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The 2023 Oklahoma wildfire outbreak: a case study in meteorological conditions, wildfire hazard, and community resilience

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Abstract

The wildfire outbreak that occurred in Oklahoma on March 31, 2023, impacted structures and transportation infrastructure, posed significant challenges to emergency response, and tested the community's resilience. Extensive structural damage, including the destruction of numerous homes and electrical power poles, shows the need for improved wildfire mitigation strategies. The significant impact of the resulting smoke from the wildfire outbreak was highlighted by road closures, which disrupted transportation and school operations. Crucial firefighting operations, led by multiple fire departments and assisted by federal agencies, played a pivotal role in containing the fires. Additionally, community resilience was evident through evacuations and sheltering efforts, with churches and organizations providing refuge. Further, widespread electrical outages, caused by damaged infrastructure due to high winds, presented additional challenges. This study examines the multifaceted effects of the wildfire outbreak by recounting and analyzing the sequence of events. Further, a meteorological and wildfire hazard assessment, using historical data, was performed to provide insights for risk mitigation. Wildfire hazard maps for the state of Oklahoma were utilized to enhance emergency response and mitigation strategies for wildfires. An examination of wildfire risk perceptions among Oklahomans, both before and after the wildfire outbreak, reveal that the degree of personal connection to or remoteness from the wildfire event has a significant impact on how they perceive the wildfire risk. This study presents lessons and recommendations to enhance wildfire resilience. The findings contribute to a better understanding of the multifaceted impact of wildfire outbreaks to enhance community resilience and disaster response to wildfires.

Keywords Risk perceptions · Fire weather · Hazard mapping · Wildland urban interface

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1 Introduction

Wildfires, or uncontrolled fires fueled by the environment and spread by winds, are now becoming a major topic of interest, especially in the fields of meteorology, social science, and civil engineering, which is highlighted by recent publications on forecasting and modeling of wildfires and their factors (Campos et al. 2023; Elhami-Khorasani et al. 2022; Shadrin et al. 2024; Shamsaei et al. 2023; Turner et al. 2024). These efforts are undoubtedly due to the escalating frequency and scale of wildfires worldwide, with North America witnessing a notable surge in wildfires over the past decade, particularly affecting grassland ecosystems (Donovan et al. 2020). Notably, regions historically less prone to large wildfires, such as the Great Plains in the United States, are experiencing an alarming increase in fire occurrences, exacerbated by changing climatic conditions and land use patterns (Donovan et al. 2017). A wildfire outbreak or firestorm is not clearly defined in the existing literature, but in this study, it is defined as an event that contains multiple ongoing wildfires due to meteorological conditions that are highly conducive to wildfire propagation (TXAM 2024). Communities, meteorologists, engineers, and emergency responders across the United States continue to navigate the wildfire hazard without fully realized wildfire mitigation strategies. This is especially true for the Great Plains, as wildfire outbreak events are rarely studied outside of the social sciences.

The overarching objective of this paper is to contribute to a better understanding of the multifaceted impact of wildfires through the lens of the 2023 Oklahoma wildfire outbreak. The wildfires that rapidly spread through the urban cities and rural areas of Oklahoma on Friday March 31, 2023 had a significant impact on the region's physical infrastructure (e.g., electrical and transportation systems) and social infrastructure (i.e., the collective, interactive components of organizations or institutions that include community relationships, trust building, and networks (Kerstetter et al. 2023)). Strong winds, gusts, and dry vegetation exacerbated the wildfires that spread rapidly, causing extensive damage to homes, leading to evacuations, and forcing the closure of roads and major highways. This study examines wildfire ignitions, how they spread, and the consequences they have on social and physical infrastructures. Further, this case study aims to explore the sequence of events, response efforts, and the community's resilience as a result of the wildfire outbreak. Additionally, this study analyzes the emergency response strategies used by different agencies and highlights the lessons learned from this event. An overview of the early warning systems, evacuation procedures, firefighting operations, and interagency coordination is performed to gain insight into the effectiveness of the response strategies to identify areas for improvement. By assessing both successful and challenging aspects of the emergency response, this study provides recommendations to enhance preparedness, response, and recovery efforts for future wildfires that may occur at the wildland urban interface (WUI). The findings contribute to the broader field of disaster management and community resilience to make informed policy decisions, encourage wildfire awareness, and strengthen communities' ability to face hazards.

In order to provide insights into Oklahoma's wildfires and their impacts on communities, an understanding of wildfire risk in Oklahoma must be established, which involves conducting an analysis that encompasses wildfire outbreaks, fire weather, wildfire hazard, and wildfire risk perceptions. The meteorological conditions during, before, and after the wildfire outbreak were analyzed by utilizing data from the Oklahoma Mesonet weather stations. The wildfire risk assessment involved the assessment of wildfire hazard maps, which utilized historical Oklahoma wildfire data from the United States Department of

Agriculture (USDA) Forest Service (Short 2022). Further, Oklahoma risk perceptions were studied by analyzing panel survey data obtained through the Oklahoma Meso-scale Integrated Socio-geographic Network (M-SISNet). A literature review of community resilience, Oklahoma weather, and wildfires is found in Sect. 2. The wildfire outbreak, meteorological conditions, and risk perceptions assessments and their respective findings are discussed in Sect. 3, followed by a discussion of the lessons learned and recommendations in Sect. 4.

2 Background

2.1 Community resilience in the context of wildfires

Various researchers (Kulig and Botey 2016; McWethy et al. 2019; Moritz et al. 2014; Smith et al. 2016; Dickinson et al. 2020; Penman et al. 2017; Miller et al. 2021; Schumann et al. 2020; Long et al. 2023) have studied community, social, and ecological resilience, as well as vulnerability, risk perception, hazard mitigation, resilience frameworks, retrofits, and hazard coexistence in the context of wildfires. In these studies, researchers attempt to understand and model the complexity of wildfires through the lens of community resilience or some other variation, analogous to community resilience. These studies take short steps, which are necessary due to the complexity of the physical nature of wildfires, to develop components of a resilience framework, theoretical framework, or to simply understand wildfire characteristics or interdependencies in the context of community resilience.

For example, Kulig and Botey (2016) focus on the experiences of community stakeholders who were directly impacted by the 2011 Slave Lake wildfire in Alberta, Canada, where the main goal of the study was to uncover the connections between individual and community resilience and the factors that contribute to their development. A key aspect of the study relates to individual resilience, where Kulig and Botey (2016) identify five core factors influencing individual resilience: personality traits, physical surroundings, economic conditions, attachment to place, and social interactions. These factors can either naturally exist within individuals or become strengthened after experiencing a wildfire. Further, the study also delves into community resilience and introduces a theoretical framework consisting of three interconnected components: collective interactions, expression of communal identity, and community action. The analysis shows how individual resilience contributes to the growth of community resilience through these components. Further, both individual and community resilience are interdependent and rooted in socio-ecological and psychological aspects. The aftermath of the Slave Lake wildfire shows a range of impacts on its community. The consequences varied based on factors such as home loss, possessions, jobs, and personal connections, where the residents' emotional responses ranged from trauma, stress, grief, and anger to resilience, optimism, gratitude, and hope. In response to the wildfire's impact, the community demonstrated a strong sense of unity, where community members engaged in mutual assistance, sharing information, resources, shelter, and emotional support. This collaborative effort was reinforced by the residents' expression of attachment to the community and a sense of pride, which was shown to effectively contribute to both individual and community resilience. While destroying residences, businesses, and communal facilities, the wildfire/urban fire was managed through timely evacuations which saved human lives. The community's recovery process highlighted the collaboration between various levels of government and the private sector (Kulig and Botey 2016).

Efforts to adapt to wildfires are crucial for community resilience, but both the government and private sector should consider the possibility of worsening weather conditions conducive to an increase in the frequency and intensity of wildfires. McWethy et al. (2019) argue that current management approaches, which strive to maintain historical or pre-fire conditions, are unsustainable. Consequently, the researchers emphasize the necessity for novel strategies that encompass various dimensions of resilience, including basic, adaptive, and transformative resilience. Basic resilience denotes a system's capability to recover or revert to a comparable state following a disturbance, like a wildfire (McWethy et al. 2019). This approach is fitting for scenarios where fire activity and its consequences remain modest, and human susceptibility and exposure are minimal. Adaptive resilience refers to a system's ability to adjust or modify its attributes in response to changing conditions, climate, and fire regimes (McWethy et al. 2019). This approach is applicable in scenarios marked by moderate or high fire activity, along with moderate or high human exposure and vulnerability. Transformative resilience refers to the capacity of a system to transition into a fundamentally novel state that is more sustainable or desirable under future meteorological conditions (McWethy et al. 2019). This strategy is applicable when confronting high or unprecedented fire activity and consequences, coupled with extreme human exposure and vulnerability. The framework acknowledges shifts in ecosystems and actions to reshape societal organization patterns to mitigate wildfire impacts on communities. Ultimately, the researchers suggest a straightforward framework that stakeholders can use to identify a range of measures aimed at enhancing resilience to wildfires more effectively.

It is important to note that some regions are naturally prone to wildfires; so, urban communities should consider strategies that allow for a coexistence with wildfires. Moritz et al. (2014) explore the notion of coexisting with wildfires and establishing sustainable solutions that complement the needs of urban communities and ecosystems in wildfire-prone regions. Moritz et al. (2014) explain the key priorities for the future of fire-prone regions, such as tailored approaches that are context-specific, enhancement of land-use planning, and the improvement of wildfire hazard mapping, ecosystem services, and climate change effects. Wildfires are a natural and essential hazard playing a critical role in sustaining biodiversity and vital ecosystems (Moritz et al. 2014), but wildfires also pose a substantial threat to communities, infrastructure, and human lives. Traditional fire management strategies, which concentrate on suppressing or excluding wildfires from landscapes, often prove ineffective, costly, and ecologically damaging. Instead, a more productive approach considers wildfires as a natural process, considering both positive and negative impacts on society and the environment. Communities in wildfire-prone regions encounter numerous challenges and trade-offs in mitigating wildfire risks and adapting to wildfire events, such as, risk perception, preparedness, responses, evacuations, safeguarding structures, vegetation management, community planning, and institutional frameworks. Further, insights from social science research uncover how communities respond to wildfires, which aid in the ability to coexist with wildfires. While the WUI experiences the most damaging wildfire impacts regarding communities, it also presents opportunities for risk reduction and adaptation. Studying wildfire-related challenges of coupled socio-ecological systems facilitates the classification of vulnerabilities and trade-offs, which may result in adaptive strategies that span diverse geographic landscapes (Moritz et al. 2014).

Social interactions are another important aspect of community resilience to wildfires and should be considered especially at the WUI. Dickinson et al. (2020) explore the impact of social interactions on wildfire risk mitigation decisions among homeowners in the WUI. The researchers analyze risk interdependency and social norms through a choice experiment, where risk interdependency highlights how neighbors' actions affect wildfire risk, while social norms emphasize conformity to neighbors' behaviors. The study proposes that more neighbors with sparse vegetation could either encourage homeowners to mitigate or discourage them, based on complementary actions. Additionally, the study hypothesizes that neighbors who have mitigated would prompt others to do the same, regardless of vegetation density. Surveying homeowners in Colorado's wildfire-prone regions, the study validates these hypotheses and finds that sparse vegetation reduces perceived risk and decreases homeowners' inclination to mitigate. The presence of mitigation-focused neighbors increases the likelihood of mitigation actions. The study concludes that risk interdependency and social norms are stronger near homes, and it highlights how these dynamics vary with respondent attributes. It is clear that understanding social interactions can enhance wildfire mitigation strategies for communities at the WUI (Dickinson et al. 2020).

Another aspect of community resilience that is especially important to those living in fire-prone regions is home retrofitting to mitigate structural damage from wildfires. Retrofitting, or altering existing structures to strengthen resilience, is a crucial process. Penman et al. (2017) investigate the viability and costs of retrofitting buildings in Australia's fire-prone zones, alongside social factors influencing resident readiness. The researchers assess ten homes across two wildfire-prone categories: intermix and interface areas, where these areas differ in housing density and vegetation cover. Intermix refers to low-density housing rural areas with over 50% vegetation, while interface refers to residential suburb areas bordering forested spaces (Penman et al. 2017). Further, preparedness criteria involve surroundings, equipment, and residents' capacity. Evaluating the Bushfire Attack Levels (BAL), a measure of exposure during wildfires, the study prescribes retrofit options in accordance with AS3959 standards (Penman et al. 2017). The study's findings show low preparedness and diverse vulnerabilities among the communities. Retrofit costs vary widely, ranging from $8,527 to $46,856 upfront or $9,313 to $48,976 over a decade. Risk perception varies where intermix residents are more proactive. Additionally, the study explores shared expense schemes with intermix support, while interface residents are more skeptical. Retrofitting for wildfire resilience appears feasible with property-specific strategies, community engagement, and cost-sharing (Penman et al. 2017).

A recurring theme in community resilience and wildfire mitigation is the notion of incorporating social and ecological systems into resiliency frameworks. Schumann et al. (2020) present a model of community recovery and adaptation after a wildfire, based on literature from natural hazard vulnerability, disaster recovery, and wildfire ecology. Smith et al. (2016) propose a comprehensive risk-to-resilience framework, which serves as a guide for addressing the complex and interconnected challenges presented by wildfires. This framework encompasses four integral components: risk, adaptation, mitigation, and resilience. Further, the proposed framework integrates natural, physical, and social sciences, as well as local wisdom, experience, and cultural considerations. To implement an effective resilience framework to mitigate the effects of wildfires on communities, an attempt must be made to facilitate discourse among stakeholders and resource managers. Miller et al. (2021) focus on developing strategies to enhance the resilience of social-ecological systems in fire-prone landscapes. Miller et al. (2021) propose an approach tailored for natural resource managers and stakeholders to identify and prioritize elements within a community at risk of wildfire damage. Miller et al. (2021) utilize a conceptual framework that distinguishes resilience into two dimensions: value-free and value-explicit, where the former pertains to inherent system properties influencing post-disturbance changes like wildfires while the latter involves human perceptions and judgments about desirable state changes. This assessment aids in identifying discrepancies between system resilience and human values, offering specific management strategies for various scenarios.

These studies have explored aspects of community resilience, social interactions, ecological factors, and vulnerability related to wildfires. For instance, some studies emphasize the need to adapt to wildfires by distinguishing between basic, adaptive, and transformative resilience strategies. Others highlight the importance of coexisting with wildfires, considering both their ecological role and threats. Social interactions play a significant role in wildfire risk mitigation decisions among homeowners, influencing their actions and behaviors. Retrofitting buildings in fire-prone areas can be a feasible strategy, but it requires community engagement and cost-sharing. These studies contribute to the understanding of and responses to wildfires in fire-prone landscapes such as the Great Plains. However, to implement these strategies in Oklahoma, it is essential to first acquire an understanding of the historic and current meteorological and wildfire hazard conditions.

2.1.1 Wildfire risk perceptions

To understand the March 31, 2023, wildfire outbreak and how this event helps assess and understand vulnerability and resilience more fully to wildfires, it is necessary to examine what shapes Oklahomans' risk perceptions regarding wildfires, as this information can be valuable in helping to reduce vulnerabilities and increase resilience. Previous research has shown that demographic characteristics such as age (Champ et al. 2013; Harter et al. 2020), gender (Brenkert-Smith et al. 2013), income (Champ et al. 2013), political ideology (Harter et al. 2020) and education (Harter et al. 2020), in addition to community/place attachment (Bonaiuto et al. 2016; Gordon et al. 2010) and trust in institutions (Bronfman et al. 2016; Ghasemi et al. 2020; Lachapelle and McCool 2012), are related to wildfire risk perceptions. Further, in the case of both natural and technological disasters (e.g., oil spill and environmental impacts from hydraulic fracturing), the concept of psychological distance can affect people's risk perceptions (Gray et al. 2019; Spence et al. 2012). Psychological distance refers to how mentally removed a person is from an event. The greater the psychological distance a person has from an event (i.e., it is not part of their direct experiences), the more abstract and distant that event is to them, resulting in low risk perceptions. However, when hazard events occur that either impact people directly, impact people they know, or occur close to where they live, these hazard events become much psychologically closer to them and are likely to increase their risk perceptions of the hazard.

2.2 Historic Oklahoma weather and climate

Oklahoma lies between the arid western and the humid eastern regions of the North American continent, which results in a sharp gradient across the state expressed in the hydroclimate, soil moisture, and vegetation (Powell 1879; Seager et al. 2018). Oklahoma's climate varies according to the Köppen climate classification, spanning from humid subtropical in the east to semi-arid in the west (Köppen 1936). Although precipitation and temperature can vary on a year-to-year basis, average annual precipitation and temperature values range from less than 50.8 cm (20 inches) and 54 degrees Fahrenheit in the far western panhandle, to over 127 cm (50 inches) and 61 degrees Fahrenheit in the southeast (PRISM 2023). This climatological gradient primarily arises from the dominant atmospheric circulations across the region and the resulting moisture transports. During the winter, the western regions are shielded from precipitation that occurs as a result of storms formed in the Pacific; these regions are also too far west to receive precipitation from storms that form in the Atlantic (Seager et al. 2018). During the summer, the blocking of the easterly trade winds by the

Rockies tend to bring dry, warm air from the interior southwest to the western regions; this same system can also bring warm, moist air from the Gulf of Mexico over the eastern plains, creating a west-to-east precipitation gradient (Seager et al. 2018). This precipitation gradient is realized in soil moisture, as well as a west-to-east transition in vegetation types from shortgrass to tallgrass prairie across the state (Bruner 1931; FDGC 1997; Hoagland 2000).

Due to lying within this transition zone, Oklahoma experiences many different weather phenomena including, but not limited to, floods, drought, heatwaves, blizzards, ice storms, significant hail, strong winds, tornados, and wildfires (Kloesel et al. 2018). The occurrence of these events can place significant strain on current infrastructure and communities, leading to loss of life and property (Kloesel et al. 2018). Oklahoma is especially vulnerable to periods of drought, most notably throughout the 1930s and 1950s and recently from 2010 to 2015, as well as periods of excessive precipitation such as throughout the 1940s, 1980s, and early 1990s (OCS 2023). The 1930s drought, known as the Dust Bowl of the Great Plains, led to the largest migration of Oklahomans in state history due to a combination of socio-economic factors, agricultural practices, and severe drought conditions (OCS 2023). Drought, a recurrent feature of Oklahoma's climate cycle closely tied to local rainfall patterns, exhibits slightly higher susceptibility in Western Oklahoma due to greater variability in precipitation, marginally adequate for dryland farming, with episodes lasting from weeks to several years, exacerbating wildfire danger, particularly those lasting beyond a few months (OCS 2023).

2.3 Historic Oklahoma wildfires and fuel sources

The Great Plains, typically deemed to have a moderate wildfire risk by experts (Donovan et al. 2020; Campos et al. 2023), have suffered significant financial losses due to wildfires, including wildfire outbreaks, amounting to billions of dollars (Smith 2020; Campos et al. 2023). As the frequency of wildfires rises, so does the economic toll, revealing a lack of preparedness in the region (Campos et al. 2023). The vast grassland ecosystems that are dominant in the Great Plains face heightened vulnerability to larger wildfires due to their extensive coverage and susceptibility to wet-dry cycles (Donovan et al. 2020; Lindley et al. 2019; Campos et al. 2023). Further, over 90% of recorded wildfire ignitions, both in the US and globally, are triggered by humans (Balch et al. 2017; Costafreda-Aumedes et al. 2017; Campos et al. 2023), which exacerbates the hazard risk, particularly as urban sprawl encroaches further into rural areas (Balch et al. 2017; Campos et al. 2023). The April 2018 Oklahoma Rhea fires megafire, a wildfire that burns over 100,000 acres, highlights the impact of unusual fire weather conditions and abundant fuel in the Southern Great Plains, necessitating substantial expenditures for restoration efforts (Lindley et al. 2019; Reid et al. 2010; Campos et al. 2023).

Campos et al. (2023) conducted an analysis on wildfire hazard assessment with a specific focus on Oklahoma. Their study utilized comprehensive historical wildfire data spanning from 1992 to 2020 sourced from the United States Department of Agriculture (USDA) (Short 2022) and the National Interagency Fire Center (NIFC) (NIFC 2023). This dataset provided crucial parameters such as ignition dates, acres burned, ignition causes, and geographic coordinates, revealing insights into the dynamics of wildfires in the region. Campos et al. (2023) categorized the wildfire entries based on the year of ignition to examine the temporal trends and patterns in wildfire occurrence and intensity. By analyzing the wildfire statistics (see Fig. 1a), the researchers were able to show notable shifts in wildfire

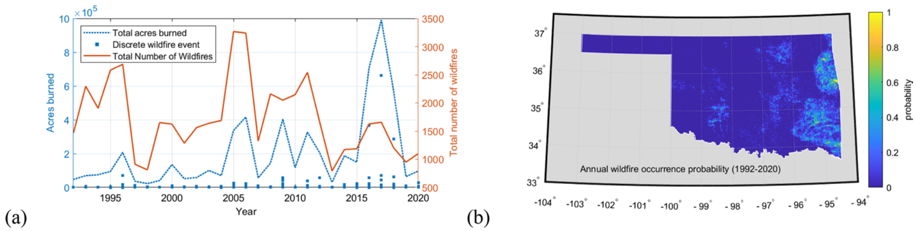

Fig. 1 Oklahoma wildfire statistics: **a** comparison of acres burned to number of wildfires and **b** wildfire occurrences probability from 1992 to 2020

behavior, showing a significant increase in megafires since 2016, which represents a deviation from historical norms. Furthermore, histograms revealed that while smaller wildfires are more prevalent, megafires are rare but becoming increasingly frequent, posing significant challenges for wildfire management and mitigation efforts in rural regions. The study also investigated the causes of wildfires, with findings indicating that human activities, including arson, debris burning, and equipment use, are the primary ignition sources in Oklahoma, accounting for most wildfire ignition incidents. This shows the importance of addressing human-induced factors in wildfire prevention strategies. In addition to analyzing historical wildfire data, Campos et al. developed wildfire hazard maps for Oklahoma with a grid cell spatial resolution of 2.5 km (see Fig. 1b). These maps, based on the probability of wildfire occurrence and intensity, offer valuable insights for stakeholders, including emergency responders, policymakers, and urban planners, enabling them to better understand and mitigate wildfire risks in the region. The study also highlighted the impact of climate change on wildfire dynamics, suggesting a potential correlation between changing climatic conditions leading to more fire weather events and the increasing frequency and intensity of wildfires, particularly megafires. This shows the urgency of implementing proactive measures to adapt to and mitigate the effects of climate change on wildfire hazards (Campos et al. 2023).

3 Oklahoma's March 31, 2023, wildfire outbreak and analysis

Wildfires often occur in rural areas, but there have been recent wildfire events that have spread through urban communities, such as the March 31, 2023, wildfire outbreak in Oklahoma. Figure 2 illustrates the extent of the March 31, 2023, wildfire activity though ignition locations and burned areas in Oklahoma. Specifically, Fig. 2a shows the recorded wildfires during the outbreak, where "Class A" refers to a small wildfire and "Class G" refers to a large wildfire. Figure 2b shows key wildfires near urban communities, and Fig. 2c and d illustrate the impact of wildfires in urban communities. Wildfire outbreaks like these consume vast forest and grassland areas, incurring significant government expenses. Climate change worsens wildfire frequency and size, driven by hot, dry, and windy conditions. Oklahoma, which is primarily grassland, is vulnerable due to wet-dry cycles and human ineractions, with 94% of recorded ignitions being human-caused (Campos et al. 2023).

Figure 2 illustrates the wildfire outbreak event on March 31, 2023, overlaying the recorded NIFC wildfires (categorized by class in Fig. 2a and by perimeter in Fig. 2b) onto the wildfire occurrence probability map (refer to Fig. 1b). Figure 2c and d, show two

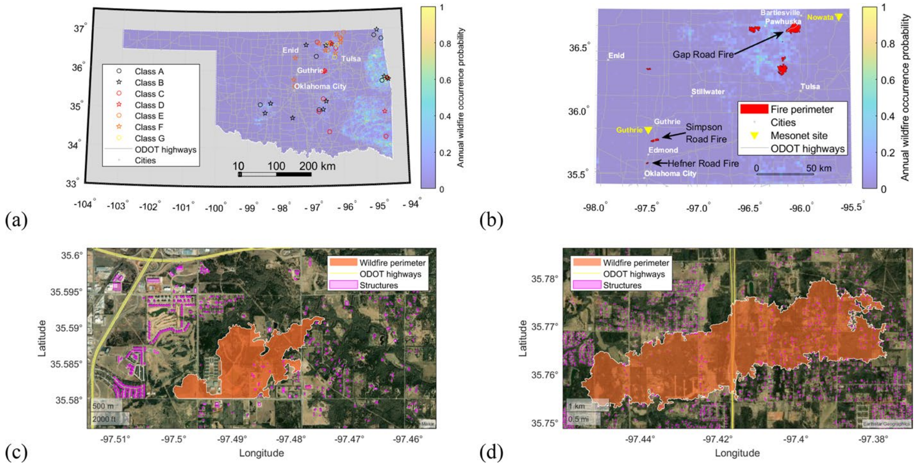

Fig. 2 March 31, 2023, wildfire outbreak: **a** wildfire ignitions by class, **b** wildfire perimeters, **c** Hefner Road Fire, Oklahoma City, OK, **d** Simpson Road Fire, Guthrie, OK

specific wildfires: the Hefner Road Fire and the Simpson Road Fire, both impacting urban communities. It's crucial to note that the NIFC wildfire perimeters represent only specific points in time and may not reflect the final burned perimeter accurately. In total, the NIFC recorded 50 wildfire ignitions, of which only seven had accompanying perimeter information. Figure 2a demonstrates that smaller-class wildfires tend to occur in areas with a history of wildfire activity. Conversely, larger wildfires were observed outside these active regions, often spreading through sparsely populated forested areas in rural northeast Oklahoma. It is also shown that the probability of ignition increases near roads and major highways (see Fig. 2a, b). This is understandable as the majority of ignitions in Oklahoma are human-caused (Campos et al. 2023). The Simpson and Hefner Road Fires had the most significant impact on communities due to their proximity to populated roads and neighborhoods. Figure 2c and d show that dry wooded and tall grassland areas served as fuel sources for the wildfires, possibly exacerbated by nearby flammable structures. Given the prevailing wind direction, it's reasonable to assume that the wildfires ignited at the southwest end of their respective perimeters. The shape of these two wildfires, as depicted in Fig. 2c and d, further illustrates the influence of wind direction, with the fires spreading from southwest to northeast. Additionally, the fires scattered at the northeast end of the perimeter, highlighting the impact of wind direction on firebrand spread.

Oklahoma is experiencing an increase in wildfire risk potentially linked to climate change. Small wildfires are more common, while large megafires remain rare. Although annual wildfire numbers have decreased, the threat remains due to large and rare fires near urban communities. The westward shift of wildfires, occurring with more intensity, is due to a combination of grassland and woodland biomes in central and western Oklahoma, posing a higher risk to urban communities. Megafires have become more frequent in the western and northwestern parts of the state. Smaller wildfires tend to cluster around historically active areas, and larger fires often spread through sparsely populated forested regions and areas near roads, influenced by wind patterns. The Simpson and Hefner Road Fires have notably impacted communities due to dry fuels, high winds, and ignitions in densely populated areas.

3.1 Fire weather and analysis

Wildfires across Oklahoma have been shown to be intrinsically linked to the state's weather patterns (Lindley et al. 2019). Using data from the Guthrie and Nowata Mesonet sites located at 35.85° N, −97.48° W and 36.74° N, −95.61° W, respectively, the atmospheric conditions and soil moisture response in the week preceding the wildfires of March 31 can be examined (McPherson et al. 2007). In particular, average air temperature, relative humidity, rainfall totals, wind speed, and maximum wind gusts were chosen to examine the atmospheric conditions. All measurements, excluding rainfall totals, are sampled every 3 s and then averaged over a 5-min period to give a 5-min temporal resolution. Rainfall measurements are event-driven but the calculated rainfall totals still have a 5-min temporal resolution. Average air temperature and relative humidity are measured at 1.5 m above the ground, whereas wind speed and maximum wind gust are measured at 10 m above the ground. The Oklahoma Mesonet also measures the calibrated change in temperature (ΔT_{ref}) of the soil over time after a heat pulse is introduced, which can be used to examine the soil moisture at the two sites. In particular, the soil moisture can be analyzed by computing the fractional water index (FWI) at three different levels; 5, 25, and 60 cm below the natural sod cover (Schneider et al. 2003; Illston et al. 2008). The FWI is a unitless value that ranges from 0.00 for very dry soils to 1.00 for soils at full capacity (Illston et al. 2008), it also does not depend on soil type, texture, and/or wetness so can be compared across different sites, and is computed using Eq. 1:

$$\mathrm{FWI} = \left(\Delta T_d - \Delta T_{ref}\right)/\left(\Delta T_d - \Delta T_w\right) \tag{1}$$

where FWI = fractional water index (unitless), $\Delta T_d = 3.96$ °C, $\Delta T_w = 1.38$ °C, and ΔT_{ref} = reference temperature difference.

Friday, March 31st, at the Guthrie Mesonet site in Logan County, was a relatively warm day with an average temperature of 70.4°F compared to an average March temperature of 56.5°F computed over the 15 years prior from 2007 to 2022 (Fig. 3a). The day also began with high relative humidities before a sharp drop in relative humidity, from 80% at 1:30 p.m. to 9% by 6:45 p.m. local time. During the same time period, wind speed increased from 19 to 39 m/s and the maximum wind gust measured during each 5-min interval increased from 28 to 56 m/s (Fig. 3c). This time frame corresponds with the ignition and growth of the fires located near Oklahoma City which started around 2 p.m. on Friday and burned through Saturday morning. Additionally, the Guthrie Mesonet site received only 13.76 mm (about 0.54 in) of rainfall during the week prior, between March 24 and March 30, with the year-to-date rainfall accumulation by March 31 at 45% of average. Between January 1 and March 31, 2023, 60.198 mm (about 2.37 in) of rainfall was observed at the site compared to an average of 133.858 mm (about 5.27 in) computed over the 15 years prior (2007–2022). This lack of rainfall is reflected in the soil moisture conditions with a steady decline in FWI from 0.70 to 0.50 at 5 cm and 0.83 to 0.65 at 25 cm below the natural sod cover over the 2-week period (Fig. 3b). Similarly, the Nowata Mesonet site in Delaware County observed a sharp decline in relative humidity and a sharp increase in wind speed and maximum wind gust over the course of Friday afternoon (see Fig. 4). However, unlike the Guthrie Mesonet site, the FWI remained high throughout the 2-week period with neither the 5 cm, 25 cm, or 60 cm FWI dropping below 0.93. In the context of wildfire hazard, the analysis of the metrological conditions leading up to and during the wildfire outbreak on March 31, 2023, in Oklahoma shows the affect that meteorological and soil factors have on wildfire ignition rates, propagation, and intensity. The significant

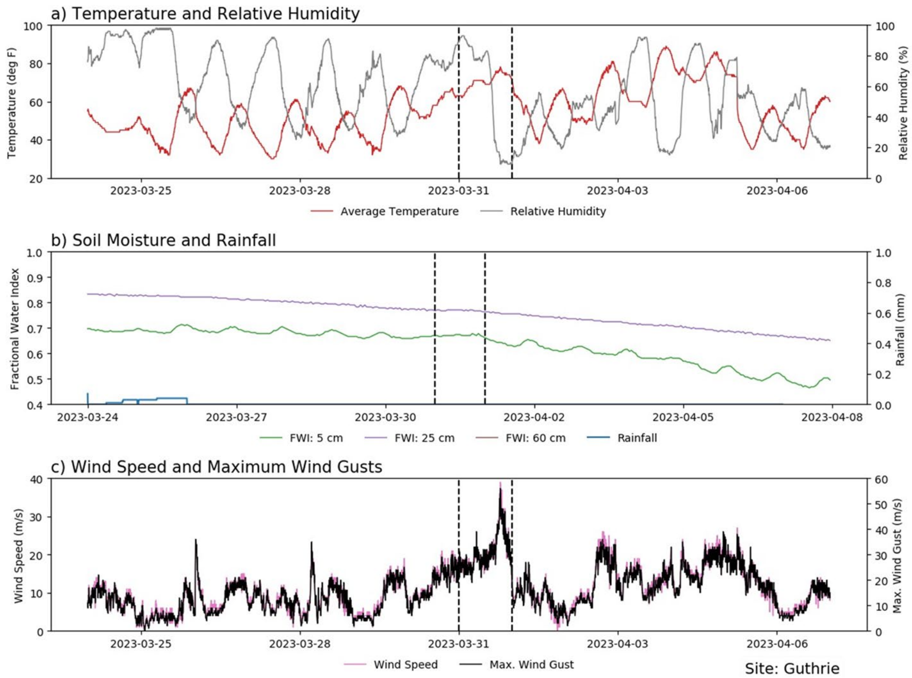

Fig. 3 Timeseries of **a** 5-min Average Temperature in degrees F (red) and 5-min Relative Humidity as a percentage (grey), **b** hourly Fractional Water Index (FWI) for three levels; 5 cm (green), 25 cm (purple) and 60 cm (brown) and 5-min rainfall totals in mm (blue) and **c** 5-min Wind Speed in m/s (pink) and 5-min Maximum Wind Gust in m/s (black) for the Guthrie Mesonet Site located at 35.85° N, −97.48° W between March 24 and April 8, 2023. March 31 (date of the wildfires) is designated by the dashed black lines

deviations from the average temperature, rapid drops in relative humidity, and substantial increases in wind speed and gusts during this period are indicative of fire weather, characterizing a highly conducive wildfire environment. Further, the shortage of rainfall and the decline in soil moisture levels highlight the importance of understanding these factors for wildfire risk assessment. The elevated wildfire risk because of the fire weather conditions on March 31, 2023, resulted in the wildfire outbreak in Oklahoma that affected communities and resulted in the destruction of multiple structures.

3.2 Aspects of community resilience: response, impact and recovery

The National Institute of Standards and Technology (NIST) defines community resilience as “the ability to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions” (NIST 2024). Additionally, NIST considers prevention, protection, mitigation, response and recovery as key steps towards resilience (NIST 2024). Community resilience is linked to how communities prepare for and respond to natural, or human-caused hazards like wildfires. During the March 31, 2023 wildfire outbreak, the response of various agencies and organizations exemplified community resilience in action. It should be noted that while measurements for community resilience exist, NIST indicates that these methods may not accurately represent actual community resilience (Gu et al. 2023). Therefore, it is crucial to validate these measurement methods

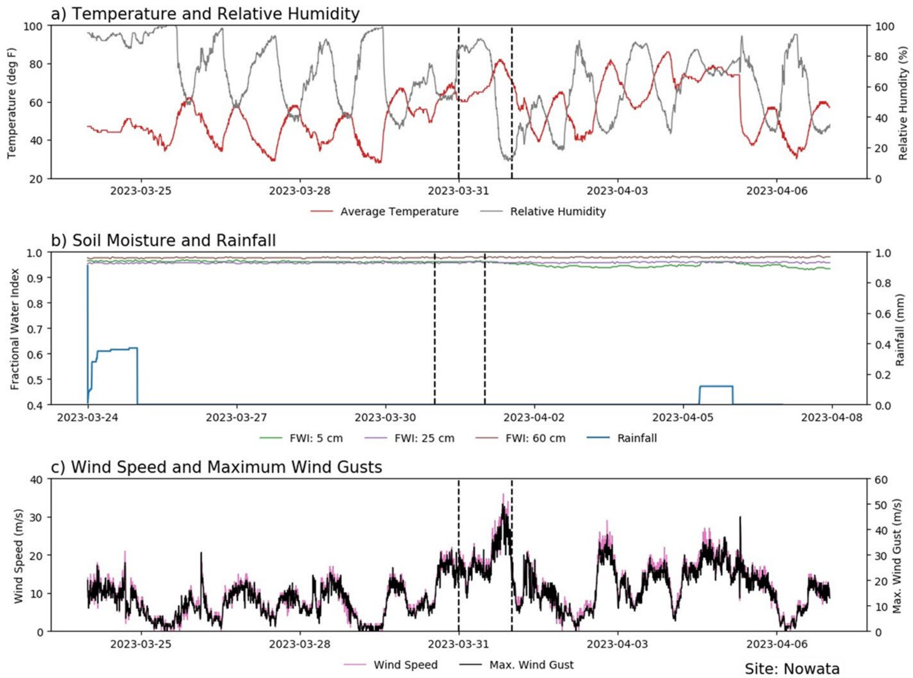

Fig. 4 Timeseries of **a** 5-min Average Temperature in degrees F (red) and 5-min Relative Humidity as a percentage (grey), **b** hourly Fractional Water Index (FWI) for three levels; 5 cm (green), 25 cm (purple) and 60 cm (brown) and 5-min rainfall totals in mm (blue) and **c** 5-min Wind Speed in m/s (pink) and 5-min Maximum Wind Gust in m/s (black) for the Nowata Mesonet Site located at 36.74° N, −95.61° W between March 24 and April 8, 2023. March 31 (date of the wildfires) is designated by the dashed black lines

through comprehensive empirical evidence and rigorous testing of their internal consistency and external validity (Gu et al. 2023). Understanding this specific outbreak is significant because it underscores crucial challenges and responses that can shape future wildfire management and emergency preparedness, especially as climate change exacerbates fire activity in urban communities. The wildfire outbreak, as documented by news agencies and the local government (Kliewer 2023; OEM 2023), provides a solid foundation for an accurate recounting and analysis of the event. Due to the absence of comprehensive survey data on wildfires in Oklahoma, the information from these sources will serve as the primary evidence for understanding the wildfire outbreak.

In Oklahoma on the afternoon of March 31, 2023, the State Emergency Operations Center was activated due to the high fire danger, wildfires, and high winds that were prevalent across the state. This activation was a coordinated effort involving various agencies and organizations, all working together to respond to the fires and ensure the safety of the residents. Further, the Federal Emergency Management Agency (FEMA) approved three Fire Management Assistance Grants for the Simpson Fire, the Hefner Road Fire, and the Gap Road Fire on the evening of March 31, 2023 (OEM 2023). These grants are designed to reimburse local governments and first responders for the costs incurred during firefighting efforts, playing a crucial role in supporting the state's response to the wildfires. In response to the Gap Road Fire, an evacuation shelter was opened in Bartlesville to provide refuge for residents affected by the fire. The city of Bartlesville was nearly impacted by the Gap Road Fire (see Fig. 2b) due to southwesterly winds propagating the fire towards the northeast. The severity of the situation also led to evacuations in Oklahoma City and Logan County, which is located north of Edmond, south of Stillwater, and near Guthrie. The fires caused significant damage across the state, with several structures being destroyed or damaged, highlighting the destructive capability of these wildfires. More than 65 fires were reported in 27 counties, demonstrating the widespread nature of this outbreak (Kliewer 2023). Additionally, it was reported that over 28,000 customers statewide were without power due to high winds and wildfires, which further complicated emergency response efforts, increasing the risk to repair crews working under dangerous fire weather conditions (OEM 2023).

3.2.1 Property damage and injuries

The wildfires caused significant damage to residential and commercial structures. Specifically, the Simpson Road fire in Logan County destroyed over 30 homes (Kliewer 2023). Similarly, the Hefner Road fire in Oklahoma City led to the loss of three homes and minor damage to three more houses. The Gap Road fire in northeast Oklahoma also had a substantial impact, destroying seven homes. In the Bartlesville/Washington County area, multiple structures were reported as damaged by the fires. In Oklahoma City, authorities documented two house fires and five grass fires. On the human health impact, local hospitals reported a total of 32 injuries related to the fires, fire weather conditions, and high winds (OEM 2023). In addition, a few firefighters required medical attention, primarily due to physical strain and exhaustion. The total number of structures damaged or destroyed remains uncertain at the time of this study. This demonstrates community resilience through the existence and engagement of community resources by local emergency services and healthcare providers, enabling them to manage and respond to the widespread impacts of the wildfires, which helps the community despite the danger and uncertainty caused by the wildfire outbreak.

3.2.2 Road closures and disruptions

The wildfires that occurred in the Oklahoma City metropolitan area (see Fig. 1) had a significant impact on road traffic and transportation due to the smoke visually impairing drivers and emergency responders (Kliewer 2023). Authorities and the Oklahoma Department of Transportation had to close major roads like Interstate 35 and the Turner Turnpike at several locations due to the fires. Residents living near Hefner Road and 122nd Street (from Eastern Avenue to Interstate 35) were asked to evacuate, as were those in Logan County, located near southbound Interstate 35 between Seward Road and Waterloo. Roads in the vicinity of Western Avenue and Charter Oak Road were also closed as fire departments attempted to suppress the fires (Kliewer 2023). The fires even disrupted school transportation, where Edmond Public Schools officials reported that bus drivers couldn't safely reach some neighborhoods, prompting parents to pick up their kids from school. These road closures and evacuations caused significant inconvenience and danger for travelers, residents, and emergency responders. Traffic was heavily affected by the fires, especially the thick smoke, which inhibited mutual aid crews trying to reach the affected areas (Kliewer 2023). The combination of the high fire danger across the state, smoke, and extended travel times also impeded firefighters' ability to assist other departments beyond their jurisdictions. Even with these challenges, local authorities were able to manage the wildfire outbreak and coordinate with the community to safely navigate the wildfire hazard. This shows community resilience through the engagement of local authorities, emergency services, and schools to manage road closures, evacuations, and safety challenges despite the unpredictability and disruption caused by the wildfires and thick smoke.

3.2.3 Firefighting/police operations

Fire departments across the affected areas, including the Oklahoma City Fire Department, Guthrie Fire Department, and Norman Fire Department, worked to suppress the wildfires. The Oklahoma Department of Emergency Management and Homeland Security played a crucial role in coordinating local requests for task force support and asked FEMA for three Fire Management Assistance Grants to help with firefighting (Kliewer 2023; OEM 2023). Oklahoma Forestry Services mapped the burned areas and supported firefighting, working with task forces from different counties to fight the wildfires. The Oklahoma City Fire Department received over 350 emergency calls (Kliewer 2023), which included handling six grass fires and two structure fires in their area. The Guthrie Fire Department faced water supply issues and traffic problems due to the closure of Interstate 35, but they managed to control hotspots in Logan County. The Norman Fire Department successfully controlled a wildfire covering 100 to 130 acres without losing any homes or structures (Kliewer 2023). The Oklahoma governor reported that the emergency response team used satellite technology to track 70 hotspots and reported more than 65 fires in 27 counties (Kliewer 2023), highlighting the scale of the wildfire outbreak. The Oklahoma Highway Patrol assisted with traffic control and road closures in affected areas, ensuring public safety. Additionally, the Oklahoma City Police Department assisted with damage assessment and evacuation orders in Oklahoma City, playing a crucial role in maintaining order during the wildfire outbreak. This shows aspects of community resilience through the coordinated efforts of various fire departments, emergency management, and law enforcement agencies to tackle wildfires, allocate resources effectively, and maintain public safety amid significant challenges and uncertainty.

3.2.4 Evacuations and sheltering

The wildfire outbreak had an impact on evacuations and sheltering in various regions. In areas such as Oklahoma County, Logan County, and Washington County, the rapid spread of fires posed a substantial threat to residential homes and structures, necessitating the evacuation of multiple areas. These encompassed neighborhoods near key road intersections, such as Hefner Road and 122nd Street, Simpson Road and Coltrane Road, Highway 123 and Gap Road, in addition to the Bella Terra, Highland Meadows, and Highland Farms neighborhoods (Kliewer 2023). In response to this outbreak, the Red Cross established an evacuation center at the Town and Country Christian Church in Bartlesville to accommodate residents affected by the Gap Road Fire (Kliewer 2023). Further, the Waterloo Road Church of Christ extended shelter to individuals impacted by the fires in Logan County. The wildfire outbreak also had impacts on local educational institutions, where both Guthrie Public Schools and Edmond Public Schools were forced to either detain school buses or request parents to pick up their kids, due to road closures and the inherent danger associated with the fires. This demonstrates aspects of community resilience through the use of existing resources and coordinated evacuations and sheltering efforts by the Red Cross, local churches, and schools, ensuring the safety of residents and students who were faced with the wildfire outbreak's challenges of rapid smoke spread and disrupted infrastructure.

3.2.5 Electrical power restoration

The strong winds caused extensive damage to the electrical infrastructure, resulting in widespread power outages. Power companies such as Oklahoma Gas and Electric (OG&E) and the Public Service Company of Oklahoma (PSO) swiftly mobilized their crews to restore electricity. Despite the immense scale of the outages, the power companies' response teams worked throughout the night and into the weekend to ensure that service was gradually restored to affected customers. Strong winds and fires damaged nearly 50 utility poles and their associated lines, which OG&E crews had to repair or replace (Kliewer 2023). The downed power lines also posed safety risks for the public and firefighters, who were advised to stay away from them and report issues to OG&E. At the height of the outbreak, 16,481 customers lost power, mostly in Logan County. By 9 p.m. on Friday, March 31, the number of outages dropped to 4000 customers and by 9 a.m. on Saturday, April 1st, it was further reduced to 900 customers. OG&E reported that more than 800 restoration personnel were working to restore power to homes and businesses throughout the weekend (Kliewer 2023). The PSO expected to have power restored to most customers by 1 p.m. on Saturday, April 1st, and to all customers by 7 p.m. on the same day. This exemplifies community resilience as power companies quickly restored power despite extensive damage from strong winds and fires, demonstrating the community's ability to mobilize resources and prioritize safety to ensure the continuation of lifeline/essential infrastructure in response to wildfires.

3.2.6 Discussion

The community's ability to quickly mobilize and respond to this wildfire outbreak may be attributed to Oklahoma's history of severe natural events such as tornadoes, ice storms, and floods, which may have contributed to its heightened ability to manage and navigate hazardous events, including wildfires. The account of the wildfire outbreak shows several critical aspects of community resilience. Effective coordination among emergency responders, government agencies, and community organizations was important for mitigating wildfire impacts. By working together during the wildfire outbreak, these emergency responders and stakeholders contribute directly to the community's ability to recover swiftly and maintain stability, thereby showing community resilience in practice. This includes not only immediate response efforts but potentially long-term initiatives for recovery, rebuilding, and enhancing both physical infrastructures (e.g., road networks, power distribution lines) and social infrastructures (e.g., support systems). The devastating societal impacts—property damage, injuries, road closures—show the interdependencies between social and physical infrastructures and how community resilience plays an important role. These infrastructures are vital for daily functioning and effective emergency response, which shows the importance of strengthening them through robust planning, maintenance, and preparedness measures.

The quick restoration of the electrical power distribution system during the crises shows its critical role as a lifeline infrastructure for community well-being, essential for maintaining resilience to wildfires. Conducting hazard assessments before wildfires could provide valuable insights to strategically allocate resources and implement preventive measures, thereby reducing vulnerabilities and enhancing readiness. Further, establishing a resilience framework may be essential for adapting current wildfire mitigation strategies and improving emergency response capabilities. Additionally, understanding wildfire risk perceptions among residents and stakeholders is crucial for informed decision-making. By acknowledging and addressing these perceptions, communities can tailor outreach efforts and enhance public awareness for wildfire damage prevention and response. Further, understanding risk perceptions allows stakeholders to identify which areas and populations feel most at risk, allowing for the prioritization of resources and implement targeted measures to address specific concerns and vulnerabilities, which may ultimately enhance the safety and protection for both people and ecosystems.

In summary, the account of the wildfire outbreak in Oklahoma not only shows the immediate impacts and response efforts but also demonstrates broader implications for community resilience. By utilizing existing resources, enhancing preparedness measures, and developing collaborative resilience frameworks, communities could more effectively navigate the challenges posed by urban/wildfire outbreaks and other disasters in an increasingly unpredictable environment.

3.3 Wildfire risk perceptions

3.3.1 M-SISNet data description

To examine the wildfire risk perceptions of Oklahomans, data from the Oklahoma Mesoscale Integrated Socio-geographic Network (M-SISNet), which is a panel survey that is administered twice a year (winter and spring) since 2021 (IPPRA 2021), is utilized. The panel contains over 2000 adult Oklahoma residents (age 18 and older), based on an address-based random sample. Each wave of the survey contains some questions that appear in all waves and others that appear in only select waves. The panel surveys ask questions designed to measure perceptions and beliefs about weather, household water and energy use, along with demographic and core values questions (e.g., political ideology). In this study, wave 4 of the M-SISNet survey that was administered from February 28, 2023, through April 12, 2023, is employed. Recall that the wildfire outbreak studied in this paper occurred on March 31, 2023, resulting in a natural experiment. Wildfire risk perceptions of Oklahomans can be compared directly before and after a large-scale fire event. The dependent and independent variables as well as their corresponding scales are described in Table 1.

3.3.2 Analytic strategy

To examine how these different variables were associated with current and future wildfire risk perceptions, bivariate and multivariate analyses were conducted in Stata 18.0. First, the results of two-independent-samples t-tests of all the dependent and independent variables with the before/after wildfire outbreak variable were presented to begin to unpack whether the wildfire outbreak had impacts on Oklahomans' wildfire risk perceptions. Next, two sets of two Ordinary Least Squares (OLS) regression models were estimated, treating the two dependent variables as continuous. The assumptions of OLS regression were tested, and no major violations were found, including low Variation Inflation Factor values indicating the absence of multicollinearity. The first two equations modeled the wildfire risk perception variable, while the second two equations modeled the future wildfire risk

Table 1 Description of variables

	Description
Dependent variable	
Wildfire risk	To measure current and general wildfire risk perceptions, respondents were asked, "How do you rate the risk of wildfires to the people of Oklahoma. This variable was measured using a five-point ordinal scale where 1 = no risk to 5 = extreme risk (IPPRA 2021)
Future wildfire risk	Future wildfire risk perceptions were assessed using the following question, "When you think about the next 25 years in Oklahoma, do you think the risk (frequency and severity) of wildfires will increase, decrease, or stay the same?" The answer choices ranged from 1 = significantly decrease to 5 = significantly increase (IPPRA 2021)
Independent variable	
Before/after March 31 wildfire outbreak	This is a dichotomous variable that is coded "0" if the respondent took the survey before March 31, 2023, and coded "1" if the respondent took the survey on or after March 31, 2023. This variable is used to assess the psychological distance argument that risk perceptions of wildfires will be higher after a fire event that brings the hazard psychologically closer to the respondent (IPPRA 2021)
Age	Age was measured with a question that asked, "How old are you?" Respondents were asked to fill in their age in years (IPPRA 2021)
Gender	Respondents were asked, "Are you male, female, or other?" There were a very small number of "other" responses, therefore, we recoded this variable for the analysis where "0" = male and "1" = female (IPPRA 2021)
Race	Respondents were asked, "Which of the following best describes your race?" The answer choices were, white, black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Pacific Islander, two or more races, some other race (please specify). In the analyses combined all nonwhite races into one category. This variable is coded 0 = white, 1 = nonwhite (IPPRA 2021)
Education	The survey asked, "What is the highest level of education you have completed?" This variable is measured with an eight-point ordinal scale that ranges from 1 = less than High School to 8 = PhD/JD/MD (IPPRA 2021)
Income	To measure income, respondents were asked to respond to what "was the estimated annual income for your household in 2021?," which was measured on a four-point ordinal scale where 1 = Less than $50,000 to 4 = $150,000 or more (IPPRA 2021)
Political ideology	A respondent's political ideology was measured with answers to a question that asked, "on a scale of political ideology, individuals can be arranged from strongly liberal to strongly conservative. Which of the following best describes your views?" The variable is measured with a seven-point ordinal scale where 1 = strong liberal to 7 = strong conservative (IPPRA 2021)
Length of time in OK	Respondents were asked," How long have you lived in Oklahoma?" They were given the opportunity to answer the question in years. This variable is used to test the community/place attachment argument (IPPRA 2021)
Trust	Respondents' trust in various entities to provide useful information for resilience and vulnerability were measured with three related questions. Respondents were asked, "solving problems as a group or community can be contentious and technically complex so getting information you can trust is important. How much do you trust information from the following groups and organizations, (1) state and local policymakers and elected officials (trust is policymakers), (2) state and local agencies that regulate water, land, and infrastructure resources (trust in agencies), and (3) private companies whose operations use water, land, and infrastructure resources (trust in private companies). The three trust questions were measured on a five-point ordinal scale ranging from 1 = no trust, to 5 = complete trust" (IPPRA 2021)

variable. The first model of both sets included the demographic, community attachment, and trust independent variables, and the second model of both sets added in the before/after wildfire outbreak indicator.

3.3.3 Descriptive and bivariate results

Table 2 reports the descriptive and bivariate statistics for the M-SISNet variables used in the analyses. In the case of the two-independent samples t-test bivariate results, the means of both wildfire risk dependent variables were significantly higher for those respondents who completed the survey after the March 31, 2023 (mean wildfire risk after = 3.65; mean future wildfire risk after = 3.73), wildfire outbreak compared with those respondents who completed the survey before the wildfire outbreak (mean wildfire risk before = 3.41; mean future wildfire risk before = 3.56; $p < 0.01$). The only other variables to have a significant association (t or χ^2) with the before/after wildfire outbreak variable were age and length of time residing in Oklahoma.

3.3.4 Multivariate results

To explore the association more accurately between demographic variables, community attachment, trust, and psychological distance (before/after wildfire outbreak) with wildfire

Table 2 Descriptive and bivariate statistics for variables in the analysis

Variable	Mean	*n*	SD	Min	Max	*p* value
Wildfire risk	3.43	2126	0.90	1	5	0.001
Future wildfire risk	3.58	2135	0.75	1	5	0.003
Age	53.76	2144	16.09	18	93	0.001
Education	5.00	2102	1.75	1	8	0.213
Income	1.99	2071	0.96	1	4	0.682
Political ideology	4.40	2135	1.72	1	7	0.501
Length of time in OK	40.35	2144	19.85	1	92	0.027
Trust in policymakers	2.17	2142	0.85	1	5	0.515
Trust in agencies	2.69	2139	0.89	1	5	0.920
Trust in private companies	2.25	2142	0.85	1	5	0.518
	% Yes	*n*	χ^2 and *p* value for crosstabulation with before/after wildfire outbreak			
Wildfire outbreak						
Before	90.58	1942				
After	9.42	202				
Gender			$\chi^2 = 0.708, p = 0.702$			
Female	60.98	1300				
Male	39.02	832				
Race			$\chi^2 = 0.050, p = 0.824$			
Nonwhite	15.62	331				
White	84.28	1788				

p value is for difference in means between before/after wildfire outbreak risk perceptions in Oklahoma, four OLS regression models are employed and presented in Table 3. The main findings from the first two models, which predict current wildfire risk perceptions, indicate that increases in age ($p < 0.01$), decreases in political conservative ideology ($p < 0.01$), trust in policymakers ($p < 0.01$), and trust in private companies ($p < 0.01$), along with identifying as female (p < 0.01) are all associated with increases in wildfire risk perceptions. Further, Wildfire Risk Model 2 highlights the role of psychological distance (measured by whether the respondent took the survey before or after the March 31, 2023, wildfires; see Table 1) in predicting wildfire risk perceptions. Specifically, respondents who took the survey after the wildfire outbreak had a 0.231 higher mean on the five-point wildfire risk scale ($p < 0.01$), controlling for the other covariates. The second two OLS regression models predict future wildfire risk perceptions using the same set of variables as the current wildfire risk models and have similar findings. Increases in age are associated with higher future wildfire risk perceptions ($p < 0.05$). Unexpectedly, increases in trust in agencies are associated with increases in wildfire risk perceptions ($p < 0.01$). As noted in Table 1, "agencies" in our case refers to, "state and local agencies that regulate water, land, and infrastructure resources." An example of these types of agencies would be state and local water resource boards, who work on planning for future state and local water needs. This finding should be explored in future research (see below). Decreases in political conservative ideology ($p < 0.01$), trust in policymakers ($p < 0.01$), and trust in private companies ($p < 0.01$) are associated with increases in future wildfire risk perceptions. The second Future Wildfire Risk model adds in the before/after wildfire outbreak variable. Again, support for the psychological distance argument is evident, as the mean of future wildfire perceptions is 0.148 higher on the five-point future wildfire risk scale ($p < 0.01$), controlling for the other independent variables in the model.

Table 3 OLS regression coefficients (*b*) and standard errors (SE) for determinants of wildfire risk variables

	Wildfire risk Model 1		Wildfire risk Model 2		Future wildfire risk Model 1		Future wildfire risk Model 2	
	b	SE	*b*	SE	*b*	SE	*b*	SE
Before/after wildfire outbreak	–	–	0.231**	0.066	–	–	0.148**	0.053
Age	0.008**	0.002	0.009**	0.002	0.003*	0.001	0.003*	0.001
Gender (female = 1)	0.194**	0.041	0.197**	0.041	0.032	0.033	0.034	0.033
Race (nonwhite = 1)	− 0.073	0.056	− 0.068	0.055	− 0.060	0.044	− 0.058	0.044
Education	− 0.019	0.013	− 0.018	0.125	− 0.007	0.010	− 0.006	0.010
Income	− 0.011	0.022	− 0.011	0.022	− 0.021	0.018	− 0.021	0.018
Political ideology	− 0.051**	0.012	− 0.051**	0.012	− 0.100**	0.010	− 0.097**	0.010
Length of time in OK	0.001	0.001	− 0.001	0.001	− 0.001	0.001	− 0.001	0.001
Trust in policymakers	− 0.077**	0.030	− 0.077**	0.030	− 0.140**	0.024	− 0.139**	0.024
Trust in agencies	0.051	0.028	0.050	0.028	0.083**	0.022	0.083**	0.022
Trust in private companies	− 0.090**	0.028	− 0.088**	0.028	− 0.100**	0.023	− 0.097**	0.022
Constant	3.484**	0.122	3.434**	0.123	4.247**	0.098	4.214**	0.099
N	2017		2017		2024		2024	
F	11.36**		11.49**		25.24**		23.74**	
Adjusted R^2	0.049		0.054		0.107		0.110	

**$p < 0.01$, *$p < 0.05$ significance (two-tailed)

3.3.5 Discussion

The findings from the OLS regression models support previous research. As expected, psychological distance to the hazard (wildfires) was significantly associated with increased risk perception, supporting the findings of prior research of psychological distance and environmental hazards (e.g., Gray et a1. 2019). Similar to the findings of Brenkert-Smith et al. (2013) identifying as female is associated with higher wildfire risk perception. Some prior research suggests that older respondents will have lower fire related risk perceptions (e.g. Champ et al. 2013). However, the opposite is found in the models, where increases in age are associated with higher wildfire risk perceptions. While these divergent findings should be explored further in additional research, two possibilities are offered for the different findings. First, the studies took place in different states, Colorado and Oklahoma with different demographic profiles and different wildfire seasons. Second, eleven years have passed in-between the two studies and climate change has made wildfires more frequent and dangerous, perhaps changing older people's wildfire related risk perceptions. Research has shown that being more politically progressive is associated with increasing wildfire and climate related risks (Harter et al. 2020), which is what we find in our study as well. Community attachment (measured by length of time living in Oklahoma) was not related to wildfire risk perceptions, despite some research that suggested it might be (Bonaiuto et al. 2016; Gordon et al. 2010). Finally, the findings that two "trust" variables (trust in policymakers and trust in private companies) were negatively associated with wildfire risk perceptions align with prior research (Bronfman et al. 2016; Ghasemi et al. 2020; Lachapelle and McCool 2012). However, the results from Models 3 and 4 regarding trust in agencies were unexpected. Specifically, increases in trust in state and local agencies that regulate water, land, and infrastructure resources are associated with increases in wildfire risk perceptions. It is suggested that this question be revisited when longitudinal data become available. It is possible that the positive association found is capturing increasing trust in these agencies because of increased wildfires. However, this cannot be tested with cross-sectional data.

4 Lessons learned and recommendations

The March 31, 2023 wildfire outbreak in Oklahoma serves as a valuable case study for emergency management agencies and communities. From the literature review in Sect. 2 and the discussion and results in Sect. 3, the following lessons learned and recommendations compiled here are divided into three thematic areas—wildfire risk, resilience strategies, and risk perception.

4.1 Wildfire risk

Rapid changes in temperature, humidity, wind speed, and wind gusts significantly influence wildfire conditions. These factors serve as critical indicators of increasing wildfire hazard. Inadequate rainfall and declining soil moisture levels may contribute to elevated wildfire hazard. Regular monitoring of these factors due to climate change is crucial for effective wildfire risk assessment and preparedness. Wildfires cause significant property damage and injuries, emphasizing the importance of building fire-resistant structures and implementing stricter building codes in fire-prone areas. High winds due to fire weather conditions lead to extensive electrical infrastructure component failures which may become the source of new wildfire ignitions. Wildfires and high winds can cause extensive electrical infrastructure damage and power outages. Electrical infrastructure should be assessed to understand the probability of failure due to wildfires and strong winds. The smoke produced by the wildfires, carried by strong winds, disrupted the transportation infrastructure, causing delays and hindering emergency response efforts. To better understand the risks to affected communities and emergency responders, wildfire and smoke output should be modeled in the urban setting.

4.2 Resilience strategies

During the 2023 Oklahoma wildfire outbreak, the successful coordination among emergency responders, government agencies, and community organizations was crucial in response to the wildfire hazard. This coordination was evident in the rapid response to property damage and injuries, with emergency services and healthcare providers effectively managing the impacts. Road closures and disruptions were handled efficiently by local authorities and schools, ensuring public safety despite significant challenges posed by the wildfires. Additionally, the quick restoration of electrical power and the establishment of evacuation centers by organizations like the Red Cross shows the community's resilience and ability to adapt to hazardous conditions. Oklahoma's emergency response measures, though not fully developed, have been refined through experiences with many past natural hazards. Communities in fire-prone areas, like Oklahoma, should employ adaptive strategies that include robust fuel management, community planning, and enhanced preparedness measures to address evolving wildfire risks. These efforts should focus on tailored approaches, hazard mapping, and climate change effects in Oklahoma. Communities can further enhance their resilience by promoting home retrofitting as a proactive measure to mitigate structural damage from wildfires and establishing programs that provide support, guidance, and cost-sharing options to homeowners at the WUI. Adopting or modifying resilience frameworks to develop strategies that integrate physical and social infrastructures, while acknowledging cultural considerations, is also essential. Further, developing a comprehensive evacuation plan that clearly identifies shelter locations and establishes communication channels for disseminating evacuation orders will improve preparedness. Additionally, electrical utilities should invest in infrastructure hardening and develop rapid response plans to restore power during wildfire events, while stakeholders should consider the risk of electrical infrastructure-induced wildfire ignitions during safety, maintenance, emergency response, and community/infrastructure resilience evaluations. Stakeholders should also encourage communities to promote community-building activities and individual resilience through education and awareness campaigns that emphasize the role of personal attributes and community engagement in enhancing overall resilience.

4.3 Risk perception

Age was consistently associated with higher wildfire risk perceptions both for current and future risk. This suggests that older individuals may perceive a greater risk. Understanding these demographic differences is important for tailoring wildfire mitigation strategies. Trust in policymakers and private companies, as well as political ideology, were important factors in shaping wildfire risk perceptions. Decreases in trust in these entities and a shift away from political conservative ideology were associated with higher wildfire risk perceptions. This indicates that public trust and political beliefs can influence how individuals perceive wildfire risk. The concept of psychological distance was supported in the study. Respondents who took the survey after the wildfire outbreak had higher wildfire risk perceptions, indicating that experiencing a wildfire event can make the perceived risk more personal or immediate. This has implications for risk communication and preparedness efforts.

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Declarations

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Ethical approval This project utilized survey data from an online public repository (M-SISNet); therefore, no ethical clearance is necessary.

References

Balch JK, Bradley BA, Abatzoglou JT, Nagy RC, Fusco EJ, Mahood AL (2017) Human-started wildfires expand the fire niche across the United States. Proc Natl Acad Sci 114(11):2946–2951

Bonaiuto M, Alves S, De Dominicis S, Petruccelli I (2016) Place attachment and natural hazard risk: research review and agenda. J Environ Psychol 48:33–53

Brenkert-Smith H, Kickinson KL, Champ PA, Flores N (2013) Social amplification of wildfire risk: the role of social interactions and information sources. Risk Anal 33(5):800–817

Bronfman NC, Cisternas PC, López-Vázquez E, Cifuentes LA (2016) Trust and risk perception of natural hazards: implications for risk preparedness in Chile. Nat Hazards 81:307–327

Bruner WE (1931) The vegetation of Oklahoma. Ecol Monogr 1(2):99–188

Campos R, Harvey PS, Muraleetharan KK (2023) Hazard mapping and analysis of wildfires: an Oklahoma case study. In: ASCE inspire 2023. American Society of Civil Engineers

Champ PA, Donovan GH, Barth CM (2013) Living in a tinderbox: wildfire risk perceptions and mitigating behaviours. Int J Wildland Fire 22:832–840

Costafreda-Aumedes S, Comas C, Vega-Garcia C (2017) Human-caused fire occurrence modeling in perspective: a review. Int J Wildland Fire 26(12):983

Dickinson KL, Brenkert-Smith H, Madonia G, Flores NE (2020) Risk interdependency, social norms, and wildfire mitigation: a choice experiment. Nat Hazards 103(1):1327–1354

Donovan VM, Wonkka CL, Twidwell D (2017) Surging wildfire activity in a grassland biome. Geophys Res Lett 44(12):5986–5993

Donovan VM, Wonkka CL, Wedin DA, Twidwell D (2020) Land-use type as a driver of large wildfire occurrence in the U.S. Great Plains. Remote Sens 12(11):1869

Elhami-Khorasani N, Ebrahimian H, Buja L, Cutter SL, Kosovic B, Lareau N, Meacham BJ, Rowell E, Taciroglu E, Thompson MP, Watts AC (2022) Conceptualizing a probabilistic risk and loss assessment framework for wildfires. Nat Hazards 114(2):1153–1169

Federal Geographic Data Committee (FDGC) (1997) Vegetation information and classification standard. Vegetation subcommittee for classification and information standards. United States Geological Survey, Reston

Ghasemi B, Gerard GT, Absher JD (2020) An examination of the socio-psychological drivers of homeowner wildfire mitigation. J Environ Psychol 70:101442

Gordon JS, Matarrita-Cascante D, Stedman RC, Luloff AE (2010) Wildfire perception and community change. Rural Sociol 75(3):455–477

Gray BJ, Long MA, Gill DA, Dunlap RE, Straub A (2019) Politics, climate change, and earthquakes: public perceptions of oil and gas impacts in Oklahoma. Energy Res Soc Sci 58:101251

Gu D, Dillard M, Gerst M, Loerzel J (2023) Validating commonly used indicators for community resilience measurement. Nat Hazards Rev. https://doi.org/10.1061/NHREFO.NHENG-164

Harter J, Hamilton LC, Ducey MJ, Boag AE, Salerno JD, Christoffersen ND, Oester PT, Palace MW, Stevens FR (2020) Finding common ground: agreement on increasing wildfire risk crosses political lines. Environ Res Lett 15:065002

Hoagland B (2000) The vegetation of Oklahoma: a classification for landscape mapping and conservation planning. Southwest Nat 45:385–420

Illston BG, Basara JB, Fiebrich CA, Crawford KC, Hunt E, Fisher DK, Elliott R, Humes K (2008) Mesoscale monitoring of soil moisture across a statewide network. J Atmos Ocean Technol 25(2):167–182

Kerstetter K, Bonner D, Cleland K, De Jesus-Martin M, Quintanilla R, Best AL, Hazzard D, Carter J (2023) Social solidarity, social infrastructure, and community food access. Agric Hum Values 40(3):1303–1315

Kliewer A (2023) Dozens of homes destroyed, injuries reported after Friday wildfires. https://www.koco.com/article/oklahoma-city-fire-kelley-hefner-structures/43481705

Kloesel K, Bartush B, Banner J et al (2018) Chapter 23: Southern Great Plains. Impacts, risks, and adaptation in the United States: The Fourth National Climate Assessment, vol II. U.S. Global Change Research Program

Köppen W (1936) Das geographische System der Klimate (Handbuch der Klimatologie, Bd. 1, Teil C)

Kulig J, Botey AP (2016) Facing a wildfire: what did we learn about individual and community resilience? Nat Hazards 82(3):1919–1929

Lachapelle PR, McCool SF (2012) The role of trust in community wildland fire protection planning. Soc Nat Resour 25(4):321–335

Lindley TT, Speheger DA, Day MA, Murdoch GP, Smith BR, Nauslar NJ, Daily DC (2019) Megafires on the southern Great Plains. J Oper Meteorol 7(12):164–179

Long MA, Leon-Corwin M, Peach K, Olofsson KL, Ripberger JT, Gupta K, Silva CL, Jenkins-Smith H (2023) Watts at stake: concern and willingness-to-pay for electrical grid improvements in the United States. Energy Res Soc Sci 102:103179

McPherson RA, Fiebrich CA, Crawford KC, Kilby JR, Grimsley DL, Martinez JE, Basara JB, Illston BG, Morris DA, Kloesel KA, Melvin AD, Shrivastava H, Wolfinbarger JM, Bostic JP, Demko DB, Elliott RL, Stadler SJ, Carlson JD, Sutherland AJ (2007) Statewide monitoring of the mesoscale environment: a technical update on the Oklahoma Mesonet. J Atmos Ocean Technol 24(3):301–321

McWethy DB, Schoennagel T, Higuera PE, Krawchuk M, Harvey BJ, Metcalf EC, Schultz C, Miller C, Metcalf AL, Buma B, Virapongse A, Kulig JC, Stedman RC, Ratajczak Z, Nelson CR, Kolden C (2019) Rethinking resilience to wildfire. Nat Sustain 2(9):797–804

Miller C, Higuera PE, McWethy DB, Metcalf AL, Metcalf EC, Black AE, Clarke L, Hodge H (2021) Developing strategies to support social-ecological resilience in flammable landscapes. Technical report

Moritz MA, Batllori E, Bradstock RA, Gill AM, Handmer J, Hessburg PF, Leonard J, McCaffrey S, Odion DC, Schoennagel T, Syphard AD (2014) Learning to coexist with wildfire. Nature 515(7525):58–66

National Interagency Fire Center (NIFC) (2023) Wildland fire open data. https://data-nifc.opendata.arcgis.com/search?tags=Category%2Chistoric_wildlandfire_opendata. Accessed Aug 2023

National Institute of Standards and Technology (NIST) (2024) Community resilience. https://www.nist.gov/community-resilience#:~:text=Community%20resilience%20is%20the%20ability,are%20key%20steps%20to%20resilience

Oklahoma Climatological Survey (OCS) (2023) Climate of Oklahoma. Statewide precipitation and temperature maps. Oklahoma Climatological Survey, College of Geosciences, University of Oklahoma, Norman, Oklahoma. http://www.ocs.ou.edu

Oklahoma Department of Emergency Management (OEM) (2023) March 31 Wildfire Event. https://oklahoma.gov/oem/emergencies-and-disasters/2023/march-31-wildfire-event.html. Accessed 10 May 2023

Penman T, Eriksen C, Horsey B, Green A, Lemcke D, Cooper P, Bradstock R (2017) Retrofitting for wildfire resilience: what is the cost? Int J Disaster Risk Reduct 21:1–10

Powell JW (1879) Report on the lands of the arid region of the United States with a more detailed account of the land of Utah with maps. Washington, D.C.

PRISM Climate Group, Oregon State University (2023). http://prism.oregonstate.edu

Reid AM, Fuhlendorf SD, Weir JR (2010) Weather variables affecting Oklahoma wildfires. Rangel Ecol Manag 63(5):599–603

Schneider JM, Fisher DK, Elliott RL, Brown GO, Bahrmann CP (2003) Spatiotemporal variations in soil water: first results from the ARM SGP CART network. J Hydrometeorol 4(1):106–120

Schumann RL, Mockrin M, Syphard AD, Whittaker J, Price O, Gaither CJ, Emrich CT, Butsic V (2020) Wildfire recovery as a “hot moment” for creating fire-adapted communities. Int J Disaster Risk Reduct 42:101354

Seager R, Lis N, Feldman J, Ting M, Williams AP, Nakamura J, Liu H, Henderson N (2018) Whither the 100th Meridian? The once and future physical and human geography of America's arid-humid divide. Part I: the story so far. Earth Interact 22(5):1–22

Shadrin D, Illarionova S, Gubanov F, Evteeva K, Mironenko M, Levchunets I, Belousov R, Burnaev E (2024) Wildfire spreading prediction using multimodal data and deep neural network approach. Sci Rep. https://doi.org/10.1038/s41598-024-52821-x

Shamsaei K, Juliano TW, Roberts M, Ebrahimian H, Kosovic B, Lareau NP, Taciroglu E (2023) Coupled fire-atmosphere simulation of the 2018 camp fire using WRF-fire. Int J Wildland Fire 32(2):195–221

Short KC (2022) Spatial wildfire occurrence data for the United States, 1992–2020 [FPA FOD 20221014]

Smith AB (2020) U.S. Billion-dollar Weather and Climate Disasters, 1980–present (NCEI Accession 0209268)

Smith AMS, Kolden CA, Paveglio TB, Cochrane MA, Bowman DMJS, Moritz MA, Kliskey AD, Alessa L, Hudak AT, Hoffman CM, Lutz JA, Queen LP, Goetz SJ, Higuera PE, Boschetti L, Flannigan M, Yedinak KM, Watts AC, Strand EK, van Wagtendonk JW, Anderson JW, Stocks BJ, Abatzoglou JT (2016) The science of firescapes: achieving fire-resilient communities. Bioscience 66(2):130–146

Spence A, Poortinga W, Pidgeon N (2012) The psychological distance of climate change. Risk Anal 62(6):957–972

Texas A&M Foest Service (2024) Historical fire statistics. https://fire-information-tfsgis.hub.arcgis.com/pages/historical-fire-statistics

Turner DD, Ott L, Steblein PF, Stieglitz M, Tweedy O, Furman J, James CS (2024) Improving the science for wildland fire prediction at S2S scales. Bull Am Meteorol Soc 105(2):E332–E336

University of Oklahoma Institute for Public Policy Research and Analysis (IPPRA) (2021) Public Survey on Socially Sustainable Solutions for Water, Carbon, and Infrastructure Resilience in Oklahoma. https://crcm.shinyapps.io/s3ok/

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