Chapter 6
Ecosystem Services

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Glossary

Ecosystem services	The wide array of benefits that ecosystems, and their biodiversity, confer on humanity.
Marginal value	The economic value of the next incremental unit of something. In this context, marginal values are those associated with managing the next small unit of an ecosystem in a particular way (e.g., preserving, rather than clearing, the next unit of forest). They can also be the partial contribution of natural capital to a final good that is produced with other inputs. For example, the marginal value of irrigation water for crop production is the value of the incremental crop yield that can be attributed to irrigation, rather than to labor, fertilizer, and other inputs.
Natural capital	Here we focus on living, renewable forms of natural capital, which constitute a stock – of an ecosystem and the biota that makes it up – that generates a flow of ecosystem services.

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For example, a forest constitutes a stock that generates a flow of timber, carbon sequestration, water quality, biodiversity, serenity, and other benefits, depending upon how it is managed. (Fossil fuels and other minerals constitute nonliving natural capital, which is generally nonrenewable on time scales of interest to society.)

Definition

Ecosystem services are essential to sustaining and fulfilling human life, and yet their supply is seriously threatened by the intensification of human impacts on the environment. 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 institutions recognize the values of nature, then we can greatly enhance investments in conservation and foster human well-being at the same time. In practice, scientific and policy communities have not yet developed the scientific basis or the policy and finance mechanisms for integrating natural capital into resource and land-use decisions on a large scale.

Introduction

This entry provides an overview of issues concerning the identification, biophysical and economic characterization, and safeguarding of ecosystem services. The concept of ecosystem services has a long written history, reaching back at least as far as Plato. We review this history, including a focus on recent advances such as the Millennium Ecosystem Assessment, and advances in spatial modeling, economic valuation, and policy implementation. We provide examples of novel finance and policy mechanisms, including water funds, marine spatial planning, land-use planning and human development, and global policy efforts. We conclude with a discussion of the largest research and implementation challenges in this field, identifying the issues that will frame the future growth of the concept of ecosystem services.

What are Ecosystem Services?

Definition and Classification

Ecosystem services are defined simply as the benefits that people obtain from ecosystems [38]. They sustain and fulfill human life and flow from many conditions and processes of ecosystems, and the species making them up [14]. The processes

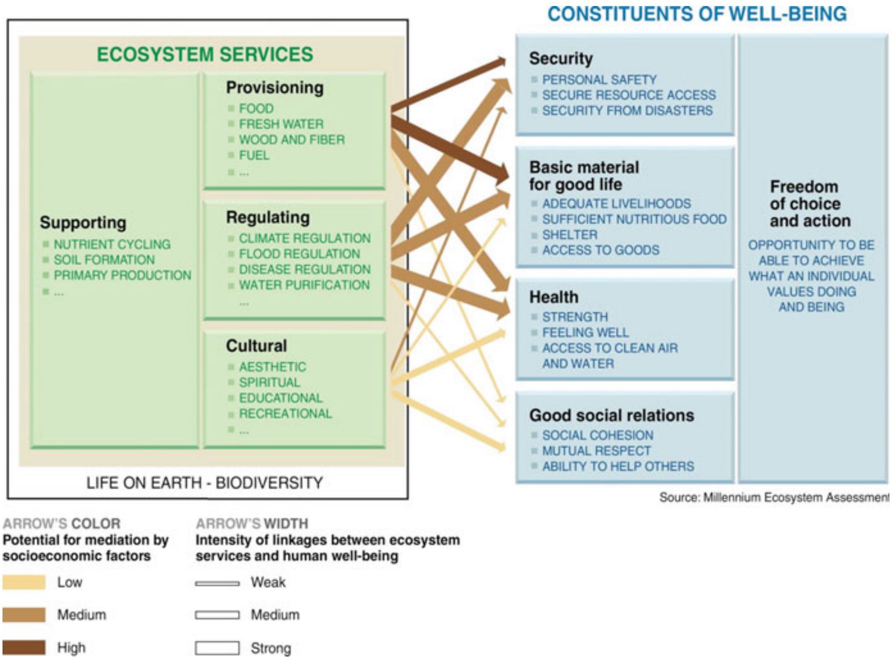

Fig. 6.1 Ecosystem service categories and their linkages to human well-being as described in the Millennium Ecosystem Assessment [38]

and features generating ecosystem services (ES) are so tightly interconnected that any classification is inherently somewhat arbitrary. The most widely used classification was developed through the Millennium Ecosystem Assessment (MA) and identifies four classes of ES based on their types of benefits to society:

1. *Provisioning services* including the production of goods such as food, water, timber, and fiber
2. *Regulating services* that stabilize climate, moderate risk of flooding and disease, and protect or enhance water quality
3. *Cultural services* that provide recreational, aesthetic, educational, community, and spiritual opportunities
4. *Supporting services* that underlie provision of the other three classes of benefits, including soil formation, photosynthesis, nutrient cycling, and the preservation of options (Fig. 6.1; [38]).

The classification of ES is still a topic of debate and several other classification approaches have been suggested [7, 19, 22, 67].

System- and scale-neutral, the ecosystem services framework applies equally to terrestrial, freshwater, and marine ecosystems and their processes, anywhere on the spectrum from relatively pristine to heavily managed conditions. Indeed, all ecosystems provide, to differing degrees, a set of ES. Human conversion of ecosystems from one type to another is often motivated by a desire for a different set of ES, though consideration of the services of the two systems and their tradeoffs is often incomplete.

Ecosystem Services Across Systems

A wide range of ES is generated in the terrestrial realm, by croplands, natural and managed forests, grasslands, and wetlands. In each of these systems, for example, vegetation can protect and enhance soils, preventing their loss through erosion and improving fertility by retaining moisture and storing and recycling nutrients. Vegetation and soils together regulate the quantity, quality, and timing of water flows, thus moderating floods and droughts and providing cleaner, more reliable supplies [8].

Forests stand out as important in regulating water and carbon cycles [30]; in their strong influence on local, regional, and global climate [30, 49]; and because of the multiple, interacting threats to their future (e.g., [44, 66]). They also provide natural products for subsistence use or sale including timber, firewood, mushrooms, fruits and seeds, medicinal plants, rubber, cork, and bushmeat. Forest and woodland habitats harbor species that provide pollination and pest control to commercial or subsistence crops. Grassland and other dryland systems play these same critical roles in addition to supporting vast livestock populations [38]. Wetlands occupy a small fraction of Earth's surface, but dominate the landscape where they are concentrated and provide a wide array of water quality, flood mitigation, coastal protection, and biogeochemical services [38]. Each of these systems, however natural or managed, can provide habitat for biodiversity and opportunities for recreational activities, spiritual experiences, and creative, cultural expression.

Freshwater ecosystems provide a suite of highly visible and widely appreciated ES [53]. The freshwater regulated by terrestrial systems and the atmosphere is used for drinking, hydropower production, irrigation, household activities (washing, etc.), industrial purposes (cooling, manufacturing, etc.), and cultural experiences. People also gain large revenues and nutrition from freshwater fisheries and aquaculture. Less appreciated is the value of sediment transport and deposition in rivers that supply river reaches and downstream beaches with important sand and gravel resources. Wetlands and other aquatic vegetation can regulate flood waters and cycle nutrients, improving water quality. Finally, freshwater systems serve as pathways for human transportation and recreational or cultural activities.

Marine ecosystems also provide all four classes of ecosystem services described in the MA. Marine fisheries and aquaculture provide nutrition, feed for animals, livelihoods, and important recreational and cultural opportunities. Harvests of other species for food additives, cosmetics, and pharmaceuticals also support health, nutrition, and livelihoods. Marine biogenic habitats (such as coral reefs, oyster reefs, and kelp forests) regulate natural hazards including storm surges, and may play a critical role in helping coastal communities adapt to sea level rise. Marine systems also transform, detoxify, and sequester wastes.

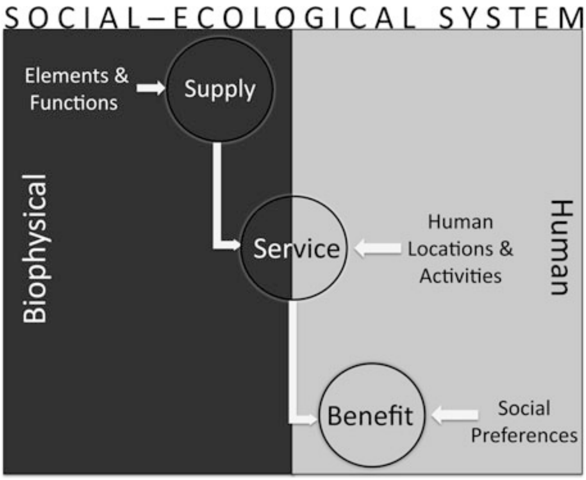

Fig. 6.2 Three measurement points for ecosystem services [63]. Supply metrics deal only with the biophysical system underpinning the service of interest. Service metrics include critical information linking supply to beneficiaries. Benefit metrics weigh the level of service based on people's preferences or social policy goals

In addition, oceans are the center of the global water cycle; they hold 96.5% of the Earth's water [24] and are a primary driver of the atmosphere's temperature, moisture content, and stability [12]. Oceans are also key players in the global cycles of carbon, nitrogen, oxygen, phosphorus, sulfur, and other major elements [51] and are responsible for approximately 40% of global net primary productivity [39, 61]. Finally, coastal communities reap many benefits from coastal tourism (one the one of world's most profitable industries [65]), and numerous coastal communities define their very identities in relation to the sea and all it brings.

The Ecosystem Service Supply Chain

Ecosystem services flow to people along a supply chain from biophysical systems to people [63]. All services are generated by some function or element of a natural or managed system (Fig. 6.2). The full suite of these elements or functions can best be considered in three discrete steps: supply, service, and benefit. For example, consider protection from coastal storm surges. Many different types of coastal elements (e.g., coral reefs, mangroves, oyster beds, barrier islands) confer protection from storm surges by attenuating waves. The full set of locations of these coastal elements represents the supply of protection from storms. People do not receive storm surge protection from all of these locations, however, because some are far from human infrastructure and settlement. Both the distribution of human infrastructure and settlement, together with the location and condition of supply, are required to give a clear picture of how much "service" is actually delivered at a given time.

Finally, the service delivered to human communities is often valued differently, depending on the context. For example, coastal protection services provided by nearshore habitats to easily accessible, popular, public beaches might be seen as more valuable, or providing greater benefit, than those to more remote sites.

History of the Concept of Ecosystem Services

It is primarily through disruption and loss that the nature and value of ecosystem services has been illuminated. For instance, deforestation has demonstrated the critical role of forests in the hydrological cycle – in particular, in mitigating floods, droughts, the erosive forces of wind and rain, and the silting of dams and irrigation canals. Release of toxic substances, whether accidental or deliberate, has revealed the nature and value of physical and chemical processes, governed in part by a diversity of microorganisms, that disperse and break down hazardous materials. Thinning of the stratospheric ozone layer sharpened awareness of the value of its service in screening out harmful ultraviolet radiation. And the loss of coastal wetlands has brought into relief their importance in regulating coastal hazards such as hurricanes and tsunamis.

Initial Development of the Ecosystem Services Concept

A cognizance of ecosystem services, expressed in terms of their loss, dates back at least to Plato and probably much earlier:

> What now remains of the formerly rich land is like the skeleton of a sick man with all the fat and soft earth having wasted away and only the bare framework remaining. Formerly, many of the mountains were arable. The plains that were full of rich soil are now marshes. Hills that were once covered with forests and produced abundant pasture now produce only food for bees. Once the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water. . ., and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true. (Plato)

Mooney and Ehrlich [40] trace modern concern for ecosystem services to George Perkins Marsh, a lawyer, politician, and scholar. Indeed, his 1864 book *Man and Nature* describes a wide array of services, again, often expressed in terms of their loss. Remarking on the terrain of the former Roman Empire, he notes that it "is either deserted by civilized man and surrendered to hopeless desolation, or at least greatly reduced in both productiveness and population" (p. 9). He continues, describing the reduction of hydrological services: "Vast forests have disappeared from mountain spurs and ridges, the vegetable earth . . . [is] washed away; meadows, once fertilized by irrigation, are waste and unproductive, because . . . the springs that fed them dried up; rivers famous in history and song have shrunk to humble brooklets" (p. 9). He also draws connections between deforestation and climate: "With the disappearance of the forest, all is changed. At one season, the Earth parts with its warmth by radiation to an open sky – receives, at another, an immoderate heat from the unobstructed rays of the sun. Hence the climate becomes excessive, and the soil is alternately parched by the fervors of summer, and seared by the rigors of winter. Bleak winds sweep unresisted over its surface, drift away the snow that sheltered it from the frost, and dry up its scanty moisture" (p. 186). Finally, he even wrote of decomposition services: "The carnivorous, and often the herbivorous insects render an important service to man by consuming dead and decaying animal and vegetable matter, the decomposition of which would otherwise fill the air with effluvia noxious to health" (p. 95).

Other eloquent writers on the environment emerged following World War II, including Fairfield Osborn (*Our Plundered Planet*, 1948), William Vogt (*Road to Survival*, 1948), and Aldo Leopold (*A Sand County Almanac and Sketches from Here and There*, 1949). Each discusses ecosystem services without using the term explicitly. In *The Population Bomb* (1968), Paul Ehrlich describes anthropogenic disruption of ecosystems and the societal consequences of doing so, addressing the need to maintain important aspects of ecosystem functioning. Along these lines, the *Study of Critical Environmental Problems* (1970) presents a list of key "environmental services" that would decline with a decline in "ecosystem function." This list was expanded upon by Holdren and Ehrlich [29]. Meanwhile, in the 1960s and 1970s, economists set out to measure "the value of services that natural areas provide" ([35], p. 12), with efforts focused on agricultural production [3], renewable resources [11, 34], nonrenewable resources [18], and environmental amenities [23].

By the early 1980s, efforts were initiated to investigate two questions: the extent to which ecosystem function (and the delivery of services) depends on biodiversity, and the extent to which technological substitutes could replace ecosystem services. The first question is addressed in chapter Species Diversity Within and Among Ecosystems, this volume. The second question was tackled by Ehrlich and Mooney [21]. Work on these topics proliferated and, in 1997, a collective effort was made to synthesize the wealth of scientific information that had accumulated on the functioning of ecosystem services, with a preliminary exploration of their economic value, and of key issues meriting further work [14].

Recent Advances

Four major advances of the last decade have revitalized research on ecosystem services and brought them into the public eye. First, the MA 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. It was requested by United Nations Secretary General Kofi Annan in 2000 and carried out

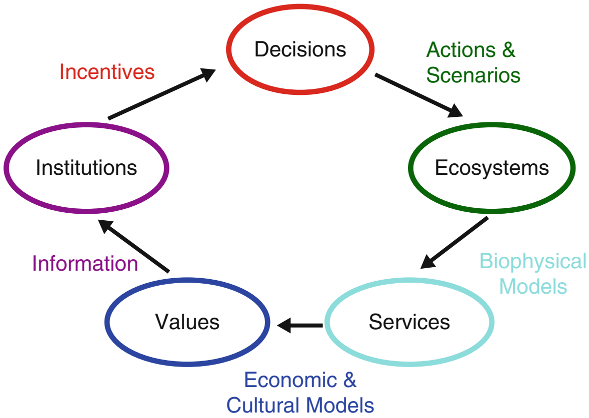

Fig. 6.3 A framework showing key elements for integrating ES into decision-making [16]. One could link any two ovals, in any direction, in different decision contexts

between 2001 and 2005 with contributions from over 1,360 experts worldwide. The key finding of this assessment was that two thirds of the world's ecosystem services were declining [38]. This captured the attention of world leaders and emphasized the connections between human decisions and the natural environment that feed back to the human condition via changes in the flow of ecosystem services.

Work following the MA clarified this chain of connections (Fig. 6.3) [16]. Human decisions shape individuals' actions relating to the use of land, water, oceans, and other elements of natural capital. These actions often alter the state or functioning of ecosystems, which in turn provide altered flows of benefits (goods or services) to people. People express different values (monetary, cultural) associated with these altered streams of benefits and it is the expression of these values that leads to changes in institutions that guide decisions. The following three recent advances all concern the connections in this flow.

A suite of recent advances has greatly improved understanding of the links between ecosystem functions and processes and the provision of ecosystem services (Fig. 6.3). For some ecosystem services, we now better understand the key ecological system components that drive provision (e.g., [33]) and we can now measure (e.g., [56]) and model, with uncertainty, the impacts of land use and resource management decisions on a wider variety of ecosystem processes and associated services. Ecological science has also advanced spatially explicit modeling, which is essential for mapping ecosystem services and their flows to people (e.g., [10, 27, 43, 57]). Finally, we are starting to see patterns in how multiple ecosystem services and biodiversity change in relation to each other. Recent work has started characterizing bundles of ecosystem services, and exploring their synergies and trade-offs (e.g., [4, 6, 20, 42, 43]).

Further, economic valuation methods have been applied to the spatial provision of ecosystem services to estimate the monetary value of benefits and, in some cases, the distribution of those benefits to various segments of society [42, 45, 52, 64]. 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., [38]).

Lastly, experiments in payments for ecosystem services [47, 48, 69], in ecosystem-based management [2], and in regional planning have begun, giving us opportunities to learn about how science can play a role in altering institutions, and how institutions alter decisions and the resulting flow of ecosystem services. The following section describes some of these efforts in more detail.

Incorporating Ecosystem Services into Decisions

Today, the urgent challenge is to move from theory to practical implementation of ES tools and approaches in resource decisions taken by individuals, communities, corporations, and governments. The framework in Fig. 6.3 connects the science of quantifying services with valuation and policy to devise payment schemes and management actions that take account of ecosystem services. This connection is expressed in the real world in a variety of ways across scales from local to global.

A great number and diversity of efforts to implement the ES framework have emerged worldwide over the past decade. Individually, most of these efforts are small and idiosyncratic. But collectively, they represent a powerful shift in the focus of conservation organizations and governments (primarily) toward a more inclusive, integrated, and effective set of strategies [15]. Taken together, these efforts span the globe and target a full suite of ecosystem services, including principally forest-generated services of carbon sequestration, water supply, flood control, biodiversity conservation, and enhancement of scenic beauty (and associated recreation/tourism values) [26, 62].

Many local or regional ES efforts focus on a single service that stands out as sufficiently important, from economic and political perspectives, to overcome the activation energy required to protect it. Under the institutional umbrella created for the focal service, it is possible that other services may be at least partially protected. Beginning in the late 1990s, larger-scale investment in natural capital for water flow regulation in China – and for a broad suite of ES in Costa Rica – set pioneering examples that are now being adapted elsewhere and scaled up.

Next, we briefly describe some contrasting models of success, at different scales and in different kinds of social-ecological systems. In each case, there is an acute or looming crisis, innovative leadership, and pursuit of dual goals: improving both human and ES condition.

Local Scale: Water Funds

New York City made one of the first and most famous investments in ecosystem service provision in recent history, in the mid-1990s. The city invested ca. USD1.5 billion in a variety of watershed protection activities to improve drinking water quality for 10 million users rather than spending the estimated USD6-8 billion needed (excluding annual operating and maintenance costs) for building a new filtration plant. This seminal example is widely cited as evidence of the business case for investing in natural capital instead of built capital [15]. Yet the effort remains very much an experiment in the science and policy of investing in natural capital, and one on which there is international focus.

Globally, watersheds are now emerging as the target of a range of creative policy and finance mechanisms that link beneficiaries to suppliers through a payment system. In these "water funds," water users voluntarily pay into a pool that is collectively managed by contributors and invested in watershed management improvements. The Nature Conservancy (TNC) has now established more than ten water funds in Latin America, has plans to create 22 more by 2015 [25], and is exploring the possibility of establishing some of the first funds in Africa.

Agua por la Vida y la Sostenibilidad, one of the recently established water funds, demonstrates the diversity of water users that are becoming engaged in these funds and the kinds of watershed management changes these funds motivate. Formally established in the Cauca Valley, Colombia in 2009, this water fund is supported by the region's sugarcane grower's association (PROCAÑA), the sugar producers' association (ASOCAÑA), 11 local watershed management groups, TNC and a Colombian peace and justice nongovernment organization (Vallenpaz). Each member of the water fund voluntarily pays a self-determined amount into the fund that is then jointly managed by the members to improve landscape management in 11 watersheds covering over 3,900 km^2.

Members in this fund have currently committed to contributing USD10 million over 5 years to be invested in five kinds of management changes: protection of native vegetation, restoration of denuded lands, enrichment of degraded forests, fencing of rangelands, and implementation of silvopastoral practices. The fund is starting a monitoring program that will ensure that these investments lead to measurable improvements in water quality for approximately one million water users downstream and significant improvements in terrestrial and freshwater biodiversity.

Local Scale: Coastal and Marine Spatial Planning

People commonly think of oceans as relatively featureless expanses that defy the drawing of lines on maps. However, recent political and scientific advances have highlighted the need for a comprehensive approach to planning marine and coastal uses and the need for practical tools to make this more comprehensive approach a reality on the ground and in the water. In a marine spatial plan, a wide range of uses of the marine environment are put on one map. But an understanding of how such plans are likely to yield changes in the delivery of the broad range of services people receive from the system has, until recently, remained elusive.

Along the west coast of Vancouver Island Canada, multiple, often competing interests are struggling to define the future character of the place. Existing extractive, industrial, and commercial uses; traditional First Nations subsistence and ceremonial uses; recreation and tourism; and emerging ocean uses such as the extraction of wave energy are all in the mix. The West Coast Aquatic Management Board (WCA) is charged with creating a marine spatial plan for the region. WCA is a public-private partnership with participation from four levels of government (Federal, Provincial, local, and First Nations), and diverse stakeholders. Ultimately, WCA's vision is to manage resources for the benefit of current and future generations of people and nonhuman species and communities.

Some key pillars of the partnership's strategy are to: use a precautionary, ecosystem-based approach to protect, maintain, and restore marine and coastal resources; respect and protect First Nations' food, social and ceremonial requirements and treaty obligations; integrate expertise and knowledge from First Nations, local, scientific, and other sources; ensure broad participation in the planning process; and foster initiatives that maintain or enhance opportunities for coastal communities to benefit from local resources, while achieving sustainable social, cultural, and economic benefits for the region. WCA has partnered with the Natural Capital Project to explore how alternative spatial plans might affect a wide range of ES and to provide information about trade-offs among ES.

Key considerations for WCA and their stakeholders include balancing important industrial and commercial activities (such as shipping, mining, logging, aquaculture, and fisheries), increased development of tourism and recreation, renewable energy generation, and a strong cultural desire for sustaining the remote, wild feeling of the place. WCA is exploring the suitability of alternative regions for these different activities. For example, maps of coastal vulnerability to erosion and flooding from storm surge are helping to direct coastal development permits to low-risk areas. Similar maps of the value of captured wave energy are being overlaid with existing ocean uses (e.g., fishing and recreational activities) to highlight regions of high wave energy value, where wave energy generation facilities might be constructed while having minimal impacts on other activities. Examinations of trade-offs among aquaculture (finfish, shellfish), wild salmon fisheries, recreation (e.g., kayaking, whale watching, and diving), coastal development (on the coast, as well as floathomes), and habitat and water quality are underway.

The general framework of ES and ES modeling, in particular, is helping to articulate connections between human activities that are often considered in isolation, to align diverse stakeholders around common goals, and to make implicit decisions explicit. ES modeling results have informed early iterations of the marine spatial plan and will inform the creation of the final plan in 2012.

National Scale: Land-Use Planning and Human Development in China

The ecosystem service investments being made in China today are impressive in their goals, scale, duration, and innovation. Following massive droughts and flooding in 1997–1998, China implemented several national forestry and conservation initiatives, into which investments exceeded 700 billion yuan (ca. USD100 billion) over 2000–2010 [37, 70]. The larger and older of these initiatives are being rigorously evaluated to determine their biophysical and socio-economic impacts, to improve their design and efficacy.

These initiatives have dual goals: to secure critical natural capital through targeted investments across landscapes and regions, and to alleviate poverty through targeted wealth transfers from coastal provinces to inland regions where many ES originate. The Chinese government aims to reduce the loss of soil, improve water retention, reduce desertification, and generally protect biodiversity and ecosystems in the west of the country for flood control, hydropower production efficiency, irrigation supply, more productive agriculture, and ecotourism. In addition, it wants to change the economic structure in rural areas to increase local household income while simultaneously making local households' patterns of land utilization and agricultural production more sustainable [36, 37].

The initiatives include two national PES programs, the Natural Forest Conservation Program (NFCP) and the Sloping Land Conversion Program (SLCP), established in 1998 and 1999 respectively. Implementation was tested in a few provinces, and then rapidly scaled to the whole country. Evaluation of the programs shows significant achievement of the biophysical goals, with remarkably rapid land conversion in the desired directions. For example, by the end of 2006, the SLCP had converted ca. 9 million hectares of cropland into forest/grassland and had afforested ca. 12 million hectares of barren land. Village-level field measurements have shown not only that the payments for ES have altered land use patterns, but in turn soil erosion has been decreased in some areas by as much as 68% [9].

Overall social impacts of the programs are mixed. In some places, payment levels and types are leading to improvements in economic measures of well-being, whereas in others payments were not sufficient to compensate for loss of income from shifting livelihoods [37]. In addition, in some places where participation in the SLCP has significant positive impacts upon household income, it has not yet transferred labor toward non-farming activities as the government wished [36]. Payments are now being adjusted to improve success in achieving goals of poverty alleviation and growth of new economic sectors in rural areas.

China is also now establishing a new network of Ecosystem Function Conservation Areas (EFCAs), specifically for ES provision. Their exact delineation is now being determined through quantitative ecosystem service mapping and valuation. They are expected to span ca. 25% of the country.

The current and potential future impacts of ES investments in China are enormous, certainly within the country – and also globally, in the form of enhanced carbon sequestration and reduced dust export, and perhaps most importantly in lessons on making the investments needed in natural capital and human well-being everywhere.

International Scale: Global Policy and Research Efforts

As described above, the MA was the first major effort to establish ES in the international policy arena. Activities stemming from that effort are now aimed at bringing countries together in making tangible commitments to safeguard ES (e.g., 2020 targets for the Convention on Biodiversity) and to assess national and international progress toward those commitments (e.g., through Group on Earth Observations Biodiversity Observation Network (GEO BON) and the Programme on Ecosystem Change and Society (PECS), which synthesize knowledge for the International Platform for Biodiversity and Ecosystem Services (IPBES), formally established in 2010). Several new international research efforts aim to feed into these international processes, including the Natural Capital Project, The Resilience Alliance, and the Stockholm Resilience Centre. Other entities are focused on establishing and tracking ES markets, as a mechanism for bringing larger attention to ES benefits to society (e.g., The Katoomba Group and The Ecosystem Marketplace, both initiated by Forest Trends). As an example of many burgeoning international efforts, we describe in greater detail the Natural Capital Project.

The Natural Capital Project (NatCap) (www.naturalcapitalproject.org) is an international partnership working to align economic forces with conservation, by developing tools that make incorporating natural capital into decisions easy and replicable; by demonstrating the power of these tools in important, contrasting places; and by engaging leaders globally. NatCap is developing InVEST, a family of tools for Integrated Valuation of Ecosystem Services and Tradeoffs.

InVEST helps decision makers visualize the impacts of potential policies by modeling and mapping the delivery, distribution, and economic value of ES under alternative scenarios (for more information, see [30]). The outputs identify trade-offs and compatibilities between environmental, economic, and social benefits. InVEST is designed for use as part of an active decision-making process (Fig. 6.4) and can be applied at local, regional, or global scales. The first phase of the approach involves working with stakeholders to identify critical management decisions and to develop scenarios that project how the provision of services might change in response to those decisions as well as to changing climate, population, etc. Based on these scenarios, a modular set of models quantifies and maps ES. The outputs of these models provide decision makers with information about costs, benefits, trade-offs, and synergies of alternative investments in ES provision.

NatCap is using InVEST in major natural resource decisions in diverse contexts around the world, including in the three examples given above (water funds, coastal and marine spatial planning, and land-use planning and human development in China). The aim is to demonstrate the power of these approaches and to learn how to replicate and scale up models of success. The Project is engaged in a suite of international efforts, including GEO BON and IPBES, to offer a common, unifying platform for regional and national efforts that are spawned by these initiatives.

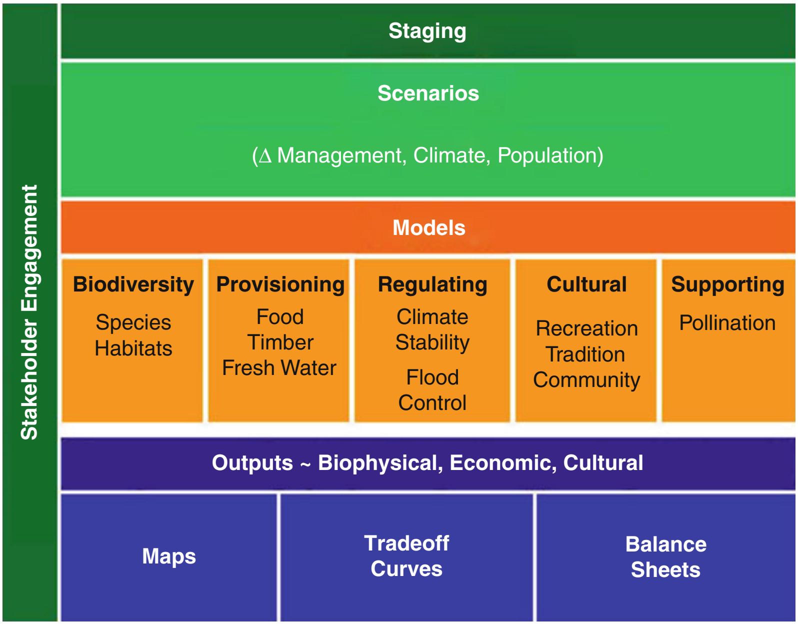

Fig. 6.4 An iterative process for integrating ecosystem services into decisions. The process begins with stakeholder engagement around impending decisions, with a focus on realistic, alternative scenarios for the future. The modeling is shaped by stakeholders, and typically focused on the services and scenarios deemed most important. Outputs are displayed in accordance with stakeholder preferences, in the form of maps, trade-off curves, and/or balance sheets. These can be expressed in biophysical (e.g., tons of carbon), economic (e.g., dollars), or cultural (e.g., visitor-days) terms

Future Directions

With the rapid rate of development of ES mapping, from the biophysical and economic modeling through to policy application in diverse socioeconomic contexts, it is likely that great advances will be made in coming years. What we report here is only a beginning. There are key arenas in which further learning is crucial to understand what drives variation in the provision of ES, how they percolate through various arms of society, and how social reaction leads to sustainable or unsustainable change in ES provision.

Relating Ecosystem Services and Human Health

The relationships between biophysical attributes of ecosystems and human health are complex [41]. Destruction of natural ecosystems can at times improve aspects of public health. Draining swamps, for example, can reduce habitat for the mosquito vector that transmits the parasite that causes malaria. On the other hand, destruction of other systems can have sharp negative consequences for human health. There is emerging evidence that loss of tropical forests, for example, leads to an increase in transmission of malaria [1, 50]. Similarly, fragmentation of, and biodiversity loss from, eastern North American forests is associated with an increase in lyme disease [32].

Natural and managed ecosystems provide many services that sustain human health, through provision of human nutrition (especially of protein and micronutrients); purification and regulation of drinking water; regulation of air quality; regulation of vector-borne disease; and psychological benefits. There is a great need for research illuminating the links between biodiversity, ecosystem conditions and processes, and human health.

Trade-offs and Synergies

The relationship between ES and biodiversity and among different ES varies with socio-ecological context. In some cases, clear trade-offs and synergies among services have been defined in specific contexts [54], but there is still much to be learned about what determines the nature of these relationships. Advancing this knowledge is essential because policies addressing management change can only be successful if management controls ES relationships. If policies are established to align multiple ecosystem services, but biophysical conditions in the system lead to innate trade-offs among services, management changes are bound to fail in delivering the desired improvements to social benefits.

Distributional Effects

Much of the science of mapping ES has focused on identifying where ES are generated and where they are delivered. However, less work has focused on identifying to whom ES actually flow. This connection is essential if policies addressing ES delivery are to be equitable and either improve the well-being of the poor or avoid unintended distributional consequences. Past work in this arena has focused on overlaying maps of ES provision with an array of poverty indicators (e.g., [68]). Missing from this spatial analysis is information on access to and ability to control the delivery of ES. In many cases (e.g., for services such as clean drinking water, hydropower production, agriculture, water for irrigation, wave power generation), the actual delivery of services to specific people is affected by the location of infrastructure or institutions regulating access to resources. New science is needed that allows the ready mapping of these connections and the prediction of how they will change under future conditions.

Dynamic Effects: Shocks and Uncertainty

Dynamic changes, such as in climate and in the nitrogen cycle – as well as changes arising through economic development and evolving human preferences over time – are very important. The possibility of feedbacks within ecosystems, and between ES and human behavior, is a key area for further development. Feedback effects can give rise to thresholds and rapid changes in systems that can fundamentally alter system outcomes [60]. 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.

Valuation in Monetary and Non-monetary Terms for Decision-Making

Monetary valuation of ES is not nearly as prevalent as sometimes assumed. More typically, real-world applications of the ES framework rely on biophysical values to inform policy design, such as measures of water quality or flood risk.

Value is not always easily characterized or fully captured in monetary terms, so it is important to characterize value in multiple dimensions, including health, livelihood support, cultural significance, etc. (e.g., [17]). This will help ensure that valuation and broader decision-making approaches are inclusive of the range of benefits and people concerned [28]. Interdisciplinary efforts are presently underway to create a conceptual framework that is useful both in theory and in practice for a broad suite of cultural ES.

Institutional Design

However ES are measured, there is a need for political and social science research to design institutions and policy mechanisms that better capture externalities. Efforts such as national accounts are blossoming now, but it is unclear how they will evolve and how successful governments will be at incorporating natural capital into national measures of wealth. There is great work to be done in determining the merits and limitations of alternative policy and finance mechanisms, in different economic, governance, and other social contexts (e.g., [5, 46, 58, 59]). There is also great work to be done in developing institutions that achieve representation and participation by stakeholders as part of adaptive governance systems (e.g., [13, 55]).

Conclusions

Ecosystem services have had a relatively long history through indirect recognition of the importance of nature for the persistence of the human endeavor. There are scientific challenges for biogeochemists, hydrologists, ecologists, economists, anthropologists, and other social scientists to understand how human actions affect ecosystems, the provision of ES, and the value of those services. At least as demanding are the social and political questions associated with incorporating this understanding into decision-making. There is also a need to design effective and enduring institutions to manage, monitor, and provide incentives that reflect the social values of ecosystem services. Information is becoming more readily available for individuals, corporate managers, and government officials who make decisions affecting ecosystems and the services to consider a more complete set of costs and benefits associated with their choices. We are likely to see continuing growth in our scientific ability to measure and predict changes in ES, our ability to design policies and institutions that accurately represent these changes and in turn, the ability of the environment to continue providing the many benefits society needs to prosper.

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