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Perceptions of wildfire risk and adaptation behaviour in California

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Abstract

California wildfires have been increasing in frequency and severity. However, there is a limited understanding to date about people's experiences with wildfire occurrences, how that experience shapes their perceptions of risk and how it affects their response in terms of actions that can reduce their household risk. In 2021, we fielded an online survey to 1204 people living in California aimed at understanding experience, risk perceptions, and decision-making strategies related to wildfires. We find that 70% of all survey respondents participants experienced poor air quality and 39% experienced a power outage in their home. Other experiences elicited (such as experiencing a school closure, a home evacuation, or home damages) were reported by less than 1/5 of our respondents. A significant portion of our survey respondents has undertaken actions to reduce the risk from wildfire to their household by having air filters, smoke-protecting masks and using informational air quality tools, and investing in back up power. Despite low number of reported prior experiences and the low perception of likelihood for the need to evacuate, a relatively large percent of respondents has taken actions to prepare for evacuation with 41% of the respondents stating packed a 'go bag', 32% securing a place to stay in case of evacuation, 35% reported having created a defensible space, and 18% have pursued retrofits to their house. Our regression models suggest that while the perception of risk is associated with action, other factors, such as being a homeowner or deriving livelihood off their land are much more likely to drive people to act. The results from our study suggest that while experience may lead to action, other policy interventions, such as clear communication on risks and consequences for households in high-risk areas, may be warranted to drive further action.

1. Introduction

In recent years, the severity and frequency of wildfires have increased in California (Hessburg *et al* 2019, Huang *et al* 2020, Taylor *et al* 2021). Fifteen of the twenty most destructive fires in California have occurred since 2015 (CAL FIRE 2022). The fires in 2020 burned over 4 million acres, destroyed over 10 000 structures, and resulted in 33 deaths to firefighters and civilians (CAL FIRE 2020).

To tackle wildfires, a wide range of decision-makers are faced with different wildfire management decisions and strategies. This heterogeneous group of decision makers ranges from fire agencies deciding how to allocate suppression resources, to land managers taking actions to reduce fuel loads, to electric utilities shutting off the power to avoid igniting a fire.

In this study, we focus on a subset of these decision-makers: households. We posit that household actions to deal with wildfires will be a shaped by their perceived risk of such fires. The perceived risk will be dependent on their prior experience, their beliefs and their specific context.

Prior experience, context, beliefs → Perceived Risk → Actions

Figure 1. Conceptional model: we posit that prior experience, context and beliefs will shape the perceived risk of wildfires, and the perceived risk in turn will shape the actions undertaken by households.

Here, we assess these perceived risk shaping factors, and we are particularly interested in understanding households' prior experience to wildfires, their perceived risk of wildfires in California, and how the perception of risks shapes their actions[5], as shown in figure 1.

In this study, we consider specifically the following types of prior experiences[6] with wildfires and respective perceived risks of future occurrences: (i) enduring poor air quality; (ii) experiencing a power outage; (iii) facing the need to evacuate from their house; (iv) home damage. While in the survey questionnaire we included other types of prior experience and risks, here we include the results for just these four given their implications for wildfire management[7].

We further broadly define risk as it is traditionally considered in the risk analysis literature, i.e. 'risk = hazard × consequence'. Hazard is defined as the probability of a wildfire of a specific severity occurring, and consequences are occurrences that would impact a household. In wildfire research and in climate change science, there is emerging research focusing on understanding the likelihood of wildfires of different severity, in different locations, and how those will change with climate change, as well as an understanding of key uncertainties and irreducible ones (Krawchuk *et al* 2009, Mann *et al* 2016). Here, however, we focus on *lay participant's perception of risk*, rather than the actual risk, as these perceptions, rather than the actual risk, will shape households' decisions and actions. Risk perceptions may differ from actual risk given that they reflect subjective probabilities (McCaffrey 2008) and perceived consequences. In studies of risk perception, the perceived and observed risk have been shown to be different due to misinformation, biases, emotional responses, differing definitions of risk, and other factors (Fischhoff *et al* 1983, Slovic *et al* 1986, Loewenstein *et al* 2001).

Experience of wildfire (defined here as having experienced direct or indirect consequences from wildfires) may influence the perception of risk. Some studies find that experience increases the perception of risk (Blanchard and Ryan 2007, Dupey and Smith 2019, Spano *et al* 2021), while others find no relationship between experience and perceived risk (Schulte and Miller 2010, Fischer 2011). Champ and Brenkert-Smith (2016) find that experience does not have a statistically significant relationship with perception of increased probability but is correlated with perceived consequences. Martin *et al* (2009) examine the processes which influence risk perception and how these same factors affect risk-reduction actions in a study that included 251 participants residing in the WUI in Colorado and Oregon and find no significant relationship between experience and risk perception and no direct impact on actions. McGee *et al* (2009) find that risk perception can vary even within a community. Velez *et al* (2017) and Spialek *et al* (2021) identify factors that influence wildfire risk perceptions, such as risk communication, messaging, and social norms.

Additional work has considered the potential link between risk perception and the choice to take actions to reduce risk. For example, Brenkert-Smith *et al* (2012) and Ghasemi *et al* (2020) show that residents that perceive a higher level of risk undertake more risk reduction activities. However, other researchers find that other factors will also play a role. For example, Hui *et al* (2022) show that political orientation explains support for public policies in wildfire resilience, with Republicans being less likely than Democrats to support using public funds for private measures to cope with wildfires, but proximity to fires lessens their opposition. Winter and Fried (2000) report that their participants often believed that forest fires were inherently random, limiting desire to take protective action. Others, like Champ *et al* (2013) find that the link between risk perception and risk reducing actions is bi-directional, i.e. risk perception increases risk reduction actions, but also taking actions can lead to a lowered perception of risk.

[5] These actions are often called 'risk mitigation' in the risk analysis literature. Because the audience from this journal may be more familiar with 'mitigation' in the climate change mitigation context (i.e. mitigation being defined as greenhouse gas emission reduction strategies) we do not use 'risk mitigation' and instead use 'risk reduction' or 'actions' as to avoid confusion.

[6] Here, we use the 'experience' as to account for prior exposure to different types of direct and indirect wildfire consequences.

[7] In the SI, figures S1 and S2, we provide the results for other types of prior experiences and perceived risks that were elicited during the survey.

Here, we aim the answer the following questions:

1. What has been the prior experience with wildfires for Californians[8], and how did this experience differ geographically and demographically?
2. What are Californians' perceptions of wildfires risks, and how have these been shaped by prior experience?
3. What actions have Californians undertaken to reduce risk, and how have those actions been shaped by their perception of risk, their specific context, and their beliefs?

2. Data and methods

2.1. Survey participants and participant recruitment process

We fielded an online survey to 1204 participants living in California. We over-sampled participants from zones with high wildfire hazard potential as we were interested in understanding if there were contextual differences on risk perceptions and risk actions depending on whether people lived in areas that are identified as having different wildfire hazard potentials. We use the wildfire hazard potential zones (WHP) developed by the United States Department of Agriculture Forest Service's Fire Modeling Institute (USDA Forest Service 2023). WHP provides information on the relative likelihood of an area experiencing a high-intensity fire that would be difficult to contain. WHP was developed to support forest management strategies. According to the Fire Modeling Institute, 'on its own, WHP is not an explicit map of wildfire threat or risk, but when paired with spatial data depicting highly valued resources and assets such as communities, structures, or powerlines, it can approximate relative wildfire risk to those resources and assets' (see SI, text S1 for more information).

Our participants sampling strategy from California's population led us to recruit 365 of the 1204 respondents from zip codes designated as moderate to high wildfire hazard potential by the WHP maps at the zip code level (Dillon and Gilbertson-Day 2020). The WHP dataset has been used in other studies with similar applications. For example, Nie *et al* (working paper) have used causal inference to show that heightened risk perception of wildfires in census tracts with high wildfire risk in California causes a reduction in residential home sale price.

The moderate to high-hazard zip codes represent around 25% of California zip codes and 10% of the population. While fire hazard may vary within a zip code, this is the smallest consistent geospatial unit of information that preserved respondent confidentiality.

To recruit participants that reflect California's population, we set response quotas for gender, age, and education based on California's adult population as per the American Community Survey (ACS). A comparison between our sample demographics and that of California's ACS is provided in table 1[9]. We used Qualtrics services for participant recruitment (Qualtrics, Provo, UT). Participants were compensated for completing the survey as described in the SI (see the PDF with the full survey questionnaire in the SI, section S2).

2.2. Survey design

The survey (see the SI, section 2 for the full survey details) includes eight sections that explore the experience of respondents with wildfires, perceptions of wildfire risk, and current and future actions to reduce or cope with risk, in addition to participant demographics. The survey sections were organized as follows:

- Survey section 1 provides initial demographic questions;
- Survey section 2 elicits respondents' prior experiences during wildfire seasons;
- Survey section 3 asks about respondents' expectations about the wildfire season that was occurring when the survey was fielded;
- Survey section 4 asks questions about wildfire preparations undertaken in previous years;
- Survey section 5 asks questions about wildfire preparations planned for the current wildfire season;
- Survey section 6 includes questions regarding respondents' knowledge of and experience related to preventative power shutoffs;
- Survey section 7 explores questions related to home insurance;
- Survey section 8 includes additional demographic questions.

[8] Here we refer to Californians as anyone living in California.

[9] We did not aim to match income or home ownership, but we still include a comparison between our participants and ACS for those attributes in table 1 in case that information is of interest to the reader.

Table 1. Summary statistics for study participants and demographics of California from the ACS survey.

		Survey sample	ACS (18+ years)
Gender	Female	51.%	50.3%
	Male	47%	49.7%
Age (years)	18–34	33.0%	32.5%
	35–64	54.2%	49.9%
	65+	12.8%	17.7%
Education	High school or <	24.1%	37.7%
	Some college	44.1%	29.1%
	Bachelor or >	31.8%	33.3%
Household income	Median income:	\$50 000–\$60 000	\$71 228
Home ownership	Homeowners:	51.9%	50.3%

ACS = American Consumer Survey.

The survey was fielded using Qualtrics, available online in both web and mobile formats and offered in both English and Spanish (53 out of 1204 responses were in Spanish). The survey was open online for 3 weeks in September and October of 2021. Notably, 2021 was a severe fire season and both the Dixie Fire (963 309 acres, July to October 2021) and Caldor Fire (221 835 acres, August to October 2021) were actively burning at the time of the survey.

Wildfire experiences included home damage, evacuation, poor air quality from wildfire smoke, electricity, water, and internet outages, transportation challenges and school closures (and the duration of each of these impacts). If the respondent indicated that they had lived elsewhere in California in the last 5 years, we repeated the set of questions for their previous residence. To understand the perception of risk, we provided respondents with slider scales (0–100 which could be changed up or down in increments of 1) to indicate their perceived likelihood of experiencing the same set of wildfire impacts in the current fire season. We asked how they believed the 2021 fire season would compare to previous years and included an open-ended question on the top three reasons they believe there has been an increase in wildfire destruction in recent years. We manually classified the open-ended responses into categories such as weather, climate change, and forest management.

Two sections focused on actions to cope with wildfires, with the first section focusing on actions taken in previous years and the second on those planned for the current fire season. The section on previous actions asked about actions of three types: preparing the home for wildfire (creating defensible space, retrofitting home with fire safe building materials, installing backup power, checking the adequacy of wildfire insurance coverage), wildfire evacuation planning (securing a place to stay, preparing transportation, packing 'go bags') and reducing smoke consequences (purchasing air filters, building air filters, purchasing masks, checking online measures of air quality). In addition to selecting all the preparations they had undertaken, respondents were asked to indicate the approximate year these preparations began. Furthermore, respondents were asked if they have ever left their homes for the duration of the fire season and if so, where they went. In the following section, they were asked if they are undertaking any additional preparations in the current year and if so, the same lists of actions were presented.

2.3. Analytical methods and regression models

We use descriptive statistics and regression models to study the survey responses. We first provide descriptive statistics and figures that characterize prior experience with wildfires (in terms of poor air quality, power outage, facing the need to evacuate their home and home damage). We estimate two sets of regression models to assess the determinants of risk perceptions and of actions. The first set of models seeks to understand how perceived risk of wildfire relates to previous wildfire experience when controlling for demographic and other geographically specific information.

We run a linear regression formulated as follows:

$$\begin{aligned} perceived\ risk_i = {} & \beta_0 + \beta_1 prior\ experience + \beta_2 household\ income\ below70k + \beta_3 highschool\ or\ less \\ & + \beta_4 nonwhite + \beta_5 homeowner + \beta_6 republican + \beta_7 livelihoodland + \beta_8 yearsinhome \end{aligned}$$

Here, we treat perceived risk as a continuous outcome variable and previous experience related to wildfire impacts is a binary explanatory variable. To understand differences between type of prior experiences and perceived risks, we use the same model formulation with i representing any wildfire impact, air quality, evacuation, home damage, and power outage. Household income below $70k, high-school or less, non-white, homeowner, republican, and livelihood land[10] are all binary variables that take the value 1 if the conditions in the name of the variable hold, and 0 otherwise. Years in home is treated as a continuous variable for the number of years lived in the home[11].

The second set of models tests the chance of respondents taking an action to reduce or cope with risk given a perceived risk level and other demographic and contextual variables using a logistic regression as follows:

$$action_i = \beta_0 + \beta_1 perceivedrisk + \beta_2 household\ \ income\ \ below70k + \beta_3 highschool\ \ or\ \ less + \beta_4 nonwhite + \beta_5 homeowner + \beta_6 republican + \beta_7 livelihoodland + \beta_8 yearsinhome$$

The outcome variable, actions taken, is a binary variable (0/1) for any action taken in the given model category. The categories (i) correspond with the previous set of models—*any action, home protection* (creating defensible space, retrofitting home, checking insurance adequacy), *air quality* (air filters, smoke protecting masks, checking measures of air quality), *essential services* (installing backup power), *evacuation* (preparing transportation, 'go bags', securing a place to stay). See SI table S1 for relationship between wildfire impacts and actions. Independent variables included an average value for the respondent's perceived likelihood of risk i, and binary variables for household income below $70k, high-school or less, non-white, homeowner, republican, and livelihood from the land and a continuous variable for the number of years that the respondent has lived in the home (i.e. the same variables as in the *perceived risk* model). We model action as a logistic regression, estimating the probability of action taken. To test for collinearity in all models, we use Spearman's rank for correlations between covariates and find most variables are weakly or not correlated. The highest correlations are between homeowner and income (0.375). The full table of correlations is provided in SI table S2.

Since we also aimed to explore the influence of the geographical risk on risk perception and on the likelihood to take action, in the SI, figures S1–S3 and table S3, we include the results for participants that live in the moderate-high wildfire hazard potentials (WHP, see data and methods section and SI for details) versus other WHP zip codes.

3. Results

We organize the results by following the key aspects shown in figure 1, where we display our conceptual framework. We start by reporting participants prior experience with wildfire risks (and, more specifically, in terms of having experienced poor air quality, power outages in their home, school closures or home damage because of a wildfire). We then display participants perceived probability of experiencing these same issues because of future wildfire occurrences, i.e. we elicit their risk perception. We then focus on summarizing the risk reduction or risk coping actions that participants have pursued in the past because of experiencing a wildfire. Then, to better understand the drivers of perceived risks and actions, we run the regressions in the data and methods section, and report on the respective results.

3.1. Prior experience with wildfires

In figures 2 and 3, we show the percent of participants that report having experienced or perceiving that they will experience poor air quality, power outages, school closures or home damage because of a wildfire. We find that 70% of all participants experienced poor air quality, 39% experienced a power outage in their home, 18% experienced a school closure, 16% had to evacuate their home, and 6% experienced home damage in this period.

3.2. Risk perceptions

Regarding participant's perception of risks associated with future wildfire occurrences, the median response is that there is around a 0.68 probability of experiencing poor air quality impacts, the median for the chance of facing a power outage in their home due to wildfires was 0.33, the median of the likelihood of

[10] 'Livelihood on land' refers to a question about whether the respondents have a source of income based on the land they live (example: farmer, rancher, vineyard). The theory here is that protection behaviours might differ if they both live and derive their livelihood from their land.

[11] Median household income is defined as at or below 80% of the statewide median income (California Department of Housing and Community Development). For California, the median household income in 2021 was $84 907 (California Department of Finance). For our analysis, we use a low-income threshold of below $70 000 and are not adjusting for household size.

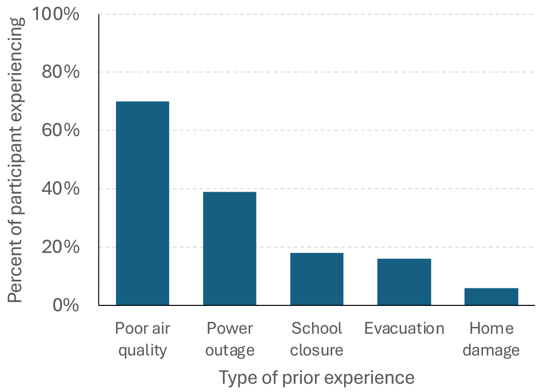

Figure 2. Percent of respondents that report having experienced poor air quality, power outages, school closures or home damage because of a wildfire in 5 years up to the survey.

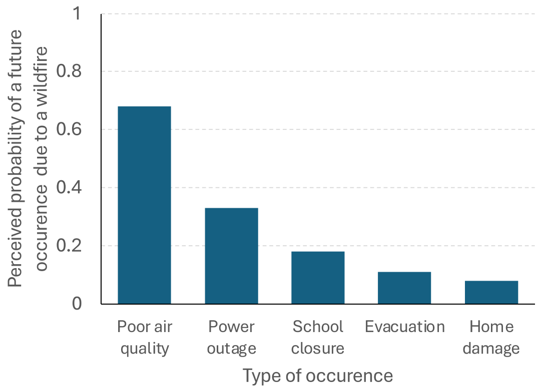

Figure 3. Median response across participants for the perceived risk of experiencing future wildfire related poor air quality, power outage, school closures or home damage. Respondents used a 100-point slider scale to address this question.

experiencing a school closure was 0.18, the median probability to need to evacuate their home in the coming fire season was 0.16, and the median probability of damage to home across participants was 0.08.

3.3. The role of actions to reduce wildfire risk

In response to our questions in the survey about actions undertaken to reduce air quality risks associated with wildfires, we found that 48% of our participants reported purchasing or building air filters, 32% of respondents reported purchasing smoke-protecting masks, and 37% reported using informational air quality tools, such as the air quality index (AQI).

Regarding actions that are associated with reducing the risk of suffering a power outage in the home, 27% of respondents reported that they have back up power.

Despite low number of reported prior experiences and the low perception of likelihood for the need to evacuate, a relatively large percent of respondents has taken actions to prepare for evacuation—41% packed a 'go bag' and 32% arranged a place to stay in case of evacuation.

Regarding actions associated with reducing the risk of property damage, 35% reported having created a defensible space, and 18% have pursued retrofits to their house.

Finally, when asked about actions they would like to take but are too costly, many respondents cited installing backup power, finding a place to stay in case of evacuation, and retrofitting their home (SI, figure S4).

In the SI, table S4 we display the summary of these results in tabular form.

3.4. The role of prior experience in determining perceived risk and actions

In figure 4, we associate the responses regarding prior experience, perceived risk and action to illustrate key patterns. In section 3.4 we then analyse these relationships more formally using regressions. In panels A to C of figure 4, 'Experience' is the share of respondents that reported experiencing either poor air quality (panel A), have suffered a power outage in their home because of a wildfire (panel B), or have previously faced the

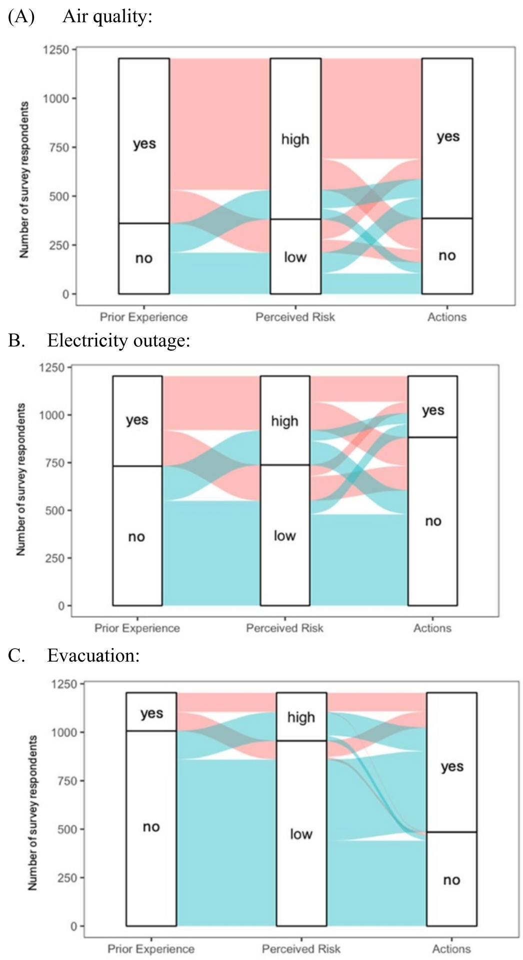

Figure 4. In A, B, and C 'Experience' represents the number of survey respondents that reported experiencing either poor air quality (panel A), having suffered a power outage in their home because of a wildfire (panel B), or having previously faced the need to evacuate due to a wildfire (panel C). 'Perceived risk' represents the number of survey participants reporting that their perceived risk of suffering poor air quality (panel A), their perceived risk of facing a power outage in the house (panel B) in the fire season during which the survey was fielded, or their perceived risk of needing to evacuate from the home (panel C) was higher than 50% ('high') or smaller than 50% ('low'). 'Action' in panels A to C shows a count of 1 for each survey respondent that has undertaken at least one action associated with reducing the risks associated with poor air quality due to the wildfire (panel A), has undertaken an action to protect its home from potential damage (panel B), or had pursued actions to address a potential power outage in the house (panel C).

need to evacuate due to a wildfire (panel C). The number shown in that part of the figure are the same as those shown previously as percentages in figure 2.

The 'Perceived risk' in panels A to C in figure 4 represent the perceived risk of suffering poor air quality (panel A), the perceived risk of facing a power outage in the house (panel B), and the perceived risk of needing to evacuate from the home (panel C) in the fire season during which the survey was fielded. If the respondents' reported perceived risk was higher than 50%, it is codified as 'high' in the figure, otherwise, it is codified as 'low'.

'Action' in panels A to C from figure 4 show yes if a participant had undertaken at least one action associated with reducing the risks associated with poor air quality due to the wildfire (panel A), pursued actions to address a potential power outage in the house (panel B), or undertook an action to protect its home from potential damage (panel C).

Panel A shows that most respondents (843 respondents; 70% of survey respondents) previously experienced poor air quality because of a wildfire, and that many (822 of our survey respondents or 68%) reported a probability of more than 50% that poor air quality would also arise in the fire season during which the survey was fielded. A correspondingly high percent of respondents took some action to reduce or cope with this risk (818 respondents took at least one action to reduce the risk associated with poor air quality).

Panel B shows that 472 survey respondents (or 39% of all survey respondents) experienced power outages in their homes due to wildfire. 466 respondents (or 39% of all survey respondents) believe the probability of experiencing power outages and other service interruptions in their homes during the fire season when the

Table 2. Results from OLS regression of perceived risk variables (any, air quality, evacuation, home damage, power outage) as a function of prior experience and other variables. See section 2.3 for model details.

	Dependent variable: perceived risk				
	Any (1)	Air quality (2)	Evacuation (3)	Home damage (4)	Power outage (5)
Prior experience (i)	10.689***	28.593***	33.819	28.079***	25.746***
	(1.557)	(1.787)	(1.902)	(2.974)	(1.695)
Household income below $70 000	−0.893	3.381**	−2.284	−2.574*	1.568
	(1.236)	(1.695)	(1.449)	(1.447)	(1.737)
High school or less	−0.120	−4.433**	1.781	2.163	−0.646
	(1.434)	(1.966)	(1.679)	(1.707)	(2.016)
Non-white	0.403	−2.363	2.104	2.580*	0.045
	(1.213)	(1.667)	(1.421)	(1.443)	(1.704)
Homeowner	4.047***	0.128	5.497***	3.910***	5.185***
	(1.268)	(1.738)	(1.482)	(1.508)	(1.780)
Republican	0.505	0.613	−0.326	−0.030	1.407
	(1.459)	(2.000)	(1.713)	(1.739)	(2.051)
Livelihood from land	15.225***	0.983	18.229***	21.163***	13.874***
	(1.807)	(2.506)	(2.155)	(2.212)	(2.540)
Years in home	0.006**	0.0005	0.013***	0.003	0.005
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	21.684***	42.813***	14.177***	13.461***	22.998***
	(1.891)	(2.324)	(1.669)	(1.680)	(2.085)
Observations	1204	1204	1204	1204	1204
R^2	0.124	0.195	0.225	0.196	0.202
Adjusted R^2	0.118	0.190	0.220	0.191	0.197
Residual Std. Error	20.224	27.719	23.703	24.088	28.429
F Statistic	21.109***	36.176***	43.452***	36.393***	37.929***

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

survey was fielded was more than 0.5. However, only 26% of survey respondents had taken actions to back up their power and lessen the consequences. This may be because this type of risk is 'high probability/ low consequence', namely when compared to other wildfire related risks, such as property damage and loss of life, as well as differences in the cost and effectiveness of different risk reduction strategies.

Panel C shows that few survey respondents had prior experience with needing to evacuate their homes due to wildfires (197 respondents, or 16%) and participants also believe the risk associated with the need to evacuate is relatively low (956 respondents thought the probability that they would need to evacuate from their home was less than 0.5). However, this is likely perceived as a 'low probability/ high consequence' type of event, as many respondents reported taking actions to prepare for an evacuation (719, or 60% of survey respondents).

3.5. Assessing the relative importance of different factors in perceived risk and action

To further explore the relationship between risk perception and risk reducing or coping actions with prior experience to wildfire, demographic characteristics and other potential drivers, we run a series of regression models. As described in section 2.3, we run regression models for both perceived risk and the decision to take action.

Table 2 shows the results of linear regression models for the relationship between perceived risk and experience to wildfire as well as key demographic variables for four impact categories. The model coefficients for experience quantify the increase in perceived risk from having been exposed to wildfire impacts, controlling for all other independent variables in the model. We find that perceived risk is statistically significantly associated with prior experience with wildfire impacts across the different impact categories, controlling for all other independent variables in the model. The association is largest in magnitude for air quality and home damage, with a 29% and 28% increase in perceived risk with experience respectively. Perceived risk of home damage, loss of electricity and evacuation are also statistically correlated with homeownership and respondents who generate part of their livelihood from their land.

Next, we employ logistic regression models to study the relationship between the decision to take specific risk reducing or risk coping actions and perceived risk as well as other demographic and contextual variables as described in section 2.3. The estimated coefficients describe an increase in the log-odds of the outcome

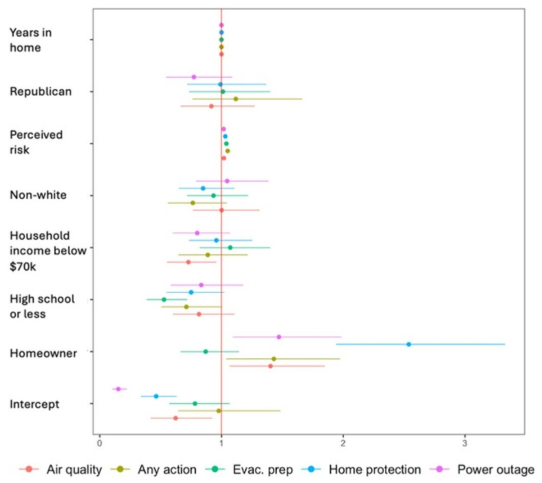

Figure 5. Results of logistic regression of taking action (any, air quality, evacuation, home damage, power outage) as a function of perceived risk and other variables. Displayed as odds ratio-exponential function of logistic regression estimate. See section 2.3 for model details.

variable per unit increase in the independent variables. The exponential function of the coefficient is therefore the odds ratio associated with a unit increase in the independent variable (for continuous variables) or with the alternate category of the independent variable compared to its default (for binary/categorical variables). For ease of interpretation, we summarise the results in figure 5 using odds ratios (dots) and their 95% confidence intervals (whiskers). Estimates are significant at the $\alpha = 0.5$ level if the confidence interval does not cross 1 (vertical red line). SI table S5 provides full regression estimates.

Here we provide the interpretation for air quality to make the results more tangible to the reader before exploring the overall findings: for example, we find that a 1% increase in perception of risk correlates with a very slight (1.02 times) increase in the chance of taking action to cope with poor air quality. The odds of taking actions are lower (0.73 times) for a respondent with household income less than $70 000. The odds of acting are higher for homeowners (1.4 times) and respondents who derive livelihood off their land (8.02 times). No other estimates are statistically significant predictors of taking actions related to air quality.

Across all models, deriving livelihood from the land largely and significantly increases the odds of acting. At the least, it increases the odds of taking actions to protect against power outages by 2.37 times and at most, it increases odds of taking home protection measures by 10.28 times. This variable is not shown in figure 5 due to its larger scale, but a full table of results is shown in SI table S6.

Homeownership likewise largely increases the odds of taking actions related to air quality (1.4 times), home protection (2.54 times), power outages (1.47 times) and the aggregate estimate of any action (1.43 times). While the association between higher perceived risk and action is positive and statistically significant in all models, the increase in the odds is small.

4. Discussion and conclusions

In this paper, we aim to improve our understanding of the experience of California residents with wildfires, how they perceive wildfire risk, and what drives them to take actions to reduce the risks associated with wildfires.

Some of our key findings are that a large portion of our survey participants experienced poor air quality and acted on it via using air filters, smoke-protecting masks and checking air quality levels. Many also experienced a loss of electricity in their home, and there too we found that some action had been taken by installing back-up power. Despite low number of reported prior experiences and the low perception of likelihood for the need to evacuate, a relatively large percent of respondents has taken actions to prepare for evacuation by packing a 'go bag', securing a place to stay in case of evacuation, and creating a defensible space around their home. Finally, when pursuing a regressions analysis that controls for several independent variables, we find that while the perception of risk is associated with action, other factors, such as being a homeowner or deriving livelihood off their land are much more likely to drive people to act.

This provides useful evidence to the literature, which has been divided on the impact that wildfire experience has on risk perception (Blanchard and Ryan 2007, Schulte and Miller 2010, Fischer 2011, Champ and Brenkert-Smith 2016, Dupey and Smith 2019, Spano *et al* 2021). We hypothesize that part of the reason we find an association between risk perception and action—albeit small—is because other studies were conducted several years ago, and the salience regarding the severity of wildfire has increased in recent years. In fact, when we asked in the survey about when respondents began worrying about the risk of wildfire, over half of them reported that they began worrying in or after 2015 (SI figure S3). Our results indicate that both the severity of the potential impact and the cost of undertaking action to reduce the risk from wildfires seem to weigh into an individual's decision making.

Currently, there are policies in place to encourage or require risk reduction actions. In 2008, the California Building Standards Commission established a comprehensive statewide ignition-resistant building code (California Building Standards Commission 2007), which requires that all new construction in CAL FIRE designated high-risk zones has to be built with fire safe materials and construction. Post-2008 homes have increased chances of wildfire survival over pre-existing housing without hardened features (Baylis and Boomhower 2021, CCST 2020). However, for houses constructed before the 2008 code, retrofits can cost up to tens of thousands of dollars (Quarles and Pohl 2018). The Home Hardening Program, a newer program established by the California Governor's Office of Emergency Services, provides financial assistance for home hardening with a focus on low- and moderate-income households (CAL OES Home hardening program). The program is still in a pilot phase but may fill an important gap for costly retrofits, especially for those without the resources to undertake home hardening themselves. State and local laws also require defensible space in high-risk areas up to 100 feet around the structure with more intense fuels management within the first 30 feet (CAL FIRE 2023). While there exist penalties for non-compliance, there is no state-wide auditing and evidence suggests that not all homes are up to requirements (CCST 2020). Other risk-reduction measures, such as evacuation planning and smoke protection do not fall under any existing legal requirements. However, there are many educational campaigns, such as CAL FIRE's 'Ready, Set, Go!' and California Office of Emergency Services' 'Listos California,' providing information on how to prepare for and respond to wildfire alerts (CAL FIRE 2024, CAL OES 2024).

Our results indicate that USFS-designated measures of risk and existing requirements for those in high-risk areas to undertake risk reduction actions may not be sufficient to motivate behavioural changes. Given the relatively high rate of evacuation actions taken, despite a low perceived risk, and our finding of a small association between risk perception and actions, it may be the case that education on how to reduce risk is more effective than improved messaging on risk itself. Further, given that ease and cost of action seem to relate to likelihood of adoption, public resources should prioritize support for effective but high-cost actions.

This study contains limitations that may influence our results but can inform future research directions. Ideally, we would have more granular risk estimates to compare to perception of risk. Second, we conducted the survey amid the 2021 fire season. We suspect that perceived risk of future impacts may be higher when asked during fire season when impacts are particularly salient. We did not separate experience to wildfire in the 2021 wildfire season from previous years but geospatial analysis of responses in historical fire footprints could provide additional insights. Despite the above limitations, this study provides useful and updated evidence on the determinants of household wildfire adaptation.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors. The survey response data cannot be publicly available as to ensure respondents individual privacy is met as stated in the survey consent form.

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