CSIRO PUBLISHING

REVIEW
https://doi.org/10.1071/WF22025

International Journal of WILDLAND FIRE
International Association of Wildland Fire

More smoke today for less smoke tomorrow? We need to better understand the public health benefits and costs of prescribed fire

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Received: 3 March 2022
Accepted: 7 August 2022
Published: 2 September 2022

Cite this:
Jones BA *et al.* (2022)
International Journal of Wildland Fire
31(10), 918–926. doi:10.1071/WF22025

ABSTRACT

Rapidly scaling up the use of prescribed fire is being promoted as an important pathway for reducing the growing damages of wildfire events in the United States, including limiting the health impacts from smoke emissions. However, we do not currently have the science needed to understand how the health impacts associated with prescribed fire smoke in the present compare to wildfire smoke exposure in the future. In particular, we lack an understanding of how the potential long-term public health benefits of prescribed fire on future wildfire smoke and health impacts compare to prescribed fire's short-term effects on human health. Answering the question 'How do we learn to sustainably coexist with wildfire?' requires a new research agenda investigating the magnitudes and distribution of the health benefits and costs associated with prescribed burning. We suggest three areas for a new research agenda: (1) improved understanding of the health costs of prescribed fire; (2) quantification of the expected health benefits of prescribed fire through possible decreased future wildfire smoke emissions; and (3) better knowledge on the distributional impacts of prescribed fire smoke. We conclude that we need to first learn to sustainably coexist with prescribed fire in order to sustainably coexist with wildfire.

Keywords: benefits of prescribed fire, benefits-costs, human health, knowledge gaps, prescribed fire, public acceptability, smoke, wildfire, wildfire management.

Introduction

Prescribed fire (also termed prescribed burning), defined as the deliberate ignition of a controlled fire for achieving forest management objectives (NCWFMS 2014), is being touted as the primary 'solution' to wildfires in the United States (US) (e.g. USDA Forest Service 2022). While significant application challenges and risks remain (see Ryan *et al.* 2013; Association for Fire Ecology 2022), including reduced deployment opportunities due to climate change (Kupfer *et al.* 2020), the use of prescribed fire for management objectives has recently expanded, and significantly so (Melvin 2020). This has occurred in combination with other wildfire risk mitigation strategies such as mechanical thinning, home hardening and planning, and greater fire prevention and suppression. One challenge to prescribed fire that has received some limited attention is understanding the human health impacts of smoke exposure (e.g. Gaither *et al.* 2019; Prunicki *et al.* 2019; Jaffe *et al.* 2020; Afrin and Garcia-Menendez 2021). For example, limited comparisons of smoke-related health impacts of wildfires and prescribed fires have found higher health costs per acre burned for prescribed fires compared to wildfires (Navarro *et al.* 2018; Borchers-Arriagada *et al.* 2021). However, we still lack a comprehensive understanding about how the reduction in future wildfire smoke–health impacts compare to immediate smoke–health impacts of prescribed fire. Yet, efforts to substantially increase the scale of prescribed fire use are moving forward without acknowledging or addressing this substantial knowledge gap.

The US$1 trillion Infrastructure Investment and Jobs Act that was signed into law by President Biden in November 2021, committed US$500 million for prescribed fire use

over the next 10 years (Gabbert 2021). Elsewhere, Governor Gavin Newsom of California signed Assembly Bill 642 in September 2021 that establishes a state-wide prescribed fire training centre and signed Senate Bill (SB) 332 in October 2021 that provides legal protections for those who conduct prescribed burns in the state (Smith 2021). Both bills are intended to remove barriers surrounding prescribed fire use in California. The California Legislature also committed US$536 million in April 2021 for forest health restoration and fuel reduction programs, with a prominent focus on expanding the use of prescribed fire beyond recent historical levels (Myers 2021).

California is not unique. Other US states have implemented bills that encourage the expansion of prescribed burns. New Mexico's Prescribed Burning Act (March 2021), similar in nature to California's SB 332, reduces liability risks and makes it easier for private landowners to conduct prescribed burns; it also uses the funds generated from burning fees to help fund state certification and training about prescribed fire. This is consistent with economic models and simulations that support increased use of prescribed fire conditional on precautionary efforts to reduce potential risks (e.g. from escaped fire) (Yoder *et al.* 2003, 2004). Comparable policies that facilitate training and certification and limit liability in states like Florida, New Jersey, Colorado, Georgia, Texas, and South Carolina have increased the pace and scale of prescribed burning (Melvin 2020; Working Group Report to New Mexico Legislature 2020). Calls to expand legislation to encourage prescribed burns at both the local and national levels are being realised.

The fire science literature has also been one of the voices calling for more prescribed burning in US forests. Miller *et al.* (2020) says that prescribed fire is 'underemployed throughout California.' Similarly, Kolden (2019) argues that 'we're not doing enough prescribed fire' and, as a result, the best available fire science 'is not being adopted into management practices, thereby further compounding the fire deficit in the Western US'. Recently, Varner *et al.* (2021) stated that 'increased prescribed burning is needed to provide a diversity of public benefits' in US forests (and see Yoder *et al.* 2004). Echoing this sentiment, researchers at Stanford recently concluded that 'we need a colossal expansion of fuel treatments', noting that 'prescribed burns are effective and safe' (Stanford University 2020).

Momentum is building around expanding the use of prescribed fire. Yet, despite this momentum, there is actually very limited scientific attention being paid to prescribed fires and their impacts (Hiers *et al.* 2020). Most of the focus and attention is on wildfires, an uncontrolled fire that burns wildland vegetation, and not on prescribed burns. Hiers *et al.* (2020) report that wildfire-focused articles appear between 50 and 300% more often than prescribed fire articles in prominent fire-related academic journals and that awarded grants from the US Joint Fire Science Program are three times more likely to be awarded to research on wildfire compared to prescribed fire. In a similar spirit, Hunter and Robles (2020) state that there is a 'critical research need' due to 'scant' studies on how prescribed fire alters air pollution emissions of wildfire on treated lands. Since pollution emissions affect public health, with associated economic benefits and costs, an implication from this literature is that we simply do not fully understand how prescribed fire, through its effects on wildfire regimes, affects public health.

If prescribed fire is being promoted and scaled up, it seems prudent to invest more into understanding its full range of multidimensional impacts on society and landscapes. Along the way, we would expect additional complicated long-run dynamic social–ecological issues to emerge. For example, prescribed fire might begin to affect locational choices for people and development, in the same way that forest amenities and disamenities can (Hand *et al.* 2008).

We recognise there are many important issues related to the tradeoffs between prescribed fire and wildfire. However, we focus in this review on the dearth of scientific evidence on the smoke-related public health benefits and costs of prescribed fire. Our goal is not to provide a comprehensive review of the tradeoffs between prescribed fire and wildfire (see US EPA 2021 for a related in-depth treatment). Rather, we articulate an important gap in knowledge and lay out a potential research agenda to address that gap. Our main thesis, elaborated in the sections that follow, is that in the absence of improved knowledge on the human public health benefits and costs of prescribed fire, we cannot simply assume that prescribed burning's health benefits outweigh its costs, nor can we safely rely on this assumption to guide fuel management objectives. Rather, this is an open empirical question that deserves further scrutiny.

Prescribed fire and its impact on future wildfire emissions

Often underlying policy and scientific research in this area are variations on the theme that prescribed fires are 'safe and effective' (Stanford University 2020). We argue, specific to the safety component in terms of public health, that we simply do not know this to be true. Prescribed fire, like any fire, creates smoke, and smoke is a well known risk factor for various adverse health outcomes (Haikerwal *et al.* 2015; Price *et al.* 2016). Documented health impacts from smoke, whether from wildfire or prescribed burns, include all-cause mortality (Reid *et al.* 2016; Cascio 2018; Afrin and Garcia-Menendez 2021), respiratory diseases (Cascio 2018; Afrin and Garcia-Menendez 2021), asthma exacerbation (Cascio 2018; Huang *et al.* 2019), low birth rate and infant prematurity (Jones and Berrens 2021), and immune responses in children (Prunicki *et al.* 2019).

The salient question is how do these health risks compare to the potential long-term public health benefits of reduced wildfire activity and associated smoke–health impacts on

lands treated with prescribed fire? As economists, we view this problem as a classic dynamic benefit–cost tradeoff of more smoke today (from prescribed fires; 'a cost') for less smoke tomorrow (from wildfire; 'a benefit'). The problem becomes even more complex if one considers climate change (Kupfer *et al.* 2020) or cases of repeated prescribed fires on the same spot of ground as an eventual wildfire. But we largely ignore such complexities here in order to focus attention on the simple two-period smoke tradeoff of interest (today vs tomorrow). When framed this way, the relevant question becomes one of quantifying the potential future public health benefits of prescribed fire compared to its short-term costs on public health. At present, this benefit–cost question has not been fully considered. This is troubling as we scale up the use of prescribed fire without an evidence-based understanding of the implicit smoke–health tradeoffs being made.

We are not the first to grapple with this issue. Early work by the US Forest Service for the Columbia River Basin, by Ottmar *et al.* (1996), recognised the need for an improved understanding of the complex tradeoffs between smoke from prescribed fire and smoke from wildfire activity on treated lands. Quoting from their 1996 technical report, 'for air regulatory agencies to consider a substantial increase in prescribed fire emissions, it will be necessary to demonstrate that the program would reduce the total emissions from both wildfire and prescribed fire' (Ottmar *et al.* 1996, p. 24). They go on to recognise this as a potential barrier to public acceptability of prescribed fire, noting that '…the public must come to understand the complex tradeoffs between increased prescribed fire, inevitable wildfire, forest health, visibility impairment, and public exposure to smoke before this issue can be resolved' (Ottmar *et al.* 1996, p. 24). The worrisome tradeoffs are echoed in the results of their Wildfire/Prescribed Fire Tradeoff Model, which showed that while simulated prescribed fire produced a substantial reduction in the number of wildfire acres burned and associated wildfire smoke emissions in the Columbia River Basin, those emissions reductions were 'largely offset' by increases in prescribed fire emissions.

In the intervening period since 1996, this literature has matured, yet the focus has been primarily on the carbon dioxide (CO_2) emissions offsets of prescribed fire (e.g. Wiedinmyer and Hurteau 2010; Allen *et al.* 2013; Santana *et al.* 2016). Hunter and Robles (2020), who recently reviewed this literature in the context of CO_2 offsets, noted that mixed results have been found. Some studies have shown that reductions in wildfire smoke emissions can *more than offset* increased emissions from prescribed fire on the same lands, while other studies show *little or no offset* or troublingly, even a *negative offset*, meaning that prescribed fire emissions are larger than avoided wildfire smoke emissions in treated areas. In fact, the majority of studies Hunter and Robles (2020) reviewed showed no offset of prescribed fire on subsequent total emissions (wildfire + prescribed fire) and the evidence for wildfire emissions alone was equally divided between a positive offset (i.e. a decrease in wildfire emissions) and no offset at all. This literature urgently needs to be extended to include other air pollutants associated with fire smoke and human health (e.g. particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs)) to determine the dynamic tradeoffs between the public health effects of prescribed fire and wildfire. It would be prudent for investments in prescribed fire to be informed by understandings of whether more smoke today is associated with more, less, or equal amounts of wildfire smoke–health impacts later.

Work in this area continues to progress. A joint report released in September 2021 by the US EPA, US Forest Service, and US Department of Interior is the first significant attempt, to our knowledge, to compare prescribed fire and wildfire smoke–health impacts on treated lands (US EPA 2021). A key conclusion from the 438-page report is that while prescribed fire has public health risks, it is 'at a much smaller scale compared to wildfire.' The report also finds, for the two wildfire case study events examined in California and Oregon, that *hypothetical* prescribed fire, had it occurred on the lands later burned by these wildfire events, would have measurably reduced respiratory and cardiovascular smoke-related impacts by 40% in one case (the California fire), but with only negligible health impact reductions in the second case (the Oregon fire). While the results are interesting and are an important first step, the study is limited in its generalisability by focusing on only two case study wildfires, retrospectively, and by the fact that the modelled prescribed fires were only hypothetical (not observed). The unsettled question is how do the *realised* public health impacts of routine prescribed fire, employed as part of forest resource management objectives, compare to the *realised* public health impacts of subsequent wildfires on the same lands? Empirical work using observed and modelled emissions data and done at-scale (i.e. across many actual prescribed fire and wildfire events in the US and over many years) is needed. Despite its limitations, the US EPA (2021) report establishes an important precedent for the need to frame prescribed fire management in terms of tradeoffs: smoke today vs smoke tomorrow.

Public acceptability of prescribed fire smoke

Public acceptance of prescribed fire is often raised as a potential barrier to scaling up. The literature in this area has identified many factors (e.g. concerns about prescribed fires escaping, trust in the agency administering the prescribed fire) related to acceptability (McCaffrey *et al.* 2012; Ryan *et al.* 2013). However, few studies have directly addressed the acceptability of prescribed fire smoke. Brunson and Evans (2005) note that without public support, wide-scale implementation of prescribed fire is unlikely regardless of its efficacy at reducing fuels. Further, long-term public support is necessary for sustained prescribed burning efforts needed to

provide long-term ecological benefits (Mylek and Schirmer 2020). Brunson and Shindler (2004) found that survey respondents across select areas of the western US largely assessed prescribed fire as a legitimate tool and considered it an effective technique for reducing fuels. However, most respondents expressed concerns about the increased levels of smoke. Weisshaupt *et al.* (2005) found that focus group participants thought they would be more tolerant of prescribed fire smoke if it reduced the amount of smoke from wildfires. This suggests that members of the US public view prescribed fire acceptability through a lens of smoke tradeoffs.

Work by Blades *et al.* (2014) found residents in the Northern Rocky Mountains and the south-central US to be generally tolerant of smoke from prescribed fire. However, study participants that had experienced adverse health effects from forest fire smoke were less tolerant of prescribed fire (Blades *et al.* 2014; Engebretson *et al.* 2016). Further, Lim 2009 found that African American and Hispanic study participants expressed higher levels of concern about prescribed fire smoke compared to White study participants. Lim *et al.* (2009)'s result is consistent with recent research that has begun to examine the disproportionate effect of wildfires on communities of colour (Liu *et al.* 2017; Davies *et al.* 2018). An important component of future research on prescribed fire could examine the distribution of health effects across under-represented and marginalised groups. An important research question should be: will there be disproportionate health impacts on different racial, ethnic, and low-income populations related to prescribed fire smoke exposure?

The limited research on the social acceptability of prescribed fire smoke does not provide strong evidence of widespread public concern about prescribed fire smoke exposure. However, that should not be interpreted as evidence of support. There is some documentation that experience with prescribed fire smoke exposure may diminish acceptability (Blades *et al.* 2014; Engebretson *et al.* 2016). It is possible that increases in prescribed fire smoke exposure, coupled with continued wildfire smoke exposure, will not be tolerated by the public. Or that it will be well-tolerated only in some places and by some populations. Additional research could help understand place-specific social acceptability of prescribed fire smoke and how that varies across diverse populations. Being able to articulate smoke tradeoffs to the public (e.g. more smoke today for a lot less smoke tomorrow) with evidence-based research using the best science available, will be important for fostering social acceptance of the expansive use of prescribed fire.

A new research agenda

Better scientific understanding of the dynamic public health tradeoffs of prescribed fire, and its expected distribution across people and places, becomes critically important as its use is significantly expanded. Fig. 1 presents a stylised depiction of two time periods. The figure could be extended to include more complex situations of repeated prescribed fires on the same landscape (across multiple periods), but we focus on the simpler two-period problem here for illustration purposes. The short-term (Time = 0) health impacts of exposure to smoke from prescribed fire need to be better understood and communicated, especially in areas that are already dealing with unhealthy levels of air pollution, in populations with co-morbidities, and in areas that may be routinely subject to smoke from prescribed burns. More challenging to understand, yet equally important, are the long-term (Time = 1) impacts of prescribed fire on future wildfire intensity, smoke emissions, and associated health impacts. It is important to understand the extent to which prescribed fire can result in lower intensity wildfire (i.e. moving from high- to low-intensity wildfire) and the impacts of this movement on smoke emissions and human health impacts and costs. This will help us obtain improved knowledge on the economic public health net benefits of prescribed fire. In particular, establishing a basis of understanding for whether the net health benefits of prescribed fire are, on average, positive, negative, or zero, as represented in Fig. 1, is critical while recognising that such net benefits may be context and place specific. In the absence of greater understanding, we cannot simply assume that the health benefits of prescribed fire outweigh their costs, nor can we rely on this assumption to guide fuel management objectives. Rather, it is necessary for the net health benefits of prescribed fire to be quantified in order to provide evidence-based guidance for forest management and public acceptability of prescribed fire activity.

To expand upon the key tradeoffs in Fig. 1, we present several potential research questions of interest in Fig. 2, which can aid in establishing a new research agenda or roadmap on the net health benefits of prescribed fire. Fig. 2 focuses on three research areas: (1) health costs of prescribed fire; (2) expected health benefits of prescribed fire through future wildfire smoke emissions; and (3) distributional impacts of smoke exposure. We discuss each research area in more detail below.

Health costs of prescribed fire

While much progress has been made on understanding the health impacts and costs of smoke exposure from prescribed fire (e.g. Haikerwal *et al.* 2015; Huang *et al.* 2019; Afrin and Garcia-Menendez 2021; Jones and Berrens 2021), there are several continuing questions of interest (see Fig. 2). In particular, what are the totality of smoke–health impacts of prescribed fire and how do they compare to wildfire? Also see Williamson *et al.* (2016) for a similar call. What actions do members of the public take to avoid exposure to prescribed fire smoke and how might improved information affect public acceptability of prescribed fire? Could prescribed fire management be adjusted (e.g. location, timing)

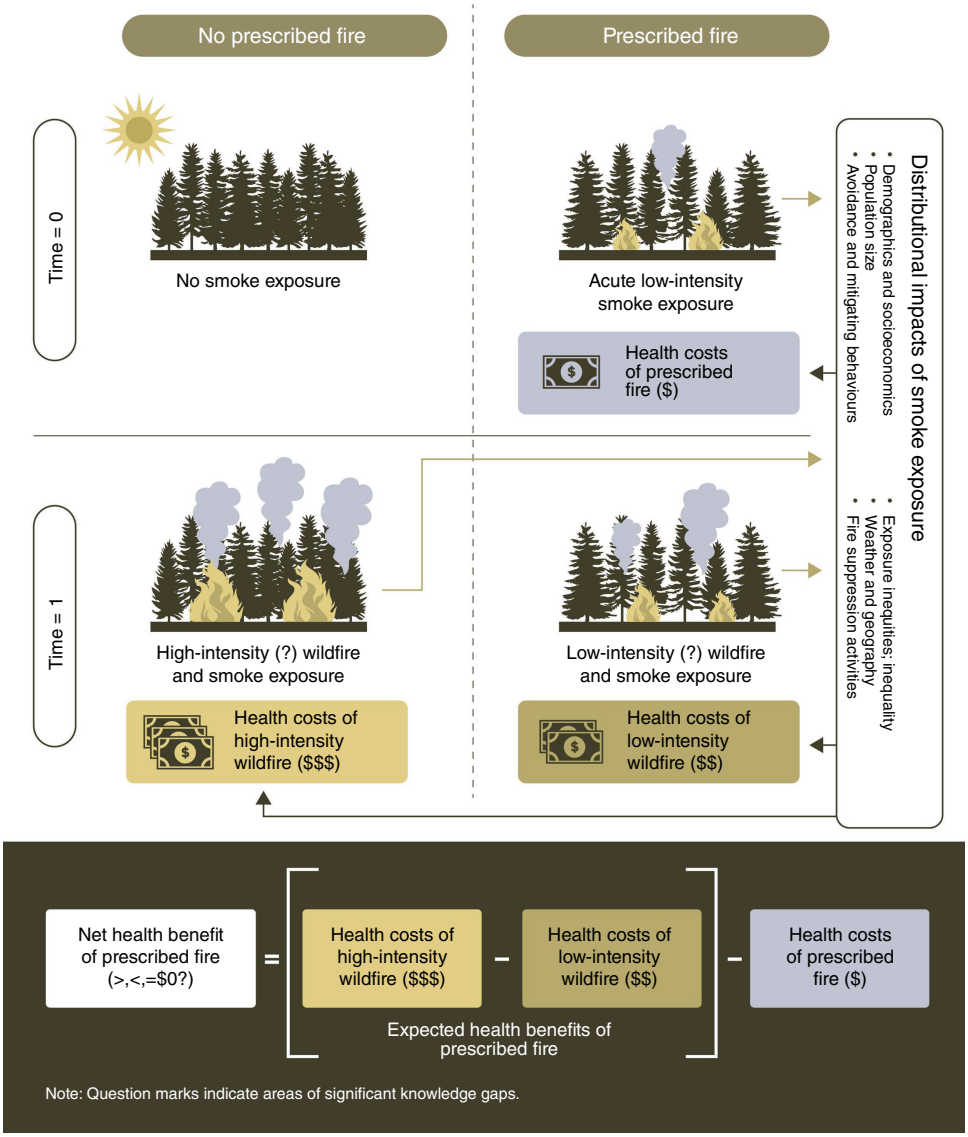

Fig. 1. Public health benefit-cost tradeoffs of prescribed fire. Notes: Only smoke-related health impacts included here. Fire suppression activities only applicable for uncontrolled wildfires. Distributional impacts of smoke exposure will likely be heterogeneous across different fire types and severity levels.

to reduce smoke–health impacts? See Liu *et al.* (2009) as one example of how the start and end times of prescribed fire can be impactful. These questions are important because as more fire is intentionally added to the landscape, understanding its associated economic costs and impacts becomes urgent. Of particular note, work that seeks to better understand public avoidance and mitigating behaviours to prescribed fire smoke, including the role of information availability and scientific communication, may be especially fruitful as we improve our knowledge on potentially effective strategies to reduce the health costs of prescribed fire.

Expected health benefits of prescribed fire

Our main thesis is that there is an implicit public health benefit–cost tradeoff of prescribed fire: more smoke today for less smoke tomorrow. In particular, research investigating the expected health benefits of prescribed fire, defined in Fig. 1 as the difference between the health costs of high- and low-intensity wildfire, is needed and urgently so. To address this research area, several key lines of inquiry should be continued and expanded (see Fig. 2). What are the impacts of prescribed fire on future wildfire smoke emissions, health impacts, and health costs on treated lands? Also see Penman *et al.* (2011) for a related set of questions. Under what circumstances can prescribed fire result in low-intensity wildfire (vs high-intensity wildfire on untreated lands)? See Fernandes and Botelho (2003) for an early discussion on this topic. What are the differences in smoke profiles and health impacts between low- and high-intensity wildfire? Will greater understanding and improved communication of the net benefits of prescribed fire improve public acceptability? In the absence of improved answers to these questions, we cannot assume that the health benefits of prescribed fire outweigh their costs or that experiencing more smoke today will necessarily mean experiencing less smoke tomorrow. To this

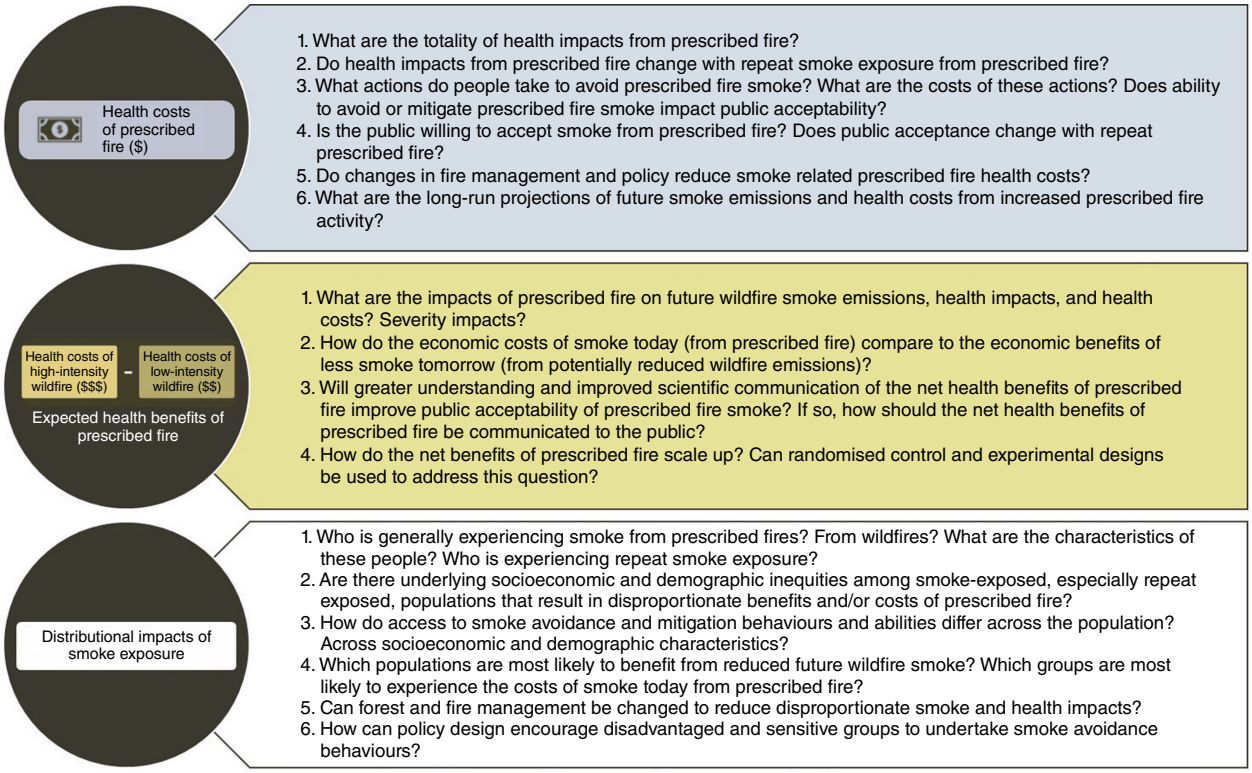

Fig. 2. Potential research areas for improved understanding of the public health benefit-cost tradeoffs of prescribed fire.

end, we cannot emphasise enough the need for research to quantify the public health benefit-cost tradeoffs of prescribed fire as its use is significantly scaled up.

The issue of successful scaling is also paramount to any policy intervention tool. The emergent field of implementation science raises inherent problems connected to significantly scaling policy interventions. For example, estimating the effects of scaling requires understanding how health cost and benefit functions change over varying sizes, including negative side effects from unintended consequences or behavioural responses, and accurately representing affected populations (see List 2022*a*, 2022*b*).

Distributional impacts of smoke exposure

Environmental justice and distributional considerations of the public health benefits and costs of prescribed fire must be further studied. Gaither *et al.* (2019) provide a recent example of this type of work, by studying prescribed fire smoke exposure among African Americans. Other research is also emerging (e.g. Afrin and Garcia-Menendez 2020, 2021; Kondo *et al.* 2022) but there remain significant opportunities for expanded efforts. More broadly, who is generally experiencing smoke from prescribed fires? Are underlying socioeconomic and demographic inequities leading to disproportionate public health benefits and costs of prescribed fire? Are different populations expected to experience prescribed fire smoke compared to those who are expected to reap the benefits of future wildfire smoke reductions? How does repeated exposure to smoke impact the answers to these questions? Similarly, how does repeated exposure to smoke from prescribed burns affect migration (i.e. among those with the resources to move)?

An important component to understanding disproportionate impacts includes better studying the ability of individuals to access smoke mitigating opportunities (e.g. access to air purifiers and knowledge of proper use, access to information about how to seal homes from smoke, ability to access clean air spaces, and access to employment that allows individuals to stay indoors). Addressing access concerns also requires simultaneously answering the question: what role can fire management policy have in mitigating disproportionate smoke–health impacts?

Improvements in wildfire and smoke modelling, data collection, and surveys of affected populations will help address these questions. For example, being able to accurately predict the smoke emissions and dispersion of a prescribed fire could aid in the development of early warning systems targeted at disadvantaged and health-sensitive populations.

Discussion and conclusions

To be clear, we have not attempted a fully-synoptic review of the current state of knowledge about prescribed fire (where we instead might point the reader to US EPA 2021). Further, our focus is centred on smoke-related public

health effects, where we have identified a significant gap in our understanding: the scientific community does not know enough about the human health costs and importantly, the human health benefits of prescribed fire. This knowledge gap especially becomes a concern on the precipice of efforts to massively scale up fire prescriptions as a wildfire risk mitigation tool. The emergent field of implementation science (see List 2022*a*, 2022*b*), and the inherent challenges of scaling policy interventions, points to the critical need for a purposeful research agenda.

We structure an initial attempt at a potential research roadmap, and hope that it spurs additional discussions to help coalesce a full research agenda. Pursuing such an agenda will require transdisciplinary collaborations between researchers in public health, epidemiology, forestry, fire science, economics, public policy, public administration, and related fields. It may also need to involve the use of backwards induction from greatly rescaled fire prescriptions in the large, and not just evidential inference from the local. Importantly, researchers, forest planners, and prescribed fire practitioners should work in partnership to develop relevant research questions and identify programmatic and policy priorities based on scientific evidence that is inclusive of public health and social equity considerations. Federal and state governments could help support research on the social costs of prescribed and wildfire smoke exposure, and develop programs based on the best available science and knowledge about scaling policy implementation.

Ours is not an argument against the use of prescribed fire, but rather is an argument for science-based evidence and analyses on the economics of health impacts of smoke. Answering the question 'How do we learn to sustainably coexist with wildfire?' (e.g. see NCWFMS 2014) will require a new research agenda focused on the magnitudes and distribution of health benefits and costs associated with our efforts to prevent and reduce future wildfire severity using prescribed fire. That is, we may need to first learn to sustainably coexist with prescribed fire in order to sustainably coexist with wildfire.

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Data availability. No data were collected or used in the writing of this manuscript.

Disclaimer. The findings and conclusions in this article are those of the authors and should not be construed to represent any official USDA or US Government determination or policy.

Conflicts of interest. The authors declare no conflicts of interest.

Declaration of funding. This research did not receive any specific funding.

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