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Accommodating non-market values in evaluation of wildfire management in the United States: challenges and opportunities

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Abstract. Forests in the United States generate many non-market benefits for society that can be enhanced and diminished by wildfire and wildfire management. The Federal Wildland Fire Management Policy (1995, updated 2001), and subsequent Guidance to the Implementation of that policy provided in 2009, require fire management priorities be set on the basis of values to be protected (including natural and cultural resources), costs of protection, and natural resource management objectives (including beneficial fire effects). Implementation of this policy is challenging because those charged with executing the policy have limited information about the value that society places on non-market goods and services at risk. This paper reviews the challenges of accommodating non-market values affected by wildfire in social cost–benefit analysis and proposes an economic research agendum to support more efficient management of wildfire in the United States.

Additional keywords: bushfire, wildfire economics, wildfire policy.

Introduction

According to Calkin *et al*. (2005), the late 1980s marked the commencement of an era of large wildfires in the western United States that have threatened lives, destroyed homes and stretched suppression resources thin. Annual suppression expenditures by the USDA Forest Service (cited henceforth as Forest Service) have increased in recent years and exceeded US$1 billion in the fire seasons of 2000, 2002, 2003, 2006, 2007, 2008 and 2009 (USDA Forest Service, Rocky Mountain Research Station, national wildfire suppression expenditure unpubl. data, 2009). Several factors have contributed to the high level of suppression expenditures, including: fuel accumulation due to past successful fire suppression activities; a more complex firefighting environment due to private development in the wildland–urban interface (WUI); climate change; limited economic accountability among fire managers; and a fire management incentive system that makes fire managers more risk-averse than may be socially optimal (National Academy of Public Administration 2002; USDA Forest Service *et al*. 2003; Calkin *et al*. 2005; Maguire and Albright 2005; Running 2006; Westerling *et al*. 2006). The United States Federal Government is concerned that fire suppression resources are not being employed in an economically efficient manner and the Forest Service is under substantial pressure to reduce fire suppression expenditures (USDA OIG 2006).

Wildfire differs from other large natural disturbances on a landscape in that managers can plan for and manage wildfire events to a greater degree than is possible with other events, such as earthquakes, floods and hurricanes. Therefore, knowledge about social values of resources at risk is helpful for setting protection priorities. Economists and other analysts have developed price-based[A] wildfire management decision-support tools that aid the allocation of wildfire suppression resources to minimise the sum of short-term direct pecuniary costs of wildfire management, as well as damage to private property, public infrastructure, timber and some non-market goods and services. However, US federal wildfire policy recognises ecosystem health benefits of fire and that 'economically viable' wildfire management must be based on the values to be protected, including natural and cultural resources, costs of protection and natural resource management objectives (USDI *et al*. 2001, p. 22). In 2009, the Fire Executive Council published guidance on the implementation of the policy emphasising that 'Wildland fire will be used to protect, maintain, and enhance resources and, as nearly as possible, be allowed to function in its natural ecological role' (FEC 2009, p. 11). To support federal land management agency implementation of contemporary federal wildfire management policy, price-based decision-support tools must better accommodate non-market benefits and costs of wildfire, including the effects of fire on air quality, wildlife habitat and recreation opportunities.

Wildfire risk assessment models based on a quantitative wildfire risk framework described by Finney (2005) are

[A]In a price-based approach, market or shadow prices are derived for all project outputs and inputs under consideration. Cost–benefit analysis is the classic example of a price-based approach.

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emerging (e.g. Ager *et al*. 2007; Calkin *et al*. 2010). These models have two common elements: estimating the probability and intensity of wildfire through landscape-scale fire simulation modelling, and spatial identification of resources that may experience value change due to wildfire. However, to guide economically efficient wildfire-management decisions, these models need estimates of the values of affected non-market resources. This paper reviews the challenges of valuing non-market goods and services enhanced or diminished by wildfire, and proposes an economic research agendum to support more efficient management of wildfire in the United States. The challenges are not unique to the wildfire context, but the authors discuss these challenges with wildfire examples with the purpose of highlighting for non-economists in the wildfire-management community why accommodating non-market goods and services in wildfire management decision-support tools is demanding, but necessary for a complete analysis.

The paper proceeds with a review of contemporary federal wildfire policy, and the application of economics to support wildfire management. Consideration is then given to the complex responses of forest resources to wildfire and empirical studies that have estimated social welfare change[B] arising from wildfire effects on non-market forest goods and services. Next, factors likely to contribute to the failure of efforts to accommodate welfare change from wildfire in price-based decision-support tools are discussed. The choice modelling non-market valuation technique is then highlighted as having potential to overcome several of the challenges associated with valuing wildfire-related welfare change. A research agendum that employs multicriteria decision analysis as an interim approach to wildfire decision-support, but that has a longer-term aim of accommodating societal preferences through non-market valuation, is proposed.

Wildfire policy and economics in the United States

With few exceptions, aggressive fire suppression has dominated Forest Service wildfire policy and practices (Stephens and Ruth 2005). The dramatic changes in fire regimes, ecosystem health, ecological patterns and processes, and species distribution and abundance that have resulted from 100 years of fire suppression in the western United States are well documented (USDA and USDI 2000; Keane *et al*. 2002; Hessburg and Agee 2003). Federal wildfire policy has been substantially modified since 1995 to recognise the beneficial role of fire as an important ecological process and acknowledge 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 (USDI *et al*. 2001, 2005). Wildfire and fuel management policies reported in the National Fire Plan (USDI and USDA 2000), the Western Governors' Association (2001) *10-Year Comprehensive Strategy* and the Healthy Forests Initiative (USDA *et al*. 2002) have shifted federal wildfire strategy 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. Nevertheless, effective implementation of these policies has been limited (Dale 2006; Steelman and Burke 2007).

In February 2009, the Fire Executive Council issued the Guidance for Implementation of Federal Wildland Fire Management Policy (FEC 2009). Prior to the issuance of this guidance, management of fire suppression events was not to include consideration of beneficial effects of wildland fire (Wildland Fire Leadership Council 2003). However, this reinterpretation highlighted the fact that 'current policy clearly states that wildland fire analysis will carefully consider the long-term benefits in relation to risks both in the short and long term' (p. 6), and provided the following guidance: 'A wildland fire may be concurrently managed for one or more objectives and objectives can change as the fire spreads across the landscape' (p. 7). This reinterpretation, along with the development and adoption of the Wildland Fire Decision Support System as the recommended decision-support documentation tool (USDI *et al*. 2008), replacing both the Wildland Fire Situation Analysis and the Wildland Fire Implementation Plan, effectively eliminated the administrative distinction between wildland fire use and fire suppression. To support this reinterpretation, fire managers need information on areas where resource value change due to fire suggests aggressive suppression and where beneficial fire effects or excessive suppression costs, relative to potential value loss, would suggest 'let burn' strategies.

Although wildfire policy has been modified over time, the least cost plus loss (LCPL) economic theory applied to support wildfire management decision-making for public land in the United States has changed little since the model was first illustrated by Sparhawk (1925).[C] It is a price-based framework that can be used by fire managers to assist development of management strategies that minimise the total cost of fire prevention, presuppression and suppression activities, and net resource value change (positive and negative changes to market and non-market goods and services) due to wildfire. Past and present wildfire management and planning tools used by the Forest Service, including the National Fire Management Analysis System (NFMAS) and Escaped Fire Simulation Analysis (EFSA), utilise the LCPL framework (Donovan and Rideout 2003; Schuster and Krebs 2004). The LCPL 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, 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 few estimates of non-market benefits and costs of wildfire are available.

[B]In this paper, the term welfare change refers to changes in society's well-being, as estimated by changes in standard consumer and producer surplus measures.

[C]Mills and Bratten (1982) modified the model to accommodate beneficial effects of fire. Donovan and Rideout (2003) identified some inherent flaws in the LCPL model and proposed a corrected LCPL framework. In recognition of the fact that wildfires generate an array of positive and negative physical effects, the contemporary form of the LCPL model is sometimes referred to as cost plus net value change (C+NVC), where the fire-damage schedule is replaced with a net value change schedule.

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 1995/2001 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 within the Department of Interior 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 2006). The basis for economic evaluation within initial runs of 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 socioeconomic and environmental attributes from wildfire (Rideout and Ziesler 2005). In effect, EOWEP is a price-based approach with expert judgment rather than economic analysis being used to derive relative prices. This approach was further described in Rideout *et al*. (2008) for a small planning area in the Southern Sierra Mountains of California. Extension to larger scales to facilitate inter-unit planning requires the identification of a 'numeraire' attribute (e.g. WUI or old-growth), the value of which is consistent across all planning units. Whether such an attribute exists is debatable.[D]

In 2006, reviews of the initial FPA model specification and test applications were published by an Interagency Science Team and a Management Team (Management Review Team 2006; Scientific Review Team 2006), resulting in a major redirection of the FPA program and a reformulation of the base FPA model. In the reformulated FPA model, the effectiveness of fire management strategies for meeting fire and land management goals 'will be assessed by these five performance metrics:

1. reducing the probability of occurrence of costly fires;
2. reducing the probability of occurrence of costly fires within the Wildland Urban Interface;
3. increasing the proportion of land meeting or trending towards the attainment of fire and fuel management objectives;
4. protecting highly valued resource areas from unwanted fire; and
5. maintaining a high initial attack success rate' (FPA 2008, p. 1).

However, the specific evaluation strategy for performance measure (4), the metric that most closely accounts for changes in non-market goods and services due to wildfire, had not been identified at the time of submission of this article.

Wildfire effects on non-market forest goods and services

Wildfires affect many non-market forest goods and services that are important to society, including air quality, soil productivity, water quality and quantity, habitat for native fauna and flora, recreation opportunities, cultural heritage, and carbon sequestration and storage. Table 1 summarises the positive and negative effects of wildfire on these seven non-market forest goods and services; a more detailed summary is provided in Venn and Calkin (2008). Although not obvious in the table, each non-market good or service exhibits a diverse range of potential responses to wildfire according to a complex set of natural environment and human management factors. Generally, in lower-elevation forests of western USA, 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 goods and services. However, this is not necessarily true for other forest types. For example, many plant and animal species in high-elevation lodgepole pine forests are adapted to and their conservation is enhanced by infrequent, high-severity wildfire regimes.

Although many studies have examined non-market values of forests in the USA and internationally, 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 effects 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 plantation forest when fires degrade timber and habitat for an endangered species. Most of the limited research on the effects of wildfire on social welfare has been conducted in North America, where the focus has been on recreation values, amenity values of the WUI capitalised in private property, and the willingness of households to pay for fuel reduction programs that reduce the risk of damage to homes and natural amenities.

Early studies on the effect of wildfire on recreation values in North America found that large fires have negative effects on recreation values (Vaux *et al*. 1984; Flowers *et al*. 1985; Boxall *et al*. 1996; Englin *et al*. 1996), but provided only limited insight into the temporal effects of fire on these values. This was an important limitation in the context of evaluating wildfire management, because ecosystems recover from wildfire and, presumably, so do recreation values. More recent studies have combined the travel cost and contingent valuation (CV) methods to estimate how recreation values change over time in response to wildfire. 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 burnt landscape, and wildflower and wildlife viewing. Annual hiker surplus was then estimated to slowly decrease until ~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

[D]Rideout *et al.* (2008) suggested a 'particular definition of WUI' as a possible numeraire for wildfire planning across forest planning units. Successful use of their measure requires that the value of that particular WUI is relatively consistent across planning areas (although, in practice, what constitutes the WUI can be highly variable between planning areas) and managers have sufficient ability to quantify other resources at risk (e.g. municipal watershed and endangered species habitat) relative to the WUI numeraire.

Table 1. Positive and negative effects of wildfire on non-market forest goods and services

Non-market forest good or service	Positive fire effects	Negative fire effects
Air quality		Human respiratory health Reduced visibility at scenic vistas and on roadways Soiling surfaces of objects
Soil productivity	Short-term increased availability of nutrients for plant growth	Soil structure is lost (reducing soil porosity) Nutrients are volatilised or made susceptible to loss through leaching and surface runoff Can make soils hydrophobic Accelerates wind and rain erosion, and dry ravel
Water quality and quantity	Increase in water quantity	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
Recreation opportunities	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
Habitat for native flora and fauna	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 mean 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 effect on stream amphibians and fish Some exotic plant species are adapted to colonise post-fire landscapes, which can negatively affect the diversity of native flora and fauna, and modify wildfire regimes
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

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 not substantially affected by crown or prescribed fire (Hesseln *et al*. 2004).

The value of private property in the WUI in the United States 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 burnt area for only the first 6 months after the fire, after which property prices rebounded. However, Loomis (2004) found that property values in a town 2 miles (~3.2 km) from the Buffalo Creek Fire in Colorado were ~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. Stetler *et al*. (2010) found that sale prices of homes in northwest Montana and less than 5 km from areas burned by wildfire within 7 years of the home sale date were 13 to 14% lower than for homes at least 20 km from a wildfire burned area. However, this effect was statistically insignificant if the wildfire burned area was not visible from the home. Mueller *et al*. (2009) analysed the effects of forest fires that were several years apart on house prices in Los Angeles County, California. House prices fell ~9.7% after the first wildfire and 22.7% after the second wildfire, indicating that many homebuyers do not want to live in areas experiencing repeated wildfires, and homebuyers may purchase homes in high-risk areas without being fully aware of actual wildfire risk. Donovan *et al*. (2007) examined the effect of a wildfire risk education campaign on home prices in Colorado Springs and found that home prices were positively correlated with wildfire risk before the campaign, but the wildfire risk coefficient was not statistically significant after the campaign had commenced.[E] Education appeared to have increased awareness of wildfire risk, which offset the positive amenity effects on property values.

Fried *et al*. (1999) and Huggett (2003) found that WUI households in the states of Michigan and Washington 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), Kaval and Loomis (2007), Kaval *et al*. (2007) and Walker *et al*. (2007) found individual 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 through increases in annual property taxes was found to be 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.

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 1000 acres (~400 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 firefighting years. In the other study, Loomis *et al*. (2002) estimated that average deer hunter welfare increased by between US\$8.73 and US\$18.00 ha^{-1} $year^{-1}$ for the first 440 ha burned and by ~US\$1.30 ha^{-1} $year^{-1}$ for the next 1480 ha burned in the San Jacinto Ranger District (SJRD) of the San Bernardino National Forest in southern California.

Few studies have attempted to quantify the pecuniary cost of wildfire smoke on public health in the USA and none have estimated WTP to avoid wildfire smoke (Kochi *et al.* 2010). These estimates have been widely cited and employed by the US federal Environmental Protection Agency (EPA) to estimate visibility benefits associated with air quality programs (e.g. EPA 1999), but they appear to overestimate the value of visibility improvement by 50 to 100% (Smith *et al*. 2005).[F] No published studies have evaluated the welfare effects of soiling due to wildfire smoke.

Few studies have valued cultural heritage assets, and these studies have focussed on European and North American historical buildings, monuments and artefacts (Pearce *et al*. 2002). Venn and Quiggin (2007) found that, although 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. González-Cabán *et al*. (2007) is the only published study that has elicited native American WTP for wildfire management, in this case alternative fuels reduction policies that reduce area and number of houses burned annually by wildfire. These WTP estimates may include some cultural heritage conservation benefits and costs, but these values were not specifically targeted by the survey.

Neary *et al*. (2005) outlined numerous gaps in our understanding of the effects of wildfire on soil and water, and the research by Loomis *et al*. (2003) and Lynch (2004) appear to be the only economic studies that have estimated the costs of wildfire effects on soil and water in the USA. Preliminary models that can estimate direct carbon emissions from wildfires are emerging (e.g. Clinton *et al*. 2006; Page-Dumroese and Jurgensen 2006; de Groot *et al*. 2007); however, further research is necessary to estimate the spatial and temporal distribution of carbon stored in fire-adapted forests. Additionally, bioeconomic models that estimate the welfare implications of net carbon emissions arising from alternative wildfire regimes have yet to be developed.

Challenges of evaluating welfare change arising from wildfire effects on non-market forest goods and services

Valuation of ecosystem enhancement or damage in any context is a complex and controversial undertaking. The challenges are particularly prominent in valuation of large natural or anthropogenic disturbance events, including major storms and wildfire, where a large and diverse suite of values may be affected, the disturbance has positive and negative welfare effects, and there is spatial and temporal variability in responses of affected non-market goods and services to the disturbance. Estimation of welfare change arising from disturbance effects on various types, quantities and qualities of non-market goods and services requires that analysts can define the direct and indirect effects of the disturbance on the spatial and temporal provision of non-market goods and services, and how marginal changes will affect social welfare. However, there is a lack of information about both the effects of large disturbances on non-market goods and services, and the implications for social welfare, making full social cost–benefit analysis of such events extremely difficult (Boardman *et al*. 2001; Gaddis *et al*. 2007). Five major challenges to evaluating welfare change arising from large

[E] The positive correlation of house price and wildfire risk arose because some wildfire risk variables also have amenity value. For example, some home buyers prefer a densely wooded lot or a house located on a ridge. Interestingly, Donovan *et al.* (2007) found evidence of diminishing effect of the education campaign on home buyer preferences over time.

[F] 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.

disturbances to the natural environment can be identified in the context of wildfire, namely:

1. insufficient scientific information to assess how non-market forest goods and services are affected by wildfire;
2. limited amenability of many non-market forest goods and services affected by wildfire to valuation by benefit transfer;
3. a dearth of studies that have estimated marginal WTP to conserve non-market forest goods and services;
4. violation of consumer budget constraints; and
5. impediments to estimating and applying indigenous cultural heritage values.

Insufficient scientific information to assess how non-market resources are affected by wildfire

The Fire Effects Information System, developed and maintained by the US Forest Service (available at http://www.fs.fed.us/database/feis/, accessed 24 March 2011), summarises from English-language literature the effects of fire on ~100 North American animal species and 900 plant species, including many threatened and endangered (T&E) species. Examination of these descriptions reveals that, although 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 focusses 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, although the likely effects 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. 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 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.

The magnitude of fire effects on water quality and quantity is primarily driven by fire severity. Through killing a high proportion of the vegetation on a site, removing the layer of forest litter protecting soil from erosion and creating hydrophobic soil conditions, the passing of a severe wildfire can substantially increase the volume of runoff from a catchment and the amount of sediment and other debris carried into streams. 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 the level of 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 goods and services 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 soil characteristics; 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 recolonisation 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 the effects of fire on aquatic life at any particular site cannot be accurately predicted with the current level of knowledge. This statement appears to be applicable to most non-market goods and services at risk from wildfire, which presents serious impediments to predicting wildfire-related value change. However, research analysing effects of wildfire on non-market goods and services is increasing, which is improving our ability to predict potential wildfire effects (Ager *et al*. 2007; Dunham *et al*. 2007; Moody and Martin 2009).

Limited amenability of many non-market forest goods and services affected by wildfire to valuation by benefit transfer

Conducting stated and revealed preference studies to estimate how non-market forest goods and services 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 utility of these techniques (Boyle and Bergstrom 1992; Spash 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.

Heterogeneous 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 (Spash 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?

Heterogeneous 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 (Spash and Vatn 2006). The underlying cause-and-effect relationships that define the responses of ecosystems to wildfire will, in part, determine the estimated welfare effect 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 vary 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, the accuracy of findings from studies that evaluate welfare change in the context of non-fire disturbances is likely to be unacceptably low when transferred to a 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. In that 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, the relevance of these studies for economic analysis of resource conservation strategies in response to a particular disturbance event is limited (Loomis and White 1996). Total and average WTP are only likely to be appropriate for analysis when large fires burn ecosystems that provide unique services, such as critical habitat for threatened and endangered 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 good or service 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 they can spend their money on, and that they face personal budget constraints. For example, the sum of individual household WTP to preserve several T&E species of the western USA – namely the bald eagle, grizzly bear, bighorn sheep, northern spotted owl, whooping crane, grey wolf, sea otter, grey whale and steelhead trout – has been estimated at US$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.

With a few notable exceptions, including some national forest areas in southern California, any particular fire is unlikely to affect many T&E species in the western USA, but it will affect many other non-market forest goods and services that have traditionally been valued 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).[G] Consequently, Loomis and White (1996) argued that studies valuing the protection of habitats and ecosystems are likely to be much more useful for comparing ecosystem management strategies than valuing the conservation of individual species. To date, few such studies have been published.

Impediments to estimating and applying indigenous cultural heritage values

Pearce *et al*. (2002) asserted that valuation of cultural heritage is challenging, but not more challenging than valuation of an environmental good with substantial non-use values. The limited literature assessing non-use values of tangible cultural assets in a Western cultural heritage context appears to support this view (Navrud and Ready 2002). There is a growing body

[G]However, Loomis *et al*. (1994) found that reminding respondents about the availability of substitute natural resources and budget constraints did not statistically significantly affect WTP to reduce wildfire hazards to old-growth forests in Oregon.

of international literature reporting valuations of particular use value elements of indigenous cultural heritage; however, no attempt has been made at total economic valuation of indigenous cultural heritage (Venn and Quiggin 2007).

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. There is concern that utilising these techniques to value indigenous cultural heritage may not produce results that are useful for supporting resource management decisions based on estimates of aggregate social welfare, because of: (i) challenges eliciting individual valuation responses from indigenous people; (ii) challenges aggregating the responses from indigenous people; and (iii) challenges in aggregating indigenous and non-indigenous welfare. These challenges include a lack of substitutability of other goods for some types of indigenous cultural heritage, the tendency for some indigenous people to accumulate and share wealth among kin-related households, and gender, generational and other demographic effects on values that indigenous people attribute to cultural heritage. There may also be incompatibilities between the conventional approach of estimating social welfare by summing the individual 'votes' of those sampled and the indigenous group's concept of social welfare.[H]

In the United States, policy decisions based on an estimate of aggregate social welfare elicited by a non-market valuation technique are likely to be affected by the systematic difference in the distribution of income between indigenous and non-indigenous people, and the small number of indigenous people relative to the total population. Non-indigenous people are likely to place lower values on indigenous cultural heritage conservation than indigenous people, and the valuations of non-indigenous people will 'swamp' the valuations made by indigenous people. Non-market valuation studies may reveal, for example, that when important recreation areas and indigenous cultural heritage sites are threatened by wildfire, protecting the recreation areas will have the greater aggregate social welfare payoff. However, it is not clear that minimising loss of aggregate social welfare is the appropriate decision-making criterion in such a situation. The use of equity weights in socioeconomic analysis is often proposed to address these kinds of dilemmas, but these methods are commonly criticised and rarely adopted in practice (Pearce 1986; Georgiou *et al*. 1997). For these and other reasons, Venn and Quiggin (2007) concluded the application of estimates of total economic value of indigenous cultural heritage derived from contemporary non-market valuation techniques will have low utility for supporting price-based economic analyses of alternative resource management policies.

A call to wildfire economics research

In light of the challenges associated with accommodating non-market forest goods and services at risk from wildfire within a social cost–benefit analysis framework, it is perhaps not surprising that wildfire management decision-support tools have been unsatisfactory in the modern wildfire policy environment. With the substantial reduction of the Forest Service timber harvest program, wildfire and fuels management may now be the single largest anthropogenic disturbance to the ecological condition of public lands. Natural scientists need to address the substantial gaps in our understanding about how wildfire and the management of wildfire can affect the spatial and temporal distribution of non-market goods and services, because economists' estimates of wildfire effects on social welfare are likely to be biased without this information. In the meantime, however, if the Federal government is serious about improving the economic efficiency of wildfire management, where should economic research be focussed?

Federal wildfire policy has declared firefighter and public safety as the highest priority wildfire management objective (USDI *et al*. 2001). If allocative efficiency is of concern with regards to protection of human life from wildfire, several estimates of the statistical value of a human life in the United States are available and relatively well accepted (Boardman *et al*. 2001). However, it is unlikely to be politically feasible to explain to the public that the deaths of particular persons in a wildfire event should be tolerated because the costs to save them exceeded the value of their lives to society. Therefore, there is little to be gained by economists valuing human life at risk from wildfire. Likewise, some other resources, including important historical or cultural sites that could be destroyed by wildfire, should perhaps always receive high wildfire protection priority, and economic valuation may not be necessary owing to their recognised importance and irreplaceability. Such highly valued resources should perhaps be focus areas for fuel treatments and presuppression efforts. For all other resources at risk, improvements in understanding the willingness of society to make tradeoffs between these resources will support more economically efficient resource allocation during wildfire events and in preseason wildfire management planning, as well as better facilitate ex-post evaluation of wildfire management.

Change in total economic value (i.e. total use and non-use values) of many ecosystem services generated by forests affected by wildfires cannot be estimated by popular revealed preference non-market valuation techniques such as the hedonic price and travel cost methods. Therefore, to improve understanding about the willingness of society to make tradeoffs between resources at risk from wildfire, economists will need to apply stated preference non-market valuation techniques. The obvious approach to stated non-market valuation of project outputs is to ask direct questions of the form, 'How much would you be willing to pay for additional units of output x?' as in early applications of the CV technique. However, there is considerable controversy over whether CV can adequately measure WTP (Sagoff 1988; Diamond and Hausman 1994; Carson *et al*. 2001; Nunes and van den Bergh 2001; Chee 2004).

The stated preference non-market valuation technique known as choice modelling (CM) or choice experiments arose in part because of the many concerns with CV, and can address many of the non-market valuation challenges highlighted above more successfully than CV. CM utilises the theory of consumer behaviour described by Lancaster (1966), which states that

[H]In many indigenous cultures, decisions are still driven by elders, not votes of individual members.

consumers do not value a good directly, but rather they value the individual characteristics or attributes associated with that good. CM is described thoroughly by Bennett and Blamey (2001), but essentially the method asks individuals to compare natural resource management strategies and then select their preferred strategy. Alternative strategies are defined in terms of expected outcomes for several (usually four to six) important socioeconomic and environmental attributes, one of which is the monetary cost of the strategy to the respondent. Each attribute is assigned several possible levels of achievement. Using experimental design techniques, attribute levels are varied to create a series of potential management strategies that offer different levels of achievement for the attributes. Respondents are presented with 'choice sets' containing between two and four potential management strategies, and are asked to select the strategy that they most prefer in each choice set. The tradeoffs between attributes that are implied by the choices respondents make facilitate estimation of WTP for the attributes in question.

CM is likely to provide more useful information to support wildfire management than say CV, because it decomposes the total welfare effects of a change in socioeconomic and environmental conditions into marginal values associated with changes in the levels of individual socioeconomic or environmental attributes (Bennett and Blamey 2001). For this reason, CM studies are likely to be better suited to benefit transfer than CV (Morrison *et al*. 2002). Relative to CV, CM also reduces the potential for consumers to violate their budget constraint by requiring respondents to make tradeoffs between several socioeconomic and environmental attributes, thus increasing respondent awareness of substitute and complementary goods they can spend their money on.

CM is not a 'magic bullet' for addressing the challenges of accommodating non-market values in wildfire decision-support tools. The method cannot close the substantial gaps in scientific understanding of wildfire and its management. The technique has several limitations, including the cognitive burden faced by respondents and the difficulty to establish an appropriate frame for the survey (Bennett and Blamey 2001). Nevertheless, economists have speculated that the method may be less prone to these biases than CV (Bennett and Blamey 2001; Holmes and Adamowicz 2003; Grafton *et al*. 2004).

Nationally, more efficient wildfire management could be supported by the implementation of several CM studies performed in strategic locations throughout the nation to capture the heterogeneous wildfire preferences of American society, heterogeneous resources at risk and heterogeneous responses of ecosystems to wildfire. The resulting estimates of society's willingness to trade off alternative resources threatened by wildfire could then be integrated into wildfire management decision-support tools to guide more economically efficient management decisions. On the basis of anecdotal evidence about differences in social and cultural values of residents, and scientific information about the ecosystems and other resources at risk from wildfire, a minimum investment of several large regionally based CM studies to estimate social wildfire management preferences in the United States may be required. As part of this research effort, the consistency of preferences among a population drawn from large diverse geographic areas would need to be evaluated against smaller regional studies where the demographics of the sampled population and associated landscape are less diverse.

A comprehensive non-market valuation exercise will require several years of surveying and analysis. In the shorter term, multicriteria decision analysis (MCDA) techniques are likely to be useful to support efficient wildfire management decision-making. MCDA methods are decision-support systems that can accommodate several non-commensurate objectives (i.e. all benefits and costs do not have to be expressed in a single unit of measure, such as dollars), and therefore several sources of judgment about a problem. However, the relative importance of different objectives in MCDA approaches is typically determined by expert opinion rather than economic analysis (i.e. social preferences). A large number of MCDA methods have been developed, including the Analytic Hierarchy Process (AHP, Saaty 1980), the technique for order preference by similarity to ideal solution (TOPSIS, Hwang and Yoon 1981), goal programming (Ignizio and Cavalier 1994), the elimination and choice corresponding to reality method (ELECTRE, Carbone *et al*. 2000), and simulation (Dayananda *et al*. 2002). Through providing a rational and structured approach to decision-support, MCDA techniques can: handle the inherent complexities and abstractness of natural resource management problems that human experts cannot (at reasonable cost); make scientific uncertainty, data gaps and assumptions explicit; accommodate expert opinion and multiple stakeholder perspectives; and improve communication between opposing stakeholder groups, and between managers and the general public (Dykstra 1984; Carbone *et al*. 2000; Mendoza and Martins 2006; Hessburg *et al*. 2007).

MCDA techniques have been extensively applied to support natural resource management, including forest management (Arp and Lavigne 1982; Turner *et al*. 2002; Ananda and Herath 2003; Vanclay *et al*. 2003; Jeffreys 2004), and applications to support wildfire management are emerging. Ohlson *et al*. (2006) discussed the application of multi-attribute trade-off analysis (MATA) to provide a clear and explicit depiction of the tradeoffs associated with alternative fuel management activities designed to reduce wildfire risk on a landscape scale. This is necessary information to support efficient fuel management decisions, but the paper did not describe a method to evaluate the management options and make the tradeoffs. Hessburg *et al*. (2007) developed a model to evaluate wildfire danger and prioritise fuel treatments on the basis of expert opinion with regards to the relative importance of four first-level criteria (fire hazard, wildfire behaviour, ignition risk and percentage of the subwatershed classified as WUI), and several second-level criteria. Weights for each first- and second-level criterion were determined using the AHP and the simple multi-attribute rating technique (SMART), which facilitated tradeoffs between alternative management actions. Rideout *et al*. (2008) presented an expert-based, consensus-driven method to estimate implicit prices for attributes at risk from wildfire, such as the WUI, *Sequoia* groves and commercial timber stands, to guide efficient resource allocation decisions for initial attack planning and budgeting. Vadrevu *et al*. (2009) paired fuzzy logic with the AHP to map forest fire risk. These maps can be used for strategic and tactical fire management planning at broad and local scales respectively.

Wildfire management agencies in the United States could develop and adopt MCDA tools as an interim approach to support more efficient management of wildfires. However, as large areas at risk of wildfire are on public land, and manager and expert preferences may not adequately represent society's preferences, there is ultimately a need to account for societal preferences in wildfire management. If both MCDA and CM methods are concurrently promoted, divergence of priorities between managerial and social preferences may be identified and decision-support models adjusted with this information.

Concluding comments

Society values many non-market goods and services provided by forests that are affected (positively and 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. In this new policy environment, models to support development of economically efficient wildfire management strategies, and ex-post evaluation of wildfire management activities require estimates of the social benefits and costs of wildfire events by accounting for changes in the total economic value (use and non-use value) of goods and services at risk from wildfire. Given the current state of knowledge about fire effects on non-market forest values and social welfare, this is not possible. In the short term, the efficiency of wildfire management may be improved by application of MCDA techniques. However, in the longer term, an economic research program that conducts CM studies in strategic locations throughout the nation could greatly improve the allocative efficiency of wildfire management in the United States.

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