

Ecosystem services: From theory to implementation

Gretchen C. Daily*† and Pamela A. Matson*

*Center for Conservation Biology (Department of Biology) and Woods Institute for the Environment, Stanford University, Stanford, CA 94305-5020; and †Environmental Earth System Science, Stanford University, CA 94305-2210

Around the world, leaders are increasingly recognizing ecosystems as natural capital assets that supply life-support services of tremendous value. The challenge is to turn this recognition into incentives and institutions that will guide wise investments in natural capital, on a large scale. Advances are required on three key fronts, each featured here: the science of ecosystem production functions and service mapping; the design of appropriate finance, policy, and governance systems; and the art of implementing these in diverse biophysical and social contexts. Scientific understanding of ecosystem production functions is improving rapidly but remains a limiting factor in incorporating natural capital into decisions, via systems of national accounting and other mechanisms. Novel institutional structures are being established for a broad array of services and places, creating a need and opportunity for systematic assessment of their scope and limitations. Finally, it is clear that formal sharing of experience, and defining of priorities for future work, could greatly accelerate the rate of innovation and uptake of new approaches.

Even in the face of intensifying pressures and risks on the global environmental front, there is a growing feeling of Renaissance in the conservation community. This flows from the promise in reaching, together with a much more diverse and powerful set of leaders than in the past, for new approaches that align economic forces with conservation, and that explicitly link human and environmental well-being (1). And this promise is flowering thanks to substantial recent advances in key areas of inquiry, such as ecology, economics, and institutions, and their integration (2–5).

Conservation efforts now are expanding into realms well beyond reserves, beyond charity, and beyond biodiversity—and into the mainstream (6). While retaining a core focus on protected areas designed to sustain biodiversity, the new arenas of conservation are much bigger and much more complex than the old. They encompass new places dominated by human activity, new revenue streams from public and private sectors, and new goals of ecosystem service provision. In fact, they encompass important elements of traditional, non-Western approaches (7, 8). Scholars and practitioners are seeking to make conservation economically attractive and commonplace, routine in the decision-making of individuals, communities, corporations, and governments (9).

Here, we feature contributions that span the fundamental science of ecosystem services through to the design, implementation, and assessment of finance and policy mechanisms and systems of governance. Each contribution is oriented around decisions, often cast in terms of tradeoffs among alternative future scenarios of change, whether in natural resource management, population, climate, or other key drivers.

Linking Conservation and Development

We open with two pieces that set the stage, presenting frameworks for linking

conservation and human development, and for incorporating material and intangible values of natural capital into decision-making. Tallis *et al.* (10) analyze World Bank projects with win-win objectives of alleviating poverty and protecting biodiversity, and find a success rate of one in six. Using case studies, they then propose a framework for anticipating and improving the outcomes of such projects.

Mäler *et al.* (11) review the history of green accounting and identify two major challenges to incorporating natural capital systematically into economic accounts: (i) the characterization of production functions for ecosystems, i.e., dynamic models that translate the structure and function of ecosystems into the provision of services; and (ii) the development of institutions whose reach and strength is tightly knitted to the estimation of accounting prices for ecosystem services. Under weak institutions, accounting prices will be low (or even negative); as institutions improve, one expects (all else equal) accounting prices to increase.

Tallis *et al.* (10) and Mäler *et al.* (11) both make compelling calls for intensive, interdisciplinary study of priority ecosystems and ecosystem service-oriented projects, in which the potential for rapid general advances in understanding is high. They also call for standardized techniques and metrics for valuing and monitoring services.

Modeling Provision of Ecosystem Services and Biodiversity Conservation

The next two contributions take big steps in the directions suggested. Nelson *et al.* (12) present a model that integrates the effects of policy on land-use decisions and the resulting consequences for the joint provision of ecosystem services and biodiversity conservation across a landscape. They use data from the Willamette Basin in Oregon, United States, a very well studied region, and find that policies aimed at in-

creasing carbon sequestration do not necessarily increase species conservation (and vice versa). A clear finding is that if payments for ecosystem services are not carefully designed, they may yield minimal gains in services of interest, and may well harm the production of other services and biodiversity conservation. However, the authors demonstrate how new tools can enable good design and progress toward multiple, potentially competing objectives.

Naidoo *et al.* (13) attempt to quantify and map the production of ecosystem services globally, to compare service production with priority sites for biodiversity conservation. They find that spatial concordance among different services and between ecosystem services and conservation priorities varies widely. Nonetheless, their analysis permits clear identification of areas in which payments for ecosystem services (PES) are more likely than elsewhere to achieve biodiversity conservation objectives.

Challenges of Implementation

The special issue then turns to policy design and implementation. Jack *et al.* (14) systematically review the history of incentive-based mechanisms for environmental policy, drawing lessons and insights for the design of PES schemes. Such schemes compensate individuals or communities for undertaking actions that increase the provision of ecosystem services. The authors illustrate how the effectiveness of PES schemes is influenced by the biophysical, socioeconomic, political, and general dynamic context, giving concrete examples.

Cowling *et al.* (15) go a step further, proposing a pragmatic, operational

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†To whom correspondence should be addressed. E-mail: gdaily@stanford.edu.

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model for achieving the safeguarding of ecosystem services in a given place. They focus on internalizing ecosystem service concerns into land- and water-use planning sectors, based on experience in South Africa. At the core of their model are three key elements, all very challenging but important to achieve: socially relevant, user-inspired research, stakeholder empowerment, and adaptive management embedded in learning organizations. With these, one can establish the necessary enabling conditions, windows of opportunity, mechanisms for change, and outcomes of effectiveness.

Through a contrasting point of entry, Olsson *et al.* (16) explore the strategies and actions that enabled the case of a recent transition to ecosystem-based management by the Great Barrier Reef Marine Park Authority in Australia. In this transition, the focus of governance shifted from protection of selected individual reefs to stewardship of the much larger-scale seascape. Olsson *et al.* identify management innovations that greatly improved coordination of the scientific community, public awareness

and involvement, and maneuvering of the political system at critical times. Although enabling legislation was essential, it was not sufficient for shifting governance toward adaptive co-management of the marine system.

Finally, we turn to China, with the world's largest population and fastest growing economy among major nations. Planned investments in ecosystem service payments in China exceed 700 billion Yuan (1 US\$ \approx 7.4 Yuan), a magnitude matched by the ambition in their goals, the massive scales over which they operate, and their potentially enormous impacts. Liu *et al.* (17) review China's foremost two ecosystem service programs, the Natural Forest Conservation Program and the Grain to Green Program. To realize the potential for these programs to benefit China and the rest of the world, Liu *et al.* call for more systematic planning, diversified funding, effective compensation, integrated research, and comprehensive monitoring.

Making Ecosystem Service Approaches Operational

Radical transformations will be required to move from conceptual

frameworks and theory to practical integration of ecosystem services into decision-making, in a way that is credible, replicable, scalable, and sustainable. There remain many highly nuanced scientific challenges for ecologists, economists, and other social scientists to understand how human actions affect ecosystems, the provision of ecosystem services, and the value of those services. At least as demanding are the social and political challenges associated with incorporating this understanding into effective and enduring institutions, to manage, monitor, and provide incentives that accurately reflect the social values of ecosystem services to society. The candid analyses presented here help light the way.

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- Hassan R, Scholes R, Ash N, eds (2005) *Ecosystems and Human Well-Being* (Island, Washington, DC).
- Dasgupta P (2001) *Human Well-Being and the Natural Environment* (Oxford Univ Press, Oxford).
- Turner BL, II, *et al.* (2003) A framework for vulnerability analysis in sustainability science. *Proc Natl Acad Sci USA* 100:8074–8079.
- Salzman J (2005) Creating markets for ecosystem services: Notes from the field. *NYU Law Rev* 80:870–961.
- Ruhl JB, Kraft SE, Lant CL (2007) *The Law and Policy of Ecosystem Services* (Island, Washington, DC).
- Goldman RL, Tallis H, Kareiva P, Daily GC (2008) *Proc Natl Acad Sci USA* 105:9445–9448.
- Berkes F, Folke C (1998) *Linking Social and Ecological Systems* (Cambridge Univ Press, Cambridge, UK).
- Ostrom E (2005) *Understanding Institutional Diversity* (Princeton Univ Press, Princeton).
- Daily GC, Ellison K (2002) *The New Economy of Nature* (Island, Washington, DC).
- Tallis H, Kareiva P, Marvier M, Chang A (2008) An ecosystem services framework to support both practical conservation and economic development. *Proc Natl Acad Sci USA* 105:9457–9464.
- Mäler K-G, Aniyar S, Jansson Å (2008) Accounting for ecosystem services as a way to understand the requirements for sustainable development. *Proc Natl Acad Sci USA* 105:9501–9506.
- Nelson E, *et al.* (2008) Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *Proc Natl Acad Sci USA* 105:9471–9476.
- Naidoo R, *et al.* (2008) Global mapping of ecosystem services and conservation priorities. *Proc Natl Acad Sci USA* 105:9495–9500.
- Jack BK, Kousky C, Sims KRE (2008) Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proc Natl Acad Sci USA* 105:9465–9470.
- Cowling RW, *et al.* (2008) An operational model for mainstreaming ecosystem services for implementation. *Proc Natl Acad Sci USA* 105:9483–9488.
- Olsson P, Folke C, Hughes TP (2008) Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proc Natl Acad Sci USA* 105:9489–9494.
- Liu J, Li S, Ouyang Z, Tam C, Chen X (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proc Natl Acad Sci USA* 105:9477–9482.