1.1 Mainstreaming ecosystem services into decisions

The past several decades have produced tremendous change in how people think about the environment and human development. The focus of environmental issues in the 1960s and 1970s was on air and water pollution with an immediate impact on the local surroundings. Actions to reduce pollution occurred primarily in relatively wealthy countries able to afford it.

Now the focus has expanded to encompass the benefits from (and losses to) living natural capital: Earth’s lands and waters and their biodiversity. Food and fiber production, provision of clean water, maintenance of a livable climate, security from floods, the basis for many pharmaceuticals, and appreciation of the wonders and beauty of the natural world are a few of the many dimensions of human well-being that hinge on living natural capital (Daily 1997).

The importance of maintaining natural capital for the ecosystem service benefits that flow from it is increasingly seen as vital in both poor and rich countries alike. Indeed, declining natural capital poses a direct threat to rural poor since they depend closely on the environment for their livelihood (Dasgupta 2010). After spending decades struggling to fence off nature from people, conservation is emerging on the global stage with a new vision that emphasizes the importance of connecting nature and people (Kareiva and Marvier 2007).

One of the largest efforts to date, the Millennium Ecosystem Assessment, illustrated the many ways in which natural systems are vital assets critical for human well-being (MA 2005). The Millennium Ecosystem Assessment took a giant step forward in developing a widely shared vision, a conceptual framework, and a synthesis of existing knowledge. It spawned a suite of further efforts, including an Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (Mooney and Mace 2009; Larigauderie and Mooney 2010). By almost any measure—scientific papers published, media mentions, Google search trends—awareness of natural capital and efforts to sustain it have skyrocketed since the Millennium Assessment.

The Millennium Ecosystem Assessment’s vision is starting to take hold. China, for instance, has invested over 700 billion yuan (approximately $100 billion) in ecosystem service payments over 1998–2010 (Zhang et al. 2000; Liu et al. 2008). In addition, China has established a new system of “ecosystem function conservation areas,” spanning 25% of the nation’s land area where the most vital elements of living natural capital will be protected for securing and harmonizing human and natural well-being.

It is not just giant modernizing nations that are bringing a new view to nature. The value of natural capital is being included in decisions taken by community leaders, traditional cultures, and global corporations. For example, payments for watershed service projects make up a significant portion of existing ecosystem services schemes (many others relate to carbon) (Goldman et al. 2010). These schemes typically involve water users paying upstream land managers for the delivery of clean, consistent water supplies (Brauman et al. 2007; Porras et al. 2007; Wunder et al. 2008), and have in some places become more extensive and sophisticated in design (e.g., Nel
et al. 2009). In Hawai`i, policies and payments for a wide array of services is being promoted through local watershed agreements, the state’s House Concurrent Resolution on Ecosystem Services (passed in 2006), the state’s Climate Bill (passed in 2007), and leadership of the state’s largest private landowner, Kamehameha Schools (Chapter 14). Companies including Coca-Cola, Lafarge, and Mondi are evaluating the role of ecosystem services within their supply chains and working to invest in them (Varga 2009, WRI 2010, McKenzie et al., Chapter 19 this volume).

Including the value of ecosystem services in the decisions of governments, corporations, traditional cultures, and individuals does not replace or undermine the intrinsic value of nature, nor the moral imperative to conserve it (e.g., Leopold 1949; Norton 1987; Ehrenfeld 1988; Rolston 2000). Instead, valuing ecosystem services and natural capital complements these moral concerns, broadening our understanding of the roles nature plays in our lives and the reasons for conserving it. If we can add how nature contributes to human well-being to the arguments for conservation, why wouldn’t we?

While the recent transformation in the way people think about nature and human development has been productive, the urgent challenge now is in moving from ideas to action on a broad scale (Carpenter et al. 2006, 2009). Mainstreaming ecosystem services into everyday decisions requires a systematic method for characterizing their value—and the change in value resulting from alternative policies or human activities. Unlike the well-established accounting tools we apply to measure the value of traditional economic goods and services, we have no ready set of accounting tools to measure the value of ecosystem services (MA 2005; NRC 2005; Mäler et al. 2008). Absent these, ecosystem services are invariably undervalued or not valued at all—by governments, businesses, and the public (Daily et al. 2000; Balmford et al. 2002; NRC 2005; Dasgupta 2010). The result is continued losses in natural capital and biodiversity. Often, it is only after their loss that we recognize the importance of ecosystem services, such as in the wake of Hurricane Katrina or cyclones in India (Stokstad 2005; Das and Vincent 2009).

But who and what will catalyze the next giant step forward? Part of the answer lies with improving science. The natural and social science communities need to attack a set of difficult and compelling issues: How can such complex processes as the role of forests in flood control or crop pollination be quantified accurately? How can such diverse values as are embodied in cultural services be characterized meaningfully? How can we make credible projections of natural capital under scenarios of change, such as in population, climate, or resource management? And how can we build the capacity in civil society and institutions—and in deep aspects of human beliefs and behavior—to take account of ecosystem services and natural capital?

This book tackles these science issues, while acknowledging the many other social and political elements to the problem. It is intended to supply one of the catalysts required for a new approach that harmonizes conservation and development.

1.2 What is new today that makes us think we can succeed?

An appreciation of ecosystems as valuable capital assets traces back to Plato and doubtless much earlier (Mooney and Ehrlich 1997), and the current research agenda on ecosystem services continues long-standing lines of work. For example, renewable resources have been an active area of study in economics since at least the 1950s, when Gordon (1954), Scott (1955), and Schaefer (1957) characterized harvesting a biological stock and 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, p. 12) that included the value of renewable resources (Krutilla 1967; Clark 1990), non-renewable resources (Dasgupta and Heal 1979), and environmental amenities (Freeman 1993). More recent advances in a broad range of areas, such as in ecology and global change, economics, policy and institutions, and especially their integration, have broadened this work to include a wider set of ecosystem services and an examination of the set of human actions needed to maintain the flow the services (e.g., Dasgupta 2001; MA 2005; NRC 2005; Ruhl et al. 2007).
Four big advances of the past decade promise to make an old good idea a new beacon for real change. First, the Millennium Ecosystem Assessment represented a visionary and seminal step in global science—it was the first comprehensive global assessment of the status and trends of all of the world’s major ecosystem services. The key finding of this assessment was that two-thirds of the world’s ecosystem services were declining, a finding that captured the attention of world leaders (MA 2005).

Second, the science of ecosystem functions and processes has made huge advances so that we can now model (albeit with uncertainty) the impacts of land use and resource management decisions on a wide variety of ecosystem processes. Ecological science has also become adept at spatially explicit modeling, which is essential for mapping ecosystem services and their flows to people (e.g., Chan et al. 2006; Rokityanskiy et al. 2007; Bennett et al. 2009; Nelson et al. 2009; Harrison et al. 2010).

Third, economic valuation methods have been applied to the spatial provision of ecosystem services to estimate the monetary value of benefits and the distribution of those benefits to various segments of society (NRC 2005; Naidoo and Ricketts 2006). In addition, qualitative and quantitative methods from other social sciences have been applied to gain better understanding of the social and cultural importance of ecosystem services (e.g., MA 2005; US EPA 2009).

Lastly, experiments in payments for ecosystem services (Pagiola et al. 2002; Pagiola and Platais 2007; Wunder et al. 2008), in ecosystem-based management (Barbier et al. 2008), and in regional planning give us the empirical data for evaluating approaches to valuing ecosystem services and incorporating values into decision-making. There is a growing recognition that bundling together of ecosystem services and explicit attention to tradeoffs will both better inform decisions, and help diverse stakeholders to appreciate the perspectives of others (e.g., Boody et al. 2005; Naidoo and Ricketts 2006; Egoh et al. 2008; Bennett et al. 2009; Nelson et al. 2009).

Our challenge today is to build on this foundation and integrate ecosystem services into real decisions. Doing so requires understanding the interlinked; joint production of services; quantifying the multitude of benefits derived from services to various segments of society; understanding the decision-making process of individuals, corporations, and governments; integrating research with institutional design and policy implementation; and crafting policy interventions that are designed for learning and improvement through time. Each of these alone is a complex task; together they form a daunting but critically important agenda requiring a global collaboration.

1.3 Moving from theory to implementation

In moving from theory to practical implementation, Figure 1.1 presents a framework of the role that ecosystem services can play in decision-making (Daily et al. 2009). This framework connects the science of quantifying services with valuation and policy to devise payment schemes and management actions that take account of ecosystem services.

Though the framework is a continuous loop, we start with the decisions oval to emphasize our focus. After all, the main point of understanding and valuing natural capital and ecosystem services is improving natural resource decisions. So we start—and end—there. These decisions encourage and constrain actions relating to the use of land, water, and other elements of natural capital.

Continuing clockwise around Figure 1.1, “biophysical sciences” are central to understanding the
link between decisions and ecosystems, and along with economics and social science, the links between ecosystems and services. We study the former link with classic ecology and conservation biology to, for example, estimate impacts of land-use change on biodiversity (e.g., Daily et al. 2001; Steffan-Dewenter et al. 2007). And we pursue the latter link with “ecological production functions” that relate, say, forest condition and management practices to the supply of carbon storage, pollination, and other ecosystem services (e.g., Ricketts et al. 2004).

Social sciences are also central to understanding the value of services to people (“economic and cultural models”). Economic valuation techniques are commonly used for this link, to place monetary value on natural capital. Value is often not fully captured in monetary terms, though, so it is important to characterize value in multiple dimensions, including, for example, health, livelihood support, cultural significance (e.g., Dasgupta 2001). This will help ensure that valuation and broader decision-making approaches are inclusive of the range of benefits and people concerned (Heal 2000a, 2000b).

Finally, valuing ecosystem services provides useful information that can help shape institutions (e.g., agricultural markets, subsidies, land-use policies, conservation NGOs) to guide resource management and policy. Having the right institutions can create incentives so that the decisions of individuals, communities, corporations, and governments promote widely shared values. The links between the value, institutions, and decisions ovals are much more the art and politics of social change than science, though scientists can inform these debates if they target specific decisions and are attuned to the social and political contexts.

This idealized framework is helpful in clarifying the many frontiers of research and implementation en route to operationalizing ecosystem services into decisions (see also Carpenter et al. 2009). This includes continued biophysical research on the impacts of human actions on ecosystems, all the way to studies on the way landowners respond to conservation incentives. Chapters in this book touch on all ovals and all arrows within the framework, but the core chapters focus on moving from ecosystems to services, and from services to value, using production functions and valuation techniques.

1.4 Using ecosystem production functions to map and assess natural capital

There are several methods for mapping and assigning value to ecosystem services, each with its own advantages and limitations. The initial valuation work in the field of ecosystem services primarily used what is called the benefit transfer approach (e.g., Costanza et al. 1997). This approach typically uses empirical estimates of the value of goods produced from some habitat type and transfers those benefits to similar habitats elsewhere, including anywhere in the world (Costanza et al. 1997). Local knowledge can be used to adjust the benefits because one knows, for instance, that the west coast marshes of North America are less productive than the east coast marshes and so forth. The general idea, however, is to use lookup tables of benefits per unit area of habitat type, and thereby quantify overall natural capital.

An alternative method favored in this book is called a “production function approach.” Instead of relying on lookup tables, we build models that predict local ecosystem service supply based on land cover, land use, ecosystem attributes, human demand, etc. These functions are analogous to those long used in agriculture, which relate amounts of water, fertilizer, and labor to resulting crop yield. In our view, production functions have key advantages over benefits transfer, and we delve into these further in Chapter 3.

1.5 Roadmap to the book

Our book begins with three chapters that introduce the core approach and hypotheses of our work on natural capital. Chapter 2 examines the philosophical bases for ecosystem service value and explores ways of measuring such value, distinguishing alternative approaches and highlighting some ethical issues underlying the choices among them. It also explores the strengths and weaknesses of these measurement approaches, and indicates which approaches are best suited to the different types of value conferred by ecosystem services. Chapter 3 then introduces the modeling approach we have developed, which strives to integrate many differ-
ent ecosystem services, to do so over scales appropriate to important resource decisions, and to assess trade-offs among services on real landscapes. All resource decisions involve these trade-offs (e.g., between biological carbon sequestration and stream flow; Jackson et al. 2005). Yet, all too often, the importan of trade-offs among services is lost in decision-making, with the result that unintended consequences arise while pursuing what at first seems like a good idea.

The middle section of the book delves into details for each of the core models of ecosystem services. The specific services we model are water supply for hydropower and irrigation (Chapter 4), flood damage avoidance (Chapter 5), water pollution regulation (Chapter 6), carbon storage and sequestration (Chapter 7), production of timber and non-timber forest products (Chapter 8), agricultural productivity (Chapter 9), crop pollination (Chapter 10), enhancement of recreation and tourism (Chapter 11), and provision of cultural services (Chapter 12). We also model biodiversity, as an ecosystem attribute (Chapter 13).

Like all early efforts in modeling, we try to strike a balance between scientific rigor, data availability, and practical usability. Some will object that the models are overly simplistic; others will find them hopelessly complicated (indeed, reviewers have made both arguments for almost every chapter). We offer two tiers of models for each ecosystem service. Tier 1 is the simplest credible model we could devise, with data needs that can be met even in data-poor regions that are often so fundamental to both conservation and human livelihoods. Tier 2 models offer more complexity, specificity, and realism for users and places with the data to support them. We include enough math in each chapter to make the modeling approach clear. And we have implemented tier 1 equations into a modeling tool available for free download at http://invest.ecoinformatics.org.

The final section of the book is based on potential applications of our approach to modeling and mapping natural capital. Applications are messy and demanding, and require links to other fields of science as well as policy. In this “getting real” section of the book, we discuss trade-offs (Chapter 14), difficult choices about how complicated or detailed models need to be (Chapter 15), the implicit but rarely quantified link between ecosystem services and poverty (Chapter 16), the challenge of extending our approach to marine ecosystems (Chapter 17), assessing the impacts of climate change on ecosystem services (Chapter 18), and ideas for how all of this science might actually enter into decision-making and policy (Chapter 19).

In all chapters we include short essays by contributors who are using concepts of natural capital in their conservation and policy work. We include these essays to emphasize that our models play only one small part in a world of innovation surrounding natural capital. There has never been a more exciting time for conservation and ecosystem science than now—but some of that excitement is shrouded in equations and modeling details. It is in our essays that one can find evidence of the tipping point that is before us, in contemplating the African boy cooking a monkey (Box 1.1, this chapter); the first national exchange for carbon storage credits (Chapter 7); the hopes we pin on agroecosystems as highways out of poverty (Chapter 16); vastly different options for a sustainable future (Box 1.2, this chapter); and many others.

**Box 1.1 The everyday meaning of natural capital to the world’s rural poor**

M. Sanjayan

The boy is no more than 10 years old, bare legs scarred by tropical parasites, clad only in dingy shorts despite the threatening rain (Figure 1.A.1). He is engrossed in his task of carefully burning the fur off a dead monkey. I have stumbled onto this unfolding scene in a village in Sierra Leone, West Africa, whose inhabitants are amongst the poorest in the world despite being surrounded by a wealth of biodiversity. The monkey is a Cercopithecus of some sort, perhaps a white-nosed Guenon, a relatively common crop-raiding monkey in these parts. Holding it carefully in...
both hands, the boy slowly turns it as the pelt singes and curls into soft gray ash. It is clearly a delicate task, with the flames struggling to catch the rain-soaked pieces of stick fed into the weak fire. Occasionally the boy pauses and, with a piece of tin sheet metal, furiously fans the smoky mess. An acrid odor hangs in the heavy air.

The monkey will soon be food. It will be dismembered, every bit from nose to tail, thrown into a pot with some okra, peppers, or other meager vegetables, and a few drops of palm oil—a stew ultimately yielding, based on the small crush of spectators, what I estimate to be about two tablespoons of meat protein for each person. A small monkey in a big pot. Fascinated by the boy's handiwork, I pull out my camera and snap a photo—and immediately feel a little shabby about it. The boy just giggles.

As I see it, six basic services provide most of the daily needs of extremely poor rural people. Fresh water is the most obvious and its procurement is taxing, particularly to women, who bear most of the load. While there are taps sprouting in many rural villages in Africa, few connect to sustainable water sources. Fuel wood, collected from forests, plantations, or local groves, is indispensable for the heating and cooking needs of 40% of rural homes. Gathering it is the second most taxing chore (after water) that impacts daily life. Fisheries provide protein to 20% of the world’s population. On the Ganges River in India, for example, ten million people in 2000 villages depend on fishing to both meet their daily needs and provide jobs. Fertility of soils, and its natural renewal through processes of nutrient cycling, is essential to places untouched by the Green Revolution and does not involve the consequences of industrial fertilization in terms of energy use and nutrient overload. Forest products, like meat for protein from forest animals, fruit, honey, medicinal plants, and fiber, have a myriad of vital uses. Fodder, in terms of grass and browse for livestock, is important in rural communities because it is one of the few ways through which the poor can access the global economy. Livestock is the common bank for rural populations. These “6 Fs” of nature (six free services) are part of the staple packet of goods and services that virtually every rural community depends upon and that governments conveniently ignore, and non-profits underestimate the importance of. Lose them and people will suffer.
1.6 Open questions and future directions

This book and the modeling approaches we introduce are only a beginning. We anticipate the research community adding other ecosystem services over time, as well as continually improving the models and data for those presented in this book. These additions and improvements will come from confronting these and other models with a variety of real-world data and challenges. Here we mention two of the many key arenas in which further understanding is crucial.

First, major advances in methods and tools are needed to incorporate dynamic effects, as well as shocks and uncertainty. Dynamic changes (e.g., in climate and in the nitrogen cycle) and changes arising through economic development and evolving human preferences over time are important to include. The possibility of feedbacks within ecosystems, and between ecosystem services and human behavior, are important areas for further development. Feedback effects can give rise to thresholds and rapid changes in systems that can fundamentally alter system states (Scheffer et al. 2001). The ability to incorporate shocks and the possibility of surprises is another area where further development is needed. Fires, droughts, and disease all can have major influences on ecosystems and affect the services produced. Changes in economic conditions or fads in human behavior can similarly cause major changes in systems (e.g., financial crises). The occurrence of each of these and other potential disturbances is difficult to predict but virtually certain to come about. Understanding their likely impacts on ecological and social systems will help us prepare for them.

A second major area for further development is in relating ecosystem condition to human health. The relationships between biophysical attributes of ecosystems and human communities are complex (Myers and Patz 2009). Destruction of ecosystems can at times improve aspects of community health. For example, draining swamps can reduce habitat for the mosquito vector that transmits the parasite that causes malaria. On the other hand, ecosystems provide many services that sustain human health, for which substitutes are not available at the required scale, such as purification and regulation of drinking water flow; regulation of air quality; nutrition (especially of protein and micronutrients); psychological benefits; and, in complex ways, regulation of vector-borne disease (Levy et al. in press). To date, there is little rigorous research establishing the links between ecosystem conditions and human health.
What gives you the most hope for the environment over the next 50 years? When we asked that question of 59 global leaders in 2003, we expected great variability in the answers. To our surprise, the answers fell rather cleanly into three clusters. Some respondents were not worried and simply had faith in economic growth, being convinced that a sustainable environment would follow automatically from economic development. Two clusters stood out, however, because they envisioned futures that were less automatic, and that would need some guidance if we were to achieve a hopeful outcome. The first of these “we need change” clusters thought that innovation and investments in environmentally friendly technology was the key. The second “we need change” group felt that governance should be restructured to motivate local innovation and learning, and thereby create sustainable landscapes from the bottom up.

These two clusters of ideas became the Technogarden and Adapting Mosaic scenarios of the Millennium Ecosystem Assessment (MA 2005). We evaluated the condition of 24 global ecosystem services from 2000 to 2050 under these and other scenarios. Technogarden and Adapting Mosaic were the most successful scenarios for maintaining ecosystem services. However, these two scenarios represent very different policies that lead to different bundles of global ecosystem services by 2050.

In Technogarden, society addresses global environmental problems such as climate heating, materials cycles, and nutrient mobilization through innovations in energy production, buildings, transportation, and agriculture (Figure 1.B.1). Improvements in agriculture and urban design make it possible to feed and house humanity without extensive new conversion of wild lands. Market mechanisms and sophisticated economic instruments are deployed to manage ecosystem services. International cooperation on incentives for better technology lays the foundation for improved cooperation on other problems of the global commons, such as pelagic marine fisheries, disease containment, and conservation of antibiotics. Expanded access to education leads to smaller family sizes and thereby slows the pace of population growth. Even though many ecosystem services are in sustainable condition by 2050, there are some downsides. Some aesthetic, cultural, and spiritual aspects of ecosystems are
lost or irreversibly changed. Local ecological knowledge is sometimes lost as management becomes more centralized. Unexpected consequences of technology lead to some big accidents. Nonetheless, Technogarden offers many successes in management of ecosystem services.

Adapting Mosaic begins with reorganization of governance around institutions tailored to naturally occurring clusters of ecosystem services (Figure 1.B.2). For example, the Headwaters of the Mississippi River in North America (Minnesota and Wisconsin, plus parts of eastern Iowa and northern Illinois) organizes around sustainable agriculture mostly for local consumption, ecosystem management for abundant clean freshwater, and urban areas known for environmentally friendly high-technology and biotechnology industries. Within the overarching Headwaters region, responsibility for ecosystem management organizes around sub-watersheds at the smallest spatial extent, and major ecoregions at an intermediate spatial extent. Governance of most other regions of the world undergoes similar adjustments to accommodate natural patterns of ecosystem services.

Adapting Mosaic stresses local innovation and learning by doing to improve ecosystem services. Even though global economic linkages are sparse, information linkages are strong. Innovations and news of failed experiments can spread rapidly. The global network makes rather fast progress on improving practices for ecosystem services. Ironically, however, the withering of global institutions hinders progress on problems of the global commons such as climate heating and pelagic marine fisheries.

The scenarios of the Millennium Ecosystem Assessment are not a prescription for solving the world’s problems. They are more like hypotheses to be tested. So why not combine the best of Technogarden and Adapting Mosaic? The global commons problems are critical, and improved technology will be needed to create better energy sources, agriculture, transportation, and infrastructure. Half of humanity lives in cities. The USA alone will replace most of its infrastructure by 2030, and in the 21st century the world will erect more buildings than in the entire history of our species before 2000. This reconstruction is an opportunity for lowering the impact of cities on the global commons and on the rural regions that feed the cities and absorb their waste. At the same time we are addressing the global commons, there are many benefits available from multiscale adaptive management of landscapes. These benefits can be financed through appropriate pricing of the ecosystem services that rural regions and wild regions provide.

Figure 1.B.2 Depiction of the Adapting Mosaic scenario of the Millennium Ecosystem Assessment. From Ecosystems and Human Well-Being: Scenarios, by the Millennium Ecosystem Assessment. Copyright © 2005 Millennium Ecosystem Assessment. Reproduced by permission of Island Press, Washington, D.C.
1.7 A general theory of change

Mainstreaming natural capital into decisions is a long-term proposition, requiring co-evolving advances in knowledge, social institutions, and culture. Certainly a single book is not sufficient for achieving this. We propose instead that our book contributes to an overall theory of change (Bradach et al. 2008) involving three key, broad elements.

First, businesses, governments, and individuals must find it easy to inculcate ecosystem services and natural capital into their decisions, and the methods for doing so must be transparent, credible, and predictable. In many cases, sectors of society are open to the idea of ecosystem services and natural capital, but simply do not know how to take the idea and use it in a concrete way.

Second, there need to be examples of projects or enterprises that—as a result of properly valuing ecosystem services and natural capital—end up with improved decisions, institutions, and human well-being. These examples both test our science against real-world problems and produce compelling stories of how an ecosystem services approach made a difference.

Lastly, political and thought leaders must appreciate these examples of success and spread the word. This is where the impact of scattered projects can be magnified into worldwide change.

None of these steps are complicated, and our theory of change does not require a brilliant and novel strategy. In fact, we are convinced that all three ingredients are within striking distance. The environmental movement has a much bigger and more diverse and powerful community behind it now than ever before (Daily and Matson 2008). Science is beginning to provide tools and methods that will reduce the transaction costs. And there are enough policy experiments underway that compelling examples of natural capital stewardship enhancing human well-being should be forthcoming.

Our book targets the first element of our theory: to make quantifying and valuing natural capital straightforward and routine. Science is not everything, but both modeling and empirical science provide the foundation for action. The models we rely on are not a fait accompli—they are the first step in an iterative process between basic science and application to real-world problems. That is why we highlight case studies in which valuation of natural capital is being used to influence land and water management. Science by itself cannot change the world, but science plus the vision and action of leaders can—and that is what we seek.

References


Box 1.2 continued

Even though the Millennium Ecosystem Assessment did not compute an optimal path to 2050, it is likely that the best mix of options is some combination of Technogarden and Adapting Mosaic. The challenge is to understand which combinations of ecosystem services are biophysically possible, the trade-offs among different bundles of ecosystem services possible from a given region, and the institutional frameworks that enable ongoing flows of ecosystem services.


