities have become so extensive that all ecosystems on the planet have been altered by them to some extent (Cronin et al., 1996; Vitousek et al., 1997). These alterations range from local changes in species populations by harvesting and habitat destruction to global changes in atmo-

sphere and climate from industrial emissions. Some degree of alteration in these ecosystems is to be expected, since humans, like any other species, affect the ecosystems of which they are a part (Diamond, 1997; Rapport et al., 1998). However, the degree to which humans can alter these ecosystems has increased dramatically in the past century. These alterations can significantly affect human welfare both now and for generations to come, so we must consider the full implications of those alterations much more seriously.

Humans have also established social institutions and technologies that allow cultural evolution to greatly exceed the speed of genetic evolution. While this cultural evolution has allowed humans to become the dominant species on Earth, it also short-circuits some of the built-in checks and balances of genetic evolution, and may allow humans to damage or exceed the ability of the rest of the biosphere to support them.

The human institutions that can lead to overuse or misuse of natural resources include markets, property rights regimes, government structures and social networks. Actions that treat resources, the environment, or ecosystems as if they were 'free' when they are not, or do not recognize the adverse consequences of their use, can only lead to reductions in potential human welfare or increased real costs of maintaining

flows of ecosystem services in the long run. Given the technological ability and scale of demand on natural ecosystems from human activity, there must be an explicit consideration of the ecological implications of social and economic decisions. Such signals provide feedback to facilitate the management of human activities, and there is therefore a need to 'value' these implications.

The question then becomes: 'what do we mean by the 'value' of nature?' There are several possible meanings. If we define value as 'the contribution of something to a condition or state of the system', then structures and functions of natural systems, by definition, have 'value'. The value of a tree to a forest is its role in perpetuating forest conditions, including nutrient and hydrologic cycling functions. There may be trade-offs between particular structures or functions; some tree species may be substitutable for others in maintaining forest health and ecological processes. So we can speak of a relative 'value' of those species without reference to human perceptions or preferences.

If we define value as 'a contribution to a goal', which is a purposeful condition, natural systems have value insofar as they contribute to that goal (Costanza, 2000). A major goal of human interaction with natural ecosystems is the support of human welfare, including the sustainability of that welfare and its distributional fairness. This goal is the criteria against which human activity and the conditions of natural systems are often measured. Trade-offs between activities and natural conditions give information about the relative contributions of these items to the goal, and hence their values. These relative values are important feedback signals that can guide the management of human activities in natural ecosystems.

An important element of this feedback is a measure of the likelihood of loss of important natural services. As Levin (1999) notes:

It may well be that natural systems are not so very fragile: they are, after all, complex adaptive systems that will probably change and become new systems in the face of environ-

mental stresses. What *is* fragile, however, is the maintenance of the services on which humans depend. There is no reason to expect systems to be robust in protecting those services—recall that they permit our survival but do not exist by virtue of permitting it, and so we need to ask how fragile nature's services are, not just how fragile nature is.

An implication of ecosystem service fragility is that valuation must include not only a measure of the magnitude of services, but also a measure of this fragility. How close is the ecosystem to some alteration that would substantially change service flows? Are these 'critical' service flows?

It is obvious that ecosystems are valuable to all the species that comprise them, including humans. They provide flows of energy and materials essential to life and are necessary for species survival. From a human perspective, natural ecosystems not only provide life support services, but also services beyond basic life support, such as recreational and aesthetic enjoyment. Societies explicitly and implicitly value not only goods or services from natural ecosystems, but also properties of those systems. For example, stability or sustainability properties are valued *per se*, insofar as people wish to avoid uncertainty and catastrophes. We may value remaining some distance from the edge of cliffs; and consequently value natural ecosystem conditions from this perspective. Biodiversity has value, not only for the known and unknown potential of particular species to provide services, but for its contribution to controlling the stability and resilience of ecosystems in an anticipatable and acceptable form; i.e. as the 'glue' that holds a system together. These can be considered insurance values, or option values in the presence of irreversible or catastrophic changes.

Economic, or monetary, measures of value are only one type of measure that can be useful in managing human activities. But they are particularly useful because most societies have some intuitive notion of economic value, and the sources of

human impacts on natural systems are frequently economic, such as the construction of a dam or harvesting timber. They are also especially useful insofar as they can be used to provide signals to regulate human activity, as in the case of environmental taxes and adjustments to national income accounts. However, like any signal in complex systems, they can also provide false or misleading information.

In the practical policy world, ecosystem management is based on understanding how natural systems work, how humans can alter them, the values we wish to protect and the costs of preservation. This suggests that the valuation of ecosystem services, from both economic and ecological perspectives, is a necessary (but certainly not the only) ingredient in practical policy. The economic perspective is obvious, since human welfare goals are based in part upon the flows of goods and services from economic and natural ecosystems. The ecological perspective is similarly obvious, since valuation reflects the role and importance of natural structures and processes to the health of ecosystems and to the maintenance of ecosystem services.

3. Motivation and process

The purpose of this special issue is two-fold. First, to introduce and describe several concepts of valuation from both economic and ecological perspectives in order to contribute to the ongoing valuation discussion and to provide concrete, practical guidance. Second, to extend initial attempts at valuation of ecosystem services to include their complex interdependencies, time and space dynamics, and distributional aspects.

Most of the papers in this special issue are a product of a working group on the 'Value of the World's Ecosystem Services and Natural Capital: Toward a Dynamic, Integrated Approach' that was sponsored by the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, CA, USA. A list of working group members is given as an Appendix A to this paper. The working group met three times over the

course of 2 years to define and complete the projects reported in the following chapters and briefly summarized below.

The working group was a follow-on activity to a previous workshop on this topic at NCEAS in June of 1996. That workshop was very successful at synthesizing the large, scattered information about the value of ecosystem services and natural capital and presenting it in a form that would be illustrative and useful for ecologists, economists, policy makers, and the general public. The results of this first workshop were ultimately published in *Nature* (Costanza et al., 1997) and stimulated much discussion, media attention, and debate, including stories in the *NY Times*, *Newsweek*, *Science*, *Science News*, and *US News and World Report*, and a forum in *Ecological Economics* (Costanza, 1998). As of February 2002, the *Nature* paper had been cited in over 375 scientific journal articles (see <http://wos.isiglobalnet2.com/>). For comparison, the average number of citations for papers published in *Nature* is about 20, the average for papers published in the scientific literature in general is less than two. This clearly indicates that the issue of the valuation of ecosystem services is important and controversial to a broad range of scientists, economists, and policy makers. There have also been several special issues and fora in other journals (including *Ecological Economics* (May 1999 Vol. 29, No. 2), *BioScience* (April 2000, vol. 50, no. 4), *Ecosystems* (2000, vol. 3, pp. 1–35), and *Environmental Science and Technology* (2000, vol. 34, no. 8) devoted to ecosystem services and their valuation. While these publications represent a broad range of often conflicting views, the take home message is that this topic is an important one, and one on which there is still a broad range of opinions.

Our working group at NCEAS sought to determine those aspects of ecosystem service valuation about which there was consensus among a diverse group of natural and social science participants, and those aspects that require ongoing discussion and new, innovative approaches. For example, the methods used in the first global synthesis were admittedly crude and imperfect, but they also pointed the way to improved assessments. In par-

ticular, they pointed to the need to develop comprehensive databases and ecological–economic models that could adequately incorporate the complex, dynamic interdependencies between ecosystems and economic systems, and the complex dynamics of these systems at the appropriate scales. The response to the article also pointed to the lack of consensus about the very meanings of the terms ‘value’ and ‘valuation’, implying the need to define these important concepts more carefully and to further examine their uses and limitations.

4. Summary of the contents of the special issue

This special issue contains eleven papers (in addition to this Introduction) that cover a broad range of issues on the dynamics and value of ecosystem services. It is a more integrated product than one might expect from a typical collection of journal papers on a particular topic. Most of the authors interacted with each other over a number of years and the results represent the evolution of ideas within this group over time. This allowed the special issue to be more structured and coherent than it otherwise would have been, with many links between the papers that would not otherwise have occurred. The first six papers in the collection cover more conceptual and theoretical topics, while the last five cover more empirical and modeling studies.

Farber et al. (this volume) present several difficult and important theoretical issues surrounding the problem of ecosystem service valuation. The concept of value is a controversial one, and the intention of this paper is to define the concepts and questions in a way that is helpful to further discussion and research. They provide some history and context, and describe and compare several approaches to valuation in order to set the stage for the other papers in the special issue.

de Groot et al. (this volume) describe and categorize ecosystem functions and services and valuation methods that may be appropriate for each, depending on their spatial and temporal scale, uncertainty, criticality, and other features. The

goals are to develop a consistent framework for characterizing ecosystem services, and to provide an improved assessment and categorization of data.

Limburg et al. (this volume) look at ecosystems (including human-dominated ecosystems) as complex adaptive systems, including their non-linear behavior, thresholds, feedbacks, and stability regimes. They point out the implications of this view for the predictability, reversibility, and other key characteristics of these systems, and ultimately their implications for valuation of ecosystem services.

Howarth and Farber (this volume) examine the implications of ecosystem services for national income accounting. They define a ‘Value of Ecosystem Services’ (VES) and its role in measuring trends in human welfare. They describe how estimating ‘price*quantity’ for the environment is a useful measure since it is how we normally do resource accounting, and stocks and flows need to be estimated separately.

Wilson and Howarth (this volume) connect the concept of social fairness with the valuation issue. Building on recent advances in social and political theory, they describe new value-articulating institutions based on small-group discourse, and delineate how these might provide a new institutional framework for valuing ecosystem services from the perspective of social fairness.

Villa et al. (this volume) describe an integrated ‘knowledge-base’ to support ecosystem service valuations. This knowledge base links a relational database and the various kinds of models needed to interpret and use the data, including valuation methods, geographic aggregation methods, empirical models, and dynamic simulation models. The result is a tool for both communication and meta-analysis of ecosystem services and their values.

The final five papers are empirical and modeling studies aimed at estimating the value of ecosystem services at several spatial scales. They explore a range of new techniques for this purpose.

Patterson (this volume) describes an ecological, production-based approach to pricing ecosystem services and applies it at the global scale. This approach to pricing is based on the production

interdependencies in an Input–Output model of the linked ecological economic system and depends only indirectly on human preferences. It provides an interesting alternative to the more typical ‘preference-based’ valuations and pricing and links more directly to knowledge about ecosystem structure and function.

Gustavson et al. (this volume) provide another approach to valuation based on the production of ecosystem services. They develop a biophysically based index of captured ecosystem values (or embodied ecosystem values) and examine the extent to which these values are proportional to monetary exchange values for a case study of Jamaican fisheries. They find that analysis of the differences between their ‘supply-side’ values and market values can aid in analysis and management of the system. Konarska et al. (this volume) performed an empirical analysis to look at the geographic scale dependence of ecosystem service valuation. They estimated the value of ecosystem services for the US using both 1-km and 30-m resolution land cover data. They found that the total value of ecosystem services more than doubled by going from the coarser scale land use data to the finer scale. This is because smaller, higher-valued ecosystems (like lakes and wetlands) tend to be underrepresented on the coarser-scale imagery.

Sutton and Costanza (this volume) estimated both marketed (GNP) and non-marketed (ecosystem service) production values at 1-km resolution globally (correcting for the scale effects found by Konarska et al. (this volume)). These unique high resolution global maps are then summed to provide a subtotal of economic production (SEP) and the spatial distribution of this index is analyzed. Maps of SEP per capita and the percent of SEP from ecosystem services production (%ESP) by country are also developed, and they reveal some interesting patterns. SEP is a closer approximation to the true wealth of nations than GNP alone, and the rankings of national wealth using this index are significantly different. The %ESP index is also compared with the 2001 Environmental Sustainability Index (not correlated) and the Ecological Deficit derived from ecological footprint analyses (correlated) and the relative

strengths and weaknesses of these indices are discussed.

Finally, Boumans et al. (this volume) describe the Global Unified Metamodel of the BiOsphere (GUMBO), an attempt to put all the pieces together in a dynamic computer simulation model. GUMBO is complex enough to capture the dynamics of ecosystem services and their links to the economy but simple enough to be run on a current generation personal computer. GUMBO is the first global model to include the dynamic feedbacks among human technology, economic production and welfare, and ecosystem goods and services within the dynamic earth system. The dynamics of 11 major ecosystem goods and services for each of 11 biomes are simulated and evaluated for the 200-year period from 1900 to 2100. The total value of global ecosystem services was estimated to be about 4.5 times the value of Gross World Product (GWP) in the year 2000 using this approach. A range of future scenarios representing different assumptions about future technological change, investment strategies and other factors were simulated. The model can be downloaded, allowing users to explore for themselves the complex dynamics of the system and the full range of policy assumptions and scenarios.

5. Conclusions

A better understanding of the dynamics and value of ecosystem services is essential in order to achieve a sustainable and desirable future. This special issue includes a number of unique conceptual and empirical contributions to this endeavor. It represents a collaborative effort of a small working group over a several year period of time. Like most good research, it raises more questions than it answers, and should stimulate others to explore those questions further.

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Appendix A. List of Working Group Participants

Vic Adamowicz

Department of Rural Economy, University of Alberta, Edmonton, Alta., Canada T6G 2H1, vadamowi@re.ualberta.ca.

Roel Boumans

University of Maryland Institute for Ecological Economics, University of Maryland, Box 38, Solomons, MD 20688, USA, boumans@cbl.umces.edu.

Robert Costanza

University of Maryland Institute for Ecological Economics, Box 38 (1 Williams St.), Solomons, MD 20688, USA, costza@cbl.umces.edu.

Ralph d'Arge

951 N. Middletown-Cane Ridge Rd., Paris, KY 40361, USA, fax: +1-606/362-7587.

Rudolph de Groot

Center for Environment and Climate Studies, Wageningen Agricultural University, PO Box 9101, 6700 HB Wageningen, The Netherlands, dolf.degroot@algemeen.cmkw.wau.nl.

Stephen Farber

Graduate School of Policy and International Affairs, 3E32-FQ, University of Pittsburgh, Pittsburgh, PA 15260, USA, eofarb@pitt.vms.cis.edu.

Monica Grasso

University of Maryland, 2110 Agriculture & Life Sciences Surge Bldg., College Park, MD 20742, USA, grasso@cbl.umces.edu.

Bruce Hannon

Geography Department, University of Illinois, Champaign IL 61801, USA, bhannon@ncsa.uiuc.edu.

John Hobbie

The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, USA, jhobbie@lupine.mbl.edu.

Richard Howarth

Environmental Studies Program, Dartmouth College, 6182 Steele Hall, Hanover, NH 03755, USA, richard.howarth@dartmouth.edu.

Glenn-Marie Lange

Institute for Economic Analysis, New York University, 269 Mercer St., Rm. 207, New York, NY 10003, USA, lange@is2.nyu.edu.

Karin Limburg

Department of Environmental and Forest Biology, SUNY College of Environmental Science and Forestry Syracuse, NY 13210, USA, klimburg@esf.edu.

Shahid Naeem

Department of Zoology, University of Washington, 24 Kincaid Hall, Seattle WA 98195-1800, USA, naeems@u.washington.edu.

R.V. O'Neill

Oak Ridge National Laboratory, PO Box 2008, Bldg. 1505, MS-6306, Oak Ridge, TN 37831, USA, rvo@ornl.gov.

Murray Patterson

Department of Resource and Environmental Planning, Massey University, Private Bag, Palmerston North, New Zealand, fax: +64-6-350-5689, a.o.cole@massey.ac.nz.

Jan Rotmans

ICIS, Maastricht University, PO Box 616, 6200 MD Maastricht, The Netherlands, rotmans@worldonline.nl.

Matthias Ruth

CEES, Boston University, 675 Commonwealth Ave., Boston, MA 02215, USA, mruth@bu.edu.

Paul Sutton

Department of Geography & Environmental Science, University of Denver, Denver, CO 80208, USA, psutton@du.edu.

Ferdinando Villa

University of Maryland Institute for Ecological Economics, Box 38 Solomons, MD 20688, USA, villa@cbl.umces.edu.

James Wilson

Resource Economics and Policy, University of Maine, 206 Winslow Hall, Orono, ME 04469-5782, USA, jwilson@maine.maine.edu.

Matthew A. Wilson

Departments of Sociology and Rural Sociology, 350 Agriculture Hall, University of Wisconsin-Madison, USA, mawilso1@students.wisc.edu.

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Robert Costanza*¹

University of Maryland Institute for Ecological Economics, Center for Environmental Science, Box 38, Solomons, MD 20688-0038, USA
E-mail: costza@cbl.umces.edu

Steve Farber²

Graduate School of Public and International Affairs, University of Pittsburgh, Pittsburgh, PA 15260, USA
E-mail: cofarb + @pitt.edu

* Corresponding author. Tel.: + (410) 326-7263; fax: + (410) 326-7354

¹ As of 09/01/2002, this corresponding author can be reached at the Gund Institute for Ecological Economics, University of Vermont, School of Natural Resources, George D. Aiken Center, Burlington VT 05405-0088, USA.

² Tel.: + (412) 648-7602; fax: + (412) 648-2605.