Ecosystem services in decision making: time to deliver

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Over the past decade, efforts to value and protect ecosystem services have been promoted by many as the last, best hope for making conservation mainstream – attractive and commonplace worldwide. In theory, if we can help individuals and institutions to recognize the value of nature, then this should greatly increase investments in conservation, while at the same time fostering human well-being. In practice, however, we have not yet developed the scientific basis, nor the policy and finance mechanisms, for incorporating natural capital into resource- and land-use decisions on a large scale. Here, we propose a conceptual framework and sketch out a strategic plan for delivering on the promise of ecosystem services, drawing on emerging examples from Hawai'i. We describe key advances in the science and practice of accounting for natural capital in the decisions of individuals, communities, corporations, and governments.

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The Millennium Ecosystem Assessment (MA) advanced a powerful vision for the future (MA 2005), and now it is time to deliver. The vision of the MA – and of the prescient ecologists and economists whose work formed its foundation – is a world in which people and institutions appreciate natural systems as vital assets, recognize the central roles these assets play in supporting human well-being, and routinely incorporate their material and intangible values into decision making. This vision is now beginning to take hold, fueled by innovations from around the world – from pioneering local leaders to government bureaucracies, and from traditional cultures to major corporations (eg a new experimental wing of Goldman Sachs; Daily and Ellison 2002; Bhagwat and Rutte 2006; Kareiva and Marvier 2007; Ostrom *et al.* 2007; Goldman *et al.* 2008). China, for instance, is investing over 700 billion yuan (about US$102.6 billion) in ecosystem service payments, in the current decade (Liu *et al.* 2008).

In a nutshell:

- Valuing nature is central to mainstreaming conservation, but is not an end in itself
- Success hinges on a better understanding of ecosystem production functions and on integrating research (and experimentation) into the development of new policies and institutions
- The Natural Capital Project is designing practical tools for this purpose, including InVEST, a system for quantifying ecosystem services produced under different scenarios
- The use of these tools in contrasting settings is opening up important conservation opportunities

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The goal of the Natural Capital Project – a partnership between Stanford University, The Nature Conservancy, and World Wildlife Fund (www.naturalcapitalproject.org) – is to help integrate ecosystem services into everyday decision making around the world. This requires turning the valuation of ecosystem services into effective policy and finance mechanisms – a problem that, as yet, no one has solved on a large scale. A key challenge remains: relative to other forms of capital, assets embodied in ecosystems are often poorly understood, rarely monitored, and are undergoing rapid degradation (Heal 2000a; MA 2005; Mäler *et al.* 2008). The importance of ecosystem services is often recognized only after they have been lost, as was the case following Hurricane Katrina (Chambers *et al.* 2007). Natural capital, and the ecosystem services that flow from it, are usually undervalued – by governments, businesses, and the public – if indeed they are considered at all (Daily *et al.* 2000; Balmford *et al.* 2002; NRC 2005).

Two fundamental changes need to occur in order to replicate, scale up, and sustain the pioneering efforts that are currently underway, to give ecosystem services weight in decision making. First, the science of ecosystem services needs to advance rapidly. In promising a return (of services) on investments in nature, the scientific community needs to deliver the knowledge and tools necessary to forecast and quantify this return. To help address this challenge, the Natural Capital Project has developed InVEST (a system for Integrated Valuation of Ecosystem

Wave attenuation

Panel 1. A tool for Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

The Natural Capital Project (www.naturalcapitalproject.org) is a partnership between Stanford University, The Nature Conservancy, and World Wildlife Fund, working together with many other institutions. The Project's mission is to align economic forces with conservation, by developing tools that make incorporating natural capital into decisions easy, by demonstrating the power of these tools in important, contrasting places, and by engaging leaders globally.

The Project is developing a software system for quantifying ecosystem service values across land- and seascapes, called InVEST. This tool informs managers and policy makers about the impacts of alternative resource management choices on the economy, human well-being, and the environment, in an integrated way.

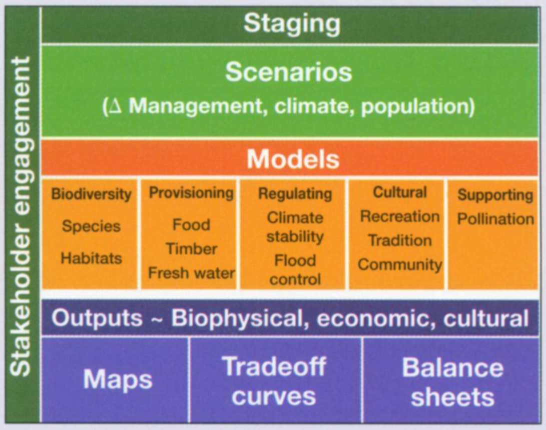

Figure 1. *An iterative process for integrating ecosystem services into decisions. The process begins with stakeholder engagement around impending decisions, with a focus on realistic, alternative scenarios for the future. The modeling is shaped by stakeholders, and typically focuses on the (subset of possible) services and scenarios deemed most important. Outputs are displayed in accordance with stakeholder preferences, in the form of maps, tradeoff curves, and/or balance sheets. These can be expressed in biophysical (eg tons of carbon), economic (eg dollars), or cultural (eg visitor-days) terms (see Nelson* et al. *page 4 in this issue).*

Examples of urgent questions that InVEST can help answer include:

- How does a proposed forestry management plan affect timber yields, biodiversity, water quality, and recreation?
- Which parts of a watershed provide the greatest carbon sequestration, biodiversity, and tourism values? Where would reforestation achieve the greatest downstream water quality benefits?
- How would agricultural expansion affect a downstream city's drinking water supply? How will climate change and population growth impact these effects?

InVEST is designed for use as part of an active decision-making process (Figure 1). The first phase of the approach involves working with decision makers and other stakeholders to identify critical management decisions and to develop scenarios to project how the provision of services might change in response to those decisions, as well as to changing climate, population, and so forth. Based on these scenarios, a set of models quantifies and maps ecosystem services. The outputs of these models provide decision makers with information about costs, benefits, trade-offs, and synergies of alternative investments in ecosystem service provision. A detailed case study of the Willamette Valley, OR, is given in Nelson *et al.* (page 4 in this issue).

InVEST uses a flexible, modular, and "tiered" modeling approach to ensure that the models are useful worldwide, including in places with sparse data. Tier 1 models have modest data requirements to estimate the relative production of ecosystem services across a landscape, and can inform prioritization exercises and general management planning. Tier 2 models compute absolute service levels and corresponding economic values, to support more information-rich planning processes, such as payment for ecosystem services schemes. Finally, Tier 3 integrates more complex models, developed by other research teams (eg hydrology models), that include time steps and feedbacks in the overall ecosystem service analysis.

Services and Tradeoffs; see Panel 1 and Nelson *et al.* page 4 in this issue). Second, ecosystem services must be explicitly and systematically integrated into decision making by individuals, corporations, and governments (Levin 1999; Heal 2000a; NRC 2005). Without these advances, the value of nature will remain little more than an interesting idea, represented in scattered, local, and idiosyncratic efforts.

Here, we propose a framework that considers a number of services simultaneously. It does so over scales appropriate to local-, regional-, and national-level resource-management decisions; it connects the science of quantifying services with valuation and policy work to devise payment schemes and management actions; and it helps in the replication and scaling up of successful models, thereby creating confidence and providing inspiration for future initiatives. We also highlight the advances in research and implementation that will be necessary to take this approach forward (see also Carpenter *et al.* in review).

We draw upon experiences from Hawai'i to illustrate each step in our framework. Hawai'i is a microcosm of the important forces at play worldwide. As a result of a rapidly growing population and intensifying development pressure, the future of Hawaii's forests, croplands, and ranchlands is in question, as are other aspects of its economy and culture. There is, however, renewed appreciation for traditional Hawaiian land management, in which watersheds are recognized for all the goods and services they produce, from the mountains to the sea. Today, diverse leaders across the public, private, and non-profit sectors are mobilizing to incorporate the values of natural capital into land-use and policy decisions. By highlighting some of the active works-in-progress there, we illustrate the promise and challenge of creating the broader institutional and cultural changes that are needed worldwide.

What's new?

An appreciation of ecosystems as valuable capital assets traces back to Plato, or even earlier (Mooney and Ehrlich

1997), and the current research agenda on ecosystem services continues a long-standing field of inquiry. For example, renewable resources have been an active area of study since at least the 1950s, when Gordon (1954) first characterized the problems of open-access fisheries. In the 1960s and 1970s, economists set out to measure "the value of services that natural areas provide" (Krutilla and Fisher 1975); they focused on agricultural production (Beattie and Taylor 1985), renewable resources (Krutilla 1967; Clark 1990), non-renewable resources (Dasgupta and Heal 1979), and environmental amenities (Freeman 1993). More recent advances have been seen in a broad range of areas, including ecology and global change, economics, institutions and policy, and especially their integration (eg Dasgupta 2001; MA 2005; NRC 2005; Ruhl *et al.* 2007).

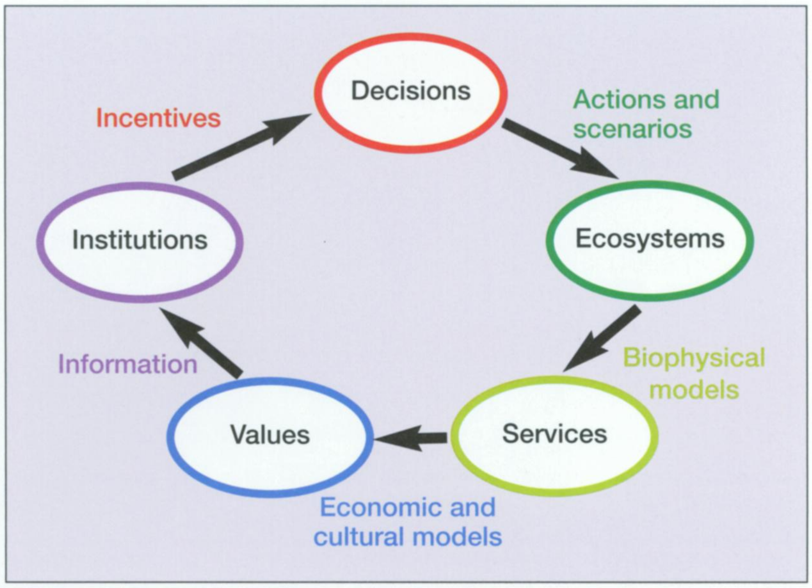

Figure 2. *A framework showing how ecosystem services can be integrated into decision making. One could link any two ovals, in any direction; we present the simplest version here.*

Yet, ascribing values to ecosystem goods and services is not an end in itself, but rather one small step in the much larger and dynamic arena of political decision making (Daily *et al.* 2000). Our challenge today is to build on this foundation and integrate ecosystem services into everyday decisions. This requires a new focus on services beyond provisioning services; an understanding of the interlinked production of services; a grasp of the decision-making processes of individual stakeholders; integration of research into institutional design and policy implementation; and the introduction of experimentally based policy interventions designed for performance evaluation and improvement over time. There are a lot of devils in the details of this work.

■ Making ecosystem services operational

Figure 2 presents a framework for the role that ecosystem services can play in decision making. Although the framework is shown as a continuous loop, we start with the "decisions" oval to emphasize our focus. The main aim in understanding and valuing natural capital and ecosystem services is to make better decisions, resulting in better actions relating to the use of land, water, and other elements of natural capital.

The biophysical sciences are central to elucidating the link between actions and ecosystems, and that between ecosystems and services (biophysical models of "ecological production functions"). The social sciences are central to measuring the value of services to people ("economic and cultural models"). Because this value is multidimensional, it makes sense to characterize it as fully and systematically as possible, in ways that will be meaningful to many different audiences.

Finally, valuing ecosystem services provides useful information that can help design the institutions that will guide resource management and policy. Having the right institutions can create incentives, so that the decisions made by individuals, communities, corporations, and governments promote widely shared values. The links between the "values", "institutions", and "decisions" ovals are much more representative of the art and politics of social change than of science, although scientists can inform these debates if they concentrate on specific decisions and are attuned to the social and political contexts.

In the following sections, we move around the schematic of Figure 2 to explore how a focus on decisions can motivate the integration of ecosystem services into management and policy decisions, and inspire a research agenda to support this change.

■ Decisions → ecosystems

In Figure 2, the science needed to inform the link that connects decisions and ecosystems is a huge challenge in itself. We do not detail this here, since readers of *Frontiers* have built a vast literature connecting past human decisions and activities to their impacts on ecosystems and landscapes, and the species that inhabit them. Looking forward is also essential, however, and scenarios that describe plausible futures, combining alternative decisions with projected changes in demographics, climate, and other factors, have become both more common and more sophisticated (eg Peterson *et al.* 2003).

In Hawai'i, there has been extensive work on how land-management decisions affect ecosystems. For example, we have learned that the decision to introduce exotic pasture grasses has dramatically changed fire frequency and intensity across landscapes (D'Antonio and Vitousek 1992), and that the introduction of cattle, non-native game, and feral ungulates has further transformed

Figure 3. *A micrometeorological station for quantifying the roles of pasture and nearby forest in recharging groundwater supplies for local water users. Palani Ranch, Kona, Hawai'i.*

native ecosystems (Cuddihy and Stone 1990; Maguire *et al.* 1997). Conservation and restoration are a key focus today (Manning *et al.* 2006; Goldstein *et al.* 2008), as are new remote sensing systems for characterizing biodiversity and ecosystem structure and function at large scales (Asner *et al.* 2008).

The scientific foundation for informing decisions that affect ecosystems could be greatly enhanced by: (1) collaborating with stakeholders to define important scenarios of alternative future uses of land, water, and other natural resources (eg MA 2005, "Scenarios" volume); (2) improving methods for assessing the current condition, and predicting the future condition, of ecosystems (eg Heinz Center 2008); and (3) establishing state-of-the-art programs for long-term monitoring of biodiversity and other ecosystem attributes (eg Scholes *et al.* 2008).

■ Ecosystems → services

Ecological production functions translate the structure and function of ecosystems into the provision of important services (Heal 2000b; NRC 2005). Production functions have a long tradition in agriculture and manufacturing, where the amount produced of a given commodity (eg grain) is related to the quantities and quality of the various inputs (eg seeds, labor, chemicals, irrigation). Estimating these functions for ecosystem services often requires a focus on different questions than are traditional in ecology (Boyd and Banzhaf 2005). The MA synthesizes our existing knowledge (MA 2005), often at the global scale. There are also many fine-scale studies of ecosystem production functions, typically focusing on a single service (Kremen *et al.* 2002; Ricketts *et al.* 2004; Jackson *et al.* 2005; Hougner *et al.* 2006). Much more work is needed now, on integrating multiple services at regional and global scales (eg Nelson *et al.* page 4 in this issue; Chan *et al.* 2006; Naidoo and Ricketts 2006; Brauman *et al.* 2007).

In Hawai'i, as in most places, ecological production functions are largely undescribed. However, efforts are now underway to quantify production functions for a range of policy-relevant ecosystem services, in fine detail, across heterogeneous landscapes, and to elucidate the tradeoffs and synergies among services under alternative management options. Historically, the production of goods through ranching and forestry has been the best described of terrestrial services. Today, there is growing interest in managing forests of the endemic hardwood *Acacia koa* as a "win–win" land use, providing high-value timber as well as other ecosystem services (eg Pejchar *et al.* 2005; Goldstein *et al.* 2006; Litton *et al.* 2006; Scowcroft *et al.* 2007). Multiple reforestation projects – some spanning thousands of acres – have recently been launched, allowing further research on production functions for services such as carbon sequestration (eg Litton *et al.* 2006; Scowcroft *et al.* 2007) and groundwater recharge (K Brauman unpublished data; Figure 3).

The translation of ecosystem condition and function into ecosystem services requires interdisciplinary and user-oriented research, including: (1) collaborating with stakeholders to define services that people care about (eg Carpenter *et al.* 2006; Cowling *et al.* 2008); (2) developing transparent, flexible models of ecological production functions at scales relevant to decision making (Panel 1); and (3) testing and refining these models in systems around the world, to derive general insights (eg Ricketts *et al.* 2008).

■ Services → values

The promise of ecosystem service analyses is that they will make explicit the costs and benefits of alternative actions to people (NRC 2005). Economic valuation methods take changes in the supply of ecosystem services as input and translate these into changes in human welfare, in monetary terms (Repetto *et al.* 1987; Daily *et al.* 2000; Arrow *et al.* 2004). Cost–benefit analyses and other methodologies express apples-to-oranges comparisons in monetary currencies, making alternative options easier to compare. In certain cases, however, service values may

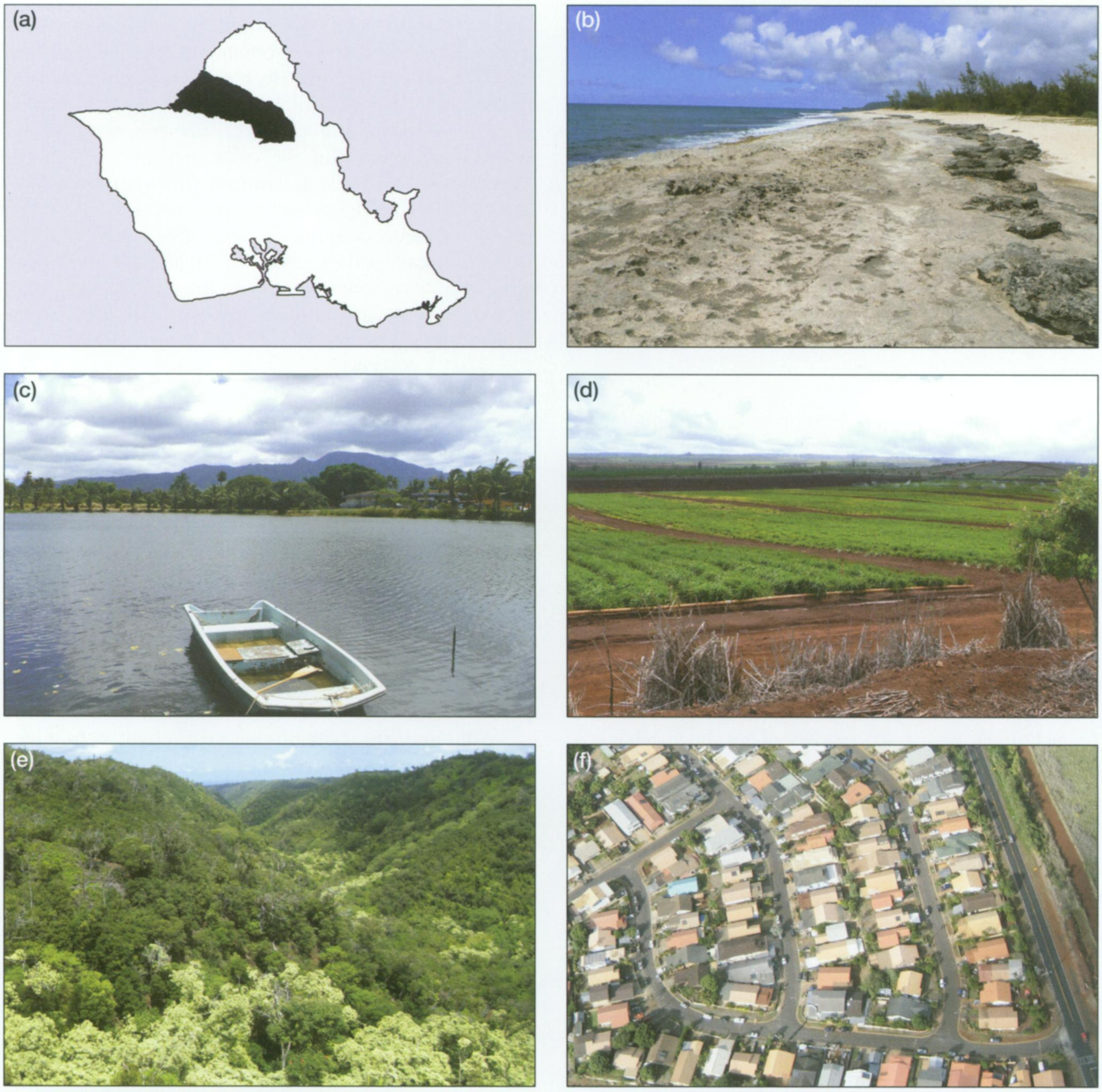

Figure 4. *Using InVEST to help assess management options for (a) a land-holding of Kamehameha Schools (Kawailoa, O'ahu). This 26 000-acre parcel has (b) prime undeveloped coastline, (c) an ancient fishpond and other important cultural assets, (d) a highly productive agricultural belt with water resources, (e) biodiverse native upland forest, and (f) commercial and residential areas.*

best be conveyed in other ways (eg the cultural importance of natural places), because assigning credible monetary values is difficult or less meaningful.

In Hawai'i, both monetary and non-monetary metrics are important to decision makers. Kaiser and Roumasset (2002), for example, examined the monetary contribution of a forested watershed in enhancing groundwater recharge, and present a clear metric for weighing the costs and benefits of alternative approaches to watershed management. Kamehameha Schools, a major educational trust, is developing a multi-dimensional perspective, including economic, environmental, educational, and community elements, with an underlying cultural foundation. To evaluate land-management decisions, the trust considers the number of student activity-days per year, the number of areas available for gathering traditional plants (eg for lei making), and access to sites of spiritual importance, in addition to monetary estimates of value. The Natural Capital Project is working with Kamehameha Schools to apply InVEST to a key tract of land on O'ahu, to determine the impacts of alternative land uses on biophysical and cultural ecosystem services (Figure 4).

More research is needed to build the credibility of ecosystem service approaches, by: (1) combining direct biophysical measurements with economic valuation to estimate the monetary value of ecosystem services at the scale of decisions; (2) developing non-monetary methods for valuing human health and security, and cultural services, and incorporating these in easy-to-use, easy-to-understand, but rigorous tools for valuing ecosystem services; and (3) developing methods for identifying who benefits from ecosystem services, and where and when those who benefit live relative to the lands and waters in question. Without this information, we risk creating or exacerbating existing social inequities with policy incentives (eg Pagiola *et al.* 2005).

■ Values → institutions

To bring about a change in decision making (Figure 1), it is important to embed the values of natural capital in institutions. Without institutional change, communities may well continue to carry on with behaviors that are widely known to be harmful to society over the long term (eg overfishing, high use of fossil fuels). Bringing about beneficial institutional change is difficult and requires careful attention to the distribution of the costs and benefits of change (in terms of power, status, wealth, etc). Many such changes are possible, from creating monetary incentives to altering cultural norms (eg in attitudes to smoking). There is no magic recipe for initiating change, and it makes sense to experiment with a wide variety of possible mechanisms (eg Olsson *et al.* 2008). In some cases, the first step toward institutional change has been in the form of a demonstration "pilot project" (eg Pagiola *et al.* 2002; Salzman 2005). In this process, it is important that researchers are linked with key leaders as well as public and private organizations from the beginning, to design policy in stages and, ideally, to improve its form and implementation as knowledge and understanding increase.

In Hawai'i, government initiatives are helping to bring stakeholders together and creating opportunities for change. In 2006, the Hawai'i House of Representatives passed a resolution requesting an analysis of incentives to promote conservation activities on private lands (House Concurrent Resolution 200, 23rd Legislature, 2006). The resolution emphasized the valuable economic and cultural contribution of ecosystem services to Hawai'i's residents, urging state policy reform "by thinking of the environment not as a 'free good,' but as a capital resource that will depreciate without appropriate care". In 2007, Hawai'i passed the nation's second state-level climate bill, mandating a reduction in greenhouse-gas emissions to 1990 levels by 2020 (House Bill 226, 24th Legislature, 2007). Motivated by this legislation, the Natural Capital Project is working to launch a pilot project, focused initially on payments for land-based carbon sequestration, while aiming to achieve a range of other environmental, economic, and cultural benefits. Being ready to infuse policy discussions with relevant scientific, economic, and cultural information is key to making effective use of these policy opportunities.

Influencing existing institutions, or building new ones as needed, is one of the most important challenges we face. We can help to cultivate a view of ecosystems as capital assets by: (1) piloting initiatives that include incentives for the protection of ecosystem services and fostering recognition of the value of these services (eg Olsson *et al.* 2008); (2) determining the merits and limitations of various policy and finance mechanisms, in different economic, governance, and other social contexts (eg Berkes *et al.* 2003; Ostrom 2005); and (3) developing institutions that achieve representation and participation by stakeholders as part of adaptive governance systems (eg Rickenbach and Reed 2002; Cowling *et al.* 2008).

■ Institutions → decisions

In concrete terms, this arrow in Figure 2 represents financial flows and other tangible incentives. However, our model of change begs an important question: what actually motivates changes in decisions and behavior (Tversky and Kahneman 1981) – monetary rewards, legal sanctions, guilt, approval by peers? How can these be included in a conscious process of cultural evolution (Kahneman 1980)? When societies have values consistent with the approach laid out here, we can foster these values. When societies either do not value nature or are obsessed with short-term economic growth, the use of ecosystem services to incorporate conservation in mainstream decision making may be much more difficult. There are many different nuances in even the most basic decisions involved in setting up payments for ecosystem services (eg contract duration, payment level, and specification and monitoring of desired outcomes). It is important to integrate social psychology and other sources of experience and insight into this work (eg Ross and Nisbett 1991; McMillan 2002).

The complexity of social change, and the diversity of values and decisions facing stakeholders in Hawai'i, highlight the need for a multi-pronged approach. For business-minded landowners, developing a suite of financial incentives linked with different ecosystem service values is of prime importance. Many landowners will require multiple revenue streams in order to move toward more conservation-oriented management (Goldstein *et al.* 2006). Cultural and educational efforts are also underway, to (re)connect people to the land. The Waipa Foundation (www.waipafoundation.org/), for example, has developed a modern approach to the traditional *ahupua'a* management system (subdivisions of land, from mountaintop to seashore, using streams as boundaries) through activities with the local community, school children, and others. The First Nations' Futures Program (www.fnfp.org/) develops values-based leadership for managing natural capital. Finally, to achieve landscape-scale management (Goldman *et al.* 2007), new institutions are being developed, involving cross-boundary cooperation between public and private land managers.

For example, the recently created Three Mountain Alliance now facilitates collaboration among groups of landowners, in the conservation and management of nearly one million acres of land on the island of Hawai'i.

The integration of conservation into decision-making processes will be aided by: (1) broad discussion and inquiry into what motivates people and how social norms evolve, especially in the context of nature (eg Ehrlich and Kennedy 2005; Pergams and Zaradic 2008); (2) incorporating traditional knowledge and practices into modern conservation approaches (eg Berkes and Folke 1998); and (3) developing a broader vision for conservation, and approaches that move from confrontation to participatory efforts seeking a wide range of benefits (eg Theobald *et al.* 2005; Manning *et al.* 2006; Goldman *et al.* 2007; Pejchar *et al.* 2007).

Conclusions

The challenge we face is to make the ecosystem services framework credible, replicable, scalable, and sustainable. There are many hurdles to implementing the agenda outlined in Figure 2. There are scientific challenges for ecologists, economists, and other social scientists, in understanding how human actions affect ecosystems, the provision of ecosystem services, and the value of those services. At least as difficult are the social and political questions associated with incorporating this understanding into decision making. We must design effective and enduring institutions to manage, monitor, and provide incentives that reflect the social values of ecosystem services. Ideally, individuals, corporate managers, and government officials who make decisions that affect ecosystems and the services they provide will pay the prices that reflect these impacts. Price is by no means the only thing that affects peoples' decisions. However, if we can get the price closer to being "right", everyday behavior and decisions will be channeled toward a future in which nature is no longer seen as a luxury we cannot afford, but as something essential for sustaining and improving human well-being everywhere.

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