Ecological Risk Assessment to Support Fuels Treatment Project Decisions

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Abstract

Risk is a combined statement of the probability that something of value will be damaged and some measure of the damage's adverse effect. Wildfires burning in the uncharacteristic fuel conditions now typical throughout the Western United States can damage ecosystems and adversely affect environmental conditions. Wildfire behavior can be modified by prefire fuel treatments, thereby reducing risks to firefighters, structures, and ecosystems, but such projects pose their own environmental risks. To support fuels treatment decisions, environmental analysis of alternatives is generally required, including taking no action. How can managers determine whether risks of actively treating fuels are greater than risks posed by no action? The risk-reduction benefits of fuel treatment are often overlooked in decision processes for comparing wildfire effects with and without fuel treatment. To fill the void, a comparative ecological risk assessment conceptual model is presented. Both prefire fuels treatment and postfire events produce sediment that can adversely affect water quality and aquatic organisms. Similarly, both prescribed fire and wildfire can adversely affect air quality. The model's tradeoff diagram tests a risk management hypothesis: The benefits of restoring natural (historical) fire regimes and native vegetation in a particular location, plus the benefits of reducing the severity of wildfire effects, balance favorably against any adverse effect, either short- or long-term, from fuels treatment. Managers may believe this hypothesis, but policies require environmental analysis to support it. A tradeoff diagram illustrates the conceptual model and graphically replies to the question: Which produces more sediment, wildfire burning under untreated conditions, wildfire burning after fuels are reduced, or the treatments designed to reduce wildfire risks? Similarly: Which situation would produce more fine particulate matter ($PM_{2.5}$) air pollution? Tradeoff diagrams of such situations may contribute to sustainable resource management decisions by improving communications between risk assessors, public agency managers, and interested nongovernmental parties.

Keywords: Comparative ecological risk assessment, conceptual model, hazardous fuel reduction, policy, risk management, wildfire.

Introduction

Compared to not taking any action, fuel treatments may or may not reduce adverse ecological and environmental effects that accompany wildfires. Risk management is central to many human enterprises and is the foundation for all fire management activities (USDA-FS/USDI and others 2001). The U.S. Department of Agriculture, Forest Service (USDA-FS), and the U.S. Department of the Interior, Bureau of Land Management (BLM), have been advised to adopt a systematic risk-based approach to target fuel reduction projects across landscapes and to make fully informed decisions about fuels treatment project alternatives and their effects (GAO 2004, USDA-OIG 2006).

Risk is usually defined as having two components: a measure of adverse effects, and the probability of the adverse effects' occurrence. Many people have difficulty comprehending risk, and its quantification has challenged and confused lay persons and professionals (Haimes 2004). A simplifying approach for fire-adapted ecosystems is to use the fire return interval as the time horizon for analyzing environmental effects. By definition, this ensures that a wildfire will occur during the analytical period, and different conditions that affect fire behavior can be compared more readily by eliminating the need for knowing the probability distribution of fire occurrence. The risk management question then becomes: What is the desired condition for a particular ecosystem and location when the inevitable lightning bolt strikes?

Wildfire risk management is a synthesis of scientific and nonscientific concerns. Information from ecological, social, managerial, and policy sciences is integrated into a decision process framework that incorporates social values and concerns. These include democratic process and institutions for governing collective decisions in our society. Risk management depends on effective communication of information between risk assessors in regulatory agencies, risk managers in land management agencies, and interested members of the public who may be directly or indirectly affected by wildfire.

Risk is related to each of the three components of the general sustainable forestry model—risk of losing ecosystem components or damaging environmental values, economic investment risk, and social risk in communities facing forest-based change (O'Laughlin 2004, 2006). This synthesis takes a problem-oriented approach (see Clark 2002) to wildfire risk management and deals primarily with the ecological and environmental aspects of wildland fire management embedded in decisionmaking and social contexts and reflected in various institutions. Whether fuels treatment should take place on public lands is a collective decision.

Managers may lack the tools and information to demonstrate the beneficial effect that fuel treatment projects could have on environmental quality. To fill the void, a conceptual model of decision tradeoffs has been developed (O'Laughlin 2005a, 2005d). Herein, it is applied to the multiobjective fire/fish risk management problem in order to compare postfire sedimentation with and without fuel treatment. This same approach can be used to assess other environmental effects including fine particulate matter ($PM_{2.5}$) air pollution from either wildfire or prescribed fire smoke. The model is based on the framework of the Environmental Protection Agency's Guidelines for Ecological Risk Assessment (EPA 1998). In a comparative risk assessment framework, the integration of sediment, smoke particles, and other environmental risks with land management objectives is accomplished not by science, but via social process, primarily the public involvement processes required by environmental and land use planning laws. Risk assessors and risk managers interact with stakeholders to determine which risks are most important. Risks to firefighters, structures, scenery and aesthetics, vegetation species and age classes, wildlife habitat, and air and water quality should be considered. Using cause-and-effect modeling results developed by risk assessors, risk managers can demonstrate for each risk whether prefire fuels reduction could potentially reduce postwildfire adverse effects.

This section is concerned with all aspects of risk analysis, including risk communication as well as risk assessment and management. First, appropriate terminology is presented. Then the wildfire situation in the Western United States is defined as a fuels management problem and placed within its decision process and social contexts. Complications from spatial and temporal dimensions, as well as risk governance, arise from policy requirements and social perceptions of risk that may require institutional changes to produce sustainable improvements in forest ecosystem conditions. This synthesis rationalizes the choice of parameters selected to adapt the EPA's ecological risk assessment framework for the purpose of supporting fuels treatment decisions by comparing wildfire risk management alternatives using a with-or-without framing consistent with National Environmental Policy Act (NEPA 1969) requirements. A conceptual model diagram is the core of ecological risk assessment and the principal product of this synthesis, where it is used to compare wildfire effects on sediment with and without fuel reduction.

Risk Analysis Terminology

Risk terms can be a barrier to effective communications if not properly defined. **Risk** is a combined statement of the probability that something of value will be damaged and some measure of the damage's adverse effect. Risk simply gives meaning to the things, forces, or circumstances that pose danger to people or what they value (NRC 1996). Risk can mean both the probability of loss and the hazard or threat that might cause that loss (Harwood 2000). A **hazard** or **threat** is something that poses danger or can cause an adverse effect. **Stressor**, an EPA term, seems to be synonymous with hazard or threat and is any physical, chemical, or biological entity that can induce an adverse response in an ecological **risk assessment endpoint**. The endpoint is an explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes (EPA 1998). **Ecological risk assessment** is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (EPA 1998). **Ecological risk assessments** are developed within a risk management context to evaluate human-induced changes that are considered undesirable and are used to support many types of management actions, including the management of watersheds or other ecosystems affected by multiple nonchemical and chemical stressors (EPA 1998).

Adverse effects and their potential damages and consequences are real components of risk (Haimes 2004). The meaning of risk has always been inherently controversial and political because it depends on value-based (i.e., nonscientific) judgments about adverse effects (Slovic 1999). Changes are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components. An evaluation of adversity may consider the type, intensity, and scale of the effect as well as the potential for recovery from the risk-inducing event (EPA 1998). The probability component of risk is an imagined, mathematical human construct (Haimes 2004). Although most people understand probability in its simplest form—the likelihood of outcomes from tossing a coin or rolling dice—conditional and joint probabilities can be perplexing.

Risk analysis is usually considered to be the process of assessing, characterizing, communicating, and managing risk (e.g., Haimes 2004, NRC 1996). Effective risk analysis is integrated into decisionmaking processes, not treated as a gratuitous add-on task (Haimes 2004). Risk assessment asks: What can go wrong, and what are the consequences? Human and organizational failures are sources of risk and may be caused by environmental and institutional elements. Risk management asks what can be done, and what are the impacts on future options? Risks cannot be managed until they have been assessed, and some form of model is necessary for that (Haimes 2004).

Fuels Problem and Context

The accumulation of fuels over time can lead to uncharacteristic wildfires and associated problems. Alteration of historical fire regimes often causes serious changes in forest ecosystem processes, resulting in unusually intense, large fires. Current forest conditions and wildfire regimes pose risks to many environmental and socioeconomic values and threaten human communities (USDA-FS 2004). Wildfires near human communities can have devastating effects, as can postfire floods (May 2008). Wildfire poses immediate threats of damage or loss to nearby structures, and endangerment of public safety is an even more important concern during a wildfire incident and for many years thereafter. Wildfires also pose secondary threats to ecological and environmental resources (Summerfelt 2003).

The acreage affected by wildfire nationwide has steadily increased over the past four and a half decades, with a trend towards uncharacteristically severe and uncontrollable fire behavior (NIFC 2006b). Trends of increasing fire size and severity have emerged over the past 20 years (USDA-FS 2004) as wildfires in the Western States have increased. The trend is influenced by changes in climate, extreme droughts, and, in some forests, overabundant fuels (Westerling and others 2006).

The combined effects of increased fuel accumulations, lengthened fire seasons, and intensified burning conditions are expected to contribute to larger and more extensive wildfires in the near future (Covington and others 1994), with increases of 74 to 118 percent in wildfire burn areas expected over the next century (Running 2006). These expectations underscore the urgency of fuels management to reduce wildfire hazards to human communities as well as actions to mitigate wildfire impacts in forests that have undergone substantial alterations from past land uses (Covington and others 1994, Westerling and others 2006).

An understanding of the decision processes ("Decision Process") and social context ("Social Context") for wildland fire management is necessary if risk analysis is to be integrated into land and resource management decisionmaking. Decision processes are defined by public policies and laws, which are a function of the social environment within which wildland fire management occurs. Although various agencies and organizations may perceive wildfire risks differently, management decision processes are affected by the same evolving institutional framework of laws and policies. By engaging collaboratively with stakeholders in formal decision process forums, managers can integrate different perspectives regarding environmental risks and thereby arrive at socially acceptable decisions regarding wildland fire management and fuels reduction.

Decision Process

The ultimate utility of decision analysis is not necessarily articulating the best policy option, but avoiding extreme events (Haimes 2004), such as large-scale, uncharacteristically severe wildfires. Risk analysis traditionally has been used for other purposes, but it can address forest management issues in a transparent way and disclose risk tradeoffs that are often not accounted for in other decision analysis techniques (Hollenstein 2001). Land and resource management decisions always involve risk, including the decision not to take action (Thomas and Dombeck 1996).

The Federal Wildfire Policy (USDA-FS/USDI and others 2001) recognizes that sound risk management is a foundation for all fire management activities. Together with the National Fire Plan (NFP), this policy provides the institutional framework for Federal agencies, States, Native American tribes, local governments, and communities to manage wildfire risk, improve land conditions, and reduce impacts to communities while ensuring sufficient firefighting capacity for the future. The NFP has established a long-term hazardous fuels reduction program in which treatments are designed to reduce wildfire risks to people, communities, and natural resources while restoring forest and rangeland ecosystems to closely match their historical structure, function, diversity, and dynamics (USDA-FS/USDI 2006a). The NFP is implemented through a collaborative framework agreed upon by Federal and State agencies, tribes, and other parties (WGA 2006). The collaborative framework is a way to address fire and fuel management problems within their social context.

The National Environmental Policy Act (NEPA 1969) is the cornerstone of our environmental laws. It requires that Federal agencies analyze the short- and long-term adverse environmental consequences of a range of proposed management alternatives, including no action. The result of the NEPA process is some type of an environmental impact assessment document. According to an EPA scientist (Fairbrother and Turnley 2005), the NEPA process has various shortcomings that have hampered decisionmaking and significantly reduced public acceptance of fuels treatment. Risk assessment integrated into the NEPA process could result in more meaningful environmental impact analyses, thereby providing a more technically sound and robust means for assessing and comparing potential adverse outcomes of proposed management alternatives (Fairbrother and Turnley 2005).

The healthy forests policy—composed of the President's Healthy Forests Initiative and the Healthy Forests Restoration Act (HFRA 2003)—has led to modification or streamlining of decision processes (see O'Laughlin 2005b). The HFRA requires that before a court can issue an injunction, there must be a weighing of the environmental effects of doing fuels treatment against not doing fuels treatment. A legacy of HFRA therefore may be the stimulation, if not institutionalization, of comparative ecological risk assessment. Courts will look to land management agencies for such analysis. At this writing, it is unclear what the analysis might look like. One option is adapting the EPA (1998) Guidelines ("EPA's Risk Assessment Framework") to a wildfire risk management problem ("Fire/Fish Risk Management Application").

Social Context

Risk is a social construction, combining science and judgment with psychological, social, cultural, and political factors (Slovic 1997). What risks are taken into account, how they are framed, and what constitutes a solution to a risk problem are all matters that go beyond scientific inquiry (De Marchi 2003). Environmental risk involves value judgments that reflect much more than just the probability and consequences of the occurrence of an event (Kunreuther and Slovic 1996). Because risk assessment brings specific values into consideration, it can help reveal which values are at greater risk (Molak 1997). Interested parties can contribute knowledge that risk assessors would otherwise overlook (NRC 1996). Serious attention to citizen participation and process issues may eventually lead to more satisfying and successful ways to manage risks (Slovic 1997). If done systematically and transparently, risk assessment can help build trust (Slovic 1993) primarily by adding transparency to forest decisionmaking processes (Hollenstein 2001).

Social interaction is the phase of the risk analysis process during which integration of different risk assessment endpoints can be addressed. To enable management actions to improve the fire and fuel problem on Federal lands, managers should focus on the things people care about. These include:

1. The condition of forests relative to forest values associated with management objectives (i.e., forest health).
2. Forest values at risk of damage from nature's forces as well as human actions.
3. The environmental and socioeconomic effects of wildland fire management policy that protects some values while putting others at greater risk (O'Laughlin 2006).

For example, trying to protect fish habitat in fire-adapted ecosystems by not allowing a riparian vegetation management project simply because it will produce a small amount of sediment may be counterproductive in the long term. Fire is inevitable, and the magnitude of adverse effects is more important than when the effects occur (O'Laughlin and others 1998).

When interacting with stakeholders, risk assessors and managers should use qualitative and quantitative approaches as appropriate, while disclosing assumptions and potential for errors. Risk assessment can help risk managers compare the environmental effects of management alternatives. Clear objectives are needed, consistent with a long-term vision of what the land should look like. Effective communication of short- and long-term risks and risk-reduction benefits can help build trust with stakeholders (O'Laughlin 2005c). The thought process that goes into evaluating a particular hazard is more important than the application of some sophisticated mathematical technique or formula (Molak 1997). More emphasis on the risk management aspects of risk analysis would mean greater stakeholder involvement and de-emphasis on quantitative characterization of risk and uncertainty (Power and McCarty 1998). Fuels management projects on several California national forests emphasize the importance of stakeholder collaboration and modeling tools to help facilitate communications (see "Strategic Fuel Treatment").

Improving the Fuels Problem

The goal for improving the wildland fire and fuels problem is to reduce the long-term risk wildfire poses to human and ecological communities. Managers need to weigh the short-term risks posed by active management against the long-term risks posed by continued inaction, and to communicate these risks in a meaningful way to the public (Bosworth, Dale. 2003. Risk assessment for decisionmaking related to uncharacteristic wildfire. Unpublished keynote address to conference in Portland, OR, November 17. On file with Jay O'Laughlin, College of Natural Resources, University of Idaho, P.O. Box 441134, Moscow, ID 83844-1134). Managers cannot change weather or topography, but fuels can be modified to change the burning and value-loss characteristics at specific locations as well as across large landscapes. This not only reduces the negative impacts on those forests but the wildfire itself may also provide benefits (Finney 2005). Benefits include environmental risks prevented by management actions (Davies 1996). For example, before enjoining "an agency action under an authorized hazardous fuel reduction project, the court reviewing the project shall balance the impact to the ecosystem likely affected by the project of (1) the short- and long-term effects of undertaking the agency action; against (2) the short- and long-term effects of not undertaking the agency action" (HFRA 2003, title 1, section 106).

Fire hazard in a given area is partly a function of the combustible materials located on site. Thinning and prescribed burning are the primary fuel management activities and repeatedly have shown reduced fire intensities and increased survival of some forest types (Finney 2005). Considering anticipated changes in interior West forests, including climate, Covington and others (1994) concluded that the undesirable consequences of inaction far exceed those of action. Without active management of fuels, many forests will continue to be subject to uncharacteristically severe fires, and the costs of firefighting will continue to increase (Stephens and Ruth 2005). Active management can mitigate wildfire risks to watersheds in some situations, but, in others, forest management may not be effective (Bisson and others 2003, Schoennagel and others 2004, Westerling and others 2006).

Benefits from prefire management are most likely to come from prioritizing treatment areas (Dunham and others 2003). Priorities can be based on ecological value, evolutionary significance, and the risk of loss (Bisson and others 2003). The scale of the problem, however, is enormous. High-priority treatment areas cover 397 million acres of forests and grasslands across all ownerships, public and private, an area three times the size of France. Some 73 million acres of forests in the low- and mixed-severity regimes are far denser than they ought to be, increasing their vulnerability to stand-replacing fires. These have been identified as high-priority treatment areas (USDA-FS 2006a).

Successful projects for reducing fire hazard depend on taking many factors into account and developing protocols for deciding which stands should be thinned and by how much, with each situation evaluated on its own merit and operations planned carefully to ensure that the cure is not worse than the disease (NRC 2000). In risk management, avoiding actions in which the cure is worse than the disease means avoiding extreme events, i.e., the worst and the most disastrous situations (Haimes 2004).

Problem fires are today's parlance for extreme fire events (NIFC 2006b). Of all ignitions, 2 to 3 percent escape initial attack and become the problem fires that damage resources, threaten communities, and cost millions of dollars in suppression efforts. Whereas not all wildland fires grow to such proportions, problem fires are those events that are large, destructive, dangerous, and costly to manage. Problem fires are the symptoms of a larger forest health issue, where ecological realities conflict with social expectations and economic limitations (NIFC 2006b). Spatial fire behavior models used in collaborative settings ("Strategic Fuel Treatment") offer some promise in dealing with social issues at various spatial and temporal scales ("Spatial Scale Issues" and "Temporal Scale Issues"). Especially on National Forest System lands ("National Forest System Issues"), institutional improvements ("Institutional Improvement") may be necessary to help put such technologies in place.

Spatial Scale Issues

Wildland fire risk reduction is a national goal that depends on landscape-level planning and project-level actions (Barbour and others 2005). The EPA (1998) guidelines have been used to compare risks at a regional scale (Landis 2005). To date, such efforts have not included forest threat assessment in general or wildfire in particular. Although sustainable forest management issues involve multiple scales, achieving the national goals of sustainability rest, in large part, on actions that are carried out at the local or forest management unit scale (USDA-FS 2004). A variety of modeling approaches are now available to meet the landscape-level planning needs. However, there is a lack of explicit guidance about how to connect perceptions of risk across vast spatial expanses of geographic or ecological regions to the outcomes of specific management activities at the project scale of a few to tens of thousands of acres (Barbour and others 2005). The guidance document for Federal healthy forests project implementation (USDA-FS/USDI 2004) recognizes the importance of scale and assumes assessments at scales larger than individual projects have been done before fuels treatment projects are initiated.

Tying small area project-level analyses to larger scales helps managers think about the importance of different resources through space and time (Barbour and others 2005). Refining analyses at the midscale helps to understand how different resources interact. Considering resource conditions and management objectives at very broad scales can help managers understand where they might concentrate efforts (Barbour and others 2005). Broad-scale assessments should set priorities for reducing the risk to social and ecological values caused by uncharacteristically dense vegetation. To reduce risk, the assessments should evaluate the potential for vegetation treatments, such as mechanical treatments and prescribed fire. A tactical schedule of priority vegetation-treatment projects should result from strategic assessments of the need for fuel treatments conducted at appropriate landscape scales (USDA-FS/USDI 2004).

Spatial data and risk-based methods are available to analyze 2-million-acre watersheds in order to prioritize treatments at the subwatershed scale of 20,000 acres

(Hessburg and others, this volume). At the subwatershed scale, it is not necessary to treat an entire landscape for effective risk reduction (Ager and Finney 2007). Instead, strategic placement of fuel treatments (SPOTS) can be used to attain the desirable outcome of modifying fire behavior (McDaniel 2006).

Strategic Fuel Treatment

Wildland-urban interface (WUI) areas are generally recognized as high priorities for fuels treatment (Pyne 2004). However, treating only WUI areas alone will not achieve the wide range of human and natural resource benefits forests provide (Summerfelt 2003). The large-scale fires of 2002—Hayman (Colorado), Rodeo-Chediski (Arizona), and Biscuit (Oregon-California)—caused considerable damage and disruption in WUI areas. These fires began miles beyond the WUI where excessive fuel loadings had accumulated (USDA-FS/USDI 2006b). In addition, at higher elevations outside the WUI, wildfire can damage riparian areas and associated watershed benefits and values (Dreesen 2003, Obedzinski and others 2001).

Firesheds are large (thousands of acres) landscapes, delineated based on fire regime, condition class, fire history, fire hazard and risk, and potential wildland fire behavior. Fireshed assessment refers to an interdisciplinary and collaborative process for designing and scheduling site-specific projects (NIFC 2006b). The purpose of fireshed assessments is designing the most effective fuel treatment program with the resources available for reducing the likelihood of a large, severe problem fire (McDaniel 2006).

SPOTS is an interagency, interdisciplinary, collaborative landscape-scale GIS-based tool that has emerged from fireshed assessment efforts on several national forests in California. The strength of the process lies in purposeful dialogue between interested parties (McDaniel 2006). The important thing is to focus on exploring everyone's ideas and not trying to find one right answer. Project leaders stress this collaborative approach and active learning by participants as the key strength. Although most people have a perception of the fireshed assessments as a set of modeling tools, project managers indicate that the models really are used to promote dialogue (McDaniel 2006).

The SPOTS concept contributes to an overall understanding of the spatial dynamics of fuel and related fire behavior by employing fire modeling tools that describe fire potential on a specific landscape. The SPOTS approach considers tradeoffs between multiple treatment options by gaming fire scenarios with fire behavior and spread modeling software. The SPOTS framework meets the need identified by the U.S. Government Accountability Office (e.g., GAO 2004) to establish a consistent way to define risk and test potential solutions. SPOTS was developed in California, and, in 2005, the Forest Service and BLM tested it in eight pilot areas across the country, including central Oregon.

SPOTS analysis approaches should dovetail with the Fire Program Analysis (FPA) system, which is a new interagency planning and budgeting tool for evaluating the effectiveness of alternative fire management strategies (NIFC 2006a). The SPOTS approach also may allow managers time to implement long-term management strategies to restore ecosystems, perhaps including effective decision support for wildland fire use (WFU) (Gercke and Stewart 2006). WFU allows lightning-ignited fires to burn in order to attain planned resource management objectives.

Temporal Scale Issues

There is a lack of explicit guidance about how to consider changes in conditions that occur over the decades or even centuries required for ecological processes to play out on the landscape (Barbour and others 2005). Proposed projects that could produce benefits by reducing risks over the long term are sometimes considered unacceptable because they pose a small amount of risk in the short term. For example, in some situations prefire hazardous fuel reduction treatments can reduce sedimentation and smoke in the long term, but, in the short term, such treatments produce additional quantities of sediment and smoke that some people may consider unacceptable, no matter how small.

Compliance with the NEPA (1969) requirement for short- and long-term effects analysis raises the issue of appropriate time horizon selection. Comparison of environmental risks should be done within the same time period, and risks prevented by management programs should be included in the comparison (Davies 1996). Extinction should be viewed over hundreds of years so that short-term considerations do not create long-term problems (NRC 1995). For risks to native fish, 100 years is a minimum (Rieman and others 2003a). By selecting the fire return interval as the minimum time horizon, the probability of a fire on the landscape is assured, and risk analysis can proceed to focus on reducing adverse effects.

National Forest System Issues

The buildup of forest fuel and changes in vegetation composition are particularly problematic on National Forest System lands (O'Laughlin 2006, O'Laughlin and Cook 2003). According to former USDA Forest Service Chief Dale Bosworth (2003), the situation on National Forest System lands is not sustainable—ecologically, economically, or socially. Active management of Federal lands that maintains forest cover and structure within a range consistent with long-term disturbance processes can reduce the potential for severe fire behavior, maintain and enhance long-term ecological integrity, and provide the mix of goods and services people want from ecosystems (Quigley and others 1998).

To improve forest health conditions on Federal lands, managers generally must support project-level decisions with NEPA (1969) analysis documents and demonstrate the short- and long-term effects on environmental values other than woody vegetation. These project-level analyses allow managers to consider protecting or enhancing specific resources (Barbour and others 2005). For example, wildfire risk and northern spotted owl (*Strix occidentalis caurina*) habitat suitability are complex issues requiring site-specific assessment and management (Lee and Irwin 2005). Managers need tools at the project level to help them work through the project approval process (USDA-FS/USDI 2004). In addition, projects need to be prioritized so that scarce resources can be used effectively (Bisson and others 2003).

The effect of NEPA—in combination with the Clean Water Act, Clean Air Act, Endangered Species Act, Federal Land Policy and Management Act, and the National Forest Management Act—has been to create increasingly difficult decisionmaking on Federal lands. The USDA Forest Service process predicament report presents an argument that because of policy-driven delays, the agency is hindered from producing on-the-ground results, including improving forest health (USDA-FS 2002). Breaking decisionmaking gridlock is one reason for applying formal risk assessment (Lackey 1994).

Institutional Improvement

Managing ecological risks depends on an integrated approach because risks arise from many sources—hydrologic, forest, rangeland, and aquatic as well as economic and social—and reducing risks from one source may increase risk to another ecological component (Quigley and others 1998). The integration will come through social process. One such approach is illustrated by the fire/fish risk management problem ("Fire/Fish Risk Management Application").

Ecologists generally recognize that barriers to improving ecological conditions may be more social or institutional than scientific (Szaro and others 1998). Improving the wildfire problem will be a complex, lengthy, expensive, and risky process, not only because of the ecological legacy on the land, but also the institutional legacy (Busenberg 2004). The framework for implementing the National Fire Plan is dependent on effective collaboration between Federal agencies, other levels of government, and interested parties or stakeholders (WGA 2006). Finding ways to meaningfully incorporate risk analysis—especially cooperative or collaborative risk assessment and risk management—into decisionmaking processes seems to be the most direct institutional path to on-the-ground improvements in ecosystem conditions.

Risk can be thought of as a game in which the rules must be socially negotiated within the context of a specific problem. This contextual approach highlights the need for interested parties to define and play the game, and emphasizes the importance of institutional, procedural, and societal processes in risk management decisions (Kunreuther and Slovic 1996). Risk assessment methods, assumptions, and conclusions differ dramatically across the Federal government (Cantor 1996). Standardization of policies and procedures among Federal agencies is an ongoing objective in wildland fire management (USDA-FS/USDI and others 2001). Nevertheless, different agencies can be expected to have different perceptions of risk based upon their agency missions and policies. Unless there are appropriate forums for reconciling differences in risk perceptions among all interested parties, information developed in risk assessments is unlikely to change the way land and resource management decisions are made.

Comparative ecological risk assessment can play a role by facilitating communications between risk managers, risk assessors, and interested parties. Two things need to be accomplished with stakeholders: (a) identify the things they care about, i.e., risk assessment endpoints; and (b) communicate what is known and unknown about the cause-effect relationships of factors ("stressors"; i.e., threats or hazards) affecting those endpoints. Slovic's (1999) advice to wildland fire managers is to forgo attempting to determine what stakeholders think may be an acceptable level of risk, and, instead, focus on demonstrating the benefits from risk management actions.

Participative governance for managing risks requires a shift of mentality, broad changes in professional and institutional practices, and the design and implementation of new instruments and procedures (De Marchi 2003). These are difficult things to change. One opportunity to incorporate societal concerns in the governance of risks is to encourage public participation from the beginning of decisionmaking processes. The twofold challenge in risk governance is first providing the forums where citizens present and debate their interests and ideas about public matters and then making such deliberations a meaningful part of democratic decisionmaking (De Marchi 2003). The design of the EPA (1998) Guidelines explicitly addresses both challenges.

EPA's Risk Assessment Framework

Spurred by considerable political interest in the 1990s, a substantial body of literature exists on environmental and ecological risk analysis (Molak 1997). A review of laws and policies supports the conclusion that Federal land and resource management agencies, and agencies responsible for environmental protection, must use some form of risk assessment in their decisionmaking processes (O'Laughlin 2005b). Neither laws nor policies prescribe how agencies should do risk analysis or what the end result should look like. The EPA's (1998) *Guidelines for Ecological Risk Assessment* provides a useful starting point.

The EPA risk assessment process estimates the likelihood of the occurrence of an unwanted adverse effect (Fairbrother and Turnley 2005). At least nine Federal agencies, including the USDA Forest Service, have used the EPA (1998) "guidelines and agreed that they provide a common basis for analyzing risks" (CENR 1999). The EPA framework (Figure 1) recognizes that the interface among risk assessors, risk managers, and interested parties at the beginning (during planning) and end of the risk assessment process (during risk communications) is crucial for ensuring that the results of the risk assessment can be used to support a management decision (EPA 1998).

The first step in the EPA framework is a well-defined problem formulation built on the involvement of stakeholders as well as scientific information about the magnitude of wildfire effects. Next, risk characterization makes a comprehensive statement about risk, including assertions about uncertainty, and clearly communicates results to resource managers and interested stakeholders (Fairbrother and Turnley 2005).

Decision analysis and other structured problem-solving methods emphasize the need for clearly articulated objectives, along with criteria to evaluate how well various alternatives might meet those objectives (NRC 1995). Sustainable resource management depends on clear objectives describing desired future conditions. Objectives provide managers with targets and others with benchmarks for holding managers accountable for their actions. For risk analysis objectives, called assessment endpoints, EPA "Guidelines recommend specific ecological entities and their attributes, and caution against the use of vague ideas such as sustainability and integrity" (EPA 1998).

Fire/Fish Risk Management Application

To enable risk-reducing fuels treatment projects, managers need to take a problem-oriented approach to reducing fuels without causing irreparable harm to fish populations. I call this integrated multiple-objective situation the fire/fish risk management problem (O'Laughlin 2005a, 2005d).

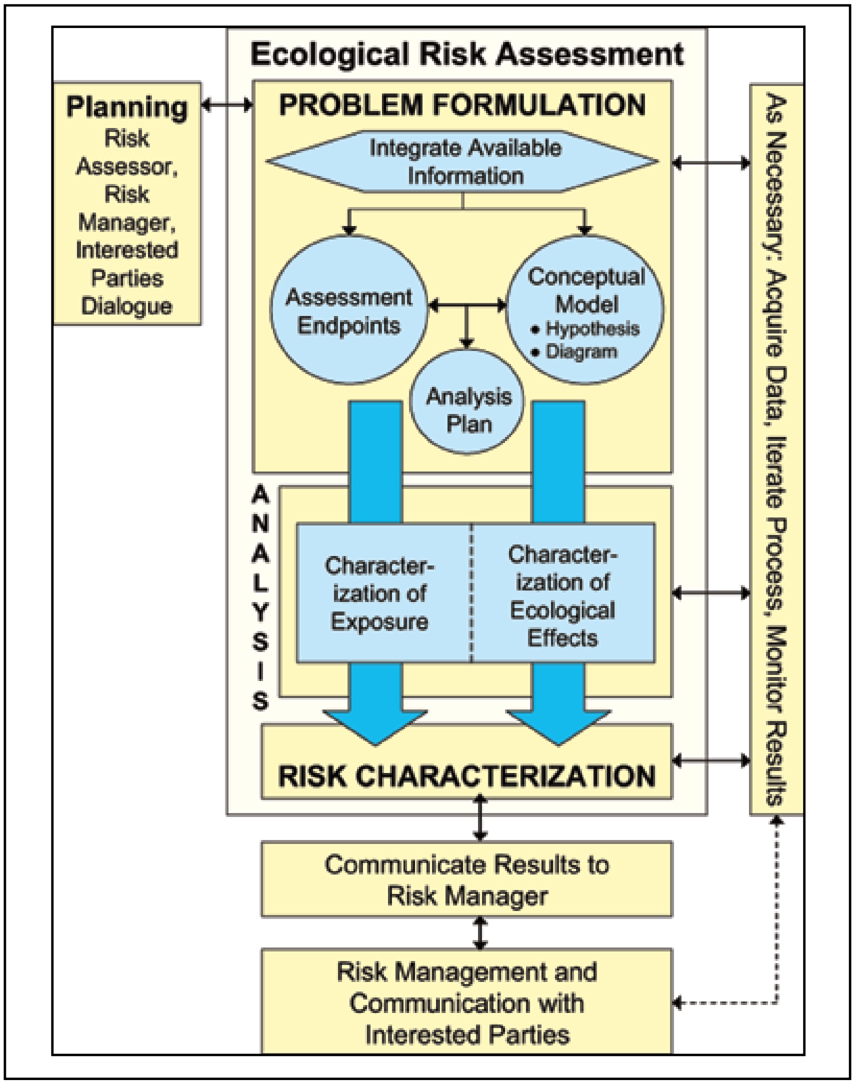

Figure 1— Framework for ecological risk assessment.
Source: Redrawn from EPA (1998)

Risk assessment can be used to support many sustainable forest management decisions, including comparing wildfire risks to various environmental values with and without fuels treatment. Herein, only the problem formulation phase of the EPA framework is covered in detail. Problem formulation ("Problem Formulation") involves understanding the situation well enough to develop a conceptual model ("Conceptual Model"), which consists of a risk management hypothesis and a conceptual model diagram. Both of these model components clearly document the risk assessor's thought process regarding cause and effect relationships. This approach facilitates risk characterization and communication with interested parties. Fish are selected as the risk assessment endpoint, and the stressor adversely affecting them is sediment from logging or wildfire burning or both under different conditions that vary according to fuel loadings. A quantitative example is provided ("Quantitative Application"), and uncertainties are explicitly addressed ("Uncertainty").

Problem Formulation

The first phase of ecological risk assessment is problem formulation, and a conceptual model is an essential part of the process (Figure 1). The inability of management and regulatory agencies and the public to articulate common goals and conceptual approaches to land management is part of the problem, and until there is improved coordination and recognition of a common conceptual framework for management actions, conflicts are likely to continue (Bisson and others 2003).

The underlying structures of belief, perception, and appreciation people have toward situations are called frames (Schön and Rein 1994). Framing resource management problems as questions is a clarifying exercise. Lackey (1997) asked: If ecological risk assessment is the answer, what is the question? In the fire/fish context, Rieman and others (2003b) replied: Which is worse, new fires that may result from past management, or new management intended to mitigate those fires? These are good questions. Providing answers to the wrong questions and missing the relevant aspects of a problem because of inaccurate framing of a risk issue should be avoided (De Marchi 2003).

To consider the "which is worse" question in a fire/fish decision model, the relevant parameters are the adverse environmental effects of fire with and without fuel treatments and the beneficial effects of treatments. Two risk analysis experts suggest focusing on risk management benefits. Haimes (2004) cautioned that suboptimal decisions are likely unless the beneficial as well as adverse effects of current decisions on future options are assessed and evaluated to the extent possible. Slovic (1999) recommended focusing on the benefits of managing wildland fire, instead of trying to determine the acceptable level of risk from adverse effects.

Many factors adversely affect fish populations. Wildfire can cause fish mortality directly and indirectly by modifying habitat quality (Rieman and Clayton 1997). By affecting vegetation, wildfire can accelerate soil erosion rates and sediment delivery to streams (Wondzell and King 2003). Although closer integration of terrestrial and aquatic management is necessary, the lack of a common understanding or conceptual foundation is a fundamental challenge to progress (Rieman and others 2003a).

Conceptual Model

Risk cannot be managed unless it has been properly assessed, and some form of model provides the best assessment process (Haimes 2004). The EPA framework relies on a conceptual model, and it has two principal components: (a) a risk hypothesis describing predicted relationships among stressor, exposure, and assessment endpoint response, along with rationales for their selection; and (b) diagrams illustrating these relationships (Figure 1). By highlighting what we know and do not know about a system, a conceptual model provides an opportunity for others to evaluate explicit expressions of the assumptions underlying decisions. Conceptual models can represent many relationships, including exposure scenarios qualitatively linking land-use activities to stressors (EPA 1998). A conceptual model for the fire/fish risk problem compares short-term effects of fuel treatment project implementation to long-term effects with and without fuel treatment, including project benefits from reducing post-wildfire environmental damage. Sediment production is the environmental effect analyzed. The idea that active management can improve conditions is a testable risk hypothesis that can be visualized and communicated in a conceptual model diagram.

Cause-and-Effect Hypothesis—
In the problem formulation phase of the EPA framework (Figure 1) the objective of the analytical phase of the assessment is called the endpoint. The stressor's ecological effects on the endpoint are described in stressor-response profiles. The EPA (1998) guidelines illustrate these concepts using salmon reproduction and age class structure as a risk assessment endpoint and logging sediment as a stressor. A key assumption in the fire/fish risk management conceptual model is that hazardous fuel reduction treatments will reduce wildfire intensity and subsequent severity of environmental effects by reducing postfire sediment delivery.

The relationship of a sediment-causing disturbance and a fish population is illustrated in a conceptual model diagram (Figure 2) describing the relationship of quantities of sediment delivered to the stream and fish biomass (Rieman 2003). This model diagram serves as the stressor-response profile called for in the EPA's approach to risk analysis. In the diagram, fish biomass is reduced almost immediately in response to a disturbance event, which could be either wildfire or logging. Sediment rapidly returns to the pre-event level, but it may take decades for fish biomass to return

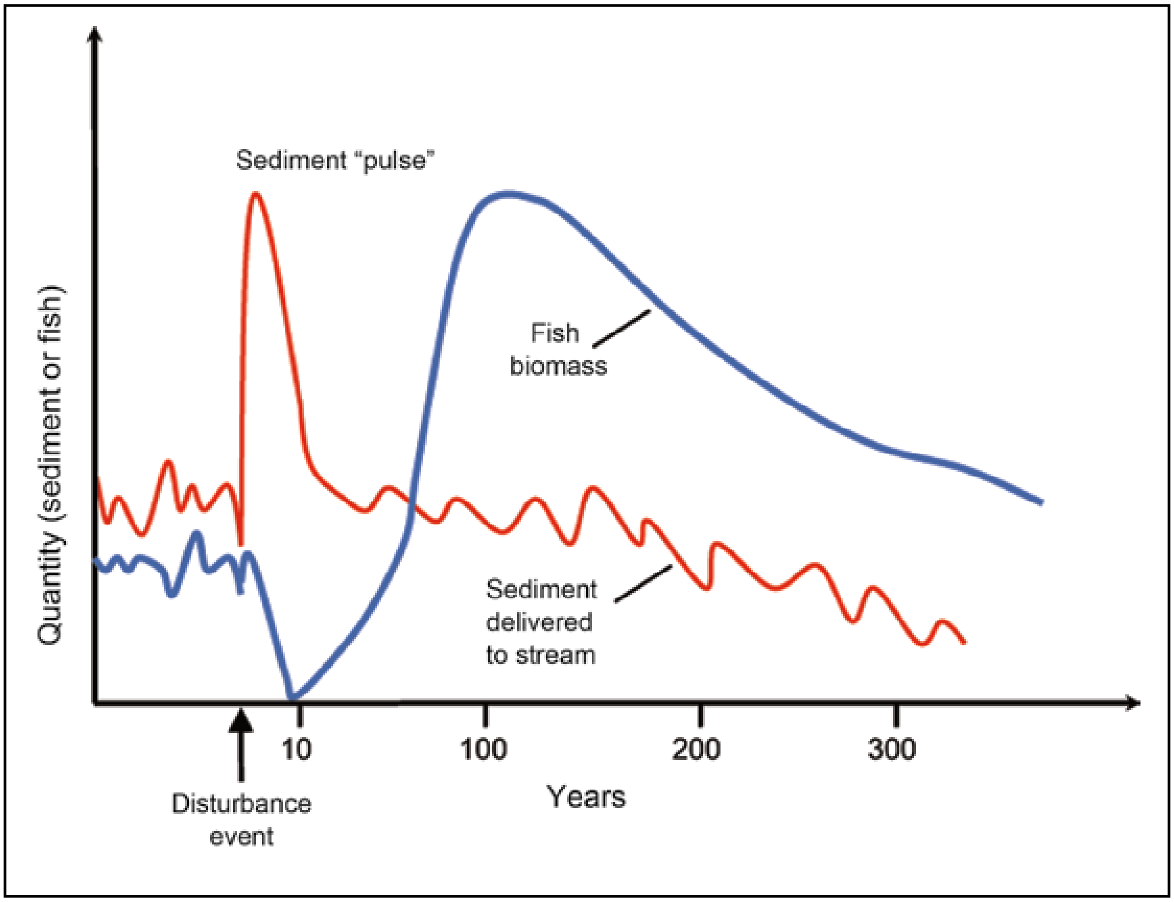

Figure 2—Conceptual model for sediment and fish relationship.
Source: Redrawn from Rieman 2003.

to the pre-event level. Over the long term, fish biomass becomes higher than before the event and remains there for centuries (Figure 2). In other words, sediment produced by a disturbance will have short-term adverse effects on fish, offset by long-term benefits.

A risk hypothesis is a fundamental component of an ecological risk assessment model (EPA 1998). Hypothesis: the benefits of restoring natural (historical) fire regimes and native vegetation on a particular site, plus the benefits of reducing the severity of effects from stand-replacing wildfires, balance favorably against any adverse effect, either short or long term, from hazardous fuel reduction treatments. The hypothesis is derived from language in a memorandum from the directors (Williams and Hogarth 2002) of the two Federal agencies charged with implementing the Endangered Species Act (ESA 1973). The memo provides guidance for ESA regulatory personnel engaging in interagency consultation with land management agencies. It is consistent with NEPA (1969) requirements that Federal agencies analyze and document short- and long-term environmental effects of proposed major actions, including the no-action alternative.

Formulating the problem as a temporal comparison of adverse effects, however, often results in decisions to reject fuels treatment projects near imperiled species habitat. Adverse effects from fuels treatment are certain in the short term, whereas wildfire occurrence in the short term is uncertain.

An alternative problem formulation focuses on the relative magnitude of adverse and beneficial effects from wildfire burning under different fuel conditions. By selecting a long-term planning horizon corresponding to fire return interval, wildfire becomes a certainty. The magnitude of postfire effects remains an uncertainty, but such effects are

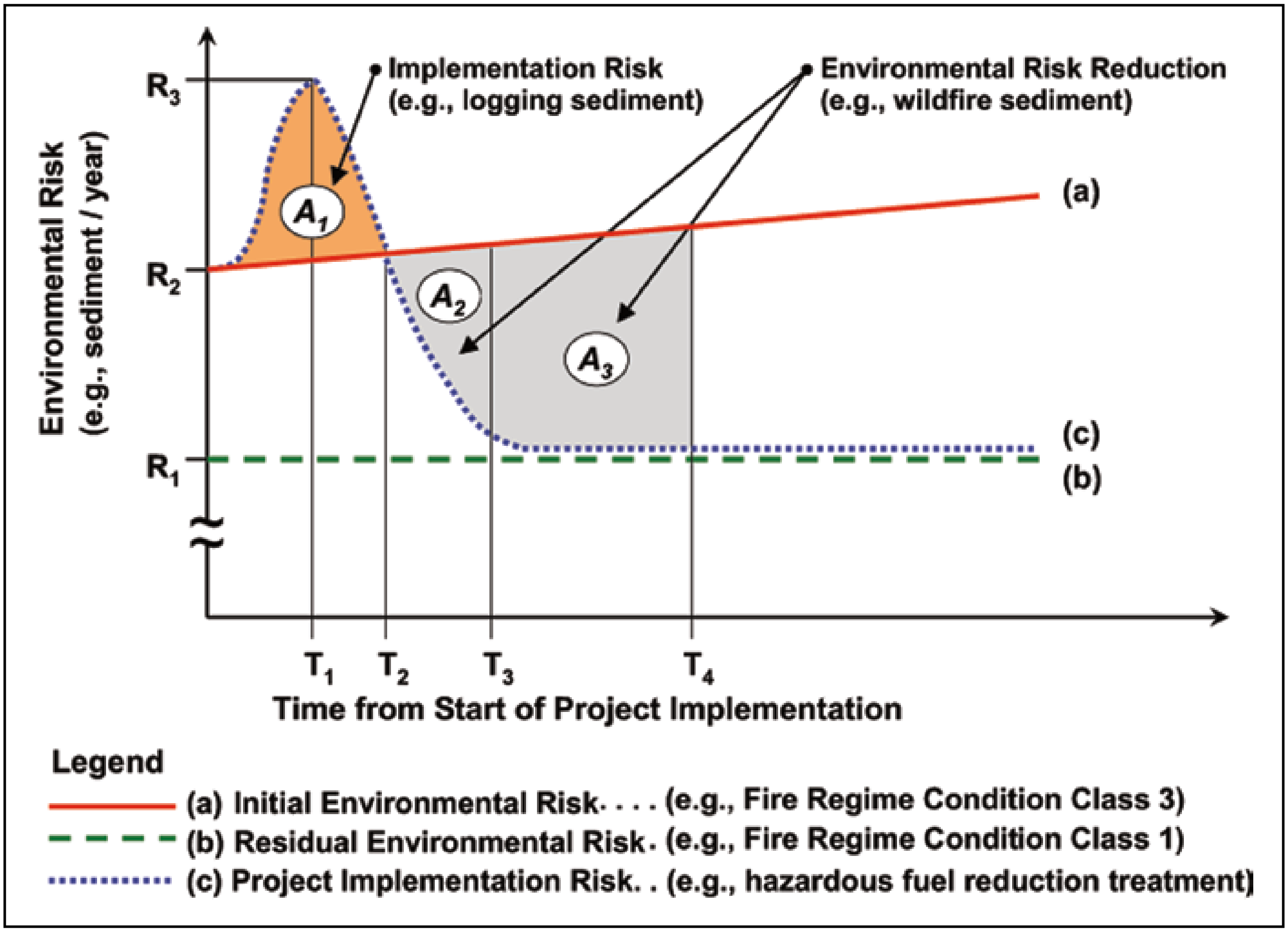

Figure 3—Conceptual model for comparing short-term fuel treatment implementation risk with long-term environmental risk reduction. Source: Redrawn from O'Laughlin (2005a); modified from U.S. Dept. of Energy (2002)

certain to occur at some level. Instead of trying to confront the landscape-level uncertainties of if, when, and where an uncharacteristically severe wildfire will occur, the environmental analysis question in the project area simply becomes "Which prefire condition produces the more desirable postfire effect—fuel treatment or no fuel treatment?" Managers may accept the fuels treatment hypothesis, but they need to present evidence in NEPA documents to convince others who may be skeptical.

Conceptual Model Diagram—
The objective of fuel treatment is modification of fire behavior (Stephens and Ruth 2005). One way to do that is to move from a higher fire regime condition class (FRCC) (Hann and others 2003) to a lower one (see, e.g., USDA-FS/USDI 2006b). In 2000, approximately 151 million acres of Federal forest land was in FRCC 2 or 3 (USDA-FS 2001). Some of these lands could be improved by restoring FRCC 1 conditions through fuels reduction. On Federal multiple-objective lands, fuels management projects must meet a variety of objectives, including water and air quality standards. How does moving vegetation from a higher to lower FRCC affect other values? In the fire/fish example, sediment that adversely affects fish habitat is portrayed as environmental risk on the vertical axis of the tradeoff diagram (Figure 3). Other effects such as increased stream temperature from reduced shade, or $PM_{2.5}$ from different smoke regimes, could be analyzed similarly.

Line (a) is the initial environmental risk of sediment produced by a wildfire burning under uncharacteristic fuel conditions (FRCC 3). Point R_2 is at the origin of line (a) and represents the current risk of postfire sediment; as fuels continue to accumulate over time, the postfire sediment load on line (a) increases without fuel treatment. In NEPA (1969) terminology, line (a) is the postfire effect of the "no-action" alternative. Line (b), a constant at R_1, is residual environmental risk, which is postfire sediment associated with the management target fuel reduction objective (FRCC 1). When a wildfire occurs at any future time, the environmental risk from the condition represented by line (a) is considerably greater than that of line (b). This reflects the difference in prefire forest conditions and the severity of postfire effects as measured by sediment production from the different FRCCs.

The project described by line (c) results in postfire environmental risk reduction. Line (c) traces over time the effect of implementing a fuels treatment project. Shortly after project initiation, the implementation risk of additional postfire sediment from logging rises above and exceeds that of the initial environmental risk on line (a). At time T_1, implementation risk is maximized at R_3, and then it begins to decline. At T_2, environmental risk reduction commences as the benefit of reduced postfire sediment from the fuel treatment project on line (c) drops below the amount of postfire sediment on line (a) that would occur without fuel treatment. At T_3, project benefits continue to increase, but implementation risk still exceeds environmental risk reduction ($A_1 > A_2$). Over time, environmental risk reduction continues, and, at T_4, project benefits exceed implementation risk ($A_1 < A_2 + A_3$). Sediment from the project results from management actions to change an ecosystem from the condition represented by line (a), or initial environmental risk, to that of line (b), or residual environmental risk.

The decision whether to undertake the management project conceptualized in Figure 3 depends on the decision-maker's time horizon, the decision rule, and the relationship of lines (a), (b), and (c). For this discussion, the contours of the lines are similar to those in the source document (U.S. Department of Energy 2002) from which the diagram and terminology are derived. The lines may be expected to take on different configurations for specific forest types, fire regime conditions, and sediment production relationships. For example, there is no particular reason to expect that line (a) would be linear.

Based on this conceptual diagram, it would be difficult to argue that a decision using only information at time T_3 or earlier would be more sustainable than a decision using information at time T_4 or later. Sustainability is about many things, but first among them is the consideration of intergenerational equity. Fairness of current decisions for future generations of fish or people cannot be determined with a short-term outlook.

Quantitative Application

Sediment production can be quantitatively modeled using Forest Service Watershed Erosion Prediction Project (WEPP) tools. An Internet interface for WEPP Fuel Management Erosion (FuME) is capable of providing the necessary sediment estimates for the conceptual model described in "Conceptual Model." The sediment prediction model estimates fuel treatment sediment and simulates postfire precipitation with or without treatment, averaging the outcomes. WEPP FuME also has a road sediment feature. The WEPP FuME user interface is currently under revision (see USDA-FS 2006b).

To estimate sediment in Western United States ecoregions from fuels treatment opportunities, researchers used WEPP tools to compare effects of thinning and prescribed burning to those of wildfire in several different representative forest ecosystems. Based on their results, the relationships in Figure 3 seem reasonable. The average of predicted results, on a per unit area affected basis, was that wildfire would yield 70 times as much sediment as thinnings employed during hazardous fuels reduction efforts (USDA-FS 2005). In lieu of empirical data on sediment production from different FRCCs on a particular forest site, consider a hypothetical example based on this 70:1 relationship. In Figure 3, $R_2 = 70$ units of postfire sediment under current conditions in a project area. A thinning project would add one unit of sediment, i.e., $R_3 = 71$. By visual inspection, the target fuel reduction goal [line (b)] to produce the depicted relationship would be a very modest 2-percent postfire sediment reduction, i.e., $R_1 = 68.6$.

The BlueSky project tools could be used to similarly estimate $PM_{2.5}$ air pollution. BlueSky is a short-term planning tool to aid land managers using fire on the landscape in making go/no-go/go-slow smoke management decisions. It is a Web-based modeling framework for predicting cumulative impacts of smoke from forest, agricultural, and range fires, including prescribed fire and wildfire. By combining data and models for fuels, fire, smoke, and weather, BlueSky makes emission, dispersion, and weather prediction model outputs easily accessible to the operational fire and air quality management communities. It provides hourly predictions of $PM_{2.5}$ concentrations based on information available from multiagency tracking systems, wildfire reports, and, in some cases, from manually entered burn data (USDA-FS/EPA 2006).

Uncertainty

Any approach to integrating fire, fuels, and aquatic ecosystem management has inherent risks and uncertainties (Bisson and others 2003). It is not safe to ignore uncertainty because it may be important to our decisions (Morgan and Henrion 1990). However, many events that affect ecosystems (e.g., disease outbreaks, fire patterns, weather) and human systems (e.g., innovation, changes in preferences, political change) cannot be predicted in advance (NRC 2004). Owing in part to uncertainty, and in part to inadequacies in risk assessment techniques, risk analyses often have failed to meet expectations that they can improve decisionmaking (NRC 1996).

Managing risks on public lands necessitates communicating the results of risk assessment with interested parties. Risk characterization is an intermediate step (Figure 1), but one of paramount importance in risk analysis (NRC 1996). Ultimately, the condition of land and resources is more important than the terms used to describe various situations, alternatives, and outcomes. However, to avoid adding another source of uncertainty, risk assessors and managers should choose their terminology carefully. Ambiguous terms like forest health and sustainability are useful to draw people into discussions, but when deliberation about management alternatives commences, clarity is more important than ambiguity.

In the fire/fish risk management problem, nuances of definitions are less important than the risk management question—Which effect on fish is worse: (1) wildfires burning uncharacteristically under high fuel load conditions, e.g., FRCC 3; or (2) wildfires following management designed to reduce wildfire intensity to a level corresponding with FRCC 1? As discussed earlier, the question can be converted during the problem formulation phase of ecological risk assessment to a risk management hypothesis and visualized in a diagram (Figure 3). The diagram presumes that in fire-adapted forests typical of the Western United States, fire is inevitable. If the analytical time horizon is far enough in the future, fire is a certainty, and its environmental effects are realized. The magnitude of the effect, however, is uncertain and affected by many variables, including fuels (Finney 2005).

If risk can be quantified, or at least qualitatively ranked, ecosystems under greatest threat can be identified and efforts to improve these situations prioritized; few ecological risks, however, can be measured accurately (Lackey 1994). The probability of wildfire occurrence in fire-adapted forests is an exception. Fire is certain to occur within the fire return interval period, but we do not know precisely when or what the magnitude of the effects will be. Molak (1997) cautions that if uncertainty is not clearly spelled out, the numbers derived by risk analysis can be misleading. Haimes (2004) concludes with a risk analysis paradox: "To the extent that risk assessment is precise, it is not real. To the extent that risk assessment is real, it is not precise."

Summary: Risk Assessment for Managing Wildland Fire Effects on Ecosystems

Table 1 lists some ideas risk assessors and risk managers should consider when adapting the EPA (1998) framework (Figure 1) and *Guidelines for Ecological Risk Assessment* for wildland fire risk management. This approach could be adapted to fit situations other than the fire/fish risk problem, such as $PM_{2.5}$ emissions in prescribed fire and wildfire smoke. The conceptual model diagram (Figure 3) can enhance communications between risk managers, risk assessors, and stakeholders by graphically demonstrating whether the reduction in environmental risk following a

Table 1—A risk assessment approach for managing wildland fire effects on ecosystems

1. Keep it simple. Resource managers need project-level decision support models. Start with the essentials and add complexity only as necessary to fit the management situation.
2. Determine desired future forest conditions. The management objective is attaining a specific forest condition that will reduce wildfire risks, expressed clearly in terms the manager can be held accountable for. Many areas in the Western United States have accumulated levels of fuels that represent uncharacteristically hazardous conditions that can be categorized by fire regime condition classes (FRCC) (Hann and others 2003). An appropriate objective would be historical species composition and stand structure prior to the time fire suppression policy was implemented.
3. Select risk assessment endpoints consistent with management objectives. An appropriate endpoint for assessing logging effects is viable salmonid fish populations and appropriate quality of spawning and rearing habitat conditions (EPA 1998). The EPA's guidelines caution against using vague concepts like "sustainability" and "integrity."
4. Develop a stressor-response profile. One effect of either wildfire or management on population viability is additional sediment, a stressor from either logging management options or wildfire disturbance events. The response is an effect on fish biomass (Figure 2). A similar approach could be taken with reduced riparian vegetation and shade effects on stream temperature, or vegetation change and wildlife habitat effects, or fine particulate matter ($PM_{2.5}$) from prescribed fire and wildfire smoke.
5. Use an appropriately long time horizon to compare postwildfire sediment production with and without fuel treatment. If the fire/fish risk management situation involves imperiled species, anything less than 100 years is inappropriate (NRC 1995, Rieman and others 2003a).
6. Wildfire is certain to occur in fire-adapted forest ecosystems. This can be assured in risk analysis by selecting an appropriate long-term time horizon, such as the fire return interval of natural (historical) or characteristic fire regimes. This deterministic approach avoids the difficulty of assessing and communicating a probability distribution of fire risk potential, but probabilistic refinements such as the relationship of precipitation and sediment production could be used to add stochastic elements if appropriate data are available.
7. Compare the magnitude of adverse environmental effects (e.g., sediment production or $PM_{2.5}$ emissions) on aquatic habitat quality from wildfire with and without fuel treatment.
8. Include the benefits of fuel treatment in the analysis. Fire regime condition class (FRCC) categorizations are useful for this. The effects of wildfire with fuel treatment (e.g., restoring to FRCC 1 or historical fuel load levels) should reflect the reduction of adverse postfire environmental effects, such as sediment or $PM_{2.5}$, that can be attributed to fuel treatment. The effect of wildfire without fuel treatment is the no-action alternative represented by current FRCCs 2 or 3. The benefit is obtained by management actions that change forests from a higher to a lower FRCC.
9. Focus on the benefits of preemptive or prefire management of forests instead of trying to determine safe or acceptable levels of risk. The problem of determining the level of risk society is willing to accept is avoided altogether, and analysis focuses on comparing two options, one against the other, rather than against a nonexistent or elusive, value-laden, socially determined standard of acceptable risk.
10. Avoid the difficulties involved in discounting future ecological effects to the present time by not discounting (Davies 1996). If economic or social considerations are added, discounting may be appropriate. To reduce bias against future generations, use a very low discount rate (Solow 1994).
11. Use quantitative data when they exist. Qualitative assessments and comparisons of ecological risks can provide useful insights for environmental decisionmaking, even if the scientific understanding of them is poor (NRC 1996).
12. Display relationships in a conceptual model decision diagram, e.g., Figure 3 that compares adverse and beneficial effects over time.

wildfire, represented by a change in sediment production, would exceed the implementation risk of pre-emptive fuel treatment. Fire management programs require repeated treatments (Franklin and Agee 2003). The model can be modified to include a series of fuel treatments to maintain desired conditions over the long term.

All the points in Table 1 have been covered in previous sections, except 10 (discounting) and 11 (quantitative and qualitative analysis). The caution on discounting is self-explanatory. Quantitative models appropriate for a given risk management situation should be used along with whatever data may be available. Deferring decisions until quantitative models and data are available, however, may create additional risk from inaction, and qualitative approaches may be necessary.

Risk management decisions rely on a mix of science and policy; the most important role for science is providing information to be used in environmental decisionmaking (Power and McCarty 1997). Ecological risk assessment parameters can be represented quantitatively with existing data or qualitatively with expert opinion. Scientific quantification exists to aid judgment, not to supplant decisions (Clark 2002). Qualitative assessments of relative ecological risks can provide useful insights for environmental decisionmaking (NRC 1996). None of the scientific difficulties of estimation negate the importance for policy decisions of considering ecological outcomes. Interested and affected parties may want to take account of ecological effects even if the scientific understanding of them is poor (NRC 1996), as in the fire/fish risk management problem.

In conclusion, simple conceptual models used in decision analysis frameworks can be powerful communication tools (EPA 1998). The tradeoff diagram in Figure 3 is capable of demonstrating to the public, regulatory agencies, and the courts the long-term net benefits of active forest management designed to modify fire behavior. The transparency and clarity of such models can help people think through the questions of if, where, and when hazardous fuels reduction projects should be undertaken. Further development and use of conceptual models may help guide us along the path to sustainable resource management.

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