CSIRO PUBLISHING

International Journal of Wildland Fire **2013**, *22*, 832–840
http://dx.doi.org/10.1071/WF12093

Living in a tinderbox: wildfire risk perceptions and mitigating behaviours

Patricia A. Champ[A,D], *Geoffrey H. Donovan*[B] *and Christopher M. Barth*[C]

[A]US Forest Service, Rocky Mountain Research Station, 240 West Prospect Avenue, Fort Collins, CO 80526, USA.
[B]US Forest Service, Portland Forestry Sciences Lab, 620 SW Main Street, Suite 400, Portland, OR 97205 USA.
[C]Bureau of Land Management, Southwest District Fire Management Program, 2465 South Townsend Avenue, Montrose, CO 81401, USA.
[D]Corresponding author. Email: pchamp@fs.fed.us

Abstract. The loss of homes to wildfires is an important issue in the USA and other countries. Yet many homeowners living in fire-prone areas do not undertake mitigating actions, such as clearing vegetation, to decrease the risk of losing their home. To better understand the complexity of wildfire risk-mitigation decisions and the role of perceived risk, we conducted a survey of homeowners in a fire-prone area of the front range of the Rocky Mountains in Colorado. We examine the relationship between perceived wildfire risk ratings and risk-mitigating behaviours in two ways. First, we model wildfire risk-mitigation behaviours as a function of perceived risk. Then, we model wildfire risk-mitigation behaviours and perceived risk simultaneously. The results of the simultaneous model suggest that perceived risk and wildfire risk-mitigating behaviours are jointly determined. By correctly specifying the relationship between risk perceptions and mitigating behaviours, we are better able to understand the relationship between other factors, such as exposure to a wildfire-mitigation program and wildfire risk-mitigating behaviours. We also find that having a wood roof, as well as homeowner age, income and previous experience with living in a fire-prone area, are associated with wildfire risk-mitigating behaviours.

Additional keywords: natural hazard, wildland–urban interface.

Received 14 June 2012, accepted 23 January 2013, published online 31 May 2013

Introduction

Significant increases in wildfires are predicted in the United States, South America, central Asia, southern Europe, southern Africa and Australia (Liu *et al.* 2010). This increase in catastrophic wildfires is particularly evident in the western United States and is not expected to abate (Climate Central 2012). During the 2012 wildfire season in Colorado, which was the worst on record, the Waldo Canyon Fire in Colorado Springs resulted in the evacuation of 32 000 residents, burned 18 247 acres (7384 ha), destroyed 346 homes, caused two deaths and cost US$16.6 million to suppress. Encouraging residents in any fire-prone area to mitigate the risk is necessary for reducing suppression costs and wildfire damages. To this end, many Colorado wildland–urban interface communities, including the city of Colorado Springs, have implemented extensive education programs to encourage homeowners to take risk-mitigation actions. Despite these efforts, Colorado has the nation's second highest number of wildland–urban interface homes rated at a 'very high' risk of wildfire damage (Botts *et al.* 2012). Although the message has been received by some wildland–urban interface residents, there is still plenty of room for improvement. To inform homeowner-education programs, we explore the relationship between perceived wildfire risk and risk-mitigating behaviours. Specifically, we examine factors related to wildfire risk-mitigating behaviours of residents in Colorado Springs, Colorado, before the Waldo Canyon Fire, with a focus on the role of perceived wildfire risk.

Literature on perceived risk and risk-mitigating behaviours

The decision to live in an area at risk of a natural hazard, as well as risk-mitigation behaviour once a person lives in an at-risk area, are influenced by risk perceptions (Whitehead *et al.* 2001; Baker *et al.* 2009; Martin *et al.* 2009; McFarlane *et al.* 2011). Winter and Fried (2000, p. 33) examined the attitudes of homeowners living in a fire-prone area. They concluded that since '…participants consider forest fires inherently uncontrollable, and the resulting damage essentially random, they are … unlikely to take all possible steps to safeguard their own properties'. Likewise, Beebe and Omi (1993, p. 22) noted that homeowners have 'a remarkable ability to live in hazardous places with relative equanimity – either by denying that a hazard is likely to occur or by discounting its potential impacts'.

However, when Martin *et al.* (2007) examined the process that homeowners go through when considering wildfire risk-mitigating behaviours, they found that homeowners were motivated by perceptions of wildfire risk. Martin *et al.* (2009) noted a similar result. McCaffrey (2002) also found that homeowners with very high risk perceptions undertook risk-mitigation measures to reduce fuels on their property. McCaffrey *et al.* (2011) asked individuals about their perceptions of wildfire risk before and after undertaking risk-mitigating actions and found that risk perceptions were lower after individuals completed some mitigation actions. Collins' (2008, p. 509) review of the wildfire literature found that 'previous studies generally support the hypothesis that heightened perception of wildfire hazard is associated with increased hazard mitigation'. However, Collins (2008) found that a respondent's reported level of fire hazard was not significantly related to the number of mitigation actions completed when controlling for other factors such as amenity values, institutional incentives, social vulnerability, place dependency, contextual influences and hazard exposure. Taking a somewhat different approach with a focus at the community level rather than the individual homeowner, Gordon *et al.* (2012, p. 77) concluded that, 'Residents understood and responded differently to the same information making risk perception as much a function of social and cultural factors as biophysical vulnerabilities'. In summary, some of the literature has suggested a positive relationship between perceived risk and risk-mitigating behaviour, whereas other studies found no relationship.

The broader natural hazards literature has also examined the relationship between perceived risk and risk-mitigating behaviours. Baker *et al.* (2009) examined the role of perceived risk on intended relocation decisions by individuals displaced after Hurricanes Katrina and Rita in 2005. In modelling perceived risk, they found that education was negatively related to perceived risk and having lost a home in the hurricane was positively associated with perceived risk. They also discovered that individuals who indicated they were unsure about their perceived risks reported higher perceived risks. They did not find an association between age or education and perceived risk. When Baker *et al.* (2009) considered the role of perceived risk on intentions to return to New Orleans, the site of the hurricanes, they found that individuals with higher perceived risks were less likely to plan a return to that city. In a similar study, Jakus *et al.* (2009) looked at the role of perceived risk of arsenic in tap water on bottled water expenditures. They first considered influences on risk perceptions, then the role of risk perceptions on actual behaviour. They found that individuals with longer tenures at their current residence had lower risk perceptions. Likewise, individuals with a lower health status, current or former smokers (smoking and arsenic exposure contribute to lung cancer) and those connected to a public water system reported higher perceived risks. The authors also included an objective measure of arsenic concentration in the perceived risk model and found that individuals with higher arsenic exposure had higher risk perceptions. Finally, Jakus *et al.* (2009) found that perceived risks were positively associated with purchases of bottled water to mitigate the exposure to arsenic. To conclude, the broader hazards literature also has examples of studies that have found positive relationships between perceived risk and hazard mitigation.

Literature on other factors associated with risk-mitigating behaviours

The literature also suggests that perceived risk is just one of many potential factors that influence risk-mitigating behaviours. McFarlane *et al.* (2011) provide a summary of the various theoretical models and the results of empirical studies of wildfire risk-mitigating behaviours. In addition to perceived wildfire risk, other factors related to wildfire risk-mitigating behaviours have been explored, such as: measures of the perceived effectiveness of wildfire risk-mitigating actions, measures of self-efficacy (sufficiency of a homeowner's resources such as time, money or ability to undertake wildfire risk-mitigating actions), informal social networks (interactions with friends and family related to risk mitigation) and personal experience. The results of the empirical analysis of McFarlane *et al.* (2011) suggest that threat assessment (perceived risk) has the largest effect on risk-mitigating behaviours, while perceived effectiveness of the actions has the second-largest effect, followed by available financial resources. Brenkert-Smith *et al.* (2012) developed a behavioural model of wildfire risk-mitigating behaviours that includes the factors summarised by McFarlane *et al.* (2011) plus wildfire information sources. They found many factors were related to higher levels of wildfire risk-mitigation in addition to perceived risk. For example, older homeowners and women reported higher levels of mitigation, as did homeowners with larger lots, those who had been evacuated or prepared to evacuate for a wildfire and those who talked with a neighbour about wildfire. Likewise, homeowners who said they did not have money for mitigation and lacked specific information about how to reduce risk reported lower levels of wildfire risk mitigation.

Modelling perceived wildfire risk and wildfire risk-mitigating behaviours

We developed a behaviour model of risk-mitigation actions similar to the wildfire hazard-mitigation models posited by Collins (2008) and Brenkert-Smith *et al.* (2012). This type of hazard mitigation model is also similar to the Jakus *et al.* (2009) model of averting behaviour related to arsenic exposure and the Smith *et al.* (1995) model of household radon mitigation behaviour.[A] We define perceived risk as the wildfire risk rating a resident gives his or her home, and wildfire risk-mitigating behaviours as actions taken by homeowners to make their property less vulnerable to wildfire damage. One approach to modelling perceived risk and risk-mitigating behaviours is to assume that perceived risk is exogenous, or determined independently of risk-mitigating behaviours. This is the approach most commonly observed in the literature on wildfire risk. The logic in this approach is simple: a homeowner who perceives a higher level of risk undertakes more (or fewer) risk-mitigating

[A]There are a variety of approaches that can be taken to model the relationship between risk-mitigation behaviours and risk perceptions. Beatson and McLennan (2011) provide an overview of various psychological models. We thank one of the reviewers for making this point.

actions. In this type of model, which we refer to as the naïve model, the level of the risk mitigation is modelled as a function of perceived risk and other explanatory variables:

$$M = \boldsymbol{\alpha_1 x} + \beta PR + \varepsilon \tag{1}$$

where M is level of risk mitigation; $\boldsymbol{x}$ is a vector of explanatory variables such as demographic characteristics and experience or knowledge of the risk; PR is the perceived risk; ε is an independent and identically distributed error term; $\boldsymbol{\alpha_1}$ is a parameter vector and β is also a parameter to be estimated. In this model, a statistically significant and positive sign on β suggests that individuals with a higher level of perceived risk undertake more mitigation.

Another approach is to treat perceived risk as jointly determined with risk-mitigating behaviour. This approach is appropriate if the determinants of risk mitigation also determine perceived risk.[B] Failure to consider simultaneity in estimation may result in biased coefficients, (Wooldridge 2006) and in turn, incorrect inference about the relationship between the dependent and independent variables. A latent-class model of risk mitigation (M^*) and perceived risk (PR^*) that takes into consideration the endogenous nature of perceived risk can be described by the following system of equations:

$$PR^* = \boldsymbol{\alpha_1 x_1} + \varepsilon_1 \tag{2}$$

$$M^* = \boldsymbol{\alpha_2 x_2} + \beta PR^* + \varepsilon_2 \tag{3}$$

where $\boldsymbol{\alpha_1}$ and $\boldsymbol{\alpha_2}$ are parameter vectors; $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$ are vectors of explanatory variables; and ε_1 and ε_2 are error terms, assumed to be jointly normal with correlation coefficient ρ and uncorrelated with all covariates in the model.

Data

Study site

Colorado Springs is a city of 414 658 people on the Front Range of the Rocky Mountains in Colorado, ~70 miles (~122 km) south of Denver. The Colorado Springs Fire Department (CSFD) was particularly concerned by the risk that wildfire posed to a 45-square-mile (~116-km^2) area on the western edge of the city containing ~35 000 houses. This area is bordered by the Pike National Forest, the Air Force Academy and the Fort Carson Army Base. Average annual precipitation of 15 inches (~38 cm) supports a dry-type forest of ponderosa pine and gambel oak with some Douglas-fir at higher elevations. The area has a mixed-severity fire regime: fires can vary from ground fires that cause little or no overstorey mortality to severe stand-replacing fires. The 230 000-acre (~93 077 ha) Pikes Peak Ranger District, which borders the study area, experiences between 40 and 50 wildfire ignitions in an average year. However, very few of these ignitions exceed 5 acres (~2 ha) because they are ordinarily suppressed by fire crews or by the rain that typically accompanies lightning. Prior to the data collection for this study, the area had experienced two major fires. In 1854, a fire started approximately 7 miles (~11 km) south-west of downtown Colorado Springs and burned north through the study area before turning west. Although exact records are not available, the wildfire is believed to have burned over 100 000 ha. In 1950, a wildfire started while land was being cleared for a golf course and resulted in nine fatalities and 92 destroyed buildings. As mentioned in the introduction, the Waldo Canyon Fire in 2012 also occurred in the study area.

In 2000, the CSFD was concerned by the area's history of periodic severe fires, 50 years of fire exclusion and the perceived failure of wildfire risk education efforts. One suspected reason for the ineffectiveness of wildfire education programs was that they typically provided general guidance; information on wildfire risk and ways to reduce this risk were not property-specific. Consequently, homeowners might regard wildfire risk as a large-scale problem that would not be significantly affected by individual action. To counter this view, the CSFD implemented a program to provide parcel-specific wildfire risk rating for the homes in the city's wildland–urban interface. The wildfire risk ratings were based on research that 'indicates a home's exterior and site characteristics significantly influence its ignitability and thus its chances for survival' (Cohen 2000, p. 15).

The CSFD developed an algorithm that used 25 variables to calculate a parcel's wildfire risk rating: low, moderate, high, very high or extreme. Three variables largely determine a parcel's wildfire risk rating owing to the weighting of each element as a function of overall significance to structure survivability. These are, in order of importance: having a wood roof, proximity to dangerous topography (steep slopes, ridges, etc.) and vegetation density around a house. The CSFD began the risk-rating process in 2000, and on 1 July 2002 posted the parcel-level wildfire risk ratings on the internet (see http://gis.springsgov.com/wildfiremitigation, accessed 4 April 2013). We refer to these parcel-level wildfire risk ratings as objective risk measures. Because a parcel's risk rating is heavily influenced by building materials and the presence of flammable vegetation, risk ratings are heterogeneous within a neighbourhood. A home with an extreme wildfire risk rating can be next to a home with a moderate or low wildfire risk rating. The second column in Table 1 contains the distribution of the risk ratings for homes in the Colorado Springs wildland–urban interface. Very few homes were rated as extreme (8%) or low (7%) risk. Most of the homes were rated as very high (16%), high (31%) or moderate (37%) risk.

The survey instrument

A mail survey was developed as part of a larger study to assess homeowners' knowledge of the CSFD's program and validate a hedonic price analysis (Donovan *et al.* 2007; Champ *et al.* 2009). The sample frame for the household survey was the 3116 homes in Colorado Springs' wildland–urban interface that sold between July 2002 and September 2004.[C] All these homes were

[B]Weinstein and Nicolich (1993) provide a very thorough discussion of correct and incorrect interpretations of the correlation between risk perceptions and risk behaviours.

[C]The first part of the larger study included a hedonic property analysis of homes that sold after the CSFD implemented their FireWise program. One purpose for the survey was to validate the results of the hedonic study. Therefore, the sample frame was the homeowners who purchased their home after the CSFD FireWise program was implemented.

Table 1. Objective and perceived wildfire risk ratings
For objective risk rating for all rated homes, there were 7308 homes that were not rated at the time of the study. The sum of the ratings is less than 100% owing to rounding error

Wildfire risk rating	Objective risk rating for all rated homes ($n = 22\,175$)	Objective risk rating for homes sold after July 2002 ($n = 3116$)	Objective risk rating for sample ($n = 898$)	Objective risk rating for survey respondents ($n = 430$)	Perceived risk rating for survey respondents ($n = 428$)
Extreme	8%	8%	7%	9%	4%
Very high	16%	17%	18%	18%	9%
High	31%	38%	37%	37%	20%
Moderate	37%	36%	36%	35%	47%
Low	7%	1%	1%	1%	21%

sold after the CSFD had put parcel-level wildfire risk ratings on the Web. A random sample of 898 households was drawn from this sample frame. Although a random sample of all residents in the Colorado Springs wildland–urban interface would have been more conventional, we see this sample had a distribution of wildfire risk similar to that of the population and the sample frame (Table 1, columns 2, 3 and 4).

Mailing procedures

The initial survey packet included the survey instrument, a cover letter signed by the Chief of the CSFD, and a postage-paid return envelope. The first survey wave ($n = 898$) was mailed on 8 November 2006. A second survey packet ($n = 534$) was mailed to non-respondents on 1 December 2006. The overall response rate of 52% was quite good, especially for just two mailings. In total 5% of the survey packets were returned as 'undeliverable', and 3% of the sample had zip codes that were not in the Colorado Springs wildland–urban interface. With any survey that does not have a 100% response rate, non-response bias is a concern. The issue is whether the pool of non-respondents is systematically different from the pool of respondents on relevant measures. Although we did not conduct a formal investigation of non-response bias, it is a promising result that respondents had a distribution of objective wildfire risk ratings that was similar to the initial sample (Table 1, columns 4 and 5). Furthermore, this research is focussed on a relational model rather than making inference about the broader population.

The respondents

Survey respondents were well educated and affluent. All respondents had graduated from high school and 37% had advanced degrees. In total 44% had a household income above US$100 000. Most (79%) were married and approximately half (51%) of the respondents were male. A majority (54%) were employed full-time. A website seems like a reasonable medium with which to communicate wildfire risk to the study population as 94% of the respondents had access to the internet from their home and 86% of these respondents accessed the internet daily. However, most of the respondents (58%) were not aware that the CSFD's FireWise program provides information to homeowners about wildfire risk. Only 14% of the respondents had ever accessed the CSFD's FireWise website (see http://gis.springsgov.com/wildfiremitigation). Further, 48% of the survey respondents did not know that their home was located in an area at risk of wildfire.

Comparing objective and perceived risk ratings

Respondents were asked to rate the wildfire risk of their home using the same scale as the objective risk ratings. Specifically, the survey question asked: 'What do you think is your home's *current* wildfire risk rating?' The response categories were: 'extreme risk', 'very high risk', 'high risk', 'moderate risk' and 'low risk'. We refer to the response to this question as the perceived risk measure.

Consistent with the literature on objective and perceived risk, study participants generally underestimated their homes' wildfire risk ratings. Table 1 (columns 5 and 6) compares the objective risk ratings for the respondent pool with the perceived risk ratings. Although only 1% of the respondents had low objective wildfire risk ratings, 21% perceived their home to have a low wildfire risk rating. Likewise, fewer respondents thought their homes had extreme or very high wildfire risk ratings compared with objective wildfire risk ratings. Although respondents systematically underestimated wildfire risk, perceived and objective wildfire risk ratings are positively correlated ($\rho = 0.393$). We expect that individuals who had visited the CSFD FireWise website would have a better sense of their objective risk ratings. In Table 2, we compare the difference between objective and perceived risk ratings by whether or not individuals accessed the CSFD FireWise website. Those who accessed the website were more likely to correctly identify their home's wildfire risk rating (50%) than those who had not accessed the website (27%). Likewise, 17% of those who accessed the website overestimated their home's wildfire risk rating compared with only 10% of those who had not accessed the website. In other words, we see a statistically significant difference between perceived and objective risk for those who had accessed the CSFD FireWise website compared with those who had not. Thus, in the multivariate model described below, we control for having accessed the CSFD FireWise website.

Wildfire risk-mitigating behaviours

The ultimate goal of the CSFD's education program is to have homeowners mitigate the wildfire risk on their parcel. To measure wildfire risk-mitigating behaviours, survey respondents were asked if they had undertaken any of five wildfire risk-mitigation actions: scheduling a consultation with the Colorado Springs FireWise program coordinator, thinning vegetation on the property, removing pine needles and debris from the ground, keeping grass and weeds mowed and moving firewood 15 feet

Table 2. Difference between objective and perceived wildfire risk ratings by whether individuals accessed the Colorado Springs Fire Department (CSFD) FireWise website (see http://gis.springsgov.com/wildfiremitigation)

Contingency table analysis suggests difference in objective and perceived risk and access to CSFD website are not independent ($\chi^2 = 16.307$; $P = 0.000$)

	Accessed CSFD FireWise website ($n = 52$)	Did not access CSFD FireWise website ($n = 317$)
Underestimate risk (objective risk rating > perceived risk rating)	33%	63%
Correct risk (objective risk rating = perceived risk rating)	50%	27%
Overestimate risk (objective risk rating < perceived risk rating)	17%	10%
Mean objective risk rating (1 = extreme; 5 = low)	2.79	3.05
Mean perceived risk rating (1 = extreme; 5 = low)	3.08	3.86

Table 3. Distribution of individual wildfire risk-mitigating actions and composite variable ($n = 377$)

Action	Percentage that completed each action
Schedule a consultation with the Colorado Springs FireWise Coordinator	6
Thin vegetation on property and remove ladder fuels	40
Remove pine needles and debris from ground	42
Keep grass and weeds mowed	72
Move firewood at least 15 feet (~4.6 m) away from house and deck	21
Total number of actions completed	**Percentage that completed**
0	23
1	21
2	23
3	22
4	11
5	0.5

(~4.6 m) or more away from the house.[D] For each activity, a respondent could answer 'yes', 'no' or 'not applicable'. We summed up the number of actions a respondent completed to create the 'number of mitigation actions' variable. The number of risk-mitigation actions is a categorical variable as the actions are not commensurate. We assume that higher categories imply higher levels of wildfire risk mitigation. Table 3 shows the percentage of respondents who completed each of the actions and the distribution of the number of actions taken by respondents. Very few respondents completed more than four actions. Indeed, so few respondents completed five actions that we combined the four- and five-action categories for the analyses.[E]

Model results

Our objective is to estimate Eqn 1 individually and Eqns 2 and 3 simultaneously. However, we do not observe the variables PR^* and M^*. Rather, we observe two categorical variables: perceived risk rating (pr) and number of completed mitigation actions (m).

$$pr = \begin{cases} 1 = \text{low perceived risk rating} \\ 2 = \text{moderate perceived risk rating} \\ 3 = \text{high perceived risk rating} \\ 4 = \text{very high perceived risk rating} \\ 5 = \text{extreme perceived risk rating} \end{cases}$$

$$m = \begin{cases} 0 = 0 \text{ actions} \\ 1 = 1 \text{ action} \\ 2 = 2 \text{ actions} \\ 3 = 3 \text{ actions} \\ 4 = 4 \text{ or } 5 \text{ actions} \end{cases}$$

One critical assumption is that the perceived risk rating and the number of risk-mitigating actions taken are ordinal but not cardinal. For example, four completed actions are more than two completed actions (order) but not considered to be twice as

[D]Respondents were also asked about replacing a wood roof. We excluded this action from our analysis as many homes would not have had a wood roof at the time of purchase.

[E]Measuring wildfire risk-mitigating behaviours is not a straightforward task. We carefully considered the trade-offs associated with alternative approaches and based our approach on the advice of a co-author who is an expert on wildfire risk-mitigation behaviours. Creating a count variable of the number of mitigation actions completed is similar to Collins (2008) and Brenkert-Smith *et al.* (2012). Our approach differs from Collins (2008) in that we assume the variable is categorical and he assumes that the number of mitigation actions is a continuous variable.

many actions (cardinality). Based on the literature, we included perceived risk along with three other categories of independent variables in the models (Table 4). First, we included variables that measured the physical characteristics of the property such as proximity to dangerous topography and dense vegetation. These variables are two of the three most heavily weighted factors in a home's wildfire risk rating as mentioned previously. Demographic characteristics of the respondents were also included in the model. Specifically, the models include measures of sex, income and age. Likewise, we include three variables that measured previous experience and knowledge about wildfire. The variables were whether the respondent ever accessed the CSFD's FireWise website, whether the respondent knew anyone whose home had been damaged or lost owing to a wildfire and whether the respondent previously owned a home located in an area at risk of wildfire.

In the simultaneous model, the equation for mitigation level can only be identified if there is at least one exogenous variable with a non-zero coefficient in the perceived risk equation that is not in the mitigation equation. This is referred to as the order condition (Woolridge 2006). Therefore, we included a variable (risklocation) that measured whether the homeowner knew his or her home was located in an area at risk of wildfire.[F]

We estimated four models, two independent univariate probit models (Eqn 1 and a similar model with perceived risk as the dependent variable) and a simultaneous bivariate probit model (Eqns 2, 3). The results are shown in Table 4. We first examine the results of the perceived risk models (the top half of Table 4). As expected, the results of the univariate and bivariate perceived risk models are very similar; therefore we can describe the results of both models together. The parcel characteristics related to wildfire risk seem to have a significant effect on perceived risk. Homeowners with moderate or dense vegetation within 30 feet (~9 m) of their home reported higher risk ratings than those with sparse vegetation near their home. Likewise, individuals who lived less than 30 feet (~9 m) from dangerous topography reported higher risk ratings compared with those living more than 100 feet (~30 m) from dangerous topography. Finally, having a wood roof was associated with higher perceived risk ratings. Respondent characteristics were also found to be related to perceived risk. Younger women with incomes over US$100 000 per year reported higher levels of wildfire risk. Research results on demographic characteristics and risk perceptions vary with the type of risk considered (e.g. health, financial, safety). In general, research studies find women perceive higher risks. The negative relationship between perceived wildfire risk and age found in this study is similar to the relationship between age and perceived mortality risks of arsenic in drinking water found by Nguyen *et al.* (2010). We speculate that older respondents have gone longer without experiencing a wildfire and therefore they perceive a lower risk. Finally, individuals who accessed the CSFD's FireWise website had higher perceived risk levels, as did those who knew their home was located in an area at risk of wildfire.

A Chi-square test of the simultaneous bivariate probit model suggests that we reject the null hypothesis that the perceived risk and mitigation equations are independent at the 5% significance level ($\chi^2 = 4.03$; $P = 0.0447$). This result supports the hypothesis that perceived risk and mitigation actions are jointly determined. We now turn our attention to the results of the mitigation models.

In addition to being correctly specified, the bivariate model provides a richer understanding of the relationships between the explanatory variables and mitigation level. In the univariate model of mitigation, the coefficients on the two perceived risk rating variables are both positive and statistically significant. As the perceived risk rating is categorical, the risk levels were entered as a series of dummy variables with low risk as the excluded variable. Therefore, we see that compared with individuals with low subjective ratings, those with moderate and high, very high or extreme risk ratings had completed more wildfire risk-mitigating actions. When the mitigation and perceived risk equations are estimated simultaneously, we no longer see a statistically significant relationship between perceived risk and number of mitigation actions.

In addition to the effect of perceived risk on number of mitigation actions, we see three other differences between the univariate and bivariate ordered probit models of mitigation actions (the bottom half of Table 4). The statistical significance of the coefficient on roof is higher in the bivariate model, suggesting a stronger relationship between having a wood roof and number of mitigation actions compared with the univariate model. As wood roofs are considered one of the biggest contributors to wildfire risk, it is encouraging to see that individuals with a wood roof do undertake higher numbers of wildfire risk-mitigation actions. We speculate that homeowners with wood roofs may recognise the additional risk that the wood roof poses and attempt to compensate by undertaking more mitigation actions. None of the other parcel attributes had coefficient estimates that were significantly different from zero in either model. The second difference between the univariate and bivariate mitigation models is that the coefficient on age is negative and significant ($P = 0.08$) in the bivariate model and not significant in the univariate model. This result suggests that older respondents reported lower levels of mitigation. This result could be related to the physical difficulty of thinning vegetation. However, Brenkert-Smith *et al.* (2012) found the opposite effect: older respondents reported higher levels of mitigation. Finally, the third difference we observe is a weak positive association (10% level of significance) between having accessed the CSFD's FireWise website and mitigation level in the bivariate model that is not found in the univariate model. This result suggests that beyond the effect on perceived risks, accessing the website is positively related to higher levels of mitigation. As the website includes detailed information about how to best mitigate wildfire risk, this result is not surprising. However, we would not have observed this effect if we had only estimated the naïve mitigation model.

[F]The actual survey question asked when the respondent realised that his or her home was in an area at risk of wildfire. We coded the responses so that individuals who chose the response 'I did not know my house was located in an area at risk from wildfire' were coded as '1' and all other responses were coded as '0'. Somewhat surprisingly, 39% of the respondents did not know their home was located in an area at risk of wildfire.

Table 4. Probit models ($n = 359$)

For the likelihood ratio test of independent equations for the simultaneous bivariate ordered probit model: $\chi^2 = 4.03$; $P = 0.0447$. CSFD, Colorado Springs Fire Department

		Independent univariate ordered probit model Coefficient (s.e.)	Simultaneous bivariate ordered probit model Coefficient (s.e.)
Dependent variable = perceived risk rating			
Thresholds	Low perceived risk = 1	−0.492 (0.487)	−0.475 (0.488)
	Moderate perceived risk = 2	1.105[B] (0.489)	1.122[B] (0.489)
Parcel characteristics	Veghigh (1 = dense vegetation within 30 feet (~9 m) of home; 0 = otherwise)	0.799[C] (0.234)	0.802[C] (0.234)
	Vegmed (1 = moderately dense vegetation within 30 feet (~9 m) of home; 0 = otherwise)	0.284[B] (0.140)	0.284[B] (0.140)
	Tophigh (1 = <30 feet (~9 m) from dangerous topography; 0 = otherwise)	0.464[A] (0.242)	0.454[B] (0.242)
	Topmed (1 = 30–100 feet (~30 m) from dangerous topography; 0 = otherwise)	0.129 (0.147)	0.131 (0.147)
	Roof (1 = wood; 0 = otherwise)	0.339[B] (0.159)	0.339[B] (0.159)
	Slope (average slope (%) within 150 feet (~46 m) of house)	−0.004 (0.019)	−0.004 (0.019)
Respondent characteristics	Sex (1 = female; 0 = male)	0.333[C] (0.127)	0.335[C] (0.127)
	Income (1 = income > US$100 000 per year; 0 = otherwise)	0.232[A] (0.132)	0.232[A] (0.133)
	Age	−0.018[C] (0.005)	−0.018[C] (0.005)
Experience and knowledge	Website (1 = ever accessed the CSFD's FireWise website; 0 = otherwise)	0.492[C] (0.196)	0.494[C] (0.196)
	Knowlost (1 = know anyone whose home was damaged or lost due to a wildfire; 0 = otherwise)	0.054 (0.164)	0.060 (0.165)
	Threat (1 = previously owned a home located in area at risk of wildfire; 0 = otherwise)	0.070 (0.139)	0.063 (0.140)
	Risklocation (1 = did not know located in area at risk from wildfire; 0 = otherwise)	−0.733[C] (0.136)	−0.732[C] (0.136)
Log-likelihood		−312.71	
Dependent variable = number of mitigating actions			
Thresholds	Numberactions = 0	0.345 (0.433)	0.133 (0.431)
	Numberactions = 1	0.967[B] (0.434)	0.731 (0.424)
	Numberactions = 2	1.601[C] (0.438)	1.343[C] (0.422)
	Numberactions = 3	2.42[C] (0.446)	2.131[C] (0.427)
Parcel attributes	Veghigh (1 = dense vegetation within 30 feet (~9 m) of home; 0 = otherwise)	0.061 (0.205)	0.196 (0.249)
	Vegmed (1 = moderately dense vegetation within 30 feet (~9 m) of home; 0 = otherwise)	−0.161 (0.130)	−0.130 (0.139)
	Tophigh (1 = <30 feet (~9 m) from dangerous topography; 0 = otherwise)	−0.138 (0.210)	−0.048 (0.232)
	Topmed (1 = 30–100 feet (~30 m) from dangerous topography; 0 = otherwise)	0.010 (0.134)	0.042 (0.138)
	Roof (1 = wood; 0 = otherwise)	0.267[A] (0.141)	0.339[B] (0.154)
	Slope (average slope (%) within 150 feet (~46 m) of house)	0.027 (0.017)	0.027 (0.017)
Perceived risk rating	Extreme, Very high, High	0.362[B] (0.151)	
	Moderate	0.347[A] (0.178)	
Predicted perceived risk			0.234 (0.180)
Demographic variables	Sex (1 = female; 0 = male)	0.016 (0.114)	0.061 (0.127)
	Income (1 = income > US$100 000 per year; 0 = otherwise)	0.240[B] (0.119)	0.285[B] (0.127)
	Age	−0.005 (0.005)	−0.010[A] (0.006)
Experience and knowledge	Website (1 = ever accessed the CSFD's FireWise website; 0 = otherwise)	0.232 (0.169)	0.332[A] (0.191)
	Knowlost (1 = know anyone whose home was damaged or lost owing to a wildfire; 0 = otherwise)	0.168 (0.147)	0.187 (0.151)
	Threat (1 = previously owned a home located in area at risk of wildfire; 0 = otherwise)	0.304[B] (0.126)	0.310[C] (0.127)
Log-likelihood		−555.84	−863.75

[A]$\alpha = 0.10$.
[B]$\alpha = 0.05$.
[C]$\alpha = 0.001$.

In both the univariate and bivariate mitigation models, we see that an annual income greater than US$100 000 is positively related to mitigation level. This result is consistent with other studies of wildfire mitigation, as mitigation can be costly.[G] We also see a strong positive relationship between having previously owned a home in an area at risk of wildfire and mitigation level.

Discussion and conclusions

Motivating wildland–urban interface homeowners to take mitigation actions is essential in avoiding catastrophic losses. However, the optimal approach to educating homeowners about wildfire risk is not obvious. In this study, we examined a particular approach to wildfire risk education. In Colorado Springs, the fire department implemented a sophisticated program that involved rating every parcel in the wildland–urban interface area for wildfire risk. This program was premised on the assumption that homeowners who understand their own wildfire risk are more likely to take mitigation actions. The program sought to close the gap between perceived wildfire risk and objective risk. However, as shown in Table 1, a substantial gap was found between perceived and objective risk for the survey respondents. Does that mean the CSFD's FireWise program is a failure? No. In Table 2, we see that individuals who had visited the CSFD's FireWise website had higher levels of perceived risk and were much less likely to underestimate the wildfire risk on their parcel. Likewise, when we examined the relationship between perceived wildfire risk and wildfire risk-mitigating behaviour, we found them to be jointly determined. Those who accessed the CSFD's FireWise website had higher perceived risk, but, more importantly, those individuals also reported higher levels of mitigation. By properly modelling the relationship between perceived risk and mitigation behaviour, we rule out perceived risk alone as a pathway for higher mitigation levels. We speculate that as individuals become better informed about the wildfire risk on their property, they simultaneously become better informed about the 'how to' of mitigating wildfire risk.

The shortfall of the wildfire education program examined in this study seems to be that few respondents (39%) were aware that they lived in a location at risk of wildfire, and even fewer (14%) had accessed the website. We expect efforts to increase awareness of the Colorado Springs FireWise program could translate into moving more homeowners to take action to reduce their risk of wildfire. Given the recent Waldo Canyon Wildfire in the study area, the residents in the Colorado Springs wildland–urban interface likely have an increased awareness that they live in an area at risk of wildfire. Although general risk awareness alone may not be related to higher levels of mitigation, perhaps this greater awareness will move homeowners to seek out the CSFD's FireWise website, which may translate into higher levels of mitigation.

This study cannot speak about the temporal aspects of perceived risk and risk-mitigating actions. Even if there is heightened awareness of wildfire risk related to an education program or a wildfire event, it may not be sustained over time. In addition to providing homeowners with the requisite information about wildfire risk and how to properly mitigate that risk, education programs can communicate that wildfire risk is perpetual, and therefore mitigation needs to be ongoing. This point is illustrated by a post-Waldo Canyon Fire news article in the local Colorado Springs newspaper (*Colorado Springs Gazette*, 19 September 2012):

> For some Colorado Springs residents, preparing for another large fire is a difficult concept to grasp. Last week, Colorado Springs Fire Department Fire Marshall Brett Lacey talked to Mountain Shadows residents at a meeting called to address the new fire codes, but he encountered resistance from homeowners who didn't see the need in a burned area.
>
> 'Why are they having us pay more when it's not going to happen again?' one resident asked Lacey.
>
> But it can happen again, Lacey said. When the fire raged into Colorado Springs on 26 June, incinerating hundreds of homes, it moved so quickly that it left underground root systems undamaged.

Along this line, an important caveat to the present study is that the mitigation measure is the number of reported actions that were completed. When managing vegetation to reduce wildfire risk, homeowners need to be vigilant. It must be an ongoing effort, not a one-time activity. Likewise, even though a homeowner reports thinning vegetation, it is not clear that a wildfire specialist would deem his or her efforts adequate. Future research exploring disparities between homeowners' reported actions and assessments by a professional is warranted, as is research on whether homeowners maintain their mitigation efforts over time.

There are a few other important caveats to this study. Our results probably do not generalise well to rural wildland–urban interface areas that are sparsely populated with large land parcels. The wildland–urban interface area described in this study is urban as it is part of the city of Colorado Springs. Another important caveat is the study population. The population of the study area is fairly affluent and well educated. When one compares the demographic characteristics of this survey's respondents with other studies such as the Collins (2008) survey of communities in Arizona, one sees drastically different demographic characteristics. However, it is interesting to note that within the relatively affluent wildland–urban interface homeowners in this study population, income appears to play an important role in both risk perceptions and risk-mitigating behaviours.

References

Baker J, Shaw WD, Bell D, Brody S, Riddel M, Woodward RT, Neilson W (2009) Explaining subjective risks of hurricanes and the role of risks in intended moving and location choice models. *Natural Hazards Review* **10**(3), 102–112. doi:10.1061/(ASCE)1527-6988(2009)10:3(102)

Beatson R, McLennan J (2011) What applied social psychology theories might contribute to community bushfire safety research after Victoria's 'Black Saturday'. *Australian Psychologist* **46**, 171–182. doi:10.1111/J.1742-9544.2011.00041.X

[G]We were also able to estimate models that included the sales price of the home as an explanatory variable. Inclusion of sales price in the models did not make a substantial difference in the models and the estimated coefficient on home sales price was not statistically different from zero.

Beebe GS, Omi PN (1993) Wildland burning: the perception of risk. *Journal of Forestry* **91**(9), 19–24.

Botts H, Thomas J, Steven K, McCabe S, Suhr L (2012) 'CoreLogic Wildfire Hazard Risk Report.' (CoreLogic: Santa Ana, CA)

Brenkert-Smith H, Champ PA, Flores N (2012) Trying not to get burned: determinants of homeowner wildfire risk mitigation behaviors. *Environmental Management* **50**, 1139–1151. doi:10.1007/S00267-012-9949-8

Champ PA, Donovan GH, Barth C (2009) Homebuyers and wildfire risk: a Colorado Springs case study. *Society & Natural Resources* **23**(1), 58–70. doi:10.1080/08941920802179766

Climate Central (2012) The Age of Western Wildfires. Climate Central. (Palo Alto, CA)

Cohen JD (2000) Preventing disaster. Home ignitibility in the wildland–urban interface. *Journal of Forestry* **98**, 15–21.

Collins TW (2008) What influences hazard mitigation? Household decision making about wildfire risks in Arizona's White Mountains. *The Professional Geographer* **60**(4), 508–526. doi:10.1080/00330120802211737

Donovan GH, Champ PA, Butry DT (2007) The impact of wildfire risk on housing price: a case study from Colorado Springs. *Land Economics* **83**(2), 217–233.

Gordon JS, Luloff A, Stedman RC (2012) A multisite qualitative comparison of community wildfire risk perceptions. *Journal of Forestry* **110**(2), 74–78. doi:10.5849/JOF.10-086

Jakus PM, Shaw WD, Nguyen TN, Walker M (2009) Risk perceptions of arsenic in tap water and consumption of bottled water. *Water Resources Research* **45**, W05405. doi:10.1029/2008WR007427

Liu Y, Stanturf J, Goodrick S (2010) Trends in global wildfire potential in a changing climate. *Forest Ecology and Management* **259**, 685–697. doi:10.1016/J.FORECO.2009.09.002

Martin IM, Bender H, Raish C (2007) What motivates individuals to protect themselves from risks: the case of wildland fires. *Risk Analysis* **27**(4), 887–900. doi:10.1111/J.1539-6924.2007.00930.X

Martin WE, Martin IM, Kent B (2009) The role of risk perceptions in the risk mitigation process: the case of wildfire in high risk communities. *Journal of Environmental Management* **91**, 489–498. doi:10.1016/J.JENVMAN.2009.09.007

McCaffrey SM (2002) For Want of Defensible Space a Forest is Lost: Homeowners and the Wildfire Hazard and Mitigation in Residential Wildland Intermix at Incline Village, Nebraska. PhD dissertation, University of California – Berkeley.

McCaffrey SM, Stidham M, Toman E, Schindler B (2011) Outreach programs, peer pressure, and common sense: what motivates homeowners to mitigate wildfire risk? *Environmental Management* **48**, 475–488. doi:10.1007/S00267-011-9704-6

McFarlane BL, McGee TK, Faulkner H (2011) Complexity of homeowner wildfire risk mitigation: an integration of hazard theories. *International Journal of Wildland Fire* **20**, 921–931. doi:10.1071/WF10096

Nguyen N, Jakus PM, Riddel M, Shaw WD (2010) An empirical model of perceived mortality risks for selected US arsenic hot spots. *Risk Analysis* **30**(10), 1550–1562. doi:10.1111/J.1539-6924.2010.01450.X

Smith VK, Desvousges WH, Payne JW (1995) Do risk information programs promote mitigating behavior? *Journal of Risk and Uncertainty* **10**, 203–221. doi:10.1007/BF01207551

Weinstein ND, Nicolich M (1993) Correct and incorrect interpretations of correlations between risk perceptions and risk behaviors. *Health Psychology* **12**(3), 235–245. doi:10.1037/0278-6133.12.3.235

Whitehead JC, Edwards B, Van Willigen M, Maiolo JR, Wilson K, Smith KT (2001) Heading for higher ground: factors affecting real and hypothetical hurricane evacuation behavior. *Environmental Hazards* **2**(4), 133–142. doi:10.3763/EHAZ.2000.0219

Winter G, Fried JS (2000) Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland–urban interface. *Society & Natural Resources* **13**, 33–49. doi:10.1080/089419200279225

Wooldridge JM (2006) 'Introductory Econometrics, Third Edition.' (Thomson South-Western: Mason, OH)