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Objective and perceived wildfire risk and its influence on private forest landowners' fuel reduction activities in Oregon's (USA) ponderosa pine ecoregion

A. Paige Fischer[A,F], *Jeffrey D. Kline*[B], *Alan A. Ager*[C], *Susan Charnley*[D] *and Keith A. Olsen*[E]

[A]USDA Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center, 3200 SW Jefferson Way, Corvallis, OR 97331, USA.
[B]USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, USA.
[C]USDA Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center, 72510 Coyote Road, Pendleton, OR 97801, USA.
[D]USDA Forest Service, Pacific Northwest Research Station, 620 SW Main Street, Suite 400, Portland, OR 97205, USA.
[E]Department of Forest Ecosystems and Society, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331, USA.
[F]Corresponding author. Email: paigefischer@fs.fed.us

Abstract. Policymakers seek ways to encourage fuel reduction among private forest landowners to augment similar efforts on federal and state lands. Motivating landowners to contribute to landscape-level wildfire protection requires an understanding of factors that underlie landowner behaviour regarding wildfire. We developed a conceptual framework describing landowners' propensity to conduct fuel reduction as a function of objective and subjective factors relating to wildfire risk. We tested our conceptual framework using probit analysis of empirical data from a survey of non-industrial private forest landowners in the ponderosa pine (*Pinus ponderosa*) region of eastern Oregon (USA). Our empirical results confirm the conceptual framework and suggest that landowners' perceptions of wildfire risk and propensity to conduct fuel treatments are correlated with hazardous fuel conditions on or near their parcels, whether they have housing or timber assets at risk, and their past experience with wildfire, financial capacity for conducting treatments and membership in forestry and fire protection organisations. Our results suggest that policies that increase awareness of hazardous fuel conditions on their property and potential for losses in residential and timber assets, and that enhance social networks through which awareness and risk perception are formed, could help to encourage fuel reduction among private forest landowners.

Additional keywords: fuel treatments, landscape models, non-industrial private forest landowners, wildfire risk, wildland–urban interface.

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Introduction

Despite significant federal and state expenditures and infrastructure dedicated to fire suppression, the area burned by wildfire annually in the USA has increased dramatically in recent years (National Interagency Fire Center 2012). Increases in fire size and severity are largely due to higher fuel loads, especially in the western US (USDA Forest Service 2009). The growing wildfire problem has policymakers and land managers searching for ways to reduce wildfire risk across fire-prone landscapes. Conceivably, managing wildfire would be more effective if federal and state efforts were augmented by fuel management activities conducted by private forest landowners. A total of 56% of forest land in the US is owned by individuals and families (Butler 2008). This land is often located at the interface of federal wildlands and populated areas (i.e. the wildland–urban interface) (Stein *et al.* 2007), making it both vulnerable to natural and human-induced wildfires and critical to mitigating wildfire threat, especially in the US West (Stein *et al.* 2009, 2013). Because private forest lands influence the connectivity of hazardous fuel and potential movement of fire across the landscape (Ager *et al.* 2012*b*), these lands offer significant potential for reducing wildfire risk if managed appropriately.

A persistent policy question is how to best induce greater fuel reduction among private forest landowners. Motivating private forest landowners to contribute to landscape-level wildfire

protection requires understanding the factors that underlie landowner behaviour regarding wildfire. Theories about why people take actions to avert risk reflect both objectivist and constructivist perspectives. Objectivist theory assumes that accurate knowledge of the probability of an undesirable event and the magnitude of its consequence will compel people to take protective actions if they have sufficient skill and capacity (Plough and Krimsky 1990). Some wildfire policy already relies on objectivist rationales. For example, federal and state agencies attempt to increase awareness of and capacity to address wildfire risk by making technical and financial assistance available to landowners and communities at the wildland–urban interface through initiatives such as the National Fire Plan's Community Assistance Grant Program, and the USDA's Forest Stewardship Program and Environmental Quality Incentive Program (Steelman *et al.* 2004).

Constructivist theory assumes that people respond to cognitive constructs, such that accurate knowledge about the probability of an event and the severity of its consequences alone do not explain human responses to environmental risks (Slovic 1987; Tierney 1993). Rather, risk perceptions are also formed as a result of people's past experiences (Hertwig *et al.* 2004), cognitive biases that inflate or deflate perceived risks (Maddux and Rogers 1983; Sims and Baumann 1983; Slovic 1987), as well as through social interactions with friends, peers, professionals and media that reinforce and shape norms, world views and ideologies (Berger and Luckmann 1967; Douglas and Wildavsky 1982; Tierney 1999). Constructivist theory suggests that policies can influence behaviour by appealing to the concerns and motivations of individuals and groups (Slovic 1987; Tierney 1993). Current wildfire policies that rely on constructivist theory attempt to shape or build upon social beliefs and norms about wildfire risk and mitigation, and harness the role of social networks rather than individuals to influence social interaction. For example, the *Healthy Forest Restoration Act* 2003 requirement that communities receiving fuel reduction funds develop a Community Wildfire Protection Plan prompts a planning process that convenes residents, property owners and local, state and federal agencies to develop their own strategies for addressing hazardous fuel in the wildland–urban interface (Steelman and Burke 2007; Everett and Fuller 2011).

Weighing the relevance of objectivist and constructivist rationales to wildfire policy depends on developing greater understanding about the factors that influence landowners' perceptions of wildfire risk and propensity to take protective actions. However, empirical evidence about the factors that influence the risk perceptions and fuel reduction activities of private forest landowners is limited. Most studies of wildfire risk reduction activities among private landowners have focussed on residential homeowners using qualitative case studies. Only a handful of papers have used quantitative methods to address factors that influence fuel reduction activities of private forest landowners (Jarrett *et al.* 2009; Fischer 2011; Fischer and Charnley 2012; Wyman *et al.* 2012) and none that we are aware of have addressed objective factors.

We build on these studies by developing a conceptual framework for examining the dual roles of objective and subjective factors in landowners' perceptions of wildfire risk and propensity to conduct management activities that reduce their exposure. We test the framework using probit analysis of data from a survey of private forest landowners in the ponderosa pine (*Pinus ponderosa* Dougl. ex C. Lawson) ecoregion of eastern Oregon (USA). Our results have implications for identifying potential policies with which to encourage landowners to take actions to reduce their exposure to wildfire hazard in fire-prone landscapes in the USA.

A behavioural model of wildfire concern and fuel treatment propensity

Natural hazards research literature offers several plausible conceptual frameworks for investigating the process by which people act to mitigate risk. Most of these frameworks rely on constructivist approaches. For example, 'protection motivation theory' explains peoples' actions to mitigate threatening events as a function of their subjective appraisals of: (1) the probability and severity of an event and its consequences (e.g. expected loss); (2) their ability to take protective actions and (3) the likely effectiveness of action (Rogers 1983). 'Personal relative to event theory' adds to protection motivation theory a fourth element: perceived responsibility for protection (Mulilis and Duval 1997). The 'social cognitive preparation model' builds on these factors by suggesting additionally that people's intentions to take protective action are influenced by the timing and predictability of a potential event, their awareness of and anxiety about the potential hazard, their sentimental feelings of attachment to a vulnerable community or place, their normative beliefs and whether they act on their intentions (Paton 2003).

Objective information about risk is notably absent from these frameworks. However, an alternative 'protective action decision model' does include both objectivist and constructivist elements (Lindell and Perry 1992; Lindell and Perry 2012). This model assumes that information transmitted within a social context (i.e. through social networks) and environmental cues (observations of environmental conditions) combine with cognitive processes to compel people to ask questions about their situation, including: whether there are real threats; whether protective action is necessary; how protective action can be taken; and what additional information is needed and from whom? This argues for a potential role for objective factors relating to risk alongside subjective factors.

Quantitative research on wildfire risk mitigation among private property owners has corroborated the influence of some of the factors hypothesised in these conceptual frameworks. Risk perception is often correlated with mitigation behaviour among both homeowners (McCaffrey 2002; Nelson *et al.* 2004; Martin *et al.* 2009) and private forest landowners (Jarrett *et al.* 2009; Fischer 2011; Fischer and Charnley 2012), but not always (Nelson *et al.* 2005; Hall and Slothower 2009). Direct experience with fire conceivably might leave individuals more aware of wildfire risk, but evidence of its influence on mitigation behaviour is mixed, with some studies suggesting little influence (Hall and Slothower 2009; Martin *et al.* 2009; Schulte and Miller 2010; Wyman *et al.* 2012) and others suggesting some influence (Jarrett *et al.* 2009; Fischer and Charnley 2012). Perceptions of mitigation effectiveness and perceptions of one's own ability to conduct mitigation activities have also been correlated with fuel reduction among homeowners (Nelson *et al.* 2004;

Martin *et al.* 2007; Hall and Slothower 2009; Martin *et al.* 2009; McFarlane *et al.* 2011).

Additionally, social communication, including receiving information from agencies or groups and interacting with neighbours, has been positively associated with mitigation (Schulte and Miller 2010), but not always (McGee 2005; McCaffrey *et al.* 2011). Socioeconomic and demographic characteristics have been associated with mitigation behaviour among homeowners in some cases, including residential status and length of tenure (Bright and Burtz 2006; Collins 2008; Jarrett *et al.* 2009; Fischer 2011), but not all (Schulte and Miller 2010; Wyman *et al.* 2012). Findings about the influence of income, age and sex have also been mixed (Collins 2008; Martin *et al.* 2009; Wyman *et al.* 2012).

Interestingly, the relative influence of objective *v*. perceived risk has not been addressed in previous studies of landowners and wildfire risk, nor in studies of risk perception and mitigation more generally (Lindell and Hwang 2008). Although research literature suggests that people are not motivated by objective facts about risk alone, an exclusively constructivist focus would underestimate the degree to which some landowners understand their immediate environment. Two important questions for policymakers seeking to influence private forest landowners towards greater mitigation of wildfire risk are: (i) to what degree do landowners act to mitigate the risk of wildfire based on their perceptions of risk and (ii) what role does actual wildfire risk play in landowners' decisions relative to other factors?

Our conceptual framework describes landowners' likelihood to take actions to mitigate wildfire risk as a function of their:

(1) perceived wildfire risk – the subjective appraisal of the probability and severity of an event and its consequences;
(2) capacity – their physical, technical and financial ability to take protective action, and perceptions of the likely effectiveness of taking action and
(3) perception of who is responsible for taking mitigation action (e.g. the landowner *v*. a local, state or federal agency).

Our conceptual framework describes landowners' perceived wildfire risk as a function of:

(1) hazardous fuel conditions on or near their parcels;
(2) the assets that landowners stand to lose in the event of wildfire;
(3) their past experiences with wildfire and
(4) the social context (i.e. social networks through which information is communicated) in which landowners' beliefs, attitudes and norms about wildfire are formed and diffused (Fig. 1).

Our conceptual framework incorporates key elements of objectivist and constructivist theory to allow empirical testing of the combined influence of conceptually relevant factors in landowners' perceptions about wildfire risk and their likelihood to take protective action.

Methods

Study area

Our study area was the ponderosa pine ecoregion east of the Cascade Range in Oregon, USA. The area includes several small cities and large expanses of forest inhabited by species of federal and state policy interest, including the Northern spotted owl (*Strix occidentalis caurina*) and mule deer (*Odocoileus hemionus*). Two-thirds of the land area is publically owned, one-sixth is held by tribes and private industrial companies, and the remaining one-sixth is owned by non-industrial private landowners (i.e. individuals, families and trusts). Frequent low-severity fires were historically characteristic in lower elevation ponderosa pine forests. Almost a century of fire suppression, commercial logging and livestock grazing has led to an accumulation of flammable forest fuel that acts as a hazard, contributing to uncharacteristic wildfire risk in ponderosa pine forests (Hessburg *et al.* 2005; USDA Forest Service 2009).

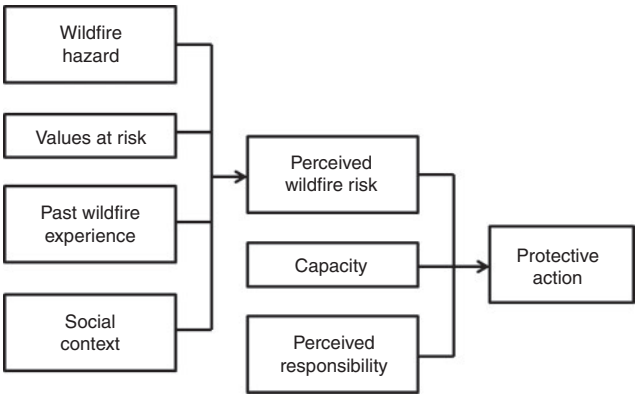

Fig. 1. Conceptual model describing landowners' perceived risk about wildfire and their propensity to take protective action to reduce risk.

Survey of forest landowners

Data describing private forest landowners' perceptions about wildfire risk and their management activities to mitigate it were obtained from a mail survey of non-industrial private forest landowners in eastern Oregon's ponderosa pine ecoregion. The survey sample was selected by casting random points across a geographic information system (GIS) map of historical and potential ponderosa pine forests (Ohmann and Gregory 2002; Youngblood *et al.* 2004; Grossmann *et al.* 2008) combined with a map of land ownerships (Fig. 2). Non-industrial private forest land polygons comprised 1.2×10^6 ha, including ~50% of all such land and 15% of all forest land east of the Cascade Range in Oregon, consistent with figures reported elsewhere for eastern Oregon (Oregon Department of Forestry 2006). The resulting point layer of landowners was combined with a state tax lot map obtained from the Oregon Department of Revenue to create a list of landowner names, addresses and tax lots.

The mail survey was conducted in September 2008 with funding and administration provided by Oregon Department of Forestry and Oregon State University. The goal of the survey was to help public agencies that administer assistance programs learn more about landowners' wildfire management motivations and practices. The survey questions asked respondents about their past (2003–2008) and intended future (2008–2013) fuel reduction activities, goals regarding their forest land, experiences with and knowledge about wildfire, concerns about wildfire risk in a broad sense and about specific types of hazards,

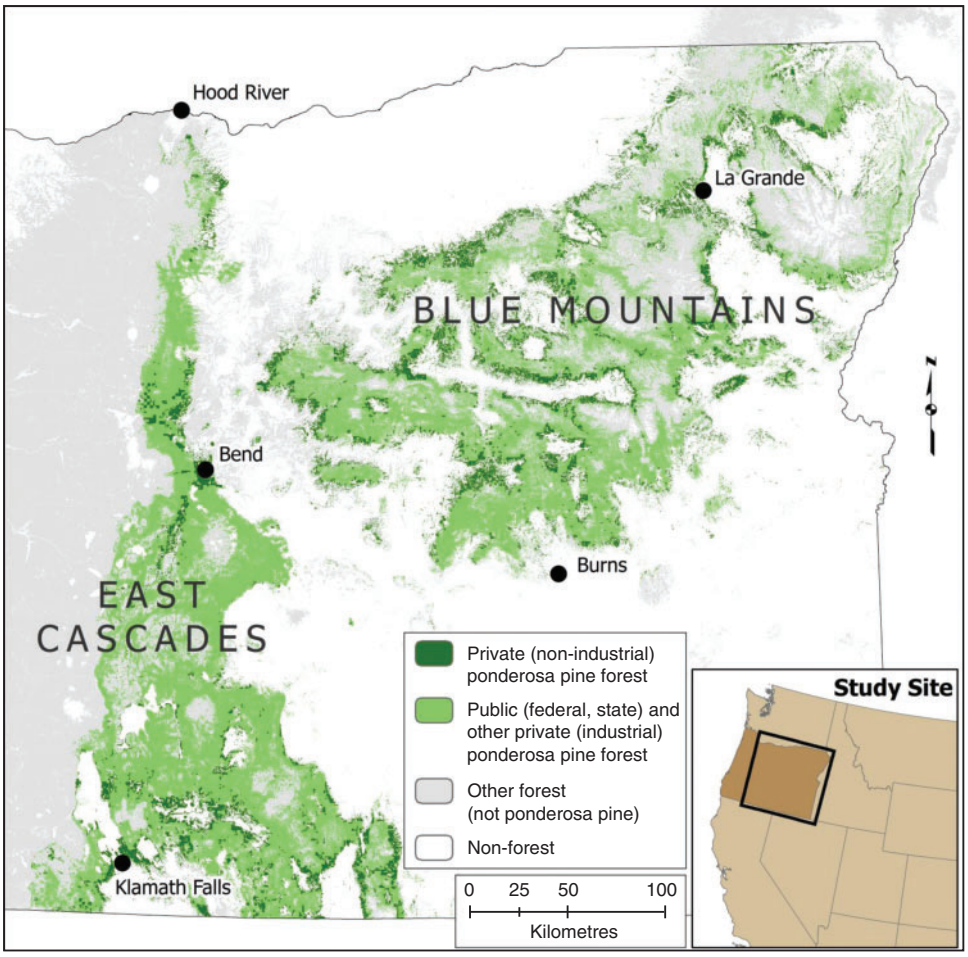

Fig. 2. Study area: Ponderosa pine ecoregion of Oregon (USA).

and demographic characteristics. When responding to the questions, survey respondents were asked to reference a specific parcel using a tax lot number printed on their survey. This enabled individual survey responses to be linked to GIS data describing landscape characteristics and objective measures relating to wildfire risk.

The survey was administered to 1244 landowners using the Total Design Method (Dillman 1978). Of the 1244 surveys mailed, 234 were disqualified because of bad addresses or respondents indicating they did not own ponderosa pine forest land, leaving 1010 valid surveys. From these, we received 505 valid responses, yielding an overall response rate of 50%. No follow-up survey of non-respondents was conducted. Of the 505 valid responses, 145 respondents did not answer all of the questions relating to variables used in the analysis for this paper and were thus eliminated, resulting in an effective response rate of 36% ($n = 360$). This was within the range needed for a 10%, and possibly 5%, margin of error depending on the exact population size (Dillman 1978), which is unknown for the ponderosa pine ecoregion.

Two survey questions of interest in this study asked respondents about their concern about wildfire and their recent fuel treatment activities. Specifically, one question asked: 'How concerned are you about a wildfire occurring on this parcel?' Survey respondents were instructed to indicate their level of concern on a five-point Likert scale: 0, not at all concerned; 1, slightly concerned; 2, moderately concerned; 3, concerned and 4, very concerned. These responses were used to develop the categorical variable – CONCERN – indicating the level of concern that individual respondents held about wildfire occurring on their forest parcel. A second question asked survey respondents, 'How many acres did you treat on this parcel to reduce the chance of wildfire?' From these responses, we developed a binary variable – TREAT FUEL – equal to 1 if respondents indicated that they had treated acreage, and equal to 0 of respondents indicated that they had not treated any acreage on their parcel. Responses to the two questions, when combined with other data describing respondents and their forest land, enable empirical testing of factors related to respondents' risk perceptions about wildfire and their propensity to take protective actions to mitigate wildfire risk.

Empirical modelling

We developed two empirical models to test the reasonableness of our conceptual behavioural model of wildfire risk perception and propensity to take protective action. The pair of recursive

Table 1. Descriptions of dependent and independent variables examined in the empirical models ($n = 360$)

Variable	Definition	Mean
CONCERN	Respondent-reported level of concern about wildfire occurring on parcel: 0 = not at all concerned; 1 = slightly concerned; 2 = moderately concerned; 3 = concerned; 4 = very concerned.	3.01
TREAT FUEL	Dummy variable equal to 1 if respondent reported that they had conducted fuel reduction activities in the past five years; 0 otherwise.	0.79
CROWN FIRE POTENTIAL	Percentage of 1-km radius from parcel centroid that has passive and active crown fire potential (Ager *et al.* 2012*a*).	37.1
PAST FIRE ON PARCEL	Dummy variable equal to 1 if respondent reported past wildfire activity on parcel; 0 otherwise.	0.44
RESIDENT ON PARCEL	Dummy variable equal to 1 if respondent reported residency on parcel; 0 otherwise.	0.28
TIMBER OBJECTIVE	Dummy variable equal to 1 if respondent reported having a timber-growing objective; 0 otherwise.	0.43
FOREST and FIRE MEMBER	Dummy variable equal to 1 if respondent reported membership in a forestry or fire protection-related organisation; 0 otherwise.	0.26
AGE	Respondent-reported age (years).	62.9
MILL DISTANCE	Travel distance (km) of parcel to nearest wood-processing mill using existing roads.	84.1
CONCERN 0	Dummy variable equal to 1 if respondent reported that they were not at all concerned about wildfire occurring on parcel; 0 otherwise.	0.04
CONCERN 1	Dummy variable equal to 1 if respondent reported that they were slightly concerned about wildfire occurring on parcel; 0 otherwise.	0.08
CONCERN 2	Dummy variable equal to 1 if respondent reported that they were moderately concerned about wildfire occurring on parcel; 0 otherwise.	0.18
CONCERN 3	Dummy variable equal to 1 if respondent reported that they were concerned about wildfire occurring on parcel; 0 otherwise.	0.26
CONCERN 4	Dummy variable equal to 1 if respondent reported that they were very concerned about wildfire occurring on parcel; 0 otherwise.	0.45

equations characterise: (1) the degree of concern that landowners hold about the possibility of wildfire occurring on their parcel (CONCERN) and (2) the likelihood that landowners conduct treatments to reduce forest fuel on their parcels (TREAT FUEL). The nature of the dependent variables in the equations necessitates two different empirical estimation approaches.

For the first equation, we assume that landowners' level of wildfire concern y^* can be described by a set of explanatory variables (x) as:

$$y* = \boldsymbol{B}'x + \varepsilon$$

where $\boldsymbol{B}$ is a vector of unstandardised estimated coefficients and ε is error. The actual level of concern y^* is unobserved. Rather, we observe each landowner's self-reported level of concern about wildfire occurring on their parcel (CONCERN) using a 5-point (0 to 4) Likert scale such that,

$$\begin{aligned}\text{CONCERN} &= 0 \text{ if } y* \le 0\\ &= 1 \text{ if } 0 < y* \le \mu_1\\ &= 2 \text{ if } \mu_1 < y* \le \mu_2\\ &= 3 \text{ if } \mu_2 < y* \le \mu_3\\ &= 4 \text{ if } \mu_3 \le y*\end{aligned}$$

where the μ_i are additional unknown parameters to be estimated (Greene 2012, p. 787). Assuming that the error term ε is normally distributed implies use of an ordered probit model.

For the second equation, the dependent variable (TREAT FUEL) consists of a binary dependent variable representing each respondent's self-reported fuel reduction activity over the previous 5 years, with 0 indicating no activity and 1 indicating activity. We similarly define the probability y^* that evidence of fuel reduction is reported by the structural model:

$$y* = \boldsymbol{B}'x + \varepsilon$$

where again x is a set of explanatory variables, $\boldsymbol{B}$ is a vector of unstandardised estimated coefficients and ε is error. Again, y^* is unobservable, but in this case our binary response variable y is defined by:

$$\text{TREAT FUEL} = 1 \text{ if } y* > 0,\ 0 \text{ otherwise.}$$

Assuming again that the error term is normally distributed implies a binomial probit model.

$$\text{P(TREAT FUEL} = 1) = \Phi(\boldsymbol{B}'x)$$

where Φ is the standard normal distribution (Greene 2012, p. 688).

Explanatory variables

We used the survey and other data to develop explanatory variables representing factors hypothesised by our conceptual framework to influence private forest landowners' concerns about wildfire and likelihood to conduct fuel treatments to reduce wildfire risk (Table 1). We lacked sufficient variation in responses to a survey question asking respondents to indicate who they felt was responsible for taking protective action

(e.g. landowners *v*. government agencies or other organisations) – most indicated 'landowners' – and so we left the perceived responsibility factor unaddressed.

To create a variable representing hazardous fuel conditions we employed wildfire simulation modelling using the fire behaviour program FlamMap (Finney 2006) and surface and canopy fuels derived from Landfire (Rollins 2009). We chose a simple metric of hazardous vegetation conditions that, if ignited under typical weather conditions during the peak fire season within the study area, would result in a fire that would cause significant losses to landowners. We assumed the hazardous fuel conditions could provide an environmental cue about the potential for wildfire, informing owners' perceptions of risk. We did not confirm respondents' awareness of the hazardous conditions through a question in the survey or through a third party; instead we assumed that if people were concerned about or took action to reduce the risk of a fire on their parcels they were also aware. Specifically, we created the variable CROWN FIRE POTENTIAL (Table 1) as the proportion of a 1-km circle surrounding each parcel centroid that could burn as either an active or passive crown fire (FlamMap codes 2 and 3) if a fire occurs (Ager *et al.* 2012*a*). Although we acknowledge the known limitations of the crown fire models (Cruz and Alexander 2010), we argue that CROWN FIRE POTENTIAL variable is useful as a broad indicator for potential of the crown (*v*. surface) fire based on surface and canopy fuel.

Whether survey respondents reported residency on their forest land (RESIDENT ON PARCEL) or a specifically timber-growing objective (TIMBER OBJECTIVE) with respect to their parcel conceivably indicates values at risk (e.g. a home site, standing timber), and would be expected to be positively correlated with their level of concern about wildfire (CONCERN). Although landowners likely have other motivations to treat their parcels to protect against fire, our preliminary statistical analysis did not identify any covariates representing values at risk aside from RESIDENT ON PARCEL and TIMBER OBJECTIVE. Moreover, we found no basis in the literature for including other values at risk on landowners' parcels. If respondents have reported a wildfire occurring on their parcel in the past (PAST FIRE ON PARCEL) this indicates that they have experienced a fire, which would be expected to be positively correlated with CONCERN. Whether respondents reported membership in any forest- or fire-protection organisations (FOREST & FIRE MEMBER) conceivably indicates a degree of social context for a given respondent's behaviour. For example, membership in forestry and fire protection organisations could indicate participation in social networks of people with greater awareness about forestry and wildfire issues and stronger social norms about how fire-prone forests and wildfire hazard should be managed. Thus, membership would be expected to be positively correlated with CONCERN.

Three of the explanatory variables included in the CONCERN equation arguably are also useful as proxy variables for describing the likelihood that survey respondents treated for fuel. A respondent's residency on their forest parcel (RESIDENT ON PARCEL) could indicate greater capacity to conduct fuel treatment activities by virtue of a respondent's physical presence on site, and would be expected to be positively correlated with the likelihood that respondents reported treating fuel on their parcels (TREAT FUEL). Holding a specifically timber objective, as well as having access to information and resources by virtue of membership in forestry or fire organisations, could also indicate respondents who are more likely to possess the capacity (e.g. knowledge, skills, equipment) necessary for conducting fuel treatments. Both TIMBER OBJECTIVE and FOREST & FIRE MEMBER thus would be expected to be positively correlated with TREAT FUEL (Table 1).

A respondent's age (AGE) could indicate their capacity (e.g. physical ability) to conduct fuel treatments, with older respondents possibly less able than younger, and would be expected to be negatively correlated with TREAT FUEL (Table 1). The travel distance to existing wood-processing mills (MILL DISTANCE) serves as a proxy for the cost of hauling harvested timber and other biomass to market. Because sale of harvested wood often subsidises fuel reduction activities, MILL DISTANCE can be viewed as an indicator of respondents' capacity for fuel treatment activities and would be expected to be negatively correlated with TREAT FUEL (shorter distance equals greater likelihood). AGE and MILL DISTANCE are admittedly imperfect measures of capacity, as capacity also depends on perception of the effectiveness of treatments for reducing fire risk. Unfortunately, we did not address self-efficacy in the survey. Moreover, financial capacity would conceivably depend on the types of products for which harvested material might be suitable, as well as specific area and unit costs of treatments. Although we tested variables that could represent factors in net financial costs (e.g. slope, aspect, site productivity), none of these other variables were found to be statistically significant.

The CONCERN variable, as a measure of perceived risk, is ordinal and so cannot be included in its dependent variable form as an independent variable in the TREAT FUEL equation. Instead, we convert the CONCERN variable to a series of five dummy variables (CONCERN0 through CONCERN4) indicating the specific level of concern about wildfire that each respondent reported (Table 1). We would expect the estimated coefficients for dummy variables indicating higher levels of concern about wildfire (e.g. CONCERN4) to be of greater magnitude than dummy variables indicating lesser levels of concern (e.g. CONCERN0).

Results

Our modelling sample included 360 survey respondents who had completed the survey questionnaire sufficiently to populate both dependent variables and all of the explanatory variables. Most (89%) respondents included in the model sample expressed moderate or greater concern about wildfire occurring on their forest parcel, consistent with what we would expect of individuals who live in a fire-prone landscape where wildfires are fairly common events. Most respondents (79%) also reported having conducted fuel reduction activities on their parcel within the past 5 years, including burning slash in piles, thinning by hand, grazing livestock, pruning and limbing trees, clearing around structures and creating fuel breaks. Initial comparisons of the CONCERN variable with both the CROWN FIRE POTENTIAL and TREAT FOR FUEL variables suggested correspondence between respondents' levels of concern about

wildfire, hazardous fuel conditions and the likelihood that landowners treated for fuel (Table 2). Specifically, higher levels of concern about wildfire (CONCERN) tended to correspond with both higher levels of CROWN FIRE POTENTIAL and higher likelihoods that respondents treated for fuel (TREAT FOR FUEL).

We estimated the equations describing survey respondents' degree of concern about wildfire (CONCERN) and likelihood that they treated for fuel (TREAT FUEL) using LIMDEP (Greene 1998). The estimated equation for CONCERN is statistically significant based on log-likelihood ratio tests ($\chi^2 = 31.98$, d.f. $= 5$, $P < 0.0001$) and the estimated coefficients for explanatory variables are statistically significant at the 90% confidence level or better. Similarly, the estimated equation for TREAT FOR FUEL is also statistically significant based on log-likelihood ratio tests ($\chi^2 = 85.50$, d.f. $= 9$, $P < 0.0001$) and the estimated coefficients for explanatory variables also are statistically significant at the 90% confidence level or better. Alternative versions of both models were estimated to test for potential heteroskedasticity and were rejected.

In the first equation (ordered probit model of CONCERN) the positive and statistically significant ($P < 0.01$) estimated coefficient for CROWN FIRE POTENTIAL indicates that respondents' self-reported level of concern about wildfire occurring on their parcel is positively correlated with hazardous fuel conditions on or near their parcel (Table 3). The positive estimated coefficient for PAST FIRE ON PARCEL indicates higher levels of concern among respondents who have had past experience with or exposure to wildfire. The positive estimated coefficients for RESIDENT ON PARCEL and TIMBER OBJECTIVE conceivably indicate higher levels of concern among respondents with real estate and financial assets at risk, including a residence and standing timber. The positive estimated coefficient for FOREST & FIRE MEMBER indicates greater concern among respondents who are members of forestry or fire-related organisations, conceivably owing to the greater awareness about forestry and wildfire issues that such membership provides.

Marginal effects computed at mean values for each of the explanatory variables indicate that the effect of a unit change in each variable on the dependent variable CONCERN varies (Table 3). Among dummy variables, PAST FIRE ON PARCEL and TIMBER OBJECTIVE seemingly have somewhat greater impacts on CONCERN than do RESIDENT ON PARCEL and FOREST & FIRE MEMBER. The comparatively smaller marginal effects computed for CROWN FIRE POTENTIAL indicates a smaller effect from this objective measure of wildfire hazard. However, because CROWN FIRE POTENTIAL is a continuous variable, its marginal effect is not directly comparable to those computed for the dummy variables. Moreover, the comparatively small marginal effect for CROWN FIRE POTENTIAL does not change the fundamental result that respondents' self-reported level of concern about wildfire occurring on their parcel is positively correlated with hazardous fuel conditions on or near their parcel.

In the second equation (binomial probit model of TREAT FUEL), the estimated coefficients for the concern variables are all positive and statistically significant ($P < 0.10$), and increase in magnitude from CONCERN1 through CONCERN4 (Table 4). This suggests that respondents possessing higher levels of concern about wildfire occurring on their parcel are more likely to conduct fuel treatments. The positive estimated coefficient for RESIDENT ON PARCEL indicates greater propensity to conduct fuel treatments among respondents whose residence is located on their parcel. Similarly, the positive estimated coefficients for TIMBER OBJECTIVE and FOREST & FIRE MEMBER indicate that respondents citing a specifically timber objective or membership in forestry or fire-related organisations were more likely to have conducted fuel

Table 2. Correspondence between CONCERN variable and CROWN FIRE POTENTIAL and TREAT FUEL variables ($n = 360$)

CONCERN	n	Mean CROWN FIRE POTENTIAL	Mean TREAT FUEL
1	13	28.56	0.308
2	27	24.55	0.593
3	65	37.07	0.708
4	93	37.83	0.806
5	162	39.54	0.876

Table 3. Estimated coefficients of the ordered probit model of CONCERN ($n = 360$)

Coefficients based on a t-test are statistically significant at *, 10%; **, 5%; ***, 1%. The μ_i are estimated threshold parameters for the dependent variable CONCERN (Greene 2012, pp. 787–788). Model statistics are: log-likelihood = −463.6; $\chi^2 = 31.98$; d.f. $= 5$; $P < 0.0001$

Explanatory variables	Estimated coefficient	t-statistic	Marginal effect given value CONCERN				
			0	1	2	3	4
Constant	1.272***	9.42	–	–	–	–	–
CROWN FIRE POTENTIAL	0.007***	2.58	−0.000	−0.001	−0.001	−0.000	0.003
PAST FIRE ON PARCEL	0.307**	2.53	−0.019	−0.033	−0.050	−0.019	0.121
RESIDENT ON PARCEL	0.248*	1.83	−0.014	−0.026	−0.041	−0.017	0.098
TIMBER OBJECTIVE	0.303**	2.39	−0.019	−0.033	−0.050	−0.018	0.119
FOREST and FIRE MEMBER	0.244*	1.68	−0.014	−0.025	–0.040	–0.017	0.097
μ_1	0.626***	7.91	–	–	–	–	–
μ_2	1.345***	19.50	–	–	–	–	–
μ_3	2.052***	26.94	–	–	–	–	–

Table 4. Estimated coefficients of the binomial probit model of TREAT FUEL ($n = 360$)

Coefficients based on a *t*-test are statistically significant at *, 10%; **, 5%; ***, 1%. The variable CONCERN 0 is omitted from model estimation to avoid perfect collinearity between the constant term and the concern variables. Model statistics are: log-likelihood = −144.1; $\chi^2 = 85.50$; d.f. = 9; $P < 0.0001$

Explanatory variables	Estimated coefficient	*t*-statistic	Marginal effect
Constant	0.806	1.22	0.252
RESIDENT ON PARCEL	1.440***	4.82	0.231
TIMBER OBJECTIVE	0.472**	2.54	0.102
FOREST and FIRE MEMBER	0.445*	1.94	0.088
AGE	−0.027***	−2.35	−0.006
MILL DISTANCE	−0.002**	−2.10	−0.000
CONCERN 1	0.863*	1.77	0.125
CONCERN 2	1.114**	2.51	0.167
CONCERN 3	1.602***	3.59	0.241
CONCERN 4	1.660***	3.79	0.347

treatments. The negative estimated coefficient for AGE indicates that older respondents were less likely to have conducted fuel treatments. The negative estimated coefficient for MILL DISTANCE suggests that respondents located in greater proximity to existing wood-using mills were more likely to conduct fuel treatments. Marginal effects computed at mean values for the explanatory variables indicate that RESIDENT ON PARCEL tends to influence TREAT FUEL to a greater magnitude than TIMBER OBJECTIVE and FOREST & FIRE MEMBER.

Our empirical results are consistent with a conceptual framework that characterises private forest landowners' propensity to conduct protective actions to reduce wildfire risk (TREAT FUEL) as a function of their perceived wildfire risk on their property and their capacity to take protective action. Our empirical results also suggest that that private forest landowners' perceived wildfire risk on their property (CONCERN) can be characterised as a function of hazardous fuel conditions, landowners' values at risk, past wildfire experience and social context. Given the strong representation in our sample of individuals who have moderate to greater concerns about wildfire, it is conceivable that our empirical results rely rather substantially on a small number of sampled individuals who have only slight or no concerns about wildfire. However, we have no reason to believe that our sample is not representative of the general population of landowners, as concerns about wildfire are prevalent throughout the study area. Moreover, our empirical results support many of the individual factors hypothesised by objectivist and constructivist theories regarding risk mitigation behaviour regarding natural hazards.

Discussion

Our empirical results suggest that landowners' perceptions of wildfire risk and propensity to conduct fuel treatments derive from factors considered important in objectivist and constructivist theory. Our results confirm that perceived wildfire risk strongly influences private forest landowners' propensity to conduct fuel reduction treatments, as well as their capacity to conduct fuel treatments. Our results confirm that landowners' wildfire risk perceptions are associated with hazardous fuel conditions on their parcels as well as the values they stand to lose in the event of a fire, their past wildfire experience and social context (i.e. social networks). Although risk perception is well recognised as an influencing factor in risk mitigation behaviour, and perhaps a better predictor of behaviour than objective knowledge (Rogers 1983), few conceptual frameworks and to our knowledge no empirical studies address the role of objective hazard awareness in wildfire risk perception and mitigation among private forest landowners. Our finding that the existence of hazardous fuel conditions on or near one's parcel has an influence on landowner risk perception and mitigation behaviour provides justification for including variables that represent environmental cues about wildfire risk (e.g. hazardous fuel conditions) in future models. Other natural hazards research has found similar positive associations between risk perception and mitigation behaviour and proximity to earthquake faults, flood, hurricane, volcanic and low-elevation coastline zones, toxic chemicals and air pollution (Farley *et al.* 1993; Elliott *et al.* 1999; Peacock *et al.* 2005; Brody *et al.* 2008; Lindell and Hwang 2008). These studies suggest that landowners, in some cases, may be aware of their exposure to natural hazards and motivated by this awareness to mitigate risk. Our finding that landowners' perception of wildfire risk is associated with hazardous fuel conditions on their parcels suggests that private forest landowners may be somewhat savvy in their wildfire risk assessments and motivated to respond to them.

The factors that derive from constructivist theory – personal experience, values at risk in the event of a fire and social context – also had significant effects on landowners' perceptions of risk. The influence of personal experience and values at risk on landowners' perceptions of risk is not surprising; these factors are well established in the literature and our results suggest that they may be among the more influential on wildfire risk perceptions, based on the magnitude and statistical significance of related explanatory variables. Landowners who have experienced fear and anxiety associated with vulnerability to wildfire, or who have important financial or personal assets vulnerable to loss, would likely be more motivated to reduce risk. Future research could extend examination of this factor by including explanatory variables representing whether landowners possess home or timber insurance coverage for wildfires, as such variables could provide additional insights.

Also notable is the finding that landowners who are members of forestry or fire protection organisations are more likely to be

concerned about wildfire risk and conduct fuel reduction treatment activities. This finding could indicate that forestry and fire protection group members share common beliefs and norms of behaviour with respect to forest management and wildfire. The finding could also owe, in part, to the possibility that such group members are more cognisant of the need to address wildfire in dry forest ponderosa pine ecosystems and have ready access to a pool of knowledge, skills and equipment necessary for conducting fuel treatments themselves. The finding supports the notion that wildfire risk perceptions are formed and shaped, in part, through social interaction and networks. Social networks (i.e. patterned interactions among people or organisations) may amplify perceptions of risk derived from objective knowledge and personal experience. Although little quantitative work has investigated the role of social networks in wildfire risk mitigation, qualitative case studies about wildfire risk mitigation in rural communities suggest that linking private property owners with social networks that include local fire-wise councils or community wildfire protection planning groups has helped to encourage fire management activities on private property (Everett and Fuller 2011). Moreover, research regarding climate change suggests that people linked to social networks that espouse high concern about a hazard are more likely to be concerned themselves about the hazard and to take mitigation action (Jaeger *et al.* 1993; Wakefield *et al.* 2006).

Lastly, our findings suggest the importance of landowners' capacity to undertake wildfire risk mitigation activities. In particular, our results suggest that residency may be one of the more influential factors on the propensity of forest landowners to conduct fuel treatment activities, based on magnitude and statistical significance. Maintaining a primary residence on a forest parcel could afford greater familiarity with fuel conditions and greater convenience for addressing fuel conditions than living off site. Possessing timber production objectives and membership in forestry and fire protection organisations may give landowners greater knowledge about forests, wildfire and the management of fire-prone forests. Such group membership also may give landowners greater access to the information and equipment necessary to carry out fuel reduction work. Proximity to mills would offer landowners potential opportunities to finance or subsidise their fuel treatment activities with the sale of the material that results from fuel reduction, such as small diameter timber or chips. Although many conceptual frameworks of risk mitigation behaviour incorporate variables representing people's perceptions of their ability to mitigate a risk (e.g. self-efficacy) (Brenkert-Smith *et al.* 2012), the combination of variables that represent capacity in our study arguably do so from more of an objective standpoint.

We suspect that the factors that contribute to landowners' wildfire risk perceptions and mitigation activities could vary by region. In the case of landowners' capacity to mitigate risk, for example, proximity to wood-processing mills seemed to be a reasonable proxy variable for representing financial capacity in our eastern Oregon study area, because such mills are still located there. In regions lacking wood-processing mills, landowners may have few, if any, marketing opportunities for harvested material. In these regions, financial capacity may be more strongly associated with household incomes or some other financial proxy. Although the conceptual framework we have outlined to describe landowners' wildfire risk perceptions and mitigation activities may be broadly useful, the specific variables used to characterise hypothesised influencing factors as well as their likely correlation with actual risk perceptions and mitigation activities are likely to be subject to regional variations.

Policy implications

Our findings provide some support for objectivist policy approaches to encouraging fuel reduction activities among private forest landowners. They suggest that landowners' wildfire risk mitigation activities are correlated with actual fuel conditions on the ground. This suggests the possibility that landowners may respond to environmental cues regarding wildfire risk such as hazardous fuel conditions on their properties. If true, policies that aim to increase landowner awareness about hazardous conditions and the potential for severe wildfire occurring on their parcels (e.g. through wildfire risk assessments) conceivably could raise their level of concern about wildfire and increase the likelihood that they will conduct risk mitigation actions. Judging the reasonableness of this interpretation and associated policy implications may require additional research focussed on the degree to which landowners perceive and react to forest and fuel conditions associated with increased levels of wildfire risk. Our findings also suggest that cost and physical ability may be factors in fuel reduction such that providing technical and financial assistance to increase landowners' capacity to conduct fuel treatments and reduce the cost may help encourage treatments by landowners.

Our findings also confirm constructivist policy rationales – specifically that landowners' risk perceptions may be formed through personal experiences with risk, sensitivity to potential losses to wildfire and participation in social networks. Symbolic campaigns that appeal to landowners' personal or financial stake in their property could contribute to increasing landowners' concerns and awareness about wildfire risk and interest in mitigation actions. For example, our finding regarding the influence of affiliation with forestry and fire protection organisations suggests that forestry and fire protection organisations and the social networks that extend from them may provide effective avenues for outreach to private forest landowners to improve adaptation to wildfire risk. Conceivably, persuasion through existing social networks in which landowners are involved or helping such networks to form, could help amplify perceptions of risk and likelihood of mitigation. Policy strategies that harness or build networks may also be especially important for increasing landowners' capacity for long-term adaptation to increasing fire risk. Social networks and the patterns and types of interaction they engender can enhance communication of information, mobilisation of resources and coordinated decision making, as well as the generation of new knowledge and strategies regarding natural hazards such wildfire and how to mitigate them (Adger 2003; Pelling and High 2005; Bodin *et al.* 2006). Although current campaigns to promote fire-adapted communities (e.g. Living with Fire, see http://www.livingwithfire.info/fire-adapted-communities; Fire Adapted Communities, see http://www.fireadapted.org/role/residents-and-homeowners.aspx, both accessed 26 July 2013) draw on notions of adaptive capacity, they largely rely on objectivist approaches of raising awareness and facilitating

access to technical and financial assistance. Policies that draw on constructivist approaches, such as the Community Wildfire Protection Plan provision of the *Healthy Forest Restoration Act*, could make capacity-building grants contingent on engaging private forest landowners along with homeowners, public land management agencies and stakeholders in local wildfire risk assessments and mitigation planning in order to build networks.

Future research could help to refine policy approaches by examining the relative influence of the variety of factors that influence landowners' perceptions of wildfire risk and their propensity to address it through management. Linking social science with wildfire science, such as we have attempted in this study, can help to inform wildfire policy generally and to set regional priorities for risk mitigation effort by identifying locations where high wildfire hazard conditions coincide with limited mitigation activity among landowners. Indeed, this later purpose is one of the objectives of the *Healthy Forest Restoration Act* mandate for developing Community Wildfire Protection Plans. Research that integrates social science with wildfire science can help to operationalise Community Wildfire Protection Plan concepts and make real reductions in the exposure of landowners, homeowners and communities to wildfire hazards.

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