Seminar

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Theory of Ecosystem Services

Speaker

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Valuing Nature: Economics, Ecosystem Services, and Decision-Making

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INTRODUCTION

The past hundred years have seen major transformations in human and ecological systems. There has been a rapid rise in economic activity, with a tenfold increase in the real value of global gross domestic product (GDP) (DeLong 2003). At the same time, the Millennium Ecosystem Assessment found many negative environmental trends leading to declines in a majority of ecosystem services (Millennium Ecosystem Assessment 2005). A major reason for the rapid increase in the production of goods and services in the economy and deterioration in the provision of many ecosystem services is the fact that market economic systems reward production of commodities that are sold in markets and accounted for in GDP, but does not penalize anyone directly for environmental degradation that leads to a reduction in ecosystem services. As Kinzig et al. (2011) recently wrote about ecosystem services: "you get what you pay for" (or, alternatively, you don't get what you don't pay for).

Ecosystems provide a wide array of goods and services of value to people, called ecosystem services. Though ecosystem services are valuable, most often no one actually pays for their provision. Ecosystem services often are invisible to decision-makers whose decisions have important impacts on the environment. Because of this, decision-makers tend to ignore the impact of their decisions on the provision of ecosystem services. Such distortions in decision-making can result in excessive degradation of ecosystem functions and reductions in the provision of ecosystem services, making human society and the environment poorer as a consequence. Unless we fix this imbalance and begin to properly account for ecosystem services, and provide proper incentives for their sustainable provision, global society is unlikely to see the type of fundamental change necessary to sustain environmental quality, ecosystem services, and human well-being.

The question is how to remedy this situation and make ecosystem services visible to decision-makers. How can we "mainstream" ecosystem services so that individuals, businesses, and government agencies factor in the impact their decisions have on ecosystem services? In principle, the answer is easy; it lies in providing incentives for people to provide services, either through programs that provide payments for ecosystem services, or through taxes on actions that lead to environmental degradation, or by directly regulating activities that affect ecosystem service provision. In practice, there are numerous scientific uncertainties about the impact of choices on the provision of ecosystem services, economic uncertainties about the relative values of services, and institutional and policy design considerations. The three main tasks that must be performed in order to successfully mainstream ecosystem services are to:

1) Link actions to impacts on the ***provision*** of services: improve understanding of the likely consequences of human actions on ecosystem processes and of their ultimate impacts on the natural capital that sustains ecosystem services
2) ***Value*** services: improve understanding of the contribution of ecosystem services to human well-being
3) Provide ***incentives***: incorporate an understanding of the value of ecosystem services into policy and management frameworks, to provide incentives for the continued provision of valuable ecosystem services

Accomplishing these three tasks requires a better understanding of the natural science involved, better economic analysis, and better integration of science and policy. In some respects these tasks represent a tall order, and it may not be possible to be successful in all situations. But in many cases the policy tools and scientific knowledge are already in place. Doing a much better job than is currently being done is simply a matter of deciding that mainstreaming ecosystem services is a high priority. This white paper provides a brief review of the policy mechanisms, science, and economics relevant to the sustainable provision of ecosystem services. It provides examples of the use of InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) to evaluate the provision and value of multiple ecosystem services provided by landscapes under alternative policy scenarios.

There are a growing number of examples at both local and national scales of policies that provide incentives for the provision of ecosystem services. In the U.S., agricultural programs like the Conservation Reserve Program pay farmers to take land out of active crop production and plant perennial vegetation in order to reduce soil erosion, improve water quality, and provide habitat and other ecosystem services. Similarly, China's Grain for Green program pays farmers to take steeply sloping lands out of production to provide a range of ecosystem services. Costa Rica's Pago de Servicios Ambientales pays landowners for carbon sequestration and to protect water quality, biodiversity, and scenic beauty.

At the local level, numerous municipalities provide payments to protect watersheds that supply drinking water. The success of an early program in Quito, Ecuador, that collects a small surcharge on water users to protect and restore watersheds has led to the rapid spread of "water funds" throughout Latin America. Private companies are also looking at how ecosystem services affect their bottom line. Dow Chemical Company and The Nature Conservancy have embarked on a joint project to assess the value of ecosystem services to Dow and surrounding communities.

Some conservationists and natural scientists have expressed grave doubts about "valuing nature" and ecosystem services, as well as the role of economics and economists in conservation and environmental policy. Some scientists have complained that economists pay almost no attention to biological or physical constraints (Hall et al. 2000), and that economists are hooked on growth and therefore enemies of conservation and the environment (Czech 2000). Others have argued that working with economists to value nature is either distracting or dangerous, because it plays into the hands of business interests and takes away from the strong moral arguments for conservation (e.g., Ehrenfeld 1988; McCauley 2006). But most conservationists and natural scientists realize that engaging with economists to demonstrate the value of nature, and how ecosystem services contribute to human well-being, can provide powerful arguments for the conservation of nature (Daily 1997; Millennium Ecosystem Assessment 2005). In fact, continuing to put no value on ecosystem services will likely continue the pattern of overexploitation and environmental degradation that we have witnessed in the 20th century.

Many economists, including several who are high-profile, such as Nobel laureate Ken Arrow (Arrow et al. 1995, 2004) and Sir Partha Dasgupta (Dasgupta 2001), have applied economics to environmental issues and have developed economic tools and methods applicable to addressing the value of nature. Economics is an essential component of efforts to measure the provision and value of ecosystem services, and to understanding how mechanisms to mainstream ecosystem services are likely to work in practice. A fully developed economics should routinely incorporate the value of ecosystem services into its analyses. It is bad economics as well as bad policy not to account for the value of nature.

HISTORICAL AND METHODOLOGICAL FOUNDATIONS OF ECOSYSTEM SERVICES

Though the term ecosystem services is fairly new — among the first uses appears to be Ehrlich and Mooney (1983) — the idea is quite old. Throughout most of human history, it was probably so obvious that nature contributed to human well-being as to be totally unremarkable. Both hunter-gatherer societies and agricultural societies are clearly tied to the functioning of ecological systems, even if these systems are heavily modified in agro-ecosystems. It is only with increasing wealth, supporting specialization and the rise of urban populations, that the most obvious ties to nature have been cut. And though we might like to think that overpopulation, pollution, and the overuse of resources are modern problems, concerns about them go back at least to the Greeks and Romans, if not before. For example, the following quote is from Roman times:

> "…farms obliterate empty places, ploughed fields vanquish forests, sandy places are planted with crops, stones are fixed, swamps drained…. The resources are scarcely adequate to us; and our needs straiten us and complaints are everywhere while already nature does not sustain us." — Quintus Septimus Florence Tertillianus 200 AD (quoted in Johnson 2000).

Concerns about human demands exceeding what nature could supply are present in some the first contributions by economists. Thomas Malthus famously wrote that population, when unchecked, grows geometrically, while food supply grows arithmetically, so that eventually demand for resources outstrips their supply. According to Malthus, starvation and disease would ultimately check human population. For such thinking, economics gained distinction as "the dismal science." Another early economist, David Ricardo, derived the theory of rent and diminishing returns by observing that the best agricultural land would be utilized first and that further expansions of agriculture would be forced to use less productive land.

Much of the theory underlying modern economic thinking about the environment was developed in the 19th and early 20th centuries. Optimal use of natural resources has been a recurring theme in economics. Martin Faustmann solved the problem of the optimal rotation age for timber harvests in 1849. Harold Hotelling described the optimal use of exhaustible resources such as oil or mineral deposits (1931). Perhaps the most important advance for understanding the problem of providing incentives to preserve ecosystem services came from British economist A.C. Pigou (1920) who developed the notion of externalities, where the actions of one individual or firm directly impact the welfare of other individuals or firms.

Negative externalities involve actions by one party that directly harm other parties, like emitting pollution, but for which the first party pays no cost. Positive externalities involve cases where the actions of one party directly benefit other parties, but the first party receives no payment. Unless some type of corrective policy is undertaken to "internalize" the externality, too many negative externalities and too few positive externalities will occur. Pigou recommended that actions generating negative externalities be taxed (now called Pigouvian taxes) and actions generating positive externalities be subsidized. Payments for ecosystem services can be thought of as one form of Pigouvian subsidy.

Currently there is a vast body of work by economists relevant for thinking about the value of ecosystem services. Much of this work lies in the fields of environmental economics, natural resource economics, and ecological economics. Environmental economics builds on the Pigou's insights to analyze problems caused by externalities and public goods. Public goods are "non-rival" (one person's enjoyment of the good does not diminish the ability of others to enjoy the good) and "non-excludable" (if the good is available for one it is available for all). Many ecosystem services are public goods — for example, water purification or climate regulation services. Public goods are typically under-provided because there is an incentive to free-ride: why pay to provide a public good when you can freely enjoy the good provided by others?

Environmental economists have also developed a range of policy approaches to internalize externalities and provide incentives for the provision of public goods, including payments for ecosystem services, taxes on pollution and other negative externality–generating activities, and cap-and-trade systems, which limit the overall level of a negative externality–generating activity but allow entities to trade permits that entitle them to engage in that activity. This topic is by now quite well developed, with many textbooks describing alternative policy mechanisms that could be applied to internalize externalities and provide public goods (e.g., Hanley et al. 1997; Tietenberg and Lewis 2009).

In addition, environmental economists have developed methods of nonmarket valuation. Most ecosystem services are not traded in markets and so have no market prices to act as a signal of value. Nonmarket valuation uses observed behavior, such as how much more people pay for houses near environmental amenities, where they travel for outdoor recreation, and responses to survey questions, to gauge the value that people place on environmental quality or other aspects of nature. Nonmarket valuation began to be applied to what we would now call ecosystem services in the 1960s and 1970s, in work centered at Resources for the Future (Krutilla 1967; Krutilla and Fisher 1975).

Natural resource economics and ecological economics address sets of issues related to human–nature interactions and sustainability. Natural resource economics analyzes the use of renewable and exhaustible resources, and has been applied to analyze other "resources," including aspects of nature (species, habitats, natural beauty), that are important for recreational and spiritual or cultural reasons. Reflecting this, some economists have begun to use the term "ecosystem services" rather than "natural resources" to discuss the broad set of ecosystem contributions to the generation of benefits for people. Natural resource economics is useful for those interested in ecosystem services because it has developed integrated bioeconomic models, particularly for fisheries, that help link ecological conditions with provision of services. Such models are also useful for analyzing the sustainable provision of services, and how overharvesting or degrading natural capital would lead to a lower supply of services in the future. These models laid the groundwork for the "ecological production functions" used in ecosystem service models.

The central theme of ecological economics revolves around sustainability and the long-term evolution of social-economic-ecological systems. Ecological economists have long called for the integration of economics with ecology and other natural sciences to better understand ecosystem services and the life-support system provided by the biosphere (Costanza 1991). Ecological economists have also called for a broader dialog between economists and other social scientists to better understand the many contributions of nature to human well-being. Ecological economists have produced many ecosystem service assessments, including relatively early work on the value of wetlands (e.g., Farber and Costanza 1987) and a widely cited but highly controversial effort that estimated the value of Earth's ecosystems at US $33 trillion per year (Costanza et al. 1997). Economist Mike Toman characterized the valuation of US $33 trillion for Earth's life-support system as "a serious underestimate of infinity" (Toman 1998).

Over the past few years there has been an explosion of interest in ecosystem services. The 2005 publication of the Millennium Ecosystem Assessment, which made ecosystem services its central focus, prompted a chain of efforts to address ecosystem services. Major recent studies include *Valuing Ecosystem Services: Towards Better Environmental Decision-making* (National Research Council 2005), *Valuing the Protection of Ecological Systems and Services* (U.S. Environmental Protection Agency Science Advisory Board 2009), *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature* (TEEB 2010), *Natural Capital: Theory and Practice of Mapping Ecosystem Services* (Kareiva et al. 2011), and the U.K. National Ecosystem Assessment (2011). All of these efforts blend economics with ecology and other disciplines to measure the provision and value of ecosystem services, and to think about policy levers to provide incentives for the sustainable provision of services.

Economics has many tools and analyses that can be applied to ecosystem services. Ecologist Joan Roughgarden provides a nice summary of how economists can add value in addressing issues such as the mainstreaming of ecosystem services:

> "It's tempting to suppose that the environment poses new problems that economists haven't begun to deal with. Yet this is less true than one might think. Economics in the first half of the 1900s considered limits to growth. Land area was taken as a constraint in early agricultural economics. Economists can deal conceptually with limits to growth perfectly well. Economists have long known how to fold into the price of an item all the costs of its production. A company that pollutes the environment can sell a product at an artificially low price because the public pays the cleanup. But the cost of the cleanup, called the social cost, should be fed back to the company with a special tax called a Pigovian tax. This topic is called "internalizing" an "externality" and has a long history of discussion. … Dealing with ecology does pose some new challenges for economics, but it is polite to know which these are. It is rude to assume that economists haven't considered the environment at all. In fact, they are often on our side, so let's keep them there." (Roughgarden 2001, 87)

MAINSTREAMING ECOSYSTEM SERVICES: "TIME TO DELIVER"

The building blocks for analyzing ecosystem services have been developed by prior work in economics and ecology. There is great interest on the part of many public and private entities in analysis of ecosystem services. Despite this, much of the work on ecosystem services to date has been largely conceptual. On-the-ground applications have been much rarer, though this is now beginning to change.

To some extent the largely conceptual stage was unavoidable in the early period of development. Ecosystem service analysis requires integration of ecology and economics (at a minimum), collection of new data, and a more holistic systems view to capture the joint provision of multiple services provided by ecosystems.

But now ecosystem service analysis has begun to mature, and has reached the stage where it can produce quantitative assessments of ecosystem service provision and value that are useful in policy and management contexts. It is high time to push forward on this front to make ecosystem service analysis practical and easy to implement, so that it becomes routine to include it (Daily et al. 2009). This section briefly explains a framework and set of tools useful for the analysis of ecosystem services. The next section provides example applications of the framework and tools to generate quantitative estimates of the provision and value of ecosystem services under policy and management alternatives.

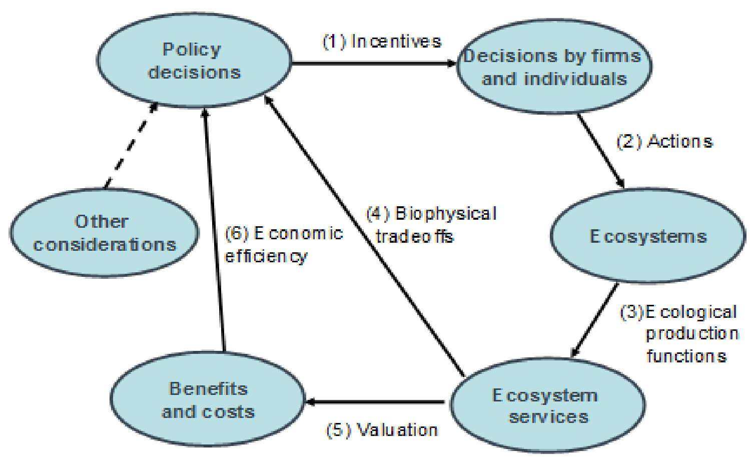

Figure 1: An integrated ecosystem services framework. *Source: Adapted from Polasky and Segerson (2009)*

As discussed in the introduction, there are three main tasks to address to successfully mainstream ecosystem services: 1) understand the *provision* of ecosystem services, 2) understand the *value* of services, and 3) provide *incentives* for their sustainable provision. Tackling these three tasks requires an integrated ecological–economic framework. Since most ecosystem services have elements of externalities or public goods, it is useful to begin by thinking about policies and incentives to internalize externalities or to create incentives for the provision of public goods (Link 1 in Figure 1). Policies provide the context for decision-making by individuals, businesses, and government agencies that make on-the-ground decisions that affect ecosystems (Link 2). Predicting behavioral responses to policy, such as the responses of businesses and individuals to shifts in taxes or subsidies, are well-studied in economics (Hanley et al. 1997).

Ecological and other natural science analyses often focus on understanding the environmental impacts of human actions. Translating human actions to impacts on ecosystems, and then from the condition of ecosystems — their structures, functions, and processes — into the provision of ecosystem services, is the key step in understanding the provision of ecosystem services (Link 3). This mapping from structure and function to services is called the ecological production function. It takes as input ecosystem conditions and predicts outputs of ecosystem services, much like a standard production function in economics maps from inputs to production of goods and services (National Research Council 2005). The output of an ecological production function is measured in physical units, e.g., tons of carbon sequestered, or amount of phosphorus exported to surface water. It is possible to provide information about the tradeoffs in provision of services under alternative scenarios directly to managers and policy-makers (Link 4).

Alternatively, methods of economic valuation can be applied to provide estimates of the contribution of ecosystem services to human well-being in a common currency, typically in monetary terms (Link 5). Reporting in a common unit makes it easy for managers and policy-makers to understand the tradeoffs in the net benefits of services provided under alternative scenarios (Link 6). The advantage of using economic valuation is that it weighs all ecosystem services in terms of their contribution to human well-being using the consistent framework of welfare economics.

There are, however, several disadvantages to trying to measure all ecosystem services in monetary terms. Some ecosystem services, such as spiritual and cultural values, cannot be easily expressed in monetary values. In addition, there are practical measurement and data issues that can make the translation from biophysical measures to value difficult. A good example is the difficulty of establishing robust estimates of the value to society of clean water, or the value of the continued existence of a species. Whether it is better to report results in biophysical or monetary terms really comes down to which approach is easier to communicate. Sometimes it is easier to communicate with decision-makers and the general public in monetary terms, but in other instances it is clearer and more direct to keep things in biophysical terms.

The goal of The Natural Capital Project, a partnership between Stanford University, the University of Minnesota, The Nature Conservancy, and World Wildlife Fund, is to mainstream ecosystem services. As part of this objective, The Natural Capital Project has developed a software package called InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs). InVEST was developed to analyze the provision and value of multiple ecosystem services under alternative scenarios of land use and land management. Doing so allows users to see how alternative land use or land management choices will affect the provision and value of multiple ecosystem services. Doing so can generate useful information for decision-makers in evaluating which alternatives are better for achieving management or policy objectives.

InVEST is integrated in the sense that it predicts the joint provision of multiple ecosystem services generated by a landscape, and can evaluate tradeoffs or synergies in the provision of services. InVEST uses input on land use along with environmental information (e.g., soil, topography, climate) to generate spatially explicit predictions of the supply of ecosystem services. This information is combined with economic data on the demand for ecosystem services to generate estimates of the value of ecosystem services. InVEST can report outputs in either biophysical terms or economic terms. The modeling approach uses general functional relationships along with site-specific data, and is both flexible and widely applicable. The following section describes several applications of InVEST that illustrate the types of ecosystem service analyses that can be done.

EXAMPLE APPLICATIONS OF INTEGRATED ANALYSIS OF ECOSYSTEM SERVICES

Where to Put Things: Spatial Land Management with Biological and Economic Objectives

Land-use decisions often affect multiple and competing objectives. For example, clearing land for agriculture will increase food production but can result in declines in carbon sequestration and water quality. There will inevitably be some tradeoff among different societal objectives, but sometimes careful thought about the spatial pattern of land use or the methods used to accomplish certain activities can lead to overall improvement in system performance. In "Where to Put Things?" Polasky et al. (2008) analyzed land-use decisions in the Willamette Basin in Oregon to find land-use plans that achieved high levels of a conservation objective (conserving terrestrial vertebrate species) and an economic objective (generating income for landowners). The analysis showed that it was possible to do better on both biological and economic objectives compared to the current situation.

The starting point in the analysis was to specify the spatial pattern of land-use activity in the Willamette Basin to use as input for both a biological model and an economic model. The biological model evaluates a land-use plan's ability to support viable populations for a set of 267 terrestrial vertebrate species that inhabit the Willamette Basin at present. How well each species does for a given land-use pattern depends on three species-specific traits: 1) habitat compatibility that includes geographic range, habitat type, and special features like whether there is access to water; 2) the amount of habitat required for a breeding pair; and 3) dispersal ability between suitable patches of habitat. For each species, the biological model predicts the probability of persistence of the species as a function of the pattern of habitat under the land-use plan. The overall biological score is the expected number of species expected to persist on the landscape.

The economic model predicts the present value of monetary returns generated by a land use. For each land parcel, the economic returns depend upon the land use in the parcel and characteristics of the parcel. For parcels in forestry or agriculture, the model predicts timber yield or crop yield as a function of the parcel's soil quality, climate, and topography. Combining yield estimates with timber and crop prices and production cost data then generates an estimate of economic returns. For housing development, the model predicts property value for housing based on location relative to urban areas and the county in which the parcel is located. The overall economic score for the landscape is the sum of the present value of returns over all of the parcels.

The biological and economic models were used to score how well different land-use patterns fared in the dual objectives of conserving terrestrial vertebrate species and generating income for landowners. Using algorithms that intelligently searched over possible land-use patterns, the authors generated an efficiency frontier (Figure 2) showing the maximum biological score for a given economic score (or the maximum economic score, given a biological score). Starting from a landscape that maximizes the value of residential development and agricultural and timber production (point A in Figure 2), it is possible to increase species conservation with very little decrease in economic returns (shifting to point B or C in Figure 2).

Increases in species conservation can be accomplished by conserving relatively rare habitats such as prairie and oak savanna in places that do not have high economic value. Trying to conserve all species, however, may entail high costs (shifting to points F–H in Figure 2). The efficiency frontier shows that careful thinking about the arrangement of activities across the landscape makes it possible to sustain high levels of biodiversity and economic returns. Compared to the current land-use pattern, both species conservation and the value of economic activity can be increased substantially (Figure 2).

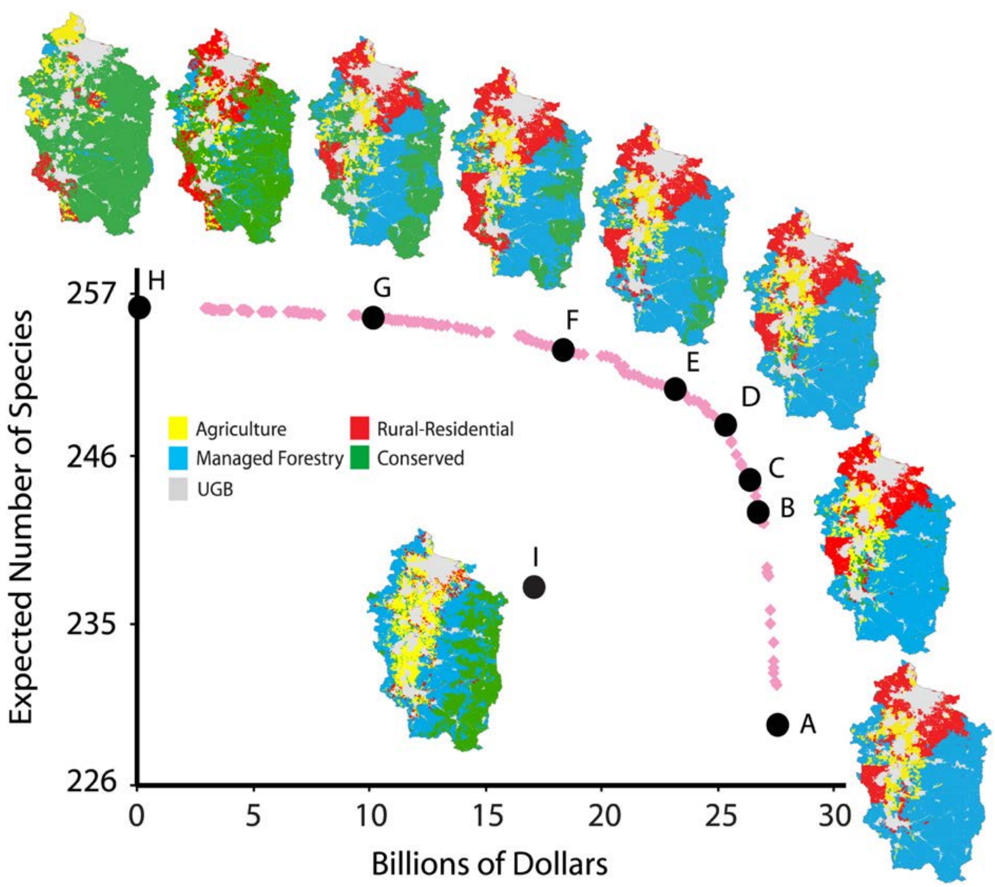

Figure 2: Land-use patterns associated with specific points along the efficiency frontier and the current landscape. *Each land-use pattern shown outside of the efficiency frontier corresponds to a lettered point on the frontier. The current land-use pattern is also shown (point I). Compared to the current landscape, points on the efficiency frontier have less agriculture and more rural-residential use. There is a shift from predominantly managed forest toward conservation land as the biological objective is emphasized relative to the economic objective. Source: Polasky et al. (2008)*

Modeling Multiple Ecosystem Services and Tradeoffs at Landscape Scales

"Where to Put Things" illustrates the basic approach of evaluating alternative land-use plans in terms of more than one objective, illustrating tradeoffs between objectives along the efficiency frontier and the potential for win-win outcomes relative to the current situation. "Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production, and Tradeoffs at Landscape Scales" uses the same basic data for the Willamette Basin but expands the set of objectives to include a bundle of ecosystem services (Nelson et al. 2009).

In this analysis, the InVEST model was used to track water quality (phosphorus loadings), flood control, soil conservation (sediment retention), climate stabilization (carbon sequestration), species conservation, and market returns to landowners (agricultural crop production, timber harvest, and housing values). These outcomes are a function of land characteristics and land-use and land-cover patterns using data at 30x30 m resolution. The water quality, flood control, and soil conservation models all use models that track water flows, accounting for input from precipitation minus evapotranspiration and routing via a digital elevation map. Phosphorus loadings are a function of inputs from fertilizers as well as retention, while sediment loading is calculated using the Universal Soil Loss Equation (Wischmeier and Smith 1978). The model tracks the amount of carbon stored in above- and below-ground biomass, soil, and harvested wood products. Species conservation is modeled using species-area curve relationships. Economic returns use the methods from Polasky et al. (2008) discussed above.

Rather than consider all possible land-use plans to find the efficiency frontier, this analysis used the results from the Pacific Northwest Ecosystem Research Consortium, a multi-stakeholder alliance of government agencies, non-governmental organizations, and universities convened to imagine different future scenarios for the Willamette Basin (Hulse et al. 2002). The Consortium generated three scenarios of land-use and land-cover change: 1) plan trend — a "business-as-usual" trajectory that continues past trends, 2) development — a trajectory with increased population growth and more extensive housing development, and 3) conservation — a trajectory that emphasizes preserving and restoring natural habitat. For each scenario, the Consortium produced a map of land use and land cover for the entire Willamette Basin for each decade from 1990 to 2050 (Figure 3). Each of these maps was used as input for InVEST. The outcome of the analysis was a score for each objective for each scenario for each decade (Figure 4).

The conservation scenario scored higher than either of the other two scenarios for all objectives except the market value of returns to landowners. Since landowners do not currently receive payments for providing ecosystem services, it is likely that they would choose outcomes that more closely follow the plan trend or development scenario than the conservation scenario. If, however, landowners received payments for ecosystem services so that they internalized at least some of the value of the services the land provides, the situation would be quite different. Including payments for just one ecosystem service, carbon sequestration, was enough to make the monetary returns for the conservation scenario exceed the monetary returns for either the plan trend or development scenario. This type of analysis points to the potential for policies that internalize the currently external values of ecosystem services to create vastly different decisions, with consequent changes in provision and value of ecosystem services, biodiversity conservation, and returns to landowners.

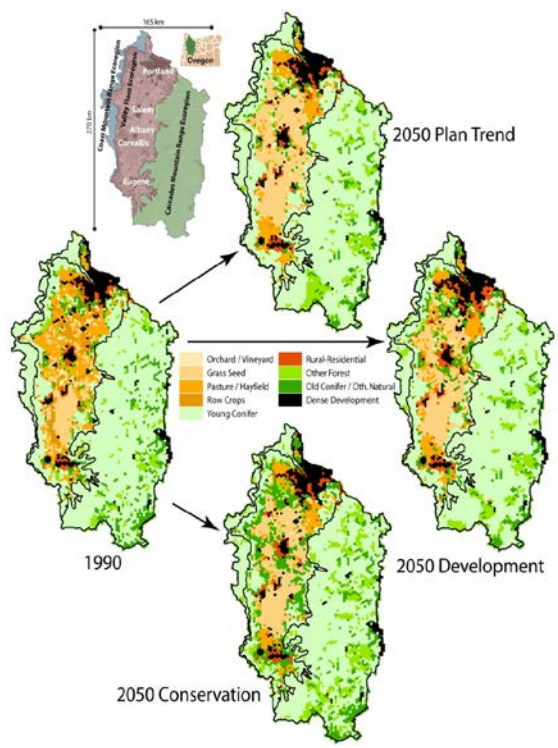

Figure 3: Maps of the Willamette Basin with the land use/land cover patterns for 1990 and three scenarios for 2050. *Source: Nelson et al. (2009)*

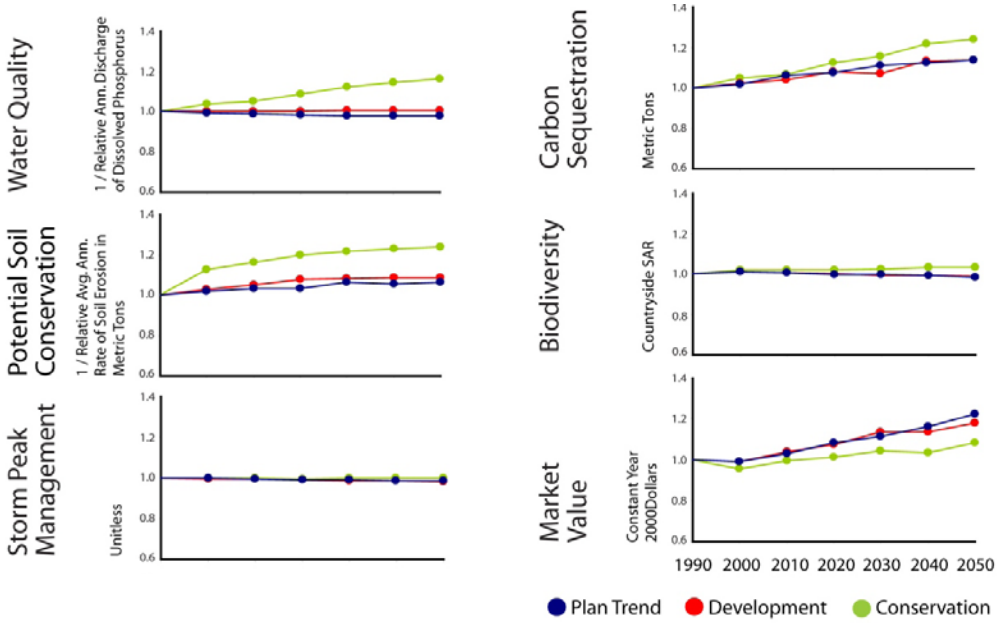

Figure 4: Comparison of landscape ecosystem services scores, biodiversity conservation status, and market values of commodity production for the three land-use change scenarios from 1990 to 2050. *Source: Nelson et al. (2009)*

Ecosystem Service Analysis Kamehameha Schools, O'ahu, Hawai'i

The Natural Capital Project worked closely with Kamehameha Schools, an educational trust and the largest private landowner in the State of Hawai'i, to evaluate the consequences of alternative land-use scenarios for a large block of land it owned on the north shore of the island of O'ahu (Figure 5). Representatives of Kamehameha Schools, working with researchers from the Natural Capital Project, developed three spatially explicit land-use scenarios: 1) sugarcane ethanol — returning former plantation lands to sugarcane cultivation to produce ethanol biofuel, 2) diversified agriculture and forestry — using irrigated fields near the coast for diversified agriculture and planting native trees on higher-elevation fields, and 3) residential subdivision — selling coastal and former plantation lands for a residential housing development. Representatives of Kamehameha Schools also determined the endpoints they were interested in evaluating: water quality (nitrogen discharge), carbon storage, and income generation. InVEST was then used to evaluate the impacts of each land-use scenario on each ecosystem service of interest.

All three scenarios generated higher income than the base case land use, which actually lost money, but only the diversified agriculture and forestry scenario also increased carbon storage (Figure 6). Representatives of Kamehameha Schools used the results of the InVEST analysis along with other considerations, such as how each scenario would affect the number of jobs, the rural character of the north shore, the sense of place, the maintenance of sacred burial grounds, and other historical factors, to help them determine which land-use plan was most desirable.

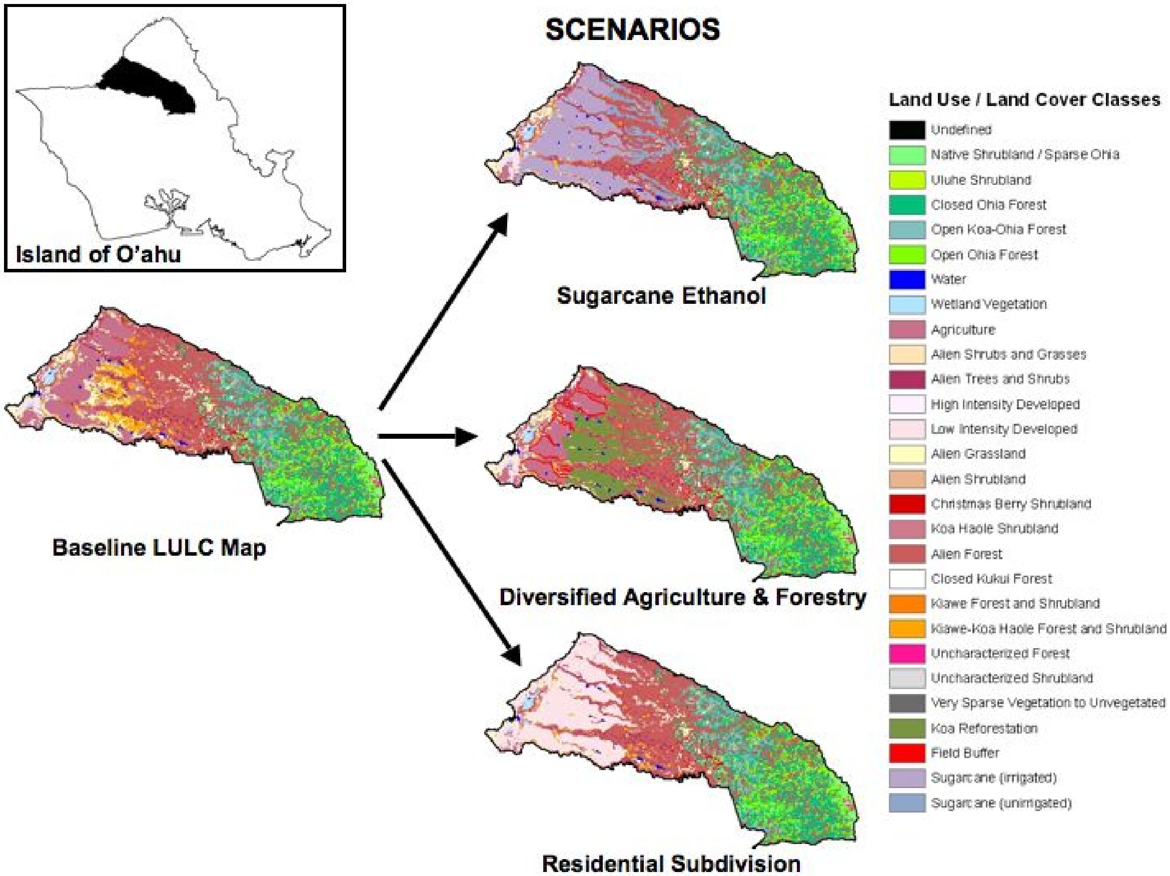

Figure 5: Land-use/land-cover maps for the InVEST analysis on O'ahu's north shore. *The area shown here includes all of Kamehameha Schools' landholdings, as well as small adjacent parcels that make a continuous region. The baseline map is from the Hawai'i Gap Analysis Program's land-cover layer for O'ahu (2006). Source: Polasky et al. (2011a)*

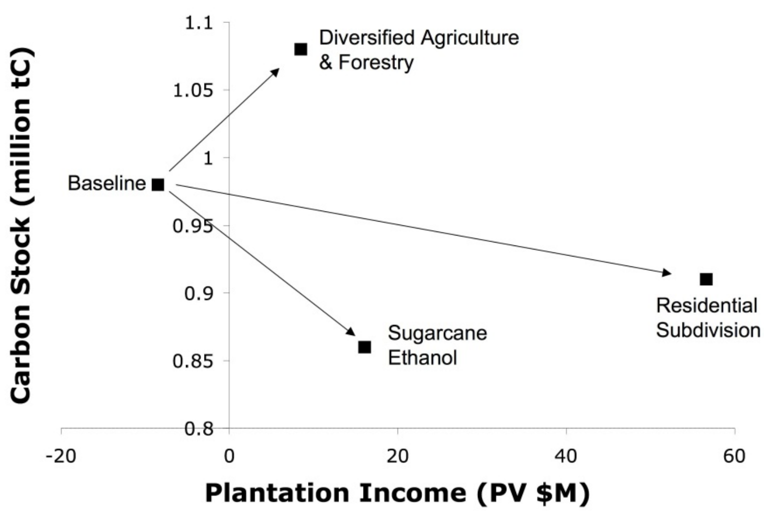

Figure 6: Projections of carbon stock and income from the plantation lands for the north shore region of O'ahu for the baseline land-use/land-cover map and the three planning scenarios (sugarcane ethanol, diversified agriculture and forestry, residential subdivision). *Source: Polasky et al. (2011a)*

Efficiency of Incentives to Jointly Increase Carbon Sequestration and Species Conservation on a Landscape

The prior three applications all started their analysis with land-use plans, either generated by stakeholders or, in the case of "Where to Put Things," as part of the analysis to generate an efficiency frontier. In most landscapes (Kamehameha Schools being an exception), there are multiple landowners, each of whom makes a decision on how to use his or her parcel of land. Laws and regulations, such as zoning or environmental laws, can prohibit certain uses or influence decisions, but individual landowners retain great discretion in determining land use. In cases where multiple landowners have decision-making power, it is important to analyze the link between policy framework and landowner decision-making that determines actual land use. Nelson et al. (2008) provide an example of how to analyze the impact of incentives that pay landowners to enroll in a conservation program.

The first step in this analysis was to build a statistical model of land-use change using data on past land-use choices and parcel-level characteristics that predict the economic returns landowners would receive had they chosen different land uses. This model estimates how much more likely a landowner is to choose a particular land use as the returns for that land use increase. The statistical model is then used to simulate each landowner's willingness to accept a payment to enroll in the conservation program. If the conservation payment offered to a landowner exceeds the willingness-to-accept, the landowner enrolls in the conservation program; otherwise, he or she does not. The statistical model and conservation policy simulation determined the land-use map for a given conservation policy. The resulting land-use map was then evaluated in terms of species conservation, carbon sequestration, and economic returns, similar to the evaluations in the studies discussed above.

The outcomes under various policies were compared with each other and with the efficient outcomes (Figure 7), using methods similar to those in "Where to Put Things." The policy scenarios considered varied eligibility criterion for who could enroll, as well as the total budget available for conservation. The various policy scenarios included were:

- all landowners — everyone was eligible to enroll
- native habitat — eligibility was restricted to land in certain rare habitat types
- carbon storage — eligibility was restricted to land that could be converted to forest
- riparian — eligibility was restricted to land along riparian corridors
- species of concern — eligibility was restricted to land shown by prior analyses to be important habitat for species of concern

All of the policy scenarios for each annual budget level (US $1, $5, and $10 million) produced changes in species conservation and carbon scores relative to the baseline of no conservation program that were well inside the efficiency frontier showing the maximum potential gain. The inefficiency of the conservation programs occurred because the policy induced the wrong set of landowners to enroll in the program, resulting in a land-use pattern that generated inferior results in terms of species conservation and carbon storage. The analysis also showed that it was possible to target policies to obtain certain ecosystem services (e.g., carbon storage), but that such targeting did not necessarily also obtain good outcomes for other objectives (e.g., species conservation).

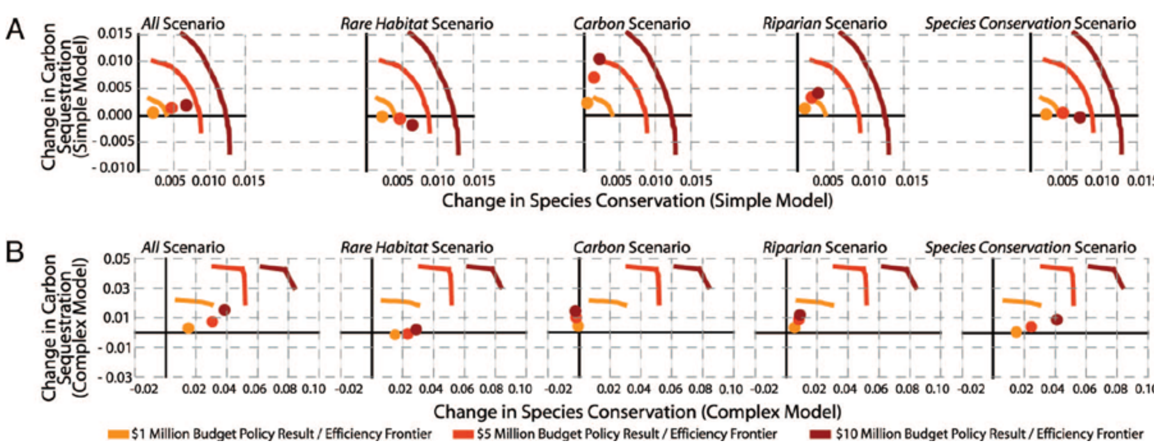

Figure 7: Comparison of increase in species conservation and carbon sequestration relative to the base case with budgets of US $1, $5, and $10 million dollars for different policy scenarios. *Each circle represents an outcome under a policy scenario for a given size budget. The lines indicate estimates of the efficiency frontier. (A) Uses simple species conservation and carbon sequestration models; (B) uses more advanced models. Source: Nelson et al. (2008)*

THE PATH FORWARD

The ability to analyze the provision and value of a bundle of ecosystem services at a local or regional scale is advancing rapidly. Spatially explicit data and models have been developed to help decision-makers assess the impact of various policy alternatives on ecosystems and ecosystem services, and thus link their decisions to consequences for human well-being. Tools such as InVEST can help to show the impacts of alternative decisions on the joint provision of multiple ecosystem services (ecological production functions), show the value of ecosystem services in terms of their contribution to human well-being, and analyze the impacts of policy mechanisms intended to internalize externalities and provide public goods.

There is an emerging information base on which to proceed with "mainstreaming ecosystem services," so that the value of such services is factored into the everyday decisions of individuals, businesses, and government agencies. While there are still improvements to be made, existing data, models, and understanding can yield significant improvements in societal decision-making and management compared to current performance. For example, the Willamette Basin studies have shown that analyses that include explicit spatial analysis and incorporate both ecological and social-economic factors can improve outcomes in terms of economic and conservation objectives. Studies based in other regions, including Hawai'i (discussed above), Minnesota (Polasky et al. 2011b), and elsewhere, have come to similar conclusions. Application of InVEST or similar models is ongoing in Colombia, China, South Africa, Tanzania, and elsewhere. Perhaps the silver lining of starting from poor baseline performance is that it is easy to improve.

At this point there are no major impediments standing in the way of mainstreaming ecosystem services. There are, however, numerous scientific, economic, and institutional details that are important to get right and will require careful attention from scientists, economists, and practitioners. There is great interest in mainstreaming ecosystem services, and major efforts are underway in a number of countries to tackle these issues (e.g., TEEB 2010, Kareiva et al. 2011, The U.K. National Ecosystem Assessment 2011). Bridging this interest and desire to reality will require careful attention to questions such as whether contracts are being adequately monitored and enforced, and whether payments for ecosystem services are really generating additional provisions of services and ensuring the maintenance of natural capital that is required for continued future supply of services.

Mainstreaming ecosystem services should be viewed as a long-term process rather than a quick-fix solution. We will learn from experience, and should use what we learn to improve our collective ability to sustain the provision and value of ecosystem services. Putting what we know into practice will require further advances and refinements of the science, but perhaps more importantly, it will require a concerted effort to reform policies and institutions. Perhaps most important of all is a shift in the collective mindset, from taking nature for granted to recognizing the importance of investing in natural capital and ecosystem services. Doing so might result in a true "green revolution," with increases in ecosystem services similar to 20th century accomplishments in the provision and value of marketed commodities.

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