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44. CHALLENGES OF SOCIO-ECONOMICALLY EVALUATING WILDFIRE MANAGEMENT IN AND ADJACENT TO NON-INDUSTRIAL PRIVATE FORESTLAND IN THE WESTERN UNITED STATES

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Non-industrial private forests (NIPFs) in the United States generate many unpriced benefits for both the landholder and society generally. These values can be enhanced or diminished by wildfire management in situ and on adjacent public land. This paper considers the problem of accommodating non-marketed NIPF values affected by wildfire in social benefit-cost analysis to evaluate the efficiency of fire suppression activities. There are substantial gaps in scientific understanding about how the spatial and temporal provision of non-market values are affected by wildfire, and considerable challenges in evaluating social welfare change arising from specific wildfire events. This presents serious impediments to adapting price-based decision-support tools to incorporate non-market values. Departure from the historic range and variability of ecological conditions is proposed as an alternative framework to support wildfire management decisions in and adjacent to NIPF when non-market values are important.

INTRODUCTION

There are approximately 9.9 million non-industrial private forest[1] (NIPF) owners, including 9.3 million individuals and families, collectively holding 145 million ha (49%) of forestland in the United States (1996). Most NIPF holdings are small, with about 40% being less than 4 ha and 96% less than 40 ha (Birch 1996). Non-timber benefits often constitute the major management objectives for NIPF landholders in the United States, with timber production typically having low priority, (Hodgdon and Tyrrell 2003, Carroll *et al.* 2004, Zhang *et al.* 2005, Raunikar and Buongiorno 2006).

In the western continental United States (inclusive and west of the Rocky Mountain states, but excluding Alaska), where almost 70% (63.8 M ha) of forestland is publicly owned, NIPF owners only account for 24% (23.1 million hectares) of forestland holdings (Smith *et al.* 2004). However, as a result of early settlement patterns in the west, NIPFs are prevalent at lower elevations and at the fringes of metropolitan areas (commonly termed the wildland-urban interface (WUI)), providing important wildlife habitat along riparian corridors, and open space and aesthetic viewscapes for urban dwellers (Bliss 2003). Thus, NIPFs are important sources of forest-based non-market goods and services for both the landholders and society at large in the American west.

The quality and quantity of many non-marketed benefits generated from small forest landholdings, including wildlife habitat, recreation opportunities and water quality, are affected by management of adjacent forestland. The principle neighbour of NIPF landholders in the western United States is the Department of Agriculture Forest Service (Forest Service). One hundred years of fire suppression by federal government agencies, including the Forest Service, has contributed to dramatic changes in fire regimes, ecological patterns and processes, and species distribution and abundance on private and public forestland (USDA and USDI (U.S. Department of Agriculture and U.S. Department of the Interior) 2000, Keane *et al.* 2002; Hessburg and Agee 2003). Departure from historic fire regimes is recognised as a major factor contributing to dramatic increases in federal wildfire suppression expenditures in recent years and the decreasing flow of many non-timber benefits from public and smallholder forests (National Academy of Public Administration 2002; Calkin *et al.* 2005). The Forest Service is under substantial pressure from the federal government to improve the socio-economic efficiency of its wildfire suppression activities.

To support wildfire management decisions about fire-adapted forests, economists and other analysts have developed price-based decision-support tools to assess optimal forest rotations (including for NIPFs) in the presence of fire risk and to assist allocation of federal wildfire

[1] Non-industrial private forests are owned by farmers, other individuals and corporations that do not operate wood processing facilities.

suppression resources. However, while non-marketed forest resources are of increasing interest to NIPF owners and the general public, they are poorly accounted for within existing models. This paper evaluates the potential for accommodating the full range of non-market values enhanced or diminished by wildfire in and adjacent to NIPF within a social benefit-cost analysis (BCA) framework. Given the state of knowledge about fire effects on non-market values of forests and the wildfire preferences of society, it is argued that a central focus on prices, while characteristic of standard methods of non-market valuation, is unlikely to be appropriate for accommodating many important non-market values affected by wildfire.

The paper begins with a brief review of contemporary federal wildfire policy, and the application of economics to support fire adapted forest and wildfire management. Consideration is then given to the complex responses of non-marketed forest resources to wildfire and empirical studies that have estimated social welfare change arising from wildfire effects on non-traded goods are reviewed. Next, factors likely to contribute to the failure of efforts to evaluate welfare change arising from wildfire are discussed. We then argue that an alternative decision-support framework that measures departure of current and post-fire ecological conditions from the historic range and variability of ecological conditions of that area may be suitable for accommodating many non-market values in assessment of wildfire management.

CONTEMPORARY WILDFIRE POLICY AND ECONOMICS IN THE UNITED STATES

With few exceptions, aggressive wildfire suppression has dominated Forest Service wildfire policy (Stephens and Ruth 2005). However, in response to rising wildfire suppression costs, which exceeded US$ 1 billion in 2000, 2002, 2003, and 2006 (NIFC 2006), and concerns about declining ecological health and integrity of fire-adapted ecosystems, federal wildfire policy has been substantially modified since 1995 to recognise the beneficial role of fire as an important ecological process (USDI *et al.* 2001; USDI *et al.* 2005). The policy also acknowledges the need for measures of economic efficiency of wildfire suppression to accommodate non-market values, including ecosystem health, conservation of flora and fauna, air quality, water quality, recreation opportunities and cultural heritage.

While United States federal wildfire policy has been modified to account for the beneficial roles of fire in forestland, existing decision-support models for smallholders and public forest fire managers have not. Price-based models developed to evaluate smallholder forest management in fire-adapted forest ecosystems in the United States treat the arrival of fire as having only negative impacts on market and non-market values (Reed 1984; Englin *et al.* 2000; Amacher *et al.* 2005a, b). The least cost plus loss (LCPL) economic theory applied to support wildfire management decision-making on public land has changed little since the model was first illustrated by Sparhawk (1925). It is a price-based framework that can be used by fire managers to assist development of fire management strategies that minimise the total cost of fire prevention, presuppression and suppression activities, and fire damage. The model served the Forest Service well when the primary focus of the agency was timber production, society placed relatively low values on non-timber goods and services provided by forests, human settlement in the WUI was relatively limited, and wildfire policy was to aggressively suppress all fires. However, this is no longer the case.

The Hubbard report (Review Team 2001) reviewed the suite of fire budget and planning models of federal agencies, including NFMAS and EFSA, and found them to be inadequate for supporting decisions consistent with the 2001 Federal Wildland Fire Management Policy. The Hubbard report's recommendations guided the Fire Program Analysis (FPA) project, which was a major investment by the Forest Service and other federal land management agencies to develop a wildfire management planning and budgeting decision-support tool to accommodate the full range of market and non-market land management objectives in evaluation of alternative fire management strategies (FPA (Fire Program Analysis) c2006). The basis for economic evaluation within FPA was termed the expert opinion weighted elicitation process (EOWEP), with wildfire protection priorities estimated by querying fire management officials about the relative importance of protecting different socio-economic and environmental attributes from wildfire (Rideout and Ziesler 2005). In effect, EOWEP is a price-based approach with expert judgement being used to derive relative prices in place of economic analysis. In 2007, there was no peer reviewed literature available describing the EOWEP process and the application of EOWEP within future developments of the FPA system is unclear.

VALUATION OF WILDFIRE EFFECTS ON NON-MARKETED FOREST RESOURCES

The limited utility of existing price-based models to support wildfire management decisions of smallholders with non-timber management objectives, and public forestland managers operating within the modern wildfire policy environment, has arisen because wildfire effects on non-marketed resources are inadequately accounted for, particularly positive wildfire effects. Wildfires affect many non-marketed resources that are of value to NIPF owners and society at large, including air quality; soil; water quality; flora, fauna and invasive species; recreation opportunities; cultural heritage; and carbon. Table 1 summarises the positive and negative effects of wildfire on these seven non-market resource categories. It is not obvious in the table, but each non-marketed resource exhibits a diverse range of potential responses to wildfire according to a complex set of natural environment and human management factors. Generally in the lower elevation forests of the western United States, where NIPFs are common, the more severe the wildfire (i.e. the higher the proportion of biomass consumed), the greater the magnitude of negative effects on non-marketed natural resources.

Price-based approaches to wildfire management on NIPF and adjacent public land requires non-market valuation of the positive and negative effects of wildfire on the resources described in Table 1. While many studies have examined non-market values of forests in the United States and internationally, surprisingly few have been conducted to estimate welfare change as a consequence of wildfire.

The value of private property in the WUI, including but not limited to NIPF owners, is a function of many property, neighbourhood and environmental attributes, including perceived wildfire risk and natural amenities (e.g. recreation opportunities and aesthetically pleasing vistas) that may be enhanced or diminished by wildfire. Employing the hedonic pricing technique, Huggett (2003) found that the 1994 fires in Wenatchee National Forest, Washington, decreased willingness to pay (WTP) to live near the burned area for only the first six months after the fire, after which property prices rebounded. However, Loomis (2004) found that property values in a town two miles from the Buffalo Creek Fire in Colorado were about 15% lower five years after the fire than they would have been if the fire had not occurred. This was attributed to an increase in perceived wildfire risk and lost amenity values

Fried *et al.* (1999) and Huggett (2003) found that WUI households in the states of Michigan and Washington respectively, had limited WTP for forest management activities such as prescribed fire or mechanical thinning (which would affect amenity values) to reduce fuels on adjacent public land. However, Kim and Wells (2005), Loomis *et al.* (2005) and Walker *et al.* (2007) found WUI households in Arizona, California, Colorado, Florida and Montana were willing to pay hundreds of dollars annually for fuel treatments that would protect forest health, public recreation values, down stream water quality and forest dependent wildlife, in addition to reducing the number of homes threatened by wildfire. In Colorado, the willingness of urban and WUI households to pay for fuel treatments were similar, even though urban respondents face little to no risk of property loss due to wildfire (Walker *et al.* 2007). These findings indicate that households in some states are willing to pay to protect natural amenities from wildfire, but none of these studies separated the welfare effects of changes in perceived wildfire risk from changes in natural amenity provision.

Englin *et al.* (2001) estimated consumer surplus for hiking trips in Wyoming, Colorado and Idaho, and found an initial positive annual consumer surplus response for hikers in the first few years following a fire. This was attributed to the novelty of the burned landscape, and wildflower and wildlife viewing. Annual hiker surplus was then estimated to slowly decrease until about 27 years after the fire, and then increase until steady-state values associated with a mature forest were established. Loomis *et al.* (2001) examined the temporal effects of crown and non-crown (including prescribed) fires on the welfare hikers and bikers in Colorado and found that the annual surplus of hikers and bikers from the year of the fire to 50 years post fire were much higher after a crown fire than following a non-crown fire or for the existing (pre-fire) forest condition. Relative to the existing forest conditions in New Mexico, Hesseln *et al.* (2003) found that hikers and bikers would experience decreases in annual consumer surplus following either crown or prescribed fire (the decline in surplus was found to be less for prescribed fires) from the year of the fire to 40 years post fire. In contrast, Montanan hiker and biker welfare was unaffected by crown or prescribed fire (Hesseln *et al.* 2004).

Table 1. Positive and negative effects of wildfire on non-marketed resources generated by NIPFs that are valued by society

Non-market resource	Positive fire effects	Negative fire effects	Sources
Recreation	• Improved wildflower and wildlife viewing • New scenic vistas may be revealed • Novelty of a burned forest • Improved ungulate habitat increasing hunting success • Improved fish habitat in the long-run increasing fishing success	• Campsites destroyed • Debris on hiking, biking and four-wheel-drive trails • Burned forest may be aesthetically displeasing • Short to medium-term reduction in fishing success due to stream habitat deterioration	(Despain *et al.* 2000, Englin *et al.* 2001, Keane *et al.* 2002, Toman 2006)
Flora, fauna and invasive species	• Short-term increase in wildlife foods and habitat diversity often increases the numbers of individuals and species of birds, mammals, reptiles, terrestrial amphibians and insects • Low severity fire will favour native plants adapted to wildfire and facilitate ecosystem restoration • Conservation of locally rare plants is improved by diverse disturbance histories • Diverse disturbance histories likely to reduce the potential for epidemic insect and disease infestations • Long-term improvement of aquatic habitat quality	• Decades of fuel accumulation due to fire suppression means that contemporary wildfires have a greater probability of being large, severe and stand replacing. This may have long-lasting negative ecological consequences, particularly for threatened and endangered flora and fauna. • Short-term highly negative impact on stream amphibians and fish • Some exotic plant species are adapted to colonise post-fire landscapes	(Hessl and Spackman 1995, Hutto 1995, Lyon and Smith 2000, Keane *et al.* 2002, Rieman *et al.* 2003, Bury 2004) (Burton 2005, Rinne and Jacoby 2005)
Air quality		• Human respiratory health • Reduced visibility at scenic vistas and on roadways • Soiling surfaces of objects	(Sandberg *et al.* 2002)
Soil	• Short-term increased availability of nutrients for plant growth	• Soil structure is lost (reducing soil porosity) • Nutrients are volatised or made susceptible to loss through leaching and surface runoff • Can make soils hydrophobic • Accelerates wind and rain erosion, and dry ravel	(Ice *et al.* 2004, Neary *et al.* 2005)
Water quality		• Increased peak flood flows, and increased sediment and debris washed into waterways can damage or reduce the effective life of infrastructure including bridges, dams, water distribution systems and hydroelectric power turbines • Impair suitability of water for municipal and other purposes, which increases water treatment costs	(Landsberg and Tiedemann 2000, Scatena 2000, Neary *et al.* 2005)
Cultural heritage	• Wildfire consistent with historical fire regimes is likely to maintain or enhance cultural heritage	• Uncharacteristic wildfire may be detrimental to or destroy cultural heritage	See text
Carbon	• More frequent wildfire will limit fuel accumulation such that future wildfires will be less severe and emit less carbon	• Potentially large immediate release of sequestered carbon	See text

Only two published studies have estimated changes in social welfare arising specifically from the responses of wildlife to wildfire. Loomis and González-Cabán (1998) estimated the national marginal WTP nationally to protect critical northern spotted owl habitat in California and Oregon from wildfire. They found the social value of preventing the first 1000 acres/year of old growth forest burning is greater than the annual national fire suppression expenditure by the Forest Service in recent high cost fire fighting years. The fact that the Forest Service is under enormous pressure to reduce wildfire suppression costs, seems to indicate that Loomis and González-Cabán (1998) may have overestimated the national marginal WTP to suppress fire to protect the northern spotted owl. In the other study, Loomis *et al.* (2002) estimated that average deer hunter welfare increased by between $3.49/acre/year and $7.20/acre/year for the first 1,100 acres burned and about $0.52/acre/year for the next 3,700 acres burned in the San Jacinto Ranger District (SJRD) of the San Bernardino National Forest in southern California.

International evidence suggests that the health costs of wildfire smoke can be substantial (Glover and Jessup 1999, De Mendonça *et al.* 2004); however, only one preliminary published study has attempted to quantify the pecuniary cost of wildfire smoke on public health in the United States (Butry *et al.* 2001). Chestnut and Rowe (1990) estimated willingness to pay for guaranteed levels of visibility at national parks in the United States. These estimates have been widely cited and employed by the EPA to estimate visibility benefits associated with air quality programs (EPA (U.S. Environmental Protection Agency) 1997, 1999a, b), but they overestimate the value of visibility improvement by approximately 70% (Smith *et al.* 2005). No published studies have evaluated the welfare effects of soiling due to wildfire smoke. Knowledge about the economic effects of wildfire on soil and water is poor (Neary *et al.* 2005), with the research by Loomis *et al.* (2003) and Lynch (2004) appearing to be the only published studies that have estimated the cost of sedimentation in particular reservoirs following wildfire in the United States.

Forested landscapes of the United States have important cultural heritage values for indigenous and non-indigenous Americans. Although indigenous people have a richer cultural heritage associated with the North American landscape, heritage values for people in both groups are expressed and evidenced in many ways, including as sources of food, tools, arts and crafts, settings for stories, religious places, burial places, physical evidence of historical occupation, battlegrounds and recreation areas. Venn and Quiggin (2007) found that, while many studies have attempted to value particular use values of indigenous cultural heritage, there is no history of total economic valuation of indigenous cultural heritage. There are no published studies valuing indigenous cultural heritage conservation benefits and costs of wildfire.

Since indigenous American cultures evolved in landscapes where fire is an important ecological process and was used by tribes as a land management tool, wildfires that are consistent in size, severity and frequency with historical fire regimes appear likely to maintain or even enhance indigenous cultural heritage values. For example, many culturally important plant and animal food resources require fire to maintain suitable habitat conditions. However, uncharacteristic wildfire is likely to be detrimental to or even destroy other forms of cultural heritage, including burial sites, 'medicine' and sacred trees, cultural relics, and archaeological sites and structures (Arno and Fiedler 2005, Keane *et al.* 2006a).

Emissions of carbon from combustion of vegetation are social costs of wildfire. However, fire is ultimately an unavoidable ecological process in many forests of the western United States. Irrespective of the level of contemporary and future wildfire detection and suppression technology, forest managers are not faced with the question of whether a forest will burn, but rather under what fire regime will the forest burn?

Brown and Bradshaw (1994) found that, although wildfires currently burn less forest area annually than was the case under native fire regimes, annual smoke emissions are higher because consumption of fuel per unit area is greater due to the relatively high frequency of uncharacteristically severe, stand replacing fires as a result of past forest management and fire suppression policies. The same emissions relationship applies for carbon. More frequent wildfire will prevent the accumulation of surface and ladder fuels that leads to stand replacing conflagrations, and encourage vigorous vegetation regrowth that will sequester carbon. Furthermore, simulations reported by Keane *et al.* (1997) revealed that respiration associated with advancing succession in North American forests can release substantial volumes of carbon. It is conceivable that more wildfire, not less, may reduce carbon emissions from North American forests in the long-run. The bioeconomic models necessary to estimate the welfare implications of net carbon emissions arising from alternative wildfire regimes have not been developed.

CHALLENGES OF EVALUATING WELFARE CHANGE FROM WILDFIRE EFFECTS ON NON-MARKETED RESOURCES

Five major challenges to evaluating welfare change arising from wildfire management in and adjacent to NIPFs are:

1. scarcity of scientific information about how non-marketed resources are affected by wildfire;
2. limited amenability of many non-marketed resources affected by wildfire to valuation by benefit transfer;
3. a dearth of studies that have estimated marginal WTP;
4. violation of consumer budget constraints; and
5. valuation of indigenous cultural heritage is unlikely to be feasible.

Several of these challenges are general problems in non-market valuation research, but they are particularly prominent in non-market valuation of wildfire effects because of the large number and diversity of resources potentially affected by wildfire, and the spatial and temporal variability of responses of affected resources to wildfire.

Scarcity of Scientific Information about how Non-marketed Resources are Affected by Wildfire

The Fire Effects Information System developed and maintained by the Forest Service (available at URL: http://www.fs.fed.us/database/feis/), summarises from English-language literature the effects of fire on about 100 North American animal species and 900 plant species, including many T&E species. A review of these descriptions revealed that, while fire effects information is substantial for some species, scientific and anecdotal information is sparse for many. Most of what is known about the effects of fire on fauna in the United States focuses on mammals and birds, with only limited information available for aquatic fauna, herpetofauna and insects (Raphael *et al.* 2001, Rieman *et al.* 2003, Bury 2004). Lyon and Smith (2000) asserted that, at the landscape level, little is known about the combination of vegetation mosaics and patterns best suited to specific wildlife populations, and how to maintain landscapes for biodiversity conservation. Furthermore, while the likely impacts of fire of various levels of severity on timber species in forests are relatively well-known, knowledge about the ecological role and importance of fire for many other plant species and plant communities in the United States, particularly those that are rare, is generally poor (Brown 2000).

Currently, the most comprehensive guidelines in the United States for assessing the visibility implications and human health risk of exposure to PM, including from wildfire smoke plumes, are produced by the EPA (1999a, EPA (U.S. Environmental Protection Agency) 1999b). However, these guidelines are largely based on visibility and epidemiological studies conducted over long periods in urban centres with urban pollution problems. There is no evidence that PM pollution from cars and industry affect visibility and human health in the same way as wildfire smoke, and Sandberg *et al.* (2002) warn that these guidelines may be of little value for air quality regulators judging health risks of short-term exposure to high levels of wildfire smoke.

The social value of soil is derived from the value of goods and services it can produce. On-site soil damage costs associated with wildfire arise largely from reduced site productivity due to water repellency, nutrient loss and soil erosion. Timber growth and yield models can be useful for estimating likely effects of reduced site productivity on the growth of important timber species. However, timber production is only one of many ecosystem services related to site productivity. For example, soil conditions will directly and indirectly affect the habitat of non-timber flora and fauna, cultural heritage values and recreation opportunities. But knowledge about the relationships between site productivity and the production of these important ecosystem services is limited in most parts of the United States.

Landsberg and Tiedemann (2000) and Neary *et al.* (2005) identified several knowledge gaps that limit our ability to predict water quality in post-fire environments. These include:

- lack of data on extreme water flow and erosion events that can follow wildfire, and the complex interactions of variables that contribute to the extent of postfire flooding and erosion;
- limited data for estimating the likely effects of fire on the magnitude and duration of water quality change in municipal watersheds;
- scarce information on the effects of fire on heavy metals in drinking water;

- a lack of understanding of how fire affects water quality at the landscape level as opposed to burned stream reaches; and
- limited information about the effectiveness of potential mitigating factors in protecting water quality, such as streamside buffers.

Complicating evaluation of potential fire effects on particular non-marketed resources is that the ultimate positive or negative effects of a fire may only become apparent some time after the fire and depend on a complex set of factors, including: pre-fire human management and infrastructure; topography; soils; pre-burn composition and structure of the vegetation; time since the last burn; fire intensity, severity, patchiness, and seasonality; the potential for demographic support or recolonization by particular plant and animal communities; postfire weather; the nature of fire suppression; and post-fire management. Consequently, in the context of aquatic ecosystems, Rieman *et al.* (2003) asserted that accurately predicting the effects of fire on aquatic life at any particular site is impossible with the current level of knowledge. This statement appears to be applicable to most non-marketed resources at risk of wildfire, which presents serious impediments to predicting wildfire-related value change.

Limited Amenability of Many Non-traded Resources Affected by Wildfire to Valuation by Benefit Transfer

Estimates of welfare change arising from wildfire are scarce, and conducting stated and revealed preference studies to value non-traded resources affected is time consuming and costly. Benefit transfer methods have arisen in response to this limitation, but economists are divided about the usefulness of these techniques (Boyle and Bergstrom 1992, Splash and Vatn 2006). Some believe the methods are valid, while others believe that it is impossible to apply results from one study to another because of differences in the attributes being valued, the cause and effect relationships that define responses of ecosystems to policy or natural environment change, and social preferences. In the context of wildfire in the United States, there are at least three limitations associated with transferring non-market benefit and cost information from previous studies to a new study site.

Effects of wildfire on the spatial and temporal provision of ecosystem goods and services differs from the effects of other disturbances

To overcome the scarcity of information on welfare effects of wildfire, it is tempting to transfer welfare change estimates arising from non-fire disturbances. However, wildfire effects on non-marketed goods and services associated with forest ecosystems are unique and will differ spatially and temporally from the effects of other types of disturbances, such as severe storms, logging, land clearing and climate change (DellaSala and Frost 2001, Franklin *et al.* 2001, Kauffman 2004). Consequently, findings of studies that evaluate welfare change in the context of non-fire related disturbances are unlikely to be transferable to the fire context.

Heterogenous responses of ecosystems to wildfire

Scientific information transfer is a common and often essential part of benefit transfer, but goes largely unnoticed and is rarely noted (Splash and Vatn 2006). The underlying cause and effect relationships that define the responses of ecosystems to wildfire will, in part, determine the estimated welfare effects of fire at a particular site. These relationships often differ appreciably between sites, even for the same types of resources. For example, estimates of production functions relating game animal populations and harvest probability to post-fire ecological conditions indicate that responses of ungulate populations and harvest success to fire varies substantially throughout the United States (Kie 1984, Klinger *et al*. 1989, Toman 2006). Therefore, biases are likely to arise when transferring estimates of hunter welfare change due to wildfire from one study site to another.

Heterogenous wildfire preferences of society

If non-demographic factors, such as specific social and cultural values that affect preferences, are important in explaining non-market values, then benefit transfer is not appropriate for valuation at a new study site (Splash and Vatn 2006). The limited economic research that has estimated the effects of wildfire on the welfare of homeowners and recreationists indicates that the wildfire preferences of society do vary substantially throughout the United States. On the basis of existing studies, an economist would have little confidence in interstate benefit transfer of welfare change arising from wildfire. In addition, social preferences are likely to vary over time, contributing to temporal biases with benefit transfer. For example, do severe wildfires and the resulting change in scenery and vegetation composition and structure, still constitute the novelty value they purportedly did at the time of the Englin *et al.* (2001) and Loomis *et al.* (2001) studies.

Dearth of Studies that have Estimated Marginal WTP

There is a large and increasing volume of literature reporting estimates of society's WTP to conserve particular species and other non-traded goods and services provided by the natural environment. However, most of these studies have estimated total or average WTP (Van Kooten and Bulte 2000, Rosenberger and Loomis 2001). Since any particular fire (and most other natural or anthropogenic disturbances) will typically only affect the provision of non-market goods and services at the margin, these studies fail to be useful for economic analysis of resource conservation strategies in response to a particular disturbance event (Loomis and White 1996, Van Kooten and Bulte 2000). Total and average WTP is only likely to be appropriate for analysis where large fires are burning in ecosystems that provide unique services, such as critical habitat for threatened and endangered (T&E) species or locally rare, but non-T&E species, that have vulnerable, isolated populations in the vicinity of the fire event. In response to scarce marginal data, linear relationships between expected value and probability of species survival have been adopted in the literature to generate marginal WTP schedules (Spring and Kennedy 2005), but this is not supported by economic theory.

Violation of Consumer Budget Constraints

The focus of most non-market valuation studies is on valuing a particular characteristic of the environment, such as spotted owls. A concern with this approach is that respondents may not recognise that their WTP for the particular environmental good evaluated in the survey is only one of many substitute and complementary goods that they can spend their money on, and that they face personal budget constraints. For example, the sum of household willingness to pay to preserve several T&E species of the western United States, namely the bald eagle, grizzly bear, bighorn sheep, northern spotted owl, whooping crane, gray wolf, sea otter, gray whale and steelhead trout is $450 per annum in 2006 dollars (adjusted by the consumer price index from estimates reported in Van Kooten and Bulte (2000)). Is the average household in the United States willing to make additional payments annually to preserve other T&E species such as the white sturgeon, bull trout, Canada lynx and black-footed ferret?

In the western United States, a particular fire is unlikely to affect many T&E species, but will affect many other non-marketed resources that have traditionally been evaluated in isolation by economists, such as water, air and recreation quality. Summing WTP estimates from several non-market valuation studies that have each evaluated a single environmental characteristic at risk from wildfire is unlikely to be valid, because of the high likelihood that the budget constraints of respondents will be violated (Van Kooten and Bulte 2000). Consequently, Loomis and White (Loomis and White 1996) argued that studies valuing the protection of habitats and ecosystems are likely to be much more useful for evaluating ecosystem management strategies than valuing the conservation of individual species. To date, few such studies have been published.

Valuation of indigenous cultural heritage is unlikely to be feasible

Even in the context of a developed market society, economists, ecologists and environmentalists have expressed doubts about the degree to which non-market valuation techniques can estimate total economic value (Diamond and Hausman 1994, Nunes and Van den Bergh 2001, Chee 2004). It is likely that members of indigenous cultures hold many more non-use and indirect-use values than non-indigenous people. In this context, sacred values are particularly important, and particularly resistant to price-based trade-offs. If the total economic value of indigenous cultural heritage cannot be captured by price-based valuation approaches, then indigenous values will be systematically underrepresented relative to non-indigenous values in price-based economic analyses of alternative resource management policies.

Adamowicz *et al.* (1998) and Venn and Quiggin (2007) found that, in addition to the traditionally identified non-market valuation method biases, there are likely to be several areas where non-market valuation efforts may fail in an indigenous context. These include: a lack of substitutability of other goods for some types of indigenous cultural heritage; gender, generational and other demographic effects on values that indigenous people attribute to cultural heritage; and systematic differences in income levels between indigenous and non-indigenous people. Venn and Quiggin (2007) concluded that it is unlikely to be feasible to achieve total economic valuation of indigenous cultural heritage using contemporary social welfare theories and non-market valuation methods, which do not account for the social welfare concepts, property rights regimes and political structures of indigenous communities.

AN ALTERNATIVE TO NON-MARKET VALUATION FOR ACCOMMODATING EFFECTS OF WILDFIRE ON NON-MARKETED RESOURCES

In light of the challenges associated with accommodating non-marketed resources at risk from wildfire within a social BCA framework, it is little wonder that price-based approaches to supporting NIPF and public forest management in fire adapted ecosystems have failed to adequately account for non-timber values. The authors do not argue that it is impossible to assess wildfire-related resource value change, but rather that with the exception of a few well-studied forest areas, total economic valuation of wildfire effects will require extensive ecological and socio-economic research. In the meantime, however, wildfire managers must continue to make decisions that will affect non-market values generated by NIPFs. Until more estimates of social value change arising from wildfire become available, alternative wildfire decision support frameworks should be considered.

A critical component of any wildfire decision framework is that resource effects information must be made available within a 'real-time' environment and represent important resource values and tradeoffs without overloading the decision maker with information. Thus, the most useful and feasible fire management decision support system may currently be a relatively simple proxy that identifies general trends for the suite of values that cannot be easily incorporated within a monetary framework, while recognizing the current Forest Service ecosystem management paradigm. Venn *et al.* (in progress) considered several decision-support frameworks and identified departure from historical range and variability (HRV) as having high promise. For the purposes of ecological assessment in the western United States, USDA and USDI (2000) defined HRV as the estimated natural fluctuation of ecological and physical processes and functions that would have occurred during a specified period of time prior to settlement by Euro-Americans, i.e. pre 1850 to 1900. HRV is in reference to vegetation types, compositions and structures, fire regimes, fish and wildlife habitats and populations, and does include the management practices of native Americans prior to European settlement.

Departure from HRV provides a way to measure how much disturbance regimes and ecological systems have changed. The higher the departure from the HRV, the lower is a region's ecological integrity in terms of present and operating ecosystem processes and functions, and the less desirable are the consequences for ecosystems (USDA and USDI (U.S. Department of Agriculture and U.S. Department of the Interior) 2000). Keane *et al.* (2006b) described statistical algorithm and simulation methods used to generate HRV and departure indices for the LANDFIRE project, which appear suitable for modification and extension to many applications, including non-marketed resources at risk from wildfire.

HRV landscape dynamics can be quantified from three main sources: sequences of maps in one landscape over many time periods; vegetation maps from many similar, unmanaged landscapes, taken from one or more time periods that are gathered across a geographic region (space-for-time substitutions); and simulation of historic dynamics to produce a chronosequence of simulated maps to compute landscape statistics (Keane *et al.* 2006a). The first method is limited by the short period of recent history over which useful and reliable mapped vegetation information is available, while confidence in the second method is low because landscape similarity is difficult to assess and is highly dependent on scale, recent disturbance history and topography. Keane *et al*. (2006a) asserted there are now many spatially explicit models suitable for simulating disturbance and succession processes in the western United States, and that simulation methods appear to provide the best means for assessing HRV.

Although reducing departure of current landscapes from HRV has not yet been applied to support 'real-time' wildfire management decisions, there is growing scientific consensus that the approach is suitable for guiding long-term conservation of many non-marketed resources at risk from wildfire in the United States (Bisson *et al.* 1997, Covington *et al.* 1997, Swetnam *et al.* 1999, DellaSala and Frost 2001, Keane *et al.* 2002, Hessburg and Agee 2003, Kauffman 2004, Hessburg *et al.* 2005, Van Lear *et al*. 2005). In ponderosa pine ecosystems of the western US that dominate NIPF holdings, a return to the historic fire regime of more frequent and less severe fires will create landscapes that will be more similar to those that occurred historically, and these landscapes will contain lower and less contiguous fuel accumulations that reduces the chance of uncharacteristically severe, stand replacing wildfires. Historic fire regimes will improve the ecological health, integrity, and resilience of these ecosystems by thinning stands, reversing tree and shrub invasion of grasslands, and providing a shifting mosaic of patches and habitats for flora and fauna that will facilitate biodiversity conservation and reduce the potential for epidemic infestations of insects and disease (Mutch *et al.* 1993). Lower stand densities will reduce transpiration and canopy interception of rain and snow, which is likely to increase streamflow and soil water (DeBano *et al.* 1998, Keane *et al.* 2002). Less severe wildfires consuming less biomass per unit area are also likely to be less damaging to soil physical properties, water quality and aquatic biota, and reduce PM and carbon emissions per acre burned. Since native American culture evolved with and contributed to historic fire regimes, it is probable that indigenous cultural heritage values will be better conserved under historic fire regimes than contemporary fire regimes (Ostlund *et al.* 2005, Keane *et al.* 2006a). It can also be argued that, if historic fire regimes better conserve many of the non-market attributes that recreationists value, then recreation values may also be best conserved by historic fire regimes.

Measures of ecological departure from HRV could be used as a proxy for social value change arising from wildfire for those resources where estimation of value change at the margin is challenging. A departure index, or several departure indices representing different ecological characteristics, could be computed from a statistical algorithm that compares ecosystem characteristics of the current landscape and simulated post-fire landscape with the simulated characteristics of the historical landscape. If the post-fire landscape is estimated to reduce departure from HRV relative to the current landscape, and market and other values at risk are low, then this would support a management decision to let the fire burn. Alternatively, if the post-fire landscape is estimated to increase departure from HRV relative to the current landscape, then suppression may be warranted.

CONCLUDING COMMENTS

NIPF owners value many non-marketed goods and services provided by their land that are affected (either positively or negatively) by wildfire. United States federal wildfire policy has been modified to recognise the beneficial ecological role of fire and acknowledge the need for measures of economic efficiency of wildfire suppression to accommodate non-market values. Price-based models to support management in fire adapted NIPFs and public forests will be useful only if they can accommodate social benefit-cost analyses of wildfire events by accounting for change in the total economic value (use and non-use value) of resources at risk from wildfire. Given the current state of scientific and economic knowledge about wildfire effects on ecosystems and social welfare, this appears unlikely.

Until fire effects on ecosystem functions and social welfare are more fully understood, measures of departure of ecosystems from their historical range and variability (HRV) of ecological characteristics are likely to provide one of the more useful sources of knowledge for predicting wildfire effects on ecological conditions and welfare, and for supporting future management of fire-adapted ecosystems. However, departure from HRV is not a panacea for wildfire decision-support – there will still be difficult tradeoffs and decisions to make. Nevertheless, the method does appear to provide a framework useful for considering potential fire effects on many non-market attributes for which estimating social welfare change remains challenging. Further investigation of the departure from HRV method is required to confirm which non-market values can be meaningfully accommodated, to develop departure indices for non-market values that convey relative magnitudes of benefits and costs of wildfires, and to determine how the non-pecuniary information generated can be best integrated with pecuniary benefit and cost information to support wildfire management decisions. The authors are examining these issues as part of continuing research on wildfire decision-support.

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REFERENCES

Adamowicz, W., Beckley, T., Hatton MacDonald, D., Just, L., Luckert, M., Murray, E. and Phillips, W. (1998), 'In search of forest resource values of indigenous peoples: Are nonmarket valuation techniques applicable?', *Society and Natural Resources*, 11(1): 51–66.

Amacher, G.S., Malik, A.S. and Haight, R.G. (2005a), 'Nonindustrial private landowners, fires, and the wildland-urban interface', *Forest Policy and Economics*, 7(5): 796–805.

Amacher, G.S., Malik, A.S. and Haight, R.G. (2005b), 'Forest landowner decisions and the value of information under fire risk', *Canadian Journal of Forest Research*, 35(11): 2603–2515.

Arno, S.F. and Fiedler, C.E. (2005), *Mimicking Nature's Fire: Restoring Fire-prone Forests in the West*, Island Press, Washington, DC.

Birch, T.W. (1996), 'Private forestland owners of the United States, 1994', Resource Bulletin NE-134, USDA Forest Service Northeast Experiment Station, Radnor.

Bisson, P.A., Reeves, G.H., Bilby, R.E. and Naiman, R.J. (1997), 'Watershed management and Pacific salmon: desired future conditions', in D.J. Stouder, P.A. Bisso, and R.J. Naiman (eds), *Pacific Salmon and their Ecosystems: Status and Future Options*, Chapman and Hall, New York.

Bliss, J.C. (2003), 'Sustaining family forests in rural landscapes: rationale, challenges, and an illustration from Oregon, USA', *Small-scale Forest Economics, Management and Policy*, 2(1): 1–8.

Boyle, K.J. and Bergstrom, J.C. (1992), 'Benefit transfer studies: myths, pragmatism, and idealism', *Water Resources Research*, 28(3): 657–663.

Brown, J.K. (2000), 'Ecological principles, shifting fire regimes and management considerations', in J.K. Brown and J.K. Smith (eds), *Wildland Fire in Ecosystems: Effects of Fire on Flora*, General Technical Report RMRS-GTR-42, Vol. 2., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden.

Burton, T.A. (2005), 'Fish and stream habitat risks from uncharacteristic wildfire: observations from 17 years of fire-related disturbances on the Boise National Forest, Idaho', *Forest Ecology and Management*, 211(1-2): 140–149.

Bury, R.B. (2004), 'Wildfire, fuel reduction, and herpetofauna across diverse landscape mosaics in northwestern forests', *Conservation Biology*, 18(4): 968–975.

Butry, D.T., Mercer, D.E., Prestemon, J.P., Pye, J.M. and Holmes, T.P. (2001), 'What is the price of catastrophic wildfire', *Journal of Forestry*, 99(11): 9–17.

Calkin, D.E., Gebert, K.M., Jones, G. and Neilson, R.P. (2005), 'Forest service large fire area burned and suppression expenditure trends, 1970-2002', *Journal of Forestry*, 103(4): 179–183.

Carroll, M.S., Cohn, P.J. and Blatner, K.A. (2004), 'Private and tribal forest landowners and fire risk: A two-county case study in Washington State', *Canadian Journal of Forest Research*, 34(10): 2148–2158.

Chee, Y.E. (2004), 'An ecological perspective on the valuation of ecosystem services', *Biological Conservation*, 120(4): 549–565.

Chestnut, L.G. and Rowe, R.D. (1990), 'Preservation values for visibility protection at the national parks', Draft final report under U.S. EPA Cooperative Agreement No. CR813686, U.S. Environmental Protection Agency, Research Triangle Park.

Covington, W.W., Fule, P.Z., Moore, M.M., Hart, S.C., Kolb, T.E., Mast, J.N., Sackett, S.S. and Wagner, M.R. (1997), 'Restoring ecosystem health in ponderosa pine forests of the Southwest', *Journal of Forestry*, 95(4): 23–29.

De Mendonça, M.J.C., Diaz, M.C.V., Nepstad, D., Da Motta, R.S., Alencar, A., Gomes, J.C. and Ortiz, R.A. (2004), 'The economic cost of the use of fire in the Amazon', *Ecological Economics*, 49(1): 89–105.

DeBano, L.F., Neary, D.G. and Ffolliott, P.F. (1998), *Fire's Effect on Ecosystems*, John Wiley and Sons, New York.

DellaSala, D.A. and Frost, E. (2001), 'An ecologically based strategy for fire and fuels management in national forest roadless areas', *Fire Management Today*, 61(2): 12–23.

Despain, D.G., Beier, P., Tate, C., Durtsche, B.M. and Stephens, T. (2000) 'Modelling biotic habitat high risk areas', *Journal of Sustainable Forestry*, 11(1–2): 89–117.

Diamond, P.A. and Hausman, J.A. (1994), 'Contingent valuation: is some number better than no number?', *Journal of Economic Perspectives*, 8(4): 45–64.

Englin, J.E., Boxall, P.C. and Hauer, F.R. (2000), 'An empirical examination of optimal rotations in a multiple use forest in the presence of fire risk', *Journal of Agricultural and Resource Economics*, 25(1): 14-27.

Englin, J.E., Loomis, J.B. and González-Cabán, A. (2001), 'The dynamic path of recreational values following a forest fire: A comparative analysis of states in the Intermountain West', *Canadian Journal of Forest Research*, 31(10): 1837–1844.

EPA (U.S. Environmental Protection Agency) (1997), Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule, Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park.

EPA (U.S. Environmental Protection Agency) (1999a), Regulatory Impact Analyses for the Final Regional Haze Rule, Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park.

EPA (U.S. Environmental Protection Agency) (1999b), The Benefits and Costs of the *Clean Air Act 1990* to 2000, prepared by the Office of Air and Radiation, Office of Policy, U.S. Environmental Protection Agency for U.S. Congress,, Washington, DC.

FPA (Fire Program Analysis) (c2006), Overview, available at: http://www.fpa.nifc.gov/Information/Overview/index.html, accessed 15 November 2006.

Franklin, J., Perry, D., Noss, R., Montgomery, D. and Frissell, C. (2001), Simplified Forest Management to Achieve Watershed and Forest Health: A Critique, The Scientific Panel on Ecosystem Management, National Wildlife Federation, Seattle.

Fried, J.S., Winter, G.J. and Gilless, J.K. (1999), 'Assessing the benefits of reducing fire risk in the wildland-urban interface: A contingent valuation approach', *International Journal of Wildland Fire*, 9(1): 9–20.

Glover, D. and Jessup, T., (eds) (1999), *Indonesia's Fires and Haze: the Cost of Catastrophe*, Institute of Southeast Asian Studies, Singapore and International Development Research Centre, Ottawa.

Hessburg, P.F. and Agee, J.K. (2003), 'An environmental narrative of the Inland Northwest United States forests, 1800-2000', *Forest Ecology and Management*, 178(1–2): 23–59.

Hessburg, P.F., Agee, J.K. and Franklin, J.F. (2005), 'Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras', *Forest Ecology and Management*, 211(1–2): 117–139.

Hesseln, H., Loomis, J.B. and González-Cabán, A. (2004), 'The effects of fire on recreation demand in Montana', *Western Journal of Applied Forestry*, 19(1): 47–53.

Hesseln, H., Loomis, J.B., González-Cabán, A. and Alexander, S. (2003), 'Wildfire effects on hiking and biking demand in New Mexico: A travel cost study', *Journal of Environmental Management*, 69(4): 359–368.

Hessl, A. and Spackman, S. (1995), Effects of Fire on Threatened and Endangered Plants: An Annotated Bibliography, U.S. Department of the Interior, National Biological Service, Washington, DC.

Hodgdon, B. and Tyrrell, M. (2003), Literature Review: An Annotated Bibliography of the Published and Grey Literature on Family Forest Owners, GISF Research Paper 002, Global Institute of Sustainable Forestry, Yale University, New Haven, available at URL: http://research.yale.edu/gisf/assets/pdf/ppf/lit_review_10_03.pdf, accessed 14 May 2007.

Huggett, R.J. (2003), Fire in the Wildland-urban Interface: An Examination of the Effects of Wildfire on Residential Property Markets, unpublished PhD thesis, Economics – College of Management, North Carolina State University, Raleigh.

Hutto, R.L. (1995), 'Composition of bird communities following stand replacement fires in Northern Rocky Mountains (USA) conifer forests', *Conservation Biology*, 9(5): 1041–1058.

Ice, G.G., Neary, D.G. and Adams, P.W. (2004), 'Effects of wildfire on soils and watershed processes', *Journal of Forestry*, 102(6): 16–20.

Kauffman, J.B. (2004), 'Death rides the forest: Perceptions of fire, land use, and ecological restoration of western forests', *Conservation Biology*, 18(4): 878–882.

Keane, R.E., Arno, S.F. and Dickinson, L.J. (2006a), 'The complexity of managing fire-dependent ecosystems in the wilderness: Relict ponderosa pine in the Bob Marshall Wilderness', *Ecological Restoration*, 24(2): 71–78.

Keane, R.E., Frescino, T., Reeves, M. and Long, J.L. (2006b), 'Mapping Wildland Fuel across Large Regions for the LANDFIRE Prototype Project', in M.G. Rollins and C.K. Frame (eds), *The LANDFIRE Prototype Project: Nationally Consistent and Locally Relevant Geospatial Data for Wildland Fire Management*, Gen. Tech. Rep. RMRS-GTR-175, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Keane, R.E., Ryan, K.C., Veblen, T.T., Allen, C.D., Logan, J. and Hawkes, B. (2002), Cascading Effects of Fire Exclusion in the Rocky Mountain Ecosystems: A Literature Review, General Technical Report, RMRS-GTR-91, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Kie, J.G. (1984), Deer Habitat Use after Prescribed Burning in Northern California, Research Note RN-PSW-369, USDA Forest Service Pacific Southwest Forest and Range Experiment Station, Albany.

Kim, Y.S. and Wells, A. (2005), 'The impact of forest density on property values', *Journal of Forestry*, 103(3): 146–151.

Klinger, R.C., Kutilek, M.J. and Shellhammer, H.S. (1989), 'Population responses black-tailed deer to prescribed burning', *Journal of Wildlife Managment*, 53(4): 863–870.

Landsberg, J.D. and Tiedemann, A.R. (2000), 'Fire management', in G.E. Dissmeyer (ed.), *Drinking Water from Forests and Grasslands: A Synthesis of the Scientific Literature*, General Technical Report GTR-SRS-39, US Department of Agriculture, Forest Service, Southern Research Station, Asheville.
Loomis, J. (2004). 'Do nearby forest fires cause a reduction in residential property values?' *Journal of Forest Economics*, 10(3): 149–157.
Loomis, J.B. and White, D.S. (1996), 'Economic benefits of rare and endangered species: summary and meta-analysis', *Ecological Economics*, 18(3): 197–206.
Loomis, J.B. and González-Cabán, A. (1998), 'A willingness-to-pay function for protecting acres of spotted owl habitat from fire', *Ecological Economics*, 25(3): 315–322.
Loomis, J.B., González-Cabán, A. and Englin, J.E. (2001), 'Testing the differential effects of forest fires on hiking and mountain biking demand and benefits', *Journal of Agricultural and Resource Economics*, 26(2): 508–522.
Loomis, J.B., Le, H.G. and González-Cabán, A. (2002), 'Estimating the economic value of big game habitat production from prescribed fire using a time series approach', *Journal of Forest Economics*, 8(2): 119–129.
Loomis, J.B., Le, H.G. and González-Cabán, A. (2005), 'Testing transferability of willingness to pay for forest fire prevention among three states of California, Florida and Montana', *Journal of Forest Economics*, 11(3): 125–140.
Loomis, J.B., Wohlgemuth, P., González-Cabán, A. and English, D. (2003), 'Economic benefits of reducing fire-related sediment in southwestern fire-prone ecosystems', *Water Resources Research*, 39(9): 1260, doi:10.1029/2003WR002176.
Lynch, D.L. (2004), 'What do forest fires really cost?' *Journal of Forestry*, 102(6): 42–49.
Lyon, L.J. and Smith, J.K. (2000), 'Management and research implications', in J.K. Smith (ed.), Wildland Fire in Ecosystems: Effects of Fire on Fauna, General Technical Report RMRS-GTR-42, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden.
Mutch, R.W., Arno, S.F., Brown, J.K., Carlson, C.E., Ottmar, R.D. and Peterson, J.L. (1993), Forest health in the Blue Mountains: A management strategy for fire-adapted ecosystems, PNW-GTR-310, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.
National Academy of Public Administration (2002), *Wildfire Suppression: Strategies for Containing Costs*, National Academy of Public Administration, Washington, DC.
Neary, D.G., Ryan, K.C. and DeBano, L.F. (2005), 'Summary and research needs', in D.G. Neary, K.C. Ryan and L.F. DeBano (eds), Wildland Fire in Ecosystems: Effects of Fire on Soil and Water, General Technical Report RMRS-GTR-42-vol.4., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden.
Nunes, P.A.L.D. and Van den Bergh, J.C.J.M. (2001), 'Economic valuation of biodiversity: Sense or nonsense?' *Ecological Economics*, 39(2): 203–222.
Ostlund, L., Keane, R.E., Arno, S.F. and Andersson, R. (2005), 'Culturally scarred trees in the Bob Marshall Wilderness, Montana, USA – Interpreting Native American historical land use in a wilderness area', *Natural Areas Journal*, 25(4): 315–325.
Raphael, M.G., Wisdom, M.J., Rowland, M.M., Holthausen, R.S., Wales, B.C., Marcot, B.G. and Rich, T.D. (2001), 'Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River Basin', *Forest Ecology and Management*, 153(1–3): 63–88.
Raunikar, R. and Buongiorno, J. (2006), 'Willingness to pay for forest amenities: The case of non-industrial owners in the south central United States', *Ecological Economics*, 56(1): 132–143.
Reed, W. (1984), 'The effects of the risk of fire on the optimal rotation of a forest', *Journal of Environmental Economics and Management*, 11(2): 180-190.
Review Team (2001), Developing an Interagency, Landscape-scale, Fire Planning Analysis and Budget Tool, Report to the National Fire Plan Coordinators: USDA Forest Service and USDI, available at URL: http://www.fpa.nifc.gov/Library/Memos/Docs/Hubbardrpt.pdf, accessed 17 November 2006.
Rideout, D.B. and Ziesler, P.S. (2005), Weight system (EOWEP) for FPA-PM, working draft version 2.5, Fire Economics and Management Laboratory, Fort Collins, available at URL: http://www.fpa.nifc.gov/Library/Docs/Rideout/EOWEP_V2_2005.pdf, accessed 15 November 2006.
Rieman, B., Lee, D., Burns, D., Gresswell, R., Young, M., Stowell, R., Rinne, J. and Howell, P. (2003), 'Status of native fishes in the western United States and issues for fire and fuels management', *Forest Ecology and Management*, 178(1-2): 197-211.
Rinne, J.N. and Jacoby, G.R. (2005), 'Aquatic biota', in D.G. Neary, K.C. Ryan and L.F. DeBano (eds), Wildland Fire in Ecosystems: Effects of Fire on Soils and Water, General Technical Report RMRS-GTR-42-vol.4., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden.
Rosenberger, R.S. and Loomis, J.B. (2001), Benefit transfer of outdoor recreation use values: A technical document supporting the Forest Service Strategic Plan (2000 revision), General Technical Report RMRS-GTR-72, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Sandberg, D.V., Ottmar, R.D., Perterson, J.L. and Core, J. (2002), Wildland Fire in Ecosystems: Effects of Fire on Air, General Technical Report RMRS-GTR-42-vol.5., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden.

Scatena, F.N. (2000), 'Drinking water quality', in G.E. Dissmeyer (ed.), Drinking Water from Forests and Grasslands: a Synthesis of the Scientific Literature, General Technical Report GTR-SRS-39, US department of Agriculture, Forest Service, Southern Research Station, Asheville.

Smith, A.E., Kemp, M.A., Savage, T.H. and Taylor, C.L. (2005), 'Methods and results from a new survey of values for eastern regional haze improvements', *Journal of the Air and Waste Management Association*, 55(11): 1767-1779.

Smith, W.B., Miles, P.D., Vissage, J.S. and Pugh, S.A. (2004), Forest Resources of the United States 2002, USDA Forest Service, North Central Research Station, St. Paul, available at URL: http://www.ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf, accessed 24 April 2007.

Sparhawk, W.R. (1925), 'The use of liability rating in planning forest fire protection', *Journal of Agricultural Research*, 30: 693-762.

Splash, C.L. and Vatn, A. (2006), 'Transfering environmental value estimates: issues and alternatives', *Ecological Economics*, 60(2): 379-388.

Spring, D.A. and Kennedy, J.O.S. (2005), 'Existence value and optimal timber-wildlife management in a flammable multistand forest', *Ecological Economics*, 29(3): 365-379.

Stephens, S.L. and Ruth, L.W. (2005), 'Federal forest-fire policy in the United States', *Ecological Applications*, 15(2): 532-542.

Swetnam, T.W., Allen, C.D. and Betancourt, J.L. (1999). 'Applied historical ecology: Using the past to manage for the future', *Ecological Applications*, 9(4): 1189-1206.

Toman, T. (2006), Director of Conservation Programs, Rocky Mountain Elk Foundation, Missoula, 11 July, personal communication.

USDA and USDI (U.S. Department of Agriculture and U.S. Department of the Interior) (2000), Supplemental Draft Environmental Impact Statement, Interior Columbia River Basin Ecosystem Management Project, USDA Forest Service and USDI Bureau of Land Management, Portland, available at URL: http://www.icbemp.gov, accessed 19 July 2006.

USDI, USDA, and NASF, (United States Department of the Interior, United States Department of Agriculture and National Association of State Foresters) (2005), Quadrennial Fire and Fuels Review Report, National Advanced Fire and Resource Institute, Tucson.

USDI, USDA, Department of Energy, Department of Defence, Department of Commerce, U.S. Environmental Protection Agency, Federal Emergency Management Agency and National Association of State Foresters (2001), *Review and Update of the 1995 Federal Wildland Fire Management Policy*, Bureau of land Management, Office of Fire and Aviation, Boise, available at URL: http://www.nifc.gov/ fire_policy/history/index.htm, accessed 15 November 2006.

Van Kooten, G.C. and Bulte, E.H. (2000), *The Economics of Nature: Managing Biological Assets*, Blackwell, Malden.

Van Lear, D.H., Carroll, W.D., Kapeluck, P.R. and Johnson, R. (2005), 'History and restoration of the longleaf pine-grassland ecosystem: implications for species at risk', *Forest Ecology and Management*, 211(1-2): 150-165.

Venn, T. J. and Quiggin, J. (2007). 'Accommodating indigenous cultural heritage values in resource assessment: Cape York Peninsula and the Murray-Darling Basin, Australia', *Ecological Economics*, 61(2-3): 334-344.

Venn, T. J., Calkin, D. E. and Keane, R. E. (in progress), Accommodating non-market values in assessment of wildfire suppression with measures of departure from historic range and variability, working paper, The College of Forestry and Conservation, The University of Montana, Missoula.

Walker, S. H., Rideout, D. B., Loomis, J. B. and Reich, R. (2007). 'Comparing the value of fuel treatment options in northern Colorado's urban and wildland interface areas', *Forest Policy and Economics*, 9(6): 694-703.

Zhang, Y., Zhang, D. and Schelhas, J. (2005). 'Small-scale non-industrial private forest ownership in the United States: rationale and implications for forest management', *Silva Fennica*, 39(3): 443-454.