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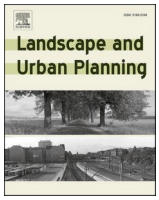

Review Article

Social drivers of vulnerability to wildfire disasters: A review of the literature

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HIGHLIGHTS

- Wildfire risk assessments have increased significantly but remain largely focused on wildfire exposure.
- Social vulnerability indices overlook the intersecting and contextual ways that vulnerability to wildfire emerges in different populations.
- Current paradigms for reducing wildfire vulnerability do not acknowledge or address inequalities that create differential vulnerability.
- Centering adaptation equity, rather than landscape outcomes, can mitigate differential exposure to wildfire risk.

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ABSTRACT

The increase of wildfire disasters globally has highlighted the need to understand and mitigate human vulnerability to wildfire. In response, there has been a substantial uptick in efforts to characterize and quantify wildfire vulnerability. Such efforts have largely focused on quantifying potential wildfire exposure and frequently overlooked the individual and community vulnerability to wildfire. Here, we review the emergent literature on social vulnerability to wildfire by synthesizing factors related to exposure, sensitivity, and adaptive capacity that contribute to a population's or community's overall vulnerability to wildfires. We identify how those factors subsequently affect an individual's or community's agency to enact change, and highlight that many of the current paradigms for reducing wildfire vulnerability fail to acknowledge and address the importance of inequalities that create differential vulnerability. We suggest that paying attention to the systems and conditions that give rise to such vulnerability can ameliorate these shortcomings by centering solutions which address adaptation equity rather than landscape outcomes.

1. Introduction

In the last decades a proliferation of wildfires stemming from anthropogenic climate change has produced increasingly disastrous outcomes globally (Bowman et al. 2017; Bowman et al., 2019; Bowman et al. 2020). Wildfire activity is tied to climatic conditions at multiple spatial and temporal scales, from the long-term climatology that delineates fire regimes to the more acute daily-to-monthly anomalous conditions that influence ignition probability and behavior (Bowman et al. 2020). Extreme wildfire seasons and events have been recorded globally, particularly in Mediterranean ecoregions where human vegetation management and wildfire suppression throughout the 20th century have amplified climate-fuel feedbacks (Bowman et al. 2017; Bowman et al., 2020). As mass fatality and record loss wildfire events mount, affected regions increasingly seek solutions to mitigate disastrous outcomes. Achieving the most effective and efficient solutions, however, requires an understanding of who and what elements of the human sphere are most vulnerable to wildfires.

Vulnerability to natural disasters has been defined in a multitude of ways based on different conceptualizations. Cutter et al. (2003) developed an enduring framework that has been applied broadly across the natural hazards field, and includes biophysical, social, and place

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vulnerability, the latter of which is the integration of biophysical and social vulnerability as it applies to specific places or regions (Cutter, Mitchell, and Scott, 2000). In a study that traces vulnerability frameworks, Adger (2006) similarly contends that vulnerability is a function of the stress/shock a system is exposed to, its sensitivity, and its adaptive capacity.

Wildfire science has only recently begun to utilize such vulnerability frameworks to inform research into the understanding and mitigation of fire-induced disasters (Holmes et al., 2007) and relatively recent assessments of wildfire vulnerability have built on these frameworks to offer a more systemic approach to understanding social vulnerability (i.e. Wigtil et al., 2016; Davies et al., 2018). Most of the research on wildfire, however, remains targeted at quantifying exposure (Carreño et al., 2007) as the probability of a high-risk wildfire event based on the three biophysical elements that determine fire behavior: weather, topography, and fuel (Pyne et al., 1996). This literature has largely focused on the occurrence of fire and its biophysical impacts rather than impacts to humans (Miller and Ager, 2012), particularly when excluding studies on wildland firefighter fatalities. This is consistent with most natural hazards research, which initially focuses on understanding the physical processes that produce the hazard and secondarily develops coupled socio-technological solutions to mitigate public exposure to the hazard.

The primary objective of this article is to review knowledge and definitions surrounding the social dimensions of wildfire threat and loss, paying particular attention to human sensitivity and adaptive capacity elements of vulnerability. We synthesize the existing and emergent literature and trace the characteristics that comprise distinct social vulnerability indices in the literature.

2. Methodology

To better understand how social vulnerability is assessed in wildfire research, we conducted a systematic review of the literature on wildfires and social vulnerability. We compiled quantitative and qualitative studies that discuss the human impact and social dimensions of fires, drawing especially from the fields of urban planning and environmental justice. This included research conducted since the 1990 s but with a particular focus since the seminal 2003 Cutter at al. study, which also offers a theoretical framing that is relevant for the structure of this review. We first conducted a database search for academic articles in a number of databases using the search terms 'social vulnerability,' and 'wildfire' or 'bushfire' (Fig. 1). Once we identified potential articles for inclusion based on an initial abstract review, we carried out a more careful examination of the remaining articles, reviewing the full text to identify those which directly addressed our research interests. We excluded articles that were not directly tied to the intersection of wildfires and social vulnerability, as well as those studies where wildfires were not the focus, but included as part of a broader natural disasters discussion. We also excluded articles that focused exclusively on the effects and behavior of wildfire smoke (e.g. epidemiological studies that assessed elevated morbidities), but included those studies where smoke-related hazards were part of a larger discussion on the effects of wildfires in relation to social vulnerability.

We also added articles that explicitly referenced a social vulnerability index (SoVI) or a community vulnerability framework to identify the wildfire vulnerability of a population based on a certain set of sociodemographic characteristics combined with a range of other biophysical characteristics, however, we excluded articles that applied a social vulnerability index to a wide range of disasters generally. Additionally, we used a snowball approach to identify and include references that were consistently cited and relevant to the question of social vulnerability but had not been captured by our initial search. For example, missing from our initial set of articles were studies that reference 'exposure, sensitivity, and adaptive capacity' (i.e. Yu et al. 2021) rather than the more comprehensive term 'vulnerability.' These additional articles were mainly focused on social vulnerability in disaster literature, and may not have had an exclusive wildfire focus.

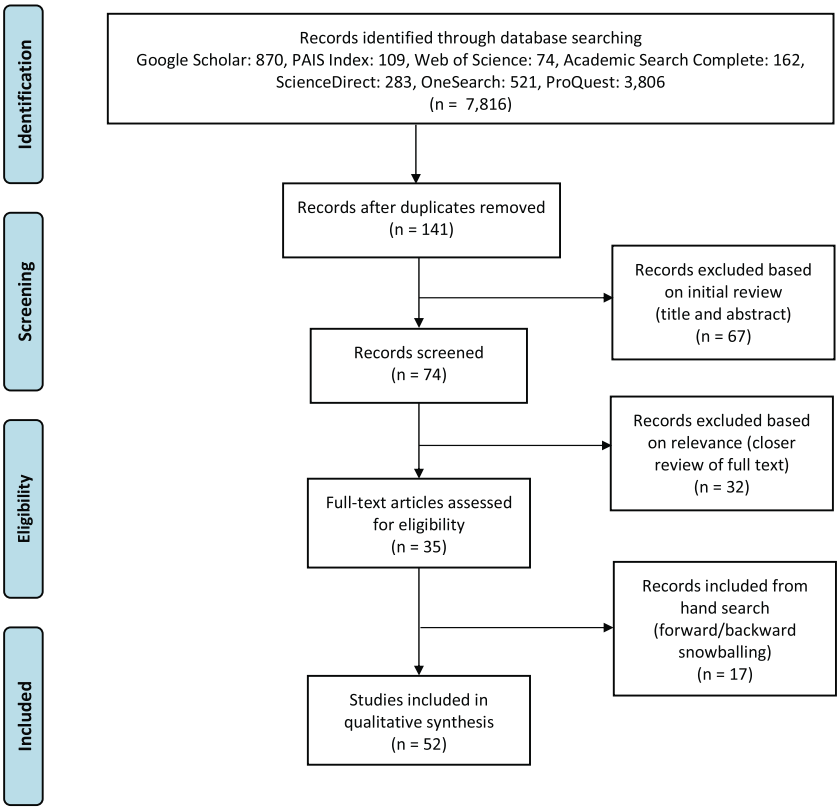

Fig. 1. PRISMA Flow Diagram.

Given their prevalence in the wildfire literature examined, however, we included these studies to understand how social vulnerability is applied to wildfire. We did not exclude any articles based on methodology, so our review considers a combination of social vulnerability indices applied to case studies as well as to broader quantitative work, including mapping assessments. We also did not seek to compare how distinct bodies of literature approach wildfire vulnerability, but rather to review the application of social vulnerability to wildfire research and identify potential gaps or emergent themes. Much of wildfire literature draws from how social vulnerability has been defined and understood in disaster studies disciplines, and is then applied in various ways to wildfire-specific research. It is this specific use of social vulnerability as a framework that we are interested in.

Our search dates ranged from 2006 to 2022, capturing the increase in both citations and publications on this subject that rose sharply beginning in 2018 (Fig. 2). While the majority of articles meeting our criteria are by North American scholars, there is a growing interest in social vulnerability and wildfire globally (i.e. Jakes and Langer, 2012; Kapuka and Hlásny, 2020). We only reviewed articles published in English and limited our geographic scope to North America, Australia, and Europe in order to reduce variability attributed to different approaches in disaster preparedness and recovery efforts that might be driven by policy, funding, and cultural context. We identified the disciplinary fields from which the majority of scholarship is drawn in order to trace how social vulnerability to wildfire is taken up in different disciplines.

From the total articles reviewed (n = 52), we first identified a subset of categorical attributes for each of the three main components of vulnerability - exposure, sensitivity, and adaptive capacity (Engle, 2011) - which framed many of the definitions of vulnerability these studies leverage (i.e. Cutter et al., 2003; Adger, 2006.) These attributes capture the characteristics assessed in the selected studies (Fig. 3), and intersect in fundamental ways, such that it is often difficult to have a comprehensive review of one characteristic without discussing an interdependent characteristic that is identified in another category of this framework. For example, the literature identifies a strong correlation between income and risk perception, which each appear in different components of the vulnerability framework. The interdependence and integration of the various components of the framework are critical to understanding social vulnerability, as they highlight the complexity of trying to ameliorate vulnerability and address inequality. Thus, we reiterate the role of a given attribute multiple times across components in our review.

We begin by reviewing the spectrum of definitions of vulnerability and address the pitfalls and benefits of measuring social vulnerability as an index. We then discuss the literature related to three components of wildfire social vulnerability, and conclude by reviewing the implications of this work for preparedness, recovery, and rebuilding efforts through the lens of adaptation equity.

3. Vulnerability

3.1. Definitions and assessments

Vulnerability is related to a wide range of concepts, such as resilience, adaptive capacity, and risk (Liverman, 1990), and is defined and framed in different ways by researchers in large part depending on their disciplinary focus. It is neither a single nor static measure, but is instead multidimensional and variable across scales (Thomas et al. 2019). While there is a substantial body of literature associated with the keywords "wildfire/bushfire" and "vulnerability" (934 articles; Fig. 4), only 8% of these focus on "social vulnerability" associated with "wildfire/bushfire" (74 papers), suggesting that the majority of work on wildfire vulnerability does not explicitly reference social aspects of wildfires. The disciplinary fields of the publishing journals reveal that when the broader "vulnerability" term is used, the top ten fields publishing such papers are all either in the biophysical or in interdisciplinary sciences, such as Environmental Sciences, Ecology, Forestry, and Geosciences and Atmospheric Sciences. Our review of papers for inclusion indicates there has been relatively limited study of how human systems, demographies, and identities vary in terms of wildfire vulnerability. Research over the last two decades has increasingly focused on the social dimensions of wildfires, such as understanding decision-making regarding preparedness and response during wildfires, which contributes to the broader wildfire literature on vulnerability (McCaffrey, 2015), because studying decision-making implies studying who has agency in a process. However, less attention has been paid to the structural conditions that facilitate or hinder certain populations from having agency, participating in decision-making processes, and accessing the resources necessary to actualize mitigation efforts towards wildfire risks.

To date, there is no consistency or uniformity in wildfire research on what constitutes vulnerability to wildfire and how to measure it, potentially because vulnerability and risk are localized and context-specific. Despite the relative lack of research, there is a clear link between social conditions and a population's vulnerability to wildfires, a key consideration in directing resources for protection, mitigation, and recovery (Solangaarachchi et al., 2012). Morrow (1999) showed that specific populations in the US are at greater risk to disaster broadly because they lack economic, social, and political resources, and therefore depend on local vulnerability mapping and emergency management efforts. Similarly, Palaiologou (2019) leveraged the Cutter et al. (2003) framework that addresses both social and biophysical systems and found that small groups with high social vulnerability are disproportionately exposed to wildfire risk per area burned. A more nuanced and comprehensive approach to characterizing wildfire vulnerability would take into account factors that create vulnerability.

As vulnerability is largely related to demographic characteristics that stem from structural inequalities, such as poverty and housing precarity, making fire management decisions based on vulnerability requires integrating across exposure, sensitivity, and adaptive capacity. One barrier to such an approach is that there is no consensus in the literature on which characteristics are the best indicators for assessing wildfire vulnerability (Davies et al. 2018). For example, certain studies may include age and gender in their demographic assessment but not race/ethnicity (e.g., Collins, 2005), while others look at age and race/ethnicity but not gender (e.g., Gaither et al., 2011).

Further confusing vulnerability assessments, the term *community* is used by different authors interchangeably, to represent either a geographic location with place characteristics and/or a population with shared identities, often at different and multiple scales. We suggest that the use of the term *community* to define a specific geographic location at a given scale, while technically accurate when focusing on entire municipal cohorts, is inadequate when addressing social vulnerability. This is because a single city or town includes multiple neighborhoods and types of socially vulnerable populations, and generalizing across a geospatial location obscures these different forms of vulnerability. To assess vulnerability more equitably, we define *community* here as a group of people who share a set of individual characteristics that affect their vulnerability that may include, but need not be limited to, place-based characteristics.

Social vulnerability is not simply a matter of exposure to wildfire. Rather, it is a measure of the likelihood that a wildfire will both occur and have a significant impact on vulnerable populations. As such, it is critical to examine how we define, understand, and frame vulnerability. Mapping social vulnerability as a function of a set of individual attributes or characteristics, as a number of well-cited studies have done through indices, assumes a homogeneous and universal understanding of what constitutes vulnerability. This is the case even as vulnerability is contextual, embedded, and not the result of a single determinant, or even a single set of determinants. In the following sections, we examine some of the socioeconomic characteristics that consistently appear in social vulnerability indices of wildfire sensitivity, and the relationship between these characteristics and exposure to wildfire.

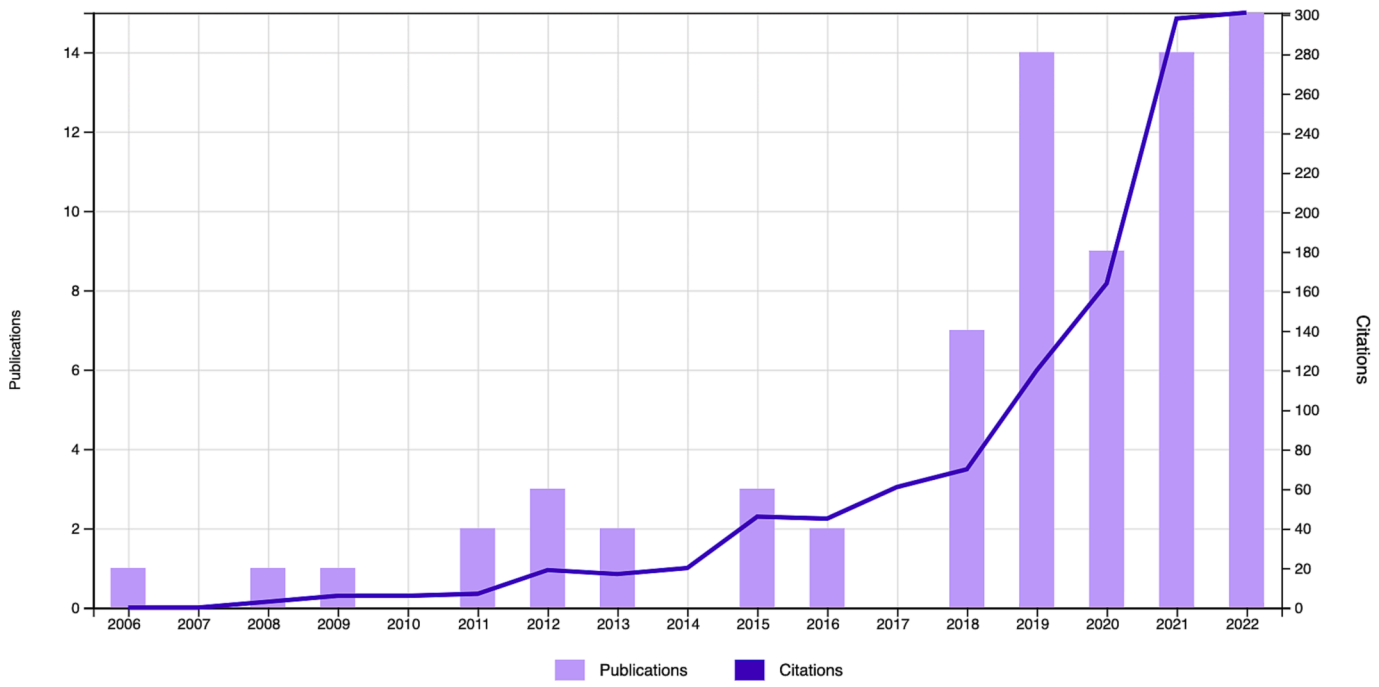

Fig. 2. Publications and Citations for 'Wildfires' and 'Social Vulnerability' 2006–2021 (Source: Web of Science).

3.2. *The social vulnerability index as a framework*

Disaster management practices have traditionally focused on technocratic assessments of physical vulnerability in assessing risk (Masterson et al., 2014), while more recent work has pivoted to include the underlying political, social and economic context that gives rise to differential exposure to disasters (Bolin, 2007; Wisner et al., 2004). Social vulnerability emerged in the disaster management literature in the 1970 s as researchers correlated social and demographic factors to a population's resilience to hazards and risks (Juntunen, 2005). Prior to Cutter et al. (2003), social vulnerability was characterized as a function of limited, often poorly represented, characteristics (Chakraborty et al., 2005; Cutter et al., 2000) derived from case studies which could not be reproduced or generalized. The social vulnerability index (SoVI) introduced by Cutter et al. (2003) was based on the social characteristics found to be consistently associated with vulnerability in the natural hazard and disaster literature (see Table 1 for a detailed list of characteristics collated from wildfire literature that incorporates SoVI). The index is also applicable at different scales of spatial aggregation, from city to county to census tract levels (Schmidtlein et al., 2008).

A number of characteristics define different SoVIs; we discuss several here to show the range of approaches in defining wildfire social vulnerability. Wigtil and colleagues (2016), for example, predicted wildfire vulnerability by selecting 26 dominant variables (see Table 1) to develop seven principal components: Hispanic/education, material resources, socioeconomic status, age, housing, female, and Native American.[1] The specific variables were selected based on the disaster-specific work established by Cutter et al. (2003) on social vulnerability, and by wildfire-specific studies (Gaither et al. 2011; Ojerio et al. 2011; Poudyal et al., 2012). To measure the adaptive capacity of a given census tract, Davies et al. (2018) combined wildfire exposure potential with the SoVI developed for disaster management by Flanagan et al. (2011), categorizing social vulnerability indicators into four groups: socioeconomic status (income, poverty, unemployment), demographics (under 17 or over 65 years of age, single-parent households, disabled), housing and transportation (no vehicle, mobile or multi-unit housing crowding or group quarters), and language and education (no high school diploma, speaks English 'less than well').

While these studies recognized the social dimensions of disasters that make some populations more vulnerable than others, the studies in Table 1 that produce SoVIs utilize fuzzy logic and expert opinion to determine which variables to include. To the best of our knowledge, no research to-date has conducted a modeling analysis to quantify the specific drivers of social vulnerability to wildfire impact, such as home loss, loss of employment, and fatalities, using training or validation data. Most studies mapping social vulnerability to wildfire focus instead on the spatial coincidence of wildfire perimeters with certain sociodemographic characteristics. Further, they demonstrate variability in expert opinion as to which characteristics matter the most in determining wildfire vulnerability, which is reflected broadly across the literature and points to the importance of understanding interactions among social characteristics, and the context and place in which they are embedded. Despite key terms such as *community* and *vulnerability* lacking consensus definitions, a common theme emerging from this literature is that wildfire vulnerability is as much about a geographic location that populations share (i.e., exposure) as it is about the shared characteristics that are a function of specific identities (i.e., sensitivity). Those shared characteristics may transcend specific place-based analyses but they nevertheless give rise to vulnerability, as in the case of Indigenous migrant workers (Méndez et al., 2020).

Moreover, as research continues to show that certain populations face higher exposure to disasters (Bullard, 1999; Highfield et al., 2014; Wisner and Luce, 1993), the disproportionate impacts borne by those communities are often attributed to a lack of access to resources (Bankoff 2003; Pellow 2000), even while overlooking the structural inequalities that perpetuate barriers to gaining access. Attempts to index the social vulnerability of populations may hide less obvious forms of vulnerability that cannot be measured and which, instead, require a

[1] Multiple studies, including the Wigtil et al. (2016) referenced here, refer to categories as 'components', each of which is made up of a number of 'dominant variables'. For example, the 'Age' component includes populations under 5 or over 65, households receiving social security, and median age. In our table this is marked simply as 'age'. We made many similar generalizations across the different studies in order to create a table for comparing the characteristics used in each index.

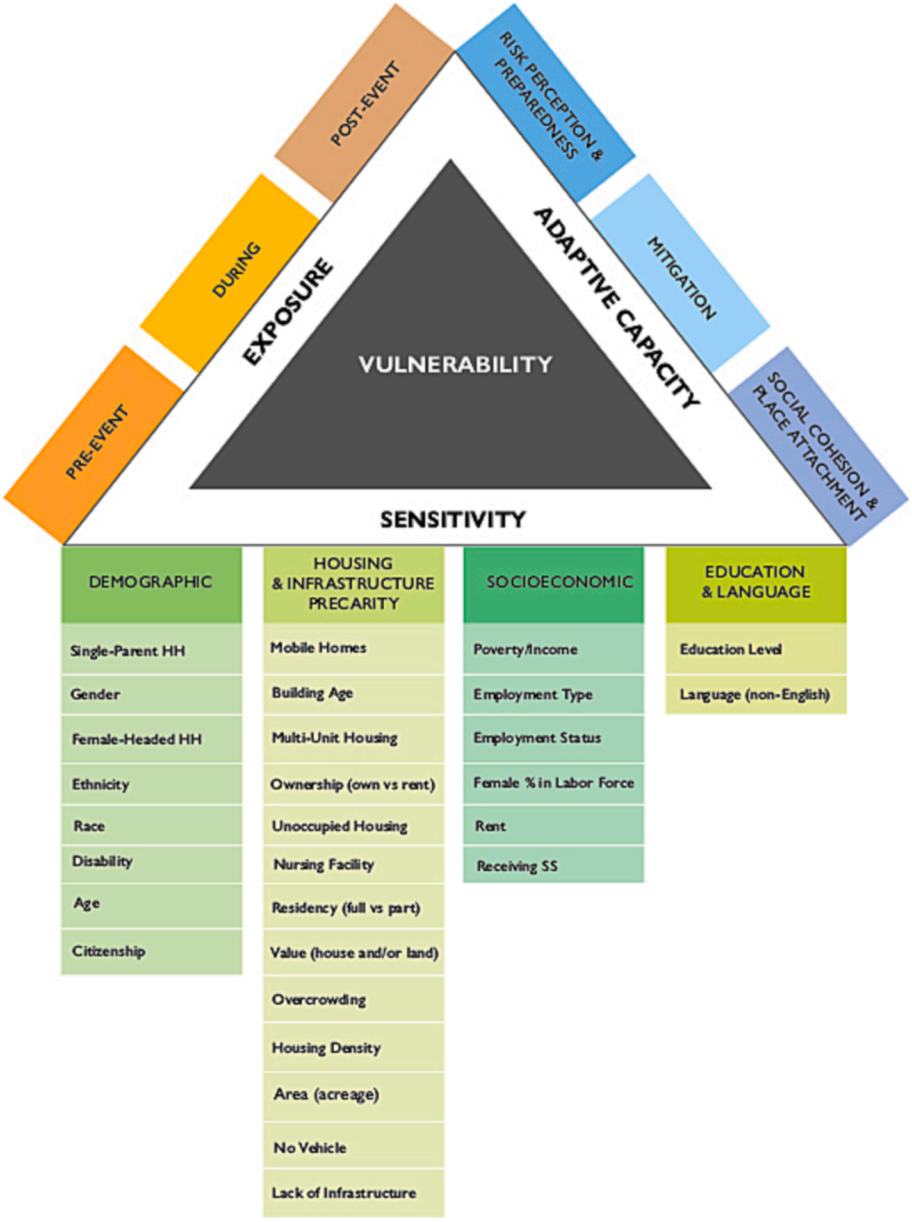

Fig. 3. Vulnerability Framework.

place-based assessment, even in regions of relative affluence (Eriksen et al., 2020). The utility of such social vulnerability indices for planning remains questionable where community knowledge is not centered and where intersectional oppressions, specifically racism, classism, and sexism, are not acknowledged (Jacobs, 2018).

Research on wildfire vulnerability has primarily focused on characterizing communities without acknowledging why certain characteristics make communities vulnerable. We propose that vulnerability stems from the characteristics that are coupled with higher exposure and lack of agency to mitigate vulnerability. For example, Indigenous communities are more vulnerable to wildfire (Wigtil et al. 2016) not solely as a function of their race but because they are largely denied the agency to manage and control fires based on ancestral knowledge and cultural practices (Marks-Block and Tripp, 2021) and face challenges associated with the legacy and policies of colonization (Hoffman et al. 2022). While community cooperation is critical to mitigation (Paveglio et al. 2014; Paveglio et al., 2018), a lack of agency and structural inequities may raise barriers that even cooperative efforts struggle to overcome.

A relatively small number of studies dedicated to wildfire research assess social vulnerability factors critically, with a focus that moves beyond social constructs and characteristics, such as poverty, race, and gender, to include the broader oppressive and intersecting systems that deny certain populations access to fundamental resources and which expose them to greater vulnerability. In this sense, social vulnerability frameworks can be critiqued as inadequate to meet the needs of the communities that those frameworks are meant to identify. Below, we critically evaluate the exposure, sensitivity, and adaptive capacity components of vulnerability to identify persistent gaps in the literature around social vulnerability.

4. Exposure

Assessing wildfire exposure is often the precursor to distributing funding and other resources in ways that correspond to expected risks (Scott et al., 2013). However, assessments of exposure ignore critical characteristics of affected populations, including sensitivity and adaptive capacity. The majority of wildfire risk research deals with individual household mitigation of risk and the treatment of fuel in Wildland Urban

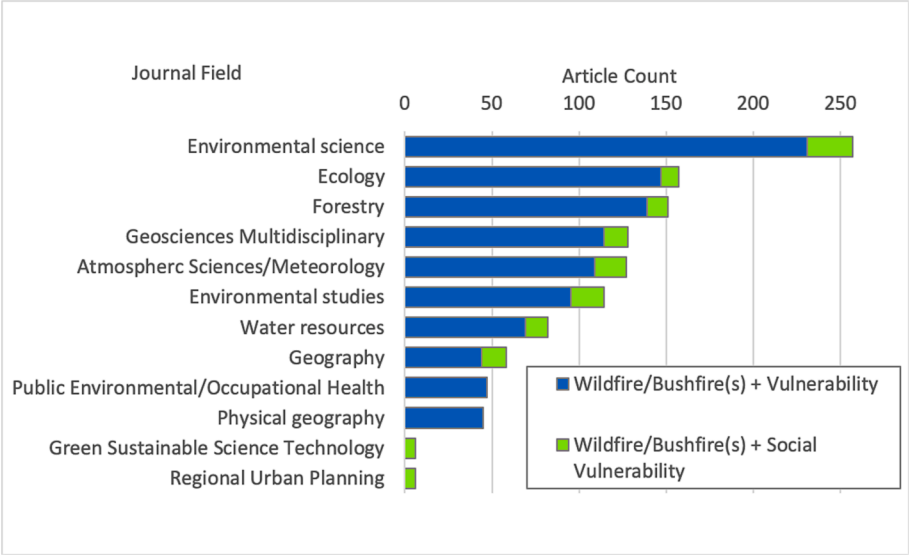

Fig. 4. Distribution of Publications on 'Wildfire/s' or 'Bushfire/s' and 'Vulnerability' (blue) and 'Social Vulnerability' based on Disciplinary Field (2006–2021). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Interface (WUI) locations (Thomas et al., 2022). Both framings are exposure-oriented, and ignore critical connections to sensitivity and adaptive capacity in producing overall vulnerability. The limited exposure literature that does try to integrate the concept of social vulnerability has also unfortunately made assumptions made about those who are most likely to be exposed to wildfire, namely, that it is primarily people of means and with social agency who choose to live in wildfire-prone areas. Wigtil et al. (2016) and Gaither et al. (2011) both propose that certain populations facing high exposure probability generally have access to social and economic safety nets, thereby reducing their vulnerability, while also acknowledging that more moderate hazard may conversely have a more significant impact on populations of high social vulnerability. Wigtil et al. (2016) found that that ~ 10% of housing occupants in areas of high wildfire potential also exhibit high social vulnerability, leading them to posit that incentives encouraging settlement in wildfire-prone landscapes benefit already privileged populations, so those landscapes are associated with lower social vulnerability. They also found that only 0.3% of all US housing units are characterized by high wildfire potential and high social vulnerability, further amplifying the idea that that social vulnerability and wildfire potential are largely decoupled (Wigtil et al. 2016).

This narrative is furthered by incentives such as availability of and access to response aid, fire insurance, new expensive subdivisions advertised as fire-proof, and social and environmental amenities supported by institutional and state agencies facilitate the settlement of economically and socially secure populations in wildfire-prone areas (Collins, 2008b; Fu, 2013; Wigtil et al., 2016). Public-sector fire suppression activities, access to homeowner's insurance that doesn't account for wildfire risk, and post-wildfire disaster assistance tend to subsidize the cost of wildfire risk (Holmes et al., 2007; Fu, 2013; Simon and Dooling, 2013). While some of these incentives and subsidies are accessible to socially vulnerable populations, most are not. Even local municipal fire agencies are severely under-resourced in areas where they depend on volunteers or have low tax bases. Thus, a glaring omission in the exposure literature, and how wildfire vulnerability literature characterizes exposure, is acknowledging a substantial population of socially vulnerable residents in areas of moderate to high fire exposure potential. Research queries built on the assumption that most people who live in high wildfire exposure areas are not socially vulnerable will miss the critical needs of these communities and struggle to develop solutions for them.

5. Sensitivity

Sensitivity is rarely acknowledged in holistic studies on wildfire vulnerability. Even when studies address demographics of wildfire vulnerability, as noted previously, they do not assess the structural inequalities that make certain sociodemographics more vulnerable to disastrous outcomes. In this section, we bring a critical perspective to social drivers of vulnerability to examine how they make populations more sensitive in a vulnerability context.

As with the literature that focuses primarily on exposure, one of the key patterns made clear in research concerned with sensitivity is that higher income decreases vulnerability because it is associated with access to institutional and social safety nets. Higher income is correlated with increased wildfire risk and exposure given that higher income populations have a greater capacity to absorb risk, including ability to evacuate (Paveglio et al. 2014; Paveglio et al., 2018) and increased willingness and ability to pay for home risk reduction (Sánchez et al. 2022). Such households also have greater access to fire insurance and firefighting resources even when high income households do not participate in wildfire mitigation services, despite financial ability to do so (Smith et al., 2016; Collins and Bolin, 2009).

By contrast, though poorer individuals are more likely to perceive greater disaster risks, lower income households may not be able to afford wildfire mitigation practices (Collins, 2005; Poudyal et al., 2012; Sánchez et al. 2022), are more likely to lack the resources needed to prepare for and recover from a disaster (Morrow, 1999; Cutter et al., 2003; Blaikie et al., 1994), and are less likely to adequately respond to disaster warnings and more likely to suffer disproportionate mental and physical impacts from the effects of disasters (Fothergill and Peek, 2004; Lynn and Gerlitz, 2005). Wildfires in poorer communities take longer to extinguish because such communities lack adequate access to resources to prepare for or combat fires (Mercer and Prestemon, 2005), and have less access to a vehicle or fuel, which hinders their ability to evacuate during an emergency (Brodie et al., 2006).

In terms of housing precarity in low-income communities, a greater amount of total household assets is likely to be in the value of their homes, making it a proportionately greater expense to replace (Tierney, 2006). Additionally, the sensitivity of lower income households is also increased in post-fire settings because of lack of access to affordable housing or adequate means to rebuild (Fothergill and Peek, 2004). As a result, in the aftermath of a fire, low-income populations tend to stay in temporary housing and shelters longer (Wisner et al., 2004). Therefore,

Table 1
Social Vulnerability Characteristics in Select/Key Studies.

	Gaither et al 2011	Palaiologou et al 2019	Wigtil et al 2016	Davies et al 2016	Paveglio et al 2018	Cutter et al 2003	Méndez et al 2020
Type of Study	GIS Mapping (Census Block Groups)	GIS Mapping (Census Block Groups)	GIS Mapping (Census Block Groups)	GIS Mapping (Census Tracts)	Survey	GIS Mapping (County)	Case Study (2017 Thomas Fire)
Social Vulnerability Index	No	Yes	Yes	Yes	No	Yes	No
Wildfire	x	x	x	x	x		x
Demographics							
Age	x		x	x	x	x	
Gender						x	
Race/Ethnicity	x		x			x (African American, Hispanic, Native American, Asian)	
Disability		x		x			
Single-Parent HH	x			x			
Female-Headed HH			x				
Citizenship							
Education	x		x	x	x		
Language	x		x	x			x (Mexican Indigenous)
Housing & Infrastructure Precarity							
Households	x						
Mobile Homes	x		x	x		x	
Ownership (own/rent)			x		x	x	
Multi-Unit Housing	x			x			
No Vehicle		x	x	x			
Lack of Infrastructure (water, roads, etc.)							
Overcrowding/People per unit	x		x	x			
Group Quarters	x			x			
High-Unity Density/ House Units	x						
House/Land Value			x		x		
Nursing Facility							
Unoccupied Housing Units			x				
Residency (full vs part)					x		
Building Age					x		
Area of Land					x		
Socioeconomic							
Poverty		x	x	x			
Income		x	x	x		x	
Employment Status		x	x	x			x (seasonal)
Employment Type (i.e. extractive ind, service, gov, nat res)	x		x			x (service, transp, comm, public util)	x (farmworkers)
Median Gross Rent			x				
Female % in Labor Force			x				
Receiving SS			x				

wildfires in low-income communities can intensify poverty by having prolonged effects on households who lack the ability to fire-proof their homes and surrounding landscapes or wildlands, respond adequately to a wildfire event, and recover from its impacts (Niemi and Lee, 2001; Bolin and Bolton, 1986). It is equally important to highlight that many studies are often focused on the effects of wildfires on homeowners, thereby rendering invisible the vulnerability of populations who are not part of the property-ownership model (Chase and Hansen, 2021).

One key issue compounding these challenges is unemployment prior to and following a fire event, which matters because employee benefits that can provide injury or life insurance and access to healthcare are not available (Brodie et al., 2006). Unstable or seasonal employment is also associated with lower and inconsistent income that makes it unlikely for households to rely on earnings for better disaster preparedness. Moreover, seasonal and migrant workers are less likely to be assimilated in an extended social network within the neighborhood that experiences a disaster, putting them at further risk for future hazards (Morrow, 1999). In many places in the US, such workers are also minoritized groups, necessitating a closer look at the demographic characteristics that shape vulnerability.

Wildfire perception and engagement with wildfire mitigation practices tend to vary by race and ethnicity, but existing scholarship does not critically examine why. Bowker et al. (2008) found that White Americans more readily agree that they should be prepared for and accept wildfire risks compared to Black Americans and Latinx populations, but presenting this finding without questioning what drives such differences in attitude risks problematizing race as driving vulnerability rather than understanding the historical and systemic factors at play, which potentially shape these different responses.

For example, Méndez and colleagues (2020) highlight that Latinx and Indigenous immigrants suffer increased vulnerability as farm workers due to their low income, lack of health insurance, increased incidence of chronic diseases, low educational attainment, high number of residents per dwelling unit, and lack of authorized work status. They point out that even the more recent disaster planning literature tends to group Latinx and Mexican Indigenous immigrants into a single ethnic group, homogenizing significant differences within these populations, including but not limited to differences in language, literacy rates, and

rates of health care, housing, and education, undocumented status and precarious labor, and lack of access to health and safety information associated with that labor (Méndez et al., 2020). While Méndez et al. have done considerable research investigating the precarity these populations face, it is worth noting that their research still does not rectify the larger challenge of understanding the vulnerability of migrants of various backgrounds and migrant households of diverse compositions. There is a troubling tendency to not simply homogenize Latinx and Mexican migrants, but to treat "migrant" as a monolithic entity, and an absence of scholarship that more rigorously explores vulnerability of different migrants populations: different ethnic backgrounds (e.g. Asian Americans), long-term residents of households that are documented but poor, undocumented or mixed status households, households constituted by intergenerational families, first generation students from migrant families, and individuals living and working in the WUI and more central urban areas, to list some of the many groups who are impacted. The physical, psychological and long-term economic impacts of fires and the barriers migrants face to increasing adaptive capacity remain vastly understudied.

Recent studies also find that census tracts with majority Black, Hispanic or Native American populations have experienced about 50% greater vulnerability to wildfire (Davies et al., 2018). The current dominant research and policy focus, therefore, on majority-White land areas further marginalizes the non-White ethnic and racial minorities that live among those same fire-prone landscapes, and whose limited adaptive capacity to even a moderate wildfire makes them especially vulnerable. While Davies et al. (2018) developed a socio-ecological framework for measuring vulnerability to wildfire specifically, paying particular attention to minority and poor communities, their data about the counties affected by the 2017 Thomas Fire uses US census tracts as the unit of analysis. Méndez et al. (2020) argue that such studies render immigrant and Indigenous populations, who are not adequately reflected in the US Census, invisible and point to the need for a "contextual vulnerability framework".

6. Adaptive capacity

The adaptive capacity of an individual or group refers to their ability to cope with, manage, or adjust to a hazard, risk, or opportunity (Smit and Wandel, 2006). Most of the wildfire research on adaptive capacity has focused on the importance of communicating risk, forming stronger partnerships and social networks, and adopting mitigation measures. We find that the literature on adaptive capacity as it relates to wildfire vulnerability focuses primarily on risk perception, mitigation, and social cohesion coupled with place attachment.

6.1. Risk Perception & Preparedness

Risk perception is a function of the perceived probability that a hazardous event will take place and the perceived consequences of that event. Research on wildfire risk perception points to the complexity of this topic. Risk perception and preparedness are closely linked, but many recent studies on risk perception have consistently shown that higher risk perception alone does not lead to increased preparedness. This suggests that risk perception is mediated by individual choices based on the benefits and costs of taking action (Champ et al., 2013; McFarlane et al., 2011). Perceived benefits, rather than perceived risks, is the more influential factor in predicting whether people accept fuel management activities, such as prescribed burning and thinning (Ascher et al., 2013; Toman et al., 2014).

Risk perception alone is a weak indicator of social vulnerability to wildfire, with the exception that higher risk perception in individuals is linked to higher personal mitigation measures (Paveglio et al., 2018). However, wildfire preparedness is associated with the perceived *consequences* of a wildfire event as opposed to its perceived *probability* (McNeill et al., 2013), suggesting that information that focuses on the likelihood of a wildfire event taking place is not adequate in preparing individuals and communities, though it may increase the perceived probability that a wildfire event will take place (Brenkert-Smith et al., 2013).

Risk perception also depends on scale; individuals are more likely to perceive risk if what they have in mind is exposure to wildfire of the community they are part of, and less likely to perceive the risk of their own house, even when the exposure at these two scales (community and individual house) may be the same (Collins, 2012). The perceived context surrounding residents therefore matters, and studies have established a link between risk perception and the conditions of adjacent and surrounding lands, as well as the actions of adjacent and surrounding landowners (Brenkert-Smith et al., 2013), and whether adjacent land is privately or publicly owned (Fischer and Charnley, 2012). Even in cases where resident trust and willingness to involve government agencies is low, the threat of wildfire to people who depend on public lands for their livelihoods proved to be an incentive for them to work with fire professionals (Jakes et al., 2007), while fire professionals were equally willing to involve local residents in wildfire management planning in order to rely on their aid with wildfire response efforts (Stasiewicz and Paveglio, 2017).

Much of the work on wildfire risk perception, especially as a foundation for adaptive capacity, implies or assumes a shared understanding of what community entails, and the scale at which collective action takes place. In fact, as Paveglio and colleagues (2018) note, understanding what defines community takes place at different scales and involves a myriad of individuals, identities, histories, and knowledge sets, an understanding of which is a prerequisite for effectively tailoring programs, policies, and incentives.

Parcel characteristics, in particular, explain much of the variability in wildfire exposure and risk, suggesting that aggregating demographic or perceptual characteristics in developing social vulnerability models may not account for variance across populations (Paveglio et al., 2018). As such, in a related study Paveglio and Edgeley (2017) attempt to understand the diversity of responses to wildfire threats by identifying distinct communities within a given area: a high-amenity and high-resource one whose residents are more likely to formalize communication practices, a rural and small town community more likely to align with individual mitigation preferences, and resource-dependent residents of 'working' landscapes with a lack of trust in formal agencies and a stronger desire to protect their livelihoods by staying in place.

Regardless of community typology, however, people who have greater access to social and economic resources are potentially better able to recover from wildfire impacts because they are better prepared (Collins, 2005; Poudyal et al., 2012). Conversely, communities that are socially vulnerable are generally not engaged with wildfire mitigation programs (Gaither et al., 2011), even when their exposure to wildfire is high (Ojerio et al., 2011).

6.2. Mitigation

In the US, it is assumed that individuals are largely responsible for wildfire mitigation activities on their private property (Fu, 2013; Collins, 2008a). Thus, higher income populations can overcome the costs of living in wildfire-prone landscapes, since they are better equipped to undertake wildfire mitigation projects (Simon and Dooling, 2013). While policies can assist communities to build their adaptive capacity through mitigation efforts such as fuel-reduction burns and the development of wildfire protection plans, adoption of these practices depends largely on what resources individuals have access to (Jakes et al., 2011). Similarly, people who have greater access to social and economic resources are potentially better able to recover from wildfire impacts because they are better prepared (Collins, 2005; Poudyal et al., 2012). Conversely, communities that are socially vulnerable are generally not engaged with wildfire mitigation programs (Gaither et al., 2011), even when their exposure to wildfire is high (Ojerio et al., 2011).

Further, participation in mitigation planning is critical to strengthening adaptive capacity, but communities with high social vulnerability (less white, less educated, more renters, and lower income) are less likely to do so (Gaither et al., 2011). People who recently moved to a high-wildfire-risk area or who are part-time residents, and people who do not have a strong social or economic dependence on the land, are also less likely to be actively involved with wildfire mitigation planning efforts in their communities (Collins, 2008a).

A potential reason that Gaither et al. (2011) cite to explain why socially vulnerable communities seem to be less engaged with fire mitigation programs has to do with lack of resources to enact planning efforts. They found that even though Black Americans were more likely than White Americans to say they were aware of information on mitigation measures, nearly 46% said they had not taken any wildfire mitigation action on their land, indicating that awareness of risk and of information did not translate into action. Ojerio (2008) found that census block groups with majority low-income non-Whites, such as Navajo and Apache, were also less likely to inquire about, apply for, or receive state-sponsored funding for wildfire mitigation programs.

Literature on how well-prepared Indigenous communities threatened by wildfires are, what resources they may require to further build their adaptive capacity, and how these communities respond to and recover from fire is lacking (Christianson, 2014). Similarly, inquiries about the relationship of households, especially of marginalized populations, to decision-making processes that affect them is also lacking in wildfire research. In a foundational study that looks at mapping disaster vulnerability within the US, Morrow (1999) points out that a critical factor in a household's ability to reduce its risk towards disasters is the extent to which that household has control over decision-making processes. Risk reduction, then, depends as much on access to resources as it does on access to power. People and agencies in positions of power that make decisions which affect all households in a community are not impartial, and are likely to represent the interests of some groups over others, often disguising the fact that disasters are social and not natural (Cannon, 1994). Similarly, the nature of disaster recovery can often depend on a community's political power, rendering unincorporated and rural areas more vulnerable (Gladwin et al., 1997).

The connection between property-level risk exposure and household risk management decision-making, however, cannot be reduced to a set of sociodemographic characteristics. As Collins (2005) points out, the perception of wildfire risk by WUI residents is fairly accurate, and their vulnerability is a function of abstaining from fire mitigation practices for many reasons that range from lack of service infrastructure or funding to aesthetic choices about what the vegetation in the surrounding landscape should be. Interventions directed only at educating and informing residents are therefore not likely to be effective.

Gaither et al. (2011) conclude that although individual characteristics may be important vulnerability markers, looking at community-level resources and variables, such as the number and type of housing stock and mitigation services offered by agencies, is equally important in understanding a community's adaptive capacity to wildfire risk. As emphasized by Collins (2008b), this points to the need for a political ecology framework to better understand wildfire risk, where risk is recognized as manufactured. Risk is inequitably distributed insofar as the provision of services and amenities (provided by state agencies and market forces) facilitates, paradoxically, both exposure to and protection from wildfire risk. Importantly, these systems privilege populations considered socially and economically secure. The individual agency of both marginalized and well-off populations has to be contextualized within this more comprehensive approach of the institutional forces that shape decision-making.

6.3. Social cohesion & place attachment

A common thread in many studies related to a community's adaptive capacity to wildfire risk is the importance of social interactions and connections (Stasiewicz and Paveglio 2017; Mannakkara and Wilkinson, 2012; Frandsen et al., 2011; Webber and Jones, 2011), as a precursor for building trust (Sharp et al., 2013; Lachapelle and McCool, 2012). For example, an important characteristic cited widely in the disaster literature, but not as prevalent in wildfire research, is the availability of social capital, such as familial and other social relationships, that can supplement other assistance that households receive before, during, and after a disaster (Morrow, 1997). Residents in fast-growing, new communities may lack important social networks, and may therefore be less likely to reach out beyond those in their immediate context. Racial and ethnic minorities are more likely to rely on social networks and kin for information and support (Morrow, 1997), but they are also more likely to be excluded from community planning and preparedness processes (Bolin and Bolton, 1986).

Inclusive and participatory processes that build social networks and engage a diverse set of stakeholders can help mitigate wildfire risks but also require that more attention be paid to incorporating knowledge of local ecological conditions and how these interact with social systems, otherwise referred to as coupled human-natural systems (Fischer et al., 2016). Similarly, some research points to the value of what Jakes and Sturtevant (2013) refer to as community-based collaborative wildfire planning. In their study they point out that the social learning that takes place during a wildfire event can help catalyze a community's capacity-building efforts, and that the process of creating community wildfire protection plans facilitates learning not only of wildfire management practices but also of community and ecosystem health. While local officials and residents may both see the benefit of creating and participating in official fire management practices and programs, these need to be adapted to the specific social dynamics of the context in question, including an acknowledgement of the nature of the relationship between residents and the surrounding landscape, as well as residents' personal views on how to manage their properties (Paveglio and Kelly, 2017).

Given diversity within communities, however, policies that are directed towards building a community's adaptive capacity must recognize those community-level differences (Olsen and Sharp, 2013; Fischer et al., 2013). Creating typologies of communities is one way to direct policies towards places most vulnerable to wildfire events, if policy goals are operationalized at the community level (Paveglio et al., 2015). Several factors, however, contribute to the variability within communities and point to how problematic the term community can be in disguising people's differential access to resources and the varying relationships between distinct populations and the land, or place, they inhabit.

Addressing community diversity entails not only recognizing diversity but also responding to it by offering multiple pathways for processes, policies, and other wildlife-related management tools to be taken up and enacted by individuals living in the same location (Kolden and Henson, 2019; Paveglio et al., 2016; Paveglio et al., 2018). Key to understanding and promoting adaptive capacity is framing and shaping those pathways to local social dynamics such as people's histories, experiences, and knowledge, as well as their relationships with local landscapes and government institutions and agencies (Paveglio et al., 2018). In adopting a formal fire protection association and management plan, Stasiewicz and Paveglio (2017) found that when local residents were involved in the development process of those plans, the trust between fire professionals and residents facilitated plan adoption and implementation.

Wildfires also result in ecological damage, which in turn can have a negative impact on populations that rely heavily on local natural resources as their economic and employment base (Butry et al., 2001). In addition to available income and whether homeownership is primary or secondary, other characteristics that influence the adoption of wildfire protection actions include how cohesive community attitudes are when it comes to risk perception. This social cohesion is a function of, among other factors, the perceived efficacy of wildfire action in mitigating local fire risk (Absher and Vaske, 2011) and place-based knowledge

(McCaffrey, 2015; Paveglio et al., 2015), importance of landscape aesthetics (Paveglio et al., 2017), and trust in wildfire managers and agencies (Absher and Vaske, 2011).

The relationship between people and landscapes is a function of the value people ascribe to places (Brown, 2004; Williams and Patterson, 1996), as well as the personal connection they form with those places (Williams and Vaske, 2003). Referred to as place attachment, this is a theme that wildfire research is increasingly paying attention to, proving to be a factor in social dynamics related to a community's sense of social cohesion (Prior and Eriksen, 2013; Christianson et al., 2014; Cox and Perry, 2011). Place attachment is a significant predictor of social capital and leads to improved community preparedness (Bihari and Ryan, 2012). Insofar as place attachment is an indication of shared local knowledge, programs meant to strengthen preparedness tend to be more effective when the local context is considered, including existing social networks for information-sharing, local values, ecosystem and infrastructure knowledge, and acknowledging barriers (Stidham et al., 2014). Integrating local knowledge, values, and concerns in wildfire-management decisions is a key factor in building trust between communities and agencies and, by extension, is a predictor of how well resulting management plans will be adhered to by community members (Sharp et al., 2013; Carroll et al., 2011).

Nevertheless, a high level of variability continues to introduce exceptions to any unifying conclusions on the effect of these considerations on wildfire management adoption and enactment (Paveglio and Edgeley, 2017; Sword-Daniels et al., 2016; Gordon et al., 2012). A multi-scaled effort that acknowledges the diversity of populations inherent in each community is necessary to increase adaptive capacity towards wildfire (Dunlop et al., 2014), yet values or attitudes, which may otherwise contribute to social cohesion and facilitate and reinforce action, vary substantially. While a number of studies attempt to quantify this variance and form archetypal communities, or a set of community typologies such as *formalized suburban* or *rural lifestyle* (i.e. Paveglio et al., 2018; Paveglio and Edgeley, 2017; Paveglio et al., 2015), few wildfire studies delve further to examine social cohesion through a framework of social vulnerability.

7. Conclusion

The techniques used by disaster management processes to decrease vulnerability in communities, ranging from community-based management plans to identifying increased sensitivity through SoVIs, are increasingly deployed as tools in societies facing and planning for climate uncertainty and risk. Vulnerability is not only largely depoliticized, but becomes a marker for those populations requiring government intervention through technocratic means (Grove, 2013). Warranted critiques of these approaches point out that a focus on reducing exposure diverts resources and attention away from the very systems and processes that manufacture risk, and create vulnerability, in the first place. Reducing wildfire exposure in poor rural communities, for example, may alleviate the risks associated with an immediate wildfire threat but perpetuates the inequalities that continue to produce the threat in the first place. Similarly, building a community's adaptive capacity perpetuates the risks that populations face and enables them to live with vulnerabilities (Reid, 2012).

In this context, adapting to wildfire threat becomes a framework, or set of techniques, for managing and perpetuating the sources and effects of inequality rather than challenging them (Duffield, 2011). While much of the research on wildfire risk, as has been shown, often acknowledges vulnerability as a function of existing inequalities, as Ranganathan and Bratman (2019) state, "relatively little is done to assess the rooted experiences, knowledges of, and approaches to sudden and slower-moving stressors among frontline communities." A more critical approach to how we understand, frame, and define vulnerability in relationship to wildfires could potentially broaden an otherwise singular trajectory of climate-proofing efforts to include addressing the historical and current grounds that give rise to harm. Further, it must acknowledge the multiple scales through which power structures influence the three determinants of vulnerability by including or excluding individuals and communities from the decision-making processes that manufacture or mitigate risk (Fig. 5).

7.1. Adaptation Equity

Adaptation strategies, when conceived of and implemented within existing social and political systems, such as those of property ownership and ideas of individualism, re-entrench inequalities because they continue to favor certain communities over others, what Marino (2018) refers to as adaptation privilege. With this in mind, wildfire research that characterizes vulnerabilities without questioning or challenging the context in which that vulnerability is created is necessarily incomplete. Asking or enabling communities to adapt to wildfire threats implies they are responsible for the effects of the risk they face, and by extension of the marginalization that placed them in a position of vulnerability (Chandler and Reid, 2016; Swyngedouw, 2009), ignoring the socio-political conditions that gives rise to vulnerability.

Wildfire research has shown that higher exposure to wildfire risk is associated with populations with lower social vulnerability, reinforcing the possibility that promoting adaptation in populations with higher social vulnerability may perpetuate their long-standing exposure to climate risk. As many rebuilding efforts have shown, adapting to climate change favors a 'build back better' approach to managing risk, with an emphasis on green and adaptive designs promoted by planners and architects. These processes are accessible to groups who are already in a privileged position. Even when disaster events reveal the inequitable distribution of harm that is disproportionately borne by minority populations, these kinds of rebuilding efforts continue to ignore structural inequalities. By failing to account for what created risk, and the need for adaptation in the first place, inequalities are further exacerbated (Kaika, 2017).

In this context, questioning for whom adaptation is for and asking "resilient to what?" can help move us away from responses that would further entrench inequalities (Ranganathan and Bratman, 2019). If we argue that adaptation is for vulnerable populations facing wildfire disasters and other climate risks and stop there, we ignore that the main beneficiaries of disaster recovery in the US are those who stand to benefit from rebuilding efforts, including developers, contractors, and consultants involved in the real estate industry. Moreover, if our focus is narrowly on adapting to unpredictable and extreme weather events caused by climate change, this erases the possibility of addressing historic and ongoing structural inequalities that actively produce vulnerability and risk.

A focus on adaptation equity, rather than adaptation alone, involves understanding the environment as a function of both environmental and social (history, labor, land, housing, health, social justice) relations (Ranganathan and Bratman, 2019). In their systematic review of socio-demographic and environmental justice implications for wildfire, Thomas et al. (2022) also conclude that incorporating sociodemographic characteristics alone to identify vulnerability is not sufficient for a study to fully address a justice framework. Indeed, currently lacking in wildfire research is not only a more comprehensive approach to identifying populations at risk, but also an equity framework that considers the social and political context that gives rise to greater wildfire sensitivity in specific populations.

7.2. Future Research

Anthropogenic climate change is leading to an increase in both the number and devastating impacts of wildfires globally. In efforts to understand who and what elements of the human sphere are most vulnerable to wildfires, researchers have started utilizing frameworks that examine vulnerability as it manifests at the intersection of exposure,

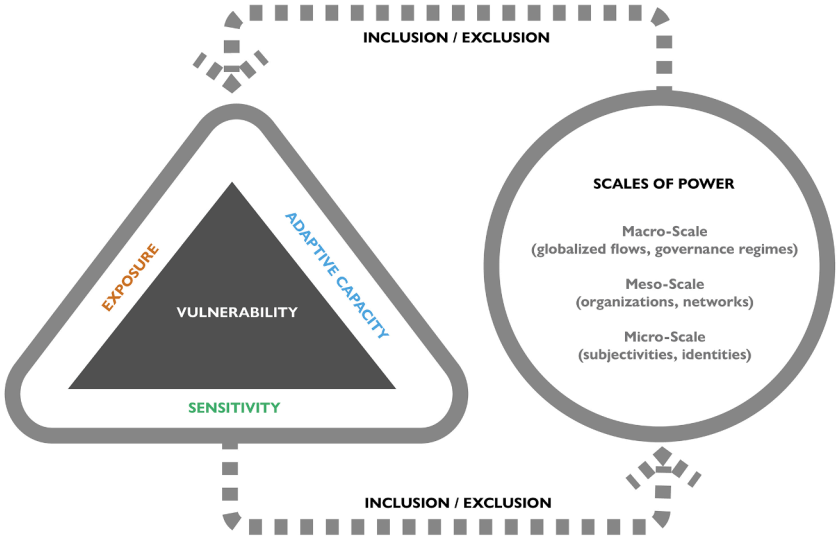

Fig. 5. Circular process by which systems of inequity amplify or modify vulnerability at multiple scales.

sensitivity, and adaptive capacity. Despite the significant body of scholarship produced in disaster planning circles, in wildfire science and other disciplines there is a tendency to overemphasize the physical dimensions of exposure in overall vulnerability. This is in part because it is easier to measure the physical drivers and outcomes of exposure in quantitative studies than its social parameters. Nonetheless, this tendency skews our perspective of who is vulnerable and why with important implications for resource allocation. For instance, we have discussed at length that high (physical) exposure is not synonymous to high sensitivity: in the US, higher income groups face greater physical exposure but due to greater access to resources, institutional support and social safety nets, they are less vulnerable.

In our review of the literature on wildfire vulnerability we find that perceptions of vulnerability often do not include social vulnerability, focusing instead on exposure before, during, and after a wildfire event. To address this misperception around vulnerability, it is important that researchers pay attention to the social parameters of exposure and build on existing models that focus on the social dimensions of vulnerability. Next, we find that many studies driven by quantifying socio-demographic characteristics often do not capture vulnerability in certain populations, but more recent literature (i.e. Méndez et. al. 2020) offers a more hopeful and critical approach by incorporating questions of agency and visibility when attempting to understand the ways in which certain populations are denied resources and protection. Finally, we find there is a dearth of literature that critically addresses all three components of vulnerability (exposure, sensitivity, and adaptive capacity) through a political ecology lens that tackles context, intersectionality, and structural inequities.

Social research that aims to understand the challenges populations face may provide valuable insights on how to increase the adaptive capacity of the most vulnerable communities, and bridge the gap between theory and policy/practice (Thomas et al, 2019.) Since decreasing vulnerability depends as much on access to power as to resources, it is critical that attempts to address wildfire vulnerability empower communities by partnering with them during the process of research and the implementation of policies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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