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Prescribed burning in your backyard? Connecting perceptions of wildland fire, smoke and exposure mitigation actions

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ABSTRACT

Background. There is interest in expanding the use of prescribed fire, but smoke management is often seen as a barrier to burning. Information about perception of prescribed fire smoke is limited. **Aims.** This study examines perceptions of wildland fire and smoke, and willingness to minimize smoke exposure. We further investigate variations in perceptions relative to fire activity and smoke concentrations. **Methods.** We surveyed residents of an area with regular prescribed burning to assess their opinions of fire and smoke, how they would reduce smoke exposure and the influence of prior experience with fire. **Key results.** There is a high acceptance of prescribed fire among survey respondents. Prescribed fire smoke is perceived as a low concern and is more acceptable than smoke from other sources. The largest differences in perceptions were observed among different land types. **Conclusions.** This study finds strong support for the use of prescribed fire among respondents. Concerns about health impacts from smoke decrease with increasing prescribed fire acceptance. Most respondents expressed a high willingness to act to reduce smoke exposure. **Implications.** With expanding prescribed fire use, effectively communicating smoke risks will be increasingly important as public concerns, perceived vulnerability and willingness to act may not align.

Keywords: air pollution, air quality, health, prescribed fire, public perception, smoke, wildfire, willingness to act.

Introduction

As wildfire risk increases due to climate change (UNEP 2022), the use of prescribed burning for fire management is increasingly being considered a critical tool to mitigate wildfire impacts. In contrast to unplanned and sometimes catastrophic wildfires, prescribed fires are planned landscape fires conducted under controlled conditions for various land management objectives, including mitigation of hazardous wildfire risk (James *et al.* 2020). In the US, recent legislation has sought to improve forest health and mitigate wildfire damages by increasing prescribed burning on federal lands (e.g. the National Prescribed Fire Act of 2021) and several states have developed plans to treat more land with prescribed fire (e.g. California Wildfire and Forest Resilience Task Force 2022).

Expanding prescribed fire use will require public acceptance and trust regarding the practice (Shindler *et al.* 2002; Toman *et al.* 2013). Public support of a fire management program is important for its success, and many studies find that education and communication regarding prescribed fire and impacts are key for public buy-in (Jacobson *et al.* 2001; Loomis *et al.* 2001; Toman and Shindler 2006; McCaffrey and Olsen 2012; Blades *et al.* 2014). An important component of this is adequately managing air pollution from prescribed fires and the health risks associated with exposure to smoke. Many land managers consider smoke management an important barrier to prescribed fire use and the prescribed burning can have significant detrimental impacts on regional air quality and public health (Raab *et al.* 2023; Maji *et al.* 2024; Johnson and Garcia-Menendez 2025).

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While prior research has assessed public perception of wildfire and prescribed fire, fewer studies have examined perceptions and concerns specifically related to smoke from fires – particularly from prescribed burns. The relationships among perceptions of prescribed fire use, concerns about smoke exposure and individuals' willingness to take action to mitigate smoke-related health risks remain largely unexplored. Following decades of failed fire suppression policy (van Wagtendonk 2007), acceptance of fire in the US has shifted. Studies suggest that there is a general acceptance and tolerance for prescribed fire across the country (McCaffrey 2006; Blanchard and Ryan 2007; McCaffrey and Olsen 2012; Wu *et al.* 2022; Rosen *et al.* 2023), but have also observed that perceptions are impacted by various factors. Trust in the groups managing fire and information sources plays a major role in public acceptance, with government agencies often perceived as trustworthy (Weisshaupt *et al.* 2007; Jarrett *et al.* 2009; Wu *et al.* 2022). However, recent negative experiences (e.g. escaped prescribed fires) can diminish trust in agencies (Brunson 2023), and public trust may be higher for local agencies than for state or federal governments (D'Evelyn *et al.* 2023). This pattern is consistent across US regions, with geographic differences in perceptions of prescribed fire being smaller than might be expected (Brunson and Evans 2005; Weisshaupt *et al.* 2007; Shindler *et al.* 2009, 2011). However, variations between rural and urban communities have been reported (Rosen *et al.* 2023). The mixed evidence in prior studies regarding differences in perceptions among rural and urban populations (McCaffrey and Olsen 2012) suggests that further research is needed.

Limited research has investigated perceptions and concerns regarding smoke from landscape fires. Most of the research to date has focused on wildfire smoke. However, the nature of exposure to smoke from wildfires differs inherently from that of prescribed fires. Wildfire smoke can travel long distances and severely degrade air quality near and far from active fires (McClure and Jaffe 2018). In contrast, efforts can be undertaken to manage smoke from lower-intensity prescribed fires (NWCG 2020). Previous work examining public tolerance of smoke has found that the nature of the source (e.g. wildfire, prescribed fire, agricultural burning) matters and that advance smoke warnings are valued (Weisshaupt *et al.* 2005; Blades *et al.* 2014; Engebretson *et al.* 2016; Olsen *et al.* 2017). Individuals with health concerns, which may include nearly one-third of US households (McCaffrey and Olsen 2012), consider smoke a significant issue (Blades *et al.* 2014; Engebretson *et al.* 2016). For example, a survey of medically vulnerable residents of a high fire risk county in California found that over 50% of respondents reported being impacted by wildfire smoke and over 25% reported being impacted by prescribed fire smoke, even though they strongly supported prescribed burning (Hoshiko *et al.* 2023).

To mitigate exposure to smoke from landscape fires, the most common public health recommendation is to remain indoors (U.S. EPA 2021). However, the extent to which smoke impacts can be reduced through interventions or individual actions is uncertain. A systematic review of interventions aimed at reducing exposure to wildland fire smoke found that interventions such as filtration, communication and respiratory protective equipment may protect health, but additional research is needed to assess their effectiveness (Goodman *et al.* 2025). Additionally, a study of modeled smoke-related interventions (e.g. reduced outdoors exposure, relocation, use of filters) suggests that 'good' public compliance at lower fine particulate matter ($PM_{2.5}$) concentrations (i.e. $< 20\ \mu g/m^3$) can be effective to mitigate the health effects of smoke (Rappold *et al.* 2014). However, research exploring the effectiveness of public messaging is mostly focused on large wildfire smoke events (Kolbe and Gilchrist 2009; Fish *et al.* 2017; Marfori *et al.* 2020; Santana *et al.* 2021; Williamson *et al.* 2022), as opposed to regions where less severe yet more frequent prescribed fire smoke is more common (Afrin and Garcia-Menendez 2020; Huang *et al.* 2021). Among vulnerable residents in a fire-prone location in California, survey results showed nearly all respondents take actions to protect themselves from wildfire smoke and over half did so to protect against prescribed fire smoke (Hoshiko *et al.* 2023).

To gain insight into how acceptance of prescribed fire relates to concern about smoke exposure and the potential for personal actions to mitigate associated health risks, this study explores perceptions collected from residents of North Carolina. We conducted a survey, developed in collaboration with the North Carolina State Division of Parks and Recreation (NC State Parks), to assess participant knowledge, opinions, and concerns regarding fire and smoke. Motivated by research emphasizing the importance of targeted messaging related to fire and smoke (e.g. Rosen *et al.* 2023), we also analyze responses in relation to proximity to fire activity, satellite-detected fire events, land type classification and estimated smoke levels. Building on prior analyses examining public perceptions of wildland fire and land management, this study specifically explores the association between perceptions of prescribed burning and concerns about the health risks of exposure to smoke from prescribed burns, as well as the public's willingness to undertake actions to reduce these personal risks. While previous studies have examined attitudes toward prescribed fire, our analysis links smoke-related health concerns with behavioral intentions. We also use multiple data sources to assess whether proximity to fire-prone land and areas of more intense prescribed burning is associated with variations in these perceptions. Prior research has found that public perceptions of prescribed fire are generally consistent across regions of the US, but local practices and experiences have been found to drive variability in those perceptions (McCaffrey and Olsen 2012). The analysis focuses on an area of the Southeastern US, the region where prescribed burning is most used (Altshuler *et al.* 2020) and where population may be especially vulnerable to the health impacts of smoke exposure (Rappold *et al.* 2017; Jung *et al.* 2024).

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Findings from a region with experience in prescribed fire use can provide insight into perceptions of expanding this practice nationally and strategies to mitigate the negative health impacts of increased smoke exposure.

Methods

Survey design and dissemination

The survey used in this study was created in collaboration with interpretation and fire management staff from NC State Parks. NC State Parks manages over 210,000 acres of parks, recreation areas, natural areas, and lakes and treats thousands of acres with prescribed fire each year. Wildfires also occur occasionally on NC State Park lands (Johnson and Garcia-Menendez 2022). Several survey questions were adapted from the fire module of the US Forest Service National Survey on Recreation and the Environment (NSRE) with permission (Bowker *et al.* 2008). A few questions were adapted from a survey of Utah residents living in areas where prescribed fire was used regularly (Brunson and Evans 2005). We included several questions about actions to mitigate smoke exposure, an area with limited coverage in previous studies. The survey addressed knowledge and awareness, trust and concern, and willingness to act. Most questions were formatted as multiple choice or included Likert-like scales (i.e. degrees of agreement or concern), although there were some options for open-ended, written responses. Participants had the ability to skip any questions they did not wish to answer. Participants were allowed to submit only one response. The responses were spatially analyzed using the participants' ZIP code and only responses with a valid North Carolina ZIP code were included in the analysis. The survey conducted was approved by the North Carolina State University Institutional Review Board to ensure that the research activities were ethical in practice and compliant with the federal regulations governing research with human subjects (IRB Protocol 16864). To ensure participant anonymity, no personally identifying information was collected from survey respondents, which precluded differentiation of responses by demographic or socioeconomic subgroup.

The survey was generated as an electronic form using Qualtrics software and was made available online via a public link. The survey was shared via the NC State Parks social media accounts and through the email lists and social media accounts of the North Carolina Prescribed Fire Council. Participants completing the survey were offered the opportunity to enter a random draw for a NC State Parks Pass. Entry into the draw was optional and contact information provided for the draw was not connected to survey responses to ensure anonymity. Our analysis is comprised of 750 responses collected between September 2019 and early March 2020, and as such, avoiding the period during and after the coronavirus pandemic. The survey questionnaire is included in the Supplementary material.

Fire activity and smoke exposure

We used several data sources to group respondents and evaluate whether proximity to fire and smoke affects perception in North Carolina. The statistical significance of differences in responses between these proximity-based groups were evaluated using a Chi-squared test. Because the survey was distributed through NC State Parks and NC Prescribed Fire Council outreach networks, the responses represent a convenience sample of the state's population. Therefore, statistical associations and differences across groups are limited to the observed dataset of 750 participants. Given the survey design, these findings should be interpreted as indicative rather than representative of North Carolina's population. Fully random sampling or replication studies would be needed to further assess differences in perceptions across the complete state population (McHugh 2013).

NC State Parks burning records

Burning records from NC State Parks for the years 2009–2016 were used to examine whether proximity to this operational program has a relationship with respondents' perceptions. Records include the burn date, coordinates and size of the burn. While significant uncertainty exists regarding the occurrence, size and location of prescribed burns in satellite- and permit-derived fire inventories (Huang *et al.* 2018; Nowell *et al.* 2018; Afrin and Garcia-Menendez 2020), NC State Parks records include confirmed burns and information about the area treated. As such, the NC State Parks fire inventory represents one of the most reliable and long-term datasets on prescribed burning for a major statewide land management program.

Responses from ZIP codes within a 20 km radius of a state park where prescribed burning has occurred were categorized as near NC State Parks activity (labeled '20 km'), based on prior research quantifying the association between prescribed fire activity and pollutant concentrations recorded at monitoring sites, to quantifying the distance over which Southeastern prescribed fires typically influence $PM_{2.5}$ (Afrin and Garcia-Menendez 2020). Within this set of parks, we also identified locations where frequent burning has occurred (>1000 total acres during the period considered). Respondents from ZIP codes within 20 km of these parks were designated as 'high burn.' Fig. 1*a* shows these parks and spatial distribution of survey responses.

Wildland–urban interface classification

Data on public perceptions and behaviors as a function of ecosystem type has been identified as a research need to improve outreach and education efforts (Dupéy and Smith 2018). To examine whether residential land type is associated with perception of wildland fire, we used Wildland–Urban Interface (WUI) – areas intermixed or neighboring wildland vegetation – and land type classification maps from Radeloff *et al.* (2018). In WUI areas, human development

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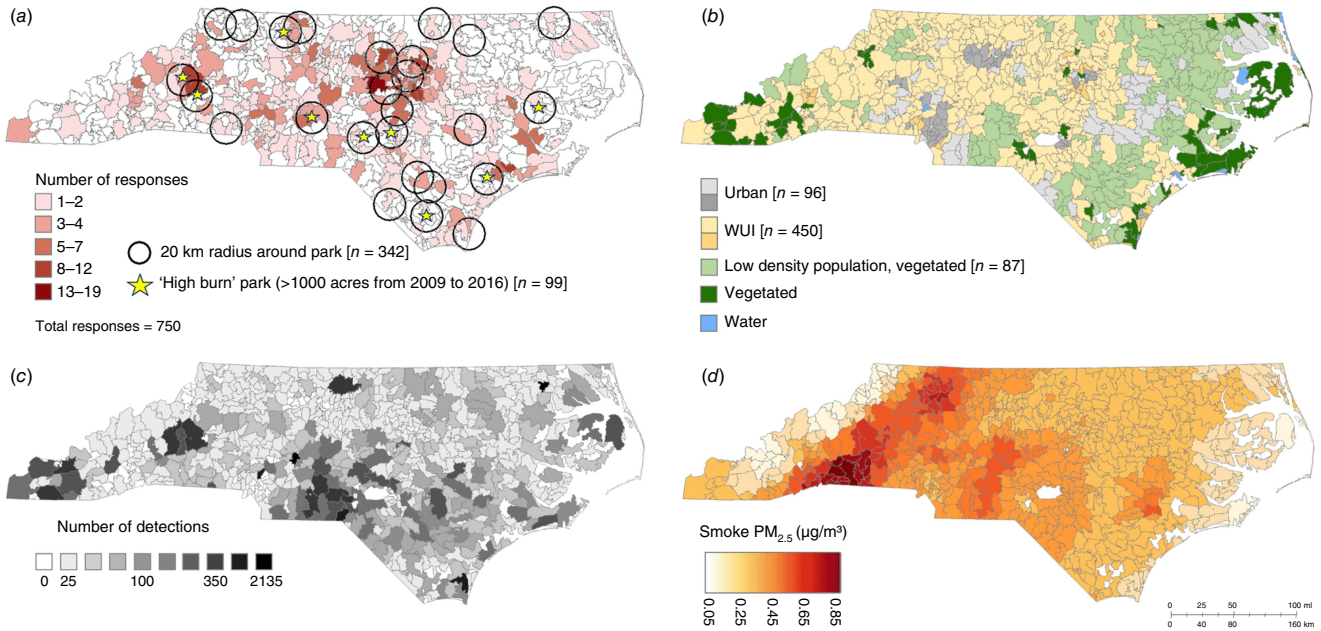

Fig. 1. (*a*) Survey responses and locations of state parks conducting prescribed burning. Responses grouped by North Carolina ZIP code. Responses from ZIP codes intersecting a 20 km radius around parks are classified as '20 km' and those within a 20 km radius of a park denoted by a star are classified as 'High Burn.' (*b*) Wildland–Urban Interface (WUI) classification resampled to the North Carolina ZIP code level. WUI areas include 'intermix' and 'interface' designations. Urban areas include 'high' and 'medium housing density non-vegetated' designations. Low population density vegetated (LDV) areas include 'very low density, vegetated' and 'uninhabited vegetated' designations. (*c*) Total Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m Active Fire and Thermal Anomalies product detections summarized by North Carolina ZIP code for 2015–2019. (*d*) Average daily smoke $PM_{2.5}$ concentrations for 2015–2019, as predicted by the National Oceanic and Atmospheric Administration (NOAA) operational smoke forecast. Concentrations are resampled to the North Carolina ZIP code level.

meets undeveloped areas and wildfire risk may be higher. North Carolina has one of the largest and fastest growing WUI areas in the US (Radeloff *et al.* 2018). We resampled the land types from the census block group level to the ZIP code level based on the classification with the maximum area in the ZIP. The WUI includes 'intermix' (where housing and vegetation 'intermingle') and 'interface' (where housing borders wildland vegetation). We grouped these two classifications into the single classification of WUI, and also analyzed responses from high and medium housing density areas (Urban), and those with low population density in vegetated areas (LDV). Fig. 1*b* shows the WUI classifications in North Carolina.

Satellite-detected fire activity

As an additional indicator of proximity to any type of wildland fire (i.e. not limited to prescribed burning on NC State Parks land), we used satellite-based retrievals of fire activity from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership satellite (Schroeder *et al.* 2014). The 375 m resolution of the Active Fire and Thermal Anomalies product allows for improved detection of smaller fires compared to other satellite products. Detections indicate the center of a pixel that contains one or more fires; they do not indicate the size of the fire nor the type of fire (i.e. wildfire or prescribed). We summarized detections of the Standard VIIRS 375 m product for the years 2015–2019 by total number of detections per ZIP code. Fig. 1*c* shows the distribution of these detections across North Carolina. To examine whether proximity to VIIRS detections of fire activity may be related to perception, we compared the responses from the ZIP codes in the 85th percentile for total detections (43, 'High Detects') to those from the ZIP codes with the 15th percentile for detections (0, 'Low Detects'). The number of fire detections across across all ZIP codes during the period considered ranged from 0 to 705, with an average of 28 detections.

Smoke-attributable $PM_{2.5}$ concentrations

To investigate whether average smoke exposure is associated with perception, we used archived daily forecasts of smoke $PM_{2.5}$ produced by the National Oceanic and Atmospheric Administration (NOAA) (Rolph *et al.* 2009). These forecasts are generated using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Stein *et al.* 2015) and are informed by satellite detections of wildland fire locations, meteorological fields from the North American Mesoscale Forecast System, and US Forest Service

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estimates of vegetation and emissions. We calculated a multi-year 24-h average $PM_{2.5}$ concentration at 5 km resolution and resampled this to the ZIP code level. Fig. 1*d* shows 2015–2019 average daily smoke $PM_{2.5}$ concentrations across North Carolina. We compared responses from ZIP codes in the 85th percentile for average smoke-related $PM_{2.5}$ concentration (0.41 μg/m^3, 'High Smoke') to those from ZIP in the 15th percentile for concentrations (0.19 μg/m^3, 'Low Smoke'). The average daily $PM_{2.5}$ concentration across all ZIP codes during the period considered was 0.30 μg/m^3.

Results

Few statistically significant differences ($\alpha \leq 0.05$) were observed among response categories. Differences in responses by land type (WUI, LDV, Urban) and by NC State Parks burning activity (20 km and High Burn) were the most likely to significantly differ.

Trust and knowledge

Overall, survey respondents express a high level of trust in land management groups and acceptance of prescribed fire. Eighty five percent of all respondents trust land managers to select the best methods to deal with wildfire risk. Ninety percent of respondents agreed that land managers should use prescribed fire as part of a fire management program (Table 1). This is in line with findings from previous surveys, including the US Forest Service's NSRE (71% nationally and 91% for the Southern region) (Bowker *et al.* 2008). Urban respondents have the most trust in management, although higher uncertainty in their knowledge, while LDV respondents have the least. However, support for prescribed burning as part of a fire management program is greatest for LDV respondents and lowest for Urban participants. Ninety-four percent of those living near High Burn parks support the use of prescribed burning for mitigating wildfire risk.

Awareness of prescribed fire and its benefits is high across respondent categories, as shown in Table 2. High Burn and LDV responses tended to express the least uncertainty in their knowledge and were more likely to check government sources for fire information (Supplementary Fig. S1). While 38% of participants believe prescribed fire is used near their homes, respondents in High Burn, LDV and High Detects categories were most likely to think this. Conversely, Low Detects and Urban respondents were least likely to believe they were close to prescribed fire activity and were most unsure. Of those who think that prescribed burning is used near them, the majority of respondents identified state agencies as responsible for the activity, which may be influenced in part by the survey's primary distribution by NC State Parks social media. Prescribed fire in the Southeastern US however, is conducted by a variety of groups, including federal and local agencies, conservation organizations and private practitioners, with state agencies responsible for a fraction of the area burned (Johnson Gaither *et al.* 2019; Melvin 2023). Less than 10% of respondents indicated they were unsure what entity was responsible for burning near them. The vast majority of respondents from any category indicated that prescribed fires reduce the risk of wildfire, improve wildlife habitat and do not kill most trees in the burned area (Table 2).

Acceptability of smoke

We find that the source of smoke is an important factor for acceptance among respondents (Fig. 2), in agreement with previous research (Blades *et al.* 2014; Engebretson *et al.* 2016; Olsen *et al.* 2017). Prescribed fire smoke is most acceptable to survey participants. Ninety-five percent of all respondents indicated that smoke from prescribed fire is either 'acceptable' (63%) or 'somewhat acceptable' (32%). Greater acceptance of prescribed fire smoke compared to wildfire smoke is inconsistent with some of the results reported by previous multi-region studies (Blades *et al.* 2014; Engebretson *et al.* 2016; Olsen *et al.* 2017). High

Table 1. Participants' agreement with statements regarding land management and fire.

	Percent of respondents									
Statement	**All**	**High smoke**	**Low smoke**	**High detects**	**Low detects**	**20 km**	**High burn**	**WUI**	**LDV**	**Urban**
Land managers should use prescribed fire as part of a wildfire management program										
Agree	90	86	94	94	92	90	94	90	96	85
Disagree	3	5	4	2	2	3	4	3	2	4
Uncertain	7	9	3	4	6	7	2	7	2	11
Land managers and forest professionals can be trusted to select the best methods for dealing with wildfire risks										
Agree	85	87	75	85	87	86	85	85	83	90
Disagree	4	2	7	3	2	3	3	4	3	2
Uncertain	11	11	18	12	10	11	12	11	13	8

Note: WUI = Wildland–Urban Interface, LDV = low population density in vegetated areas.

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Table 2. Awareness of prescribed fire activity and impacts.

	Percent of respondents									
Statement	**All**	**High smoke**	**Low smoke**	**High detects**	**Low detects**	**20 km**	**High burn**	**WUI**	**LDV**	**Urban**
Is prescribed fire, also known as controlled burning, used on land near your home?[A]										
Yes	38	46	57	52	23	42	70	38	60	14
No	53	48	32	40	63	46	27	51	34	73
Unsure	10	6	10	8	15	12	3	11	6	14
Prescribed fires reduce the risk of wildfire										
True	93	90	95	96	94	93	96	94	97	94
False	3	4	5	3	2	3	4	3	1	3
Uncertain	4	6	0	1	4	4	0	4	2	3
Prescribed fires improve wildlife habitat										
True	82	83	87	89	85	83	90	83	82	78
False	4	8	5	3	3	5	5	4	3	3
Uncertain	13	9	8	8	12	12	5	13	15	19
Prescribed fires kill most trees in the burned area										
True	3	2	3	1	5	4	2	3	0	5
False	92	92	94	96	92	92	97	92	97	90
Uncertain	5	6	4	3	3	4	1	5	3	5

[A]Differences in responses significant by fire detects (High and Low Detects), NC State Parks burning activity (20 km and High Burn) and land type (Wildland–Urban Interface (WUI), low population density in vegetated areas (LDV), Urban) at $\alpha \leq 0.05$.

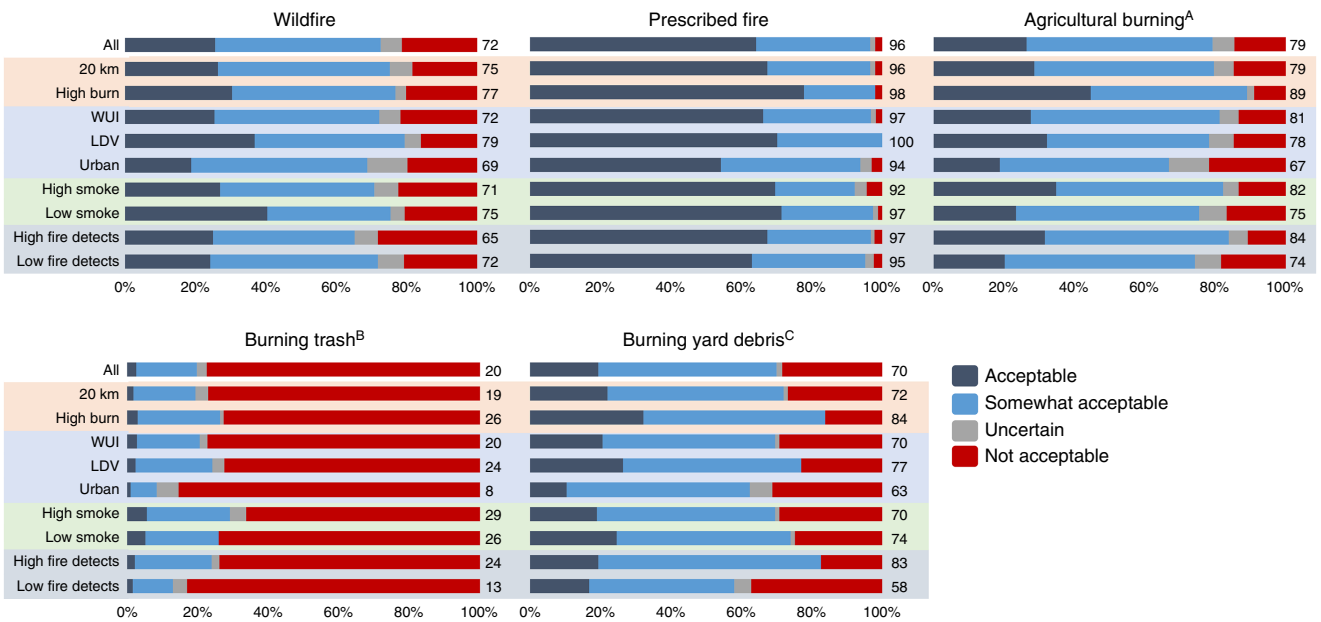

Fig. 2. Acceptability of smoke from different sources among survey respondents and respondent categories. Percentage of respondents that selected either 'acceptable' or 'somewhat acceptable' is listed next to each color bar. Shading indicates respondent category types. Differences in responses significant at $\alpha \leq 0.05$ by [A]NC State Parks burning activity (20 km and High Burn) and land type (Wildland–Urban Interface (WUI), low population density in vegetated areas (LDV), Urban); [B]land type; and [C]NC State Parks burning activity, land type and fire detects (High and Low Detects).

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Burn and LDV respondents are most accepting of prescribed fire smoke, and there is little variation in acceptability between those experiencing the most and least smoke. Smoke from wildfire, agricultural burning and burning yard debris is largely perceived as 'somewhat acceptable' by survey participants, while smoke from burning trash is overwhelmingly considered 'not acceptable.' Overall, Urban respondents are the least tolerant of any source of smoke and High Burn respondents are the most tolerant.

Concern regarding smoke

Survey respondents' level of concern regarding prescribed fire smoke is generally low (Fig. 3). This result may be linked to high levels of prescribed fire awareness. Prior studies have found that lower levels of concern related to prescribed fire associated with higher knowledge levels (Toman *et al.* 2013). Less than 26% of respondents are 'very' or 'moderately' concerned about this source of smoke and approximately 40% are 'not concerned.' LDV respondents, likely closer to prescribed fire, were the least concerned, although differences within groups were not statistically significant. This may align with research showing that rural communities, compared to urban communities, are more concerned about the risk of prescribed fires becoming uncontrolled wildfires and thus less concerned about smoke (Rosen *et al.* 2023). Respondents expressed greater concern about smoke from wildfire than from prescribed fire. Overall, 60% of respondents are 'very' or 'moderately' concerned about wildfire smoke while only 12% are 'not concerned'. As with smoke acceptability, the source of smoke is associated with the level of concern. Smoke from prescribed fire is perceived as less concerning among participants, despite uncertainty regarding differences in toxicity of prescribed fire smoke relative to wildfire smoke. While community exposures to $PM_{2.5}$ from prescribed fire are generally lower than those from wildfire, the risks will depend on the area and vegetation burned (Navarro *et al.* 2018). A notable difference in responses across categories came from High Burn respondents when asked if they or a family member is especially vulnerable to health impacts from smoke. Approximately 50% of High Burn respondents believed this to be true, while only 20–25% of other groups believed the same (Supplementary Fig. S2). This fraction is larger than reported in previous studies (30%) (McCaffrey 2006).

Although prescribed fire smoke is largely acceptable and of low concern to survey participants, the responses reveal distinctions in perception of this pollution source. Approximately half of the respondents indicate that smoke from prescribed fire has never been an issue for them and that it is a necessary inconvenience, yet less than 40% of respondents in any category consider it to be managed acceptably (Fig. 4). This perception seemingly contradicts the low level of concern and high acceptability of prescribed fire smoke reflected in responses to other survey questions, but may lend support to the assertion of fire practitioners that smoke management is a main barrier to using prescribed fire (Haines *et al.* 2001; Diaz *et al.* 2015; Kobziar *et al.* 2015). Few respondents believe that prescribed fire is not worth using because of the smoke and less than 15% are concerned about public health impacts from prescribed fire smoke. This is lower than levels of concern observed in previous studies (Jacobson *et al.* 2001; Loomis *et al.* 2001; Shindler and Toman 2003; Brunson and Evans 2005; Ryan and Wamsley 2008).

Willingness-to-act

Respondents express a high willingness-to-act when experiencing smoke, regardless of their proximity to burning activity, and public recall of the common message to go or remain indoors is high. When asked what actions they might take to reduce smoke exposure, a vast majority would close windows, most would check air quality reports and a slightly smaller fraction would reduce time outdoors (Fig. 5). Respondents indicated that they are most willing to take actions to avoid exposure to smoke when they are experiencing symptoms or if they were given an evacuation order (Fig. 6). The willingness

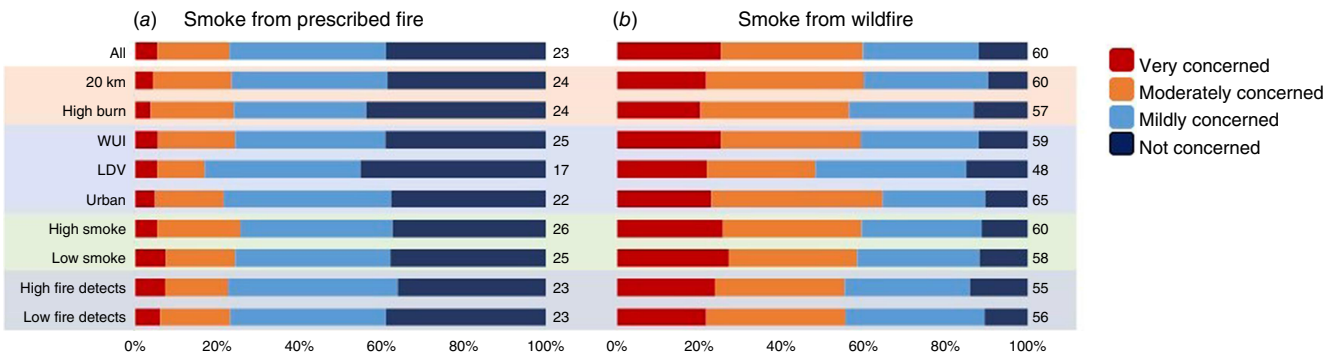

Fig. 3. Level of concern regarding smoke from (*a*) prescribed fire and (*b*) wildfire among survey respondents and respondent categories. Percentage of respondents that selected either 'very concerned' or 'moderately concerned' is listed next to each color bar. Shading indicates respondent category types. Note: WUI = Wildland–Urban Interface, LDV = low population density in vegetated areas.

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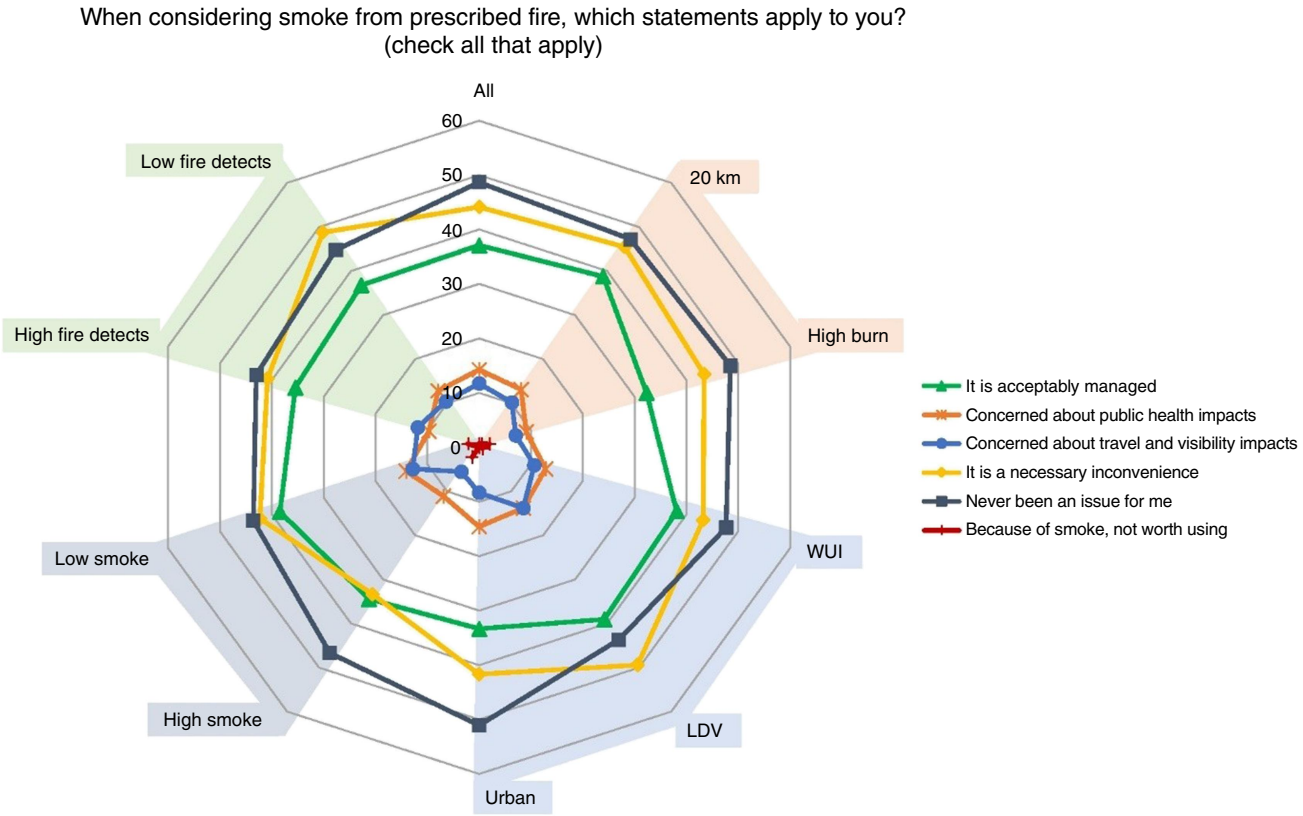

Fig. 4. Perceptions of prescribed fire smoke among survey respondents and respondent categories. Participants could choose more than one response. Colored rings indicate the percentage of the respondent group that chose a statement and ring colors correspond to different statements. Gray rings show reference percentages. Shading indicates respondent category types. Note: WUI = Wildland–Urban Interface, LDV = low population density in vegetated areas.

to respond to symptoms rather than for preventative reasons has also been observed among early users of the US Environmental Protection Agency's (EPA) Smoke Sense application (Rappold *et al.* 2019). A large share of respondents would act based on a report of unhealthy air quality, although this fraction is smallest among respondents closer to fire activity (i.e. High Burn, High Detects). The High Burn group is the least likely to check air quality reports, avoid smoke exposure if it is hazy or smoky, or act if an air quality report indicates that conditions are unhealthy.

Connections between acceptance, concern, and mitigation

We observed that respondents who agreed with the use of prescribed fire expressed the least concern about smoke from any source and about the possible health impacts of smoke exposure. Of the participants who agreed with the statement, 'Land managers should use prescribed fire as part of a wildfire management program' (n = 643), only 12% expressed concern about health impacts from prescribed fire smoke. Conversely, 33 and 29% of those who disagreed with (n = 22) or were uncertain (n = 49) about prescribed fire use, respectively, expressed concern about health impacts from prescribed fire smoke. Willingness to reduce personal smoke exposure by checking air quality reports and act based on them was higher among the respondents who agreed with the use of prescribed fire compared to those who disagreed.

Similarly, smoke concerns differed with perceived acceptability of smoke from prescribed fire. Concern about the health impacts of smoke increased from 9 to 21 to 57% among respondents who rated smoke from prescribed fire as acceptable, somewhat acceptable, and not acceptable, respectively. Respondents uncertain about the acceptability of prescribed fire smoke, or that rated it as somewhat acceptable, were the most likely to check and act on air quality reports. The number of respondents who disagreed with the use of prescribed fire (2–5% across groups) and rated prescribed fire smoke as not acceptable (0–4.5% across groups) was small, reflecting findings from previous studies (Blades *et al.* 2014; Engebretson *et al.* 2016). This subset of participants was less trusting of land managers, was less likely to believe that prescribed fire benefits wildlife habitat or reduces wildfire risk and was most likely to say that prescribed fire should not be used because of the smoke it produces.

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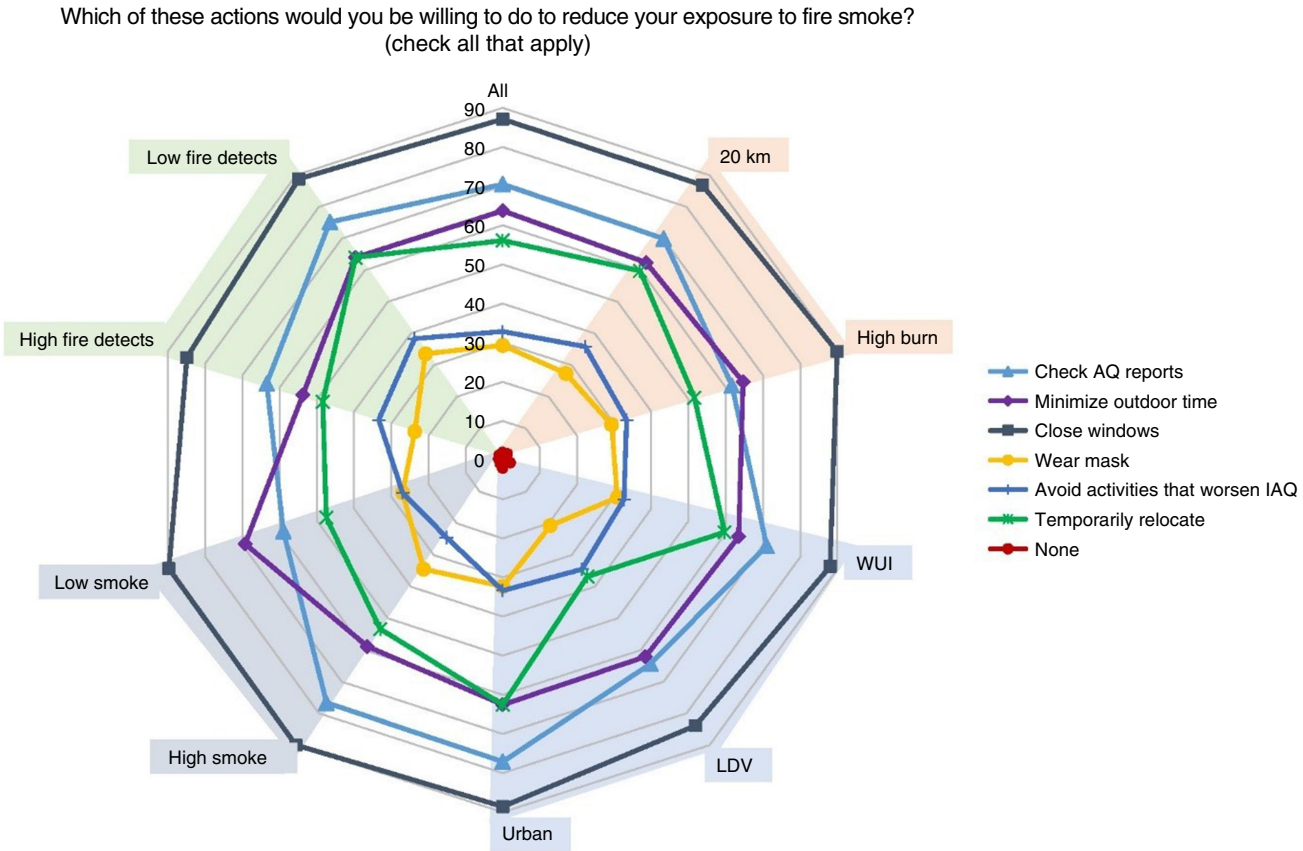

Fig. 5. Actions respondents are willing to take to reduce exposure to smoke among respondent categories. Participants could choose more than one response. Colored rings indicate the percentage of the respondent group that chose a statement and ring colors correspond to different statements. Gray rings show reference percentages. Shading indicates respondent category types. Note: WUI = Wildland–Urban Interface, LDV = low population density in vegetated areas, AQ = air quality, IAQ = indoor air quality.

Discussion and conclusions

Prescribed fire is regularly used in the Southeastern US, and decades of work have been undertaken to reintroduce fire to the region. The results of this study and prior research, find that awareness and knowledge of prescribed fire among Southeastern residents is high. However, smoke from a prescribed fire must be managed to minimize health risks and this requirement is perceived as a barrier by fire practitioners (Johnson and Garcia-Menendez 2025). Consideration of public perceptions of smoke and willingness to act is important to develop effective communication regarding prescribed fire and interventions to mitigate smoke exposure.

Here, we examined public perceptions of wildland fire and smoke in North Carolina and the influence of proximity to areas where fires (both natural and prescribed) had burned. Among study participants, we found high levels of acceptance, trust and general knowledge of prescribed fire activity in the state, in agreement with US Forest Service NSRE results for the Southern region (Bowker *et al.* 2008). Smoke from prescribed fire is widely seen by respondents as acceptable and of low concern, while smoke from wildfire is less acceptable and of greater concern. Respondents expressed a high willingness to take some form of action to reduce exposure to smoke, and a large percentage indicated they would check and follow guidance from air quality reports. Differences in perception among respondents were small but most evident among different land type classifications (WUI, LDV, Urban) and for respondents near NC State Parks with the most prescribed fire. This agrees with previous research findings that local practices and experiences related to wildland fire explain most location-based variations in perceptions (Brunson and Evans 2005; Bowker *et al.* 2008). In this analysis, average concentration of fire-related $PM_{2.5}$ does not show a significant relationship to perceptions of wildland fire and smoke. Similarly, prior research has found that previous experience with smoke-related health impacts did not relate to perceptions or acceptability of smoke (Olsen *et al.* 2017).

There are limitations to this study. Although we gathered responses from across the state, there are regions with little to no representation in our analysis and close to half of the responses came from residents living near NC State Parks. Sharing the survey through NC State Parks social media likely influenced responses by tying perceptions of fire and

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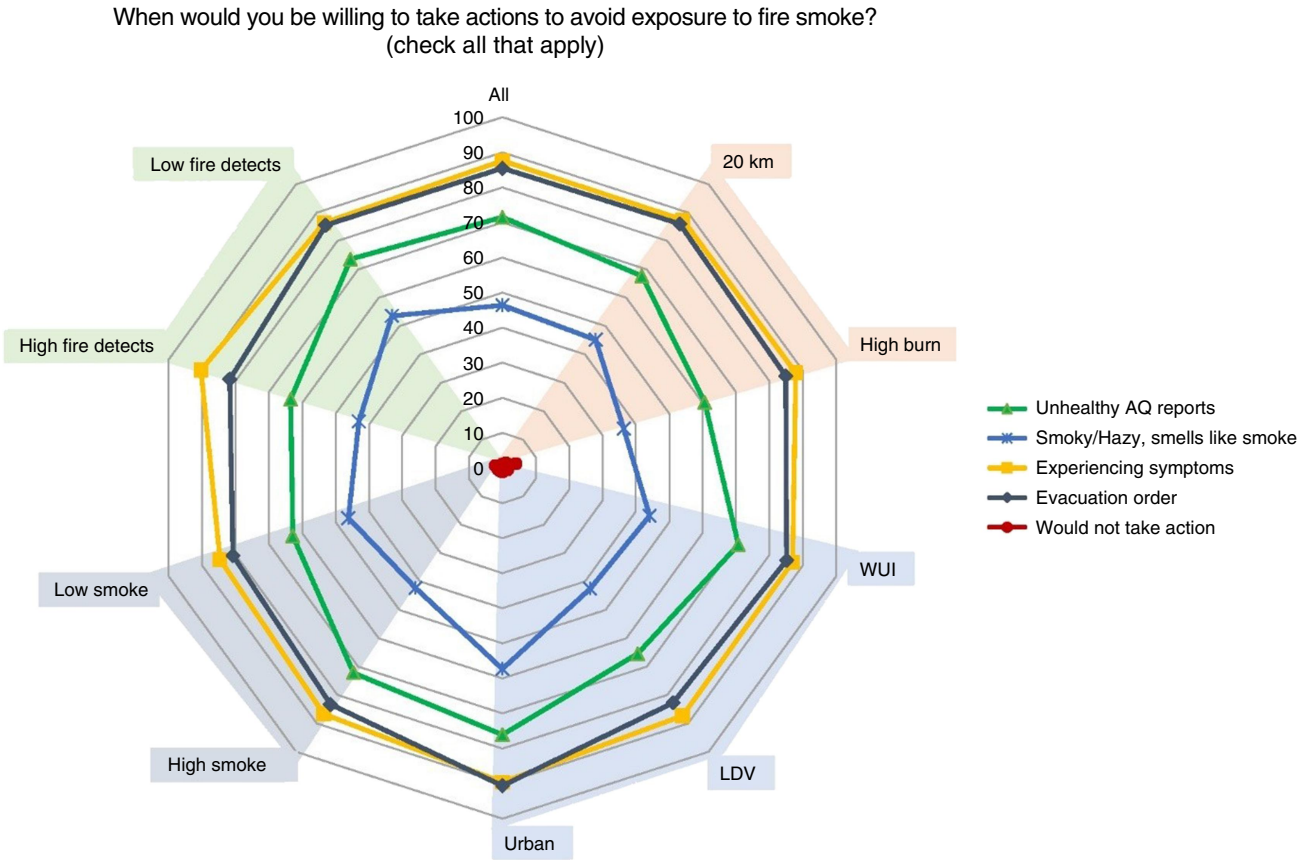

Fig. 6. Times at which respondents are willing to take action to reduce exposure to smoke. Participants could choose more than one response. Colored rings indicate the percentage of the respondent group that chose a statement and ring colors correspond to different statements. Gray rings show reference percentages. Shading indicates respondent category types. Note: WUI = Wildland–Urban Interface, LDV = low population density in vegetated areas, AQ = air quality.

smoke to perceptions of the NC Division of Parks and Recreation, but it also provides feedback relevant to the Division's operations and communications. Personal demographic or socioeconomic information was not required from survey participants and the collected responses are susceptible to bias. Therefore, the results should not be interpreted as a comprehensive representation of public perceptions across North Carolina's entire population. Instead, the analysis explores the relationships between acceptance of prescribed burning, concern about smoke exposure and willingness to take actions to mitigate that exposure among the study's 750 participants. While we used several years of satellite detections of fire activity to investigate proximity to wildland fire, this data does not discern between wildfire or prescribed fire or fire management programs beyond NC State Parks. Our analysis based on smoke forecast data suggests that smoke exposure does not influence perceptions of wildland fire and smoke among study participants, yet other data products, metrics and study populations may yield different results.

The findings of this study highlight several research needs. While prior research suggests that advisories can effectively mitigate public exposure to smoke (Rappold *et al.* 2014), data examining the willingness of the public to act is limited, typically focuses on wildfire smoke and has shown mixed evidence that messaging elicits behavior change (Fish *et al.* 2017; Marfori *et al.* 2020). Our analysis finds that most respondents are willing to take some form of action to reduce their exposure to smoke. However, the drivers most likely to elicit action may be unreliable to avoid health impacts. Acting when experiencing symptoms entails exposure high enough that a health response has already occurred. Moreover, we find that 70% of respondents here would be willing to act based on reports of unhealthy air quality, suggesting awareness of air quality alerts and willingness to follow air quality guidance. However, US EPA's Air Quality Index (AQI) considers air quality 'unhealthy' when the index exceeds 150, equivalent to a 24-h $PM_{2.5}$ concentration $\geq 55.5\ \mu g/m^3$. Further, recent research suggests that detrimental health impacts of smoke at lower but more frequent concentrations may be significantly larger than those associated with extreme concentrations (Henderson *et al.* 2024). Effective smoke interventions may require residents responding to air quality alerts at lower concentrations than currently considered 'unhealthy' (Rappold *et al.* 2014). Revised air quality messaging specific to smoke and fire type may be necessary (Haikerwal

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et al. 2015). The decrease in fraction of respondents willing to act based on air quality reports with increasing proximity to fire suggests that targeted outreach may be needed to reach residents in these areas, particularly given the effectiveness of communications from local sources (D'Evelyn *et al.* 2023). Greater proximity to fire activity is also likely associated with higher vulnerability to smoke in the Southeastern US (Rappold *et al.* 2017; Afrin and Garcia-Menendez 2021).

In this study, we find that most respondents recognize and are willing to take simple actions to mitigate smoke exposure (e.g. close windows, reduce time outdoors). The primary message to the public during smoke events is to remain indoors (U.S. EPA 2021). However, analyses of the indoor/outdoor fraction of $PM_{2.5}$ during wildfires suggests that the effectiveness of remaining indoors as an intervention is limited (O'Dell *et al.* 2023). Respondents also expressed low willingness to avoid activities that increase indoor pollution (e.g. vacuuming, burning candles). Low willingness to avoid activities that degrade indoor air quality may further impede the effectiveness of staying indoors as an intervention to reduce smoke exposure (Reisen *et al.* 2019). New interventions and strategies may be necessary to successfully reduce public exposure to smoke from prescribed fires.

This study and its data focus on the Southeastern US, a region with an extensive and long-standing history of prescribed fire use. Although prior analyses have reported regional variations in public perceptions of prescribed fire, they suggest that local practices are the strongest drivers of these differences and that key predictors of public acceptance remain consistent across regions (McCaffrey and Olsen 2012). As interest in expanding prescribed fire grows in regions where burning is less common, this study's findings can also support practitioners in other geographic areas. In particular, public communication efforts in areas with less familiarity with prescribed fire should integrate not only the benefits of the practice but also information about the risks of smoke exposure. Doing so may help address the diminishing concern about health impacts that accompanies increasing acceptance of prescribed fire, as observed in this study.

Public acceptance will be important to expand prescribed fire use, particularly if climate change reduces the frequency of meteorological conditions adequate for burning (Kupfer *et al.* 2020; Gao *et al.* 2021). Under the strengthened US National Air Quality Standard for $PM_{2.5}$, prescribed fire may additionally have a larger impact on compliance with air quality regulations. Communication and education will be key to establishing trust in practitioners and acceptance of increased prescribed fire. Addressing the smoke-related risks in communities will be needed as perceptions of fire, health risks and willingness to act may not align.

Supplementary material

Supplementary material can be accessed from the article page online.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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