

# Management objectives for the protection of ecosystem services

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## Abstract

People find themselves confronted with ever starker tradeoffs in the allocation of resources to competing uses and users. At the local level, for instance, allocation of land or water to agricultural, industrial, municipal, recreational, and conservation activities often involves a zero sum game. This is apparent in the widespread loss of water and land from native habitat to farms and increasingly to urban and industrial purposes. These tradeoffs are becoming increasingly vexing and difficult to resolve, from both ethical and practical perspectives. The Ecosystem Services Framework integrates biophysical and social dimensions of environmental protection in a way that holds great promise for addressing the environmental crisis that will likely peak in the 21st century. Here, I provide a brief overview of this framework and suggest a plan for immediate action. © 2001 Elsevier Science Ltd. All rights reserved.

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## 1. Introduction

As human influence on the natural environment increases, setting priorities for environmental protection becomes ever more important and urgent. Landmark policies established more than two decades ago in the US, address largely local, reversible, and direct threats to human health. These do not suffice in managing impacts of the human enterprise today, impacts that are transforming the environment at a pace, at a geographic scale, and with problems of irreversibility that are totally unprecedented.

When considering environmental protection in the US, it is helpful to maintain a global perspective. The US is a major contributor to, and recipient of global impacts, both directly through its own economic activities and indirectly through its intimate biophysical, socioeconomic, and political links to other regions of the world. Worldwide, humanity has heavily transformed ~40–50% of the ice-free land surface; coopted ~50% of accessible, renewable fresh water; fully exploited or overexploited ~65% of marine fisheries; increased the carbon dioxide concentration in the atmosphere by ~30%; increased the rate of fixation of atmospheric nitrogen by more than 100% over natural

terrestrial sources; and driven ~25% of bird species to extinction (Vitousek et al., 1997). The rapid increase projected globally in demand for food, fresh water, energy, and other resources over the next few decades implies greatly intensifying human impacts (Pinstrup-Andersen, 1994; Crosson and Anderson, 1995; Postel et al., 1996; UNFAO, 1996; Daily et al., 1998; Gleick, 1998; Hoffert et al., 1998).

How do these profound ecosystem changes influence human well-being, and how should they be addressed by policy? Which merits the most attention? What levels and types of changes are acceptable? How can appropriate standards be developed and evaluated? And what institutions and policies will be effective in conferring the desired protection?

To address these questions, we must recognize that the Nation's — and the world's — ecosystems are capital assets; if properly managed, they yield a flow of vital services. Ecosystem services include the production of goods — such as seafood, timber, and precursors to many industrial and pharmaceutical products — an important and familiar part of the economy. They also include basic life-support processes (such as pollination, water purification, and climate regulation), life-fulfilling conditions (such as serenity, beauty, and cultural inspiration), and preservation of options (such as conserving genetic and species diversity for future use) (Daily, 1997a).

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Proper accounting would value the flow of ecosystem services, while costing out the depreciation of the underlying asset, just as for physical capital, for example. Unfortunately, relative to other forms of capital, ecosystem capital is poorly understood, scarcely monitored, and — in many important cases — undergoing rapid degradation and depletion. Often the importance of ecosystem services is widely appreciated only upon their loss. As a result, the depreciation of ecosystem capital is typically undervalued, to the extent that it is considered at all.

This unfortunate situation is not difficult to understand. Until fairly recently, ecosystem capital was available in sufficient abundance that most ecosystem services could be treated as ‘free.’ Moreover, economic activity was comparatively limited, and had minimal impact on ecological systems. There was, accordingly, little interaction between the fields of ecology and economics. However, in recent decades the situation has changed dramatically, as indicated above.

The situation today demands a much improved capability for characterizing ecosystem services, in ecological and economic terms. This would make possible the weighing of the full social costs and benefits of alternative policies and courses of action. Ideally, it would reveal what is really at stake to allow for better decision-making, before ecosystem changes become so entrained as to be very costly and difficult (or impossible) to reverse. The benefits of developing and using this capability are manifest in the efforts by a growing number of municipalities in the US to secure natural water purification services in their watersheds (The Trust for Public Land, 1997). Such efforts are often justified solely on the basis of the avoided costs of building and maintaining physical treatment plants; they may confer many other unquantified benefits as well, however, in the form of flood/erosion control, carbon sequestration, recreational opportunities, scenic beauty, and so on.

## 2. The ecosystem services framework

A new conceptual framework is emerging to describe, monitor, and manage ecosystem changes and their impacts on society. The framework holds promises for generating practical and flexible approaches to environmental protection that integrate biophysical, economic, and other important social factors.

The Ecosystem Services Framework focuses on the wide array of important services that ecosystems and their biodiversity confer on society (Table 1). These services are generated by a complex interplay of natural cycles powered by solar energy and operating across a wide range of space and time scales. The generation of soil fertility, for example, involves the life cycles of

bacteria — occurring in a space smaller than the period at the end of this sentence — as well as the planet-wide cycles of major chemical elements, such as carbon and nitrogen. Ecosystem services are essential to human existence and operate on such a grand scale, and in such intricate and little-explored ways, that most could not be replaced by technology (Ehrlich and Mooney, 1983;

Table 1

A classification of ecosystem services with illustrative examples

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Ecosystem service
Production of goods
<i>Food</i>
Terrestrial animal and plant products
Forage
Seafood
Spice
<i>Pharmaceuticals</i>
Medicinal products
Precursors to synthetic pharmaceuticals
<i>Durable materials</i>
Natural fiber
Timber
<i>Energy</i>
Biomass fuels
Low-sediment water for hydropower
<i>Industrial products</i>
Waxes, oils, fragrances, dyes, latex, rubber, etc.
Precursors to many synthetic products
<i>Genetic resources</i>
Intermediate goods that enhance the production of other goods
Regeneration Processes
<i>Cycling and filtration processes</i>
Detoxification and decomposition of wastes
Generation and renewal of soil fertility
Purification of air
Purification of water
<i>Translocation processes</i>
Dispersal of seeds necessary for revegetation
Pollination of crops and natural vegetation
Stabilizing processes
Coastal and river channel stability
Compensation of one species for another under varying conditions
Control of the majority of potential pest species
Moderation of weather extremes (such as of temperature and wind)
Partial stabilization of climate
regulation of hydrological cycle (mitigation of floods and droughts)
Life-fulfilling functions
Aesthetic beauty
Cultural, intellectual, and spiritual inspiration
Existence value
Scientific discovery
Serenity
Preservation of options
Maintenance of the ecological components and systems needed for future supply of these goods and services and others awaiting discovery

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Daily et al., 1997). Yet, escalating impacts of human activities on natural ecosystems imperil their supply.

There is an urgent need for a systematic characterization of ecosystem services — locally, regionally, and globally — in biophysical and economic terms. Incorporation of their value into decision-making processes will require both developing ways to estimate their social value and developing institutional mechanisms through which that value can be realized.

There are four key elements of the Ecosystem Services Framework (Daily, 1997b).

### 2.1. Identification of ecosystem services

In comparison to record-keeping of physical and financial capital, little attention has been paid to the stocks of natural capital (ecosystems, their geophysical structure, and their biodiversity) that supply ecosystem services. A systematic, quantitative cataloguing of the sources and consumers of ecosystem services is needed. This would require classifying and mapping the US according to ecosystem type and land use to allow for a national assessment of ecosystem service flows. For any given location, one would like to know which services are produced and consumed locally (e.g. pollination, pest control, renewal of soil fertility, serenity), which are produced and consumed globally (e.g. preservation of the genetic library, climate stabilization), and which are imported or exported (e.g. seafood, timber, flood control, water purification) regionally.

### 2.2. Characterization of the services

Once the major service types and flows are identified, their ecological and economic (and possibly other) attributes must be determined. An ecological characterization of ecosystem services is needed to inform decision-makers, prior to any attempt to value the services, of the ecological trade-offs associated with alternative courses of action. Ecological characterization would determine the shapes of the production functions describing how ecosystems generate services. In other words, it would illuminate the relation between the level of services (quantity and quality) supplied by an ecosystem and its areal extent, as well as the type and degree of human modification of the ecosystem. For instance, an ecological characterization of the hydrological services supplied by a forest catchment would describe water flow and quality as a function of forested area and the type and level of human activities in and around the catchment.

Ecosystem services are highly interdependent, so that another goal of ecological characterization would be to illuminate how exploiting or impairing one service would influence the functioning of others. For the same forest catchment, one would specify which combina-

tions of services and human activities — and what levels of each — could be sustained. Other important services might include timber production, provision of pollinators to nearby farmland, flood control, options conservation, and carbon sequestration ('Options conservation' refers to the preservation of flexibility to change policies, and activities, in the future. The point here is to avoid irreversible losses of some services, for which there are no perceived need now, so that they could be reestablished in the future). Given the mass extinction presently underway, one would especially like to know the extent to which various services depend on biodiversity (Mooney and Schulze, 1994; Hughes et al., 1997). In addition, one would like to identify 'umbrella' services, whose protection would greatly aid the maintenance of others.

Ecological characterization would also determine the extent, and time scale over which, the ecosystems supplying particular services are amenable to repair. Ecosystems typically respond nonlinearly to perturbation; their supply of services may hardly appear to change with incrementally increasing human (or natural) impacts up until a point, whereupon the response can be dramatic and very slow and difficult to reverse. Anticipating such critical points is essential in establishing sound policy; yet, they are poorly known and are likely to remain elusive.

The ecological characterization would be used to assess the importance, or value, of ecosystem services in economic and other terms. No standard method exists for determining the social value of ecosystem services. Fostering the development of a rigorous and transparent process for valuation would be most useful, for several reasons. First, it could illuminate the importance of ecosystem assets prior to decisions leading to their destruction; even lower bound and qualitative measures of importance can be very helpful in this context. Second, such a process could create an 'information market,' stimulating needed inquiry into the functioning and importance of these services (Salzman, 1997, 1998). Third, the process could stimulate the creation of institutions, such as markets, for realizing ecosystem service values. Innovative approaches to conservation finance are now being developed and deployed worldwide (Daily et al., 2000).

An economic methodology for characterizing ecosystem services would address several important issues, such as:

- What would be the social benefits and costs associated with alternative ways of managing ecosystem assets (e.g. land, water)?
- How can individual preferences for alternative options be aggregated fairly?
- How can the costs and benefits of alternative schemes be distributed fairly?

- How effectively, and at how large a scale, can existing or foreseeable human technology substitute for ecosystem services?
- Given that the value of ecosystems lies mostly in the future and will always lie mostly in the future, how should future benefits be valued, in economic, cultural, or other terms?
- How can the parties with the most at stake — future generations — be represented at the bargaining table?

We are a long way from being able to use valuation as a scientific method of decision making. Rather, at present valuation is merely one tool in the much larger politic of decision-making — it is a way of organizing information to help guide decisions, but not a solution in itself. Nonetheless, valuation methods have already had a positive influence on decision-making and will likely assume a larger role in the future. The most important decisions to get right are the ones where benefits greatly outweigh costs, or vice versa, and in those cases complete accuracy is unnecessary.

For example, by constructing crude lower bound estimates for the value of ecosystem services in the Catskills watershed, New York City was able to determine that it was better to attempt restoration of natural water purification services than to construct a water treatment plant (Chichilnisky and Heal, 1998). Is there a broader scope for watershed protection via this mechanism? New York City is a somewhat unique case, with some unusually favorable legal circumstances, and yet long-term success of this approach there is by no means secured (Vaux and Chair, 2000). Nonetheless, it would be informative to assess what might be possible, at least in principal. Ecologist Walter Reid made a crude, first approximation for the US, as follows. He compiled data on 74 municipal water supplies within the lower-48 states and derived a representative value of 0.3 ha as the land area needed per person to sustain a supply of safe drinking water. With a population of ca. 265 million people, the lower-48 states might, thus, logically consider managing about 80 million ha (265 million people  $\times$  0.3 ha per person) with water quality as a major goal. This amounts to 10% of land area — a significant fraction (Reid, 2000). Of course, the feasibility of watershed protection for drinking water supply will vary by geographic region with ecological, economic, and political circumstances. But, the potential for safeguarding a whole suite of economically important services associated with watersheds certainly appears great enough to merit pursuit.

### 2.3. *Establishing safeguards*

There are two key aspects to safeguarding ecosystem services. The first is determining the desired mix of service production, especially where exploitation of one

service (such as timber production) may impair the delivery of another (such as water purification). The second is creating the institutional means of securing the desired range of options.

Clearly, there exists no single optimal mix, or level, of ecosystem service production. The environmental demands and impacts of human societies are ever shifting, highlighting the need to maintain flexibility and options in the supply of services. An explicit accounting of ecosystem services and the impacts of alternative courses of action on them is a critical first step to informed decision-making. A related key step is to identify the main sources of uncertainty regarding the protection of ecosystem services, and their importance. Developing methods of quantifying this uncertainty, and incorporating it into flexible policy, is key. For now, many would argue that the level of uncertainty in our understanding of ecological processes, together with the prevalence of non-linearities and irreversibilities, calls for invoking a precautionary principle. That is, it would be prudent to avoid courses of action that involve possibly dramatic and irreversible consequences and, instead, to wait for better information before putting ecosystem capital at great risk.

The institutional mechanisms appropriate for protecting ecosystem services are likely to vary considerably with ecological and social context. The acquisition of locally based information is essential; ecosystems are idiosyncratic and the devil is in the detail, so that what holds true in one region may not apply well elsewhere. For instance, certain species perform keystone roles in some ecosystems, but play minor roles in others (Power et al., 1996). In some cases, protection of a relatively well understood or valued service could confer protection on others that lack the understanding or institutional support to bring about their own protection directly (known as the ‘umbrella’ effect in conservation). In this way, the interdependence of services might be exploited to maximize the benefits of protecting a single service. In theory, then, poorly known pollination services might be protected in farmed, hilly regions by ensuring that erosion control measures used native vegetation (to serve as habitat for pollinators).

What financial, legal, and other social institutions are needed to safeguard critical ecosystem services? How can their development be catalyzed, and tailored to local circumstances? Without appropriate institutions, notice from ecologists and economists that ecosystems are important and valuable assets will do nothing. Promising new institutions for safeguarding ecosystem services have emerged in a wide array of cultures and economies (e.g. Australia, Costa Rica, Madagascar, US, Vietnam) at a variety of scales, from local to international, and in government, NGO, and private sector contexts (Castro and Tattenbach, 1998; Daily et al., 2000). The services safeguarded by these emerging

institutions include pollination, pest control, water supply (for drinking, for irrigation, and for hydropower generation), maintenance of soil fertility, sustainable harvesting of tropical timber, provision of aesthetic beauty, and even decomposition (of orange peels produced by Del Oro, an orange juice company in Costa Rica).

#### *2.4. Monitoring the services/evaluating the safeguards*

What indicators could be used to monitor changes in the supply or quality of ecosystem services, both accurately and efficiently? Some aspects of monitoring, such as of certain fish stocks or of water quality, are highly developed and widely implemented. There is, however, no systematic monitoring of most ecosystem services; examples of great importance and interest include (among many) pollination (Allen-Wardell et al., 1998) and carbon sequestration (Field and Fung, 1999). This is not the place to review the extensive and diverse literature on environmental monitoring. It suffices to say that proven monitoring methods could be established much more widely, in conjunction with efforts to safeguard ecosystem services. Meanwhile, more research is needed to develop reliable monitoring programs for less-known services. Monitoring ecosystem services is critical to evaluating the efficacy of institutional safeguards designed to protect them.

### **3. Implementing the ecosystem services framework**

US legal policy has few explicit protections for ecosystem services. Generally speaking, pollution laws (Clean Air Act, Clean Water Act) rely on human health-based standards; conservation laws (Endangered Species Act, Marine Mammal Protection Act) are species-specific; and the planning mandates of our resource management laws (National Forest Management Act, Federal Land Policy and Management Act) are of multiple-use. Of course, parts of these laws clearly can conserve ecosystem services, such as the Clean Water Act's §404 wetlands permit program and water quality standards, the Endangered Species Act's critical habitat provisions, and the National Forest Management Act's indicator species (e.g. the spotted owl). These laws were not primarily intended to provide legal standards for protecting ecosystem services, however, and in practice they usually do not (J. Salzman, American University, personal communication, 6 September 1999).

Within the federal government, there are some offices within agencies that deal with valuation and incentives for conservation, but only in a tangential way. For instance, the EPA Office of Policy Planning and Evaluation is partnering with the World Resources Institute to develop natural resource accounting, and with The

Nature Conservancy to devise Compatible Economic Development Centers through the Community-Based Environmental Protection program. The NSF and EPA together have a grants program in Decision-Making and Valuation for Environmental Research, and the Water and Watersheds program requires researchers to include sociological components within their ecological research. But, none of these efforts is specifically geared toward the discovery of practical methods of economic valuation of ecosystem goods and services and the devising of new economic incentives for conservation (Raven, 1998).

The development of effective institutions and legal safeguards to protect ecosystem services is in its infancy. It will require the interaction of natural scientists, economists, legal scholars, and policy makers in an interactive process. The challenge is great, but the high level of interest shown by individuals in these various groups — along with that of stakeholders in geographic regions where such safeguards are being tested — makes the prospects seem promising. Steps to further the implementation of the Ecosystem Services Framework include, first, the setting of priorities based on existing information and, second, the strategic acquisition of new information.

#### *3.1. Setting priorities*

Apart from a few isolated examples, we have virtually no appreciation of the nature or the value of the services provided by the ecosystems of the US. As we enter the new millennium, with alarming indications of lack of resource sustainability in many regions, it is timely and appropriate that US should develop such an understanding.

At this stage four useful steps could be taken. First, pick the low-hanging fruit. That is, assess the ecological, economic, and social justification for establishing safeguards for comparatively well-known ecosystem services (such as water purification and flood control, where certain types of market institutions already exist; and for carbon sequestration, where a market may be emerging). Developing a systematic, transparent method for such assessment would in itself be a very valuable exercise, as would involving relevant stakeholders in its development. Second, learn vicariously. It would be most helpful to monitor carefully the outcome of efforts to safeguard ecosystem services, both in the US and internationally. The compilation of such experience could inform discussions about what works, what doesn't, and why. Third, experiment and innovate. There could be great payoff to fostering small-scale, experimental efforts to safeguard less appreciated, but valuable ecosystem services. Fourth, promote models of success. A lot could be done in the existing legal and economic framework, with institutional mecha-

nisms that have proven very successful in the communities where they have been implemented.

### 3.2. *Acquiring information*

While a great deal is known about the functioning of ecosystems and the supply of services in general and in abstract terms, there is a paucity of information on particular, local ecosystems and economies. Moreover, while the services are known to be extremely important and to be highly threatened, very little is known about marginal values (the net benefit or cost associated with protecting or destroying the next unit of an ecosystem) or about the nonlinearities in ecosystem responses to human impact. Often this information is not acquired until after it is too late to reverse the harm done (e.g. after heavy flooding).

Further development of case studies addressing these issues would be most helpful. Such work would define the envelope of opportunities and limitations in applying the Ecosystem Services Framework; it would illuminate how general are the findings from specific localities; and it would serve as a guide to policy development. In the New York City case, for instance, officials are purchasing land and changing agricultural and municipal practices in the hope of restoring the natural water purification services of the Catskills — all with quite limited scientific information. Careful studies are underway to determine the effectiveness of the measures, but the political window of opportunity for pursuing this approach (as opposed to building a physical filtration plant) may close soon. In this particular case, and generally, success in the policy arena hinges on whether the scientific underpinnings of policies are sound. Today there exist many laws on the books that could be used for environmental protection, but whose application awaits better scientific information.

### 3.3. *Taking action*

Implementing the Ecosystem Services Framework clearly involves a long-term, iterative process that will evolve with experience and improved scientific and socioeconomic understanding. Where to begin? One possible productive start would be to map out ecosystem ‘service area’ maps for water purification, on a regional or national basis in US. Natural water purification has a scientific and regulatory basis, sufficiently substantial to (i) define criteria for prioritization and (ii) apply these geographically, to determine both the scope for using ecosystem approaches to water purification and the places that merit the most attention and effort.

While priorities for biodiversity conservation have been extensively mapped based on distributions of bio-

diversity and threats (e.g. Ricketts et al., 1999), maps of ecosystem service priorities are virtually non-existent. Ecosystem ‘service area’ maps could be used just as are those of species or ecosystem distributions, and their associated threats to persistence (Balvanera et al., 2001). The mapping process could illuminate three key things, (i) alternative land management regimes required to achieve a given societal benefit, (ii) the degree of spatial congruence between services and the management regimes needed to sustain them (e.g. how much managing of an area for water purification would confer timber, flood control, carbon sequestration, or recreational benefits), and (iii) forecasted changes both in services, and societal need for them, under alternative future scenarios of demographic and land-use change.

The mapping process would also provide a focus around which to involve stakeholders, integrate social and ecological aspects of ecosystem service management, experiment with innovative incentive/financing schemes, and advance the policy agenda. Starting with water purification would involve picking low-hanging fruit (virtually everyone appreciates the importance of safe drinking water), learning vicariously (ecosystem approaches to water purification are well underway in the US and internationally), developing new methodological approaches that integrate science, economics, and policy; and, certainly not least, promoting models of success.

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