Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Forest Ecology and Management xxx (2005) xxx–xxx
Forest Ecology and Management
www.elsevier.com/locate/foreco

Predicting risks of uncharacteristic wildfires: Application of the risk assessment process

Anne Fairbrother [a,*], Jessica G. Turnley [b]

[a] *U.S. EPA, Western Ecology Division, 200 SW 35th Street, Corvallis, OR 97333, USA*
[b] *Galisteo Consulting Group Inc., 2403 San Mateo Blvd., NE, Suite W-12, Albuquerque, NM 87110, USA*

Abstract

The National Environmental Policy Act (NEPA) mandates that the U.S. Forest Service (USFS) conduct an Environmental Impact Assessment (EIA) as its fire management policy evolves to cope with a legacy of over 100 years of fire suppression on national forest lands and an increasing occurrence of uncharacteristically large, intense wildfires. This paper argues that integration of a risk assessment approach into the EIA is a logical extension of the EIA process and provides a more robust method for assessing comparative risks of proposed alternatives, and integrating ecological risks with economic and social cost-benefit analyses. Risk assessment is the process of estimating the likelihood and magnitude of the occurrence of an unwanted, adverse effect. It begins with a well-defined problem formulation step that ensures involvement of stakeholders, uses available or newly developed scientific information to ascribe probabilities to the likelihood of fire initiation under various forest management practices, and describes or quantifies the magnitude of effects associated with fires of various frequencies and intensities. The risk characterization step provides comprehensive statements of risk, including assertions about uncertainty, and communicates results in a clear and intelligible manner to resource managers and interested stakeholders. Risk assessment uses probabilistic modeling to incorporate environmental stochasticity and experimental uncertainty, and incorporates spatial attributes, simultaneous multiple risks, comparative analyses of different risks, socioeconomic concerns, and ecological effects into the analysis. Placed within the EIA process, risk assessment provides a robust framework for reaching agreement on risks of uncharacteristic wildfires under a variety of proposed management scenarios.

Keywords: Risk assessment; NEPA; Environmental impact assessment; Wildfire; Forest

1. Introduction

The U.S. Forest Service (USFS) is struggling with a legacy of over 100 years of fire suppression on the country's national forest lands. The resultant build-up in fuel loads likely is contributing to an increasing number of uncharacteristically large, intense wildfires. However, significant controversy remains regarding corrective management practices, largely because of uncertainty inherent in predicting when, where, and with what intensity fires will occur as well as understanding the potential consequences of all

* Corresponding author. Tel.: +1 541 754 4567; fax: +1 541 754 4799.
E-mail address: Fairbrother.anne@epa.gov (A. Fairbrother).

0378-1127/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2005.01.026

possible management options (e.g., from continuation of current fire suppression practices to controlled burns or mechanical thinning). Further confounding fire policy and forest management decisions are legal constraints for protection of endangered species, in both near- and long-term scenarios.

Fire management is a major Federal policy that has the potential to significantly affect the environment. In the implementation of such a policy, the National Environmental Policy Act (NEPA) mandates that the USFS conduct a comprehensive, written Environmental Impact Assessment (EIA) that includes all potential alternatives (Bausch, 1991; Carson, 1992). EIAs can be conducted at the national scale when setting overall agency policy (referred to as Policy Environmental Assessments, or PEAs; Baley and Dixon, 1999), or at the individual forest level in support of on-the-ground decisions for implementation of national policy. However, there are those who contend that EIAs have become more about process than about whether adequate information is presented in support of environmental decision making (Bausch, 1991; Salk et al., 1997; Wood, 1999). Others have argued that the large amount of time and monetary investment in an EIA process hinders development of new and innovative management approaches, such as appears to be needed for fire management on Federal lands (Borchers, 2003). In particular, Environmental Impact Statements (EIS; the technical reports generated during the EIA process) have been criticized as being unfocused, too lengthy, and lacking rigorous science or incorporation of ecological principles (Salk et al., 1997; Philips and Randolph, 2000). Acceptance of EIS reports often is hampered by a lack of unifying guidelines for conduct of the assessment (Fuller, 1999). Philips and Randolph (2000) reviewed EIAs from three different National Forests and concluded that they are deficient in supporting NEPA goals, as well as in their facilitation of public involvement and inclusion of unquantifiable environmental values.

Philips and Randolph (2000), along with various other authors (e.g., Ugoretz, 2001; Salk et al., 1997), have suggested incorporating principles of ecosystem management into the EIA process as a means of overcoming these deficiencies in the current EIA process. We argue here that application of a risk assessment approach would provide a more robust framework for the EIA. Specifically, it would specify a process that would more fully support NEPA principles, particularly the requirement for a ‘‘systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decisonmaking . . .’’ (Section 102 (2)), and the further stipulation in Section 102 (2) (B) that potential ecological effects be considered on an equal footing with technical and economic factors. Risk assessment principles can easily be incorporated into the standard EIA approach and will substantially enhance decision making for fire management on public lands.

2. Risk assessment

Risk assessment is the process of estimating the likelihood and magnitude of the occurrence of an unwanted, adverse effect. It has its roots in the insurance industry, and initially was applied to engineering and nuclear science. It evolved within the Federal government during the 1980s, from an initial focus on cancer risks to its current applications in all human health assessments and was formalized by The National Academy of Sciences to bring consistency to health assessments within the Federal government (NRC, 1983). Application of the paradigm to ecological systems occurred in the early 1990’s with U.S. Environmental Protection Agency’s (U.S. EPA’s) publication of the *Framework for Ecological Risk Assessment* (U.S. EPA, 1992) and subsequent *Guidelines for Ecological Risk Assessment* (U.S. EPA, 1998). Since that time, the U.S. EPA and other Federal and State agencies have published many guidelines that provide the details for conducting human health and ecological risk assessments for a variety of applications, endpoints, and spatial scales.

Risk assessments, like EIAs, are management decision tools that organize and integrate different types of information. They generally are proactive in that they inform the risk manager about the future. Because the future is inherently unpredictable, such information by necessity is presented as a probability (or a series of probabilities). The risk assessment approach also often is applied to areas where multiple stressors may be interacting or where comparative risks need to be assessed (Ugoretz, 2001). It is used to delineate stressor-induced ecological responses and can be used to make predictions about the potential for future recovery. Furthermore, predicting the efficacy and associated risks of alternative management scenarios as required by the NEPA process is a natural application of the risk assessment paradigm.

Regardless of the type of risk being assessed, all assessments begin with a description of the questions being asked and how the various risk factors may affect the assessment endpoints (Fig. 1). This is equivalent to the scoping process of the EIA (Fig. 2, from Wood, 1999). The analysis portion, which is analogous to the environmental impact statement (EIS), is composed of two parts: the exposure assessment and the effects assessment. The exposure assessment identifies the probable or predicted magnitude and spatial and temporal relationships of the causative factors, while the effects assessment defines the response of the assessment endpoints to varying levels of the risk factors. The analysis is completed during the risk characterization stage, where the predicted levels for the risk factors are compared to the response functions of endpoints of concern and a probability statement is made about the likelihood and magnitude of the undesirable outcomes. Risk communication (both to the public and to the risk managers) is the final step of both the risk assessment (Fowle and Dearfield, 2000) and EIA (Wood, 1999) processes. There are four main principles for effective communication: transparency, clarity, consistency, and reasonableness, of which ''clarity'' is the most important. Risk assessment guidance states that clarity means, ''the assessment is free from obscure language and is easy to understand'' (Fowle and Dearfield, 2000). The use of plain language, brevity in the presentation, and simple tables, graphics, or equations will help achieve this goal. Guidance for the EIA process also states that EIA reports should be ''short and concise and written in non-scientific language . . .'' (Carson, 1992).

In concert with NEPA requirements (Wood, 1999), risk assessment uses an open process and involves the public in identifying assessment endpoints (i.e., those environmental attributes that are of concern to the risk managers; Suter, 1992). This is equivalent to the scoping process of an EIA (Wood, 1999; Bass et al., 2001). By following the requirement to clearly state assumptions and areas of uncertainty in the analysis, risk assessments enhance communication and clarify areas of potential disagreement and conflict. This encourages discussion on the scientific merits of the work, rather than on the process itself, a shortcoming of the EIA process (Bausch, 1991). By stepping through a formal, prescribed process, there is greater assurance that the correct questions will be asked and answered, and that cause-and-effect linkages will be clearly articulated.

The conclusion of a risk assessment should be a statement of probability that describes the nature and intensity of effects, their spatial and temporal extent, and the potential for recovery. Most EIAs, on the other hand, are general statements of ''impact'' or ''no impact'', although it has been suggested that a

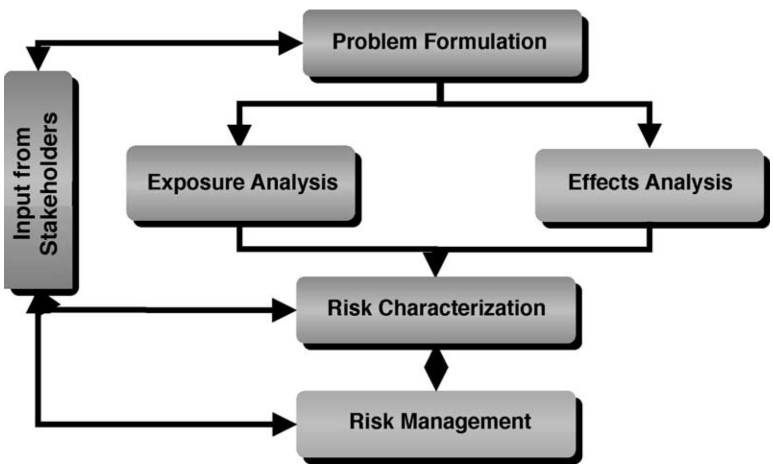

Fig. 1. Ecological risk assessment framework (U.S. EPA, 1992).

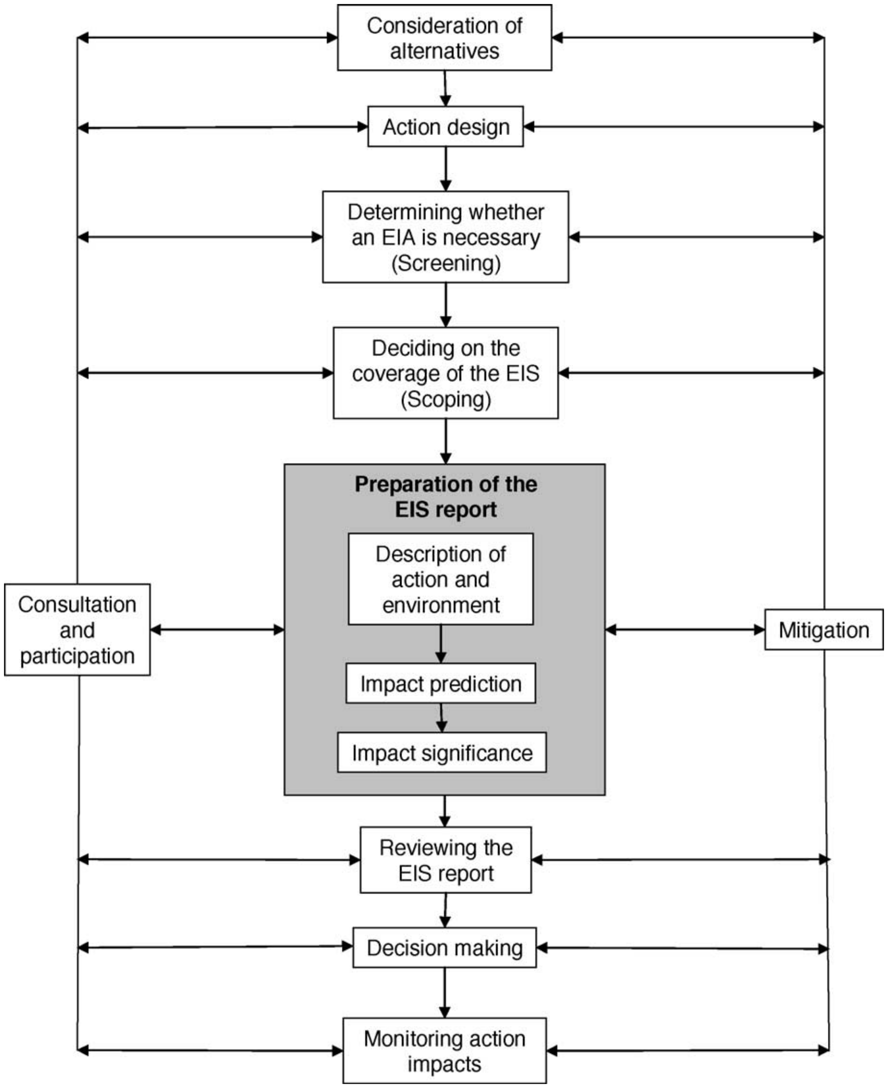

Fig. 2. Environmental impact assessment process (Wood, 1999).

standard vocabulary of comparative terms (e.g., low, moderate, high or unsure, possible, probable, definite; Weaver and Caldwell, 1999) will enhance the utility of EIS conclusions and also may be applied to a qualitative risk assessment (Landis and Wiegers, 1997; Obery and Landis, 2002). Because ecological systems are inherently highly variable, and because large scale assessments necessarily enhance this variability, understanding sources of uncertainty and their propagation through the assessment process will contribute significantly to public acceptance, funding of appropriate research, and the ability to correctly formulate policy or risk management decisions (Warren-Hicks and Moore, 1998). Risk assessment is better suited to accomplish this than is the more traditional deterministic EIS (Eduljee, 1999).

3. Application to uncharacteristic wildfires

In the case of uncharacteristic wildfires, there are two types of risk that need to be assessed: risk of the occurrence of the fire under various forest management scenarios, and risk to the ecosystem as a result of the fire and/or as a consequence of the fire management practices (including the ‘‘no action’’ alternative and continued suppression of all fires). Both categories of risk also include associated management costs and economic effects as a result of changes in harvest practices. Therefore, the proposed alternatives and their underlying assumptions must be stated with sufficient clarity to allow an appropriate and comparable economic assessment to be conducted.

Risk of occurrence of fires is of primary concern to the USFS, other land management agencies, and fire suppression companies and constitutes the bulk of the literature on this topic (e.g., *International Journal of Wildland Fires*). There appears to be a relatively good understanding of the basic risk factors for catastrophic wildfires (e.g., fuel load, climate, presence of ignition sources, etc.), although the relative contributions and interactions of these factors on a landscape scale requires additional refinement for accurate predictions (Cardille et al., 2001). Most assessments of fire risk have been done on a site-specific basis, although larger landscape level models are now being tested. This type of analysis is most comparable to an engineering risk assessment, as it looks at the probability of occurrence of an event rather than at the alteration of ecological systems. Thus, information is required about spatial and temporal frequency of the risk factors as well as their associated magnitudes. The corresponding ‘‘effects assessment’’ describes the size and intensity of a fire, and frequency of occurrence, under expected or predicted combinations of various levels of the risk factors. For example, EMBYR, an Ecological Model for Burning the Yellowstone Region, is being designed by Oak Ridge National Laboratories to investigate landscape-scale risk factors and related effects of fire from single seasons to millennia (Hargrove, 2004). The FORPLAN (FORest PLANning) model (Kent et al., 1991) which determines economic efficiency in forest management by optimizing land allocation and scheduling of resource harvest, is being adapted to use for landscape level fire risk management (Roloff et al., 2003).

Unless there is an understanding of the type, likelihood, and magnitude of ecological changes that result from fire (either catastrophic fires or the controlled burns used as forest management tools), or conversely from the lack of fire, it will not be possible to quantify the relative risks and benefits associated with various fire management alternatives. Assessments of ecological change generally address questions about effects to wildlife (especially threatened or endangered species such as the spotted owl; Bond et al., 2002) or vegetation loss and regeneration rates that directly affect economic considerations such as changes in timber harvest rates (Calvo et al., 2003; Horney et al., 2000). Aquatic ecosystems are indirectly affected by fire in the surrounding watershed with consequent effects on fish populations, especially those with narrow niche requirements (Dunham et al., 2003). Positive effects on invasive fish species have been documented as a result of fires, perhaps due to increased phosphorus and nitrogen levels and decreased carbon input to streams and rivers, and species reliance on algae rather than terrestrial leaf litter or other allochthonous food sources (Spencer et al., 2003). This demonstrates the importance of estimating risks to physical attributes of the ecosystem that support the biota. For example, rates of soil erosion or nitrogen and carbon loss have been shown to be positively correlated with fire intensity (Shakesby et al., 1993; Pierson et al., 2002) and have a direct impact on vegetation growth rates (Baird et al., 1999). Furthermore, the time-scale at which the risk is being assessed (decades to centuries) must be clearly identified prior to initiation of the assessment, as temporal changes in system response result in differing risk predictions depending upon the time frame. For example, bird communities have been shown to increase in diversity following fire, and gradually converge toward their non-fire reference state, although one study has shown that even after nearly 30 years they had not returned to what they had been (Hobson and Schieck, 1999). Such changes may be due to increasing amounts of habitat diversity and edge with concomitant decreasing interior habitat immediately following a burn, and subsequent coalescence of habitat patches over time (Kushla and Ripple, 1998).

Several recent studies by the USFS have reported on observed effects following catastrophic wildfires (e.g., http://www.fs.fed.us/r6/umpqua/publications/weep/-Wildfire_EffectsEvaluation_Project.pdf; http://www.fs.fed.us/r1/nfp/research/-project11.shtml), although there is still a preponderance of studies on predicting when and where such fires will occur. Furthermore, with the exception of a review of the impact of forest management policies, including timber harvest and fire management, on the spotted owl (Bond et al., 2002), none of the USFS studies or those in the peer reviewed scientific literature were conducted within the context of a risk assessment. Rather, they followed standard scientific research methodology to look at cause-and-effect relationships without including a probability analysis; i.e., they provided an effects assessment without the associated exposure assessment. Therefore, what remains to be done is the risk characterization step, where the predicted probabilities of the frequency, intensity, and location of fires are combined with ecosystem response functions to develop a statement of risk (i.e., likelihood and magnitude of effects) to forest biota, habitat, and ecosystem processes.

One difficulty with risk assessment applications is that concepts and principles of probability theory are not universally understood, particularly when different types of mathematical distributions are manipulated simultaneously or a priori knowledge is used to inform the mathematics (e.g., Bayesian theory; Howson and Urbach, 1989). While problems with understanding results of highly technical analyses may be the most obvious, errors in comprehension based on personal experience with data also are relevant, for personal experience always constrains the interpretation of messages from others. This is particularly true when communicating probabilities, which confounds risk communication more than simple impact statements. For example, a statement about a ‘‘one in a million chance’’ could be interpreted to mean ‘‘one out of a million people will be affected’’ or, alternatively, that ‘‘each person has a one-in-a-million chance of being affected.’’ These are two very different outcomes, so the risk assessor must be explicit and use appropriate terminology to convey the intended message (Bennett, 1998).

4. Risk management decisions

Although the analysis and characterization phases of the risk assessment are highly technical, the risk manager has responsibility as an active participant in the process. His or her input is essential when selecting assessment endpoints and in determining how broad the actively participating stakeholder base will be. Most importantly, the risk manager must decide what constitutes an (un)acceptable risk level. Certainly, the extreme cases are easily determined, that is, a 100% chance of a management policy resulting in the near-term occurrence of a catastrophic wildfire clearly is not acceptable while a 0% chance obviously is permissible. The difficulty lies in defining the boundary between acceptable and unacceptable likelihood – is a 50% chance of fire occurrence within a stated timeframe a risk worth taking (given associated socioeconomic trade-offs as well as endangered species considerations), or should risk reduction measures be put into play? How about a 75% chance? – or a 25% chance?

All actions of fire management policy carry some level of associated risk of fire occurrence (including the ‘‘no action’’ alternative). The degree of institutional and individual risk aversion by forest managers will significantly influence fire management decision making and policy. Because risk can be represented as statements about control (Beck, 1995; Giddens, 1998), it clearly follows that exotic risks are perceived as

Table 1
Factors affecting risk perception (Fischoff et al., 1981)

Risks perceived to	Are more accepted than risks perceived to
Be voluntary	Be imposed
Be under one’s control	Be controlled by others
Have clear benefits	Have little or no benefit
Be fairly distributed	Be unfairly distributed
Be natural	Be man-made
Be generated by a trusted source	Be generated by an untrustworthy source
Be familiar	Be exotic
Affect adults	Affect children

more threatening than familiar risk. Table 1 outlines risk aversion parameters that affect risk management decisions (Fischoff et al., 1981). Individuals differ in how much they are influenced by these parameters, thereby reflecting different degrees of risk aversion. Institutions (businesses, government agencies, etc.) also respond with different degrees of risk aversion. For Federal agencies, the type of risk aversion may be determined by enabling legislation. For example, under the Multiple-Use Sustained-Yield Act of 1960, the USFS is charged with overseeing ‘‘multiple uses’’ of forest resources (Ott, 1992). Thus, it must be willing to take some risks regarding the protection of one resource (e.g., wildlife) when making use of another (e.g., timber harvest). Other agencies have a clear mandate for protection of a single resource (e.g., the U.S. Fish and Wildlife Service manages wildlife exclusively), and so have a very low risk threshold in regard to activities that may affect this resource. Furthermore, the cost of various actions in relation to the realized benefits must also be considered (U.S. EPA, 2002). Additionally, political and various societal pressures can be brought to bear to influence how organizations perceive and respond to risk (Maguire, 2003).

5. Conclusion

Fire management policy on Federal lands significantly influences ecological systems and, as such, is subject to the NEPA process. However, various shortcomings of the EIA have hampered the ability to make appropriately informed management decisions and significantly reduced public acceptance of changing forest practices. Use of the risk assessment approach as an alternative to the traditional EIS is gaining favor as a technically sound, robust means for quantifying potential adverse outcomes of proposed alternatives (Arquiaga et al., 1992). It easily includes incorporation of spatial attributes, analysis of simultaneous multiple risks, comparative analyses of different risks, and integration of economic and social impacts and ecological risk assessments. Placed within the EIA process, risk assessment provides a robust framework for reaching agreement on risks of uncharacteristic wildfires under a variety of proposed management scenarios.

Acknowledgments

The information in this document has been funded by the U.S. Environmental Protection Agency. It has been subjected to review by the National Health and Environmental Effects Research Laboratory’s Western Ecology Division and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

References

Arquiaga, J.C., Cantor, L.W., Nelson, D.I., 1992. Risk assessment principles in environmental impact studies. Environ. Profess. 14, 202–219.

Baird, M., Zabowski, D., Everett, R.L., 1999. Wildfire effects on carbon and nitrogen in inland coniferous forests. Plant–Soil 209, 233–243.

Baley, J., Dixon, J.E., 1999. Policy environmental assessment. In: Petts, J. (Ed.), Handbook of Environmental Impact Assessment, vol. 2, Environmental Impact Assessment in Practice, Impact and Limitations. Blackwell Science, Oxford, pp. 251–272.

Bass, R.E., Herson, A.I., Bogdan, K.M., 2001. The NEPA Book: A Step-by-Step Guide on How to Comply with the National Environmental Policy Act. Solano Press Books, Point Arena, CA.

Bausch, C., 1991. Achieving NEPA’s purpose in the 1990s. Environ. Profess. 13, 95–99.

Beck, U., 1995. Ecological Enlightenment: Essays on the Politics of the Risk Society. Humanities Press International, New Jersey.

Bennett, P., 1998. Communicating about Risks to Public Health: Pointers to Good Practice. Department of Health, The Stationery Office, London, UK. , accessed Decemberhttp://www.doh.gov.uk/pub/docs/doh/pointers.pdf.

Bond, M.L., Gutierrez, R.J., Franklin, A.B., LaHaye, W.S., May, C.A., Seamans, M.E., 2002. Short-term effects of wildfires on spotted owl survival, site fidelity, mate fidelity, and reproductive success. Wildlife Soc. Bull. 30, 1022–1028.

Borchers, J., 2003. Accepting uncertainty, assessing risk: a decision quality approach. In: Proceedings of the Conference on Risk Assessment for Decision-Making Related to Uncharacteristic Wildfire, 17–19 November 2003, Portland, OR.

Calvo, L., Santalla, S., Marcos, E., Valbuena, L., Tarrega, R., Luis, E., 2003. Regeneration after wildfire in communities dominated by *Pinus pinaster*, and obligate seeder, and in others dominated by *Quesrcus pyrenaica*, a typical resprouter. Forest Ecol. Manage. 184, 1–3.

Cardille, J.A., Ventura, S.J., Turner, M.G., 2001. Environmental and social factors influencing wildfires in the upper midwest. U.S. Environ. Appl. 11, 111–127.

Carson, J.E., 1992. On the preparation of environmental impact statements in the United States of America. Atmos. Environ. 26A, 2759–2768.

Dunham, J.B., Young, M.K., Gresswell, R.E., Rieman, B.E., 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecol. Manage. 178, 183–196.

Eduljee, G., 1999. Environmental impact assessment and waste management. In: Petts, J. (Ed.), Handbook of Environmental Impact Assessment, vol. 2, Environmental Impact Assessment in Practice, Impact and Limitations. Blackwell Science, Oxford, pp. 300–330.

Fischoff, B., Lichtensein, S., Slovic, P., Keeney, D., 1981. Acceptable Risk. Cambridge University Press, Cambridge, MA.

Fowle, J.R., Dearfield, K.L., 2000. Risk Characterization Handbook. Science Policy Council, USEPA, Washington, DC.

Fuller, K., 1999. Quality and quality control in environmental impact assessment. In: Petts, J. (Ed.), Handbook of Environmental Impact Assessment, vol. 2, Environmental Impact Assessment in Practice, Impact and Limitations. Blackwell Science, Oxford, pp. 55–82.

Giddens, A., 1998. Risk Society: the context of British politics. In: Franklin, J. (Ed.), The Politics of Risk Society. Polity Press, Malden, MA, pp. 23–34.

Hargrove, W.W., 2004. Simulating fire Patterns in Heterogeneous Landscapes. Oak Ridge National Laboratories, Oak Ridge, TN. , accessed May 2004http://research.esd.ornl.gov?embyr/embyr.html.

Hobson, K.A., Schieck, J., 1999. Changes in bird communities in boreal mixedwood forest: harvest and wildfire effects over 30 years. Ecol. Appl. 9, 849–863.

Horney, M., Standiford, R.B., McCreary, D., Tecklin, J., Ricards, R., 2000. Effects of wildfire on blue oak in the northern Sacramento Valley. USDA Forest Service Gen. Tech. Re PSW-GTR-184, pp. 261–268.

Howson, C., Urbach, P., 1989. Scientific Reasoning. The Bayesian Approach. Open Court, La Salle, IL.

Kent, B., Bare, B.B., Field, R.C., Bradley, G.A., 1991. Natural resource land management planning using large-scale linear programs: the USDA forest service experience with FORPLAN. Operations Res. 39, 13–27.

Kushla, J.D., Ripple, W.J., 1998. Assessing wildfire effects with Landsat thematic mapper data. Int. J. Remote Sensing 19, 2493–2507.

Landis, W.G., Wiegers, J., 1997. Design considerations and a suggested approach for regional and comparative ecological risk assessment. Human Ecol. Risk. Assess. 3, 287–297.

Maguire, L., 2003. Risk attitudes: behaviorial decision theory for resource managers. In: Proceedings of the Conference on Risk Assessment for Decision-Making Related to Uncharacteristic Wildfire, Portland, OR, 17–19 November 2003.

National Research Council (NRC), 1983. Risk assessment in the Federal government. National Academy Press, Washington, DC.

Obery, A.M., Landis, W.G., 2002. A regional multiple stressor risk assessment of the Codorus Creek watershed applying the relative risk model. Hum. Ecol. Risk Assess. 8, 405–428.

Ott, R.A., 1992. The history of national forest planning. Agroborealis 24, 16–20.

Philips, C.G., Randolph, J., 2000. The relationship of ecosystem management to NEPA and its goals. Environ. Manage. 26, 1–12.

Pierson, F.B., Carlson, D.H., Spaeth, K.E., 2002. Impacts of wildfire on soil hydrological properties of steep sagebrush-steppe rangeland. Int. J. Wildl. Fire 11, 145–151.

Roloff, G., Mealey, S., Barry, J., Clay, C., Yanish, C., Neuenschwander, L., 2003. A system for evaluating ecological risk in fire-prone landscapes: indexing the effects of different management strategies. In: Proceedings of the Conference on Risk Assessment for Decision-Making Related to Uncharacteristic Wildfire, Portland, OR, 17–19 November.

Salk, M.S., Tolbert, V.R., Dickerman, J.A., 1997. Guidelines and techniques for improving the NEPA process. Environ. Manage. 23, 467–476.

Shakesby, R.A., Coelho, C.D.O.A., Ferreira, A.D., Terry, J.P., Walsh, R.P.D., 1993. Wildfire impact on soil erosion and hydrology in wet Mediterranean forest. Portugal Int. J. Wildland Fire 3, 110–395.

Spencer, C.N., Gabel, K.O., Hauer, F.R., 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. Forest Ecol. Manage. 178, 141–153.

Suter II, G.W., 1992. Ecological Risk Assessment. Lewis Publishers, Boca Raton, FL.

Ugoretz, S.M., 2001. Towards a new model of environmental review: preparing the US National Environmental Policy Act for new management paradigms. Impact Assess. Project Appraisal 19, 3–8.

U.S. Environmental Protection Agency (U.S. EPA), 1992. Framework for Ecological Risk Assessment. US Environmental Protection Agency, Washington, DC. EPA/630/R-92/001, http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=30759, accessed December 2003.

U.S. Environmental Protection Agency (U.S. EPA), 1998. Guidelines for Ecological Risk Assessment. US Environmental Protection Agency, Washington, DC, EPA/630/R-95/002F, http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=30759, accessed May 2004.

U.S. Environmental Protection Agency (U.S. EPA), 2002. A framework for the economic assessment of ecological benefits, http://www.epa.gov/osp/spc/feaeb3.pdf; accessed May 2004.

Warren-Hicks, W.J., Moore, D.R.J. (Eds.), 1998. Uncertainty Analysis in Ecological Risk Assessment. SETAC Press, Pensacola, FL.

Weaver, A., Caldwell, P., 1999. Environmental impact assessment for mining projects. In: Petts, J. (Ed.), Handbook of Environmental Impact Assessment, vol. 2, Environmental Impact Assessment in Practice, Impact and Limitations. Blackwell Science, Oxford, pp. 377–403.

Wood, C., 1999. Comparative evaluation of environmental impact assessment systems. In: Petts, J. (Ed.), Handbook of Environmental Impact Assessment, vol. 2, Environmental Impact Assessment in Practice, Impact and Limitations. Blackwell Science, Oxford, pp. 10–34.