Chapter 9.2—Ecosystem Services

Trista Patterson[1]

Summary

Since its inception, the ecosystem service approach has stimulated interest from numerous planning, management, and partnership perspectives. To date, however, research that quantifies ecosystem services in the study area (in the form of explicit ecosystem service studies) has been limited. This chapter reviews and synthesizes the concept of ecosystem services, focusing on information to assist forest planners and managers in framing and describing concerns and tradeoffs in social, ecological, and economic values. It does not repeat information about specific ecosystem services that is found throughout the full synthesis document; rather, it provides examples of how the term "ecosystem services" may be used and understood in different ways by different people.

The Forest Service has a long history of managing and providing what are now called ecosystem services, beginning long before the term itself came into use. Many individuals in the agency are reporting applications of the concept, advances in quantification of service values, and some successes in engaging more diverse stakeholders and promoting interchange between management and research. Although situational in nature, these examples illustrate breadth in the potential management application of the concept, and they are highlighted in sidebar boxes throughout this chapter.

Owing to the cost of assessment and valuation efforts, it is likely that the team performing bioregional assessments will assess the condition and trend of most ecosystem services in general terms by selecting only a few to quantify and model. The information provided here may help inform which ecosystem services, datasets, and approaches could be emphasized during the assessment phase. Themes explored in this chapter are not prescriptive, but are intended to help identify information and expertise to help inform assessment of ecosystem services. The "Frameworks for Adaptive Management" section below reviews how Forest Service assessments to date have characterized relationships between elements of the ecosystem service system. Although certain relationships are highly quantified and familiar, other relationships are of emerging importance and are less likely to have established quantified relationships. The "Frameworks" section underscores the importance of investments in data and efforts to understand relationships that are less well known—specifically, documenting factors affecting both supply **and demand** for ecosystem services. This information would be particularly important in describing the ability of the study

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area to provide future ecosystem services and to anticipate deficits or shortfalls. To address such shortfalls, this chapter highlights emerging options and broader arrays of management interventions and opportunities in agency operations planning. It also acknowledges that some challenges may require coordinated effort over time (e.g., new datasets, or new strategies to support both supply and demand challenges of ecosystem service issues).

Extensive detail in valuation methodology is beyond the scope of this document. Appropriate experts can be consulted when market or nonmarket services need to be valued either in dollar or other social terms. Rather, this chapter is intended to enable natural and social scientists from other disciplines to participate in meaningful discussion and deliberation over what kind of information regarding values might best inform management goals.

Overview and Chapter Organization

The first section of this chapter provides a summary of definitions, concepts, and uses of the ecosystem services concept by the U.S. Forest Service. The second section provides a general framework for defining the scope of an ecosystem service assessment and characterizing the relationships among its various components. Particular emphasis is placed on relationships that reveal new or emerging management options for addressing ecosystem service deficits. The final section describes approaches in more detail, as well as methods for valuing ecosystem services.

Information on ecosystem services related to specific land covers, habitats, or species is covered in other chapters of this synthesis. The social science chapters characterize many of the dynamics of the local community, economy, and visitors, which all rely upon these ecosystem services to some extent for their well-being and resilience. The majority of data and information regarding ecosystem services for the study area is found in non-peer-reviewed sources or working papers (Richardson 2002, Richardson and Loomis 2009), mapping efforts, or other overview efforts. Of particular note are extensions of the Natural Capital Project and related partnerships (Kareiva et al. 2011, Myers 1997, Polasky 2008, Polasky and Segerson 2009).

Although many single-service studies exist for the study area (e.g., carbon, water, grazing, etc.), they are often not explored with a specific ecosystem service framework as the lens, and the diversity of perspectives, units of quantification, and spatial scales that result often render efforts to combine data and information somewhat unwieldy (Patterson and Coelho 2009). To date, the most comprehensive resource covering ecosystem services (though they are not termed as such) is the Sierra Nevada Ecosystem Project (SNEP) 1996 report to Congress; however, the

various chapters of the SNEP report focus almost exclusively on elements of provision. As the "Frameworks" section of this chapter points out, a more systematic ecosystem service assessment will complement this supply-side information with quantified information about use of ecosystem service benefits on and off site. Information about ecosystem service supply and demand is needed to characterize ecosystem service scarcity and to articulate present and future value.

Importance of Ecosystem Services Within the Synthesis Region

The Millennium Ecosystem Assessment (MEA), one of the most widely cited global assessments of ecosystem services, defines ecosystem services as the benefits people obtain from ecosystems (MEA 2005). These benefits include provisioning, regulating, and cultural services that directly affect people, as well as the supporting services needed to maintain other services. Ecosystem services provided by the Sierra Nevada contribute to the quality of life for millions of people, many living a great distance from the Sierra Nevada. A dramatic example is San Francisco's drinking water, which originates in Yosemite National Park. More broadly, the Sierra Nevada snowpack provides nearly 65 percent of California's water supply (SNEP Science Team 1996). The area produces over $2.2 billion worth of commodities and services annually in water resources, agricultural and timber products, ranching, and mining, and provides more than 50 million tourism and recreation visitor days annually (SNEP Science Team 1996, White and Stynes 2010).

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Despite the many benefits they provide, many Sierra Nevada ecosystems, species, and their respective ecological processes are being negatively affected by development trends, rising population, habitat fragmentation, and intensification of human activity. By 2040, almost 20 percent of Sierra Nevada private forests and rangelands could be affected by projected development (SNEP Science Team 1996). These effects are of concern from an ecosystem services perspective, as they have resulted in diminished, interrupted, suspended, or redirected flows of ecosystem services. Primary concerns include forest disturbance events and trends, and phenomena such as climate change (Deal et al. 2010, McKenzie et al. 2004), erosion (Neary et al. 2009), invasives (Eiswerth et al. 2005, Zavaleta 2000), housing development (Stein et al. 2005), losses in species diversity and redundancy (Tilman 1997), and successional phases following timber extraction (Beier et al. 2008). Increasingly, studies are attempting to determine the economic impacts and tradeoffs of these losses before they occur (Barbier 2007, Murdoch et al. 2007, Sukhdev et al. 2010). As discussed later in this chapter, incentives to restore lost services, or to prevent losses before they occur, are becoming increasingly common in market-based approaches to private forest conservation.

Characterizing Ecosystem Services

Ecosystem services are generally described according to how they contribute directly and indirectly to human benefit (MEA 2005). Specifically, an introductory schema organizes goods and services according to whether they are provisioned (e.g., timber, drinking water, fuels, mushrooms, berries, venison, fish); regulate (e.g., carbon sequestration, erosion control, riparian forest cleaning, filtering and cooling streamside water); provide cultural services (such as recreation, spiritual enrichment, educational opportunities); or support the other services (biological diversity, nutrient cycling, etc.) (fig. 1).

Which Definition Is Best, and for Which Purpose?

In part, an articulate depiction and accurate assessment of ecosystem services of the Sierra Nevada hinges on how the term "ecosystem services" is used and approached. The ecosystem services literature is derived from the fields of ecology and economics (Ehrlich et al. 1977, Ehrlich and Ehrlich 1981, Krutilla 1967, SCEP 1970, Westman 1977), and has resulted in a particularly wide range of definitions (Kline and Mazzotta 2012, Patterson and Coelho 2009). In general, one can imagine a spectrum of increasing need for precise typology and definition to guide selection of terms and literature (fig. 2, adapted from Kline and Mazzotta 2012).

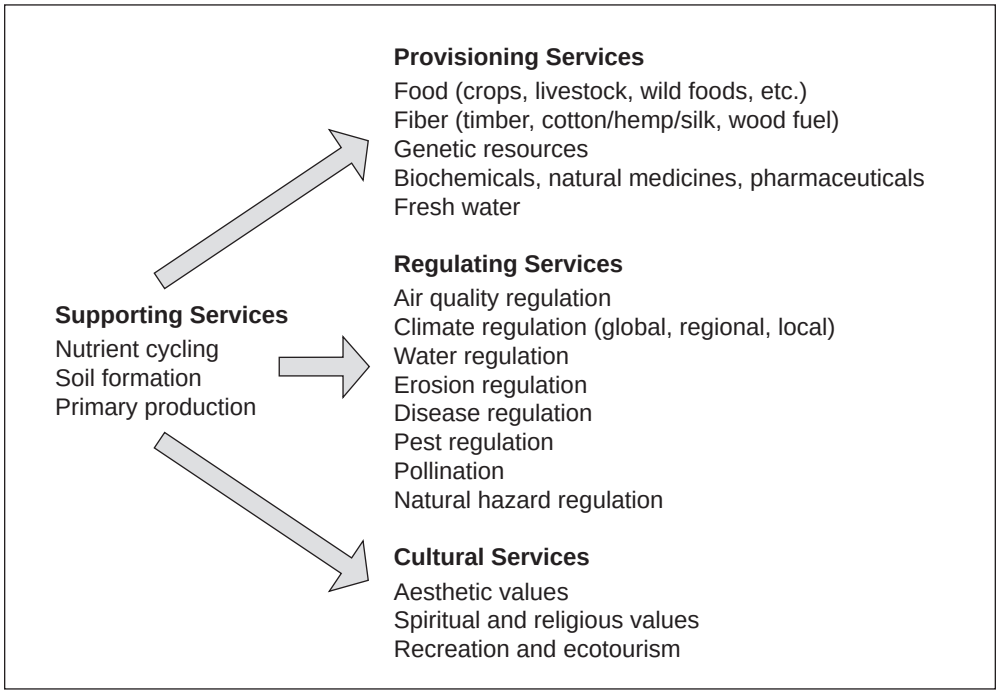

Figure 1—Broad categories of ecosystem services (adapted from MEA 2005, used with permission from Patterson and Coelho 2009).

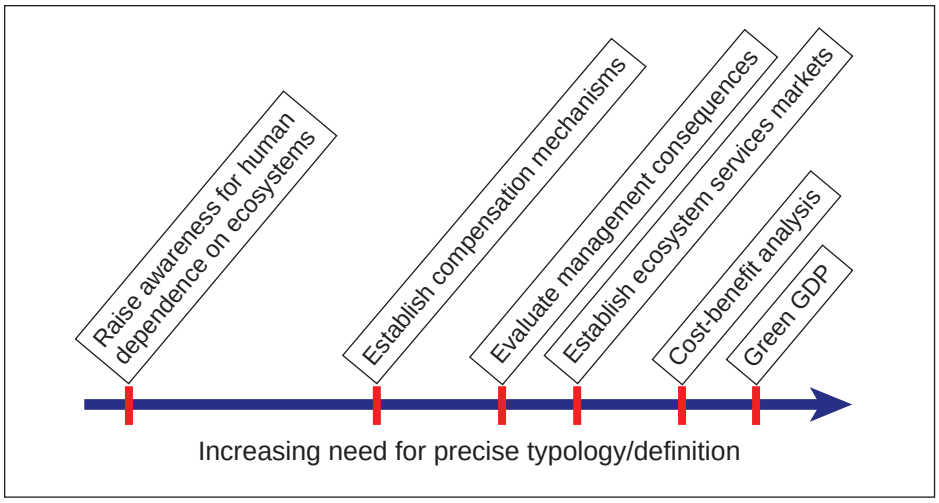

Figure 2—Specificity of terms can be based on intended uses of the ecosystem service concept (adapted from Kline and Mazzotta 2012). GDP = gross domestic product.

Two oft-cited works describe ecosystem services as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life, thereby supporting quality of life on earth (Costanza et al. 1997, Daily 1997). Forest Service projects designed to raise awareness of forested ecosystems and public investment tend to use similarly general language (Collins and Larry 2008, Daily 1997, MEA 2005). More specific definitions may be used to estimate replacement cost of lost ecosystem services, or to incorporate these benefits into conceptual framing of important social issues (Costanza et al. 1997, US EPA 2006). The narrowest definitions are needed to provide the criteria for specific accounting, tracking, and decisionmaking (Boyd and Banzhaf 2006, Boyd 2007, see also reviews in Costanza 2008; de Groot et al. 2002, Fisher and Turner 2008, Kline and Mazzotta 2012).

Forest Service Use of the Ecosystem Service Concept

Ecosystem services, and their values and meaning to society, are important to consider as the Forest Service attempts to grow as a "learning organization" (Apple 2000), and they are important to consider as one component of emerging and strategic foresight initiatives (Bengston et al. 2012). To this end, the ecosystem service concept broadens the scope and the spatial and temporal scales of what scientists, managers, and public-private partnerships consider in forest management. An ecosystem services approach therefore relies on a mix of traditional and new performance measures that are important to society, based on the management targets from the activity site itself, and in conjunction with other measurable outcomes and influences experienced in the wider forest area.

The Forest Service has managed for ecosystem services since its establishment as an agency (MacCleery and Le Master 1999), but it currently uses the concept as a means to inform management decisions, to increase funding directed at the management/conservation of ecosystem services, and to raise the visibility of the value of forests and the diversity of benefits they provide to the American people (Collins and Larry 2008, Kline 2006, Patterson and Coelho 2009, Smith et al. 2011). Box 9.2-1 details uses of the ecosystem service concept within Forest Service management efforts, as adapted from a summary effort from the Deschutes National Forest (Smith et al. 2011).

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Incorporating information about ecosystem service values into management planning is important because ecosystem service harvests, uses, and exchange often do not take place in markets. They might be collected by individuals, or shared among family and friends (e.g., game meat, subsistence salmon, mushroom picking, etc.). They may accrue to everyone publically as part of ecosystem function, and may not be particularly visible (e.g., carbon sequestration, water purification, etc.). Benefits may flow far from the landscapes where they are produced. Tracking indicators of ecosystem service supply and demand, and their status over time, is important because most common economic indicators (e.g., gross domestic product [GDP]) do not account for quantity or quality of natural capital stocks, or the value of many ecosystem services (Boyd and Banzhof 2006). The indicators used in many civic decisions often do not weigh the consequences of ecosystem service losses (Boyd and Banzhoff 2006, Patterson and Coelho 2009) until after those losses have already occurred.

Worldwide, national and international policies are increasingly reporting on ecosystem services from public lands (EUSTAFOR and Patterson 2011). The concept is consistent with USDA's emphasis on collaborative approaches and outreach to increasingly diverse stakeholders. Consistent with the USDA 2012 planning rule, Forest Service integrated resource management must use the best available scientific information to guide management of National Forest System (NFS) lands so that they have the capacity to provide people and communities with ecosystem services and multiple uses that provide a range of social, economic, and ecological benefits for the present and into the future. Changes to NEPA requirements are still anticipated, and the extent to which approaches across different forests will be coordinated is not known. However, some attempts at guidance documents have been made to guide management of NFS lands, and it is anticipated that future ecosystem service assessments will be needed to support planners in their work to support social and economic sustainability.

Box 9.2-1

Uses of the Ecosystem Service Concept Within Forest Service Management[2]

1. **Describing the value of forests**
   The ecosystem service concept has been effectively used to generate awareness of values from public and private goods from forest systems and to help improve wider understanding of the ways in which funded, sustainably managed forests can support those benefits in perpetuity.

2. **Characterizing and evaluating tradeoffs between different values, functions, goods, and services**
   Forest management activities (e.g., for timber, biomass, recreation, riparian enhancement) affect ecosystem services in different ways, and new tools are needed to describe and evaluate the benefits that result (e.g., a more complete account of the range of values, a better analysis of the relationships between multiple values, or a better analysis of the benefits of management activities that are relevant to particular stakeholders or potential partners).

3. **Identifying ecosystem service decline and providing a wide range of potential mitigating or restorative options**
   Informed changes to forest policy, actions, and techniques can redress some declines. Meanwhile, planning, education, and public-private and federal-state-municipal partnerships can affect ecosystem service use and conservation, reducing pressure on the resource and raising awareness of its value.

4. **Providing a basis for consultation and collaboration with stakeholders by defining common objectives for forest stewardship**
   By clearly describing benefits, the ecosystem services approach offers a common language for forest owners and interest groups to describe and articulate management objectives.

5. **Supporting the emergence of markets, products, and payments for ecosystem services**
   Many forest benefits, such as freshwater production, protection of topsoil, carbon sequestration, and preservation of biological and genetic diversity, as well as traditional commodities and services, such as timber, grazing, recreation and aesthetic beauty, and cultural and educational benefits, can be supported through various mechanisms, which transfer payments to the lands producing those services.

[2] Adapted from Smith et al. 2011.

Frameworks for Adaptive Management

In 2005, the Millennium Ecosystem Assessment reported declines in more than two-thirds of the world's ecosystem service systems. Stemming ecosystem service declines will require more than simply quantifying provision of ecosystem services or willingness to pay for them, because even the healthiest ecosystem has upper limits to the rates at which it can provide ecosystem services in perpetuity (Patterson and Coelho 2008, 2009). When consumption exceeds production of ecosystem services, management issues can arise quickly. Harvest/transport/waste systems related to ecosystem service consumption can adversely affect ecosystem service production systems (Beier et al. 2008, Patterson and Coelho 2009). Exceedances of certain thresholds can increase the probability and severity of ecological impairment, and can reduce system resilience to similar shocks over time (Folke et al. 2004). Reduced ecosystem service flows that result may limit management options for present and future generations. Thus, an important component of resilience in socioecological systems is the ability of management to keep a system within certain system boundaries (Chapin et al. 2009; Toman 1994, 1998; Wackernagel et al. 2002).

One of the most important steps at the outset of any ecosystem service assessment is the declaration of an explicit framework, because it is within this construct that system boundaries can be defined, current status can be benchmarked, relations between system components can be examined for possible management or intervention options, and with quantification, progress can be tracked against overarching goals (Patterson and Coelho 2008). Just as ecosystem services may have various definitions, conceptual frameworks also vary widely (Boyd and Banzhaf 2006, Brown et al. 2007, de Groot et al. 2002, Fisher et al. 2009, Kline and Mazzotta 2012, Norgaard 2010, Patterson and Coelho 2009, Smith et al. 2011). Guidance on framework selection specific to forest management is only beginning to emerge.

An often overlooked step in declaring an assessment framework is evaluation of whether the system description contains all the necessary components and expresses the necessary relationships to address gaps between the present and desired state of the system (Patterson and Coelho 2008). Figure 3 reflects elements of the most common ecosystem service approaches, as summarized in a pending review of existing frameworks for Forest Service management applications. The arrows between system components in figure 3 reflect the relationships most frequently emphasized in ecosystem service study: between management decisions and forest resources/supply of ecosystem services, between stressors and resources/conditions, between resources/conditions and the supply of services, between

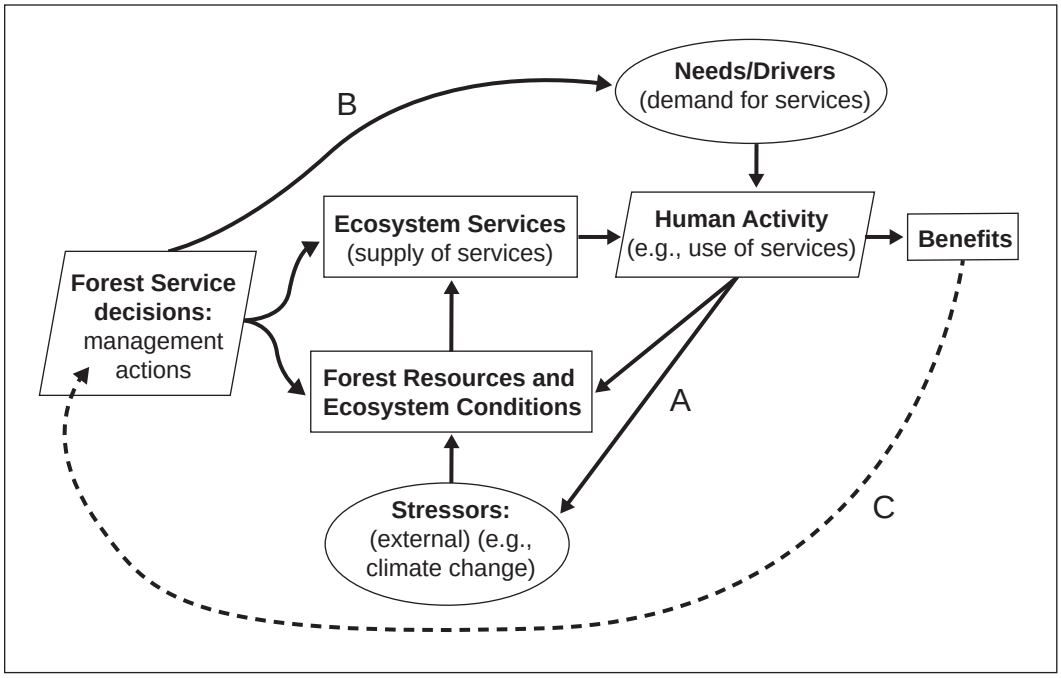

Figure 3—Ecosystem services as a framework for forest management (modified from Kline and Mazzotta 2012 and Patterson and Coelho 2009). Three challenge areas are highlighted with labels A, B, and C.

supply of services and human use of them, and between the drivers for services and use of services. Each of these relationships lead to net benefits anticipated from the system.

Long-standing resource management challenges can be deeply embedded within systems and structures that may push back on efforts to resolve them or reinforce their persistence (Folke et al. 2004). A systems approach to system intervention can assist in identifying intervention that will have more enduring, or systemic, impact and can thereby make best use available of scarce funds (Patterson and Coelho 2008). A systems assessment begins with articulation of important system components and agreement upon relationships and feedbacks among component parts. This step is particularly important, as system definition is often assumed as a tacit, rather than explicit, element of ecosystem service study (Patterson and Coelho 2008), and lack of consensus in this regard leaves ecosystem service assessment subject to a few typical pitfalls—namely, failure to allocate sufficient resources to addressing data, informational, and relational gaps (Patterson and Coelho 2009).

As data and understanding of interdependency between people and ecosystem service systems become more commonplace, these connections and relationships will become easier to establish and communicate. For now, this chapter will point out three general relationships for which ecosystem service information has tended to be less available, but which are critical to establishing the feedback loops that

can govern human use of ecosystem services within the bounds of ecological limits. Establishing these relationships is the first step to broadening management actions to include them. Each of these connections represents a whole range of possible management options to address ecosystem service system resilience. The more diverse the suite of management options, the broader the options to ensure effective and sustainable management of ecosystem service systems into the future.

The first connection involves identifying and quantifying ecological system capacities and limits (Rockström et al. 2009), in particular in cases where use of ecosystem services borders on "over consumption" (Erlich and Goulder 2007, Wackernagel et al. 2002) and impairs regenerative capacity or otherwise stresses the system (labeled A, fig. 3). A second connection involves examining ways in which effective management can inform "best practice," "informed decisions," and awareness of system vulnerabilities (labeled B, fig. 3). A third connection is using information about benefits resulting from forest management to feed back into those actions themselves (labeled C, fig. 3). This can serve to raise awareness for the benefits of the actions themselves, or to help anticipate system shocks (price or otherwise) when ecosystem service deficits arise and management for resulting ecosystem service losses is needed.

Addressing and Assessing Value

It is often assumed (incorrectly) that the terms "value" or "valuation" are explicitly referring to the use of dollar figures as a common denominator, when in fact, a much broader interpretation is being implied.

A clearly defined system is a necessary starting point for discussions of tradeoffs and value. Many disciplines across the social sciences are needed to fully articulate the meanings of the word "value." It is often assumed (incorrectly) that the terms "value" or "valuation" are explicitly referring to the use of dollar figures as a common denominator, when in fact, a much broader interpretation is being implied. If and when it has already been decided that a dollar value is indeed useful, the discussion can then progress to whether the dollar value needed should be estimated by market or nonmarket terms, and in which form this information might be meaningful in a decisionmaking context.

Once conceptual and then quantified assessments of ecosystem services have been made, moving to application, evaluation of tradeoffs, and characterization of value becomes an increasingly specialized effort (Kline and Mazzotta 2012, Patterson and Coelho 2009). There are many ways to approach value, and the social tools employed to canvas and incorporate diverse user perspectives also affect ecosystem service emphasis (Spash 2008, van den Belt et al. 1998).

The selection of participants, and their awareness and perception of ecosystem services and their importance, can affect reported values. Studies relying on participant perception may not reflect important components of system complexity

(Norgaard 2010), or they may emphasize market over nonmarket contributions or reflect other equity and distributional predispositions both within and between generations (Brown et al. 2011). More recent approaches designed to control for this shortcoming may facilitate group deliberative techniques, wherein a group is assembled and facilitated with the goal of coming to common agreement on value (Howarth and Wilson 2006, Spash 2007). As with other techniques, a representative sample of the general public needs to be used for the deliberative process to yield values generalizable to the broader public (Brown et al. 1995). And, no matter which method is used, important equity issues remain.

The total economic value (see fig. 4) is inclusive like the MEA model and is suited to the many ecosystem services provided by forests. Although many benefits from forests are tangible and benefit people through direct use (such as timber products), other forest benefits are harder for people to identify in their daily lives, especially in any quantified form that would be easily associated with forest management actions. Some examples might be additional units of carbon sequestration, or additional quantities of water that may be "embedded" in production of a final consumer product (e.g., Hoekstra and Hung 2005). Whether ecosystem service uses are categorized as direct or indirect, it is important to underscore that this changes the way they must be accounted for and the clarity and ease by which many consumers and citizens understand benefits. It does not change the fact that many benefits accrue to people indirectly. For example, biodiversity and scenic, cultural/recreational uses are particularly challenging to address as ecosystem services. Cautions abound in the literature, as each ecosystem service model is only as strong as its ability to describe these indirect connections and values (Brown et al. 2011). Although trends in values are beginning to emerge, meta analyses of existing values have suggested that prediction of a value based on previous studies remains uncertain, and the need for site-specific valuation efforts remains important (Woodward and Wui 2001).

Valuation Methodologies

Economic valuation exercises may provide a useful way to compare change in certain conditions resulting from a management action to a change in welfare experienced by a given set of individuals. This may be relatively straightforward in cases where the tradeoffs are well defined, and where market prices exist for each element that the user considers of value. However, particularly in the public goods context, this is often not the case, and it adds a great deal of complexity to the task of evaluating tradeoffs among land use and land management objectives (NRC 2005).

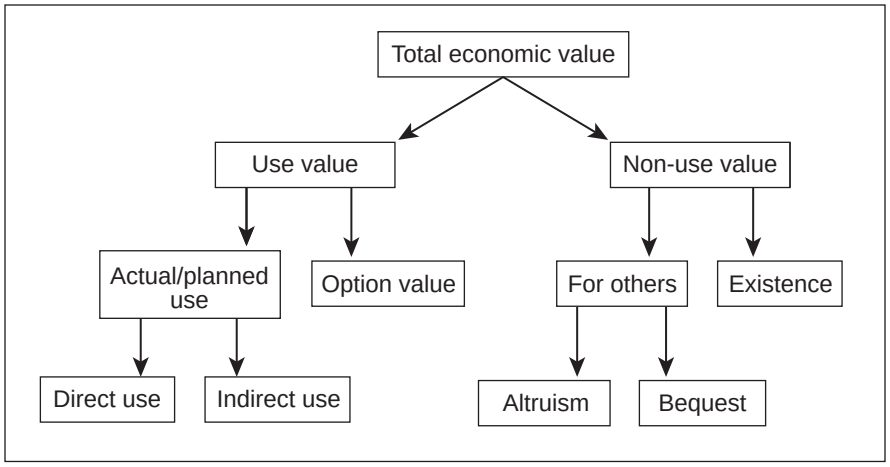

Figure 4—Components of total economic value of ecosystem services. Values are less tangible the further to the right.

Nonmarket estimation techniques for ecosystem service valuation have advanced a great deal in recent years.

Traditional approaches offer many techniques to elicit value. Values may be stated (Sugden 2005), revealed in preference studies (Bockstael and McConnell 2007), queried via willingness to pay (Brouwer et al. 1999, Carson and Mitchell 1993, Wilson and Carpenter 1999), estimated by travel cost method (Smith and Desvousges 1985), or transferred from other studies (Rosenberger and Loomis 2001), among other approaches.

Nonmarket estimation techniques for ecosystem service valuation have advanced a great deal in recent years (Freeman 2003, Loomis 2005). These techniques have included travel-cost methodology and contingent valuation (Loomis 1999), among others, to estimate use of many ecosystem services. Although valuation efforts of ecosystem services have often focused on direct uses, passive uses are also of high value to users of public forest lands (ibid). Existence values, option values, and bequest values may be the highest economic values for certain protected areas (Loomis 1987, 1989), and also serve as important values to biodiversity, science, and education (Balmford et al. 2002). Despite this awareness in general, pragmatic and specific decisions are still reliant on effective collaboration between ecologists and economists to ensure that the model is accurately reflecting the necessary level of ecosystem complexity. As Brown et al. (2011) reported, the devil often lies in the details of these valuation exercises.

Quantifying ecosystem service changes that result from changes in ecosystem conditions, land use, and land management is a substantial challenge and therefore adds costs and, sometimes, barriers to ascertaining value (Kline and Mazzotta 2012). Benefit transfer techniques (taking an average value from existing valuation studies or using estimates from an existing study in a new one) (e.g., Loomis and Rosenberger 2006, Rosenberger and Loomis 2001) are therefore attractive, particularly where cost, method, and logistics on public lands are otherwise

prohibitive (Iovanna and Griffiths 2006). However, numerous writers have pointed to shortcomings in these techniques (Ready and Navrud 2006, Spash and Vatn 2006), which require concerted efforts to overcome (Feather and Hellerstein 1997, Hoehn 2006, Loomis and Rosenberger 2006, and Smith et al. 2002, as summarized by Wainger and Mazzotta 2011).

Payments for Ecosystem Services

Public goods have long been a challenge in natural resource management (Hardin 1968). Increasingly, public institutions are relying on the emergence of market mechanisms to incentivize the provision of ecosystem services, especially to conserve forest as land cover (Collins and Larry 2008). Addressing "provision" of ecosystem services represents only a partial solution to rising ecosystem service deficits, as addressed in the next section of this chapter.

A great deal of enthusiasm has been expressed for market-based approaches to ecosystem service provision. Overextensions of market-based tools have led to pleas for a more "rational exuberance" (see review in Kline et al. 2009). Markets are not a complete solution for the challenge of ecosystem service provision, because the vast majority of ecosystem services are not and will never be marketable. Certain characteristics of ecosystem services can determine whether a market-based tool may result in a useful and efficient way to incentivize production (table 1). Yet even if these characteristics fit the ecosystem service issue at hand, distribution and equity issues may be left unaddressed, and this also entails management consideration.

Market efficiency assumes that certain characteristics apply to the good or service at hand. In the most basic terms, each credit (or equivalent ecosystem service unit) must be able to be consumed as a private good (as opposed to collective consumption), and be excluded from those who do not pay (Randall 1993), for markets to be efficient in their provision. Table 1 summarizes these characteristics.

Table 1—The public/private nature of goods: markets are generally most effective when applied to the ecosystem services categorized here as "private goods"

	Low rivalry (collective consumption)	High rivalry (private consumption)
Difficult to exclude (unlimited access)	Public goods: scenic views, biodiversity, clean air, carbon sequestration	Common goods: fresh water, fish stocks
Easier to exclude (limited access)	Club goods: private parks, car parks, recreation areas, ski areas	Private goods: timber, food, nonwood products

Adapted from Randall 1993; see Daly and Farley 2004 for extended discussion.

Increasingly, efforts are being made to move certain explicit and quantified ecosystem services from one quadrant to another, by modifying the excludability and rivalry characteristics of a well-defined "proxy," such as design of credits with which to track and trade in carbon sequestration (EUSTAFOR and Patterson 2011). The Forest Service, in partnership with other private and not-for-profit partners, has suggested that this may offer potential for more market-diversified product offerings (Collins and Larry 2008).

In market-based applications, additionality is a key concept that is often overlooked (Engel et al. 2008; Patterson and Coelho 2009; Wunder 2005, 2007). Additionality characterizes the extent (if any) to which the action, market, and payment increase the provision of the ecosystem services above and beyond that which would have been provided under a business-as-usual scenario. Payment systems may be initiated with seed funding, but in the absence of additionality, the credibility and longevity of ecosystem service market structures over time may be undermined (Wunder 2005, 2007).

Addressing Rising Demands for Ecosystem Services

Successfully addressing emerging deficits in ecosystem services requires stemming decline in ecosystem service production, as well as ensuring ecosystem service use is not wasteful or needlessly impactful to the systems that provide them (Beier et al. 2008; Patterson and Coelho 2008, 2009). Management tradeoffs are often considered in planning because they produce different bundles of services (Maness 2007), and awareness for and interest in various ecosystem services changes over time. Assessment of tradeoffs over space and time will thus require explicit definition of the area and time-step being considered, and identification of beneficiaries both near and far (information that is often lacking). For this reason, forest management and valuation efforts often focus on the supply side of ecosystem service information. Yet public funds can be spent both on maintaining or increasing supply of ecosystem services as well as on preventing waste or conserving ecosystem service use. The latter options can also be highly cost effective in addressing situations where ecosystem services have become particularly scarce.

Although ecosystem service data describes in general terms human dependence on natural systems, this information is difficult to tie to the management organizations, municipalities, households, and individuals making decisions about ecosystem service use. Visualization efforts have attempted to raise awareness of where ecosystem services are produced (Naidoo and Ricketts 2006, Natural Capital Project 2010, Ricketts et al. 1999), but only a few studies have mapped ecosystem service uses or potential for disturbance (Beier et al. 2008). Synthetic

indices (e.g., ecological footprints, carbon calculators, sustainability indicators, and sustainability report cards) are increasingly being used by states, cities, corporations, and individuals (Patterson and Coelho 2009, USDA FS 2007, Wackernagel and Rees 1996, Wackernagel et al. 1999). Forest Service management, as a requirement of Executive Order 43514, has targeted reductions in each of seven "footprint" areas since 2007 (USDA FS 2007).

Federal entities, which often have large building footprints, fleets, and equipment portfolios, offer valuable opportunities for experimentation, innovation, and investment in conserving resources and reducing pressure on ecosystem service systems. The Forest Service Sustainable Operations program[3] works actively to daylight consumption trends of the agency, provide tools for cost-benefit analysis, and promote efficiency and behavior change. Decreasing the agency's demand for resources and

[3] http://www.fs.fed.us/sustainableoperations/.

Courtesy of California State University–Fresno research team

Figure 5—Riparian area on Sequoia National Forest.

energy affects multiple ecosystem service systems and operating costs simultaneously. These business practices can include behavioral changes, such as turning off lights and computers when not in use; watering landscapes less frequently; recycling; using fuel efficient vehicles, energy efficient appliances, and electronics, and water aerators on faucets; minimizing packaging; and fixing water leaks—these are just a few of the items summarized by the Sustainable Operations program.

Conclusions and Directions for Future Research

This chapter has provided a review and synthesis of the ecosystem service concept, which will be important as planners and managers conduct assessments in the synthesis area. The chapter discusses different definitions of the ecosystem service concept, offering examples of its diverse applications. The "Frameworks" section of this chapter highlights the current emphasis on the supply of ecosystem services, but it also describes three "challenge areas" that can assist the agency in its aim to "tell the story differently" and ultimately utilize a broader range of ecosystem service interventions to address deficits before they become acute.

The Sierra Nevada synthesis area has a unique opportunity to contribute a vivid and prominent case study to an emerging area of concern nationwide—specifically, quantifying and illustrating the dependence of urban areas, communities, and households on surrounding natural systems and the flows of ecosystem services that they produce. To date, this has been done in an abstract "ecological footprint" approach, but the Sierra Nevada case illustrates an opportunity to be more explicit both in spatial and in ecosystem service terms. Habits, lifestyle, technology, social norms, and rules, incentives, and penalties all determine the rate at which humans collectively use ecosystem services. Urban areas are examples where this use is particularly concentrated, and this concept is acutely felt in California because of population expansion, land conversion, drought, and other factors that escalate demand for ecosystem services, or interrupt their supply. These systems serve as valuable test cases that underscore the value of well-managed landscapes, and demonstrate the degree to which quality of life is dependent on flows of reliable ecosystem services. Unfortunately, the presence of tipping points for provision of ecosystem services is often not explicitly understood until after substantial economic, cultural, and social losses have occurred, and by then, the cost to replace those services is often prohibitive.

Unfortunately, the presence of tipping points for provision of ecosystem services is often not explicitly understood until after substantial economic, cultural, and social losses have occurred, and by then, the cost to replace those services is often prohibitive.

A wide range of perspectives on the concept of sustainability exists in the literature, and although those are not summarized here, some elements are covered in other chapters of this synthesis. Thomas (2012) addressed the important distinction between strong and weak sustainability, and how it bears on the agency's ability

to use concepts developed or outlined in PSW-GTR-220, *An Ecosystem Management Strategy for Sierran Mixed-Conifer Forests* (North et al. 2009), to build on stakeholder collaboration and system sustainability. Notions of intertemporal social well-being (Heal 2012, Jaeger 1996) may also be useful in framing conceptual tradeoffs that are examined in future studies. Future research is needed to articulate how methods and approaches from information management, systems analysis, and business and capital management strategies can help address the challenges described above in a cost-effective way. Increasingly, ecosystem service scarcities are spurring partnerships between public, private, nongovernmental, and academic sectors (Smith et al. 2011). Forest Service Sustainable Operations provides several place-based, strategic, and quantified efforts in this regard, and these have been of great interest also to partnering organizations from municipal and nongovernmental sectors. To date, however, these findings have been post-hoc, with few to no studies systematically comparing options, testing hypotheses, or establishing baselines, experimental design, or statistical controls. These shortcomings can be overcome with some foresight, planning, and sharing of information, particularly between scientists familiar with experimental design, engineers familiar with the systems (water, electrical, fleet), and members of business operations who can reveal units and current and historical billing and prices for the ecosystem services currently consumed in agency operations. Systemic solutions that address declines in ecosystem services require a coordinated approach to energy and material inputs to the economy (and the resulting waste and emissions), and projections of these for future time periods (Folke et al. 2004, Rockstrom et al. 2009). The ecosystem service concept presents an opportunity for the agency to take a more diversified approach, and in doing so, it may offer an opportunity for experimentation with a broader, whole-systems strategy to support landscape and community, resilience and sustainability.

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