Applying the Ecosystem Services Concept to Public Land Management

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We examine challenges and opportunities involved in applying ecosystem services to public land management with an emphasis on national forests in the United States. We review historical forest management paradigms and related economic approaches, outline a conceptual framework defining the informational needs of forest managers, and consider the feasibility of its application given the types of ecological information typically available and the expanding set of services considered in management decisions. Economists can make their work more relevant to managers by broadening their focus to include qualitative approaches and more directly and effectively collaborating with managers and natural scientists.

***Key Words*:** landscape analysis, national forest planning and management, public benefits

In recent years, federal agencies in the United States and other nations have enthusiastically adopted the concept and language of ecosystem services with the hope that it will improve the process of natural resource management and its outcomes (e.g., Collins and Larry 2007, The Economics of Ecosystems and Biodiversity 2010, President's Council of Advisors on Science and Technology 2011). The U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the U.S. Geological Survey (USGS) are a few examples in the United States (e.g., Hogan et al. 2009, EPA 2009). Despite this burgeoning interest and years of related work by economists and others since at least the 1960s to describe nonmarket benefits, many challenges remain for making ecosystem service concepts operational in resource management

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decisions. Here, we consider these challenges as they apply to management of public lands in the United States. Although our discussion and conclusions are applicable generally, we focus on issues specific to the USDA Forest Service and its management of national forests. Our work is based on our involvement with a team of Forest Service managers and researchers exploring ways to address ecosystem services in national forest management decisions (e.g., Smith et al. 2011, Asah, Blahna, and Ryan 2012, Kline and Mazzotta 2012).

The USDA Forest Service manages 193 million acres of forest and grassland in 44 states. The ecosystem services derived from these lands have direct impacts on both rural and urban communities by providing water, recreation opportunities, and other forest-related benefits. The concept of ecosystem services formally was incorporated into national forest management under a new planning rule (USDA Forest Service 2012) that requires forest personnel to address ecosystem services as they prepare national forest plans. By extension, although not explicitly required by the planning rule, forest managers may consider outcomes generated by ecosystem services as they conduct project-level assessments. The Forest Service hopes that the ecosystem service concept will allow forest managers to tell a richer story to Congress and the public about the benefits and tradeoffs associated with managing national forests, support decisions that promote sustainability, and facilitate partnerships with local communities, cities, and other entities that benefit from forest ecosystem services to accomplish needed ecosystem restoration on national forest lands. Adoption of the ecosystem service concept by the Forest Service is one part of an emerging "all lands" approach to landscape management that seeks to administer public lands for their various ecosystem service benefits while providing incentives for supplemental management activities on private land that can augment efforts to manage public land (USDA Forest Service 2006, Collins and Larry 2007).

For decades the Forest Service has invested in developing methods for measuring nonmarket benefits and incorporating those economic benefits into national forest planning documents and project-level assessments. Yet those efforts have not led to widespread application of economic principles and methods in national forest management (Loomis and Walsh 1992, Morton 2000, Loomis 2002). National forest managers still struggle with how to demonstrate the value of national forest management to the public and to stakeholders. The persistence of this problem implies that economists have much more work ahead of them before economic principles and methods are routinely incorporated into national forest planning and project-level analyses. Managers need accurate and cost-effective tools to address management questions and landscape complexity in ways that both they and the public can understand. With the shift to a focus on ecosystem services, many Forest Service officials and staff members find themselves immersed in discussions about how to identify and produce the information necessary to support their decisions.

We consider how economists might best help the Forest Service and other public land management agencies to address emerging objectives regarding ecosystem services. We begin by reviewing the evolving policy context of national forest management and what it has implied for economic analysis. We then develop a conceptual model of national forest management that defines the informational needs of forest managers. We discuss the challenges that economists and ecologists face in developing needed information and what the

challenges imply about feasible types of economic analysis to evaluate marginal changes in the ecosystem services produced on landscapes over time. Finally, we consider the types of analyses that might be beneficial to forest managers and suggest how economists and ecologists can most effectively help managers use such information in making decisions about national forests. Our intent is to foster broader thinking about how economists can best aid public land managers to describe and evaluate the tradeoffs among the various potential outcomes of public land management decisions.

Evolving Forest Management Paradigms and Economics

A review of the evolution of paradigms for national forest management and how economists have responded to them provides the foundation for considering the role that economics might play in a public land management process that focuses on ecosystem services. Rooted in the Forest Reserve Act of 1891 and the Organic Administration Act of 1897, national forests were intended originally to protect water and secure an adequate supply of timber resources for the benefit of the nation. For much of the first half of the twentieth century, national forest management was primarily custodial with the nation's demand for timber largely met by private land, and conflicts among national forest users were rare (Kessler and Salwasser 1995). That changed after World War II, and national forest management over the past 70 years can be divided into three distinct eras, each of which can be traced to specific socioeconomic forces and laws enacted by the U.S. government, resulting in a parallel evolution in economic research focused on public land management (Table 1). Emergence of the concept of ecosystem services in national forest management arguably can be viewed as an emerging fourth era, though it may be too early to know for sure.

With timber demand soaring during and after World War II, the custodial approach to national forest management was supplanted by a dominant-use focus on timber production. Economists and managers viewed the new approach largely in terms of maximization of timber yield (e.g., Faustmann 1849 (translated to English in 1968 in Oxford Institute Paper 42)) and other extractive, marketed resources. The emphasis on timber production eventually came into conflict with other emerging nontimber interests and values held by the public, including recreation and wildlife (Kessler and Salwasser 1995). Economic approaches began to adapt by working to incorporate various nontimber values. For example, Gregory (1955) applied traditional production-economics theory to define forest management as a problem of joint production of multiple outputs. That work focused on the forest outputs of interest at the time, including timber, forage, water, recreation, and habitat for species of commercial and recreational interest.

The continued emergence of nontimber interests and values in the collective mind of the public in the United States eventually led to passage of the Multiple Use Sustained Yield Act (MUSYA) of 1960, which initiated the era of multiple-use. The intent of multiple-use was to significantly broaden the national forest mission to formally include both market and nonmarket public benefits (MacCleery and Le Master 1999). Additional legislation, including the Resources Planning Act of 1974 and the National Forest Management Act of 1976, incorporated the multiple-use concept into new mandates for national forest planning and public involvement (Kessler and Salwasser 1995).

The dawning of the multiple-use era dramatically changed how resource economists addressed public land management problems. The legislative acts also led to many of the enduring challenges faced by national forest managers today regarding how to evaluate the outcomes expected from forest plans and projects. The MUSYA required that managers consider the value of amenity services derived from national forests along with traditional forest products. This provided greater impetus for extensions of the conceptual model of timber maximization to include amenity resource values. For example, Krutilla and Fisher (1975) presented a theoretical framework and approach for maximizing the value of an extracted product while considering the cost associated with

Table 1. General Approaches to National Forest Management from World War II to the Present and Their Implications for Economic Analysis

Management Approach	Time Frame	Initial Impetus	Management Emphasis	Example Economic Approaches
Dominant-use	1940s through 1950s	World War II and post-war timber demands	Sustained timber yield	Optimal rotation age for the single stand (e.g., Faustmann 1849), eventually multi-resource joint production (e.g., Gregory 1955)
Multiple-use	1960s through 1980s	Multiple-Use Sustained Yield Act (1960), Resources Planning Act (1974), National Forest Management Act (1976)	Regional production targets met via forest-level planning, including eventually FORPLAN and IMPLAN	Multi-stand and multi-resource models (e.g., Gregory 1955), eventually nonmarket valuation and tradeoff analyses (e.g., Peterson and Randall 1984, Bowes and Krutilla 1989)
Ecosystem management	1990s through 2000s	Public's dissatisfaction with multiple-use's seemingly continued emphasis on timber and increasing support for ecological objectives; numerous appeals and litigation	Forest sustainability coupled with a desire to reduce conflict and avoid litigation	Public preferences and safe minimum standards (e.g., Swallow 1996, Garber-Yonts, Kerkvliet, and Johnson 2004), tradeoff analyses (e.g., Lichtenstein and Montgomery 2003)
Ecosystem services	2012 to present	Continued appeals and litigation; Millennium Ecosystem Assessment (2005); new national forest planning rule (USDA Forest Service 2012)	Renewed commitment to participatory processes and forming collaborative partnerships	Call for trans-disciplinary approaches to address tradeoffs among multiple ecosystem services over space and time

Note: National forest management prior to World War II can be described as largely custodial and focused on protecting watersheds and securing national timber reserves (Kessler and Salwasser 1995). The table represents our attempt to synthesize information presented in Bowes and Krutilla (1989), Kessler and Salwasser (1995), MacCleery and Le Master (1999), Loomis (2002), Stevens and Montgomery (2002), and Collins and Larry (2007). Any errors remain our own.

foregone nonmarket recreation values. Krutilla and Fisher (1975) formulated the model in terms of a production function for the extracted good (using the example of kilowatts of hydroelectric power) that was optimized to provide the greatest social benefit. In the model, social benefit was defined as the sum of the value of extractive uses and of recreational benefits; recreational uses that were eliminated by extractive uses represented the environmental opportunity cost of the extracted good.

Krutilla's work, perhaps more than any other, was a prime motivation for economists' increasing focus, starting in the late 1970s, on incorporating nonmarket services into natural resource models to maximize net present values from managed landscapes. Initially, economists focused their efforts mostly on recreation and aesthetics, but the scope later expanded to address other resource and nonuse values. Much of this especially intensive period of research among resource economists focused on management of public forests. Krutilla's work was funded in part by the USDA Forest Service during the 1970s as the agency sought to define "a rational basis for multiple-use" (Kline and Mazzotta 2012). Krutilla's efforts for the Forest Service eventually formed the foundation for the widely cited *Multiple-Use Management: The Economics of Public Forest Lands* by Bowes and Krutilla (1989). Other works on multiple-use forestry included Pearse (1969), O'Connell and Brown (1972), Walter (1977), Alston (1979), and Teeguarden (1982) to name a few.

Bowes and Krutilla (1989) noted two key informational needs: (i) characterization of the responses of vegetation and wildlife to management and (ii) economic valuation of biophysical products. In response, much of the environmental economic research in forestry from the 1980s to the present has focused on valuing nonmarket benefits of ecological and environmental services provided by forests. Those research efforts are exemplified in works such as *Valuation of Wildland Resource Benefits* by Peterson and Randall (1984) and *Amenity Resource Valuation* by Peterson, Driver, and Gregory (1988), both of which involved Forest Service funding and scientists. This work continues within the Forest Service today with examples such as *A Primer on Nonmarket Valuation* by Champ, Boyle, and Brown (2003).

Despite these and similar efforts by others, the role of emerging environmental economic techniques in on-the-ground national forest management remained limited. Multiple-use was intended to enforce greater consideration of resource outputs other than timber, but in practice, it was difficult to overcome the inertia of the dominant-use era owing to prior training of forest managers in resource-specific disciplines (e.g., production forestry). Forest Service budget processes also tended to promote a dominant-use approach by focusing on achieving output-related (e.g., timber, grazing) targets that were assigned by Congress and were formulated entirely separately from forest management decisions (e.g., Bowes and Krutilla 1989, Stevens and Montgomery 2002).

An increasing reliance by economists on complex linear programming and other empirical models likely made matters worse. An enlightening example is the Forest Service's adoption of an optimization model, FORPLAN, for use in forest planning beginning in 1979 (it was later replaced by newer variants and other models) (Morton 2000, Loomis 2002, Leefers, Gustafson, and Freeman 2003, Gustafson, Roberts, and Leefers 2006). The FORPLAN model was nonspatial, which limited its ability to account for landscape changes and the effects of those changes on many nontimber benefits of interest to the public. Moreover, although much of the economic research conducted in the 1980s

focused on developing nonmarket values as data input into FORPLAN, early versions of the model tended to omit nonmarket values, sometimes producing known biases in favor of timber production (Morton 2000). FORPLAN eventually became unwieldy to implement as more considerations were added and user groups with a greater knowledge of the model's workings were able to use it to influence outcomes in their favor (Kent et al. 1991). The complexity and limitations of forest economic models generally resulted in a disconnect between the models and public perceptions about how national forests should be managed (Kant 2003). Rather than improving forest management for multiple values, the economics discipline began to be viewed as part of the problem (e.g., Nautiyal 1996).

These and other factors combined to perpetuate a growing public distrust of national forest management that was manifested in an increasing number of appeals and litigation (Kessler and Salwasser 1995). Environmental appeals during the 1980s were estimated to add 15 to 20 percent to the average time necessary for preparing national forest sales of timber, and at one point the number of appeals in process exceeded 2,000 (Flora 2003). Other environmental legislation was beginning to impact public land management as well. The National Environmental Policy Act of 1970 placed environmental considerations on an equal footing with economic and technical forestry considerations, while the Endangered Species Act of 1973 gave precedence to management of habitat to maintain and protect endangered and threatened species (Stevens and Montgomery 2002). These laws were further evidence of changing public views regarding how forests and other public lands should be managed. In response, by the early 1990s the Forest Service and other federal land management agencies began to shift away from a resource-specific management approach toward ecosystem management.

Ecosystem management was advocated as a broader approach to managing public lands—one that recognized that plant and animal communities are interdependent and interact with their physical environments in ways that transcend the boundaries of public lands (Hennesey 1998). For the Forest Service, formal adoption of ecosystem management in 1992 shifted its analytical focus from consideration of flows of forest outputs (as under multiple-use) to an ecological approach that prioritized ecological states and conditions (e.g., ecological health) over a large landscape and made forest outputs secondary (Sedjo 1995, Swallow 1996, Kennedy and Quigley 1998, MacCleery and Le Master 1999). One effect of that change in priorities was a shift in national forest management away from utilitarian-based analyses meant to support decisions and toward analyses aimed at achieving political efficacy. The controversy related to spotted owls and development of the Northwest Forest Plan in response is one example (Marcot and Thomas 1997).

The shift to ecosystem management highlighted many of the limitations of economic models of forests up to that time, including difficulty identifying specific attributes of ecosystems that are relevant to human welfare and the corresponding spatial scale at which ecosystem attributes should be evaluated for management (Toman and Ashton 1996). Given the inherent uncertainty and complexity associated with ecological knowledge, managers have tended to operationalize ecosystem management by imposing goals for the ecosystem as constraints on the production of market outputs (e.g., timber), a method that is similar to a safe-minimum-standard approach (Swallow 1996). This led some economists to frame management questions in terms of identifying the

public's preferences to determine an appropriate level for the safe minimum standard. Forest managers would then consider that minimum standard when weighing the public's financial and political support for particular programs (e.g., Swallow 1996). For example, Garber-Yonts, Kerkvliet, and Johnson (2004) sought to identify the public's preferences for biodiversity conservation programs that were distinguished by specific attributes, including the likely degree of protection afforded to specific threatened or endangered species. Meanwhile, advances in geographic information systems coupled with ongoing developments in optimization techniques lent economists some hope that the complexities introduced by ecosystem management could eventually be adequately addressed by economic models (e.g., Montgomery 2002).

National Forest Management Today

Although the introduction of ecosystem management represented a distinct paradigm shift, it also can be seen as a maturing of the multiple-use approach toward more earnest consideration of the diversity of uses and values derived from national forests and to a broader number of interested public parties. The recent emphasis on ecosystem services is a continuation of that trend. The shift to ecosystem management did not alleviate the burden of appeals and litigation that managers face. In part, an ongoing emphasis on accomplishing output-related targets has tended to obscure the degree to which multiple forest benefits have been considered in national forest management. The lack of integrated assessment, whether real or perceived, has continued to foster distrust among nongovernmental organizations and the public about whether the Forest Service adequately considers all factors affected by proposed management actions (e.g., Shindler and Toman 2003, Winter, Vogt, and McCaffery 2004, Liljeblad and Borrie 2006). Inspired by the Millennium Ecosystem Assessment (2005), the ecosystem service era emerged, in part, as a way to help managers highlight the connection between public benefits and ecological conditions (Collins and Larry 2007, Smith et al. 2011). The Forest Service also hopes that touting the many ecosystem service benefits provided by national forest management will help to attract partners and build working relationships with stakeholders who can provide political, if not financial, support to management efforts (Smith et al. 2011).

The shift to an ecosystem service approach is part of an emerging policy initiative within the Forest Service to broaden the focus of public land management to an "all lands" approach. The all-lands approach is based on recognition that many desired or beneficial ecological conditions and processes occur at the landscape scale, transcend national forest boundaries, and require management at a broader level (USDA Forest Service 2006, Collins and Larry 2007). The Forest Service initiative seeks to augment management of public lands by influencing how private lands are managed through partnerships with state and local government agencies and conservation groups and using various incentives and educational and technical assistance programs targeted at private landowners. The all-lands initiative involves numerous issues and research areas of significant interest to economists—land use change, incentives that can motivate private landowner behavior, and optimal designs and spatial arrangements of protected areas to name just a few. Our focus here, however, is on national forest management and the need to describe and evaluate the tradeoffs inherent to the all-lands approach.

Today, national forest management includes (i) forest planning—development of broad, long-term objectives for individual forests, and (ii) project-level planning and implementation—development and execution of specific management activities on the ground (e.g., harvesting, thinning to reduce forest fire fuel, and habitat restoration). The National Environmental Policy Act (NEPA) of 1970 required managers to assess the environmental effects of any ground-disturbing project proposed and to include the public in the decision-making process (Broussard and Whitaker 2009). The Forest Service's new planning rule (USDA Forest Service 2012) intends to make public participatory processes more open and meaningful so that management of national forests is more transparent and less contentious. The rule calls on managers to formally address ecosystem services and thus describe a more comprehensive set of benefits accruing from management activities. It has removed all reference to maximizing net benefits and efficiency and focuses instead on goals of providing benefits and contributing to social and economic sustainability.

A Conceptual Framework for Public Land Management

Under an ecosystem service management paradigm, the basic informational challenge for national forest managers is to describe the full suite of beneficial returns that can be gained from budget expenditures on management activities. National forest managers use this information to select various management options or evaluate the benefits of different management scenarios in achieving overarching policy goals. In the context of public land management, ecosystem services are beneficial outcomes that derive from landscape conditions (e.g., forest structures, species compositions) and ecological processes as they are altered by both natural disturbance and management activities.

Within the ecosystem service context, national forest managers each year consider the existing condition of a landscape (e.g., its forest structures, the stand age, the biomass) with respect to their objectives for that landscape and identify a set of management activities to pursue (e.g., harvesting, thinning, habitat restoration) given the available budget (Figure 1). Their decisions must consider the significant role that natural disturbances (e.g., wildfires, insects,

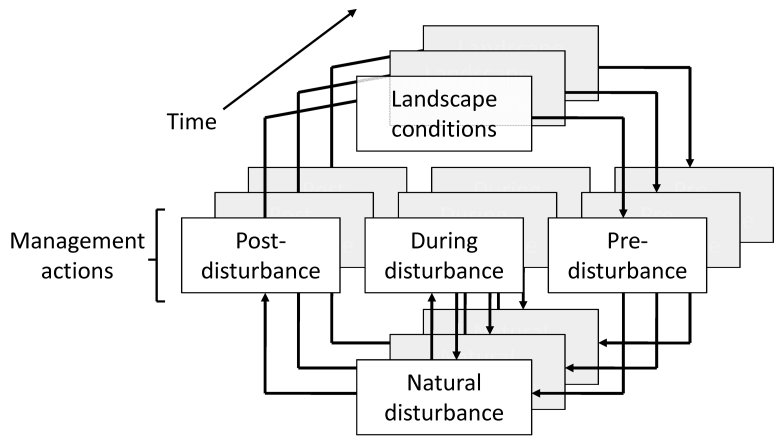

Figure 1: Conceptual Model of Public Land Management over Time

Source: Kline and Mazzotta 2012.

diseases) can play in altering the condition of the landscape and how the likelihood of such events might change in response to management activities. National forest management activities, changes in the landscape that result from those activities, and vegetative growth and natural disturbances all define the condition of a landscape year by year.

Similarly, the type and quantity of ecosystem services generated and the cost of managing a landscape in any given year depend on the landscape conditions already present, management actions taken, and natural disturbances that occur (Figure 2). The degree to which any given ecosystem service is a benefit depends on the combined influences of stakeholders' preferences for the ecosystem service, its scarcity and accessibility to the public, and how many people value it, among other factors. For example, vegetation, riparian conditions, and other landscape characteristics determine the quality and quantity of surface water and ground water that is available for human use. Meanwhile, regional demand for water, the availability of water resources, infrastructures that currently deliver water, and the availability of substitute sources all contribute to the value of that water to people in the area. Similarly, spatial arrangements of forest structures and species compositions determine habitat conditions and wildlife populations. The variety of recreation opportunities available depends on the existing recreation infrastructure plus desirable features offered by the landscape.

Management costs come from several directions. Administratively, management actions involve financial investments in planning and labor and depreciation of equipment used to implement projects. Natural disturbances produce additional costs. A wildfire, for example, affects air quality because of the smoke it produces and damages property. There also can be significant costs associated with wildfire suppression. Any ecological damages or improvements are reflected in altered landscape conditions and associated changes in ecosystem services in future years (wildfires, for example, can produce longer-term ecological changes related to biodiversity and ecological productivity (e.g., Kline 2004). The entire process takes place in the larger context of climate change and of landscape changes that occur on private land, both of which can alter forest landscapes and natural processes and influence how management actions will affect specific forests.

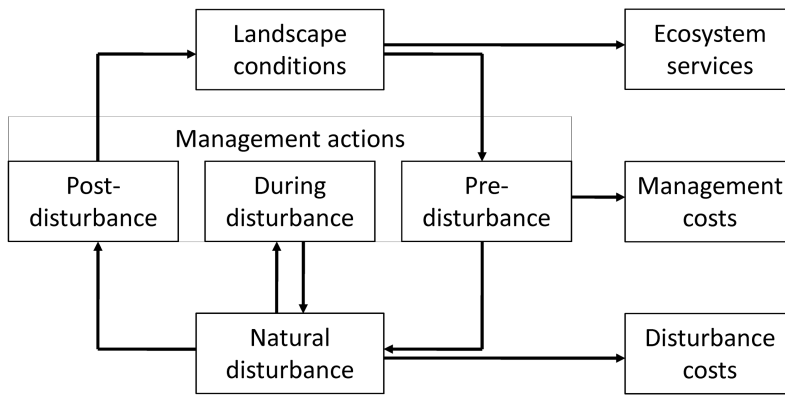

Figure 2. Ecosystem Services Associated with Landscape Conditions

Source: Kline and Mazzotta 2012.

The forest landscape thus can be viewed as a stock of natural capital with a capacity to produce flows of ecosystem services over time. Landscape conditions at any point in time, combined with social and economic factors, determine the type, quality, and quantity of ecosystem services produced and the potential benefits that people receive. Guided by the landscape objectives outlined in forest plans, forest managers decide how to influence landscape conditions through management activities that will inevitably affect the ecosystem services provided. The value of the ecosystem services produced by the landscape minus the cost of managing it make up the net social benefit or economic return that the landscape provides to the public in a given year.

National forest planning and management can be viewed as striving to produce a "portfolio" of ecosystem services that provides the greatest overall benefit to the public within a landscape's capacity to produce the services and within existing safe minimum standards, mandated institutional constraints, and legal requirements (e.g., the Endangered Species Act). National forest plans identify desired landscape conditions and the portfolio of ecosystem services intended to be produced by outlining broad long-term objectives over a 15-year planning period. Project-level planning and implementation takes the forest plan to the ground to alter particular landscape conditions and enhance flows of particular ecosystem services.

However, flows of ecosystem services are not constant; they fluctuate over time according to changing landscape conditions that are only partly controlled by management actions. Managers plan and implement projects primarily in the present with the objective of affecting changes in the flow of ecosystem services in the future. In this way, each management action taken or not taken contributes to defining an ecological time trajectory of landscape conditions and associated ecosystem services (Figure 3). For example, a manager might consider excluding livestock from a stream corridor to reduce soil compaction

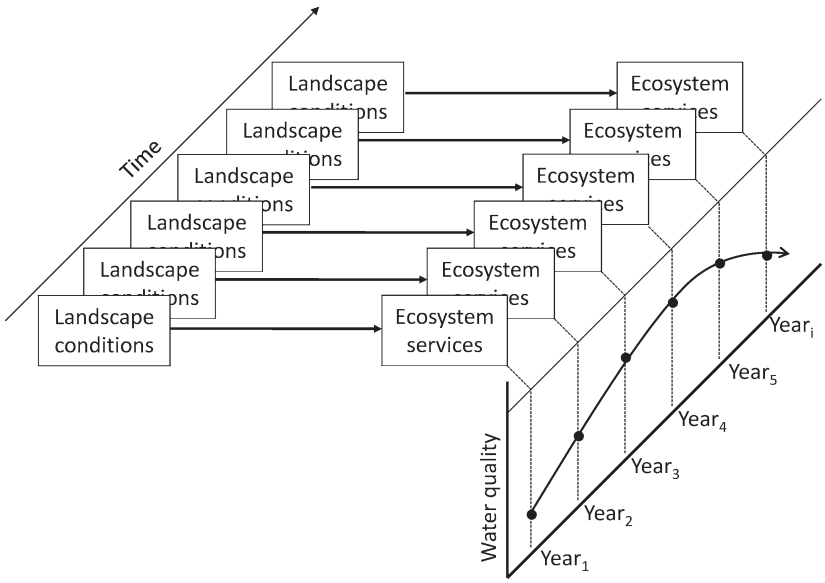

Figure 3. Hypothetical Ecosystem Service Time Trajectory

Source: Kline and Mazzotta 2012.

and erosion, which would allow riparian vegetation to recover and water quality to improve. Or a manager might consider addressing declines in a local elk population by selectively harvesting forest stands to improve their forage value. The trajectories that actually occur in response to those decisions reflect a complex interaction of management and unpredictable natural disturbance processes and their influence on forest structures and species compositions in the years thereafter.

Natural disturbances, such as wildfires, insects, and disease, can contribute to variations in the flow of ecosystem services from year to year. For example, a wildfire may at first diminish grazing opportunities because of temporary closure of an area and then quickly give rise to better grazing opportunities in the near term as forage thrives on the burned landscape. Woodpecker populations can increase with an increase in snags—remnants of trees killed by fire—and then decline as the snags collapse. Planning decisions thus must be based on informed estimates of how individual ecosystem services will be affected by management activities and natural disturbances over time.

If we think of a national forest as capable of producing a joint production set, we can define the manager's task as striving to achieve improvement in jointly produced outcomes through management over long periods of time. Managers would seek to initiate ecological time trajectories that would move outcomes from interior positions out toward the production possibility frontier for various ecosystem service combinations. The degree to which such an analysis is feasible largely depends on the ability of landscape ecologists and economists to predict the effects of each potential management action on ecosystem services given the uncertainty associated with natural fluctuations and disturbances.

Challenges

Operationalizing the foregoing conceptual framework in a formal or empirical way requires information about (i) current landscape conditions and how they are changing; (ii) forecasts of how management activities will alter the time trajectory of landscape change in a context of likely natural disturbances and climate change; and (iii) what people value about the landscape, how much they value those things, and how their values might be changing. These factors encompass and elaborate on the information needs noted by Bowes and Krutilla (1989). However, meeting those informational needs involves enduring methodological challenges—the extent to which economic analysis can adequately address public land management and the availability of ecological data and models with which to do so. Moreover, applying economic principles and methods to national forest management is likely to involve overcoming institutional barriers that currently impede the use of economic analysis in decision-making.

Methodological Challenges

The evolution of public land management toward a focus on ecosystem services has introduced a need for economic analyses of a potentially significant array of forest outputs. It also requires a set of interacting ecological production functions to predict changes in joint outputs and their variations over space and time, information that is needed for relevant valuation endpoints used

to evaluate tradeoffs. Economists have made progress in addressing multiple forest outputs and values, as well as in understanding the spatial and temporal complexity of contemporary forest management (e.g., Swallow, Parks, and Wear 1990, Swallow and Wear 1993, Swallow, Talukdar, and Wear 1997, Alix-Garcia 2007) and other resource applications (e.g., Sanchirico and Wilen 1999, Smith and Wilen 2003, Costello and Polasky 2008). The difficulties, however, are by no means resolved. It is theoretically possible to modify economic models to optimize a set of benefits from multiple market and nonmarket values using a joint production framework (e.g., Stevens and Montgomery 2002, Nalle et al. 2004). However, as many economists who have worked in the public land management context already know, managers often lack information concerning the expected effects of their actions on ecological conditions and processes and their resulting influence on ecosystem services of interest—ecological production functions. Even if likely ecological responses are known, the complexity of the economic models required to optimize management over time and space for more than two or three forest goods or services is unlikely to be practical for routine management applications. A number of models based on geospatial interactions currently are in development, including InVEST, ARIES, and MIMES (Waage, Stewart, and Armstrong 2008). The objective of the models is to assess multiple ecosystem services in a spatially explicit manner. However, while such models are a promising development, they too will require information about the ecological effects of management to be relevant to national forest applications.

The ecological information currently available often does not allow national forest managers to characterize a complete joint production choice set for the ecosystem services of interest. Although repeated simulations can allow ecologists to provide best-guess approximations of joint production possibility sets (e.g., Arthaud and Rose 1996, Lichtenstein and Montgomery 2003, Nalle et al. 2004), in many if not most cases, managers will not have the time and budget necessary for such detailed and intensive assessments. At best, economists typically can expect ecologists to provide a rough idea of the expected time trajectories for individual ecosystem services resulting from particular management actions within a range of uncertainty associated with environmental variability and natural disturbance. Consequently, the ecological information available to support an economic analysis of public land management tends to be more limited than is implied by economic theory and methods.

The uncertain nature of ecological information characterizing ecosystem service outcomes of management points to a widening set of confidence bounds on ecosystem service predictions over time. Analysts may be able to anticipate the confidence bounds and define a range of values over which a true ecosystem service trajectory might stray. But widening confidence bounds imply that the time trajectories that managers might expect from proposed management alternatives may overlap at times such that distinctions between the expected outcomes of two alternatives are ambiguous. Consequently, although analytical methods have advanced in both economics and ecology, even the best models may not adequately address many of the fundamental questions that managers have about forest planning and management. Moreover, the inscrutable nature of large, complicated models seems only to exacerbate distrust among stakeholders and can even be manipulated to promote the interests of more savvy users (Kent et al. 1991). This is particularly true of economic optimization

models, which, in our experience, often prompt scorn even from some national forest managers, at least in part owing to FORPLAN's legacy.

Although economists generally have met the challenge of developing methods by which to estimate economic values for biophysical characteristics of ecosystems, valuation alone does little to inform management questions. Also essential are good estimates of how the valued biophysical characteristics could change in response to management. Relatively abstract or complex concepts used to describe biophysical characteristics of ecosystems, such as biodiversity, watershed processes, and scenic values, are an additional impediment. As a result, economists and ecologists can point to few successes in developing tools that can be routinely applied by managers to characterize marginal changes in ecosystem services that are likely to result from their management activities. This limitation need not be viewed as a shortcoming on the part of economists and ecologists. Rather, it can be viewed as resulting from public land management agencies' reluctance to invest enough resources in developing effective and workable approaches based on integration of economics and ecology.

Understanding how social welfare changes in response to various forest management actions and how such actions can lead to more optimal solutions is undoubtedly useful information (e.g., Ervin, Larsen, and Shinn 2012). However, the process of managing public land and negotiating acceptable actions requires broader thinking. Forest managers want to accomplish beneficial projects cost-effectively and with a minimum of conflict and litigation. For managers, the goal may not be to maximize the net present value of social benefit measured in dollars. There are NEPA requirements to meet so there always will be a desire for better economic information. But economics does not "rule the day" (e.g., Bockstael et al. 2000) in public land management decisions. Other methods and metrics also must be weighed to address community impacts, public acceptability, and other factors. Moreover, the analytical components exist within a public engagement process that involves input from the public and stakeholders.

Institutional Challenges

Institutional challenges within the Forest Service also can constrain how well economic and ecological methods and analyses can be integrated and applied to national forest management. Those challenges include a continued mandate to focus on accomplishing output-related targets assigned by Congress and a staffing structure that is organized by associated resource areas. As a result, management decisions have tended to be fragmented by resource specialties and dismissive of the need for integrated analysis that goes with evaluating joint economic and ecological implications of management (e.g., Smith et al. 2011). One of the Forest Service's objectives in moving forest management toward an ecosystem service focus is to provide a conceptual framework in which national forest staff members in separate resource areas can work collectively toward shared, outcome-related goals rather than focusing on individual resource targets (Smith et al. 2011). How malleable the existing organizational structure will be remains to be seen.

An additional institutional challenge is a decline in economics capacity within the Forest Service, which limits the number of economists available both to develop methods for addressing ecosystem services and to assist

managers in applying economic principles and methods. Within the research and development branch, the number of permanent full-time economists has declined from approximately 47 in 2003 to 29 in 2012 (Langner 2012). The National Forest System, the branch that manages national forests and grasslands, retains just a handful of economists at the regional level (Langner 2012), a level where economists could be especially useful serving in somewhat of an extension role for individual national forests within regions. To our knowledge, there currently are very few, if any, economists assigned directly to national forests, though we have met individual analysts who have taken one or more college-level economics courses. With fewer economists in the agency, there are fewer voices to advocate the usefulness of economic approaches to national forest management, a state that is likely to lead to further declines in economic analyses.

The declining economic capacity within the Forest Service also reduces the agency's ability to take advantage of outside economic expertise. Although economists outside of the Forest Service have produced a considerable body of relevant work pertaining to public forest management, much of the work has been theoretical and mathematical and was published in academic journals. So, although it is meaningful to economists and important for advancing theory and methods, those studies have not been easily accessible to managers, who increasingly work without ready access to a Forest Service economist who can explain their relevance and application.

For example, despite decades of development of techniques for nonmarket valuation, public benefits and economic analyses in general have not been effectively incorporated into planning and project analyses for national forests (Loomis and Walsh 1992, Morton 2000, Loomis 2002). Aside from a few high-profile cases and fairly widespread application of recreation values (Loomis 1995, Morton 2000, Rosenberger and Loomis 2001, Loomis 2005), nonmarket valuation has mostly taken a back seat to economic impact analysis. In some cases, economists have successfully conducted issue-specific and site-specific studies using choice experiments to weight and value alternative ecosystem service outcomes (e.g., Johnston et al. 2003, Hanley, Wright, and Alvarez-Farizo 2006, Loomis 2012). But these methods generally are impractical for routine management applications. Federally funded surveys of the public require review and approval by the Office of Management and Budget for compliance with the Paperwork Reduction Act of 1995, which can increase the time required for studies considerably (Kline 2006). Given the service's declining economics capacity and limited budgets, routinely designing and administering formal public choice surveys to support forest planning and project implementation likely will not be feasible without greater investment by public land management agencies in such methods.

Implications for Economic Analysis

Economists have accomplished much good work and will continue to make important contributions to public land management. However, their contributions to national forest management will be constrained in the near term by limited availability of ecological data and the level of economics capacity within the Forest Service. National forest managers typically will lack quantitative information concerning how some or many ecosystem services of interest are affected by proposed management activities, and any information

they will have will be characterized by greater uncertainty as predictions extend farther into the future. This will limit economists' ability to value marginal changes in ecosystem services expected from management plans and projects. And, even given useful ecological predictions of joint products under different management scenarios, the limitations inherent to economic models will restrict economists' ability to find "optimal" solutions. Moreover, at least in the near term, structural and staffing characteristics within the Forest Service will impede how readily national forest managers can apply complex economics principles and methods to on-the-ground management problems. For these reasons, economists may need to rethink how they can best contribute to public land management.

For example, dollar values may not always be necessary for evaluating management plans and the expected effect of proposed projects. Nonmarket valuation guidelines developed for federal agencies acknowledge that dollar estimation is not always feasible and allow for qualitative alternatives to quantitative measures (Office of Management and Budget 2003). Following this guidance, it may be sufficient for economic analysis of management effects to rely partly on qualitative approaches and development of benefit indicators and narratives ("economic stories") (Boyd 2007b, Wainger and Boyd 2009). Economists can help managers and ecologists understand and apply basic economic theory to assessments of management outcomes that are qualitative in nature and devise ways to make qualitative assessments rigorous enough to be considered on a par with quantified metrics.

When implemented as part of the public participatory processes called for in the Forest Service's new planning rule, qualitative analysis could form the basis of a discourse-based collaboration between national forest managers, interested members of the public, and stakeholders. Moves toward such efforts already are underway at other federal land management agencies. For example, the U.S. Fish and Wildlife Service has been working with the U.S. Geological Survey to apply structured decision-making and adaptive management to management of national wildlife refuges (e.g., Runge 2011). Decision science can provide methods for combining and presenting the results of analyses that draw on a combination of qualitative, quantified but not monetized, and monetized values in a way that supports a fair assessment of the tradeoffs (Gregory et al. 2012, Keeney and Raiffa 1993).

Ultimately, even if the analytical complexities of public land management problems preclude a perfect economic analysis, problems still boil down to how we can best inform choices that involve tradeoffs. Economists are well suited to address this question, and it is arguably the issue to which they can make the greatest contribution to public land management. However, the weighing of tradeoffs is likely at times to be less a numerical exercise and more a building of consensus among would-be partners and stakeholders in public land management (e.g., Kessler and Salwasser 1995). The need for transparency may require simplified but scientifically credible approaches to evaluating potential management outcomes (Ervin, Larsen, and Shinn 2012). This shift in focus from complex modeling and nonmarket valuation to more direct collaboration with managers, ecologists, and biophysical scientists in participatory decision-making describes a revised role for economists. The assistance economists provide can and should continue to be consistent with economic theory. However, their economic assistance also must be compatible with the type of ecological information that managers generally have to

support decisions about national forest management, must be amenable to collaborative decision-making, and must be applicable within the timeframes in which public land management decisions are made.

We propose that economists can have the greatest influence on advancing policy-relevant analysis of public land management by addressing the factors having to do with problem formulation, development of ecological information, and communication of economic theory and analysis. First, economists can work with managers and ecologists to conceptualize the economic problem of tradeoffs among joint products of a landscape that may be complementary or competing in a context of the uncertainty associated with natural disturbance and other factors. One simple conceptualization that can provide a structure for discussing tradeoffs with the public and stakeholders is to ask what services will be provided, where will they be provided on a landscape, and who stands to benefit from their provision.

Second, economists can guide managers and ecologists in identifying the type of ecological information needed to evaluate tradeoffs, both quantitatively and qualitatively, and to address uncertainty associated with natural disturbances. This task includes formulating relevant ecological measurement endpoints, conceptualizing and estimating ecological production functions that relate the endpoints to management actions of interest, and conceptualizing and estimating joint production relationships among the endpoints (Boyd 2007a, Wainger and Boyd 2009, Wainger and Mazzotta 2011, Kline and Mazzotta 2012). It also includes specifying and acquiring information about complementary and substitute goods and services that affect the value of and benefits from ecosystem services and how best to incorporate risk posed by natural disturbances and other factors.

Third, and more broadly, economists must seek ways to communicate more effectively with managers, ecologists, stakeholders, and the public. This objective includes presenting policy-relevant research using nontechnical language and occasionally publishing in industry-related outlets to build a broader audience for economics. Economists must do more than advance economic methods; they must learn to pass those methods on to policymakers and managers more effectively (Banzhaf 2010). Economists also must set reasonable expectations about the information that is likely to be available. Given that managers often will not have defined ecological production functions, economists must provide guidance about how to do without them. This assistance would include developing repeatable methods for conducting and presenting the results of economic analyses that do not require an advanced degree in economics to implement but still provide information that is scientifically valid and meaningful. Through these efforts, economists can continue to help managers understand the value of an economic approach to public land management.

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