PROTECTING NATURAL CAPITAL THROUGH ECOSYSTEM SERVICE DISTRICTS

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Introduction

Societies invest a great deal of effort in monitoring and cultivating their physical, financial, and human capital. By comparison, they typically pay scant attention to their natural capital, especially that embodied in ecosystems. If properly managed, ecosystems supply a stream of critical life-support services. These "ecosystem services" include the production of goods (such as seafood and timber), life support processes (such as pollination, flood control, and water purification), and life-fulfilling conditions (such as beauty and serenity), as well as the conservation of options for the future (such as genetic diversity).

Specialized governmental institutions do, of course, pay attention to some of these services but their focus is primarily on the provision of services through artificial means. For example, local officials have historically built dikes and levees to minimize flood damage in the United States rather than protected or restored wetlands. In some cases, artificial provision of services will in fact be an optimal strategy, providing social benefits at the lowest cost. In many instances, however, the net value of the joint products yielded by ecosystems will exceed that of human-made substitutes. The joint products of a wetland may include, for instance, flood control, water purification, recreation, scenic beauty, and habitat conservation. Yet with rare exception, local, state and national governments simply do not consider ecosystems as valuable providers of services. Without such explicit comparisons between natural and built provision of services, however, we will continue missing opportunities where natural capital provides the lowest-cost services necessary for human welfare.

This issue of the Stanford Environmental Law Journal explores how ecosystem services might be better protected. In this article, we focus on the potential of governmental authorities dedicated to management of ecosystem services. We argue that the creation of such Ecosystem Service Districts (ESDs) will improve the efficient provision of services necessary for human welfare. At the moment, when agencies manage for natural resources, they typically do so in a

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defined geographical area or district. Given the prevalence and importance of districts for soil conservation, resource conservation, flood control, and other local services, we explain how ESDs could provide a coherent and efficient governmental institution for monitoring and investing in natural capital. A focus on ESDs would create a mechanism to help ensure that natural capital is protected and maintained with the same care and concern as that given to built and human capital.

Establishing and managing ESDs will involve an exploration of the underlying ecological processes that provide the services, of the economic significance of the services, and of the legal issues involved in managing natural ecosystems for the good of a local or regional community. Central in all these analyses will be land use decisions. Land use determines which of the initial ecosystems and services are maintained intact. In addition, many of the key trade-offs between the continued functioning of natural ecosystems and the extension of economic activities arise naturally in the context of land-use choices, such as farming versus forestation, development versus conservation, etc.

In examining the geographical, economic, and legal obstacles in designing ESDs, we suggest an integrative framework for managing the patterns of land use in a district that can provide several different ecosystem services, and that also has the potential to support many different types of economic activity, some of which can conflict with the continued integrity of the natural ecosystems. Part I of the article explains the why ecosystem services are under threat and the potential benefits of managing their conservation through ESDs. Part II lays out the basic ecological-economic framework and principles for district design. Part III sets out the key legal issues and Part IV presents a tentative roadmap of how to put theory into practice. The importance of ecosystem services is no longer disputed. How to realize more fully their value, and hence their conservation, however, remains an active research area. ESDs, though fraught with challenges, provide a potentially powerful institutional mechanism to address the relative neglect of ecosystem services in public policy by bringing their crucial importance into focus and aiding in their preservation.

I. Threats to ecosystem services

A. What are ecosystem services?

Ecosystem services refer to the conditions and processes through which ecosystems, and the species that make them up, sustain and fulfill human life.[1] An ecosystem is the array of organisms – plants, animals, and microbes – found in a defined area and the physico-chemical environment with which that living community interacts. Ecosystems are a key part of our "natural capital".[2] Just as human and human-made capital supply a stream of benefits, so does natural capital supply a stream of goods and other life-support services (set out in Table 1,

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[1] Daily, G. C., NATURE'S SERVICES: SOCIETAL DEPENDENCE ON NATURAL ECOSYSTEMS (ed. 1997).

[2] Jansson, AnnMari, Hammer, Monica, Folke, Carl, and Costanza, Robert, Eds., INVESTING IN NATURAL CAPITAL: THE ECOLOGICAL ECONOMICS APPROACH TO SUSTAINABILITY (1994).

below).[3] Ecosystems deliver these societal benefits “for free” and, in many cases, on a scale so large that humanity would find it impossible to substitute for them.[4]

Table 1.

Ecosystem Services
Production of Goods
food
terrestrial animal and plant products
forage
seafood
spice
pharmaceuticals
medicinal products
precursors to synthetic pharmaceuticals
durable materials
natural fiber
timber
energy
biomass fuels
low-sediment water for hydropower
industrial products
waxes, oils, fragrances, dyes, latex, rubber, etc.
precursors to many synthetic products
genetic resources
intermediate goods that enhance the production of other goods
Regeneration Processes
cycling and filtration processes
detoxification and decomposition of wastes
generation and renewal of soil fertility
purification of air
purification of water
translocation processes
dispersal of seeds necessary for revegetation
pollination of crops and natural vegetation
Stabilizing Processes

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[3] Daily, G.C., *Developing a scientific basis for managing Earth’s life-support systems*, 3(2) CONSERVATION ECOLOGY 14 (1999). [online] URL: http://www.consecol.org/vol3/iss2/art14.

[4] Ehrlich, P. R., and H. M. Mooney, *Extinction, substitution and ecosystem services*, 33 BIOSCIENCE 248-254 (1983).

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
provision of aesthetic beauty and serenity
provision of cultural, intellectual, and spiritual inspiration
existence value

Ecosystem services are generated by a complex of natural cycles, driven by solar energy, that constitute the workings of the biosphere -- the thin layer near Earth's surface that contains all known life. These cycles are ancient, the product of billions of years of evolution, and have existed in forms very similar to those seen today for at least hundreds of millions of years. They are absolutely pervasive, but unnoticed by most human beings going about their daily lives.

B. Why should we care about ecosystem services?

Noticed or not, human beings depend on the continuation of natural cycles for their very existence. If, for instance, natural pest control services ceased – that is, if the life cycles of natural pest enemies were interrupted – there would be disastrous, worldwide crop failures.[5] If the life cycles of bees and other pollinators ceased, society would face similar dire consequences.[6] If the carbon cycle were badly disrupted, rapid climatic change could threaten the existence of civilization.[7]

An example from a decade ago in the Arizona desert explains well our dependency on functioning ecosystems and the consequences of loss of those systems.[8] In 1991, a giant greenhouse was built covering 3.15 acres. Called Biosphere 2 (to differentiate it from Biosphere 1, in which we are all living now), the greenhouse (which was intended to be hermetically sealed) housed constructed ecosystems. There were grasslands, marshlands, an ocean (including a coral reef), and even a tropical rainforest. Plants and animals and soils to represent all of these were brought in, and a fairly large portion of Biosphere 2 was devoted to intensive agriculture. The whole system was designed to support eight human beings – "Biospherians."

In mid-1991, four men and four women were sealed into Biosphere 2 to stay for two years. The situation deteriorated rapidly. One after another, the ecosystems collapsed and ceased providing their essential services. Oxygen concentrations in the atmosphere dropped to

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[5] Naylor, R., and P. R. Ehrlich, *Natural pest control services and agriculture*, in G.C. DAILY ED., NATURE'SERVICES: SOCIETAL DEPENDENCE ON NATURAL ECOSYSTEMS 151-174 (1997).

[6] Buchmann S. L., and G.P. Nabhan, THE FORGOTTEN POLLINATORS, DC (1996).

[7] Intergovernmental Panel on Climate Change, THIRD ASSESSMENT REPORT (2001).

[8] *See* James Salzman, *Valuing Ecosystem Services*, 24 ECOL. L. QUART. 887 (1997).

levels normally found at 17,500 feet elevation. Nitrous oxide concentrations spiked upward to the point of impairing brain function, and carbon dioxide levels fluctuated erratically.

The outcome of the Biosphere experiment was disastrous. Nineteen of twenty-four vertebrate species went extinct almost immediately, as did all of the pollinators, limiting the persistence of many of the plants to the lifetimes of the original individuals. Morning glories and other vines that had been added to the experiment to absorb excess carbon dioxide ran rampant. The Biospherians strove to weed them out, but their efforts fell short and their crops were overgrown. The occupants started to starve, and in desperation decided to cut down their tropical rainforest in order to plant more food crops. They also sneaked in candy bars and other rations from Biosphere 1. Natural pest control services failed: ants swarmed everywhere; cockroaches and katydids were the other prominent animal survivors.

The aquatic systems – the source of irrigation and drinking water – accumulated excess nutrients, which needed to be removed by growing and harvesting by hand large mats of algae (known less technically as stinking slime). A planned brackish estuary had to be permanently isolated from the "ocean" because of the problems encountered with managing water chemistry. Huge amounts of electricity, at a cost of about $1 million each year, were required to supplement the solar energy. And there were tales of considerable friction among the Biospherians as food supplies dwindled. The Biosphere 2 experiment did, however, teach us four important lessons[9]:

* the crucial importance of ecosystem services;
* how little we know about maintaining them;
* the possibly severe consequences of disrupting them;
* and the need for great caution where human impacts threaten ecosystem services.

Biosphere 1 is much larger, better "tested and designed," and thus more resilient than Biosphere 2. Nonetheless there are many signs that its ecosystem services are faltering, including increasingly extreme weather and other climatic problems[10] , deterioration of the ozone

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[9] Cohen, J. E., and D. Tilman, *Biosphere 2 and biodiversity: The lessons so far*, 274 SCIENCE 1150-1151(1996).

[10] Schneider, S. H., LABORATORY EARTH: THE PLANETARY GAMBLE WE CAN'T AFFORD TO LOSE (1997); Intergovernmental Panel on Climate Change. 2001. Third Assessment Report. Pages in preparation.

layer[11], increased problems with pest control[12], declines in pollinator populations[13], the collapse of oceanic fisheries[14], and the general decay of biodiversity.[15]

C. Why are they under threat?

Ecosystem services are under threat for two basic reasons. The first is that the scale of the human enterprise is now so large that humanity is drastically altering natural ecosystems and the processes they control.[16] For millennia, human impacts were typically local, minor, and reversible. Today, human influence can be discerned in the most remote reaches of the biosphere; it is global in effect, rivaling or overshadowing natural biogeochemical and evolutionary processes; and many of the impacts are irreversible, certainly on a time scale of interest to society. Although much more by accident than by design, humanity now controls conditions over the entire biosphere.

To list just a few of many impacts, human activity has heavily transformed 40-50% of the icefree land surface; coopted 50% of accessible, renewable fresh water; fully exploited or over exploited 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.[17]

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[11] Molina, M., and S. Rowland, *Stratospheric sink for chlorofluoromethanes: chlorine atom catalyzed destruction of ozone*, 249 NATURE 810-814 (1974); Farman, J., B. Gardiner, and J. Shanklin, *Large losses of total ozone in Antarctica reveal ClO_x/NO_x interaction*, 315 NATURE 207-210 (1985); World Meteorological Organization. 1995. SCIENTIFIC ASSESSMENT OF OZONE DEPLETION: 1994. National Oceanic and Atmospheric Organization, Washington, DC.

[12] Georghiou, G. P., and A. Lagunes-Tejeda, THE OCCURRENCE OF RESISTANCE TO PESTICIDES IN ARTHROPODS, Food and Agriculture Organization, UN, Rome (1991); Tabashnik, B. E., Y.-B. Liu, T. Malvar, D. G. Heckel, L. Masson, V. Ballester, F. Granero, J. L. Mensua, and J. Ferre, *Global variation in the genetic and biochemical basis of diamondback moth resistance to Bacillus thuringiensis*. 94 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA 12780-12785 (1997).

[13] Buchmann S. L., and G. P. Nabhan, THE FORGOTTEN POLLINATORS (1996); Kearns, C. A., D. W. Inouye, and N.M. Waser, *Endangered mutualisms: the conservation biology of plant-pollinator interactions*. 29 ANNUAL REVIEW OF ECOLOGY AND SYSTEMATICS 83-112 (1998).

[14] Raloff, J., *Fishing for answers: deep trawls leave destruction in their wake -- but for how long?* 150 SCIENCE NEWS 268 (1996); Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr., *Fishing down marine food webs*, 279 SCIENCE 860 (1998); Jackson, J. B. C. 2001. What was natural in the coastal oceans? Proceedings of the National Academy of Sciences USA, In press.

[15] Myers, N., THE SINKING ARK (1979); Heywood, V. H., GLOBAL BIODIVERSITY ASSESSMENT (ed. 1995); Hughes, J. B., G. C. Daily, and P. R. Ehrlich, *The loss of population diversity and why it matters in*, NATURE AND HUMAN SOCIETY (P.H. Raven ed. 1998).

[16] Holdren, J. P., and P. R. Ehrlich, *Human population and the global environment*. 62 AMERICAN SCIENTIST: 282-292 (1974); Vitousek, P. M., P. R. Ehrlich, A. H. Ehrlich, and P. A. Matson, *Human appropriation of the products of photosynthesis*, 36 BIOSCIENCE 368-373 (1986); Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo, *Human domination of Earth's ecosystems*. 277 SCIENCE 494-499 (1997).

[17] Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo, *Human domination of Earth's ecosystems,* 277 SCIENCE 494 (1997).

The second reason that ecosystem services are under threat is that ecosystem capital is unrecognized as such by most people. Even when recognized, it tends to be ignored in policy because it is "free."

Markets explicitly value and place dollar figures on "ecosystem goods" (such as timber) that are perceived as important and limited in supply. Yet the services underpinning the production of these goods (such as soil maintenance and nutrient recycling) almost without exception have no market value – not because they are worthless (or their interruption cost-free) but, rather, because there is no market to capture and express their value directly. Until fairly recently, they were so abundant relative to human demands that such markets were not needed. As a result, no efficient price mechanisms exist to signal scarcity or deterioration of most ecosystem services. A further impediment to markets for these services is that their use cannot be exclusively controlled. In economic terms, they are classic public goods.

Historically, ecosystem services have been easy to forget and hard to imagine disrupting beyond repair. Recent ecosystem failures, however have attracted public attention. The disastrous flooding in Central America, Venezuela, China, and other places has revealed the critical role of forests in the hydrological cycle – in particular, in mitigating flood, drought, and the forces of wind and rain that cause erosion. The appearance of a dangerous "ozone hole" sharpened awareness of the value of the ozone layer (put there mostly by the work of plants) in screening out harmful ultraviolet radiation.[18] Release of toxic substances, whether accidental or deliberate, has revealed the nature and value services provided by a diversity of microorgamisms that break down hazardous materials.[19]

D. To what extent do our institutions protect ecosystem services?

The political process largely fails to value humanity's natural capital properly. There are few explicit protections for ecosystem services either in domestic or international law. Ironically, our major environmental laws' inability to protect ecosystems is intentional. Legal protection of ecosystems was not a primary objective when the laws were drafted over two decades ago. Generally speaking, our pollution laws (Clean Air Act, Clean Water Act) rely on human health-based standards. Our conservation laws (Endangered Species Act, Marine Mammal Protection Act) are species-specific. And planning under our resource management laws (National Forest Management Act, Federal Land Policy and Management Act) must accommodate multiple and conflicting uses. 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). The point, though, is that these laws were not primarily intended to provide legal standards for conservation of natural capital and the services that flow from it and, as many have pointed out, in practice they usually don't.[20]

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[18] Roan, S., OZONE CRISIS: THE 15-YEAR EVOLUTION OF A SUDDEN GLOBAL EMERGENCY (1989).

[19] (e.g., Colburn et al.)

[20] Robert B. Keiter, *Beyond the Boundary Line: Constructing a Law of Ecosystem Management*, 65 U. COLO. L. REV. 293 (1994); J.B. Ruhl, *Who Needs Congress? An Agenda for Administrative Reform of the Endangered Species Act*, 6 N.Y.U. ENVTL. L.J. 367 (1998); David R. Hodas, *NEPA, Ecosystem*

By contrast, consider the laws and institutions we have created to protect more traditionally recognized forms of capital. Since the Great Depression, conservation of financial capital has been protected by disclosure laws to ensure that investments are preceded by accurate data on the attendant risks, trusts and estates laws requiring trustees to exercise a fiduciary duty on the behalf of beneficiaries, and governmental institutions such as the Federal Reserve and the Treasury Department that support the currency's solvency and promote dependable transactions of financial capital. The overlapping safeguards in place to ensure efficient and predictable financial markets are impressive. Similarly, the prominent place occupied by education in the 2000 Presidential election, or the historic struggle leading to reorganization of the legal relationships between labor and management during the Great Depression,[21] testifies to the importance given to human capital.

E. The potential of ESDs for improved environmental protection and social welfare

For wise policy, we need to ensure a careful comparison of the different means of providing services. In some cases, relying on human-built rather than natural capital for provision of services may be entirely appropriate. At present, however, we have weak scientific, economic, and legal bases upon which to rest the comparison. To begin, we should attempt to capture as many as possible of the social costs and benefits of each alternative. Similar benefit-cost evaluations should be done for alternatives such as water purification by filtration plants versus natural purification through watershed protection; pollination by commercial beekeeping versus encouragement of populations of native pollinators; and pest control by broadcast use of insecticides versus integrated pest management. Moreover, we must assess the benefits and costs of protecting those services that have no viable alternative, such as climate regulation.

Explicit consideration of ecosystem services, even with imperfect understanding, can lead to more efficient allocation of funds. As described in the introductory essay to this issue, for example, New York City was faced with the task of restoring its drinking water to levels that satisfied EPA standards. The City chose to restore natural water purification services in the Catskills watershed at a cost of roughly $1.5 billion in lieu of constructing a much more expensive water filtration plant. This amounts to an investment in natural capital rather than physical capital, on economic grounds. New York City taxpayers will receive clean water at the lowest cost; stewards of the watershed (in the Catskill Mountains, ca. 100 miles away) will be compensated for the purification services they provide to the City; and those concerned with other services supplied by the Catskills ecosystem (e.g., carbon storage, aesthetic and recreational benefits, cultural preservation) will see these better protected under the umbrella of water purification.

Management and Environmental Accounting, 14 NAT. RESOURCES & ENVIRONMENT 185 (2000); Dianne K. Conway and Daniel S. Evans, *Salmon on the Brink: The Imperative of Integrating Environmental Standards and Review on an Ecosystem Scale*, 23 SEATTLE U.L. REV. 977 (2000); David W. Burnett, *New Science But Old Laws: The Need to Include Landscape Ecology in the Legal Framework of Biodiversity Protection*, 23 ENVIRONS ENVTL. L. & POL'Y J. 47 (1999).

[21] Kennedy, D. M. , FREEDOM FROM FEAR: THE AMERICAN PEOPLE IN DEPRESSION AND WAR, 1929-1945 (1999).

Political institutions that provide services exist throughout the world. These are local district authorities charged with flood control, soil conservation, water purification, sewage, erosion control, etc. The U.S. alone has 2,935 soil conservation districts (within 3,209 counties).[22] In some instances, these districts have been provided with significant legal authority, including the powers of taxation, eminent domain, and zoning. They do not, however, generally consider ecosystems as providers of services. Flood control, for example, is managed at the federal level by the Bureau of Reclamation, by states in inter-state compacts, and within states by local flood districts. But the toolkit these institutions carry generally contains three construction tools – dikes, dams and levees – overlooking the ecosystem service of flood prevention.

II. An Ecological-Economic Framework for Managing Ecosystem Services Within a District

To illustrate the issues that arise and the approach that we suggest, we consider the management of ecosystems services in a simplified hypothetical district. This district has three main features, and is portrayed below in Figure 1.

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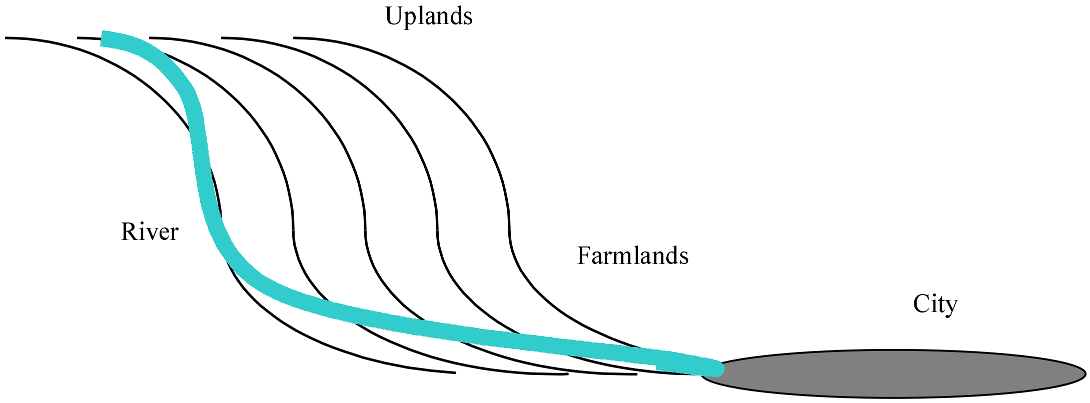
[22] John B. Braden and Donald L. Uchtmann, *Soil Conservation Programs Amidst Faltering Environmental Commitments And The "New Federalism",* 10 B.C. ENVTL. AFF. L. REV. 639, 642 (1982) [hereinafter Braden and Uchtmann].

Figure 1



1. An upland forest, which provides timber and acts as a watershed.
2. Lowland farmland irrigated by the forest.
3. A city, getting its drinking water from the forest. A river flows from the forest through the farmland to the city.

This system provides the following ecosystem services:

1. Food
2. Timber
3. Climate stability (via carbon storage and sequestration)
4. Flood control
5. Pure water
6. Recreation
7. Options for future changes in policies.

The district also provides other services, namely pollination and pest control, that are valued not in their own right but as key inputs to the production of food.

"Options" refers to the possibility that we will change agricultural policies in the future and so wish to preserve the flexibility to do this. The point here is not to drive local populations to extinction but to maintain a reservoir so that even if their services are not needed now their populations can be expanded in the future.

There are of course interactions between many of these services – for example, water purification and flood control affect the productivity of agriculture. Table 2 elaborates on the services provided by ecosystems in the district, which systems supply them, and who consumes them. "Market" here denotes a market operating on a geographic scale larger than that of the district under consideration.

Table 2

Service	**Supplier**	**User**
1. Food production	Farmland	Market
1a. Pest control	Farmland (set aside)	Farm
1b. Pollination	Farmland (set aside)	Farm
2. Timber	Forest	Market
3. Climate stability (C-sequ'n)	Forest & farmland	Market
4. Flood control	Forest	City & farms
5. Water purification	Forest	City & farms
6. Recreation	Forest	City
7. Options	Farmland (set aside)	All

In order to make policy decisions for this district, we need three types of information:

- What combinations of the seven goods and services is it possible to produce from the land and natural resources in the district? What are the tradeoffs among services? For example, how does enhancing the provision of carbon storage, or of timber, affect the production of food, or of recreation or flood control? And, how much can technological substitutes of ecosystem services contribute? In economic terms, we are asking about the "production functions" for ecosystem services.
- What are the policy variables that let us attain different combinations of the outputs? For example, what do we have to do to produce more carbon storage and less food? Or more pure water and less timber? What are the levers that move this system?
- What are the relative values that society places on the different ecosystem goods and services that are available, and how do these values compare to those of other outputs whose generation destroys natural ecosystems (e.,g., housing or farmland)?

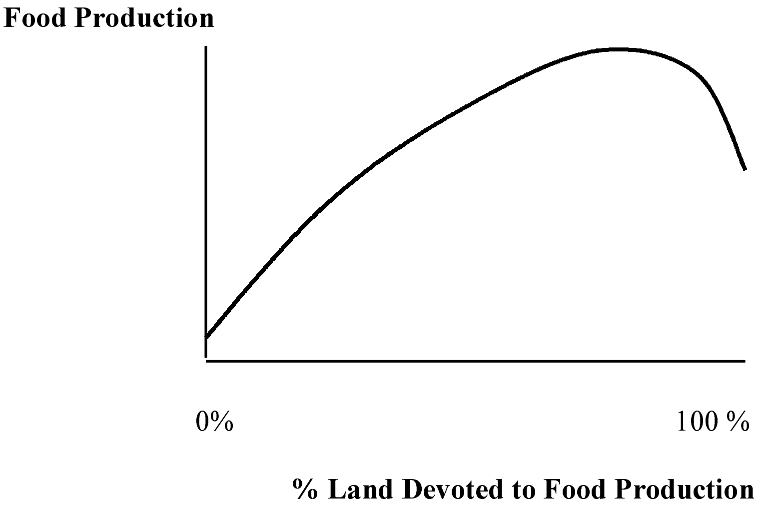
With tentative answers to the first two questions, we can plot out the alternative "product mixes" that the district can produce, and specify the policy choices that will lead to each. The final stage of the analysis is to find out which of these alternative product mixes is the best for society. This of course cannot be determined just by analyzing the district: for this stage we need to bring in indicators of society's preferences between the different products. This is where we use information about relative valuations. Some of these may be reflected in market prices for the goods or services.

A. Modelling tradeoffs

To answer these questions, we have to study the interactions between the provision of the various goods and services, and the consequent rivalries or complementarities between them. How does the level of one good or service affect those of the others?

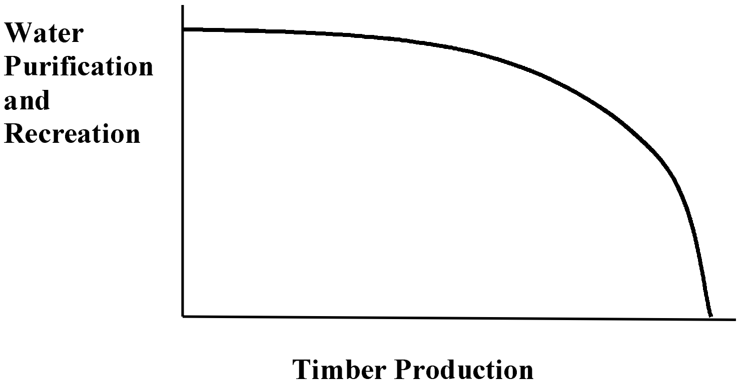
Consider first the relationship between the land set aside for the provision of pest control and pollination services, and the production of food. Assume that we are working with crops that require pollination and are vulnerable to insect pests. If all land is devoted to food production (i.e., none is set aside for pest predators or pollinators), there will be greatly reduced production of food because there will be greatly reduced pollination. A small proportion of land set aside will suffice to shelter sufficient pollinators and pest predators to manage the crop and any increase in the land set aside beyond this will lead to no further increase in food production. Hence we have a relationship like Figure 2.

Figure 2



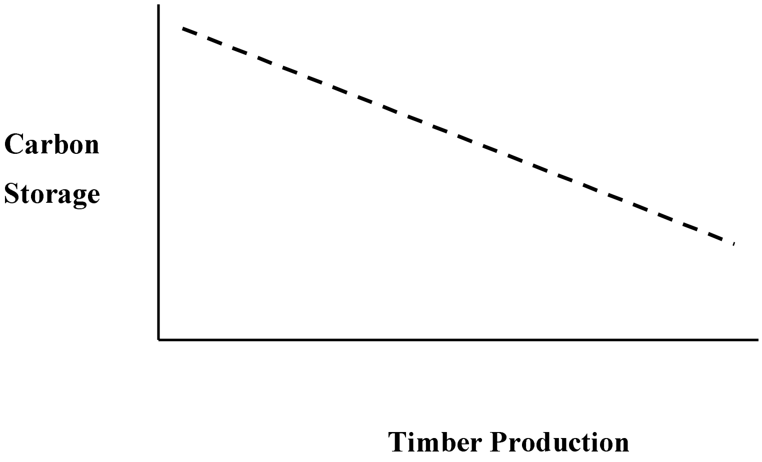
In the case of the forest, there will be tradeoffs between timber production and other services provided by the forested region, such as recreational services, pure water and carbon storage. These services will probably decline as the extent of timber production rises, so that the tradeoff here may look as in Figure 3.

Figure 3



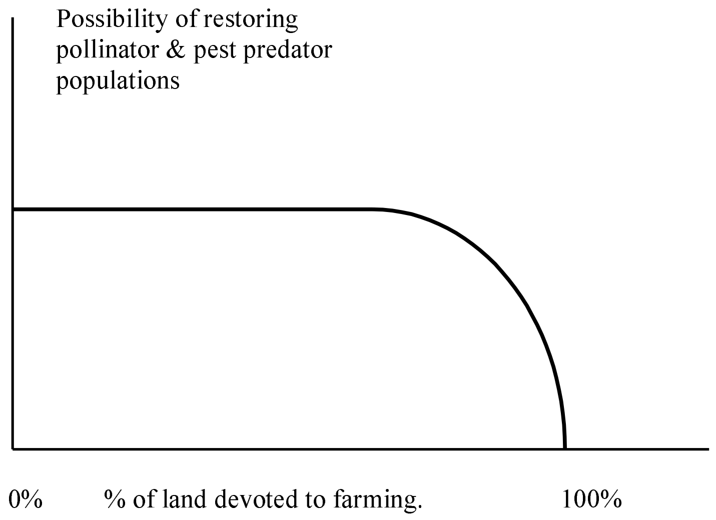
In the case of carbon storage services, there will be a similar relationship, though probably closer to linear, as in Figure 4 (shown as a dotted line because this relationship is particularly sensitive to assumptions about production regime and unknowns about carbon storage).

Figure 4



Let us now explore the relationship between option value and the production of food and timber. The possibility of restoring adequate local populations of pollinators and pest predators will be zero if no land is set aside as habitat for these. It will however reach a maximum quite quickly as the land set aside increases to reach their minimum necessary habitat. Hence we have the relationships in Figure 5, which assumes no possibility of outside sources for reestablishment of pollinators and pest predators. Likewise for the conservation of diversity in the forested area, some land must be preserved for old growth but the amount of diversity preserved will rapidly peak as the land set aside for this rises.

Figure 5



How do we use the information in the Figures 2 through 5? Can we construct a single function that describes the relationships between the various possible output mixes? To understand this, we need the concept of a production possibility frontier. Consider a production process that can produce several different outputs from a fixed set of inputs. Then the production possibility frontier does the following: for any levels of outputs of all but one of the goods produced, it shows the maximum possible output of the last good. Suppose there are two outputs only, say water purification and timber: then the production frontier shows for any level of timber output the maximum amount of water purification that can be performed.

Figure 6 shows the frontier for three outputs – carbon storage, timber production and pure water. The figure assumes that maximum timber production leads to no storage or pure water, and that no timber production maximizes carbon storage and pure water.

Figure 6

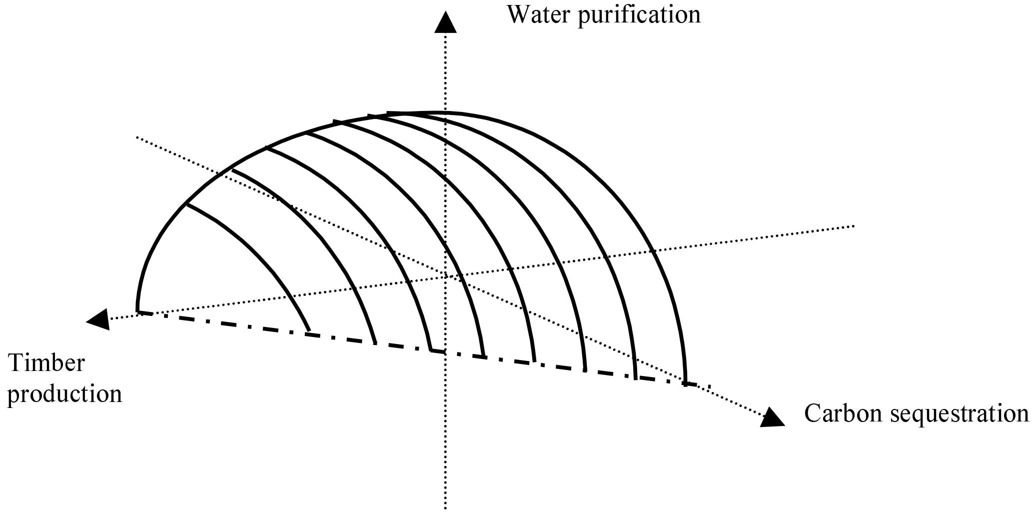


Figure 6

The frontier shaded in Figure 6 (in three dimensions) shows the maximum output of water purification that can be obtained for any levels of carbon storage and timber production. With only three outputs, the policy problem is to choose a point on this frontier – i.e. a product mix of the three outputs. Thus Figure 6 shows that figures 3 and 4 are actually simplifications. In fact, the relationship between timber production and pure water in Figure 3 also depends on the level of carbon storage. For example, we might have planted fast-growing trees to maximize storage, which will have an impact on the relationship between timber production and pure water. A complete analysis requires that we spell out these interrelationships between the various activities, and model them all explicitly.

In the context of our hypothetical district, there are seven outputs so that the overall production possibility frontier is a surface in $\mathbf{R}^7$ – not easily visualized in seven dimensions. Finding the optimum in this case is an exercise in non-linear optimization in $\mathbf{R}^7$.

One key observation is that the patterns of land use in the forest and on the farms determine the services provided by the district. All seven outputs are determined by these two variables – though they are quite complex variables, incorporating land use and the entire rotation and harvesting patterns in the case of both farms and forest. An implication of this is that when it comes to providing economic incentives for the provision of the ecosystems services that seem desirable, we can either pay directly for these services or we can use policy measures that encourage the particular uses of farms and forest that lead to their provision. From an economic perspective, there are several aspects of these relationships that are important. Are there thresholds in the relationships between some of these variables? Are there diminishing or increasing returns to the scale of the processes? The answers to these questions determine whether we can use prices to decentralize decision-making and provide incentives.

There is a second approach to the issues underlying figure 6. Rather than trying to optimize the tradeoffs between many different services, we can choose several different possible land management strategies and then plot out the levels of services that would result from these. For example, we could consider the following five management strategies for the upland region:

A. Convert entirely to pasture.

B. Maintain as mature forest with no harvesting.

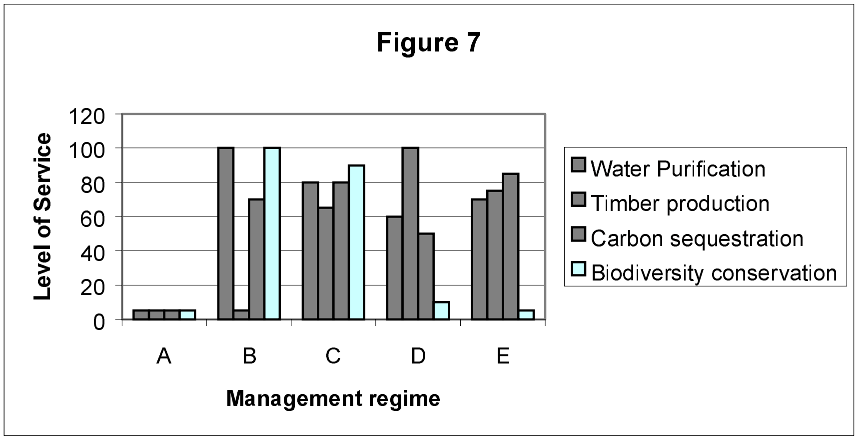
C. Adopt sustainable forestry with native species.

D. Unsustainable forestry.

E. Sustainable forestry with an exotic species.

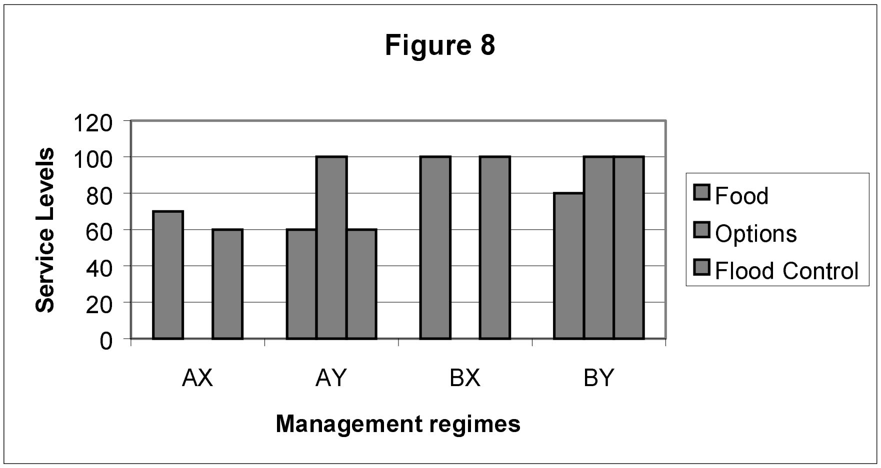
Figure 7 shows the outputs of four services (pure water, timber production, carbon storage, and biodiversity conservation) that might result from these alternative policies. (The numbers are of course purely illustrative.) This approach to representing the tradeoffs has the advantage that it can present data on more than three variables. The five management strategies chosen can be thought of as points selected from the overall frontier (as in figure 6, but 7-dimensional), with the selection criterion being the feasibility of the land management strategy.

Figure 7



In fact, matters are a little more complex than we have suggested so far, as the way the upland regime is managed will affect the value of agricultural output in the lowland. So the choices of management regimes in upland and lowland cannot be independent, and therefore we have to value combinations of these. Just as an illustration of the issues involved, consider upland regimes A and B, converting to pasture and maintaining mature forest with no harvesting. The first of these will lead to no flood control services and no water purification services being provided and will therefore affect the food production possibilities of the farmland differently from the second. We would expect that food production possibilities under the second regime would be higher than under the first. Let X and Y represent alternative lowland management regimes. X will be taken to represent a regime in which all land is used to produce a single crop that does require pollination, and Y to represent one in which some land is kept as semi-natural pollinator and pest predator habitat. Figure 8 replicates figure 7 for three outputs of the lowland region (food, options and flood control) under four possible regime combinations, AX (pasture, and all farmland utilized), AY (pasture, and farmland set-asides), BX (maintaining forests, and all farmland utilized)and BY (maintaining forests, and farmland set-asides). The total output of a management regime AX will be the sum of the upland outputs, shown as the A case in figure 7 plus the associated lowland outputs, shown as AX case in figure 8, for AY it will be the sum of the A and AY cases, etc If we had prices for all seven goods and services we could then value the output of all possible combinations of management regimes.

Figure 8



B. The optimal output

The socially optimal product mix is that mix of outputs that produces the maximum possible value for society from the natural resources that constitute the ecosystem district. This value is measured at "shadow prices," prices that reflect accurately the marginal contribution of each service to society's welfare. The socially optimal output of ecosystem services may or may not involve the production of some particular ecosystem service. Which services and what amount will be produced is determined by the relative prices of those services. For example, if the price of water purification is high, then the optimal product mix will contain water purification services. Conversely, if the price of water purification low, the optimal product mix will contain something of even higher value and water purification will be met by an alternative method that is less costly than the corresponding ecosystem service. Provided the prices used to value all of the outputs are correct, the value of the services provided by the ecosystem and by alternative methods (under the chosen management regime) will be known.

In principle there are two different ways of finding the socially optimal product mix on the production possibility frontier. One is to describe the frontier mathematically and use information about society's preferences to determine the best point on it. This reduces the selection of the best point to a programming problem or, as we have illustrated above, to the selection among feasible management regimes. An alternative approach, which is completely equivalent, is to face each decision-maker in the district with the incentives that would force the system toward an optimal allocation of ecosystem services. In other words, face each farmer and timber producer with a "correct" set of prices for all of the outputs that he or she produces. This means facing the timber producer with (positive) prices for carbon storage, water purification, flood control, recreation and biodiversity support. Farmers would face (negative) prices that reflect the full social costs of using pesticides and fertilizers, giving them incentives for preserving pollinators and pest predators. Because the farmers are themselves the beneficiaries of conservation that facilitates pollination and pest services, it may be possible to internalize the returns from this function. If the prices are chosen to reflect society's valuations then profit-maximizing behavior in a competitive market automatically solves the problem of mathematically locating the optimal solution. Basically this is the first theorem of welfare economics.[23]

In our hypothetical example, the optimal output is that produced by the combination of upland and lowland management regimes that lead to the maximum value of the services produced. The prices used to value the services will be the same whichever method we use to set out the problem of selecting the best output.

III. Legal Analysis of Managing Ecosystem Services Districts

Now that we have established the ecological tradeoffs among services and the economics of service production, we turn to the legal status of our proposed districts. The United States has a rich experience with service districts. Throughout the country, local and county government units routinely make on-the-ground management decisions relevant to provision of ecosystem services. District authorities oversee most local land use decisions and, west of the Mississippi, many water management issues, as well. Created either by state statutes or local initiative, these

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[23] GEOFFREY HEAL, NATURE AND THE MARKETPLACE 21-41 (2000).

sub-state units exercise substantive authority over conservation, drainage, natural resource management, erosion control, water supply, and flood control.[24]

The powers of these districts vary considerably. As an example, under authorization of the Soil Erosion Act of 1935 every state in the U.S. has created soil conservation districts to address soil erosion locally. The typical district has the authority to:

> conduct surveys, investigations, and research relating to soil erosion and its prevention; to develop comprehensive plans for conservation within the district; to conduct demonstrations and disseminate information; to enter into contracts or agreements with landowners and operators to carry out conservation programs; to enter into agreements with government agencies; to purchase, lease, or otherwise acquire or dispose of land and equipment.[25]

Do such districts provide useful models for an ESD? The effectiveness of any institution, whether a soil conservation district or and ESD, depends upon both its jurisdictional and substantive authority.

As the discussion in Part II made clear, the geographic coverage of an ESD, its jurisdictional scope, is integral to its success. Unless the district contains or exercises some control over the relevant habitat generating an ecosystem service, it cannot ensure efficient or adequate provision of the service. For example, an ESD in Missouri (or even shared by Missouri and Illinois) would not be able to control the provision of flood control or water purification services in those areas adequately because of the vast watershed areas outside of its jurisdiction. As a matter of institutional design, this can pose a considerable challenge because, as a rule, local political jurisdictions are not closely aligned with naturally demarcated areas such as watersheds, exercising authority instead over politically-bounded areas as defined by municipality, county or state lines. A small number of interstate initiatives, such as the Chesapeake Bay Initiative, have sought to better align political actors within the Bay's watershed.[26] A number of states, as well, have aligned political and natural boundaries (such as the New Jersey Pinelands Commission and the Adirondack Park Agency of New York).[27] But these are the rare exceptions that prove the rule.

In addition to overlapping geographic jurisdictions, the interactions of overlapping *political* jurisdictions are critical to the legal control of natural resources. This may also be

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[24] *See* William Goldfarb, *Watershed Management: Slogan or Solution?*, 21 B.C. ENVTL. AFF. L. REV. 483, 496 (1994) (citing Charles J. Meyers, et al., WATER RESOURCES MANAGEMENT: A CASEBOOK ON LAW & PUBLIC POLICY (1988)).; *See also* Larry C. Frarey, Ron Jones and Staci J. Pratt, *Conservation Districts as the Foundation for Watershed-Bound Programs to Prevent and Abate Polluted Agricultural Runoff*, 18 HAMLINE L. REV. 151, 158 (1994).

[25] 16 U.S.C. § 590a (1976).

[26] *See* William Goldfarb, *Watershed Management: Slogan or Solution?*, 21 B.C. ENVTL. AFF. L. REV. 483, 494 (1994) (citing T. Horton and W. M. Eichbaum, TURNING THE TIDE: SAVING CHESAPEAKE BAY (1991).

[27] *See* William Goldfarb, *Watershed Management: Slogan or Solution?*, 21 B.C. ENVTL. AFF. L. REV. 483, 496 (1994) (citing Helen M. Ingram, *The Political Economy of Regional Water Institutions*, 55 AMER. J. AGRI. ECON. 10 (1973). Also - New Jersey Pinelands Commission: N.J. Stat. Ann. § 13:18A-8 (West 1993); Adirondack Park Agency: N.Y. Exec. Law § 803 (McKinney 1993).

termed substantive authority. For example, water resource issues are overseen by 13 different congressional committees and subcommittees, 8 cabinet agencies, 6 independent regulatory agencies, 2 White House offices, 200 state departments, and approximately 100,000 local entities.[28] As a matter of coordination, the larger the number of political entities required for a decision the greater the costs of collective action and, therefore, the less likely it will be taken. Hence all other things being equal, those ecosystem services requiring larger areas for their provision will prove more difficult to administer.

As quoted above, soil conservation districts have broad-ranging authority, from developing conservation plans and conducting research to entering into contracts and purchasing land. In spite of these broad powers, however, the majority of soil conservation districts, and there are over 6,000 today, do not have powers of taxation or condemnation. Authority to regulate land use is not uniform, either.[29] What legal powers would an ESD need to operate effectively?

Considering district powers from least to most controversial, at a minimum ESDs could play a *coordinating function* across districts. Because district jurisdictions rarely track ecological or watershed boundaries, efforts in one district to enhance ecosystem services can be weakened, or in some cases frustrated, by activities in another district working at cross-purposes. One district's management for natural pollination, for example, can be nullified by a neighboring district's spraying of pesticides on crops and adjacent lands. ESDs could also be granted authority for *information generation*. As a simple first step toward ESDs, for example, existing districts could be mandated by the state legislature to explicitly compare the cost of service provision through both natural and constructed means. This mirrors many of the regulatory reform proposals in Congress since 1995 mandating more transparent and inclusive cost-benefit comparisons. Mandating districts to pay closer attention to provision of services by ecosystems does not, of course, require rejection of human intervention.

More controversially, ESDs could be granted zoning authority or other *land use powers* (such as condemnation). The challenge in granting such authority, however, is that it would require transferring that power from its current source (unless the ESD acted concurrently with the zoning authority) and no doubt threaten certain vested interests. Finally, the ESD might be granted *taxation authority*. This could provide funds to pay for condemnation and, through charges and subsidies, attempt to move toward the optimal allocation of services described *infra* through pricing. Needless to say, the powers listed above may be found together in municipal governments but rarely, if ever in districts. Thus from an environmental and economic efficiency perspective, single coordinated districts aimed at the production of mixed services would be beneficial, but also significantly outside the historical norm.

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[28] Braden and Uchtmann, *supra* note __, at 484.

[29] *See* John H. Davidson*, State Soil Conservation Plans and Nonpoint Pollution*, 1 GREAT PLAINS NATURAL RESOURCES JOURNAL 421, 423-24, 440 (1996); Dean T. Massey, *Land Use Regulatory Power of Conservation Districts in the Midwestern States for Controlling Nonpoint Source Pollutants*, 33 DRAKE L. REV. 35, 38-39 (1983-84); **Frarey, 155.**

IV. Priorities for Putting Theory of Ecosystem Service Districts into Practice

To foster the implementation of ESDs, we suggest four useful steps. First, pick the low-hanging fruit: 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 storage, where a market may be emerging). Depending on local circumstances, many of these services may be "bundled," i.e., protecting one service (such as flood control) may equally conserve other services such as biodiversity or water purification. Second, learn vicariously. Monitor carefully the outcome of efforts to safeguard ecosystem services, both in the U.S. 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. These efforts could be overseen by management districts. Fourth, promote models of success. Many aspects of ecosystem service management could be implemented in the existing legal and economic framework, with institutional mechanisms that have proven very successful in the communities where they have been implemented.

A. Characterizing the production functions of ecosystem services

In comparison to record-keeping of physical and financial capital, little attention has been paid to the stocks of natural capital that supply ecosystem services. A systematic, quantitative cataloguing of the sources and consumers of ecosystem services will be needed to institute ecosystem districts. Starting from the district level, this would require classifying and mapping the U.S. according to ecosystem type and land use to allow ultimately 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 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.

Once the major service types and flows are identified, their ecological and economic (and possibly other) attributes must be determined. While a great deal is known about the functioning of ecosystems and the supply of services in general and abstract terms, there is a paucity of information on particular, local ecosystems and economies. 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.[30] 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

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[30] HAL R. VARIAN, MICROECONOMIC ANALYSIS (1978) 1-21 (describing the use of production functions).

flow and quality as a function of forested area and the type and level of human activities in and around the catchment.

Because ecosystem services are highly interdependent, 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 combinations of services and human activities – and what levels of each – could be sustained. Ecological characterization would also determine the extent, and time scale over which, the ecosystems supplying particular services are amenable to repair. Anticipating the responses of ecosystems to perturbation is essential in establishing sound policy, yet these are poorly known.

Ecosystem services also need to be characterized in an economic context. 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. Economic characterization would identify the social benefits and costs associated with alternative ways of managing ecosystem assets. It would also aim to determine how individual preferences for alternative options can be aggregated fairly, and how the costs and benefits of alternative schemes can be distributed fairly. The most important valuation decisions to get right are the ones where benefits greatly outweigh costs, or vice versa, and in those cases complete accuracy is unnecessary.

Further development of these assessments 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.

B. Mapping ecosystem services

The second item needed to begin implementing Ecosystem Service Districts is to map out ecosystem "service areas." While priorities for biodiversity conservation have been extensively mapped based on distributions of biodiversity and threats,[31] 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., in review). The mapping process could illuminate three key things: (i) the bundles of services supplied by alternative land management regimes; (ii) the degree of spatial congruence between individual services and associated management regimes; and (iii) forecasted changes both in services, and societal need for them, under alternative future scenarios of demographic, land-use, and climatic change

Natural water purification is a good service to begin mapping efforts, as it 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.

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[31] Ricketts, T.H., Dinerstein, E., Olson, D.M., Loucks, C.J., Eichenbaum, W., DellaSala, D., Kavanagh, K., Hedao, P., Hurley, P.T., Carney, K.M., Abell, R., and Walters, S, TERRESTRIAL ECOREGIONS OF NORTH AMERICA: A CONSERVATION ASSESSMENT, (1999).

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.

C. Transitioning toward a system of ecosystem service districts

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. Thus, as described above, 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. At present, 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 the 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. In the meantime, we need 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 districts-oriented policy, while challenging, is key.

The institutional mechanisms appropriate for protecting ecosystem services are likely to vary considerably with ecological and social context. Management districts provide an institutional framework for acquiring essential locally based information. Ecosystems are idiosyncratic and the devil is in the details, 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.[32] 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). This need for coordination is a further argument for the creation of districts.

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 provide important and valuable assets will do nothing. As described in the Introduction to this issue, promising new institutions for safeguarding ecosystem services have emerged in a wide array of cultures and economies (e.g., Australia, Costa Rica, Madagascar, the United States, Vietnam), at a variety of scales from local to international, and in government,

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[32] Power, M, D Tilman, JA Estes, BA Menge, WJ Bond, LS Mills, GC Daily, JC Castilla, J Lubchenco, and RT Paine. 1996. Challenges in the quest for keystones. *BioScience* 46: 609-620.

NGO, and private sector contexts.[33] 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 – a service provided by allowing their deposition in a regional national park).

Conclusion

Despite the challenges described throughout this article, we clearly could, given sufficient political will, design and implement effective ESDs. A Mississippi Valley Authority, for example, might be charged with coordination of land use policies throughout the watershed to ensure provision of flood control and water purification services. This institution would, with local involvement, consider the trade-offs and benefits in providing natural rather than built services. In practice it might resemble a hierarchy of ever-larger ESDs, depending on the geographic scope of service provision. Such an approach has obvious benefits over the current fragmented and inadequate institutional structure but, equally, we obviously do not anticipate a series of ESD's to spring up across the nation tomorrow. Our current political structures do not, with rare exception, manage the provision of natural services. The reasons for this are many – inertia, vested economic interests that profit from the sale and maintenance of artificial provision of services, ignorance of the benefit provided by natural systems, scientific uncertainties, political institutions with inadequate substantive and geographic authority, political institutions that would lose power with a focus on services, etc. the What will it take for a focus on ecosystem services and the creation of ESD's to occur?

If one considers the era of modern environmental law, a clear trend has been the passage of sweeping legislation following a high-profile environmental disaster. With the national spotlight uncovering the failue of current institutions and protections, reforms have followed. The best-known example of this is the passage of CERCLA (popularly known as "Superfund) following the national uproar following the discovery of contaminated soil in Love Canal, New York. While we clearly do not hope for an increase in flooding events, degraded water quality and other ills, these are increasing and may, in time, provide the wake-up call to focus on services. In order to build the political constituency to demand a services approach, however, requires more than bad weather and misfortune. The importance of ecosystem services and how they are provided must be much better understood by the general public.

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[33] Daily, GC, T Söderqvist, K Arrow, P Dasgupta, P Ehrlich, C Folke, A-M Jansson, B-O Jansson, S Levin, J Lubchenco, K-G Mäler, D Starrett, D Tilman, and B Walker. 2000. The value of nature and the nature of value. *Science* 289: 395-396.

[33] Castro, R., F. Tattenbach, L. Gámez, N. Olson. 1998. *The Costa Rican Experience with Market Instruments to Mitigate Climate Change and Conserve Biodiversity.* MINAE and FUNDECOR, San José, Costa Rica.

While the scientific community's current educational efforts obviously must be increased, building the necessary political base for a transition to administrative structures to protect ecosystem services will require much more. We believe that the relative success of the Intergovernmental Panel on Climate Change (IPCC) in keeping the public and governments informed about the state of the climate, the consequences of different patterns of change, and the possibility for ameliorating those that are negative could provide a model for an institution to encourage the development of administrative structures (ESDs) for the preservation of natural capital. In the United States, establishment of a federal Interstate Panel on Ecosystem Capital could begin to promote (and perhaps fund) the sorts of activities listed above in Part IV. It could involve environmental scientists, resource managers, attorneys, state officials, concerned business firms, NGOs, and representatives of the general public in transparent investigations and discussions of the ways to capture and control the social benefits of the nation's ecosystem endowment. If successful, it could provide a model for similar institutions in other nations, and perhaps feed back positively to enhance the activities and influence of the IPCC and (we would hope) other institutions necessary to protect international public goods. In fact, efforts to this end are already underway internationally. The Millennium Ecosystem Assessment aims to provide the first global appraisal of the condition and future prospects of ecosystems, and to build local and global capacity for evaluating the complex tradeoffs involved in managing ecosystems for societal benefit.[34]

The task seems daunting, but perhaps Americans can take hope from their history. In 1760 British colonies in North America were a diverse and squabbling collection held together primarily by their ties to the Crown. In 1790 thirteen of them were a new nation with an extraordinary Constitution that has endured for more than two centuries. All that came about without benefit of phones, TV, fax machines, or even the internet, based simply on a shared belief that there should not be taxation without representation.[35] In the context of the day, the challenge to the colonists was fully as great as that of saving the systems that support our lives is to us today. The diversity of views and interests among the actors, and the arguments about the righteousness and importance of the cause, and the possible courses of action, were fully as heated. But the colonists overcame the differences and the odds and got the job done in less than three decades with few of the advantages for the sharing of knowledge that we possess today. They created the political will to succeed; we need to do the same.

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[34] E. Ayensu, Edward Ayensu, Daniel van R. Claasen, Mark Collins, Andrew Dearing, Louise Fresco, Madhav Gadgil, Habiba Gitay, Gisbert Glaser, Calestous Juma, John Krebs, Roberto Lenton, Jane Lubchenco, Jeffrey A. McNeely, Harold A. Mooney, Per Pinstrup-Andersen, Mario Ramos, Peter Raven, Walter V. Reid, Cristian Samper, José Sarukhán, Peter Schei, José Galízia Tundisi, Robert T. Watson, Xu Guanhua, and A. H. Zakriet, International Ecosystem Assessment *Science* 286, 685-686 (1999).

[35] Morgan, E. S. 1992. The Birth of the Republic 1763-89. Third Edition. University of Chicago Press, Chicago, IL.