United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Note
PNW-RN-542
October 2004

Issues in Evaluating the Costs and Benefits of Fuel Treatments to Reduce Wildfire in the Nation's Forests

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Abstract

Wildland fire has been perhaps the most vexing forest management and policy issue in the United States in recent years, stirring both passionate and reasoned debate among managers, policymakers, researchers, and citizens alike. Years of fire suppression and increasing constraints on natural and prescribed burning, possibly along with climate change, have altered historical wildfire regimes resulting in increased wildfire severity in the Nation's forests. The growing wildfire threat has motivated increasing interest in reducing hazardous fuels through prescribed burning, thinning, and harvesting. Debate about whether such fuel treatments are necessary persists owing in part to the complexity of the wildfire issue and to general disagreement among managers, policymakers, researchers, and citizens about whether long-term wildfire impacts and current trends present a real problem. Although scientific research continues to resolve many aspects of the wildfire issue, comprehensive economic analyses examining the wisdom of investing in fuel treatments to reduce wildfire threat are lacking. This report presents one way of conceptualizing the costs and benefits of fuel treatments and wildfire and briefly reviews issues related to their evaluation. The intent is to enrich ongoing debate by organizing management and policy dialogue around a conceptual framework that characterizes the long-term impacts of fuel treatments on forest conditions and wildfires, within an analytical context that includes both wildfire- and nonwildfire-related forest management activities.

Keywords: Fuel treatments, wildfire, wildland/urban interface, cost-benefit analysis.

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Introduction

By investing in fuel treatments, forest managers attempt to purchase an incremental reduction in the likelihood of extreme fire behavior. Fire research has shown that physical setting, fuel, and weather combine to influence wildfire intensity—the rate at which fires consume fuel—and severity— the effects fire has on vegetation, soil, buildings, watersheds, and other resource values (Russell and others 2004). Fuel treatments are implemented to help produce forest structures and fuel characteristics that reduce the likelihood that wildfires will cause large and rapid changes in biophysical conditions, and modify fire behavior sufficiently to make fire suppression easier (Russell and others 2004). Although not guaranteed, the expectation is that fuel treatments over the long term will result in lower fire suppression and postfire restoration costs, less smoke, less wildfire-related property damage, and fewer lost socioeconomic and ecological forest benefits. Evaluating the changes in net benefits that we can expect from fuel treatments involves estimating the effects of treatments on reducing the likelihood of extreme wildfire events by reducing wildfire intensity, severity, and scale, as well as the effects that treatments and wildfires have on forest management costs and the variety of forest benefits.

The USDA Forest Service and other researchers have been examining parts of the fuel treatment issue for some time. To date, however, little comprehensive analysis exists addressing whether fuel treatments are a worthwhile investment. One reason for this has been a general lack of sufficient information describing fuel treatment and wildfire effects on the full range of timber and nontimber forest outputs and landscape processes, as well as their relative values to society. Also, perhaps lacking until the few big fire years of the past 10 years, has been sufficient political interest in funding comprehensive analyses evaluating fuel treatments. More generally, misunderstanding exists among many managers, policymakers, and researchers about the larger role that economics can play in evaluating forest management issues such as fuel treatments, beyond merely accounting for market-based timber values and jobs. This report is intended to meet increasing managerial, political, and scientific interest in fuel treatments, by describing conceptual and scientific issues relevant to evaluating whether fuel treatments are a worthwhile investment from an economic perspective. The report is intended as an economic primer for managers, policymakers, and noneconomist researchers who find themselves engaged in decisionmaking and research regarding fuel treatment and related wildfire issues.

Fire severity has a large influence on the composition and structure of plant communities that follow fire. Although landscapes subject to low-intensity fires generally experience the return of prefire flora relatively quickly, landscapes subject to large, severe fires often recover slowly (Brown 2000: 186–187). Years of wildfire suppression and increasing constraints on natural and prescribed burning, among other factors, have altered historical wildfire regimes—their patterns, sizes, uniformity, and severity (Brown 2000, Parsons 2000). These changes, possibly along with climate change (for example, Whitlock and others 2003), have resulted in increased wildfire severity, which in turn has motivated interest among forest managers and policymakers in recent years to reduce forest fuel loads to lessen the wildfire threat. That fire historically has been an important agent of landscape change and now should be restored to its natural role in the Nation's forests generally is not disputed. What is debated is the manner and extent to which managers should intervene in natural processes by reducing fuel loads to lessen severity of wildfires.

For much of the 20th century, wildland fire suppression was a major component of federal forest policy. Since the late 1960s and early 1970s, recognition of the natural role of fire in ecosystem processes as well as mounting fire suppression expenditures gradually led to an easing of the fire suppression mandate, refocusing forest policy to consider fire by prescription, subordinate to broader landscape objectives (Pyne 1997). Restoring fire to ecosystems after decades of fire suppression poses many challenges owing to long-term changes in the structure and composition of plant communities, as well as increased presence of people, homes, and other structures near forests (Hourdequin 2001, Parsons 2000). Any restoration path we choose for a given landscape defines a particular ecological trajectory characterized by a flow of goods and services accruing from the natural capital inherent in healthy ecosystems (Science and Policy Working Group 2002, 2004). Ecosystem restoration decisions ultimately are economic decisions whereby society evaluates the utility of different management alternatives, including inaction (Weigand and Haynes 1996). Embarking on one particular management and policy alternative necessarily carries costs associated with other opportunities that are foregone. Although fuel treatments undoubtedly can be used to alter forest structure and modify wildfire behavior and severity (Graham and others 2004), to date there has been little scientific evidence demonstrating whether fuel treatments make economic sense.

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The fuel treatment issue raises several questions, with potential answers to be found in different types of analyses. Both wildfires and the fuel treatments intended to reduce them, can result in costs and benefits over time. These costs and benefits could be examined by using cost-benefit analysis if sufficient data were available to do so. Also of interest are local and regional economic impacts associated with changes in economic activity and employment resulting from fuel treatments and wildfires. In addition to these scientific questions are philosophical questions arising from ambiguity, if not general disagreement, regarding society's objectives and self-defined role in forest management. Public debate about the wisdom of fuel treatments often becomes clouded by the indeterminate nature of questions at hand, as well as the imperfect state of scientific information describing the impacts of fuel treatments and wildfires on socioeconomic and ecological benefits provided by forests. This report presents one way of conceptualizing the costs and benefits of fuel treatments and wildfire, and their long-term impacts on forest conditions. The intent is to enrich ongoing debate by organizing dialogue around a conceptual framework that includes wildfire suppression and postfire restoration. This largely economic discussion of fuel treatments, however, admittedly exists within a broader management and policy debate that at times centers as much on noneconomic issues.

Benefits and Costs of Wildfires and Related Forest Management Actions

Fuel treatments are just one of three general types of management actions conducted on forest landscapes directly to address wildfire. Other management actions are wildfire suppression (including initial response, extended attack, and large fire support) and postfire restoration (including emergency stabilization and rehabilitation). By investing in fuel treatments in a location, we must recognize that we are making implicit tradeoffs between the benefits and costs of those particular treatments and the benefits and costs of other potential investments, such as other treatments, postfire restoration, or greater fire suppression in other locations. All management actions that we conduct today have the potential to affect future forest conditions and wildfire regimes, as well as our range of management choices in future years.

The effects of wildfires and fire management decisions over time can be illustrated by using a simple conceptual framework (fig. 1). Current forest conditions, such as fuel loads, their proximity to valued resources or structures, and topography, largely determine the types of fuel treatments deemed necessary in a particular location in a given year. The combination of forest conditions and fuel treatments determines the wildfire regime—the intensity, severity, and scale of wildfires—that occur on the forest landscape, and the likelihood of extreme wildfire events requiring significant suppression effort. How the wildfire regime affects the forest landscape—the patterns, sizes, and severity of burns—depends partly on wildfire suppression actions taken during wildfire events, which are formed in response to the characteristics of individual wildfires that occur. The lasting impacts of the wildfire regime are further modified by postfire restoration actions, resulting in the particular forest conditions managers face the following year (fig. 1). Management

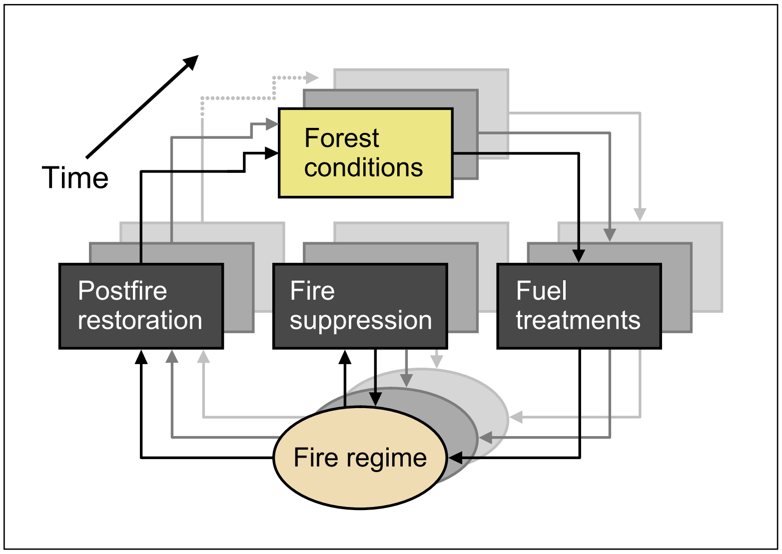

Figure 1—Fire management decision cycle through time.

actions derive from management and policy goals that are developed in the political process, and generally informed by science. The entire process takes place within a larger context of weather and other exogenous factors largely beyond the control of forest managers and policymakers.

Also of interest, although not included in figure 1, are long-term effects of other management actions such as harvesting and grazing that may be unrelated to specific wildfire management and policy goals, but may indirectly affect the wildfire regime by their direct impacts on forest structure, density, and species composition. In Southwestern ponderosa pine forests, for example, logging practices that exposed mineral soil to pine seedling establishment combined with grazing, which reduced competition from other species, contributed to abundant pine regeneration in the early 1900s, resulting in dense pine thickets in present-day forests (Covington and Moore 1994: 44). More generally, grazing can contribute to reducing fine fuels (for example, Graham and others 2004: 3). The long-term effects of fuel treatments and wildfire must be considered within a larger management and policy context that includes evaluating the effects of wildfire suppression and postfire restoration, as well as other management actions that may be unrelated to fire. Although management and policy goals, and perhaps weather, may change over time, the cycle of forest management decisions and wildfire effects continues through time, repeating year after year. To simplify the foregoing figures, we will henceforth show the cycle without the dimension of time (fig. 2).

The long-term effects of fuel treatments and wildfire must be considered within a management and policy context that includes evaluating wildfire suppression and postfire restoration, as well as other management actions unrelated to fire.

The particular forest conditions that exist on a given landscape produce an annual flow of benefits that are valued by society (fig. 3). Benefits might include

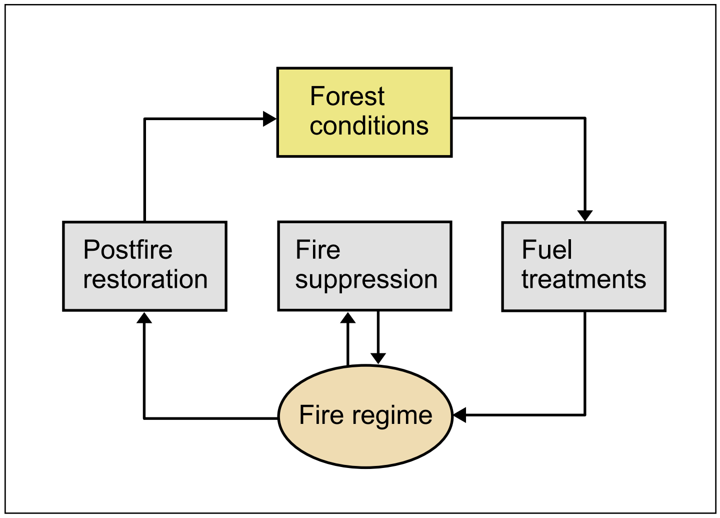

Figure 2—Simplified fire management decision cycle eliminating the dimension of time.

the production of timber and other wood products, recreation, scenery, habitat for fish and wildlife, and reliable sources of clean freshwater, among others. Wildfires may either increase or decrease the annual flow of particular benefits, depending on how they affect particular forest characteristics. For example, wildfire might decrease recreation benefits associated with large trees if they are killed by heat or fire, but might increase recreation benefits in a shrub-dominated setting by clearing underbrush and creating a more open forest. Wildfire effects on forest benefits also can change over time. For example, recreation might be significantly curtailed immediately following wildfire by damage to access and facility infrastructure. However, over time, opportunities to view the aftermath of wildfire, and resulting processes of forest recovery such as wildflowers, may attract numbers of recreationists exceeding prefire visitation rates (Englin and others 2001, Loomis and others 2001). The conceptual framework allows for the possibility that wildfire might be beneficial in some landscapes while accounting for its potential costs and damages that make it harmful in other landscapes.

Fire-related management actions, such as fuel treatments, wildfire suppression, and postfire restoration, produce financial costs in the years in which they are planned and implemented. These costs sometimes can be partially offset by sales of timber and other wood products produced during thinning and harvest treatments. Management actions also may produce nonfinancial costs, such as smoke in the case of prescribed burning. Additionally, the wildfire regime produces costs associated with smoke and property damage caused by wildfires (fig. 3). As with forest benefits, costs resulting from management actions and wildfires can vary over time,

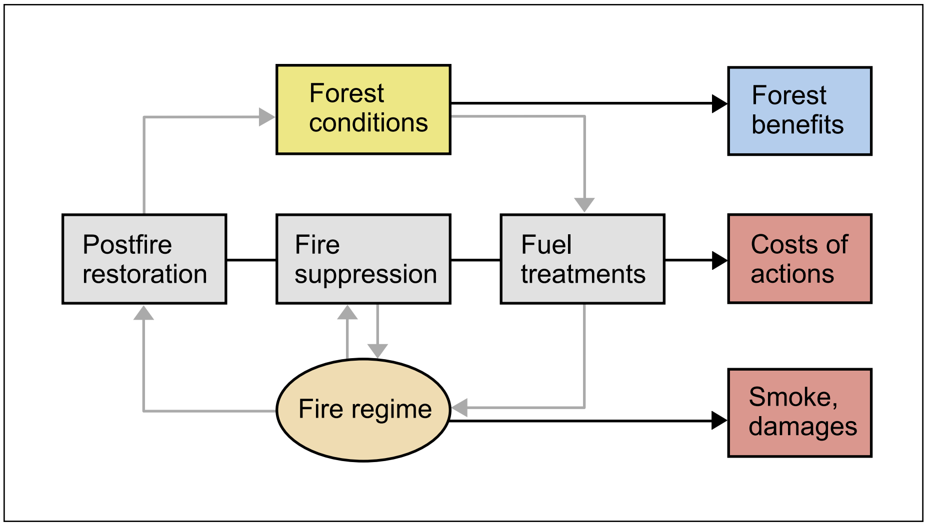

Figure 3—Fire management decision cycle with resulting annual benefits and costs.

depending on the particular forest conditions present, the types of management actions implemented, and the types of wildfires that burn. For example, we would expect that successful fuel treatments would reduce wildfire severity and lead to lower wildfire suppression costs in the years following their implementation, but their effectiveness might wane as forest growth and succession gradually increase fuel loads over the longer term. The beneficial effects of fuel treatments in reducing wildfire severity, intensity, and extreme wildfire likelihood diminish over time.

Evaluating Fuel Treatments

The objective of fuel treatments on a given forest landscape is to maintain or enhance the annual flow of forest benefits and reduce costs associated with wildfires, by reducing the intensity, severity, and likelihood of extreme wildfire events. A simple conceptual example spanning a single fire year shows factors that would be involved in evaluating the costs and benefits of alternative fuel treatment scenarios. Suppose a fuel treatment—a thinning—is considered on a forest prior to fire season in a given year (fig. 4). For simplicity, assume that it is possible for only one extreme wildfire event to occur on the forest in any single year. Without the thinning, either one of two things can happen: (1) no fire occurs and the forest simply adds a year's growth (fig. 4a) or (2) a fire occurs—call it fire *x*—requiring a particular level of suppression and postfire restoration effort specific to fire *x* and mandated under current forest policy (fig. 4b). If, instead, the thinning is conducted, either one of two things can happen: (1) no fire occurs and the forest, after its alteration by thinning, adds a year's growth (fig. 4c) or (2) a different fire occurs—call it

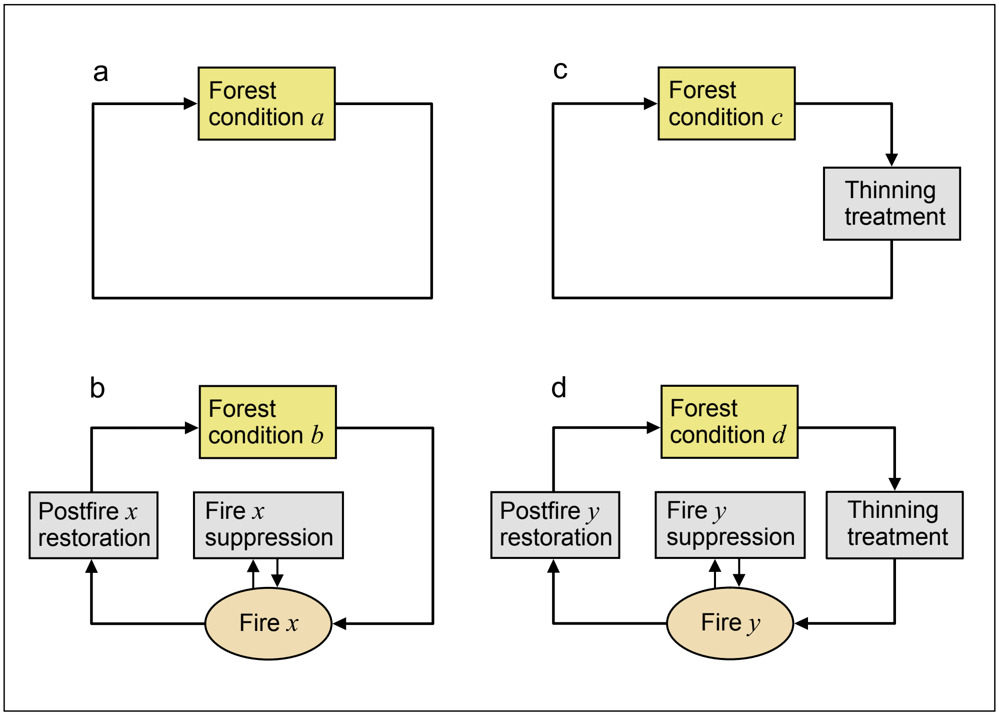

Figure 4—Example outcomes with and without fuel treatment.

fire *y*—requiring a level of suppression and postfire restoration effort specific to fire *y* and mandated under current forest policy (fig. 4d).

Evaluating the costs and benefits of fuel treatments necessitates considering net benefits expected to result with and without treatments, and with and without wildfires that may or may not occur.

Each of the four outcomes results in a particular set of costs and benefits (fig. 5). With no thinning and no fire, we get annual forest benefits *a* and no costs. With no thinning and fire *x*, we get annual forest benefits *b*, as well as suppression and postfire restoration costs, and smoke and property damages associated with fire *x*. With thinning and no fire, we get annual forest benefits *c* and thinning costs. Assume for now that thinning costs are net of any revenue generated from sales of any resulting timber and other wood products outputs. With thinning and fire *y*, we get annual forest benefits *d* and thinning costs, as well as suppression and postfire restoration costs, and smoke and property damages associated with the fire *y*.

If the thinning was successful as a fuel treatment, we would expect fire *y* to be less likely, smaller, less intense, or less severe than fire *x*, resulting in lower suppression and postfire restoration costs, less smoke, and fewer property damages. However, whether the thinning makes economic sense would depend on the incremental change in annual net benefits we can expect by conducting the thinning, over and above those we can expect without the thinning. This incremental change in annual net benefits depends on thinning costs as well as incremental changes in annual forest benefits resulting from changes in forest conditions brought about by thinning, and any resulting wildfires, fire suppression, and postfire restoration that follow. It

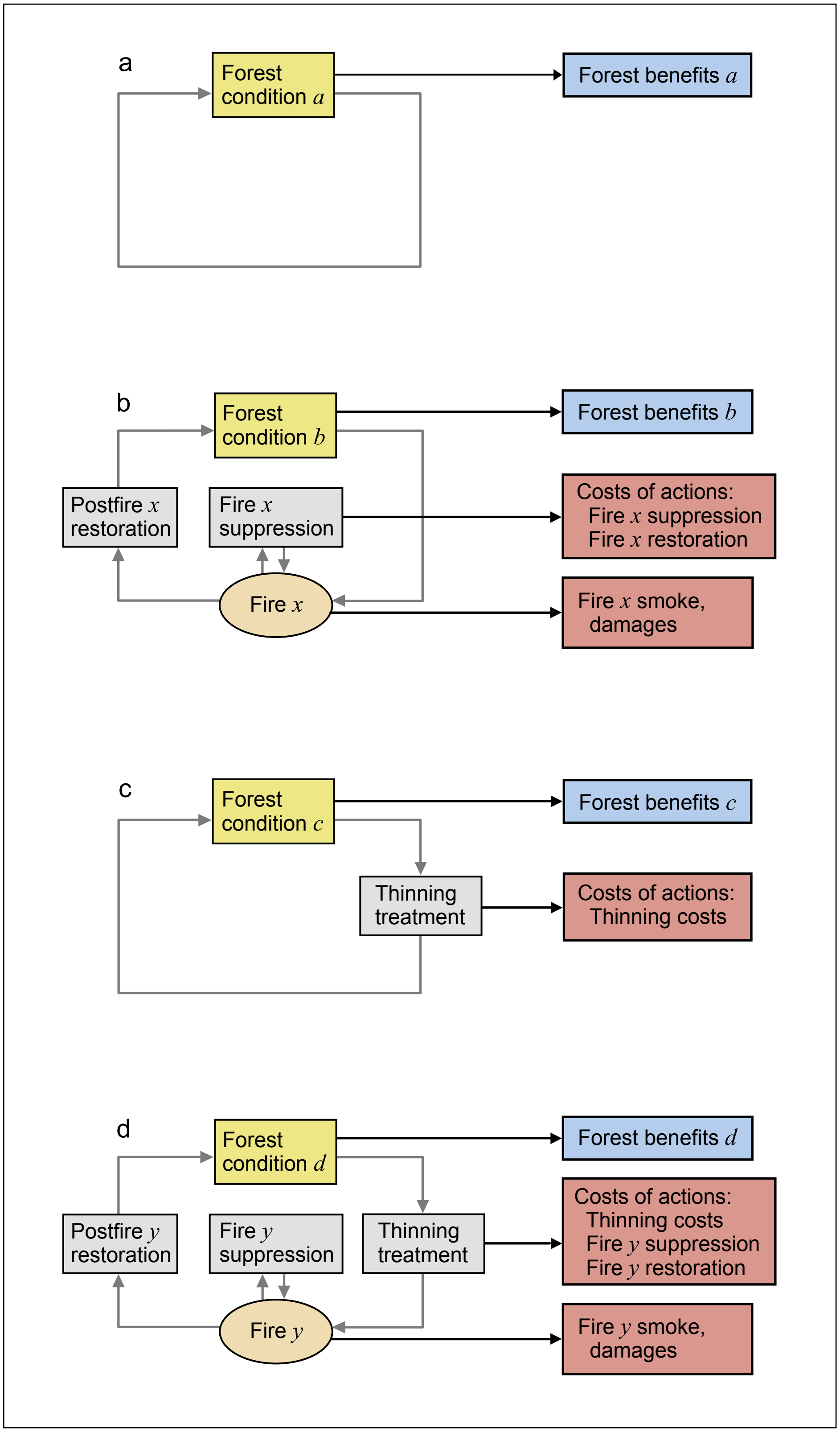

Figure 5—Example outcome benefits and costs with and without fuel treatment.

also depends on the likelihood, intensity, scale, and severity of fire *x*, and the degree to which thinning reduces the likelihood, intensity, scale, and severity of fire *y* below that of fire *x*.

Economists would evaluate the value of net benefits associated with a proposed fuel treatment, such as thinning, by comparing the total expected value of net benefits to be gained with the treatment (fig. 5c, d), to the total expected value of net benefits to be gained without treatment (fig. 5a, b)—the "baseline" (Office of Management and Budget 1996: 10). Total expected values of net benefits in each case would comprise the annual costs and benefits associated with both the fire and no-fire potential outcomes, weighted by the likelihood of each fire occurring, and discounted over time. Evaluating the total expected value of costs and benefits of proposed fuel treatments necessitates considering net benefits expected to result with and without treatments, as well as with and without the wildfires that may or may not occur.

Cost-Benefit and Alternative Analyses

Given sufficient information, the costs and benefits resulting from different sets of forest conditions, management actions, and wildfires could be evaluated by using cost-benefit analysis to evaluate incremental changes in the total discounted net benefits resulting from alternative fuel treatment scenarios over time. Cost-benefit analysis involves a systematic accounting of all relevant changes in costs and benefits associated with resource changes generally in terms of a single metric, such as dollars, to evaluate the social profitability of that change (Johansson 1993: 1). Cost-benefit analysis attempts to enumerate all that is good and bad about a resource change by using a common measure. In this case, costs would include the direct cost of conducting fuel treatments, as well as costs of suppression, postfire restoration, and smoke and property damages associated with any wildfires (table 1).

In forestry, benefits are determined by socially desired outputs produced from existing forest conditions, and the values society places on those outputs. Examples of forest benefits include timber and nontimber forest products, range and forage, freshwater, flood protection, terrestrial and aquatic habitat, wildlife, recreation, scenery, and carbon sequestration (table 1). Some examples of output measures for different forest benefits are timber volumes produced, numbers of recreation visitor-days, and tons of carbon sequestered. Values for some of these outputs, such as timber, can be determined from market prices. Other outputs, such as recreation, may involve nonmarket values, which often can only be determined by using indirect methods such as user surveys. Examples of value measures related to different forest outputs are prevailing timber prices, forest visitors' willingness to pay for

Table 1—Example costs and benefits relevant to examining the net benefits resulting from fuel treatment scenarios

Example costs	Example benefits[a]
Fuel treatment costs	Timber and nontimber forest products
Fire suppression costs	Grazing
Smoke from wildfires and prescribed burns	Ecological benefits (wildlife, fish, water quality, clean air)
Postfire restoration and rehabilitation costs	Recreation
Fire-related damages to private property, public buildings, roads, and other infrastructure	Scenery and aesthetics
	Carbon sequestration

[a] Based on Haynes and Horne (1997: 1818).

a day of recreation, and perhaps sequestered carbon values based on actual emissions-trading transactions.

Values for some forest benefits also may include combinations of use and nonuse values. Use values are values people hold for specific uses of natural resources and may include consumptive uses, such as timber harvesting, and nonconsumptive uses such as sightseeing (Rideout and others 1999b: 10). Nonuse values do not involve direct use of natural resources and may include option (knowing a resource will be available for future personal use), existence (knowing a resource exists even when the likelihood of using it is small), bequest (knowing future generations will be able to enjoy the resource), and stewardship (knowing forests are maintained in a healthy condition) values (Haynes and Horne 1997: 1817). Evaluating nonuse values associated with natural resource management actions typically is more complex and often attracts more controversy than does evaluating use values.

Enumerating the costs and benefits associated with fuel treatment scenarios involves compiling output and value measures describing all relevant benefits produced over time by different combinations of forest conditions resulting from treatments and wildfires, and all relevant costs incurred over time from fire-related management actions, smoke, and property damages. Care is necessary to avoid double counting. Incremental increases in costs resulting in one scenario often can be represented as incremental reductions in forest benefits, and vice versa. Costs associated with lost recreation caused by wildfire, for example, also can be represented as reduced recreation benefits. Certain costs and benefits also can manifest themselves in multiple ways. Lost soil nutrients, for example, can be reflected in less timber production in future years.

Enumerating all costs and benefits resulting from management actions often is not possible owing to a general lack of information describing changes in forest benefit outputs and their values.

Although conceptually feasible, enumerating the full range of costs and benefits resulting from forest management actions often is not possible in practice owing to a general lack of information describing changes in forest benefit outputs and their values. Output measures that may exist for one landscape, such as expected numbers of a particular wildlife species given a set of forest conditions, for example, may not be transferable to other landscapes possessing different characteristics. When such measures do exist, they often may not support evaluating potential wildfire and fuel treatment effects, because they may not be based on data relevant to analyzing such effects. Similarly, the relatively limited body of information describing forest benefit values tends to be quite specific to particular outputs, such as specific fish or wildlife species or specific recreational activities, and is altogether absent for a wide range of forest outputs. The general lack of information describing forest benefit outputs and values and their sensitivity to wildfires and fuel treatments is the most significant obstacle to cost-benefit analysis of fuel treatments. Indeed, use of cost-benefit analysis in fire management and policy decisionmaking has been proposed at least since the 1970s (Gorte and Gorte 1979, Mills and Bratten 1982) but has been hampered by difficulties in measuring changes in forest outputs and their values resulting from management and policy alternatives proposed.

What About Jobs?

Federal projects and programs (including fuel treatments) often are advocated, because they create jobs—jobs are noted as a benefit. When newly created jobs are included in a cost-benefit calculation, the net benefits of pursuing a project or program appear more attractive (Johansson 1993: 84). However, whether jobs creation justifiably can be considered a benefit in cost-benefit analyses is debatable. One reason is that wages paid to workers newly employed by federal projects or programs are monies that are transferred from federal taxpayers to workers (Mishan 1982: 81–82). Cost-benefit analyses of actions on federal lands or those paid with federal funds usually are conducted by using a national accounting stance (Althaus and Mills 1982: 5; Rideout and others 1999a: 221), considering costs and benefits to all residents of the United States rather than distinct regions. Viewed from a national accounting stance, increased wages paid to workers in a particular region are offset by increased taxes paid by all taxpayers, resulting in zero net benefit. Also, because jobs gained (or lost) in a given region from federal management or policy changes usually are lost (or gained) somewhere else (Loomis 2000: 11; Sassone and Schaffer 1978; U.S. Water Resources Council 1983), counting jobs creation as a benefit in one region discounts potential job losses in other regions. Advocating fuel treatments as a way to provide jobs in a particular region thus assumes that there is some social benefit to favoring that particular region over all others, as far as economic effects are concerned.

Another reason why jobs usually are not counted as a benefit in cost-benefit analyses is that under generally full employment, wage rates just compensate workers for their time—what workers gain in wages they lose in leisure—so that the employment of additional new workers results in zero net benefit (Sugden and Williams 1978: 95). With full employment, all individuals who desire work have jobs, and unemployed individuals are either indifferent between working and not working or value their leisure time at greater than prevailing wages. During times of relative unemployment, however, individuals may desire work at prevailing wages but may be unable to find jobs. With unemployment, prevailing wages might more than compensate unemployed workers for their time, resulting in a net benefit to newly employed workers that partially offsets wage costs incurred by employing agencies (Sugden and Williams 1978: 102-104). Also, there can be some public benefit to not letting job skills grow stale or unemployed workers become depressed or disillusioned with the job market. For these reasons, a stronger case can be made for federal projects and programs in times of low employment, if they employ otherwise idle workers (Mishan 1982: 315).

Still, economists tend to place a "heavy burden of proof" on including indirect benefits such as jobs creation in cost-benefit analyses (Randall and Peterson 1984: 23). Even with unemployment, new jobs might only be counted as a benefit when unemployment is persistent and the workforce is immobile (McKean 1958, Randall and Peterson 1984: 23). If fuel treatments are advocated as a source of rural community development, the case must be made that workers cannot reasonably find suitable work opportunities elsewhere. Although cost-benefit analyses might comment on the extent of employment effects, formally accounting for those effects typically is left to economic impact analysis (Smith 1986: 23).

Economic Impacts

The socioeconomic effects of forest management actions also can be evaluated by using economic impact analysis, which differs from cost-benefit analysis. Cost-benefit analyses evaluate the total net effects of actions on the welfare of all individuals affected by those changes (Sugden and Williams 1978: 89). Cost-benefit analyses usually are indifferent to "interregional re-distributive effects" (Randall and Peterson 1984: 23) and do not give greater weight to welfare changes experienced by individuals in one region over another. As already noted, a national accounting stance—evaluating welfare effects to all residents of the United States—generally is most appropriate when evaluating management actions involving federal lands or funds. Economic impact analyses, on the other hand, evaluate the regional effects of actions on prices, outputs, employment, and other economic factors, focusing on how those effects are distributed across regions (Smith 1986: 30). Cost-benefit analyses do not necessarily ignore these distributive effects and may even include evaluating their extent, but they typically are not included as specific numerical costs or benefits (Smith 1986: 23).

For example, a cost-benefit analysis might include accounting for hikers' higher willingness to pay for better hiking conditions, perhaps owing to a profusion of wildflowers resulting from one fuel treatment alternative versus another. An economic impact analysis, on the other hand, would evaluate increases in local or regional economic activity associated with more hikers visiting a particular location to enjoy the increase in wildflowers. Although both cost-benefit and economic impact analyses might be used to evaluate the socioeconomic effects of management and policy actions, neither typically would be regarded as binding decision criteria for selecting one management or policy alternative over another. Rather, both analyses would offer sets of information that managers and policymakers could use to evaluate management and policy alternatives.

Cost-Effectiveness Analysis

Difficulties in accounting for all possible costs and benefits resulting from alternative fuel treatment scenarios arise from the broad range of forest benefits valued by society and the expense and complexity involved in their measurement. For this reason, modern economic analyses of fire management actions have tended to bypass cost-benefit analysis in favor of cost-effectiveness analysis (for example, Omi and others 1998, 1999). Cost-effectiveness analyses address problems involving outputs that cannot be evaluated by using market prices, but where inputs can be evaluated (Niskanen 1967: 18). It involves identifying physical measures of accomplishments that can be tracked to the costs associated with alternative treatments, to identify those treatments that are most cost-effective—achieve the greatest accomplishment at a given cost (Rideout and others 1999a: 222). Ideally, accomplishment measures are proxies for forest benefits of interest for which reliable output and value measures may be unavailable. Changes in fuel loads or burned area, for example, might be used in place of changes in biodiversity benefits, the extent and value of which may be difficult to reliably measure. Cost-effectiveness analyses enable managers to compare the potential outcomes of different treatment alternatives and to make informed choices regarding fire management (Rideout and others 1999a: 223).

Although cost-effectiveness analyses sidestep the potential difficulties and expense of measuring forest benefit outputs and values, selecting appropriate accomplishment measures and relating them to fuel treatment costs are challenging. Accomplishment measures, after all, are similar to resource effects models describing output levels resulting from different treatment inputs. In some cases, accomplishment measures may be as difficult or expensive to identify as actual forest benefit output and value estimates, or may poorly represent particular forest benefits of interest. A large part of estimating the value of changes in nonmarket benefits often is simply identifying what benefits are affected (see for example, Driver and Burch 1988: 34). Finally, avoiding the necessity of examining changes in forest benefit values ignores the possibility that marginal values are nonconstant—that the incremental value of saving the 1,000th-to-last spotted owl, for example, might be lower than the incremental value of saving the very last spotted owl. Care must be taken to ensure that accomplishment measures chosen for cost-effectiveness analyses adequately represent the public's objectives and interests regarding wildfire management.

Despite these drawbacks, cost-effectiveness analyses can provide a useful analytical alternative in cases where cost-benefit analysis may be infeasible. Cost-benefit analysis is intended to identify alternatives whose benefits exceed their costs, and provides a framework for comparing alternatives, giving preference to those yielding the greatest net gains. In contrast, cost-effectiveness analysis can be used to identify least-cost alternatives for achieving a target accomplishment level but does not provide guidance on which specific accomplishment level might be preferred over another. Ideally cost-benefit analysis would encompass cost-effectiveness analysis, enabling managers to select the best accomplishment level as well as the least-cost means of achieving it.

Equity Considerations

Not addressed by cost-benefit, economic impact, and cost-effectiveness analyses are equity issues related to who gains and who does not when public agencies invest in fuel treatments. All taxpayers bear the financial costs of fuel treatments. However, those who gain might include neighboring property owners who benefit from reduced wildfire threat and averted wildfire-related property damages, and individuals who use or value particular forest benefits that could be lost in large severe fires. Fuel treatments can affect the welfare of individual citizens differently because individuals often bear unequal tax burdens associated with fuel treatment costs and reap unequal net gains and net losses from resulting changes in forest benefits and wildfires.

Not addressed by cost-benefit, economic impact, and cost-effectiveness analyses are equity issues related to who gains and who does not when public agencies invest in fuel treatments.

One way of thinking about equity considerations is to consider the potential impacts of fuel treatment investments on three groups: timber producers, consumers, and landowners. If fuel treatments such as thinning increase federal harvests of merchantable timber in a region, private timber producers and landowners who grow, manage, and harvest timber are likely to lose when the increased supply of wood to timber markets results in lower stumpage prices. Lower stumpage prices also can reduce the wealth of private timberland owners, potentially reducing their ability to invest in particular forest management practices that protect or enhance nontimber values such as wildlife and riparian habitat or forest recreation. On the other hand, lower stumpage prices are likely to benefit wood processing mills and consumers who would pay less for timber and wood products. The impacts to different groups can differ by region. For example, mills benefiting from lower stumpage prices resulting from fuel treatments in one region may temporarily gain comparative advantages in wood production over competing mills paying higher stumpage prices in other regions.

Sometimes who gains and who does not can be somewhat ambiguous. For example, in some respects the issue of wildfire and homes located in forests—the wildland/urban interface—is similar to building homes in flood plains or coastal zones. It can be argued that property owners put themselves at risk by locating homes in fire-prone forests. Wildfire research suggests that building ignition probability is largely a function of materials, design, and characteristics of fuel within "a few tens of meters" (Cohen 1999: 193), all of which may be at the discretion of homeowners themselves. A reasonable question then might be why fuel treatments largely intended to avert potential property damages of a few select individuals should be paid by using the tax dollars of the general public. It also could be argued, however, that long-term wildfire suppression on public lands has increased wildfire threat above the level it would have been in the absence of long-term wildfire suppression, effectively imposing a cost on neighboring property owners in the form of greater current wildfire threat. Who then should be held responsible for property losses caused by wildfire—neighboring property owners who build their homes in fire-prone forests or public land management agencies whose history of wildfire suppression may have led to higher wildfire threat? The answer is not necessarily easy and depends on how society entitles different rights and responsibilities to each party.

There can also be environmental justice issues associated with where and when fuel treatments are implemented and whether they might benefit or harm different groups of people disproportionately. Generally, environmental justice concerns relationships between race, poverty, and environmental problems, benefits, and remediation (for example, Floyd and Johnson 2002). Environmental justice can be relevant in the context of wildland fire if fuel treatments benefit specific groups of people more than others or to the detriment of others. If, for example, political pressure from relatively affluent landowners results in a disproportionate amount of fuel treatment effort expended in a vacation community largely comprising the second homes of relatively wealthy people, less affluent landowners may perceive fuel treatment resources as lacking in their own communities. At the extreme, distributing fuel treatment efforts in a manner that unevenly affects particular groups of landowners has the potential to raise troubling liability issues should a wildfire result in significant property damage or loss of life in untreated areas.

A complicating factor regarding wildfire and the wildland/urban interface in particular is the poorly defined federal role in protecting private property from wildfire (Hesseln and Rideout 1999: 183). Although the public generally expects some wildfire protection, federal policy does not formally extend protection and management to private lands. A misconception prevails among elected officials, managers, policymakers, and the public that protecting private property is the responsibility solely of fire service agencies and organizations (USDI and USDA 1995), with property owners seemingly bearing little accountability. To the contrary, federal fire protection of private property within the wildland/urban interface might be considered by many taxpayers as unfair, because tax dollars paid by the general public are used to protect property owned by select individuals who choose to locate their homes in fire-prone forests. Such issues have led to past interagency efforts to clarify federal roles and responsibilities in protecting structures from wildfire (USDI and USDA 1995). However, a lasting solution to more efficient and equitable wildfire policy regarding the wildland/urban interface might include billing property owners for expenses associated with wildfire suppression and fuel reduction, and ensuring that insurance rates accurately reflect wildfire risks in forest landscapes (Hesseln and Rideout 1999: 183-184).

A Simple Cost-Benefit Numerical Example

A simple numerical example helps show the types of information that would have to be considered when computing the costs and benefits of fuel treatments. The example is for illustrative purposes only, and is not intended to reflect actual net benefits resulting from any particular fuel treatment scenario. The example, however, does reveal key factors that would characterize fuel treatment scenarios likely to result in positive net benefits. Imagine an acre of forest on which a fuel treatment costing $90 is being considered. Assume that the annualized timber and nontimber benefits generated by this forest acre total $100 per year, and that these benefits would be neither increased nor decreased directly by the fuel treatment itself—that is, they are affected only by the manner in which the fuel treatment alters the wildfire regime. For simplicity, we will compute the expected value of net benefits resulting from the fuel treatment over only a 3-year planning horizon (table 2).

If we do not conduct the treatment, one of four things can happen: (1) no fire occurs, (2) a fire occurs in year 1, (3) a fire occurs in year 2, or (4) a fire occurs in year 3. We will assume that only one fire can occur during the 3 years, again for simplicity. Assume that without the fuel treatment, the likelihood of a wildfire requiring some level of suppression occurring in any year is 1 in 20, or 0.05. Assume also that if a fire did occur, it would reduce annual benefits produced by the forest acre by 100 percent the year of the fire, 75 percent the year after the fire, and 50 percent the second year after the fire. Additionally, assume that the fire would result in suppression costs, smoke, and property damages totaling $600. Given these assumptions, the present values of net benefits that would result from each scenario without fuel treatment are computed as $288 if no fire occurs, -$530 if a fire occurs in year 1, -$454 if a fire occurs in year 2, and -$359 if a fire occurs in year 3 (table 2).

Similarly, we can compute the present value of net benefits that would result from each of four possible scenarios with fuel treatment. Assume that the fuel treatment would reduce the likelihood of wildfire requiring suppression by 80 percent in years 1 and 2, from 0.05 to 0.01, and by 60 percent in year 3, from 0.05 to 0.02. Assume also that if a fire did occur, it would be smaller and less intense, reducing annual benefits produced by the forest acre by only 50 percent the year of the fire, 25 percent the year after the fire, and none the second year after the fire. Additionally, assume that this potential fire would result in lower suppression costs, smoke, and property damages than those resulting from the potential fire without fuel treatment: 75 percent lower if the fire occurred in year 1 (the year of the treatment), and 50 percent lower if the fire occurred in either years 2 or 3. Given these assumptions, the present values of net benefits that would result from each scenario are computed as $288 if no fire occurs, $64 if a fire occurs in year 1, -$71 if a fire occurs in year 2, and -$35 if a fire occurs in year 3 (table 2).

The expected value of net benefits resulting from the fuel treatment is the difference between the total expected value of net benefits resulting from all scenarios possible without fuel treatment, and the total expected value of net benefits resulting from all scenarios possible with fuel treatment less treatment cost (table 3). Those expected values depend on the likelihood that different wildfires occur with and without treatment. We have assumed that without fuel treatment the likelihood of a wildfire occurring in any year is 0.05, and that the fuel treatment reduces that likelihood to 0.01 in years 1 and 2, and 0.02 in year 3. The likelihood that no fire occurs

Table 2—Example computation of discounted (r = 0.04) net benefits resulting with and without fuel treatment on a forest acre

	Possible scenarios without fuel treatment					Possible scenarios with fuel treatment				
Scenario	Assumed present value of annual benefits possible	Assumed reduction in annual benefits owing to fire	Present value of annual benefits received	Costs of fire suppression, smoke, property damages	Present value of potential net benefit	Assumed reduction in annual benefits owing to fire	Present value of annual benefits received	Assumed reduction in all fire costs owing to fuel treatment	Reduced fire suppression, smoke, property damages costs	Present value of potential net benefit
	Dollars	*Percent*	- - - - - - - - - *Dollars* - - - - - - - - - -			*Percent*	*Dollars*	*Percent*	- - - - - *Dollars* - - - - -	
No fire occurs										
1	100	—	100	—		—	100	—	—	
2	96	—	96	—		—	96	—	—	
3	92	—	92	—		—	92	—	—	
Total			288	—	288		288		—	288
Fire in year 1										
1	100	-100	0	600		-50	50	-75	150	
2	96	-75	24	—		-25	72	-50	—	
3	92	-50	46	—		-0	92	-50	—	
Total			70	600	-530		214		150	64
Fire in year 2										
1	100	—	100	—		—	100	-75	—	
2	96	-100	0	577		-50	48	-50	288	
3	92	-75	23	—		-25	69	-50	—	
Total			123	577	-454		217		288	-71
Fire in year 3										
1	100	—	100	—		—	100	-75	—	
2	96	—	96	—		—	96	-50	—	
3	92	-100	0	555		-50	46	-50	277	
Total			196	555	-359		242		277	-35

Table 3—Example computation of expected value of discounted (r = 0.04) net benefits resulting with and without fuel treatment on one forest acre

	Without fuel treatment			With fuel treatment		
Potential scenarios	Assumed likelihood	Present value of potential net benefit	Expected value net benefits	Assumed likelihood	Present value of potential net benefit	Expected value net benefits
		- - - - - - *Dollars* - - - - - -			- - - - - - *Dollars* - - - - - -	
No fire occurs	0.85	288	245	0.96	288	276
Fire in year 1	.05	-530	-26	.01	64	1
Fire in year 2	.05	-454	-23	.01	-71	-1
Fire in year 3	.05	-359	-18	.02	-35	-1
Total			178			275
Treatment cost			—			-90
Revised total			178			185

Note: Fuel treatment cost is assumed to be $90. Potential net benefits computed in table 1. Expected value equals likelihood times potential net benefit.

during the 3-year planning horizon then is 0.85 without fuel treatment, and 0.96 with fuel treatment. Given these probabilities, the expected value of net benefits resulting without fuel treatment total $178, whereas the expected value of net benefits resulting with fuel treatment total $275 less the $90 cost of treatment, or $185 (table 3). In this example, the expected value of net benefits resulting from the proposed fuel treatment on our imaginary forest acre equals $7 ($185 – $178), slightly favoring conducting the treatment.

The example simplifies the analysis in several ways. We have considered only a single forest acre, but we want to consider the spatial and temporal effects of fuel treatments over large landscapes. We have used only a 3-year planning horizon, but at a minimum we would want to consider the net benefits of fuel treatments over their expected duration of effectiveness. We have assumed that only one wildfire can occur and have not accounted for the diversity in wildfire conditions and behavior that are possible. We have only guessed at the values of key parameters: the likelihood of wildfire, the value of forest benefits and wildfire costs, and how each of these is affected by fuel treatment. We have assumed that the fuel treatment affects forest conditions only indirectly by its impact on the wildfire regime, rather than directly by altering forest conditions. We have not considered the potential beneficial effects that wildfires may have in reducing the likelihood, intensity, scale, and severity of future wildfires by reducing fuel. Despite these shortcomings, the example shows how several factors contribute to determining the net benefits likely to result from fuel treatments in different locations.

General conclusions can be gleaned from the example computations, and arise as much from common sense. The expected value of net benefits resulting from fuel treatments will most likely be positive when combinations of the following conditions exist: (1) timber and nontimber forest benefits are high and would be significantly and adversely affected by wildfire for long periods; (2) potential costs resulting from wildfire, including wildfire suppression and postfire restoration, smoke, and property damages, are high and would be significantly reduced by fuel treatments; (3) wildfire threat is high and would be significantly reduced by fuel treatments; (4) the effects of fuel treatments in reducing potential benefit losses and wildfire costs and reducing wildfire threat are relatively lasting; and (5) fuel treatment costs are relatively low, but treatment significantly reduces wildfire threat.

Evaluating the net benefits of fuel treatments by using cost-benefit analysis involves accounting for fuel treatment costs, potential changes in wildfire suppression and postfire restoration costs, and smoke and property damages resulting from alternative fuel treatment scenarios. Evaluating net benefits also involves considering how fuel treatments will affect forest conditions and their associated forest benefits, directly by reducing fuel through thinning or prescribed fire for example, as well as indirectly by changing the likelihood, intensity, scale, and severity of wildfire. Any cost-benefit analysis of fuel treatments would need to obtain information pertaining to each factor sufficient to meet prevailing demands for scientific quality in forest management and policymaking. Such information, however, may not always be available.

Ideally, there is an optimal strategy of fuel treatments, wildfire suppression, and postfire restoration that maintains forest benefits while lowering smoke and property damages at a price society can afford.

A Brief Summary of Existing Information

Ideally, there is some optimal strategy of fuel treatments, wildfire suppression, and postfire restoration that maintains or enhances forest benefits while lowering smoke and fire-related property damages at a price society is willing and able to afford. Determining that optimal strategy, if indeed one exists, is a difficult task. Evaluating the net benefits of fuel treatments involves accounting for several factors: the cumulative cost of fuel treatments, the likelihood of extreme wildfire events with and without treatments, the effects and costs of fire suppression and postfire restoration, and the combined influence of management actions and wildfires on forest conditions and forest benefits over time. Although no comprehensive analyses exist, forest researchers have begun examining parts of the problem. A brief review of the state of current knowledge regarding wildfires and fuel treatments reveals a number of issues pending further research and policy development.

Fuel Treatment Costs

The total cost to reduce fuels on 39 million acres nationally identified as high wildfire risk has been estimated as high as $725 million per year through fiscal year 2015, but these costs likely could be reduced by targeting areas at highest risk (General Accounting Office 1999: 45). Several types of fuel treatments typically are proposed to reduce wildfire threat, including prescribed burning, precommercial thinning, pruning, commercial timber harvests, and other mechanical treatments. The effectiveness of any treatment differs depending on prevailing forest conditions where it is implemented. Fuel treatments themselves also involve some risk. Prescribed burning, for example, generates smoke and under rare circumstances can itself result in catastrophic wildfire, as exemplified by the 2000 Los Alamos fire in New Mexico. Commercial timber harvesting and its resulting slash, as well as precommercial thinning, pruning, and other mechanical treatments can temporarily increase ground fuels, which must be properly treated to minimize their contribution to wildfire threat (Gorte 2000: 10–15). Prescribed burning also can increase fuel in the years immediately following a burn, as a result of fire-induced mortality.

Although the effectiveness and resulting net benefits of fuel treatments are not always certain, potential implementation costs generally are known. The costs of USDA Forest Service fuel treatments in fiscal years 1998 and 1999, comprising mostly prescribed burning in the South, were $34 and $46 per acre, repectively. Costs can, however, range as high as $1,500 per acre depending on location, fuel load, and the extent of thinning (Gorte 2000: 15). Average forest fire protection expenditures per acre from 1987 to 1995—those typically spent on prescribed natural fire or management-ignited prescribed fire—differ widely by region, from a low of $13 (1995 dollars) per acre in Region 8 (Southern) to $381 per acre in Region 10 (Alaska). Average expenditures per acre in other regions fall in between: $23 in Region 3 (Southwestern); $47 to $71 in Regions 2 (Rocky Mountain), 4 (Intermountain), 6 (Pacific Northwest), and 9 (Eastern); $85 in Region 1 (Northern); and $130 in Region 5 (Pacific Southwest) (Schuster and others 1997: 23).

Fuel treatment costs also differ by treatment type. Estimated average costs per acre for prescribed burning conducted by national forests from 1985 to 1994 were $172 (1995 dollars) for slash reduction burning, $80 for management-ignited prescribed fire, $107 for prescribed natural fires, $59 for brush, range, and grassland prescribed fire, not including Region 10 (Cleaves and others 2000: 17). These costs, too, can differ by region depending on management and policy objectives, burning conditions, and site characteristics. Treatment scale (size of treated area) and labor costs often are cited as the most important factors influencing cost (Cleaves and others 2000: 17).

In the case of prescribed burning, institutional constraints and policy guidelines regarding the scale of burns also are important factors influencing costs (Gonzalez-Caban 1997: 542). For example, new and stricter regulation of atmospheric particulate matter by the Environmental Protection Agency will increasingly oblige forest managers to comply with state-approved smoke management programs when planning and carrying out prescribed burns (Mahaffey and Miller 2001, Riebau and Fox 2001). Also of note are increasing costs associated with regulation, permitting, liability risks, and insurance costs (Cleaves and Haines 1997, Hesseln 2000).

Wildfire and Fuel Treatment Effects

An important factor affecting whether the benefits of fuel treatments outweigh their costs is the degree to which fuel treatments incrementally reduce the likelihood of severe intense wildfires. Despite significant recent media coverage, wildfires typically affect only a small proportion of the forest landscape in any given year. The average annual acreage burned between 1990 and 1999, considered a relatively bad recent decade for fire, averaged 554,577 acres on USDA Forest Service-protected land and 3.1 million acres on other protected land (Gorte 2000: 5). With almost 747 million acres of forest land under public and private ownership in the United States (Smith and others 2001: 63), the decadal average annual burned area represents just under 0.5 percent of the total. This rate is fairly consistent with decadal averages over the past 40 years and well below those experienced during the first half of the 20th century (fig. 6). Although decadal averages have remained relatively constant in recent decades, significant fluctuation in annual acreage burned from one year to the next does occur. Total acres burned in 2000 (8.4 million) and 2002 (6.9 million), for example, were higher than average (4.1 million) over the past four decades (1960-2003) (fig. 7).

Any analysis must make a reasonable attempt at characterizing the existing wildfire regime and how it can be altered by fuel treatments.

Much of the general decline in burned acreage during the 20th century has been due to greater wildfire prevention and suppression efforts by the Forest Service and other land management agencies during the same period. These efforts generally are viewed as resulting now in increased fuel loads and increased potential for larger, more catastrophic wildfires. Recent trends suggest that the proportion of total acres burned by large intense wildfires may be increasing (General Accounting Office 1999: 29). For example, although the total number of wildfires generally has been decreasing since 1981, the number of acres burned per fire does appear to be increasing (fig. 8). It is primarily this recent trend in acres burned by large intense wildfires, and accompanying increases in wildfire suppression and postfire restoration costs, that is motivating our current national interest in fuel treatments.

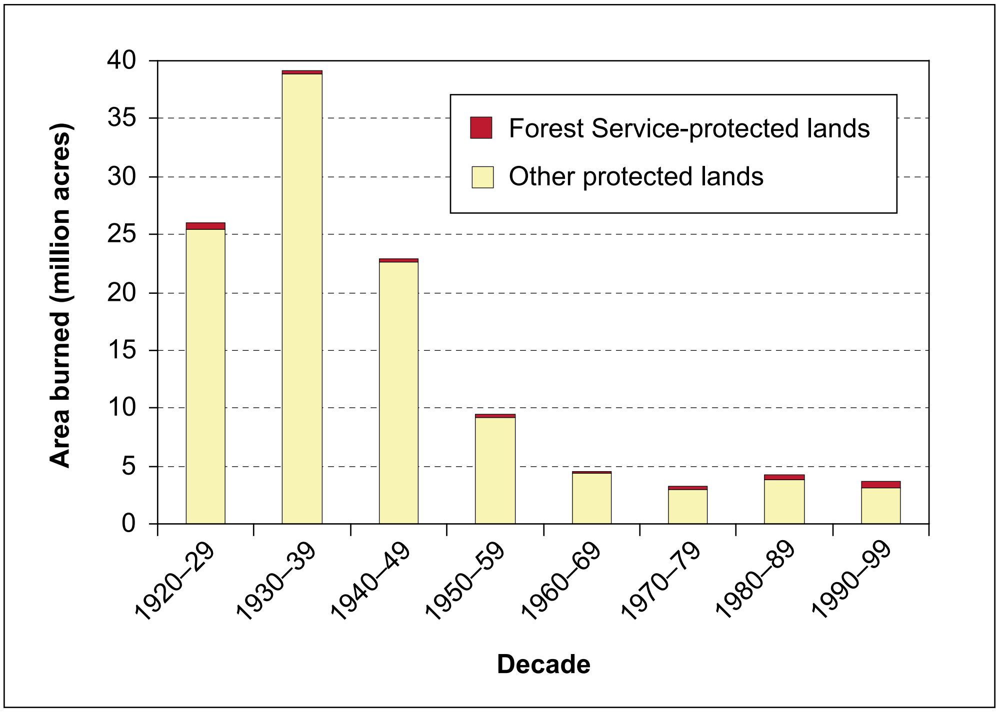

Figure 6—Decadal average annual acreage burned on Forest Service-protected and other protected lands, 1920 to 1999 (Gorte 2000: 5). Under several cooperative agreements developed to improve protection efficiency, the Forest Service protects some nonfederal lands while other organizations protect some national forest lands. The total acres protected by the Forest Service roughly equals the acres in the National Forest System (Gorte 2000: 4).

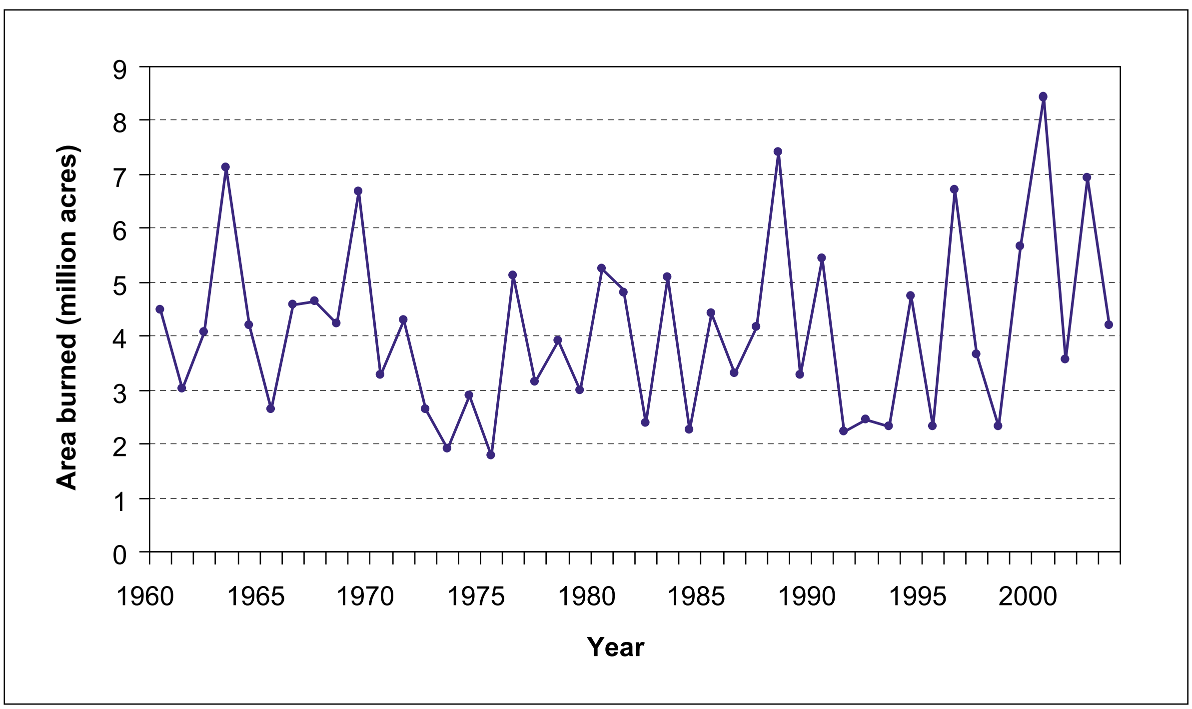

Figure 7—Total acres burned by all fires, 1960 to 2003 (National Interagency Fire Center 2004b).

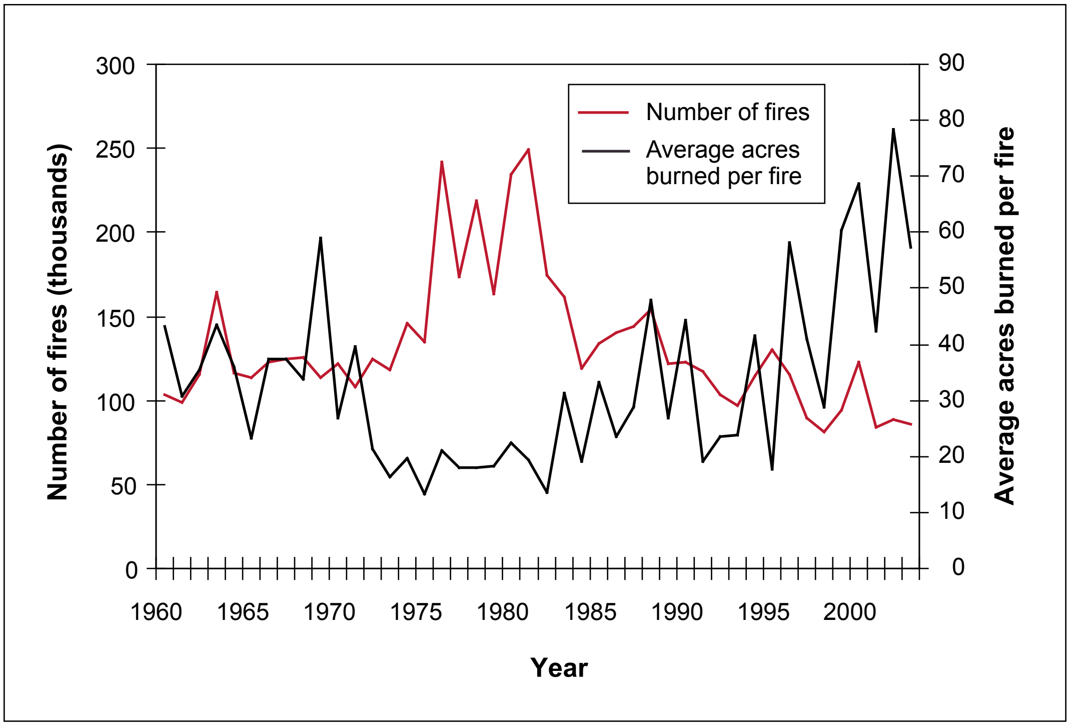

Figure 8—Number of fires and acres burned per fire, 1960 to 2003 (National Interagency Fire Center 2004b).

The uncertainty associated with where, when, and what types of wildfire will occur presents significant challenges to evaluating the net benefits of fuel treatments. Any analysis must make a reasonable attempt at characterizing the existing wildfire regime and how it can be altered by fuel treatments. Two research areas of particular interest in evaluating the costs and benefits of fuel treatments are (1) efforts to forecast wildfire occurrence and (2) efforts to model fire as a stochastic process. Efforts to forecast fire occurrence generally have relied on historical data comprising the dates and locations of wildfires, such as national fire occurrence data (Schmidt and others 2002), to estimate probabilistic empirical models describing wildfire occurrence as a function of geographic, topographic, and weather-related factors. Such models have shown some potential for forecasting the likelihood of wildfire occurring at a given time and location based on given weather conditions (Brillinger and others 2003, Preisler and others 2003).

Efforts to model wildfire as a stochastic process generally rely on simulation and optimization models to describe wildfire occurrence and resulting ecosystem responses under different fuel treatment scenarios for well-defined geographic areas. Examples of the evolution of this body of research include Wiitala and others (1994), Schaaf and others (in press), Jones and others (1999, 2003), Weise and others (1999, 2000), Merzenich and others (in press), and Chew and others (2000), among other studies. The objective of these studies generally is to determine which fuel treatment strategies would be most cost effective in given locations, by predicting the extent, intensity, and resource effects of wildfires likely to occur following treatment. Model outputs that can be evaluated often include acres burned summarized by intensity level, smoke, suppression costs, and various resource measures describing forest and habitat conditions.

An important contribution of these research efforts is their accounting of the complex probabilistic nature of wildfire and the degree to which fuel treatments reduce the likelihood of severe intense wildfires. However, few attempts have been made to express all potential wildfire impacts resulting from alternative fuel treatment scenarios as changes in net benefits. Wildfire habitat effects, for example, must be characterized in terms of changes in forest conditions resulting from fire. Values of those changes are not always quantified or comparable to other wildfire impacts, such as smoke emissions or increased stream sediment, because data describing the values of such changes are lacking. These research efforts, however, likely serve as a basis from which to conduct more comprehensive cost-benefit analyses in the future, should sufficient information describing wildfire impacts and forest benefit values become available.

Property Damage

A significant political motivation for conducting fuel treatments is protecting private property located on forest landscapes at the wildland/urban interface. Homes consumed by uncontrolled wildfire serve as dramatic footage for nightly news broadcasts, fuelling public concern about fire. Effort expended to save homes often is cited as a key factor in rising suppression costs (for example, Office of Management and Budget 2002: 66). For these reasons, reducing fuel at the wildland/urban interface has become a primary focus of forest policy on federal lands (for example, USDA Forest Service 1995: 20). Ongoing research is identifying places where housing and other developed uses are most at risk to potential wildfire (for example, Kline 2004, Stewart and others 2003). Maps of the wildland/urban interface increasingly can be combined with wildfire and fuel treatment effects models to simulate potential private property losses resulting from wildfire under alternative fuel treatment scenarios (for example, Jones and others, in press).

Research, however, suggests that home ignitability—a function of materials, design, and fuel located within the immediate vicinity of homes—is the principal cause of private property losses during wildfires (Cohen 1999, 2000). Fuel characteristics beyond immediate home sites have little, if any, effect. Also, property owners appear to be willing to pay for both public and private risk-reduction activities (Fried and others 1999). For these reasons, reducing fuel on federal lands to protect homes may be less effective or efficient than inducing homeowners to reduce structure ignitability through private actions focused on the immediate home site. Public efforts to reduce wildfire risks to private property through fuel treatments and wildfire suppression may even provide perverse incentives to private landowners to locate homes on fire-prone landscapes, because they perceive wildfire risks are minimized (Rideout 2003). These issues suggest a need to rethink federal policy regarding wildfire to identify situations in which federal involvement in protecting private property from wildfire is appropriate.

There may be a need to rethink wildfire policy to identify situations in which federal involvement in protecting private property is appropriate.

Smoke

Smoke from wildfires contributes carbon dioxide and other greenhouse gases to the atmosphere and can threaten public health in nearby communities, cause smoke damage and soiling of buildings and materials, disrupt community activities, and reduce scenic values and highway safety by reducing visibility. Prescribed burning also produces smoke, resulting in similar impacts and socioeconomic costs, though these can be lessened by using appropriate smoke management practices. Smoke often is the limiting factor determining where and when prescribed burning can be feasible and legal under current air quality standards.

Existing smoke models characterize emissions based on burned area, fuel characteristics, fire behavior, combustion stage, fuel or biomass consumption, and emission factors determined for different pollutants. In some cases, these models can be incorporated into existing fire simulation models to examine smoke tradeoffs between wild and prescribed fires. Smoke transport and dispersion also are important in evaluating smoke effects on public health and welfare. Historical spatial data describing windspeed and other climatic factors enable researchers to identify areas most at risk from air quality and visibility impacts of smoke resulting from wild and prescribed fire, and how risks change throughout the year (Ferguson and others 2003). Although such data can be useful in planning prescribed fires in locations and at times of the year to minimize air quality and visibility effects, they likely are not sufficient for evaluating smoke effects of different fuel treatment alternatives. Although important to evaluating fuel treatments, smoke prediction methods remain limited in coverage and scope. The full effects of wildfire and prescribed burning on air quality are not entirely known (Sandberg and others 2002) and the socioeconomic costs of smoke largely remain unexamined (Hesseln 2000: 324).

Recreation Effects

Evaluating the recreation effects from wildfire and fuel treatments requires evaluating changes in both visitation rates and values visitors hold for different recreation activities at different sites (for example, Vaux and others 1984). Resulting welfare effects depend on initial site quality and the potential impacts of any wildfires on site conditions (Englin and others 2001). How wildfire and treatments affect recreation will differ by activity, location, forest conditions, and fire characteristics and timing. Fuel treatments intended to reduce wildfires may not always be beneficial to recreation, because the direct and lasting impacts of wildfire on recreation are not always negative. Some recreation activities can be enhanced by wildfire, including even high-intensity crown fires. For example, particular crown fires have been found to benefit hiking while reducing mountain biking (Loomis and others 2001: 521).

Evaluating recreation impacts also can be complicated by time effects. Although wildfire impacts on recreation generally fade over time (Englin and others 1996: 454), they can increase or decrease visitation and values in response to changing forest conditions during postfire forest recovery, providing a range of benefits and losses in the years following a fire (Englin and others 2001: 1837). For example, recreation may be curtailed immediately following wildfire by damage to access and facility infrastructure, but opportunities to view a wildfire's aftermath as well as the resulting forest recovery processes may attract numbers of recreationists exceeding prefire visitation rates (Englin and others 2001, Loomis and others 2001). Some crown fires have been found to increase hiking visitation and values owing to the profusion of wildflowers and other novel ecological effects that often follow wildfires (Englin and others 2001: 1843; Loomis and others 2001: 520). In fact, the potential for increased recreation visitation following wildfire has been noted for the opportunity it provides to educate visitors to national forests, parks, and forest lands about fire ecology and the role of wildfire on forest landscapes (Englin and others 2001: 1843).

Specific recreation uses and values are relatively well documented for specific locations (for example, Bergstrom and Cordell 1991, Loomis and others 1986, McCollum and others 1990, Sorg and Loomis 1984, USDA Forest Service 1990). However, only a few studies have examined wildfire effects on recreation uses and values (Englin and others 1996, 2001; Hesseln and others 2003; Loomis and others 2001). Virtually no studies exist describing recreation visitors' reactions to prescribed fires (Englin and others 2001: 1837; Loomis and others 1999: 200) or other fuel treatments intended to reduce the likelihood of high-intensity crown fires. Although fire managers can transfer existing information describing recreation values to particular regions of interest (Rosenberger and Loomis 2001), they may have little empirical basis for describing how recreation uses are affected by wildfire and treatments (Loomis and Gonzalez-Caban 1997, Loomis and others 1999). What little information does exist often does not describe welfare changes associated with specific recreation activities or may not be transferable to locations outside specific study areas (see for example, Englin and others 2001: 1843). Beyond general conclusions gleaned from existing recreation research, evaluating the recreation effects of fuel treatments in specific locations likely would require original studies.

Evaluating Ecological and Other Effects

Fire decisionmaking must incorporate a broad range of forest benefits including biodiversity preservation and ecosystem values (Loomis and Gonzalez-Caban 1997: 473). Two types of information are needed to quantify the value of such changes: (1) information describing changes in forest output levels (or resource effects) resulting under alternative fuel treatment scenarios and (2) information describing people's values for those forest output levels (or resource effects). Characterizing ecological effects and their values remains among the more significant analytical challenges in evaluating fuel treatments. Several studies have examined wildfire effects on a variety of ecological resources of interest; however, few studies are designed to examine these effects separable from other effects related to site characteristics, weather, and other factors (Rideout and others 1999b: 50–51). General relationships between wildfire behavior and wildfire effects often are not well known, because individual studies tend to focus on natural resource impacts of specific fires or describe fire characteristics only in general or qualitative terms. Studies of wildfire effects do not often encompass potential fuel treatment effects. Moreover, wildfire and fuel treatment effects can differ depending on existing conditions, as well as by the nature of the direct and indirect impacts of wildfires and fuel treatments on those conditions.

For wildlife, although the immediate wildfire effects often include injury, death, and migration, resulting habitat changes generally are most significant (Smith 2000: iv) and can affect wildlife at species, population, and community levels. Stand-replacing wildfires roll back forest succession processes with corresponding changes to forest composition and structure (Rochelle 2002, Smith 2000). Wildfire effects on individual species can be beneficial, harmful, or negligible, depending on the species, stage of stand development, and the sizes, severity, and patterns of wildfires, among other factors. Many species have adapted to historical wildfire regimes over long periods of time. Although wildlife impacts of fuel treatments are less known than those of wildfire, research suggests that thinning and prescribed burning pose relatively modest risks if key habitat structures and conditions can be maintained (Rochelle 2002: 45). Where long-term fire suppression has notably altered species composition and increased fuel loads, wildfires are unlikely to result in presettlement vegetation and habitat characteristics without some type of prior fuel treatment to lessen wildfire severity (Lyon and Smith 2000: 59–60). Selecting what fuel treatments are appropriate in different locations depends on existing forest conditions and wildfire threat. Prescribed fire may be preferred over thinning or other mechanical treatments if fire would provide ecological or other benefits; mechanical treatments might be preferred in areas expected to benefit little from fire (Miller and others 2000).

For aquatic and riparian species in the short term, heat and fire and resulting debris flows can kill fish and other species and damage habitat. Over the long term, debris flows can create and maintain functioning habitat (for example, Miller and others 2003), including beneficial river landforms such as fans, flood plains, terraces, and side channels (Benda and others 2003: 114). Wildfire effects in otherwise intact unfragmented stream ecosystems are not always catastrophic nor are recovery periods excessively long, even where wildfire suppression has occurred for long periods (Minshall 2003: 158–159). Erosion, sedimentation, smoke, and ash-fall can provide important nutrients to riparian systems, stimulating phytoplankton growth well beyond the immediate burned area (Spencer and others 2003). Down woody debris generated by wildfire can benefit aquatic habitat if aquatic species that require such debris are present and the system lacks woody debris. There can be exceptions, such as when postfire flooding scours streambeds where little coarse wood is available to replace that removed. Reducing large wildfires by using fuel treatments can be beneficial, particularly to isolated, small, or otherwise vulnerable aquatic populations that face possible extinction from severe fire (Dunham and others 2003: 192). Despite high values associated with riparian areas and recognition of wildfire as an important natural disturbance, few studies have examined the behavior, properties, and influence of wildfire in riparian areas (Dwire and Kauffman 2003: 61). Fuel treatments likely are beneficial in some contexts but not others (Rieman and others 2003: 198).

Related to aquatic and riparian effects are sedimentation effects. Landslides and debris flows are important storm-driven processes of sediment delivery to stream channels in many landscapes (Miller and others 2003: 122–123). Their timing and severity can be greatly influenced by wildfires that destroy ground cover, kill vegetation, and reduce soil infiltration, with severe fires increasing their frequency and magnitude (Wondzell and King 2003: 79). However, little data exist with which to characterize wildfire effects on the frequency and magnitude of erosion and sedimentation processes (Miller and others 2003: 123) and their effects on stream ecology (Wondzell and King 2003: 84). Erosion and sedimentation impacts on stream channels likely vary, influencing stream ecological functions in different ways. However, because disturbance processes such as wildfires, floods, erosion, and sedimentation generally are viewed as important sources of physical heterogeneity and biological diversity in river systems, such processes are considered positive events that promote long-term ecological function (Benda and others 2003: 117). Such effects, however, must be weighed against other potential adverse socioeconomic consequences downstream, which may include downstream sedimentation of surface water bodies including reservoirs and boat channels (for example, Loomis 2003, Wohlgemuth and others 1999) and increased water treatment costs associated with reduced water quality (for example, Fitzgerald 2002).

Characterizing ecological effects and their values remains among the more significant analytical challenges in evaluating fuel treatments.

In summary, whether fuel treatments are beneficial in terms of biodiversity preservation and ecosystem values greatly depends on given circumstances. Little or no generalizable information exists with which to evaluate changes in ecosystem functions or outputs resulting from fuel treatments over time. This general lack of output measures makes evaluating ecosystem effects within an economic analytical framework quite difficult.

Valuing Ecological and Other Effects

Although published values can be found for a variety of forest benefits, few studies have documented the impacts of wildfires and fuel treatments on such values (Loomis and others 1999: 199). With the exception of commercially sold forest products, such as timber, most forest benefits involve nonmarket values, which generally can be estimated by economists using a variety of techniques. The relevant value measurement for evaluating wildfire or fuel treatment effects is the value associated with the marginal change in ecological output induced by fire or treatment (for example, Althaus and Mills 1982: 6). Values for nonmarket ouputs, however, can be difficult to assess on broad scales because of the wide range of outputs (Hesseln 2000). Also, the marginal benefits of some outputs—the incremental increase in benefit given an incremental increase in output—may be impractical or too costly to accurately estimate (Rideout 2003). Values for cultural resources and ecosystem functions also may include significant existence, option, bequest, and other intrinsic values, making them particularly difficult to quantify and incorporate into fire management and policy (Hesseln and Rideout 1999: 182).

Studies that have examined changes in forest benefits resulting from wildfire and fuel treatments generally have focused on relatively well-defined resource outputs—northern spotted owls (*Strix occidentalis caurina*) or big game habitat

(Loomis and Gonzalez-Caban 1997), for example, or specific geographic areas. Whether information is available for specific locations often will determine how comprehensive any evaluation of forest benefits can be. Values estimated for particular ecological effects in one location sometimes can be transferred to other locations by using benefit transfer techniques, but these depend on meeting a number of data, site, and study criteria (Desvousges and others 1992, Rosenberger and Loomis 2001), which may not be possible. For these reasons, often only a partial accounting of potential forest benefit changes likely to result from wildfires and fuel treatments is possible. Partial evaluations of benefits, however, can present problems if they lead to biased results favoring one action over another. For example, studies show considerable willingness to pay among the public for fire protection activities that reduce the number and extent of wildfires in old-growth northern spotted owl habitat (Loomis and Gonzalez-Caban 1997, Loomis and others 1996). These studies would seem to support increased funding for related fire management activities. However, a different conclusion might result if information on values derived from early-succession forest conditions and habitat were also included, which might partially offset old-growth values. Comprehensive evaluation of costs and benefits may be impractical in many cases. Analysts will need to carefully consider the potential management and policy implications of missing information.

Is Current Knowledge Sufficient?

This section has briefly described what is known about just some of the potential costs and benefits of conducting fuel treatments. Not addressed are potential fuel treatment effects on wildfire suppression and postfire restoration costs, grazing, scenery and aesthetics, carbon sequestration, and air quality benefits, among others. With sufficient funding and time, useful information regarding changes in forest benefit outputs and values generally could be obtained by using existing economics methods. However, the general lack of information describing the long-term effects of wildfire and fuel treatments on forest conditions and related resource effects is a significant obstacle to comprehensive, or in some cases, even partial analyses. The current availability of information differs by region, with more information available for places where ongoing research is already underway.

Fuel management intended to preserve, maintain, and restore ecosystems inevitably is conducted in the context of scarce resources—we can never have everything we would like (Rideout 2003). Current information describing the resource effects and resulting changes in forest benefits arising from wildfires and fuel treatments is not sufficient to support comprehensive analysis of the costs and benefits of alternative fuel treatment scenarios. Lacking such information, managers and policymakers may be unable to implement cost-effective fire management programs based on sound economic principles. Specific needs include (1) better information about fire management activities and fire effects; (2) long-term effects of fire management activities on expected suppression costs, resource and property damage, and market and nonmarket benefits; and (3) greater incorporation of nontimber market and nonmarket benefits into risk research (Hesseln 2000: 332-333). All of these factors must be examined in a fire policy context that is conducive to achieving economically efficient outcomes, which may not always necessarily be the sole objective of federal forest management.

Management, Policy, and Research Implications

The costs and benefits of fuel treatments should be considered over the long term and within an analytical context that includes other management actions, most notably wildfire suppression and postfire restoration, that also affect forest conditions and the wildfire regime. All of today's management actions and the wildfires that burn, will affect forest conditions and the necessity for fuel treatments tomorrow, as well as the likelihood, severity, and intensity of tomorrow's wildfires and their associated suppression and postfire restoration costs. How forest conditions change over time as a result of fuel treatments and wildfires will determine the levels of forest benefits received in future years. All of these costs and benefits, now and in the future, must be discounted to the present. Clearly, the information and analytical needs for conducting rigorous comprehensive analyses of the costs and benefits of fuel treatments are significant. The complexity of the fuel treatment issue is a major factor contributing to uncertainty and ultimately driving persistent debate about the wisdom of investing in fuel treatments in the Nation's forests. Sometimes wildfires result in net benefits; sometimes they result in net costs. The net benefits of conducting fuel treatments are not always certain.

The complexity of the fuel treatment issue is a major factor contributing uncertainty and driving persistent debate about the wisdom of investing in fuel treatments in the Nation's forests.

There are not likely to be sufficient data and information with which to conduct comprehensive evaluation of fuel treatments for the foreseeable future. In the near term, any economic rationale for conducting fuel treatments offered from a national perspective likely will derive more from qualitative than from quantitative analyses. Forest scientists generally agree that wildfire historically has been an important process of forest landscape change in the United States and should be restored to its appropriate role in federal forest management. Where there may be less agreement is in defining the best way to do it. There appears to be some prevailing concern among segments of the public that recent federal interest in conducting fuel treatments is motivated more by an interest in logging than in fuel reduction (see for example, Allen 2003, Bumiller 2003, Nash 2003, among others). This perception is one obstacle to reformulating federal forest policy and management to more adequately address wildfire. Given public unease with wildfire, difficulties also may exist in advocating the need for fuel treatments—prescribed burning in particular—by focusing on the potential catastrophic effects of wildfire on communities located on fire-prone forest landscapes. Effectively addressing the wildfire issue will depend on dialogue among the public, policymakers, managers, and scientists about the costs and benefits of alternative fuel treatment scenarios, including inaction, and existing uncertainties regarding fuel treatment effects.

If the public desires to maintain forest landscapes within a historical range of conditions, better incorporating wild and prescribed fire into forest management is a necessary step, including defining where and when to suppress wildfires or let them burn. Public support for burning tends to be positively correlated with public knowledge about fire and fire policy (Beebe and Omi 1993, Manfredo and others 1990). Traditional fire prevention campaigns have not recognized the beneficial role of fire in the environment (USDI and USDA 1995). Given the long-running and effective federal campaign to educate the public about the need to prevent forest fires, pursuing an elevated fire role in federal forest policy and management likely will require reeducating the public about the appropriate function of fire processes in forest landscapes. What may be as useful as improved data and analyses of fuel treatments, is a new federal public education campaign highlighting the historical role of fire in landscape change and ecosystem function, as well as the role of natural and management-ignited prescribed fire, thinning, and harvesting in a comprehensive and effective forest management strategy that fairly incorporates the full range of benefits the public desire from their forest lands.

Acknowledgments

Funding for this report was provided by the Pacific Northwest Research Station's Focused Science Delivery Program. I thank Ralph Alig, Jamie Barbour, Geoff Donovan, Richard Haynes, Linda Langner, Claire Montgomery, Ken Skog, Seth White, and Mark Wiitala for helpful comments.

Metric Equivalents

When you know:	Multiply by:	To find:
Acres	0.405	Hectares
Feet	0.305	Meters
Miles	1.609	Kilometers

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Appendix: Glossary of Descriptive Fire Terms as Used in This Report

Fire suppression—The work of extinguishing or containing a fire, beginning with its discovery, and including initial response, extended attack, and large fire support (National Interagency Fire Center 2004a).

Fuel treatments—Actions, including manipulation, combustion, or removal of fuel, intended to reduce the likelihood of ignition and/or lessen potential damage and resistance to fire suppression (National Interagency Fire Center 2004a).

Intensity—The rate at which fires consume fuel (Russell and others 2004).

Likelihood—The probability that a wildfire will occur. Because many natural-caused wildfires are small and tend to extinguish on their own, likelihood generally is used in this report to describe the probability of extreme wildfire events requiring significant suppression effort.

Postfire restoration—Actions, including emergency stabilization and rehabilitation, intended to reduce or repair damage or disturbance caused by wildland fires or fire suppression activities.

Scale—As used in this report, the size of a wildfire event in terms of acres burned.

Severity—The (presumably adverse) effects fire has on vegetation, soil, buildings, watersheds, and other resource values (Russell and others 2004).

Wildfire regime—Definitions for the term "wildfire regime" or "fire regime" differ slightly from source to source. The term "wildfire regime" frequently is used to describe the patterns, sizes, uniformity, and severity of wildfires (for example, Brown 2000, Parsons 2000). The report *Federal Wildland Fire Management: Policy and Program Review* (USDI USDA 1995), which outlines contemporary federal wildland fire policy, uses the term "fire regime" to describe "circumstances of fires, including frequency, intensity, and spatial extent." For the purposes in this report, wildfire or fire regime means the intensity, severity, and scale of wildfires that occur on a forest landscape, as well as the likelihood of extreme wildfire events requiring significant suppression effort.

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