Small-scale Forestry (2009) 8:43–61
DOI 10.1007/s11842-008-9065-z

RESEARCH PAPER

Challenges of Socio-economically Evaluating Wildfire Management on Non-industrial Private and Public Forestland in the Western United States

Tyron J. Venn · David E. Calkin

Accepted: 12 May 2008 / Published online: 3 July 2008

Abstract Non-industrial private forests (NIPFs) and public forests in the United States generate many non-market benefits for landholders and society generally. These values can be both enhanced and diminished by wildfire management. This paper considers the challenges of supporting economically efficient allocation of wildfire suppression resources in a social cost-benefit analysis framework when non-market values are important. These challenges include substantial gaps in scientific understanding about how the spatial and temporal provision of non-market values are affected by wildfire, the limited utility of benefit transfer in wildfire assessment, a lack of studies that have estimated marginal willingness-to-pay to conserve non-market values, violation of consumer budget constraints, and the infeasibility of valuing indigenous cultural heritage. These challenges present serious impediments to adapting price-based decision-support tools to accommodate non-market values and support decision-making consistent with contemporary federal wildfire policy. Departure from the historic range and variability of ecological conditions is proposed as a complementary framework to support wildfire management decisions when non-market values are important on NIPF and public forestland.

Keywords Non-market valuation · Historic range and variability · Wildfire policy · Wildfire effects · Bushfire

T. J. Venn (✉)
College of Forestry and Conservation, The University of Montana, Missoula, MT 59812, USA
e-mail: tyron.venn@umontana.edu

D. E. Calkin
Rocky Mountain Research Station, USDA Forest Service, Missoula, MT 59801, USA

Introduction

There are approximately 9.9 million non-industrial private forest (NIPF) owners,[1] including 9.3 million individuals and families, collectively holding 145 million ha (49%) of forestland in the USA (Birch 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 USA, with timber production typically having low priority (Hodgdon and Tyrrell 2003; Zhang et al. 2005).

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 account for only 24% (23.1 million ha) 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 landholders and society at large in the American west.

The quality and quantity of many non-market benefits generated from small forest landholdings, including wildlife habitat, recreation opportunities and water quality, are affected by management of adjacent forestland. The principal neighbour of NIPF landholders in the western United States is the Forest Service of the federal Department of Agriculture. 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 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).

To support wildfire management decisions about fire-adapted forests, economists and other analysts have developed price-based[2] decision-support tools to assess optimal forest rotations (including for NIPFs) in the presence of fire risk and to assist allocation of federal wildfire suppression resources (e.g. Donovan and Rideout 2003; Amacher et al. 2005). However, while non-market forest goods and services are of increasing interest to NIPF owners and the general public, they are poorly accounted for within existing models (Review Team 2001).

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

[2] In a price-based approach, market or shadow prices are derived for all project inputs and outputs under consideration. Cost-benefit analysis is the framework for price-based approaches. The least cost plus loss and cost plus net value change wildfire economic models are examples of price-based decision-support tools.

The objective of this paper is to review the fire economics and ecology literature to evaluate the potential for accommodating non-market values enhanced or diminished by wildfire in a social cost-benefit analysis (CBA) 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 in wildfire management decision-support tools is unlikely to be appropriate for accommodating some important non-market values affected by wildfire. A complementary decision-support framework that measures departure of current and post-fire ecological conditions from the historic range and variability of ecological conditions is then introduced as a potential method for accommodating many non-market values affected by wildfire.

Contemporary Wildfire Policy and Economics in the United States

With few exceptions, aggressive wildfire suppression has dominated US 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, 2006 and 2007 (NIFC 2007), 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 and USDA 2001; USDI et al. 2005). Federal wildfire policy has shifted from one based primarily on wildfire suppression to one that integrates suppression, hazardous fuels reduction, restoration and rehabilitation of fire-adapted ecosystems, and community assistance (Venn and Calkin 2008). Federal wildfire policy now 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.

Although federal wildfire policy only applies to management of fire on public land, it does directly and indirectly affect wildfire management on NIPF land because current policy calls for protection of private property commensurate with the value of those assets (USDI and USDA 2001). Empirical evidence suggests private assets near wildfires burning on public land are statistically significant drivers of wildfire suppression costs (Liang et al. in press) and the Forest Service has been criticised for overemphasizing protection of private property when managing wildfire (OIG 2006).

While United States federal wildfire policy has been modified to account for the beneficial roles of fire on forestland, existing price-based models developed to evaluate smallholder forest management in fire-adapted forest ecosystems in the USA treat the arrival of fire as having only negative impacts on market and non-market values (e.g. Englin et al. 2000; Amacher et al. 2005). The least cost plus loss (LCPL) economic theory applied to support wildfire management on public land 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 was modified in the 1980s to accommodate beneficial effects of fire (Mills and Bratten 1982), and 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, human settlement in the WUI was relatively limited, and wildfire policy was to aggressively suppress all fires. However, this is no longer the case, and estimates of non-market benefits and costs of wildfire are scarce.

The Hubbard Report (Review Team 2001) examined the suite of fire budget and planning models of federal agencies 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 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 various 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 2008, there was no peer reviewed literature available describing the EOWEP process and EOWEP has been excluded from future developments of the FPA system.

Wildfire Effects on Non-market Forest Values

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-market forest values are inadequately accounted for. Wildfires affect many non-market forest values that are of importance to NIPF owners and society at large, including: air quality; soil and water quality; flora, fauna and invasive species; recreation opportunities; cultural heritage; and carbon sequestration and storage. Table 1 (from Venn and Calkin 2008) summarises the positive and negative effects of wildfire on these seven non-market forest value categories. Each of these non-market values exhibit 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 western USA, 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-market forest values.[3]

[3] This is not necessarily the case for other forest types. For example, lodgepole pine forests at higher elevations have evolved with infrequent, high severity wildfire regimes.

Table 1 Positive and negative effects of wildfire on non-market values generated by NIPFs and public forests

Non-market forest value	Positive fire effects	Negative fire effects
Recreation opportunities	Improved wildflower and wildlife viewing	Campsites destroyed
	New scenic vistas may be revealed	Debris on hiking, biking and four-wheel-drive trails
	Novelty of a burned forest	Burned forest may be aesthetically displeasing
	Improved ungulate habitat increasing hunting success	Short to medium-term reduction in fishing success due to stream habitat deterioration
	Improved fish habitat in the long-run increasing fishing success	
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	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.
	Low severity fire will favour native plants adapted to wildfire and facilitate ecosystem restoration	Short-term highly negative impact on stream amphibians and fish
	Conservation of locally rare plants is improved by diverse disturbance histories	Some exotic plant species are adapted to colonise post-fire landscapes
	Diverse disturbance histories likely to reduce the potential for epidemic insect and disease infestations	
	Long-term improvement of aquatic habitat quality	
Air quality		Human respiratory health
		Reduced visibility at scenic vistas and on roadways
		Soiling surfaces of objects

Table 1 continued

Non-market forest value	Positive fire effects	Negative fire effects
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
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
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
Carbon sequestration and storage	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

Price-based approaches to support wildfire management decisions consistent with contemporary federal wildfire policy require non-market valuation of the positive and negative effects of wildfire on the forest values described in Table 1. While many studies have examined non-market values of forests in the USA and internationally, surprisingly few have been conducted to estimate welfare change as a consequence of wildfire. Glover and Jessup (1999) estimated the short-term health costs of the 1997 forest fires in Kalimantan and Sumatra, Indonesia. The social costs of fire use in the Amazon, including carbon emissions and impacts on human health, have been examined by de Mendonça et al. (2004). In Victoria, Australia, Bennetton et al. (1998) assessed the market and non-market benefits of wildfire prevention and suppression, while Spring and Kennedy (2005) determined optimal rotations in a flammable multistand forest when fires degrade timber and habitat for an endangered species.

The value of private property in the WUI in the United States, 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 2 miles from the Buffalo Creek Fire in Colorado were about 15–16% lower 5 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 fuel load 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, downstream 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 a 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 of hikers and bikers in Colorado and found that the annual consumer 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 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 (with greater decreases for the former) 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).

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 to protect critical northern spotted owl habitat in California and Oregon from wildfire. They found the social value of preventing the first 1,000 acres (405 ha) per 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. 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.

Only one preliminary published study has attempted to quantify the pecuniary cost of wildfire smoke on public health in the USA (Butry et al. 2001). Chestnut and Rowe (1990) estimated WTP for guaranteed levels of visibility at national parks in the USA. These estimates have been widely cited and employed by the US federal Environmental Protection Agency to estimate visibility benefits associated with air quality programs (e.g. EPA 1999), but they apparently overestimated the value of visibility improvement by 50–100% (Smith et al. 2005).[4] 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 USA.

Forested landscapes of the USA 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; as settings for stories; religious places, burial places; physical evidence of historical occupation and 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. To the best of

[4] Chestnut and Rowe (1990) assigned incorrect visual ranges to their four photographs that supposedly depicted a scenic view under visual ranges of 75, 50, 25 and 10 km, respectively. Imaging software confirmed that haziness in the photographs were actually reflective of the visual ranges 150, 50, 17 and 5 km, respectively. Thus, changes in average visual range to which the WTP responses applied were much larger than reported by Chestnut and Rowe (1990), which led to the large overstatement in benefit estimates.

the authors' knowledge, Gonzalez-Caban et al. (2007) is the only published research that has examined native American WTP for wildfire management. However, cultural heritage values were not specifically targeted by that study.

Because 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.[5] For example, many culturally important plant and animal food resources require fire to maintain suitable habitat conditions. On the other hand, uncharacteristic wildfire is likely to be detrimental to or even destroy cultural heritage, including burial sites, 'medicine' and sacred trees, cultural relics, and archaeological sites and structures (Arno and Fiedler 2005; Keane et al. 2006).

Emissions of carbon from combustion of vegetation during wildfires impose social costs. However, fire is ultimately an unavoidable ecological process in many forests of western states. Irrespective of the level of contemporary and future wildfire detection and suppression technology and effort, 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 historic 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 practices. 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 regrowth that will sequester carbon. Furthermore, simulations reported by Keane et al. (1997) revealed that senescence 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. Bioeconomic models have yet to be developed to estimate the welfare implications of net carbon emissions arising from alternative wildfire regimes.

Challenges of Evaluating Welfare Change Arising From Wildfire Effects on Non-market Forest Values

Valuation of ecosystem enhancement or damage in any context is a complex and controversial undertaking, but the challenges are particularly prominent in valuation of large natural or anthropogenic disturbance events, including wildfire, where a large and diverse suite of resources may be affected, the disturbance has positive and negative welfare effects, and there is spatial and temporal variability in responses of affected non-market forest values to the disturbance. Estimation of welfare change arising from disturbance effects on various types, quantities and

[5] Native American cultures, however, are not static or 'frozen in time', and changes in cultural, social and economic circumstances since settlement by European Americans may have altered the relationship between historic fire regimes and indigenous cultural heritage.

qualities of non-market resources requires that analysts can define the direct and indirect effects of the disturbance on the spatial and temporal provision of non-market values, and how marginal changes in non-market resources will affect social welfare. There is a lack of information about both disturbance effects on non-market resources and the social welfare implications of resource change for many non-market values, making full social cost-benefit analysis for large disturbance events extremely challenging (Boardman et al. 2001; Gaddis et al. 2007). Five major challenges to evaluating welfare change arising from large disturbances to the natural environment can be identified in the context of wildfire, namely:

(1) scarcity of scientific information about how non-market forest values are affected by wildfire;
(2) limited amenability of many non-market forest values affected by wildfire to valuation by benefit transfer;
(3) a dearth of studies that have estimated marginal WTP to conserve non-market forest values;
(4) violation of consumer budget constraints; and
(5) infeasibility of valuation of indigenous cultural heritage.

Scarcity of Scientific Information About How Non-market 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 threatened and endangered (T&E) species. Examination of these descriptions reveals that, while information on fire effects 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 USA 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). Further, 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 US plant species and plant communities, particularly those that are rare, is generally poor (Brown 2000).

Currently, the most comprehensive guidelines in the USA for assessing the visibility implications and human health risk of exposure to particulate matter (PM), including from wildfire smoke plumes, are produced by the US EPA (1999). 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) warned 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 USA.

Landsberg and Tiedemann (2000) and Neary et al. (2005) identified several knowledge gaps that limit 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 post-fire 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-market resources is that the ultimate positive or negative effects of a fire may only become apparent some years after the fire and depend on a complex set of factors, including: pre-fire human management and infrastructure; topography; the physical, chemical and biological characteristics of 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; post-fire weather; the nature of fire suppression; and post-fire management. Consequently, in the context of aquatic ecosystems, Rieman et al. (2003) asserted that accurate prediction of 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-market resources at risk of wildfire, which presents serious impediments to predicting wildfire-related value change.

Limited Amenability of Many Non-market Forest Values Affected by Wildfire to Valuation by Benefit Transfer

Conducting stated and revealed preference studies to estimate how non-market forest values are affected by wildfire is time-consuming and costly. Benefit transfer methods have arisen in response to this limitation, but economists are divided about the accuracy of these techniques (Boyle and Bergstrom 1992; Splash and Vatn 2006). In the context of wildfire in the USA, three important limitations associated with transferring non-market benefit and cost information from previous studies to a new study site may be noted.

Heterogenous Wildfire Preferences of Society

If region-specific social and cultural values affect preferences and 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 on effects of wildfire on the welfare of homeowners and recreationists indicates that the wildfire preferences of society do vary substantially throughout the country. 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?

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 USA (Kie 1984; Klinger et al. 1989). Therefore, biases are likely to arise when transferring estimates of hunter welfare change due to wildfire from one study site to another.

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-market goods and services associated with forest ecosystems are unique and will differ spatially and temporally from the effects of other types of disturbances, including severe storms, logging, land clearing and climate change (DellaSala and Frost 2001). Consequently, findings of studies that evaluate welfare change in the context of non-fire disturbances are unlikely to be transferable to the fire context.

Dearth of Studies That Have Estimated Marginal WTP to Conserve Non-market Forest Values

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, as noted by van Kooten and Bulte (2000) and Rosenberger and Loomis (2001), most of these studies have estimated total or average WTP. 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). 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 T&E species, or locally rare but non-T&E species that have vulnerable, isolated populations in the vicinity of the fire event.

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 individual household willingness-to-pay to preserve several T&E species of the western USA—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)). There are many more T&E species that the average household in the United States may like to preserve, including the white sturgeon, bull trout, Canada lynx and black-footed ferret. However, WTP must be bounded by a budget constraint.

In the western United States, any particular fire is unlikely to affect many T&E species, but will affect many other non-market forest values 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 (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.

Infeasibility of Valuation of Indigenous Cultural Heritage

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 cultural heritage 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-market Forest Values

In light of the challenges associated with accommodating non-market resources at risk from wildfire within a social CBA framework, it is little wonder that price-based approaches to support wildfire management on NIPF and public forestlands have been unsatisfactory in the modern wildfire policy environment. This is not to 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, managers must continue to allocate scarce resources to manage wildfires that affect non-market values generated by NIPFs and public forests. Until more estimates of social value change arising from wildfire become available, complementary wildfire decision-support frameworks should be considered.

Venn and Calkin (2008) reviewed decision-support needs and potential frameworks for wildfire management and concluded that departure from historic range and variability (HRV) may provide an appropriate benchmark to evaluate wildfire effects on the health and integrity of ecosystems. This requires an epistemological shift from valuing non-market resources to accommodate them within price-based decision-support tools, to quantitative (but non-pecuniary) evaluation of the effects of alternative fire management strategies on non-market resources.

For the purposes of ecological assessment in the western 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. during 1850–1900. The departure from HRV measures 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 2000). Venn and Calkin (2008) summarized how HRV landscape dynamics can be quantified and departure indices derived, as well as the importance of the spatial and temporal scales assessed.

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-market resources at risk from wildfire in the USA (Covington et al. 1997; Swetnam et al. 1999; DellaSala and Frost 2001; Keane et al. 2002; Hessburg and Agee 2003). Wildfire events expected to increase departure from HRV and negatively affect the conservation of important non-market values are likely to decrease NIPF owner and social welfare. Conversely, wildfires that are expected to decrease departure from HRV are likely to be beneficial for conservation of important non-market values and to increase NIPF owner and social welfare. Thus, measures of ecological departure from HRV could be employed as one proxy for welfare change arising from wildfire for those resources where estimation of value change at the margin is challenging. In this way, departure from HRV is likely to provide useful information to supplement pecuniary estimates of wildfire management and damage costs, and facilitate economically efficient suppression resource allocation. If the post-fire landscape is judged to reduce departure from HRV, and market (including private timber and structures on NIPF land) and other values at risk are low, then this would support a management decision to let the fire burn. Conversely, suppression may be warranted if the post-fire landscape is judged to be more departed from HRV relative to the current landscape or market and other values at risk are high.

A departure from HRV approach to wildfire cannot overcome gaps in the understanding about how forest resources are affected by wildfire. However, by not monetizing wildfire effects, departure from HRV does avoid the challenges of evaluating welfare change arising from wildfire. Another benefit of the departure from HRV approach is that it provides an explicit, documentable and repeatable method for summarizing potential consequences of alternative fire management activities for non-market forest resources. This is a substantial improvement over the status quo, where non-market resources are either excluded from assessment of fire management or accommodated via weights reflecting the personal preferences of forest and fire managers. Nevertheless, as with any multiple criteria analysis approach to decision support, there will be non-commensurability issues, because departure from HRV indices cannot easily be compared with other information, including suppression costs. However, wildfire managers have always been confronted with non-commensurate information to support their decisions.

There is debate about the usefulness of historical conditions in ecosystem management. In particular, to apply HRV in resource management it must be assumed that the record of historical conditions is reflective of possible and desirable future landscape conditions. However, this may not be the case because of factors such as climate change, exotic species introductions and human land use (Keane et al. 2006; Westerling et al. 2006). The historic fire regime of some forest types, such as the infrequent, high severity regime of high-elevation lodgepole pine, is incompatible with human settlement. In the case of low-elevation ponderosa pine ecosystems, there is potential for ecologically destructive and social welfare reducing fire during the transition to a maintainable landscape with more frequent, low-severity wildfire or prescribed fire. More frequent fire in ponderosa pine ecosystems may present an undesirable level of risk to residents in the WUI, and result in more smoky days and fewer green trees to harvest.

While a return to historic fire regimes is not a panacea for wildfire managers, many concerns about HRV appear to have arisen from a narrow conception of the departure from HRV approach to natural resource management. Estimating departure from HRV is not about attempting to create an exact replica of historical conditions, but rather to study an ecosystem's past disturbance history and develop general intuitive models of a desired future condition for that ecosystem. Climate and other ecological changes can and should be accommodated within the HRV framework.

Concluding Comments

NIPF owners and society at large value many non-market goods and services provided by NIPFs and public forestland 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 benefits and costs 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 in the near term.

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 information for predicting wildfire effects on ecological conditions and welfare, and for supporting future management of fire-adapted ecosystems. However, the departure from HRV method 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 best be 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.

Acknowledgments We are grateful to the Forest Service Wildland Fire Research Development and Application Program for funding this research. The authors would also like to thank Bob Keane, Research Ecologist from the Rocky Mountain Research Station Fire Sciences Laboratory, for his critical and insightful comments on earlier versions of this paper.

References

Adamowicz W, Beckley T, Hatton MacDonald D, Just L, Luckert M, Murray E, Phillips W (1998) In search of forest resource values of indigenous peoples: are nonmarket valuation techniques applicable? Soc Nat Resour 11(1):51–66

Amacher GS, Malik AS, Haight RG (2005) Forest landowner decisions and the value of information under fire risk. Can J For Res 35(11):2603–2515. doi:10.1139/x05-143

Arno SF, Fiedler CE (2005) Mimicking nature's fire: restoring fire-prone forests in the west. Island Press, Washington, DC

Bennetton J, Cashin P, Jones D, Soligo J (1998) An economic evaluation of bushfire prevention and suppression. Aust J Agric Resour Econ 42(2):149–175

Birch TW (1996) Private forest-land owners of the United States, 1994, resource bulletin NE-134. USDA Forest Service Northeast Experiment Station, Radnor

Bliss JC (2003) Sustaining family forests in rural landscapes: rationale, challenges, and an illustration from Oregon, USA, Small-scale Forest Economics. Manage Policy 2(1):1–8
Boardman AE, Greenberg DH, Vining AR, Weimer DL (2001) Cost-benefit analysis: concepts and practice. Prentice Hall, Upper Saddle River
Boyle KJ, Bergstrom JC (1992) Benefit transfer studies: myths, pragmatism, and idealism. Water Resour Res 28(3):657–663. doi:10.1029/91WR02591
Brown JK (2000) Ecological principles, shifting fire regimes and management considerations. In: Brown JK, Smith JK (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, pp 185–203
Brown JK, Bradshaw LS (1994) Comparisons of particulate emissions and smoke impacts from presettlement, full suppression, and prescribed natural fire periods in the Selway–Bitterroot Wilderness. Int J Wildland Fire 4(3):143–155. doi:10.1071/WF9940143
Bury RB (2004) Wildfire, fuel reduction, and herpetofauna across diverse landscape mosaics in northwestern forests. Conserv Biol 18(4):968–975. doi:10.1111/j.1523-1739.2004.00522.x
Butry DT, Mercer DE, Prestemon JP, Pye JM, Holmes TP (2001) What is the price of catastrophic wildfire. J For 99(11):9–17
Calkin DE, Gebert KM, Jones G, Neilson RP (2005) Forest service large fire area burned and suppression expenditure trends, 1970–2002. J For 103(4):179–183
Chestnut LG, Rowe RD (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, Raleigh-Cary and Durham
Covington WW, Fule PZ, Moore MM, Hart SC, Kolb TE, Mast JN et al (1997) Restoring ecosystem health in ponderosa pine forests of the Southwest. J For 95(4):23–29
DellaSala DA, Frost E (2001) An ecologically based strategy for fire and fuels management in national forest roadless areas. Fire Manage Today 61(2):12–23
Donovan GH, Rideout DB (2003) A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. For Sci 49(2):318–323
Englin JE, Boxall PC, Hauer FR (2000) An empirical examination of optimal rotations in a multiple use forest in the presence of fire risk. J Agric Resour Econ 25(1):14–27
Englin JE, Loomis JB, González-Cabán A (2001) The dynamic path of recreational values following a forest fire: a comparative analysis of states in the Intermountain West. Can J For Res 31(10):1837–1844. doi:10.1139/cjfr-31-10-1837
EPA (U.S. Environmental Protection Agency) (1999) 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
Fried JS, Winter GJ, Gilless JK (1999) Assessing the benefits of reducing fire risk in the wildland-urban interface: a contingent valuation approach. Int J Wildland Fire 9(1):9–20. doi:10.1071/WF99002
Gaddis EB, Miles B, Morse S, Lewis D (2007) Full-cost accounting of coastal disasters in the United States: implications for planning and preparedness. Ecol Econ 63(2–3):307–318. doi:10.1016/j.ecolecon.2007.01.015
Glover D, Jessup T (eds) (1999) Indonesia's fires and haze: the cost of catasrophe, Institute of Southeast Asian Studies, Singapore and International Development Research Centre, Ottawa
Gonzalez-Caban A, Loomis JB, Rodriguez A, Hesseln H (2007) A comparison of CVM survey response rates, protests and willingness-to-pay of Native Americans and general population for fuels reduction policies. J For Econ 13(1):49–71
Hessburg PF, Agee JK (2003) An environmental narrative of the Inland Northwest United States forests, 1800–2000. For Ecol Manage 178(1–2):23–59. doi:10.1016/S0378-1127(03)00052-5
Hesseln H, Loomis JB, González-Cabán A, Alexander S (2003) Wildfire effects on hiking and biking demand in New Mexico: a travel cost study. J Environ Manage 69(4):359–368. doi:10.1016/j.jenvman.2003.09.012
Hesseln H, Loomis JB, González-Cabán A (2004) The effects of fire on recreation demand in Montana. West J Appl For 19(1):47–53
Hodgdon B, 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 RJ (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

Keane RE, Hardy CC, Ryan KC, Finney MA (1997) Simulating effects of fire on gaseous emissions from future landscapes of Glacier National Park, Montana, USA. World Resour Rev 9(2):177–205

Keane RE, Ryan KC, Veblen TT, Allen CD, Logan J, 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

Keane RE, Arno SF, Dickinson LJ (2006) The complexity of managing fire-dependent ecosystems in the wilderness: relict ponderosa pine in the Bob Marshall Wilderness. Ecol Res 24(2):71–78

Kie JG (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 YS, Wells A (2005) The impact of forest density on property values. J For 103(3):146–151

Klinger RC, Kutilek MJ, Shellhammer HS (1989) Population responses black-tailed deer to prescribed burning. J Wildl Manage 53(4):863–870. doi:10.2307/3809578

Landsberg JD, Tiedemann AR (2000) Fire management. In: Dissmeyer GE (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, pp 124–138

Liang J, Calkin DE, Gebert KM, Venn TJ, Silverstein RP (in press) Factors influencing large wildland fire suppression expenditures. Int J Wildland Fire

Loomis J (2004) Do nearby forest fires cause a reduction in residential property values? J For Econ 10(3):149–157

Loomis JB, White DS (1996) Economic benefits of rare and endangered species: summary and meta-analysis. Ecol Econ 18(3):197–206. doi:10.1016/0921-8009(96)00029-8

Loomis JB, González-Cabán A (1998) A willingness-to-pay function for protecting acres of spotted owl habitat from fire. Ecol Econ 25(3):315–322. doi:10.1016/S0921-8009(97)00044-X

Loomis JB, González-Cabán A, Englin JE (2001) Testing the differential effects of forest fires on hiking and mountain biking demand and benefits. J Agric Resour Econ 26(2):508–522

Loomis JB, Le HG, González-Cabán A (2002) Estimating the economic value of big game habitat production from prescribed fire using a time series approach. J For Econ 8(2):119–129

Loomis JB, Wohlgemuth P, González-Cabán A, English D (2003) Economic benefits of reducing fire-related sediment in southwestern fire-prone ecosystems. Water Resour Res 39(9):1260. doi:10.1029/2003WR002176

Loomis JB, Le HG, González-Cabán A (2005) Testing transferability of willingness to pay for forest fire prevention among three states of California, Florida and Montana. J For Econ 11(3):125–140

Lynch DL (2004) What do forest fires really cost? J For 102(6):42–49

de Mendonça MJC, Diaz MCV, Nepstad D, da Motta RS, Alencar A, Gomes JC, Ortiz RA (2004) The economic cost of the use of fire in the Amazon. Ecol Econ 49(1):89–105

Mills TJ, Bratten FW (1982) FEES: design of a fire economics evaluation system. General Technical Report PSW-65, USDA Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley

National Academy of Public Administration (2002) Wildfire suppression: strategies for containing costs. National Academy of Public Administration, Washington DC

Neary DG, Ryan KC, DeBano LF (2005) Summary and research needs. In: Neary DG, Ryan KC, DeBano LF (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, pp 207–212

NIFC (National Interagency Fire Centre) (2007) Wildland fire statistics. Available at URL: http://www.nifc.gov/stats/suppression_costs.html. Accessed 15 November 2007

OIG (USDA Office of Inspector General) (2006) Audit report: forest service large fire suppression costs, report no. 08601-44-SF, USDA OIG, Washington DC

Raphael MG, Wisdom MJ, Rowland MM, Holthausen RS, Wales BC, Marcot BG et al (2001) Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River Basin. For Ecol Manage 153(1–3):63–88. doi:10.1016/S0378-1127(01)00454-6

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 DB, Ziesler PS (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 et al (2003) Status of native fishes in the western United States and issues for fire and fuels management. For Ecol Manage 178(1–2):197–211. doi:10.1016/S0378-1127(03)00062-8

Rosenberger RS, Loomis JB (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 DV, Ottmar RD, Perterson JL, 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

Smith WB, Miles PD, Vissage JS, Pugh SA (2004) Forest resources of the United States 2002. USDA Forest Service, North Central Research Station, St. Paul. http://www.ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf. Accessed 24 April 2007

Smith AE, Kemp MA, Savage TH, Taylor CL (2005) Methods and results from a new survey of values for eastern regional haze improvements. J Air Waste Manage Assoc 55(11):1767–1779

Splash CL, Vatn A (2006) Transfering environmental value estimates: issues and alternatives. Ecol Econ 60(2):379–388. doi:10.1016/j.ecolecon.2006.06.010

Spring DA, Kennedy JOS (2005) Existence value and optimal timber-wildlife management in a flammable multistand forest. Ecol Econ 29(3):365–379

Stephens SL, Ruth LW (2005) Federal forest-fire policy in the United States. Ecol Appl 15(2):532–542. doi:10.1890/04-0545

Swetnam TW, Allen CD, Betancourt JL (1999) Applied historical ecology: using the past to manage for the future. Ecol Appl 9(4):1189–1206. doi:10.1890/1051-0761(1999)009[1189:AHEUTP]2.0.CO;2

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, Department of Energy, Department of Defense, 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

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.

van Kooten GC, Bulte EH (2000) The economics of nature: managing biological assets. Blackwell, Malden

Venn TJ, Calkin DE (2008) Challenges of accommodating non-market values in evaluation of wildfire suppression in the United States, report prepared for the USDA Forest Service Rocky Mountain Research Station. The University of Montana, Missoula

Venn TJ, Quiggin J (2007) Accommodating indigenous cultural heritage values in resource assessment: Cape York Peninsula and the Murray-Darling Basin, Australia. Ecol Econ 61(2–3):334–344

Walker SH, Rideout DB, Loomis JB, Reich R (2007) Comparing the value of fuel treatment options in northern Colorado's urban and wildland interface areas. For Policy Econ 9(6):694–703

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier Spring increases western U.S. forest wildfire activity. Science 313(5789):940–943

Zhang Y, Zhang D, 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