



Understanding rural adaptation to smoke from wildfires and forest management: insights for aligning approaches with community contexts

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ABSTRACT

Background. Rural communities are increasingly impacted by smoke produced by wildfires and forest management activities. Understanding local influences on smoke adaptation and mitigation is critical to social adaptation as fire risk continues to rise. **Aims.** We sought to determine the role of local social context in smoke adaptation and gauge interest in adaptation strategies that might reduce exposure. **Methods.** We conducted 46 semi-structured interviews with 56 residents and professionals in Parks, Arizona, USA, a rural community adjacent to public lands regularly affected by smoke. **Key results.** Rural residents think of smoke as an acceptable risk. Efforts to adapt to potential health impacts are minimal, though inaction is driven by diverse reasoning and trade-offs. Local social context – particularly elements related to government distrust, forest management, and independence – heavily influences interest in uptake of different adaptation strategies as well as affecting access to, and interpretation of, information about smoke risks. **Conclusions.** Rural approaches to, and understandings of, smoke adaptation vary spatially and temporally. Public interest in broader forest management efforts can be leveraged to engage residents in conversations about proactive smoke adaptation. **Implications.** Smoke adaptation strategies in rural communities must meld evidence of their effectiveness with community preferences grounded in local context to overcome inaction.

Keywords: community adaptation, forest management, health, protective action, risk mitigation, smoke, smoke adapted communities, social context, wildfire.

Introduction

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Burning vegetation produces high levels of particulate matter that negatively affect human health, with existing studies finding direct linkages between smoke and cardiovascular and respiratory or pulmonary emergencies (Adetona *et al.* 2016; Reid *et al.* 2016; McClure and Jaffe 2018) and upticks in respiratory hospital admissions among other outcomes. Left unaddressed, frequent smoke events can cause psychological trauma, depression, or anxiety (Finlay *et al.* 2012; Eisenman and Galway 2022). While some studies identify variation in health impacts dependent on smoke source (e.g. prescribed fire versus wildfire smoke impacts to firefighters, Navarro *et al.* 2018), all sources have the capacity to produce unhealthy air quality. Moving beyond retroactive clinical studies of health impacts to investigate proactive mitigation activities can promote understanding of how, if at all, communities affected by smoke work to adapt to and mitigate these impacts. Rural communities typically have limited capacity to manage smoke-related consequences (e.g. health care resources that are scarce or require travel) and are more likely to be employed as outdoor workers, which can make them particularly vulnerable to smoke impacts (Navarro 2020; Riden *et al.* 2020). Examining the nuances behind how individuals make decisions about smoke adaptation in these contexts necessitates qualitative inquiry to determine effective interventions that can elevate household and community adaptive capacity (D'Evelyn *et al.* 2023).

Matching smoke adaptation resources and strategies to local social contexts can help determine more equitable pathways to living with fire. Existing wildfire social science research suggests that this may include consideration of experiences with past fires, histories of natural resource management, community identity, and social relationships between residents and professionals among other considerations (Paveglio *et al.* 2015, 2018a). Here, we explore rural smoke adaptation considerations and actions among residents and professionals in Parks, Arizona, with a focus on identifying local-level strategies that would be both supported by residents and feasible from a professional standpoint. We conducted semi-structured interviews to determine factors that influence smoke adaptation from both wildfires and forest management activities, and gauge interest in resources and programs that might support interventions to reduce exposure. Interviews also allowed documentation of local social context and examination of how these evolving conditions influenced interest in or uptake of different interventions. This research serves several purposes, including: (1) the identification of more streamlined pairing of smoke adaptation resources with community needs; (2) provision of foundational qualitative insights into decision-making related to smoke adaptation, which has historically been absent in the U.S. Southwest (Edgeley 2023); and (3) characterisation of rural relationships with smoke and the land management activities that produce it to inform more nuanced guidance on smoke adaptation.

Literature review

Understanding local social contexts for smoke adaptation

Variations in local social context, comprised of unique combination of local history, culture, interpersonal relationships, trust in or collaboration with government entities, and place-based attachments that human populations develop in a given landscape, have a well-documented influence on wildfire adaptation (Paveglio *et al.* 2009, 2015, 2018b, 2019). These conditions characterise a community's 'adaptive capacity' or ability to adapt to risks and impacts, which consists of four components: (1) demographic and structural characteristics, (2) development and application of place-based knowledge and experience, (3) interactions and relationships among residents, and (4) access to and use of scientific or technical knowledge (Paveglio *et al.* 2009; Jakes and Langer 2011). Explorations of relationships between local social context and adaptive capacity tend to focus on preparation for, and evacuation and recovery from, the fire itself rather than secondary hazards like smoke (Burnett and Edgeley 2023). Existing research on community interactions with smoke examines individual components of local context; for example, the role of trust in risk messaging (Fish *et al.* 2017; Marfori *et al.* 2020; Wood *et al.* 2022), government–citizen collaborations (Rappold *et al.* 2019; Durkin *et al.* 2020), and past experience with forest management, smoke, or wildfires (Weissaupt *et al.* 2005; Santana *et al.* 2021), but rarely explore their interactions. Fragmented examinations of local social context and its relationship to adaptive capacity around smoke have limited alignment of smoke adaptation strategies with community identity to support more comprehensive and enduring risk mitigation.

Establishing an understanding of how socially diverse communities address smoke impacts is paramount for ongoing calls to foster 'fire adapted communities' that integrate local adaptive capacity and ecosystem health while acknowledging community as the most appropriate scale for adaptive action (Smith *et al.* 2016; Paveglio and Edgeley 2020). Adjacent to this is an emerging interest in policy and practice that establishes 'smoke adapted,' 'smokewise,' or 'smoke ready' communities, although what this entails and how it does or does not differ from fire adapted communities is not always apparent (IWFAQRP n.d.). Existing efforts to understand community-level smoke adaptation tend to favour quantitative inquiry over qualitative, often overlooking the depth and nuance that investigations of local social context require in order to uncover broader patterns that can be generalised at larger scales (Humphreys *et al.* 2022; D'Evelyn *et al.* 2023). Community-focused qualitative research that can delve into local context and its relationship to smoke adaptation is critical given the diverse and deep-rooted social inequities and vulnerability that

unhealthy air quality can produce or exacerbate (Johnson Gaither *et al.* 2015; Woo *et al.* 2020; Jung *et al.* 2024).

Characterising how rural populations differ when it comes to smoke adaptation, and whether the source of smoke matters in that adaptation process, is increasingly important as they often face greater exposure to smoke than urban areas (Kondo *et al.* 2022). Existing research hints at key differences in rural communities that set these environments apart from urban spaces when it comes to smoke adaptation, such as disruption to local culture and weakened community cohesion, often causing or exacerbating impacts to mental health and wellbeing (Humphreys *et al.* 2022). Rural communities lie at the intersection of numerous social challenges regarding smoke adaptation, and varied combinations of these factors can lead to differential adaptive capacity. Factors include, but are not limited to, (1) a lack of localised, accurate air quality monitoring and resultant data to inform adaptation approaches and decisions (Kondo *et al.* 2022; Smith and Chi 2023), (2) lower levels of trust in federal agencies driven by perceived competency and experience with previous fires, which affects whether they support use of land management techniques that generate smoke (McCaffrey 2006; Olsen and Shindler 2007; Rasch and McCaffrey 2019), (3) greater social isolation and resulting fragmentation of relationships within the same landscape due to a preference for independence, which can prevent clear and inclusive lines of communication about air quality among other topics (Olsen *et al.* 2014; Durkin *et al.* 2020), and (4) wider spectrums of social-economic conditions at the household level, meaning that adaptive capacity can become more dichotomous and inconsistent. Research that explores these and other components of rural local context in greater detail with a focus on identifying insights for collective action to adapt to smoke from wildfires and land management strategies can support the generation of sustained community engagement in risk reduction practices.

Common smoke adaptation strategies

Actions to support smoke adaptation generally fall into two categories: structural modifications or behavioural modifications (Barn *et al.* 2008; Fish *et al.* 2017; Wheeler *et al.* 2021). These efforts can be implemented at the individual, household, and/or community level, depending on resident and professional interest and the severity or duration of smoke events. Numerous reviews catalogue these modifications and, where available, their efficacy (e.g. Stares *et al.* 2014; Allen and Barn 2020); below, we summarise common adaptations in rural areas. Accessibility and feasibility regarding common smoke adaptation approaches are often affected by diverse social factors that can produce inequity, including financial capacity to improve structures or evacuate, employment stability, disabilities, social capital, and property condition among other considerations (Rappold *et al.* 2017; D'Evelyn *et al.* 2022).

Structural modifications entail the design or improvement of buildings to promote high indoor air quality during smoke events, creating a 'clean air space' (sometimes referred to as clean air shelters or centres) – a concept that can be applied to homes or publicly accessible buildings such as community centres or local businesses (Javins *et al.* 2021; Wheeler *et al.* 2021; Treves *et al.* 2022). Indoor air quality can be further enhanced with the addition of filtration units; typically a portable plug-in HEPA (high efficiency particulate air) purifier unit with prescribed square footage that denotes its capacity to clean air within a certain space, or a home-made equivalent using box fans (Barn *et al.* 2016; Rajagopalan and Goodman 2021; May *et al.* 2021). Uptake of structural modifications can vary widely depending on financial capacity to invest in filtration equipment and knowledge about their use (Castillo *et al.* 2024).

Behavioural modifications represent a divergence from typical day-to-day functioning for an individual or household. This can include changes to daily routines to avoid being outdoors during periods of low air quality, ceasing activities such as vacuuming that reduce indoor air quality, and wearing medical grade face masks (Allen and Barn 2020; McDonald *et al.* 2020). Other activities include closing windows and doors to maintain higher indoor air quality; however, this is only effective when implemented prior to a burn event (Williamson *et al.* 2016; Johnston 2017). Evacuation, while more disruptive, is often advocated for when air quality is particularly low, or when combined with growing risk from the wildfire itself (Laumbach 2019; Mottershead *et al.* 2020). Access to established public clean air spaces in community or public buildings that have efficient air filtration to offer daytime respite from low air quality offer an alternative to overnight evacuation (Barn 2014; Maguet 2018). Like evacuation, clean air spaces have limited utility: identifying appropriate locations is difficult, they often do not serve the most vulnerable communities who may not have transportation to these locations, and they are often underused by those who seek amenities like WiFi that are not always present in rural clean air spaces (Wheeler *et al.* 2021; Treves *et al.* 2022).

Evidence suggests that a combination of structural and behavioural modifications across scales can minimise exposure to smoke from vegetation management and wildfire (Allen and Barn 2020), although household capacity to make these modifications is variable due to social and economic drivers of inequity (D'Evelyn *et al.* 2022; Vargo *et al.* 2023). Notably, some of the most common smoke adaptation recommendations for members of the public, such as use of HEPA filters and evacuation to areas with better air quality, are far more challenging for rural populations whose livelihoods may be land-based or whose remoteness limits the feasibility or accessibility of these options (Stasiewicz and Paveglio 2021; Smith *et al.* 2023; Short *et al.* 2024). Little is known about how communities perceive of structural or behavioural adaptation strategies, or

whether uptake varies across local contexts (Paveglio *et al.* 2019; Batdorf and McGee 2023). Across many intervention or effectiveness-oriented studies, there is an implicit assumption that because a strategy is effective, the public will adopt it. However, much of the wildfire literature reveals a disconnect between education and action, indicating that adoption of these smoke reduction strategies may not be as linear as anticipated (Martin *et al.* 2007; McCaffrey *et al.* 2011). Moving away from clinical and quantitative studies of mitigation into qualitative research allows examination of what motivates adoption of different smoke adaptation strategies and identification of approaches to increase community adaptive capacity.

Numerous factors, including experience, pre-existing health conditions or disabilities, and ability to access information, influence whether an individual or household engages in smoke-related adaptations (Humphreys *et al.* 2022; Vargo *et al.* 2023; VanderMolen *et al.* 2024). Embedded within these decisions are perceived tradeoffs between action and inaction, informed by cost-benefit analyses, risk-benefit outcomes, and potential for risk transformation (Blades *et al.* 2014; Engebretson *et al.* 2016; Hamilton *et al.* 2019; Jones *et al.* 2022). Smoke can therefore elicit behavioural responses that range from risk-taking to avoidance (Stares *et al.* 2014; Castillo *et al.* 2024). There is a growing consensus that higher risk perceptions associated with smoke appear to motivate higher engagement in mitigation (Blanchard and Ryan 2007; Rose *et al.* 2017; McGee and Healey 2021; Santana *et al.* 2021). ‘Acceptable risk’ describes a level of risk that an individual or group are willing to accept due to the low perceived likelihood of negative consequences. Fischhoff *et al.* (1981, p. 3) define it as ‘the risk associated with the most acceptable option in a particular decision problem’ in which at least one option includes a threat to life or health, implying that an option where risk is non-existent may not be realistic. Decisions about what may or may not be an acceptable risk, and how (if at all) to address that risk, can cause disagreement (Kasperson 1983; Fischhoff 1994; Renn *et al.* 2011). The myriad complexities associated with determining actions to address acceptable risk have led to its characterisation as a ‘metadecision problem’, as many parties, values, and events can influence a decision, and one singular solution may not be feasible (Fischhoff 1994; Wang 2000). While acceptable risk has been briefly examined in the wildfire literature related to management decision-making (Fairbrother and Turnley 2005; Clancy 2011; Edgeley and Paveglio 2016), examinations of smoke as an acceptable risk problem are absent.

Calls to investigate how populations understand and prepare for smoke from both wildfire and forest management and its associated consequences are intensifying (O’Dell *et al.* 2021); this must span beyond identification of adaptive actions to understand the contexts and factors that influence their uptake. Additionally, there are growing demands for resources and actions to support smoke-

adapted communities, indicating a need for empirical qualitative data collection in communities affected by smoke (D’Evelyn *et al.* 2023). Given that communities are socially diverse, and research already suggests they gravitate towards approaches that are tailored to their unique identities, we sought to identify support or opposition for adaptation strategies and their related reasoning in a specific locale. We investigate the following research questions in response to the needs identified above:

1. How do rural households currently adapt to smoke exposure?
2. Which smoke adaptation efforts are most supported by rural households?
3. What role does local social context play in support for smoke adaptation?

Methodology

Study area

Parks, Arizona, is a rural unincorporated area approximately 20 miles west of Flagstaff and 15 miles east of Williams, situated between the Kaibab and Coconino National Forests in a mix of ponderosa pine forest and prairie grasslands (Fig. 1). Approximately 1382 residents live in the area across 1134 households – 603 of which are occupied full time (U.S. Census Bureau 2022). In 2022, the average resident age was 43.9, though 28.8% of the population were 65 years or older. Most residents were Caucasian (86.2%), 6.7% were Hispanic or Latino. Around 40.1% of residents held a bachelor’s degree or higher. Approximately 11.9% of residents had a disability, and 4.7% were without health insurance. Almost half (48.0%) of the population was employed (12% of whom worked in agriculture, forestry, or similar natural resource fields – higher than Arizona’s state average of 1.4%), and the median household income was \$93,854 ($\pm \$29,230$). The homeownership rate in Parks was 86.6% in 2022 (U.S. Census Bureau 2022). In 2022, 5.9% of Parks residents had moved from another state within the last year, while a further 7% had moved from within Arizona (U.S. Census Bureau 2022). Parks is situated within Coconino County, which is government-dependent and relies heavily on recreation to bolster the economy (USDA ERS 2015). No centralised sewage or water infrastructure exists for households in and around Parks; residents haul water to their properties from a nearby water fill station. Some properties were only allocated official street addresses within the past 10 years, and phone and internet service is limited. A gas station, post office, deli, and school form the central community infrastructure. Several social groups have emerged in the area comprised of residents who meet regularly and volunteer in the community.

Air quality Parks is frequently affected by both wildfires and forest management on adjacent United States Forest

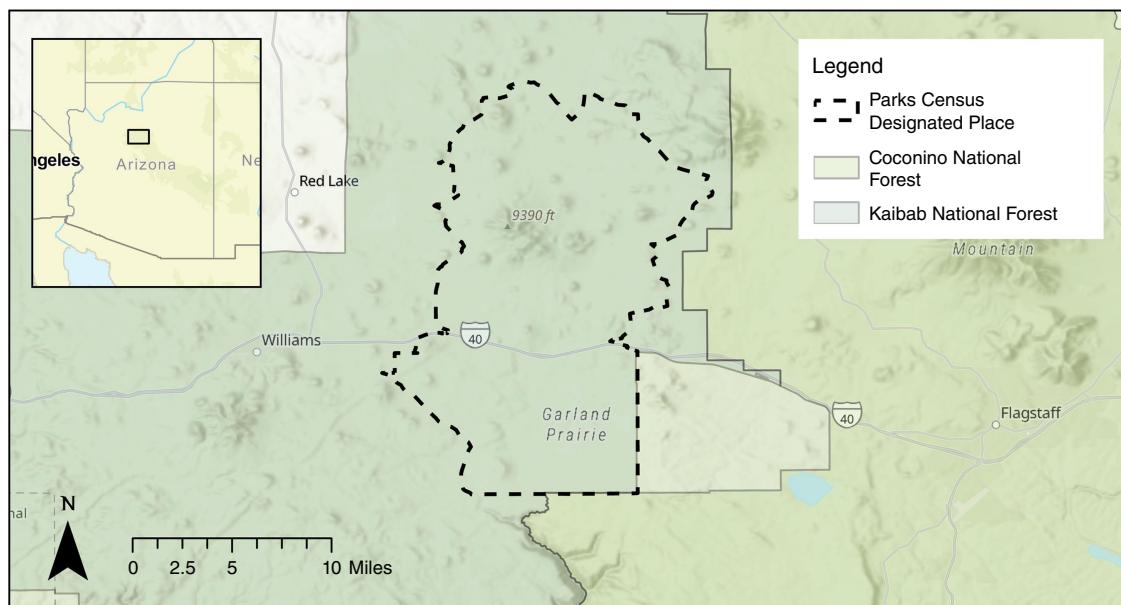


Fig. 1. Study area map of Parks, Arizona, and the surrounding area, including public land designations. While the map shows Parks as a census-designated place, interviewees described the Parks community as far greater than what is mapped here.

Service (USFS) lands, making it an ideal location for studying smoke from varied sources. Several wildfires have ignited on adjacent public land in recent years, pushing smoke into residential areas of Parks. The 10,381-acre Sitgreaves Complex was lightning ignited and managed as a resource objective fire in 2014, reducing air quality in the Parks area for several weeks. Nearby Kendrick Mountain Wilderness has also burned several times, including the 2000 Pumpkin Fire (16,086 acres) and 2017 Boundary Fire (17,814 acres). Numerous households around Garland Prairie received evacuation notices in June 2021 as a precaution during a back burn conducted to suppress the 78,065-acre Rafael Fire, which was contained less than a month prior to data collection. Such fires emphasise the need for active forest management on USFS lands surrounding Parks. Recent efforts include the Saddle Timber Sale, a highly visible 1159-acre project adjacent to Spring Valley Road and Old Route 66, both arterial roads for residents. This sale is one of several efforts in Parks nested under the Four Forest Restoration Initiative (4FRI) to improve regional forest health. Pile burning of residual materials is planned in the years following sale completion and has occurred previously on the eastern side of Parks following hazardous fuel reduction efforts. Prescribed fire is also used intermittently. The closest Environmental Protection Agency air quality monitoring equipment to Parks for PM_{2.5} and PM₁₀ is 20 miles east in Flagstaff, meaning that accurately assessing historic or current air quality conditions in the area during wildfires and forest management is difficult.

Data collection and analysis

The lead author met with five key informants, including community leaders and residents, local fire department staff, and federal land management officials, prior to beginning interviews to inform study design. These conversations and informal community visits provided context for interview protocol design and connected the authors with potential participants. Using these insights, we developed a semi-structured interview protocol that provided flexibility for follow-up questions to expand upon and explore emergent themes. Initial questions explored three topics: (1) experience with smoke from wildfires and forest management in Parks; (2) adaptive actions that interviewees engage in to reduce smoke impacts; and (3) support or opposition for different programs and strategies that may reduce smoke impacts to Parks-area households. The latter topic began with discussion of three common approaches – HEPA filters, clean air spaces, and evacuation – followed by open ended questions regarding other ideas the interviewee might have.

We conducted 46 semi-structured interviews with 56 individuals in July and August of 2021.¹ Semi-structured interviews allow follow-up questions on emergent themes, which was necessary for uncovering place-based understandings of local social context and smoke adaptation (Saldaña 2015). Interviews were held in person wherever possible at interviewees' homes, workplaces, or community spaces; video or phone calls were only used with part-time residents who were at their primary residence during data collection. Interviews ranged

¹This study was approved by the authors' Institutional Review Board (#1612344).

from 30 min to 2 h 10 min, with an average length of 55 min. Approximately a quarter of resident interviewees reported that they (or someone in their household) had a pre-existing health condition that was exacerbated by smoke. Interview participants were identified through a combination of theoretical and snowball sampling and recruited via phone, email, and household visits. First, we identified individuals who had specific knowledge or expertise about fire and smoke in the Parks area using employee directories and web searches – an approach known as theoretical sampling (Charmaz 2006). This included USFS professionals, local government representatives, fire and emergency management professionals, air quality experts, and community leaders. Many professionals were also residents of Parks. At the end of each interview, we began snowball sampling by asking participants to suggest others with similar and differing views on smoke and forest management, expanding recruitment to ensure the most representative dataset possible (Biernacki and Waldorf 1981). We acknowledge that gathering truly representative data can be challenging among rural populations, particularly those that are geographically dispersed and have limited interactions with one another.

Interviews were recorded with participant permission and transcribed verbatim for analysis. Both authors were present for most interviews and discussed emergent themes after each interview (Charmaz 2006; Saldaña 2015). Notes from post-interview debriefs formed the basis for an iterative qualitative coding process in QSR NVivo. A preliminary round of coding identified descriptive codes, or common topics across interviews to establish a comprehensive understanding of what information the dataset contained (Saldaña 2015). A second round of coding developed thematic codes to confirm and expand emergent themes identified during both post-interview debriefs and descriptive coding. Thematic codes identify commonalities across interviewee experiences and observations that allow consistent findings to emerge (Glaser and Strauss 1967). Our resultant codebook combined analytic induction and thematic analysis to establish core findings. Analytic induction refers to the process of comparing each new piece of text against existing codes and revising them or creating new codes that capture better the content when needed (Ryan and Bernard 2000). We established inter-coder reliability early in the coding process to ensure consistency in analysis before applying the emergent codebook to analysis of the remaining interview transcripts (Saldaña 2015). This entailed both authors separately coding a subset of transcripts, comparing coding efforts, and addressing any discrepancies before proceeding. Representative quotes for each theme were selected to exemplify key findings.

Results

Understanding responses to smoke in rural contexts

Resident interviewees characterised the Parks community as a large sprawling area that expanded far beyond existing

mapped boundaries to cover more than 35 miles from north to south. The area was described as socially diverse but unified by a desire to live rurally with limited external interactions. Prioritisation of self-sufficiency and privacy was connected to distrust for outside entities, particularly among long-time residents, as one interviewee described:

The Parks area doesn't trust government. So, if you're part of the federal government or the government in general, most of the time there just is this initial distrust for them. But I mean, it's kind of something that you expect with such a rural community. There's a reason why a lot of people live out here.

This identity had culminated over decades of experiences with government at different scales; most recently, there had been debate with the County over land use and concern regarding the prescription of a US Forest Service timber sale, both in highly visible areas of the community. Despite government distrust, support persisted for forest management on adjacent public lands due to perceived ecological benefits and reduced wildfire risk. Residents described frequent smoke from both wildfires and forest management in and around their community as a 'necessary evil' that was an unavoidable part of living in Parks, often discussed in tandem with other local air quality impacts like seasonal pollen and dust from dirt roads throughout the area. Interviewees felt there was a need to communicate the realities of fire and management strategies that produce smoke to newcomers as turnover began to increase in Parks, as one resident explained:

You have to know what you're moving into. This is a fire-adapted ecosystem. Not to be insensitive to people who do have issues or do have health concerns or who can't handle the smoke, but it gets to a point where you're living in a fire-adapted ecosystem; there's going to be fire.

Given the prevalence of ecological knowledge and related support for forest management, high acceptance of smoke tied to beneficial ecological outcomes among interviewees appeared to be relatively consistent, regardless of its source or cause. While acceptance was generally high, interviewees made a clear distinction between their tolerance of 'unplanned' smoke production (i.e. wildfires) versus 'planned' (i.e. prescribed fire, slash pile burning, and decisions to allow managed fire use on a wildfire instead of active suppression for forest management), perceiving the former as unavoidable and the latter as preventable or controllable. Most described only becoming concerned after several days to a week of low air quality during periods of planned burning and were often hesitant to acknowledge that they themselves might be vulnerable or need to take action – particularly if they did not have preexisting health

conditions or disabilities. One long term resident exemplified this high threshold for adaptive action when discussing prescribed fire:

Probably the last five years at least, the smoke we've had, it's annoying and it makes me cough a bit, but it isn't so bad that I've got to get out of here... it's not overpowering most of the time. And when it's bad, then yeah, something needs to be in place to help those that really need it. I hope I would not have to need it.

High acceptance of smoke from various sources meant that interviewees often felt smoke was an inconvenience rather than a risk. As a result, presence of smoke primarily drove information seeking behaviours regarding its ignition source, possible duration of low air quality, and the threat that fire might pose if it was not managed, rather than information related specifically to health impacts and local air quality index readings. Information seeking was undertaken in most instances to understand the level of threat to the interviewee's property and day-to-day activities. One resident explained how they typically reacted when they noticed smoke:

I get annoyed immediately. It's like, "Okay, how long is it going to last?" And that has more to do with it. How much smoke, how heavy is it, and is it going to be gone by morning?... I'll get on the Facebook, "Okay. Where's the fire and why have we got it?" And yeah, I want to find out where it is and how long it's going to be, and if it's going to get worse.

When deciding whether to take adaptive action during periods of low air quality caused by wildfires or forest management, resident interviewees rarely described proactively searching for information from official sources such as USFS or Arizona Department of Environmental Quality, instead favouring informal local communication channels:

We look on the Parks Exchange [Facebook group] a lot because there's a lot of people that post, "Oh, my cousin's a wildland firefighter", or whatever. At work we have several coworkers who are married to or dating firefighters. "What's burning? What's burning?" It's weird, I don't ever look up the Forest Service or anything. It's totally word of mouth.

There was little differentiation of perceived health impacts from different smoke sources (e.g. prescribed fire versus wildfire), with one interviewee stating "I see them as equal" when asked if their concern varied depending on ignition cause. Interviewees were more likely to suggest proximity of the smoke source as a factor influencing their

health concerns, most notably when smoke was present from further afield.

High tolerance of smoke paired with information seeking through informal community channels led to largely retroactive adaptation actions to mitigate potential health impacts. Among interviewees from households where members had health conditions or disabilities, retroactive information seeking was also common but uptake of mitigative actions were faster. Few interviewees proactively checked air quality forecasts or websites that listed forthcoming burns, instead relying on personal observation of air quality to determine whether conditions were poor enough to elicit a response in their household. Interviewees described how they relied on their senses to initiate reactive adaptations:

I've woken up at two o'clock in the morning, and just sit straight up in bed, because I have super sensitive sinuses and really bad allergies. And I'll just take off running and close the windows and batten down the hatches... You can smell it [smoke] inside.

When I can physically see it, I definitely reduce our exercise. I just don't think those small particulates are good for your lungs so we'll definitely keep more inside. We take the dog out every day but instead of taking a mile or two we just keep it in the neighborhood.

Interviewees retroactively adapted to smoke in one of three ways: (1) closing all windows in their home at night, which were typically left open to reduce indoor temperatures overnight during summer months, (2) staying indoors as much as possible to reduce exposure, or (3) modifying their daily routines to avoid being outside during extended periods of low air quality. Few had HEPA filters, masks, or had made additional structural modifications to their home to reduce exposure. Others had livestock, property management needs, or employment that prevented them from staying indoors. Many described 'toughing it out' when air quality dropped because it typically did not last more than several days, believing that spending money on household-level mitigations would not yield a high return on investment. However, there was anticipation that investment may be appropriate in the future if the duration of low air quality began to extend:

Construction out here is really colorful. There's a lot of builds with no codes or anything so I'm not set up to have an HVAC system when I could install an air conditioner or a nice filter or something. I think the smoke would have to get worse. There's a whole cost-benefit analysis to make there. Like, man, this is now a reality that we're going to have three weeks of consistent smoke, [then] we've got to do something.

Determining local support for different smoke adaptation strategies

Discussion of different adaptation strategies and their suitability for Parks residents revealed how rural social contexts influenced support or opposition for each mechanism. Interviewees consistently critiqued public clean air spaces and temporary evacuation as inappropriate because of the displacement these options would cause. If the location was not within Parks in a place that interviewees were familiar with, such as the local school gymnasium, anticipated use decreased. This was driven by both accessibility and the importance of being somewhere that closely aligned with Parks' culture and community identity, as one interviewee explained when asked they would prefer to relocate to:

There's also stigma in Parks about Flagstaff. No one likes to go to Flagstaff if you don't have to... if people had a choice, and if Williams had what we needed, we'd rather go to Williams.

Interviewees saw evacuation from homes to clean air spaces or hotels as a last resort because of logistical concerns surrounding the ability of such spaces to accommodate their household's individual needs. Interviewees wanted to know whether use of these spaces would limit the disruption of their day-to-day tasks: this included whether internet would be available, whether it would be open 24/7, or whether transport would be available to and from the location. Interest also hinged on whether these spaces could accommodate pets or livestock; one interviewee shared "If you can't take your animals, people are not going to go". Others noted the financial burden that displacement created, particularly for those who would benefit from temporary evacuation but often could not afford the expense of temporary relocation. This led to discussions of responsibility for the financial burden of relocation when smoke was intentionally produced by planned forest management activities or decisions to use managed fire, revealing that despite a general distrust in the government, interviewees expected government-funded solutions as a form of accountability related to health impacts:

The government should go ahead and foot the bill. I'm not at that point where oh my God it's too smoky, I need to go have a motel room. But if I was, and there are people that are, COPD people and whatnot, then I think they should be compensated because guess what: if our government is going ahead and putting them in a health issue condition, then they need to be relocated for whatever length of time. That makes sense to me.

Together, these comments indicate interviewee hesitancy around adaptations that required leaving their property or community. As a result, the most popular adaptation strategy among interviewees was access to HEPA filters. The

appeal of these units was their alignment with community identity as individualistic and self-sufficient, with many noting that it might reduce barriers to clean air for those who were unable to temporarily relocate. One interviewee explained:

People would be more open to [HEPA filters] than a hotel. I think that you'd have people who don't want to leave their homes, but this could provide them more comfortable and a safer environment during these high smoke situations. I think that you won't have such a polarized opinion on that... It's something a little bit different that's staying in the community.

Interviewees saw provision of HEPA filters as clearly aligned with their expectations regarding government accountability and relationship building for planned, intentionally produced smoke, as one resident described:

Hand those filters out to people. That would almost be like the authorities extending the hand to the community saying, "Hey, we have to do this, but here's how we can help". That would be a major thing. I think it would change their attitudes... Instead of just saying, "We're going to do this [prescribed fire]. It's going to go for so long" and telling people "This is going to be good", you need to show them.

Interviewees described several conditions necessary for the success of a HEPA filter distribution program in Parks. Full-time residents were most interested in a program that operated under a donation structure where recipients could permanently keep their filter, whereas part-time residents were more willing to engage in cost shares to purchase their own unit. Interviewees wanted the local fire department to have oversight, either independently or in partnership with a community group, rather than a government entity, due to greater trust and familiarity. However, some voiced concerns about the fire district's volunteer capacity to implement such a program, and not everyone who was considered a member of the community was within the district's jurisdiction. Despite initial support, some interviewees were hesitant; most had never owned one or been in a room where one was operating and some questioned the science behind them, indicating that they wanted explanations about how they worked and evidence of their efficacy before using one themselves. A resident explained:

I'd be skeptical on how they [HEPA filters] actually work. Because to clean the air, it would have to get air in first. If it was on a vent system that is at the house edge, it would make sense. But with it just being like a filtration system in the house, it technically would have to be filled with smoke before it would do what it needs to do to clean it.

Avenues for proactive smoke adaptation

Progress towards smoke adaptation in Parks centred around two ideas: diversified approaches to agency communication with the public, and modified fuels treatment outcomes that allowed public use of residual materials instead of their removal via slash pile burning. However, the feasibility of these approaches was debated among interviewees, as discussed below.

While agency interviewees confirmed that communication was disseminated through government websites and other appropriate information outlets, these venues were not regularly accessed by Parks residents and the COVID-19 pandemic had prevented recent face-to-face contacts. Given that most interviewees did not proactively seek official smoke information, an increase in communication through local venues about planned burning and smoke offered opportunities for improved trust in agencies and more time to enact smoke adaptation activities such as temporary relocation or switching on a HEPA filter unit. One resident was concerned that this perceived lack of USFS communication stemmed from the possibility of local pushback:

Even if they [USFS] would just say the day before. I don't need months or anything. It creates a lot of fear. I mean, we have to leave in the morning [for work] and the question is, are we going to come back to a barbecued dog, or dead chickens, or our home being gone? For me, I get very nervous about that, so even a couple days would be awesome. I wonder if they worry that people will give them heat about it like, "No, don't [burn] that area" so this isn't open for discussion.

Lack of access to, and active seeking of, information in Parks was connected to intentionally secluded lifestyles. As a result, interviewees preferred information that was funnelled straight to them on a need-to-know basis. The most common request was for text or web notifications via the County emergency alert system that many were already signed up for:

A lot of folks out here are just, "Leave us be," type of mentality. That's why we live rurally, is we don't want to be messed with so much. I don't know that I would attend something like that [a community meeting], but if I had something online where we could see, easily access, and it's been communicated, like maybe use the Coconino [County emergency alert] system to say, "Okay, here's where these are going to be posted", and then people could perhaps bookmark it or have the link and just touch and see, "Okay, there's a prescribed burn today".

Accessibility of information was a consistent challenge across Parks due to inconsistent cell service or internet.

Residents in more remote pockets of the community only drove to public areas such as grocery stores or gas stations every few weeks, meaning that receiving information about planned burning via posters or fliers at the local store and post office situated at the main access point to the community was preferred. The timing of these communications was considered most important, but preferences for advanced notices regarding planned burning were extremely varied and ranged from 24 h to more than a month. Interviewees described using this advanced notice about burns to make minor protective adjustments, such as closing windows the night before a burn began, or scheduling appointments, meetings, or trips to areas with higher air quality during those periods. However, agency interviewees were quick to note that the demand for long-term forecasts and burn dates for prescribed fires were not feasible and could lead to information fatigue among residents. This revealed a tension between being able to provide up-to-date accurate information about smoke and difficulty communicating with remote, rural residents in a timely manner. One professional shared:

Let's say there's going to be a prescribed burn just south of Parks. So that night before you send out a message going, "hey, prescribed burn tomorrow, air quality could be bad". The weather changes, they get out there, they do their test fire, that doesn't go well. Or they just don't burn that day because they have a lack of resources. Then all of a sudden, you have all this over-messaging, and then that just becomes the white noise. It is a very fine balance.

Because of perceived difficulties communicating and mitigating risks associated with smoke from planned pre-fire forest management activities, resident interviewees advocated for alternatives to burning both as a fuel treatment approach and as a technique for removing residual materials in the Parks area. This included support for a shift from removal of residual materials produced by forest management on public land via pile burning to sharing those materials with the public for personal use such as firewood, mulch, or wood chippings. Interviewees saw public access to residual materials as dual purpose: it offered a pathway for reduced smoke outputs while also providing direct benefits to residents, improving citizen-agency relations. One resident who lived near a local timber sale area described how residents had both the skillsets for processing materials and concern about risks associated with alternatives:

I look at the size of those piles and the logs that are in them, they should be turning people loose in there to take their chainsaws and harvest. There's a whole lot of wood in there to harvest and they wouldn't have such a disaster. I mean, with the size of those piles, I look at that and if they set it the wrong time again, those would set the

rest of the trees there on fire. I'm not confident that wouldn't happen...

Agency interviewees were quick to note that it rarely was as simple as making the decision to offer up residual materials to the public, depending on if the sale was contracted or whether resources were available to oversee public access to the site among other factors. Some of this access might be assessed on a case-by-case basis, as one professional explained:

In some cases, the piles that remain, they're the contractor's. The person who bid on that. So, we can't just say, "free-for-all." And a lot of times we don't want to say "free-for-all." And then the piles get all messed up because they're built in a certain way that they have the right ventilation to burn, right? Or to dry out first and then burn. So, we don't necessarily want to advertise like, "Free wood for whatever you want to do." But in a one-on-one conversation, it's like, "If you were to do it respectfully, and try not to impact land and don't forget, you can't take your vehicle more than 30 feet off the road", it may not be a problem.

Taking the assortment of smoke adaptation strategies discussed above and the varied individual and community contexts in the Parks area into consideration, interviewees ultimately recognised the need for a combination of strategies. One resident summarised:

That's the hard thing, is you're trying to meet such a diverse need for a community. So, really engaging with: At what point do we need to phase this [adaptation strategy] in? At what point do we need to phase it out? How large of an impact would it have to the community? ... Every single year it's going to change drastically based off of who now is living here.

Discussion

Rural communities are disproportionately impacted as smoke associated with wildfire and land management continues to increase (Humphreys *et al.* 2022). This study sought to understand the extent to which rural Parks, Arizona, residents adapt to smoke and their willingness to adopt behavioural and structural modifications to minimise associated risks. Findings inform and extend the existing smoke and community wildfire adaptation literature in several ways. First, we explored how rural communities experience smoke from different sources and the implications it has for how residents interpret the need for mitigation, finding that the notion of 'acceptable risk' explains widespread inaction but oversimplifies the diversity of factors that cause inaction. Second, we characterised the often-

overlooked role of local context in both uptake of smoke adaptation actions and preferences for specific approaches. Lastly, we contribute a qualitative exploration of smoke adaption, finding that rural communities think more broadly about the interconnectivity of wildfire risk management and smoke than existing studies suggest. The discussion below provides considerations for rural experiences with smoke from wildfire and forest management, with the intent to prompt more targeted discussions between communities and land management professionals and support more streamlined allocation of resources. These recommendations may be modified to suit different rural contexts where appropriate given that not all rural places may have experiences or perspectives that align with our study population.

Understandings of Parks as an independent community that prioritised privacy and a connection to the land shaped a shared characterisation of smoke associated with wildfire and forest management as an 'acceptable risk' that was an unavoidable part of living in the area (Fischhoff *et al.* 1981). This was indicative of local social context; attitudes towards smoke were tied to long-held knowledge about forest management and the importance of fire in the area, but distrust in government entities had evolved over time to include land management agencies conducting proactive forest management activities to reduce risk. However, understandings of smoke as an acceptable risk appears not as linear as Fischhoff *et al.* (1981) might suggest, and is variable among members of the same community, indicating that both local context and individual or household contexts interact in different ways to inform a spectrum of risk perceptions and related mitigation decisions. For instance, interviewees with pre-existing health conditions or disabilities perceived high risk from smoke, but often described lower capacity to mitigate that threat, forcing a decision to treat smoke as acceptable. Other interviewees saw smoke adaptation as a poor return on investment at the time of data collection but anticipated that the cost-benefit of mitigation investments would become worthwhile in the future. Together, these findings indicate that understandings of, and actions towards, smoke as an inconsistent yet acceptable risk emerge at the community level yet the context behind this conceptualisation is highly variable based on individual and household-level trade-offs. Risk trade-offs also appeared connected to smoke source; it was easier for interviewees to determine solutions for planned events like prescribed fire, but adaptations to smoke from wildfires – both nearby and from other regions of the US – raised questions about health impacts and the extent to which household-level planning was possible. This complexity spans beyond acceptable smoke risk to broader conceptualisations of wildfire as a wicked problem, for which there is no singular cause or solution (Carroll *et al.* 2007). Melding these two lenses that demonstrate social and ecological complexities associated with smoke, smoke emerges as a metadecision

problem that manifests barriers to unified adaptive action at the local level, but also necessitates localised, community-level action to be addressed effectively.

Parks residents and professionals agreed that managing smoke impacts began long before an ignition was present, and described far more temporally and spatially comprehensive efforts to reduce risk at a variety of scales via forest management. While already demonstrated in research with professionals, this is a new observation relative to community-focused studies that typically focus on the smoke event itself rather than the lead up (Olsen *et al.* 2014). Critically, interviewees saw a role for themselves in management efforts that indicated windows of opportunity for citizen-agency partnership before a wildfire. This was markedly different from discussion of smoke risk reduction during wildfires, which interviewees characterised as an acceptable risk that did not necessitate substantial action and described an implied transferal of responsibility to land managers. Acknowledgement of smoke management as a multifaceted long-term planning effort in rural communities may provide leverage for greater community involvement related to both smoke and broader land management efforts in rural spaces, particularly when they see personal benefit to engagement. This characterisation also reveals that rural communities understand the complex nature of smoke management and support multiple approaches to risk reduction; oversimplification of information and messaging from professionals may begin to cause tensions with communities over time.

Inaction regarding smoke adaptation raises questions about how to motivate adaptive actions in rural communities where local context drives high smoke acceptance and lower prioritisation of mitigation. Appeals that demonstrate both the effectiveness of behavioural or structural interventions paired with the need for their use appear likely to produce the greatest traction. Understanding whether behavioural and structural modifications extend smoke tolerance can provide additional insight for motivating the uptake of household adaptation efforts. Below, we identify several strategies for integrating smoke adaptation with local preferences: communication of specific content through local channels, evidence-based outreach using demonstrations to illustrate adaptation value, and the development of programs that align with rural context and capacity.

Distrust in government paired with reliance on informal communication channels in Parks influenced residents' passive approach to accessing information around air quality. Interviewees made a clear distinction between feasibility of notifications around planned versus unplanned smoke events, indicating an expectation for the former but not the latter. We note that categorisation of different smoke sources as planned and unplanned does not align with fire management terminology, which may result in confusion and exacerbate distrust in rural citizen-agency relationships. Managers and decision makers working in rural

communities should seek to integrate information about smoke into pre-existing informal communication channels that residents already depend on, and should expect that these channels require relationships building with community members in order to access (e.g. word of mouth, social media, fliers at centralised places). These spaces may offer the opportunity to share links or sources for more formalised information and encourage a transition to more reliable sources over time if communicated with consistency. Packaging of smoke information with other local air quality concerns like dust and seasonal pollen may heighten interest as the perceived benefit of adaptive actions is likely to increase. Such information can also be shared through existing education programs or public service initiatives such as routine smoke alarm checks for elderly residents or household energy efficiency assessments that are already conducted by trusted parties (Cole and Murphy 2014). Additionally, common themes emerging around smoke information seeking and resultant action share parallels with wildfire evacuation; these included the need to triangulate personal observations with additional sources before acting (McCaffrey *et al.* 2018; Edgeley and Paveglio 2019) and preference for actions that have minimal disruption to daily life (Cote and McGee 2014; McNeill *et al.* 2016). Future efforts to examine preferences for smoke mitigation should seek to assess the extent and conditions under which smoke mitigation decisions align with wildfire evacuation decisions, particularly in the context of 'wait and see' behaviours (Hano *et al.* 2020).

Our findings indicate that it is not enough to simply provide information on current or forecast air quality; assistance is needed translating those conditions into appropriate mitigation actions. For example, providing existing materials that document suggestions for appropriate activities during moderate versus unhealthy levels of PM_{2.5} may help members of the public better characterise the health risks posed to them. Inclusion of animals or livestock in risk messaging may also support mitigations that are more specific to rural contexts (O'Hara *et al.* 2021). Given Parks residents' reliance on personal observation as a trigger for protective action, educational materials that rely on senses rather than data may be beneficial (e.g. repeat photography of a local landmark during varied levels of air quality that can provide guidance for determining which actions to take). Timing of outreach prior to typical prescribed burning windows and fire season can further accentuate the relevancy of such communications. While wildfire social science research shows that education does not necessarily translate to action, contextualising this information by grounding it in tangible actions may help motivate some level of adaptation (Martin *et al.* 2007; McCaffrey *et al.* 2011).

Parks residents gravitated towards HEPA filters as the most desirable mitigation action for low air quality because it was least disruptive to daily life, proving the closest alignment with community context and associated values.

Interview discussions helped characterise factors contributing to a successful HEPA filter program in rural contexts. First, provision or organisation of HEPA filter distribution programs must be coordinated by a trusted local entity like a fire department, or at least conducted in partnership with them. This highlights the well-documented importance of community relationships with entities introducing adaptation approaches in rural places (Rasch and McCaffrey 2019; Edgeley *et al.* 2020). One important consideration for this localised approach is organisational capacity; rural communities often rely on volunteerism for coordination, suggesting that funding to support HEPA filter programs must not only consider the cost of the units, but also the administrative and staffing costs associated with their distribution (Smith *et al.* 2023). Second, the introduction of HEPA filters must be paired with evidence of their efficacy. We suggest that the use of a 'demonstration' unit in a well-trafficked community space may meet this need. For Parks, this might be a HEPA filter running in the local gas station during a low air quality event so that residents can observe it in use. Lastly, the process for acquiring a filter is important. Few residents were willing to pay for a unit because of the perceived low return on investment, indicating that receipt of filters via donation or cost-share may be more enticing at the outset of a HEPA filter program. Donations and cost-share mechanisms are also well-placed to alleviate financial inequities among households in rural communities that may otherwise prevent adaptation actions, but those administering such programs should consider the consequences of overreliance on financially subsidized adaptation strategies over time. Such communication would be well supported by the provision of information that helps demonstrate the financial and health benefit of such units; this could take the form of number of days with low air quality annually for the area or communication that such units serve multiple air cleaning purposes beyond smoke. Additional research beyond hypothetical discussions of HEPA filter program implementation is needed to understand whether these conditions truly enable success.

Conclusion

Interviews with residents and professionals in rural Parks, Arizona, demonstrate the importance of understanding local social context as a driver in decisions to take protective actions against smoke from wildfire and forest management. Histories of land management, government distrust, and community identity inform the most feasible and socially supported behavioural and social modifications – in this case, HEPA filters as a way of protecting community independence while improving social adaptation to fire. The concept of acceptable risk (Fischhoff *et al.* 1981) can help explain hesitancy to invest time and resources into smoke adaptation at the community level, but is limited in its

ability to demonstrate nuances and trade-offs that emerge through the establishment and proliferation of local social contexts. Parks residents appear to broadly conceive of smoke adaptation both spatially and temporally, suggesting that their interest in broader forest management efforts can be leveraged to engage residents in conversations around smoke. Enhancing flow of information and ability to interpret related data and science surrounding smoke impacts are critical to motivating action. Future research efforts should explore how actions to foster and maintain smoke adapted communities vary across different social contexts to support further tailoring of strategies and policies to reduce household health risks across a spectrum of rural conditions. For protective actions to take place, strategies must meld both evidence of their effectiveness with community preferences grounded in local context.

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