Modeling Evacuation Decisions in the 2019 Kincade fire in California

Erica D. Kuligowski[a*], Xilei Zhao[b], Ruggiero Lovreglio[c], Ningzhe Xu[b], Kaitai Yang[b], Aaron Westbury[a], Daniel Nilsson[d], Nancy Brown[e]

[a] RMIT University, 124 La Trobe Street, Melbourne, Vic 3000, Australia
[b] University of Florida, 1949 Stadium Road, Gainesville, FL 32611, USA
[c] Massey University, Private Bag 102904, North Shore Auckland 0745, New Zealand
[d] University of Canterbury, 69 Creyke Road, Christchurch 8041, New Zealand
[e] Sonoma County Department of Emergency Management, 2300 County Center Dr 220 B, Santa Rosa, CA 95403, USA

*Corresponding author: erica.kuligowski@rmit.edu.au

Abstract:

Communities around the world are increasingly exposed to larger and more intense wildfires. A common method that officials use to protect community members from harm is evacuation. Data on how people behave during wildfires is critical when planning for evacuation and deciding when and how to evacuate entire communities during an event. Using a similar method to the 2016 Chimney Tops 2 Fire study, an online survey was conducted with households impacted by the 2019 Kincade fire in Sonoma County, California. The survey measured pre-event and event-based factors to 1) predict household perceptions and evacuation decisions and 2) compare results across fire events. Regression analysis identified the factors that influenced risk perception at the time of evacuation decision, i.e., pre-fire perceptions of safety, household makeup (of adults, pets, and livestock), income, education and threat assessment. Logistic regression analyses found that risk perception, length of residence, household makeup, income, education, evacuation order, fire cues, pre-fire perceptions of the safety, and homeownership influenced evacuation decisions. These results differ widely from the 2016 fire due to differences in fire conditions and experiences across populations. Results from this work bring the field closer to a generalized theory of human behavior during wildfire evacuation and improve community-wide evacuation planning and real-time decision-making.

Keywords: wildfires; evacuation; egress modeling; decision-making; WUI; bushfires

1. Introduction

Wildfire is a growing threat to communities across the United States and around the world (Liu et al. 2010). The intensity and frequency of and the social harm due to wildfires have increased in recent years, largely as a result of climate change (Bowman et al., 2020). Meanwhile, urban and suburban growth has led to the expansion of the wildland-urban interface (WUI), making more communities vulnerable to wildfire risks (Radeloff et al., 2018). A common policy across countries to protect community members from harm is to evacuate them from exposed areas before fire conditions become life-threatening. While critical for evacuation planning and real-time decision-making, data on how people behave during wildfires is scarce (Kuligowski, 2020). In turn, planners or fire officials have little choice but to rely on past experiences or rules-of-thumb regarding evacuee behavior.

Therefore, a study was performed on household evacuation during the Kincade fire, which impacted Sonoma County, California, from October 23, 2019 to November 6, 2019 and led to the evacuation of approximately 200,000 residents and tourists (Wong et al., 2020a). The main research question in this study is what factors influenced people exposed to the Kincade fire to a) perceive a certain level of risk to themselves and/or others and b) decide to evacuate (or stay in place)?

This study provides new empirical evidence on household evacuation behavior. By studying factors that influence evacuation decisions and increasing our understanding of the role of risk perception in the decision-making process, this work confirms and expands the current theory on evacuation during wildfires. Also, and particularly because similar methods were used, additional contributions of this work include a comparison of the results from this study with those from the 2016 Chimney Tops 2 fire (Kuligowski et al., 2020), where applicable.

A more comprehensive and generalized theory of household evacuation behavior during wildfires can eventually assist communicators in targeting preparedness messages more effectively and planners and fire officials in making more informed decisions to protect residents both before and during fires. A primary example of this benefit involves the evacuation simulation models currently used for pre-event planning and real-time decision-making. These models lack underlying behavioral theory and algorithms (Kuligowski et al., 2020), and in turn, can grossly underestimate evacuation clearance times, the location or intensity of congestion points, and the overall effectiveness of optimal evacuation routes. Incorporating realistic household behaviors will allow for more accurate official plans and decisions, which can in turn, increase the resilience of communities exposed to fire events.

The paper is structured as follows: Section 2 presents a literature review of both modeling techniques to predict evacuation decision-making during wildfires and the factors found to influence risk perception and evacuation decisions. Section 3 describes the study's methods, including the study site, sampling strategy, final sample, survey instrument, and analysis methods. Section 4 provides the quantitative results from the survey as well as the results from a thematic analysis of participants' end-of-survey comments (offered by participants when asked if they would like to say anything else about their experience with the Kincade fire). Section 5 presents discussions on how these results compare with other research, a more specific

comparison between these results and results from another fire using the same methods, limitations of this work, and future research directions. The paper concludes with Section 6.

2. Literature Review

Many studies have used different modeling techniques to predict evacuation decision-making during wildfires. Early studies on wildfire evacuation behavior were mainly focused on descriptive analysis (Benight et al., 2004; McCaffrey and Winter, 2011) that simply identified the percentages of respondents who had certain traits, held certain perspectives, or performed certain actions. In contrast, and more recently, discrete choice models have been used to investigate the impact of multiple factors on a particular decision or behavior. These models have been employed to predict binary results (e.g., whether people will evacuate or stay and defend), including the use of bivariate probit models to estimate the probability of evacuation from households in a community in New Mexico, US (Mozumder et al., 2008) as well as binomial logit models to study evacuation decision-making after a wildfire in Haifa, Israel (Toledo et al., 2018), a 2014 and 2015 wildfire in Perth and Adelaide Hills, Australia (Strahan et al., 2019), wildfires in California in 2017 and 2018 (Wong et al., 2020b), and the 2016 Chimney Tops 2 fire in Tennessee, US (Kuligowski et al., 2020). In the same study, Kuligowski et al. (2020) also used linear regression modeling to predict increased levels of risk perception (at the time of evacuation decision).

In addition to binary models, multinomial logit models have been used to identify the factors that impacted the final decision to wait and see, leave early, or stay and defend in three U.S. locations (McCaffrey et al., 2018) and to identify distinct classes of evacuees within exposed areas in Western Australia (McNeill et al., 2015). Different from the maximum utility assumption of discrete choice models, Wong et al. (Wong et al., 2020c) designed a regret-based model and evaluated its performance by assuming people's decision-making is more likely to minimize their regret. Conceptual models based on the Protective Action Decision Model (PADM) (Lindell, 2017; Lindell and Perry, 2012), a generalized multi-hazard model, have also been developed to attempt to culminate the many factors influencing multiple states of the decision-making process (Folk et al., 2019). Finally, Lovreglio et al. (2020) introduced a hybrid choice wildfire decision model developed from Strahan et al. (2019), which was calibrated based on Kuligowski et al.'s (2020) study of the 2016 Chimney Tops 2 fire.

Evacuation decisions in wildfires have also been studied using qualitative methods. Researchers have used inductive, thematic analyses to interrogate rich and detailed respondent transcripts and elicit factors that influenced wildfire evacuation behavior (McCaffrey et al., 2015; McLennan et al., 2012; Whittaker et al., 2017). McGee and Langer and McGee et al. (2019; 2019) have also identified the importance of qualitative methods when performing wildfire evacuation research with Indigenous Peoples, due to its ability to capture the oral nature of Indigenous knowledge. Whereas qualitative studies have been used to provide additional insights into perceptions and experiences difficult to capture through survey research alone; some research has embraced the benefits of a mixed-methods approach where both quantitative and qualitative data are collected and analyzed; e.g., (Whittaker et al., 2016).

2.1 Factors that Influence Evacuation Decisions

Previous studies primarily focus on identifying the factors that influenced the decision to evacuate. First, preparation actions were found as influential. Studies found that having a plan to evacuate (Kuligowski et al., 2020; McLennan et al., 2012) influenced the decision to evacuate during a fire event; whereas having a plan to stay (McLennan et al., 2013) or performing mitigation actions to reduce the risks of wildfire, led to decisions to stay and defend (Kuligowski et al., 2020; McCaffrey et al., 2018; Strahan and Watson, 2019).

People's decision-making during a wildfire has also been linked to their previous experiences. Studies have found that experiencing property damage from a previous wildfire (Mozumder et al., 2008) and evacuating in previous disasters (Strawderman et al., 2012) increased the probability that households would evacuate in future events. However, experience with previous alarms deemed as unnecessary led to lower probabilities of evacuation (Whittaker and Handmer, 2010). Benight et al. (2004) indicated that such experiences did not have a significant influence on future decisions.

Studies also found that the type and number of warnings and cues received were related to residents' decision-making. Receiving mandatory or voluntary orders increased the probability of evacuating (Strawderman et al., 2012; Wong et al., 2020b), especially if they were provided by a trusted source (Kuligowski et al., 2020). Also, receiving advice from neighbors, friends and family influenced the decision on whether to evacuate (Whittaker et al., 2016)[1]. McLennan et al. (2012) indicated that visible smoke, ember, flames, and information of the fire's location were associated with major decisions. Also, McCaffrey et al. (2018) found that people who chose to wait and see relied on these physical cues to determine whether evacuation was necessary or not.

Individual and household characteristics can influence people's evacuation behavior. Gender (men), age (older individuals), and income (lower) were linked to a higher likelihood to stay and defend (Alsnih et al., 2005; Eriksen et al., 2010; Kuligowski et al., 2020; Paveglio et al., 2014; Whittaker et al., 2016). Other studies found that residence time, i.e., long-term residents and having pets or livestock had negative relationships with evacuation (Mozumder et al., 2008; Wong et al., 2020b), and families with children were more willing to evacuate (McLennan et al., 2012; Wong et al., 2020b).

Finally, the characteristics of the home and the perceived safety it provides could influence decisions. Emotional attachment to the home and/or personal responsibility for protecting their property (McLennan et al., 2013), as well as perceptions that staying in place was an effective way to minimize risk (McCaffrey et al., 2018), increased the likelihood to stay in place; however, not all studies agree (McLennan et al., 2012).

[1] It is important to note that there are differences in evacuation policies between countries, including countries that are studied in the references included in this section. In the United States, evacuation is mandatory under "evacuation orders" and non-compliance could lead to penalties (e.g., fines); whereas in Australia, evacuation is recommended but not required. Also, the policy in Australia is for people to leave early, even before fires start and/or become imminent.

While it is important to identify the factors that directly influence evacuation decision-making, the theory posits that evacuation decisions are the result of a decision-making process that eventually leads to a decision to take protective action or not (Lindell, 2017). According to the Protective Action Decision Model, a generalized multi-hazard model, people are more likely to take protective action after perceiving a credible threat (i.e., threat identification) and then, once that threat is assessed, perceiving risk to themselves or others (i.e., risk perception) (Lindell and Perry, 2012). In line with this theory, several studies have found a significant relationship between higher levels of perceived risk and the decision to evacuate in fires (Kuligowski et al., 2020; McLennan et al., 2015; Mozumder et al., 2008; Strahan et al., 2019; Strawderman et al., 2012; Wong et al., 2020b); however, not all studies agree (Paveglio et al., 2014).

Even with this established relationship, little research has been performed to identify the factors that influence threat and risk perception directly (Kuligowski, 2020). Studies have found that residence time (i.e., a shorter length of time living in an area), experiencing property damage from a previous fire, and increased fire knowledge can lead to higher perceptions of threat/risk (Benight et al., 2004; Mozumder et al., 2008). Additionally, witnessing a range of environmental cues may increase threat and risk perceptions; e.g., witnessing others evacuating (McLennan et al., 2012), perceiving fire cues – such as flames or embers (Kuligowski et al., 2020), and obtaining information about the fire's location and intensity from a trusted source (McLennan et al., 2013). Last, significant relationships were found by Mozumder *et al.* (2008) between higher income or education level and an increased perception of risk. See Kuligowski et al. (2020) for a table of hypothesized relationships between factors and the two dependent variables in this study: risk perception (at the time of evacuation decision) and the evacuation decision.

2.2 Literature Gaps and Study Hypotheses

Additional research is needed on the factors that first influence risk perception at the time of evacuation decision, and then how risk perception as well as other factors ultimately influence households' decision to evacuate. Therefore, this research focuses specifically on predicting risk perception and exploring its role as a predictor of evacuation decisions, among other factors. Also, where applicable, there is interest in understanding similarities and differences among fires, especially in cases where similar methods are used.

The overarching hypotheses of this study are as follows:

1. Significant relationships will be found between *risk perception* and the following factors: prior threat perception (or awareness), previous experience with fires, length of residence, social cues (including warnings), environmental cues, threat assessment (in the current fire), and sociodemographic factors.
2. The following factors will influence *evacuation decisions*: preparedness (including evacuation planning) and perceptions of safety, length of residence, previous experience, social cues (including warnings), environmental cues, risk perception (in the current fire), and sociodemographic factors.
3. Similar factors will be found as influential in the 2019 Kincade fire as were found in the 2016 Chimney Tops 2 fire (Kuligowski et al., 2020).

3. Methods

This study used a similar approach to data collection and analysis as the study performed by Kuligowski et al. (2020).

3.1 Study Site

The Kincade fire ignited on October 23, 2019 in Sonoma County, California, coinciding with a large-scale power shutoff brought about by high winds the day before (County of Sonoma, 2020). Beginning in the northeast area of Geyersville in Sonoma County, the fire spread for 13 days (contained on November 6, 2019) and is documented as Sonoma County's largest fire in recorded history. While there were no fatalities, the fire burned 77,758 acres, destroyed 374 structures (including both residential and commercial), damaged another 60 structures, and injured five people (four fire personnel and one civilian). The cost of this fire is estimated to be approximately $620M USD, including both lost economic output and property damage (County of Sonoma, 2020).

Approximately 186,000 people were ordered to evacuate due to the Kincade fire over several days. Sonoma County (population just under 500,000) is divided into several evacuation zones, the majority of which were under evacuation order at some point in time during the fire event. While only a small area was evacuated on the day the fire began (Geyersville, population 874), three days later, on October 26th, 6 additional zones were evacuated, and by the following day (October 27th), a total of 10 zones (population of 186,651 people) were under evacuation order ("Kincade fire incident," n.d.).

At the time of the Kincade fire, the Ready, Set, Go! program provided guidance to the public on what to do when/if a wildfire approaches ("Evacuation Steps," n.d.). Under this program, people are instructed to leave "as soon as evacuation is recommended by fire officials" and to not necessarily wait until they are ordered by authorities to leave. Sonoma County issued both warnings and orders for various locations during the 2019 fire. An evacuation warning is meant to communicate "potential threat to life and/or property" and that people who require additional time to evacuate (not defined) and those with pets and livestock should evacuate immediately. An evacuation order, on the other hand, is meant to communicate an "immediate threat to life", that this is a lawful order to evacuate immediately, and that the area is "lawfully closed to public access" ("California OES Wireless Emergency Alerts," n.d.). California Penal Code 409.5 states that anyone who refuses to comply with evacuation orders is guilty of a misdemeanor ("California Code, Penal Code - PEN § 409.5," n.d.). It is unclear whether or not these sanctions were enforced during the Kincade fire.

Additionally, this fire occurred two years after the 2017 Central LNU Complex Fire in California, which included the Tubbs Fire. According to the Kincade Fire After Action Report, the 2017 fire had prompted changes to the emergency response system, including improvements made in alerting and warning the public and informing them of changing fire conditions, and in turn, "community compliance to preparedness efforts and evacuation orders exceeded those from previous fire incidents" (County of Sonoma, 2020, p. 3).

3.2 Sampling Strategy and Final Sample

An online survey of households in Sonoma County was conducted from October 22, 2020, until January 10, 2021. The survey was coded within the Qualtrics survey platform, and the research team advertised the survey via the following channels: local news outlets, Facebook, personal contacts, and local community groups (where an official within the County of Sonoma - Department of Emergency Management introduced the survey, its purpose and our request for responses). This online outreach yielded a total of 270 completed survey responses.

To ensure that study participants were directly involved in the 2019 Kincade fire and resulting evacuation decisions, the survey began with a screening question where people had to input the zip code of their location at the time of the fire. Only those with Sonoma County zip codes were able to take the survey.

The final sample of 270 participants was 77.4% female, with a median income of $75,000 - $99,999USD. The participants were predominantly white (90.7%) and had a median age of 55 to 64 years. The majority of participants (68.5%) owned their homes, had lived in the area for at least 5 years (21.1% for 5-10 years and 40.7% for 10+ years), and had pets or livestock at the time of the fire (79.6%). A minority (31.1%) reported having children at home. Our study sample was fairly similar in relation to racial makeup (86.8% white), compared with 2019 Census data for Sonoma County, CA (population ~494,336). The median household income of the sample was similar to the Census reported value (median of $81,018) ("U.S. Census Bureau," n.d.). Also, compared with Census data, our sample is older than the County's median age (42.1 years) and the sample's homeownership rate was higher than the County's reported rate (61.5 %). Figure 1 shows a map of the location (at the time of the fire) of the 270 survey respondents, mapped by zip code boundaries.

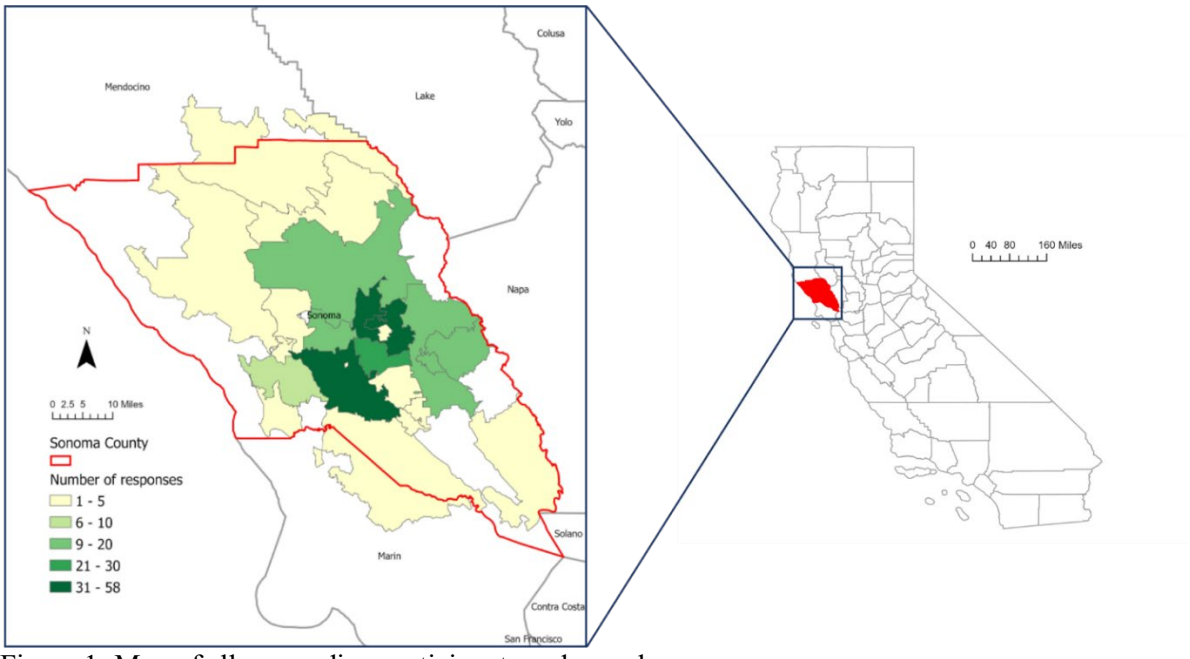

Figure 1: Map of all responding participants and sample area.

3.3 Survey Instrument

A survey was developed to collect household-level data on the factors identified as influential on risk perception and the evacuation decision. The survey used in this study was closely adapted from a previous study of the 2016 Chimney Tops 2 fire in Gatlinburg, Tennessee (Kuligowski et al., 2020). This was done to allow for comparison across the two datasets, where applicable. The survey used in both the 2016 Tennessee fire study and this study (2019 Kincade fire) were ultimately based on previously developed surveys used in evacuation studies of multiple hazards, e.g., (Sorensen et al., 2009; Sorensen and Mileti, 2018; Strahan et al., 2018).

The survey collected data on a number of variables, including sociodemographic factors, pre-event variables (e.g., previous experience and fire risk awareness), the types of warnings received, the types of fire cues perceived (e.g., smoke, embers, or flames), their level of risk perception (at the time of evacuation decision), and whether participants decided to stay in place or evacuate. See Kuligowski et al. (2020) for a list of the survey questions used in this analysis (note that "2019 Kincade fire" replaced all references to the "2016 Chimney Tops 2 fire"). Where the questions were substantially different or new to the survey used in this study, they are included in Table 1. A full list of survey questions can also be found on Github[2]. It is important to note that the survey asked the following question adapted from (Kuligowski et al., 2020) about their previous experience: *Before the Kincade fire, "how many times in the past 10 years (decade) did you evacuate your home /neighborhood /workplace (or other location) because of a wildfire"?* However, the variable was not used in the analysis because it did not have sufficient variation in responses (i.e., no one was inexperienced with evacuation).

This project received ethics approval from the University of Florida (#IRB201903432). All participants provided their consent before taking the survey.

Table 1 – New or revised survey items used in data analysis (as adapted from (Kuligowski et al., 2020)**). *Newly added or revised text is included in bold.***

Item	Item text	Scale or Response Options
Structure type (newly added)	***Which of the following best describes the type of structure of your residence?***	**Detached single family home; Multi-family, 1-2 stories; Multi-family, 3 or more stories; Mobile or manufactured home**
Pre-fire perception of safety (newly added)	***Please rate the extent to which you agreed or disagreed with each statement (before or at the time of the Kincade fire) – I believed that my home was well-built and safe for a wildfire; I believed that staying at home was safer than moving to a nearby building or shelter***	**1 (Strongly disagree) to 5 (Strongly Agree)**
Received official evacuation	***Before you decided to evacuate (or stay), did one or more emergency officials let you know that you***	Yes; No

[2] https://github.com/EvacuationBehavior/2019-Kincade-Fire-Survey-Study

order (revised from previous)	***had to evacuate immediately and/or that your area was under a mandatory evacuation order?***	
Received evacuation order (from any source) (revised from previous)	***Did you receive an evacuation order from any source (official or unofficial)?***[A]	Yes; No
Received evacuation order in-person (revised from previous)	***Did you receive an evacuation order from any source in-person (i.e., face-to-face)?*** [B]	Yes; No
Fire cues – Flames or embers (revised from previous)	***Before you decided to evacuate (or stay), did you see, hear, or feel flames or embers in your immediate vicinity (that is, your neighborhood)?***	**Yes, I observed flames in my vicinity; Yes, I observed embers in my vicinity; No, I did not observe flames or embers in my vicinity before making my decision**
Threat assessment at the time of decision (newly added)	***At the moment you decided what to do, how much did you believe each of the following statements? – 1) My home would be damaged or destroyed by fire; 2) My neighborhood would be damaged or destroyed by fire***	**1 (Did not believe) to 5 (Fully believed)**
Materials on the outside of the house[C] (newly added)	***Which of the following best describes the material(s) on the outside of your residence?***	**Brick; Fiber-cement siding; Stone; Stucco; Vinyl siding; Wood**
Roofing materials[C] (newly added)	***What type of roof materials did your residence have at the time of the fire?***	**Asphalt shingles; Clay or concrete tile; Metal roofing; Slate roofing; Wood shingles or shakes**

[A] *During data analysis, this question was developed from a combination of multiple survey questions: "Before you decided to evacuate (or stay), did one or more emergency officials let you know that you had to evacuate immediately and/or that your area was under a mandatory evacuation order?" and "Before you decided to evacuate (or stay), did someone you know tell you to evacuate or that a mandatory evacuation order was issued for your area?"*

[B] *During data analysis, this question was developed from a combination of two survey questions: (1) "What are all the ways that one or more emergency officials let you know that you had to evacuate immediately and/or your area was under a mandatory evacuation order?; and (2) Thinking about the person or people you just selected [Coworker, family member, friend, or neighbor], what were all the ways they told you to evacuate or that your area was under a mandatory evacuation order? Response options were as follows to both questions: Email message, face-to-face (in person), social media (such as Twitter and Facebook), telephone (landline or cell phone), or text message (on a mobile communication device such as cell phone). A respondent was assigned a "1" for this measure if they selected "face-to-face (in person)" for at least one of these two questions; and a "0" if they did not select "face-to-face (in person)" for both questions.*

[C] *These items were included for descriptive purposes and were not used in regression modeling.*

3.4 Data Re-coding and Analysis

The data used in this paper includes the responses from 270 participants. For some categorical variables, bins (i.e., alternative options) were combined to create more even distributions

between categories (e.g., “income” and “education”), and some demographic variables were recoded into categorical/binary to make the models easier to fit and interpret (e.g., “age”, “animals”, and “children”). More specifically, we recoded the numeric variables, i.e., number of children, number of elderly adults (65 years old and older), and number of pets and/or livestock or other farm animals, into binary variables, including children (yes/no), elders (yes/no), and animals (yes/no). Footnotes included in Table 1 provide information on the development of the warning-related variables. The “length of residence” variable was divided into three different variables, which represented short-term residents, mid-term residents, and long-term residents. The built environment variables such as “homeownership” were also made binary.

The variable “risk perception at the time of evacuation decision” was calculated by using the maximum likelihood factor analysis (the R library named ‘stats’ was used) to create item weights and a combined score for the variable’s four items (Brown, 2019). For the pre-fire perception of safety and the threat assessment variables, we simply averaged the scores for the two items within each variable to achieve their measures.

Note that “I don’t know or don’t remember”, “I prefer not to answer this question”, skipped (“”), and respondent typos were assigned with “NA” values. Among all the variables considered for modeling, we had missing values for preparation (2.2%), emergency plan (1.1%), pre-fire perception of safety (0.4%), homeownership (4.2%), age (1.9%), education (0.4%), and income (11.9%). We used mode imputation to replace missing values of the categorical variables with the mode of non-missing cases and mean imputation to replace missing values of a numeric variable with the mean of the observed values for the variable.

Completed survey responses were entered into R, version 3.6.2. This statistical tool was used to estimate descriptive statistics, correlations, and regression analyses. In terms of regression, we estimated (a) a multiple linear model to investigate the impact of multiple factors on the risk perception and (b) a binomial logistic model to investigate the impacts of multiple factors on the decision to evacuate. A binomial logistic model was selected here since discrete choice modeling represents the most popular statistical tool to predict discrete dependent variables such as the decision to evacuate (Train, 2009). While several discrete choice modeling solutions could have been used (e.g., from logit models to more complex modeling solutions such as random parameter models, latent class models, or hybrid choice models (Lovreglio et al., 2020; McCaffrey et al., 2018; Wong et al., 2020c)), a simple binomial logistic model is adopted since our aim was to investigate the impact of multiple factors on the decision to evacuate, rather than investigating latent structures or taste heterogeneity. The results of these two models are presented in Section 4 (Results).

As part of the analysis, a thematic analysis method (Braun and Clarke, 2006) was used to identify the central themes shared in the “end-of-survey” comments. Thematic analysis was performed to provide additional detail on participant perceptions and experiences oftentimes not captured by the survey’s closed-ended questions and responses. These were comments provided by respondents to the final question in the survey: *Please use the space below to tell us anything else you would like to say about your experience with the Kincade fire on October 23 to 28, 2019.* To begin, all comments were read by one team member to develop an initial list of codes. The initial codes were categorized within four themes, i.e., information/communication, the evacuation experience, fire aftermath, and general/survey feedback. Next, using Nvivo 12, two team members coded sets of 50 and 80 comments, and over several iterations, the themes, codes,

and codebook were further refined until the final versions were developed. As a check, intercoder analyses using two independent coders yielded a percent agreement of over 80%, and once that was reached, one team member coded all 192 comments (from the 270 respondents).

4. Results from the 2019 Kincade Fire

4.1 Descriptive Results and Correlations

The data show that a large majority of the sample (96%) was aware that wildfires "could be a problem in their community" before the Kincade fire. However, only 46% of the respondents believed in the possibility that wildfires would threaten *their* property. The majority of the respondents (76%) stated that they took different measures to protect their residence from wildfires prior to the Kincade fire and had household emergency plans for wildfires, with the most common plan among these to evacuate (67% of the full sample). In addition, when asked how many times in the past (prior to the Kincade fire) had they evacuated due to wildfire, none of the participants selected "zero times (I never evacuated before the Kincade fire)". Instead, 43% of respondents stated that they had evacuated at least once prior to the fire, and the rest (57%) either selected that they had evacuated more than once or that they did not remember how many times. Only 17% of the respondents believed that their home was well-built and sufficiently safe for a wildfire. Figure 2 shows how the respondents described their residences at the time of the fire.

The majority of the participants (73%) reported that one or more emergency officials let them know that they had to evacuate immediately and/or that their area was under a mandatory evacuation order. These orders were primarily received via the following channels (participants were prompted to "select all that apply"): text messages (64%); social media, such as Twitter or Facebook (36%); email messages (28%); telephone (landline or cell phone) with a recorded message (25%); outdoor warning siren (24%); and radio (21%). Few participants recalled receiving orders through methods such as face-to-face communications (in-person or door-to-door); loudspeaker or public address system; telephone (landline or cell phone) with a live person; television; and website (including streaming television, radio). Most of the participants (41%) remembered receiving their first order on October 26 or 27, 2019.

Some of the respondents (44%) were informed about the need to evacuate by someone they knew (e.g., coworkers, family members, friends, and neighbors). In this case, the most common channels were text messages (25%); telephone (landline or cell phone) (21%); and face-to-face (in-person or door-to-door) (16%). Less common channels were email messages and social media. Most of the participants (24%) remembered being informed by someone they knew on October 26 or 27, 2019.

In contrast, a small percentage of the sample (13%) reported receiving fire cues in their vicinity (as embers (7%), flames (4%), and both embers and flames (2%)) prior to making their evacuation decision. These fire cues were received mainly on October 23, 2019. Given the small percentages of respondents within each fire cue bin, these bins were combined into a single bin to carry out statistical analyses. As such, the fire cues variable includes all participants who saw embers, flames, or both.

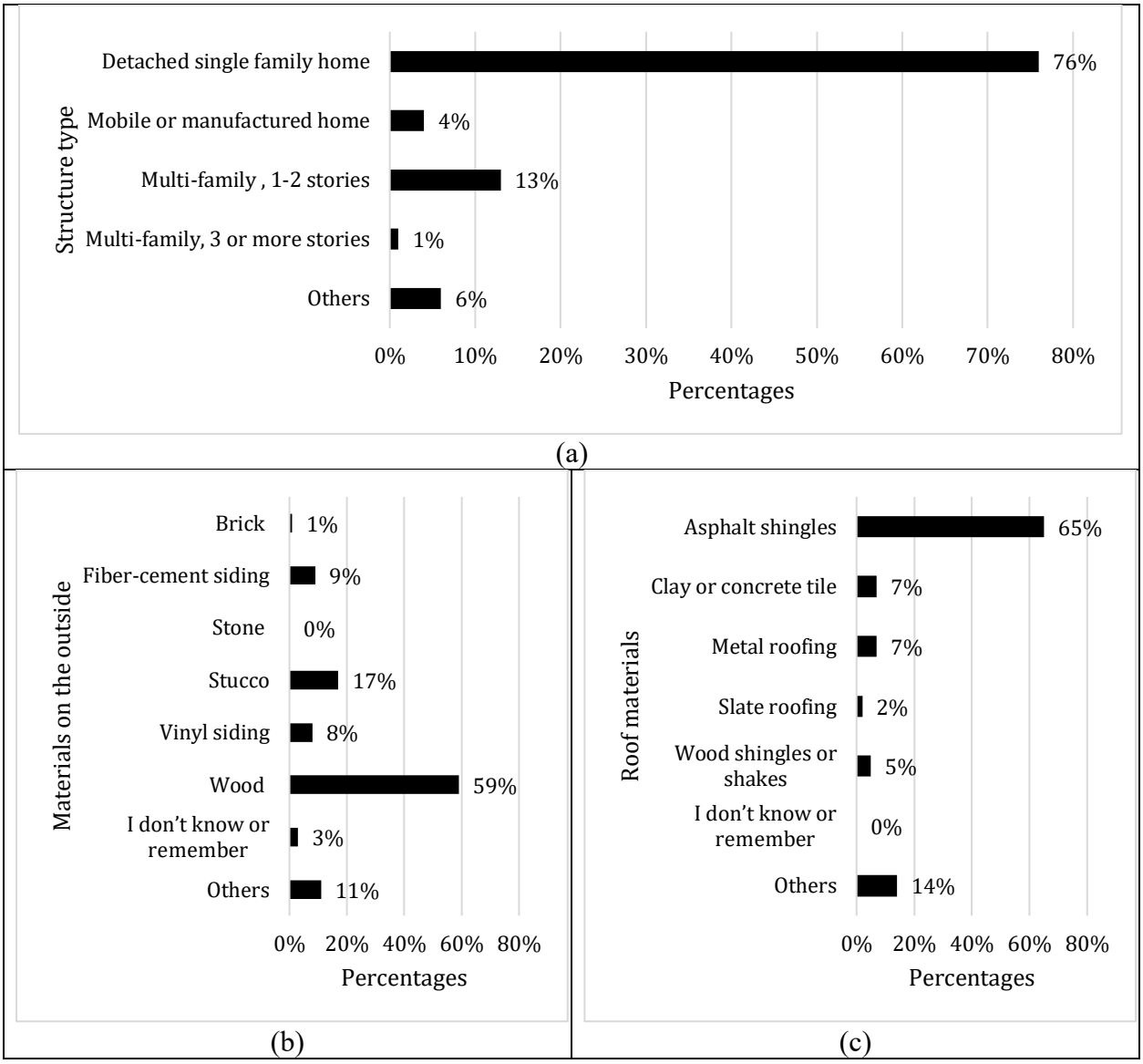

Figure 2: Descriptive statistics of (a) the structure type; (b) the materials on the outside of the residence; and (c) type of roof materials ($N = 270$).

The collected data shows that a majority of the respondents decided on evacuation (79%) as their main response to the Kincade fire. The majority of the sample (50%) made their decision on October 26 or 27, 2019. The mean level of risk perceived by the respondents, on a scale from 1 (no risk) to 5 (high risk), was 2.55 with a standard deviation of 1.52. Eventually, a slightly larger percentage (80%) of the respondents evacuated, while the remaining participants stayed in place.

As shown in Table 2, a preliminary correlation analysis was carried out to investigate which variables were correlated with risk perception (at the time of an evacuation decision) and the evacuation decision. The results indicate that risk perception is significantly correlated (i.e., p-value < 0.05) with threat assessment (0.424), prior awareness of the threat (0.139), observing fire cues (0.157), the number of adults in the household (-0.237), if the household had pets or

livestock (-0.137), if the household had a member with medical conditions (0.159), household income levels between 50k and 75k USD (0.168), the respondents' education level, and the respondents' perception of the safety of their home before the Kincade fire (-0.191). The decision to evacuate is significantly correlated (i.e., p-value < 0.05) with the risk perception (0.236), threat assessment (0.357), length of residence of fewer than 5 years (0.145), receiving an official evacuation order (0.191), receiving an order from either an official or unofficial source (0.204), the number of adults in the household (-0.162), the respondents' education level, and the perception of the safety of their home before the Kincade fire (-0.329).

Table 2: Correlations

	Risk perception (at time of decision)		Evacuation decision	
Prior awareness	0.139	*	0.095	
Preparation	-0.004		-0.078	
Emergency plan	0.062		0.036	
Residence: < 5 yrs	0.016		0.145	*
Residence: 5-10 yrs	0.030		-0.066	
Residence: 10+ yrs	-0.041		-0.088	
Own home	-0.066		0.048	
Detached home	-0.043		0.074	
Multi-family home	0.003		-0.046	
Mobile home	0.070		0.015	
Other home types	0.014		-0.084	
Pre-fire perception of safety	-0.191	**	-0.329	***
Children (yes)	-0.040		-0.025	
No. of adults	-0.237	***	-0.162	**
Elders (yes)	0.085		-0.027	
Animals (yes)	-0.137	*	-0.059	
Income: < $50,000	0.029		0.001	
Income: $50,000 – $74,999	0.168	**	0.038	
Income: $75,000 to $99,999	-0.039		-0.046	
Income: $100,000 - $124,999	0.049		0.067	
Income: $125,000 - $149,999	-0.085		-0.114	~
Income: $150,000 - $174,999	-0.060		0.049	
Income: >$175,000	-0.062		0.027	
Age: 18 – 44 yrs	-0.069		0.050	
Age: 45 – 54 yrs	0.060		-0.068	
Age: 55 – 64 yrs	-0.047		-0.055	
Age: 65+ yrs	0.069		0.062	
Gender (female)	0.094		0.111	~
Education: Associate degree	-0.102	***	-0.226	~
Education: Bachelor	-0.024		0.123	*
Education: Graduate	0.124	*	0.100	

Medical condition (yes)	0.159	**		0.053		
Official evacuation order	0.008			0.191	**	
Order: Official/unofficial source	0.071			0.204	***	
Order: In person	-0.014			-0.024		
Fire cues	0.157	**		-0.105	~	
Threat assessment	0.424	***		0.357	***	
Risk perception	/			0.236	***	
p-value:	**<0.001 *****	**<0.01 ****	**<0.05 ***	**<0.10 ~**		

4.2 Regression Models

A multiple linear regression model was estimated to identify the factors that influenced respondents' risk perception at the time they made their evacuation decision. The model was specified by adding the variables having a significant correlation with risk perception at a significant or marginally significant level of 0.10 (i.e., p-value<0.10) (see Table 2) and the variables found to be influential in the fire evacuation literature. Further, this study investigates if two built environment variables had an impact on risk perception: structure type and pre-fire perception of safety. To avoid multicollinearity issues, we computed variance inflation factors (VIFs), and found that all variables had VIF values less than 10 (i.e., an indicator that multicollinearity is not a major issue for this dataset). Therefore, all of the selected independent variables were included in the model.

The results of the multiple linear regression are illustrated in Table 3. Findings with a significant or marginally significant level of 0.10 (i.e., p-value<0.10) are included in bold. First, a marginally significant result was found for the pre-fire perception of safety variable in that the more the householders felt safe in their homes, the lower their levels of risk perception. Having a graduate degree also presented a marginally significant influence on their risk perception. The number of adults in the household and the ownership of animals had a significant impact in that they were linked to decreases in risk perception levels. The model also shows that household income had an impact on risk perception. In fact, respondents belonging to a household with an income between $50,000USD and $74,999USD had higher levels of risk perception when compared with other income categories. Further, higher levels of perceived threat were linked to higher levels of risk perception (both measured at the time of evacuation decision).

A binomial logistic model was estimated to predict the effect of multiple variables on the decision to evacuate (or not) (See Table 4). Similar to the multiple linear regression model, the logistic model was specified by adding the variables significantly correlated with the decision to evacuate (see Table 2) and the variables found to be influential in the fire evacuation literature. The logistic model in Table 4 shows that the probability of household evacuation increases with increasing risk perception levels. The model also illustrates that householders who lived in their house for less than five years (residence time) and/or owned their home at the time of the fire were more likely to decide to evacuate. Further, respondents receiving an evacuation order from a source (either official or unofficial) were more likely to evacuate. Unexpectedly, households who witnessed fire cues in their vicinity were more likely to stay; however, this relationship was only marginally significant. The modeling results show that householders within the income bracket of $125,000USD and $149,999USD were less likely to evacuate while they were more

likely to evacuate if they had a bachelor's or graduate degree (marginally significant. The number of adults in households had a negative impact on the probability of households evacuating. Finally, a households' pre-fire perception of safety also influenced decisions in that the more the householders felt safe in their homes, the less likely they were to evacuate.

Table 3: Linear regression of multiple factors on risk perception at the time of decision. Significant and marginally significant findings (p<0.10) are in bold

Variable	Estimate	Std. Error	*t* statistic	*p*-value
(Intercept)	-0.224	0.428	-0.523	0.601
Prior awareness	-0.026	0.048	-0.552	0.581
Residence: < 5 yrs[A]	-0.096	0.154	-0.621	0.535
Residence: 10+ yrs	0.009	0.151	0.059	0.953
Own home	-0.224	0.156	-1.438	0.152
Detached home[A]	-0.001	0.260	-0.004	0.997
Multi-family home	-0.182	0.292	-0.621	0.535
Mobile home	0.375	0.373	1.003	0.317
Pre-fire perception of safety	**-0.100**	**0.061**	**-1.649**	**0.100**
No. of adults	**-0.116**	**0.053**	**-2.199**	**0.029**
Animals (yes)	**-0.309**	**0.140**	**-2.216**	**0.028**
Income: $50,000 – $74,999	**0.431**	**0.214**	**2.011**	**0.046**
Income: $75,000 to $99,999	0.087	0.189	0.461	0.645
Income: $100,000 - $124,999	0.230	0.232	0.992	0.322
Income: $125,000 - $149,999	0.200	0.237	0.843	0.400
Income: $150,000 - $174,999	-0.076	0.259	-0.293	0.770
Income: >$175,000	0.248	0.229	1.086	0.279
Education: Bachelor[A]	0.036	0.139	0.258	0.797
Education: Graduate	**0.257**	**0.146**	**1.762**	**0.079**
Medical condition (yes)	0.055	0.128	0.426	0.670
Order: Official/unofficial source	0.216	0.133	1.619	0.107
Fire cues	0.189	0.176	1.071	0.285
Threat assessment	**0.287**	**0.054**	**5.322**	**0.000**

$N = 270$. $R^2 = 0.263$

[A] The base values for Income, Residence, Education, and Structure Type are Income: < $50,000, Residence: 5-10 yrs, Education: Associate degree (including high school and some college), and "Other home types", respectively.

To estimate model fit, the cross-validation of the proposed model indicates that the logistic model is capable of predicting 77.0% of the actual decisions made by the respondents.

Table 4: Binomial logistic regression of multiple factors on evacuation decision (evacuate or stay). Significant and marginally significant findings (p<0.10) are in bold

Variable	Estimate	Std. Error	z statistic	p-value
(Intercept)	2.607	1.771	1.472	0.141
Prior awareness	0.123	0.177	0.691	0.489
Preparation	-0.587	0.553	-1.061	0.288
Emergency plan	-0.412	0.531	-0.776	0.438
Residence: < 5 yrs [A]	**1.221**	**0.601**	**2.032**	**0.042**
Residence: 10+ yrs	-0.219	0.559	-0.392	0.695
Own home	**1.586**	**0.635**	**2.497**	**0.013**
Detached home[A]	1.175	0.853	1.377	0.169
Multi-family home	1.023	0.994	1.029	0.303
Mobile home	0.195	1.345	0.145	0.885
Pre-fire perception of safety	**-0.986**	**0.247**	**-4.002**	**0.000**
Children (yes)	-0.453	0.534	-0.848	0.396
No. of adults	**-0.427**	**0.197**	**-2.170**	**0.030**
Animals (yes)	-0.577	0.560	-1.030	0.303
Income: $50,000 – $74,999 [A]	-1.270	0.881	-1.441	0.149
Income: $75,000 to $99,999	-1.164	0.737	-1.579	0.114
Income: $100,000 - $124,999	-1.411	0.921	-1.531	0.126
Income: $125,000 - $149,999	**-1.601**	**0.816**	**-1.962**	**0.050**
Income: $150,000 - $174,999	-0.393	1.030	-0.381	0.703
Income: >$175,000	-0.454	0.878	-0.517	0.605
Age: 45 – 54 yrs	-0.878	0.628	-1.398	0.162
Age: 55 – 64 yrs	-0.501	0.624	-0.803	0.422
Age: 65+ yrs	-1.087	0.808	-1.345	0.178
Gender (female)	0.542	0.468	1.158	0.247
Education: Bachelor[A]	**1.522**	**0.528**	**2.885**	**0.004**
Education: Graduate	**0.891**	**0.530**	**1.681**	**0.093**
Medical condition (yes)	0.440	0.505	0.870	0.384
Order: Official/unofficial source	**1.840**	**0.505**	**3.644**	**0.000**
Order: In person	-0.618	0.522	-1.183	0.237
Fire cues	**-1.028**	**0.549**	**-1.873**	**0.061**
Risk perception	**0.646**	**0.221**	**2.920**	**0.003**

N = 270

[A] The base values for Income, Residence, Education, Age, and Structure Type are Income: < $50,000, Residence: 5-10 yrs, Education: Associate degree (including high school and some college), Age: 18 – 44 yrs, and "Other home types", respectively.

4.3 Qualitative Results

Qualitative analysis was performed on the end-of-survey comments left by (192) respondents. While these cannot be considered as generalizable findings, themes were identified that can provide important insights on both the survey results as well as aspects of the Kincade fire evacuation not addressed by the survey. Themes identified by this analysis include pre-fire risk perception and the role of previous experience, emergency information and its influence on decisions, the role of the power outage in evacuation decisions, evacuation preparation, evacuation movement, and appreciation.

Pre-event risk perception: Previous fires, specifically the October 2017 Tubbs fire and, to a lesser extent, the November 2018 Camp Fire, influenced the perceptions, decisions, and actions taken by residents in the Kincade fire. A substantial number of respondents (64) mentioned the Tubbs Fire in their end-of-survey responses. Of those respondents, some (21) reported on the impact that the Tubbs Fire had influenced their awareness, risk perception, and preparedness prior to the Kincade Fire, specifically citing how *"[Their] community has been hyper-aware and connected to each other and local/emergency agencies since the 2017 fires"* (Int. 4). Other participants (12) discussed constantly monitoring the situation and weather conditions during the Kincade fire as a result of experiencing previous fires, showing an awareness of the risk that fires can pose to communities.

Information about the fire (during the event): As stated earlier, people received information about the Kincade fire from different sources and channels. Of those who specifically mentioned how they received evacuation information, Nixle had been an important means of receiving information, with one respondent mentioning that *"Nixle alerts were key to keeping us informed"* (Int. 29). The availability of information in the Kincade Fire, compared to the Tubbs Fire was highlighted by respondents, with one stating that they were *"grateful for the many sources of information available that now exist for those of us in the fire zone"* (Int. 15).

Respondents also mentioned the types of information that they received, including evacuation warnings and orders. A number of respondents (25) mentioned receiving an evacuation warning (i.e., the notice that people receive prior to an evacuation order that warns people of a potential threat to life and/or property). A proportion of those who received that warning (9) mentioned that this was the reason that they decided to evacuate (even prior to receiving the order). In fact, a sizable number of respondents (22) evacuated before (or without) receiving an evacuation order. Of those respondents, a proportion (10) specifically mentioned leaving early (e.g., before an evacuation order was issued) *"to avoid the evacuation traffic jam"* (Int. 23).

Power Outage: Another factor that may have impacted evacuation decisions was the large-scale pre-emptive public safety power shutoff events mentioned by some respondents (20). The power shutoff impacted evacuation response with some respondents altering their means of obtaining information about the fire: *"[we] lost power and [had] no internet but knew of a cell reception site up the road and visited it often to check fire maps"* and/or deciding to evacuate when the power went out (Int. 87).

Evacuation preparation: In addition to their evacuation decisions and the factors that influenced these, respondents also mentioned experiences while preparing for their evacuation.

These experiences focused around difficulties, e.g., evacuating with or taking care of pets (6) and assisting others with their evacuation (18) or needing assistance themselves (15). Finally, although not a predominant theme from the comments, a few respondents mentioned that their family or household unit evacuated separately in response to the fire. One respondent mentioned *"[taking] separate cars and [splitting] up, taking different routes"* (Int. 48), while another mentioned that they evacuated with their son and pets while their partner stayed at home. While this study assumes that the family unit responds in a similar manner, this finding and other studies highlight that members of the same household can behave in different ways (McLennan, 2014; Whittaker et al., 2016). Multiple family members within the same household should be included as participants in future studies.

Evacuation movement: Respondents also discussed their evacuation experiences during movement to safety. First, a number of respondents (23) mentioned experiencing difficult conditions during the evacuation, including encountering heavy traffic. One respondent stated that it took them *"an hour to go the two blocks from home to the main street"*, with another feeling *"terrified that [they] would perish right there because [they] weren't moving"* (Int. 76). Alternatively, a small group of respondents (5) mentioned choosing to evacuate via the *"back roads in [the] county …to avoid the traffic jam on [the Highway]"* (Int. 226). The safe destinations chosen were homes of friends and family, evacuation shelters, and hotels and motels (as long as they could get a booking). Finally, due to the size of the fire and its spread over time, a few respondents mentioned having to evacuate multiple times.

Appreciation: In addition to providing comments on their own personal experiences, respondents often provided their perspectives on the overall evacuation. On the one hand, some respondents felt that the evacuation (at such a large scale) was unnecessary. Others were impressed by the proactive actions of the authorities, concluding that they thought that the evacuation was warranted and were grateful for the positive outcomes. In fact, many participants (23) specifically noted how the Kincade Fire *"was handled very well"* and that they had a positive view of emergency response officials.

5. Discussion

This study has identified the factors that influenced household evacuation perceptions and behavior during the 2019 Kincade fire. Focusing first on the linear regression model, some of the results align with the existing wildfire evacuation literature. In line with the PADM model (Lindell, 2017), threat assessment had a positive impact on risk perception. In other words, householders had higher perceptions of risk if they believed that the fire would damage or destroy their homes and neighborhood. Also, despite being marginally significant, having a graduate degree presented a positive impact on risk perception, which is in line with Mozumder (2008).

Counter to previous research, and in particular, our study of the 2016 Chimney Tops 2 fire (Kuligowski et al., 2020), this study did not find a relationship between fire cues or evacuation orders and increased levels of risk perception. However, the first result can be explained by the fact most of the respondents evacuated before the fire spread to their property, if it reached them

at all. The second result does not support either (McLennan et al., 2013, 2012) or (Kuligowski et al., 2020); therefore, the impact of evacuation orders on risk perception still remains inconclusive. Additionally, while studies have found that increased household income can increase levels of risk perception (Mozumder et al., 2008), this study's findings differ. Instead, the households in this study with lower household incomes ($50,000 - $74,999USD) were linked with higher levels of perceived risk at the time of the decision. One possible reason for this difference is the fact that in this study, only one category of income was statistically significant, indicating a weak or nonexistent relationship between the two variables.

This study also brings to light some new findings related to predicting risk perception. First, participants living in households with a higher number of adults reported significantly lower levels of risk perception. Although this result is not reported in the wildfire literature, similar results were reported in flood studies (Lechowska, 2018; Rana et al., 2020) where larger households, including the number of children, led to decreased risk perception. Owning pets and livestock also had a negative impact on risk perception levels at the time of the decision to evacuate or stay. This result is new in the wildfire research field and is likely linked to respondents' perceived ability to cope (or protect their animals) from harmful fire conditions (Trigg et al., 2016). Since most of the respondents had domesticated pets rather than livestock, and they mentioned being prepared well in advance of evacuation orders, this finding is logical. Finally, householders who believed that their homes were well-built and safe for a wildfire and that staying home was safer than moving to a nearby building or shelter showed relatively lower levels of risk perception. Again, we look to the research of other hazards. Several studies have shown that the type of residence and pre-fire perceptions of safety influenced both how householders perceived hazard risks (of hurricanes and floods) and their decision to evacuate (Hasan et al., 2011; Lim et al., 2016; Wilmot and Mei, 2004).

Although other wildfire research has found relationships between risk perception and prior awareness of fire risk, length of residence, and previous experience with fires, this study did not. It should be noted, however, that previous experience was not included in the linear regression analysis because the variable lacked sufficient variation in responses. Overall, the results of this study partially support Hypothesis 1.

The binomial logistic model predicting the evacuation decision illustrated that several factors had a significant impact on the decision to evacuate. First, risk perception had a positive impact on the likelihood of householders evacuating. This result aligns with previous wildfire studies (McLennan et al., 2015; Mozumder et al., 2008; Strahan et al., 2019; Strawderman et al., 2012). Also, in line with the fire literature (e.g., (Wong et al., 2020b)), householders who received an evacuation order (from either official or unofficial sources) and those with higher education were more likely to decide to evacuate than others who did not.

Householders who resided in their property for less than five years were more likely to decide to evacuate. This aligns with previous wildfire research from Wong et al. (2020b) and Mozumder et al. (2008) that found longer-term residents had a higher likelihood of staying in place.

Potentially counter to prior research, however, was the finding that homeownership was significantly linked with the decision to evacuate. In the fire literature, a few studies have found a significant relationship between staying in place and having an emotional attachment to the home and/or personal responsibility to protect the property (McCaffrey et al., 2018; McLennan et al., 2013), while others have found the opposite (Walpole et al., 2020). However, it is unclear whether homeownership can and should be equated with emotional home attachment or perceptions of personal responsibility to protect the home. In the flood literature, for example, Lim et al. (2016) showed that homeownership increased the decision to evacuate during flood evacuation. From these results, it is clear that additional research is needed to further explore the relationship between homeownership, place attachment, responsibility, and evacuations decision in a fire context (Riad et al., 1999; Thompson et al., 2017).

Other results counter to previous research are the negative impact of the fire cues and the number of adults in the household on the decision to evacuate. The marginally significant finding related to fire cues; however, can be explained by the fact that most of the householders evacuated before the fire got close to their property. In turn, the only respondents who had a chance to see the fire were the ones who stayed in place. In other words, perceiving fire cues was most likely an outcome of the decision to stay. Additionally, while hurricane evacuation research has studied the impact of household size on evacuation delay (Lindell et al., 2011), only one fire study was identified that linked the number of adults to the decision to evacuate (Toledo et al., 2018). Since Toledo et al. (2018) found that households with six or more people were more likely to evacuate when compared with smaller households; additional research on household size is needed to explore differences across studies.

Newer findings to the wildfire literature include the influence of pre-fire perception of safety on decisions. Also, while the significant relationship between pre-fire perception of safety and remaining in place is new to the wildfire literature, research into hurricanes and floods confirms results found in this study (Hasan et al., 2011; Lim et al., 2016; Wilmot and Mei, 2004). Finally, even though a significant relationship was found between the evacuation decision and income, only one category of income was statistically significant, indicating a weak or nonexistent relationship.

While other research found relationships between the evacuation decision and prior awareness of fire risk, preparedness[3], and previous experience with fires, this study did not. Also, for the same reasons it was not included in the linear regression model, previous experience was not included in the logistic regression analysis. Overall, the results of this study partially support Hypothesis 2.

[3] Preparedness was measured by asking the following question: Before the Kincade fire, had you or others taken any measures to protect your residence from wildfires? (Select all that apply)". The variable was recoded as a binary variable for the analysis where "1" was assigned to people who had taken 1 or more measures and "0" for none.

5.1 Comparison between the 2016 and 2019 fires

This work also presents a novel attempt to compare findings with the 2016 Chimney Tops 2 fire study results (Kuligowski et al., 2020), where applicable. Overall, the data from the 2019 fire show that the majority of participants (73%) reported that one or more emergency officials alerted them of the evacuation order, while only a small percentage (15%) of the sample received cues from the fire itself. As such, this wildfire emergency was very different from 2016 Chimney Tops 2 fire (Gatlinburg, TN[4]) where most of the respondents perceived fire cues and only 17% received an official evacuation warning or order (Kuligowski et al., 2020).

In fact, in the 2016 fire, fire cues (specifically witnessing embers and flames) were a significant predictor of higher levels of risk perception, and receiving warnings from a trusted source resulted in lower levels of perceived risk (Kuligowski et al., 2020). Similar relationships were not found in this study. One of the major differences between these two fires was the influence of environmental and social cues. The 2016 Tennessee fire was a fast-moving fire that gave the authorities little time to warn residents, which was further complicated by the fact that communications systems went down. In most cases, residents' warnings were receiving cues from the fire itself (Kuligowski et al., 2020). In 2019, most of the respondents received official warnings of some type and often evacuated before the fire got close to their properties (if it reached their properties at all). Therefore, if people in the Kincade fire witnessed fire cues, they had most likely already decided to stay.

Potentially more important was the role of previous experience in evacuation behavior across the two fires. The population exposed to the 2016 fire were relatively inexperienced with fires and less aware of the threat and risks it posed (Kuligowski et al., 2020). In fact, the 2016 study results found a significant relationship between 'prior awareness of fire risk' and lower levels of risk perception (Kuligowski et al., 2020). In this case, while the residents may have recognized that fires could be a problem in their community, it is clear that they were unaware of the risks that fires could pose to themselves and their loved ones. The 2019 Kincade fire, on the other hand, exposed a population highly familiar with fires and evacuation. As the qualitative data showed, previous experience with the devastating 2017 Tubbs fire had increased their awareness of fire risks, preparedness for evacuation, likelihood of evacuating and tendency to evacuate earlier than required.

A commonality between the two fires was the role of risk perception in the evacuation decision. In both fires, the higher the level of risk perception of the participant (at the time of evacuation decision), the more likely they were to evacuate. This finding, as mentioned earlier in Section 5, aligns with many other studies in wildfire evacuation research, as well as supports the general, all-hazards Protective Action Decision Model (Lindell, 2017).

[4] Although a majority of the respondents in the Tennessee study did not receive official warnings or orders due to many environmental factors, it is important to note that evacuation policies between California and Tennessee were similar at the time of the fires. In both locations, evacuation "orders" were mandatory; however, Tennessee expanded its Code (58-8-104) in 2018, 2 years after the fire, to state that any person who "willfully" violates an evacuation order commits a "Class C" misdemeanor (punishable by up to 30 days in jail, a fine of up to $50USD or both) ("2018 Tennessee Code," n.d.).

With the exception of the relationship between risk perception and evacuation decision, our results do not support Hypothesis 3. However, these insights demonstrate the need for further research into various types of fires and communities to eventually develop a more comprehensive generalized model of human behavior in wildfires.

5.2 Lessons Learned and Future Research Directions

First, our qualitative findings identified some methodological limitations. When asking participants about the day/time they received cues and information, some noted that this task was difficult due to the length of time that had passed between the fire and the survey data collection. Also, the survey asked specifically about evacuation orders; however, many people left before an evacuation order was given; flagging the fact that the survey should be expanded to ask about the evacuation warning as well. For these reasons, the data collected from the day and time questions were not used in this analysis; and responses about warnings and other factors from the end-of-survey questions were used to provide further context to our findings involving the evacuation order.

Other study limitations have also been identified. First, the study engages a convenience sample where protocols required respondents to be motivated to opt into the survey. Additionally, the study's sample size is relatively small compared with the number of Sonoma County residents. However, it should be noted that this sample is larger than the number required (234 participants) to investigate a medium effect size (0.15) from linear multiple regression analyses with 22 predictors, as shown in Table 3 (Faul et al., 2007). Another limitation of the sample used in this study is associated with the gender balance. In this case, the percentage of women participants (77.4%) is larger than the male respondents. With that said, the sample has a sufficient number of male participants to identify statistical differences in our dependent variables; and both models showed that gender did not have a significant impact on risk perception and evacuation decisions. Finally, the survey collected participant insights approximately one year after the fire occurred. It is often difficult for researchers to balance the need for perishable data and the desire to reduce any psychological impacts that can occur when collecting data too soon after an event. Because of these limitations, caution should be taken when generalizing results to the larger population.

The survey, and more specifically, the end-of-survey comments, highlighted the importance of collecting behavioral data throughout the entire evacuation timeline. As mentioned in the results section, respondents identified important aspects of their fire experiences that are often missing from wildfire evacuation research, including leaving early, routing decisions, congestion on the roads, providing assistance to loved ones, destination type, and dispersion of the family unit. These types of decisions and actions deviate from the optimal assumptions made by many of the evacuation models and/or the evacuation plans put in place by communities (Li et al., 2019); e.g., that people are familiar with and take the shortest route, that the family unit leaves at the same time and travels together to safety, etc. Instead, evacuation movement can be inefficient, potentially increasing the time that people are exposed to fire risks. These and other studies shed light on the importance of studying both evacuation decision-making and the many decisions and behaviors that follow (Kuligowski, 2020). The authors are currently working on a project that aims to understand these types of decisions and behaviors during evacuation movement from the Kincade fire via GPS data (Zhao et al., 2022).

The end-of-survey comments and 2016/2019 fire comparison highlighted the important role that previous fires can play in response behaviors. Due to the lack of variance in results, "previous experience" was ineligible for inclusion in either regression model. While this represents a limitation in our work, it is difficult to understand the nuances associated with previous experience via survey methods alone. Future studies should consider new ways to capture these diverse fire experiences and their impact on risk perception and evacuation decisions.

6. Conclusions

This study of the 2019 Kincade fire identified the factors that influenced both the evacuation decision and levels of risk perception at the time of making that decision. Findings from the regression analysis showed that pre-fire perceptions of safety, household makeup, income, education, and threat assessment were significantly linked with risk perception. Factors that influenced the decision to evacuate included risk perception, pre-fire perception of safety, length of residence, ~~age~~ evacuation orders (either from official or unofficial sources, including unofficial sources who communicated the existence of an official order), fire cues, household makeup, education, income, and homeownership. Some novel findings, such as a negative relationship between animals (having pets and/or livestock) and risk perception, may warrant further investigation from similar events where the affected population is more experienced with fire and/or evacuation and lead time for warnings allowed for early evacuation. This study also compared findings from this fire with a study of the 2016 Chimney Tops 2 fire (Kuligowski et al., 2020) that used similar methods. Differences in initial conditions and subsequent outcomes across these two fires highlight the need for researchers to study a broad range of fires in different locations around the world to develop a fully comprehensive and generalizable theory of wildfire evacuation behavior.

This study also makes important recommendations for future research, that when applied, can be used to better protect wildfire-prone communities around the world. First, the potential role of previous fire experiences in preparedness, perceptions, decisions, and actions in future fires requires further study. Also, the study illustrated the importance of collecting data closer to the event so that important details like days, times, and locations are recorded. Equally important is the need to collect data on the entire evacuation timeline, including evacuation preparation, departure times, and movement behaviors (Cova et al., 2009; Wong et al., 2020b). These improvements will assist researchers in collecting more accurate data that can begin to shed light on the ways in which to protect evacuees not only during decision-making but also once they enter the road network and travel to safety.

Acknowledgements

This research was supported by the Natural Hazards Center Quick Response Research Program. The Quick Response program is based on work supported by the National Science Foundation (Award #1635593). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NSF or the Natural Hazards Center. The authors would like to thank the many residents of Sonoma County, California for sharing their experiences with us for this study. The authors also want to thank Xiang 'Jacob' Yan from the University of Florida for providing GIS support. The authors declare no conflicts of interest.

References

2018 Tennessee Code :: Title 58 - Military Affairs, Emergencies and Civil Defense :: Chapter 8 - Mutual Aid and Emergency and Disaster Assistance Agreement Act of 2004 :: § 58-8-104. Declaration of local state of emergency -- Cost reimbursement -- Evacuation orders. [WWW Document], n.d. . Justia Law. URL https://law.justia.com/codes/tennessee/2019/title-58/chapter-8/section-58-8-104/ (accessed 8.18.21).

Alsnih, R., Rose, J., Stopher, P., 2005. Understanding Household Evacuation Decisions Using a Stated Choice Survey - Case study of bush fires 18.

Benight, C.C., Gruntfest, E., Sparks, K., 2004. Colorado Wildfires 2002 (Quick Response Research Report No. 167). Natural Hazards Center.

Bowman, D.M.J.S., Kolden, C.A., Abatzoglou, J.T., Johnston, F.H., van der Werf, G.R., Flannigan, M., 2020. Vegetation fires in the Anthropocene. Nature Reviews Earth & Environment 1, 500–515. https://doi.org/10.1038/s43017-020-0085-3

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative Research in Psychology 3, 77–101. https://doi.org/10.1191/1478088706qp063oa

Brown, G., 2019. Factor Analysis: A course using Jamovi & lavaan. The University of Auckland, Auckland, NZ.

California Code, Penal Code - PEN § 409.5 [WWW Document], n.d. . Findlaw. URL https://codes.findlaw.com/ca/penal-code/pen-sect-409-5.html (accessed 8.18.21).

California OES Wireless Emergency Alerts [WWW Document], n.d. URL http://calalerts.org/evacuations.html (accessed 8.18.21).

County of Sonoma, 2020. 2019 Kincade Fire After Action Report. Sonoma County Department of Emergency Management, Sonoma County, California.

Cova, T.J., Drews, F.A., Siebeneck, L.K., Musters, A., 2009. Protective Actions in Wildfires: Evacuate or Shelter-in-Place? Nat. Hazards Rev. 10, 151–162. https://doi.org/10.1061/(ASCE)1527-6988(2009)10:4(151)

Eriksen, C., Gill, N., Head, L., 2010. The gendered dimensions of bushfire in changing rural landscapes in Australia. Journal of Rural Studies 26, 332–342. https://doi.org/10.1016/j.jrurstud.2010.06.001

Evacuation Steps [WWW Document], n.d. . Ready for Wildfire. URL https://www.readyforwildfire.org/prepare-for-wildfire/go-evacuation-guide/evacuation-steps/ (accessed 8.18.21).

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods 39, 175–191. https://doi.org/10.3758/BF03193146

Folk, L.H., Kuligowski, E.D., Gwynne, S.M.V., Gales, J.A., 2019. A Provisional Conceptual Model of Human Behavior in Response to Wildland-Urban Interface Fires. Fire Technol 55, 1619–1647. https://doi.org/10.1007/s10694-019-00821-z

Hasan, S., Ukkusuri, S., Gladwin, H., Murray-Tuite, P., 2011. Behavioral Model to Understand Household-Level Hurricane Evacuation Decision Making. J. Transp. Eng. 137, 341–348. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000223

Kincade fire incident [WWW Document], n.d. URL https://www.fire.ca.gov/incidents/2019/10/23/kincade-fire/ (accessed 6.15.21).

Kuligowski, E., 2020. Evacuation decision-making and behavior in wildfires: Past research, current challenges and a future research agenda. Fire Safety Journal 103129. https://doi.org/10.1016/j.firesaf.2020.103129

Kuligowski, E.D., Walpole, E.H., Lovreglio, R., McCaffrey, S., 2020. Modelling evacuation decision-making in the 2016 Chimney Tops 2 fire in Gatlinburg, TN. Int. J. Wildland Fire. https://doi.org/10.1071/WF20038

Lechowska, E., 2018. What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. Nat Hazards 94, 1341–1366. https://doi.org/10.1007/s11069-018-3480-z

Li, D., Cova, T.J., Dennison, P.E., 2019. Setting Wildfire Evacuation Triggers by Coupling Fire and Traffic Simulation Models: A Spatiotemporal GIS Approach. Fire Technol 55, 617–642. https://doi.org/10.1007/s10694-018-0771-6

Lim, Ma.B.B., Lim, H.R., Piantanakulchai, M., Uy, F.A., 2016. A household-level flood evacuation decision model in Quezon City, Philippines. Nat Hazards 80, 1539–1561. https://doi.org/10.1007/s11069-015-2038-6

Lindell, M.K., 2017. Communicating Imminent Risk, in: Rodríguez, H., Donner, W., Trainor, J.E. (Eds.), Handbook of Disaster Research. Springer International Publishing, Cham, pp. 449–477. https://doi.org/10.1007/978-3-319-63254-4_22

Lindell, M.K., Kang, J.E., Prater, C.S., 2011. The logistics of household hurricane evacuation. Nat Hazards 58, 1093–1109. https://doi.org/10.1007/s11069-011-9715-x

Lindell, M.K., Perry, R.W., 2012. The Protective Action Decision Model: Theoretical Modifications and Additional Evidence: The Protective Action Decision Model. Risk Analysis 32, 616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x

Lovreglio, R., Kuligowski, E., Walpole, E., Link, E., Gwynne, S., 2020. Calibrating the Wildfire Decision Model using hybrid choice modelling. International Journal of Disaster Risk Reduction 50, 101770. https://doi.org/10.1016/j.ijdrr.2020.101770

McCaffrey, S., Rhodes, A., Stidham, M., 2015. Wildfire evacuation and its alternatives: perspectives from four United States' communities. Int. J. Wildland Fire 24, 170. https://doi.org/10.1071/WF13050

McCaffrey, S., Wilson, R., Konar, A., 2018. Should I Stay or Should I Go Now? Or Should I Wait and See? Influences on Wildfire Evacuation Decisions: Should I Stay or Should I Go Now? Risk Analysis 38, 1390–1404. https://doi.org/10.1111/risa.12944

McCaffrey, S., Winter, G., 2011. Understanding Homeowner Preparation and Intended Actions When Threatened by a Wildfire, in: Proceedings of the Second Conference on the Human Dimensions of Wildland Fire. Gen. Tech. Rep. NRS-P-84. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, pp. 88–95.

McGee, T., Langer, E.R. (Lisa), 2019. Residents' preparedness, experiences and actions during an extreme wildfire in the Far North, Aotearoa New Zealand. International Journal of Disaster Risk Reduction 101303. https://doi.org/10.1016/j.ijdrr.2019.101303

McGee, T.K., Nation, M.O., Christianson, A.C., 2019. Residents' wildfire evacuation actions in Mishkeegogamang Ojibway Nation, Ontario, Canada. International Journal of Disaster Risk Reduction 33, 266–274. https://doi.org/10.1016/j.ijdrr.2018.10.012

McLennan, J., 2014. Capturing Community Members' Bushfire Experiences: Interviews with residents following the 12 January 2014 Parkerville (WA) fire (No. 2014.005). Bushfire & Natural Hazards Cooperative Research Centre, East Melbourne, Victoria.

McLennan, J., Elliott, G., Omodei, M., 2012. Householder decision-making under imminent wildfire threat: stay and defend or leave? Int. J. Wildland Fire 21, 915. https://doi.org/10.1071/WF11061

McLennan, J., Elliott, G., Omodei, M., Whittaker, J., 2013. Householders' safety-related decisions, plans, actions and outcomes during the 7 February 2009 Victorian (Australia) wildfires. Fire Safety Journal 61, 175–184. https://doi.org/10.1016/j.firesaf.2013.09.003

McLennan, J., Paton, D., Beatson, R., 2015. Psychological differences between south-eastern Australian householders' who intend to leave if threatened by a wildfire and those who intend to stay and defend. International Journal of Disaster Risk Reduction 11, 35–46. https://doi.org/10.1016/j.ijdrr.2014.11.008

McNeill, I.M., Dunlop, P.D., Skinner, T.C., Morrison, D.L., 2015. Predicting delay in residents' decisions on defending v. evacuating through antecedents of decision avoidance. Int. J. Wildland Fire 24, 153. https://doi.org/10.1071/WF12213

Mozumder, P., Raheem, N., Talberth, J., Berrens, R.P., 2008. Investigating intended evacuation from wildfires in the wildland–urban interface: Application of a bivariate probit model. Forest Policy and Economics 10, 415–423. https://doi.org/10.1016/j.forpol.2008.02.002

Paveglio, T., Prato, T., Dalenberg, D., Venn, T., 2014. Understanding evacuation preferences and wildfire mitigations among Northwest Montana residents. Int. J. Wildland Fire 23, 435. https://doi.org/10.1071/WF13057

Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., Butsic, V., Hawbaker, T.J., Martinuzzi, S., Syphard, A.D., Stewart, S.I., 2018. Rapid growth of the US wildland-urban interface raises wildfire risk. Proc Natl Acad Sci USA 115, 3314–3319. https://doi.org/10.1073/pnas.1718850115

Rana, I.A., Jamshed, A., Younas, Z.I., Bhatti, S.S., 2020. Characterizing flood risk perception in urban communities of Pakistan. International Journal of Disaster Risk Reduction 46, 101624. https://doi.org/10.1016/j.ijdrr.2020.101624

Riad, J.K., Norris, F.H., Ruback, R.B., 1999. Predicting Evacuation in Two Major Disasters: Risk Perception, Social Influence, and Access to Resources1. J Appl Social Pyschol 29, 918–934. https://doi.org/10.1111/j.1559-1816.1999.tb00132.x

Sorensen, J.H., Mileti, D.S., 2018. Warning issuance, diffusion, and public protective action initiation during the Febuary 2017 Oroville Dam event. U.S. Army Corps of Engineers, Davis, California.

Sorensen, J.H., Sorensen, B.V., Smith, A., Williams, Z., 2009. Results of An Investigation of the Effectiveness of Using Reverse Telephone Emergency Warning Systems in the October 2007 San Diego Wildfires (No. ORNL/TM-2009/154). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Strahan, K., Watson, S.J., 2019. The protective action decision model: when householders choose their protective response to wildfire. Journal of Risk Research 22, 1602–1623. https://doi.org/10.1080/13669877.2018.1501597

Strahan, K., Whittaker, J., Handmer, J., 2018. Self-evacuation archetypes in Australian bushfire. International Journal of Disaster Risk Reduction 27, 307–316. https://doi.org/10.1016/j.ijdrr.2017.10.016

Strahan, K.W., Whittaker, J., Handmer, J., 2019. Predicting self-evacuation in Australian bushfire. Environmental Hazards 18, 146–172. https://doi.org/10.1080/17477891.2018.1512468