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Barriers and opportunities for implementing prescribed fire: lessons from managers in the mid-Atlantic region, United States

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Abstract

Background Prescribed burning is a beneficial fire management practice used by practitioners worldwide to meet multiple land management objectives, including reduction of wildfire hazard, promotion of biodiversity, and management of vegetation for wildlife and human interests. Meeting these objectives can be difficult due to the need for institutional coordination, resource and policy constraints, and community support. We examined these dynamics in the United States' mid-Atlantic region because prescribed fire use is increasing in the region to meet a broadening set of land management objectives. Managers are at the frontlines of these challenges and hold significant experience and knowledge for enhancing wildland fire management policy and strategy. Towards better leveraging this insight, we conducted focus groups with fire managers in land management agencies in the region to identify managers' perceived barriers and opportunities for implementing prescribed fire.

Results We found manager perceptions to be hierarchical, with barriers and opportunities expressed across landscape, community, and individual levels. Limited institutional coordination across landscapes was seen by managers as an opportunity for expanding prescribed fire implementation, whereas coping with shared fear or stress about burning among individual managers or individual community members was seen as a significant barrier. Yet, despite different prescribed burning histories and policies at the state level, barriers and opportunities were similar among managers in the mid-Atlantic region.

Conclusions Managers in the mid-Atlantic region confront barriers to prescribed fire use but are also uniquely positioned to recognize opportunities to enhance its implementation. This work sheds light on these barriers and opportunities, revealing that managers desire greater opportunities for landscape-level fire planning and coordination across agencies as well as greater opportunities for community engagement and interpersonal trust-building within complex social-management networks. Manager perspectives from the mid-Atlantic provide lessons for other regions across the globe grappling with new or broadened land-management strategies that include beneficial fire use.

Keywords Prescribed fire management, Pennsylvania, New Jersey, Maryland, Mid-Atlantic, Landscape, Focus groups, Beneficial fire, Social acceptance, *Pinus rigida*, *Quercus*

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Resumen

Antecedentes Las quemas prescriptas son prácticas de gestión del fuego usadas por expertos alrededor del mundo para alcanzar objetivos múltiples de manejo, incluyendo la reducción del peligro de incendios, la promoción de la biodiversidad, y el manejo de la vegetación para la vida silvestre y los intereses humanos. El lograr esos objetivos puede ser dificultoso debido a la necesidad de coordinar instituciones, y restricciones en cuanto a recursos, políticas, y el apoyo de la comunidad. Examinamos estas dinámicas en la región meso- Atlántica de los EEUU dado que las quemas prescriptas se están incrementando en la región para alcanzar un amplio conjunto de objetivos en el manejo de tierras. Los gestores están en la frontera de ese desafío y tienen suficiente experiencia y conocimientos como para mejorar las políticas y estrategias en el manejo de fuegos de vegetación. Para lograr un mejoramiento de este conocimiento, condujimos grupos focales con gestores de fuegos en agencias de manejo de tierras de la región para identificar las barreras y oportunidades que ellos percibían para aplicar las quemas prescriptas.

Resultados Encontramos que las percepciones de los gestores de recursos son del tipo jerárquicas, con barreras y oportunidades expresadas a través de niveles de paisajes, comunidades, e individuos. La limitada coordinación institucional a través de diferentes paisajes fue percibida por los gestores como una oportunidad para expandir la implementación de las quemas prescriptas, mientras que el ajustarse a temores o estreses compartidos sobre las quemas entre gestores de manera individual o comunitaria fue señalado como una barrera significativa. Aun así, a pesar de las diferentes historias y políticas de quemas prescriptas a nivel de los diferentes estados, las barreras y oportunidades fueron similares entre gestores de fuegos en toda la región meso-Atlántica.

Conclusiones Los gestores de incendios en la región meso-Atlántica se enfrentan a barreras contra el uso de las quemas prescriptas, pero también están posicionados de manera única como para mejorar su implementación. Este trabajo arroja luz sobre esas barreras y oportunidades, revelando que los gestores de recursos desean mayores oportunidades para el planeamiento de quemas a nivel de paisaje, la coordinación entre agencias, el involucramiento de la comunidad y la construcción de confianza interpersonal dentro de una compleja red de social y de gestión. Las perspectivas de los gestores de la región meso-Atlántica proveen de lecciones para otras regiones alrededor del globo y fortalecen nuevas y más amplias estrategias de manejo de tierras que incluyen el uso benéfico del fuego.

Background

Prescribed fire is a critical land management tool used in fire-adapted ecosystems worldwide for mitigating wildfire hazards and improving ecological resilience by regulating plant successional dynamics, nutrient cycling, and biodiversity (Hiers et al. 2020; McLauchlan et al. 2020; Ryan, Knapp, and Varner 2013). However, its use has been hindered by a range of operational, environmental, and social constraints (Quinn-Davidson and Varner 2011; Schultz et al. 2019). For example, the 2022 pause on prescribed fire management on federal forest lands in the United States (US) (US Forest Service 2022) in the face of escalating wildfire risks called to question the sustainable integration of prescribed fire as part of a comprehensive national land management strategy. On the other hand, prescribed fire is recognized to be a more flexible and cost-effective approach than other treatment options for managing or restoring fuel conditions, reducing wildfire severity (Harris et al. 2021; North et al. 2012), and a tool to promote ecosystem resilience, enhance biodiversity, and mitigate social costs related to unmanaged wildfire (e.g., property or infrastructure damage) (Ryan, Knapp, and Varner 2013). In addition, the use of prescribed fire is foundational to many traditional and Indigenous land management practices that have long-used beneficial fires; and the practice of burning is deeply interwoven into cultural stewardship, livelihoods, and identity across the US (Lafon et al. 2017; Lake et al. 2017). However, familiarity with prescribed fire as a sustainable land management practice is variable across communities in the US, leading to uneven social acceptance (Paveglio and Edgeley 2023; Wu et al. 2022). We expected that managers are in an important position, through day-to-day interactions with communities, policies, and natural resource environments, to characterize contemporary barriers and opportunities for successfully implementing prescribed fire as a land management practice. Characterization of these opportunities and barriers may help guide more effective and sustainable prescribed fire management practices.

It is increasingly recognized that fire management should, where possible, incorporate human values and attitudes (Bright, Newman, and Carroll 2007; Gamboa et al. 2023), coordinate activities in the context of social and organizational networks (Fischer et al. 2016; Higuera et al. 2019), and consider fire as a component of a complex and dynamic human-natural system (Smith et al. 2016). In the case of wildfire management strategies, specifically, social attitudes and beliefs about perceived forest management outcomes can depend on factors

such as trust in the agencies conducting the activity (see, for example, Mickler et al. 2013; Schindler et al. 2014; McCaffrey 2015; McCaffrey et al. 2013; Paveglio and Edgeley 2023). Moreover, differences in governance and social networks, communication strategies, and fire exposure are variable within and across communities, which may influence social attitudes toward fire management (Dickinson et al. 2015; McGrath Novak, McCaffrey, and Schultz 2023; Mylek and Schirmer 2019; Qin 2015; Wu et al. 2022). An understanding of community characteristics can be used to help guide engagement practices (Carroll and Paveglio 2016). However, communities are embedded within spatially variable landscapes (Fig. 1) that exhibit heterogeneous patterns of fire histories, forest characteristics, social vulnerabilities, and management structures that need to be considered simultaneously (Gould et al. 2023).

This study focuses on opportunities and barriers as perceived by managers in the mid-Atlantic region of the US for several reasons (Fig. 1). First, the wildland urban interface (WUI) is extensive (e.g., Pennsylvania is ranked 5th nationally in the number of houses within WUI) (US Fire Administration n.d.), and unlike in the western US where tracts of public ownership tend to occupy large contiguous areas, land ownership and management networks are intermingled at a fine scale across most of the region (Drummond and Loveland 2010; Radeloff et al. 2018). As a result, forest management with prescribed fire is likely to carry higher risks, such as smoke exposure to nearby communities (Clark et al. 2020), and to require substantial coordination and planning by managers.

Second, although wildfires are infrequent due to the generally moist climate across the region, wildfire hazard can be moderate or high due to a predominance of human ignition and highly flammable forest types, such as the pitch pine (*Pinus rigida*) forests in southern New Jersey. Moreover, dendrochronological evidence points to much higher fire frequency in some areas across the region in the past, before implementation of fire suppression in the early twentieth century (Brose et al. 2015; Howard et al. 2021; Stambaugh et al. 2018). The recent exposure of millions of people in the eastern US to wildfire smoke from the 2023 Canadian fires may be a harbinger of changing public concern or attention to

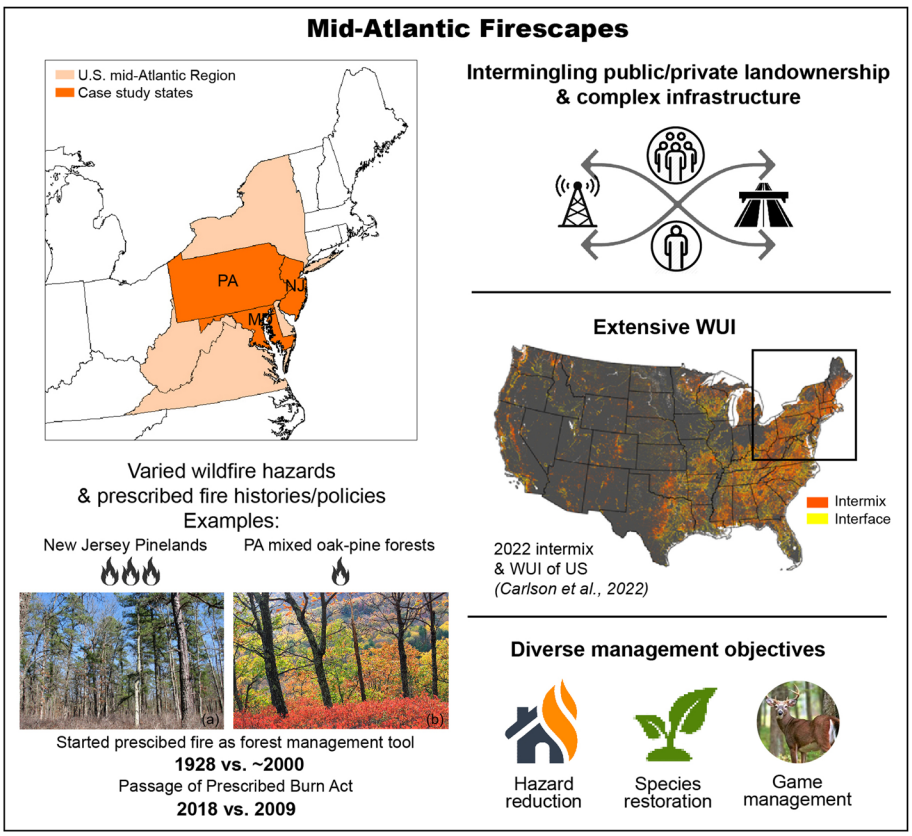

Fig. 1 Firescapes in the mid-Atlantic. Firescape in the mid-Atlantic is characterized by varied wildfire risks, intermingling public/private land ownership and complex infrastructure, extensive WUI (Carlson et al. 2022), and diverse management objectives. (Photo source: **a** https://www.flickr.com/photos/bobistraveling/4474922946; **b** https://www.flickr.com/photos/iip-photo-archive/31366298617; Creative Commons license)

fire, and fire risk is projected to increase under climate change (Kerr et al. 2018; Robbins et al. 2024), making the understanding of current barriers and opportunities essential for developing policy and strategies for expanded prescribed fire use.

Third, across the mid-Atlantic, prescribed fire use is not primarily motivated by fire hazard reduction but by other factors such as restoration of fire-dependent species, creation of wildlife habitat, and game management (US Forest Service 2000; Norman et al. 2004; Clark et al. 2014). This mix of objectives for implementing prescribed burns differs across agencies and ecosystems. For example, in New Jersey, in addition to fire hazard reduction, there is a long history of intentional burning on private land for cranberry production. Concern about individual species such as the Regal fritillary (*Speyeria idalia*) or Barren's Buck Moth (*Hemileuca maia*) or undesirable invasive plants (e.g., Japanese barberry *Berberis thunbergii* DC.) can further guide burn operations with different priorities across agencies. As a result, the barriers and opportunities perceived by managers are unlikely to be homogeneous within this region and may differ substantially from managers in regions where wildfire hazard reduction is the primary objective of prescribed fire use.

Finally, while 70% of prescribed burning occurs on state lands across the US (National Interagency Fire Center 2024), in Pennsylvania and New Jersey that number is close to 100% (Fig. 2), making state-level policies highly relevant to prescribed fire use. However, there is considerable variability in the evolution of prescribed fire policies and implementation in the region, making it possible to characterize manager perceptions in the context of state-level drivers in a relatively small area. For example, the New Jersey Forest Fire Service (NJFFS) is responsible for fire management in New Jersey, and there is a long history of wildfire suppression and prescribed fire use in the New Jersey Pinelands National Reserve's 445,000 hectares of upland and wetland forest. Recent policy changes have increased the flexibility of burn operations to include objectives beyond fire hazard reduction (Senate and General Assembly of the State of New Jersey 2018). In contrast, Pennsylvania's prescribed burn program began in 2009 following the 2009 Prescribed Burning Practices Act (Pennsylvania General Assembly 2009) and is coordinated by several state agencies, including the Pennsylvania Game Commission and the Bureau of Forestry. These historical differences in prescribed fire policy are reflected in the greater number of hectares burned each year in New Jersey compared to Pennsylvania and the uptick in area burned in Pennsylvania since 2009 (Fig. 2). Understanding manager perspectives in this context of past policy and practice provides opportunities for sustainable prescribed fire implementation more broadly.

Our previous research evaluated community perspectives and environmental effectiveness of prescribed burning in the region. Dems et al. (2021) used postfire field surveys to show that prescribed burning modified vegetation composition and structure and promoted the establishment of fire-adapted species such as oak and hickory, up to eight years following prescribed fire. Through modeling, Zhao et al. (2021) extended this analysis and forecasted oak-pine persistence under routine burning, although this work identified tradeoffs with other ecosystem services (e.g., carbon storage) at high-frequency fire-return intervals. Miller et al. (2020) and Wu et al. (2022) examined forest user perceptions of prescribed burning with a quantitative online survey of hunters and recreationalists, respectively, showing high levels of social acceptance of burning. Additionally, Wu et al. (2022) identified that the reasons underlying perceived benefits or tradeoffs differed between managers and recreationists. Other research in the region has shown acceptance for prescribed fire on private lands (Regmi, Kreye, and Kreye 2024). However, to date, no research has comprehensively examined the specific challenges facing managers in the region, despite increasing social and environmental motivations for prescribed burning expansion.

In this context, we asked how do fire managers characterize the barriers and opportunities for prescribed fire management in the mid-Atlantic? Despite recent policy shifts that enable greater use of prescribed fire, and despite recent evidence of growing support (Wu et al. 2022; Miller et al. 2020; Regmi, Kreye, and Kreye 2024), we expected that managers would perceive community acceptance as a continued challenge for successful prescribed fire use (Toman et al. 2014; Wu et al. 2022; McGrath Novak, McCaffrey, and Schultz 2023). However, we expected that barriers and opportunities would be perceived differently among states with different histories of prescribed fire implementation and policies. For example, we anticipated perceived barriers to be higher in Pennsylvania, given that expanded prescribed burning only began in 2009 and where communities have had little exposure to fire management. In contrast, we anticipated barriers to be lower in the pine barrens region of New Jersey and in Maryland, where community exposure to prescribed fire and wildfire has had a longer history. In summary, these states encompass a population of 28.4 million (US Census Bureau 2023) and are in an area of emerging and/or expanding prescribed fire use representative of regional trends.

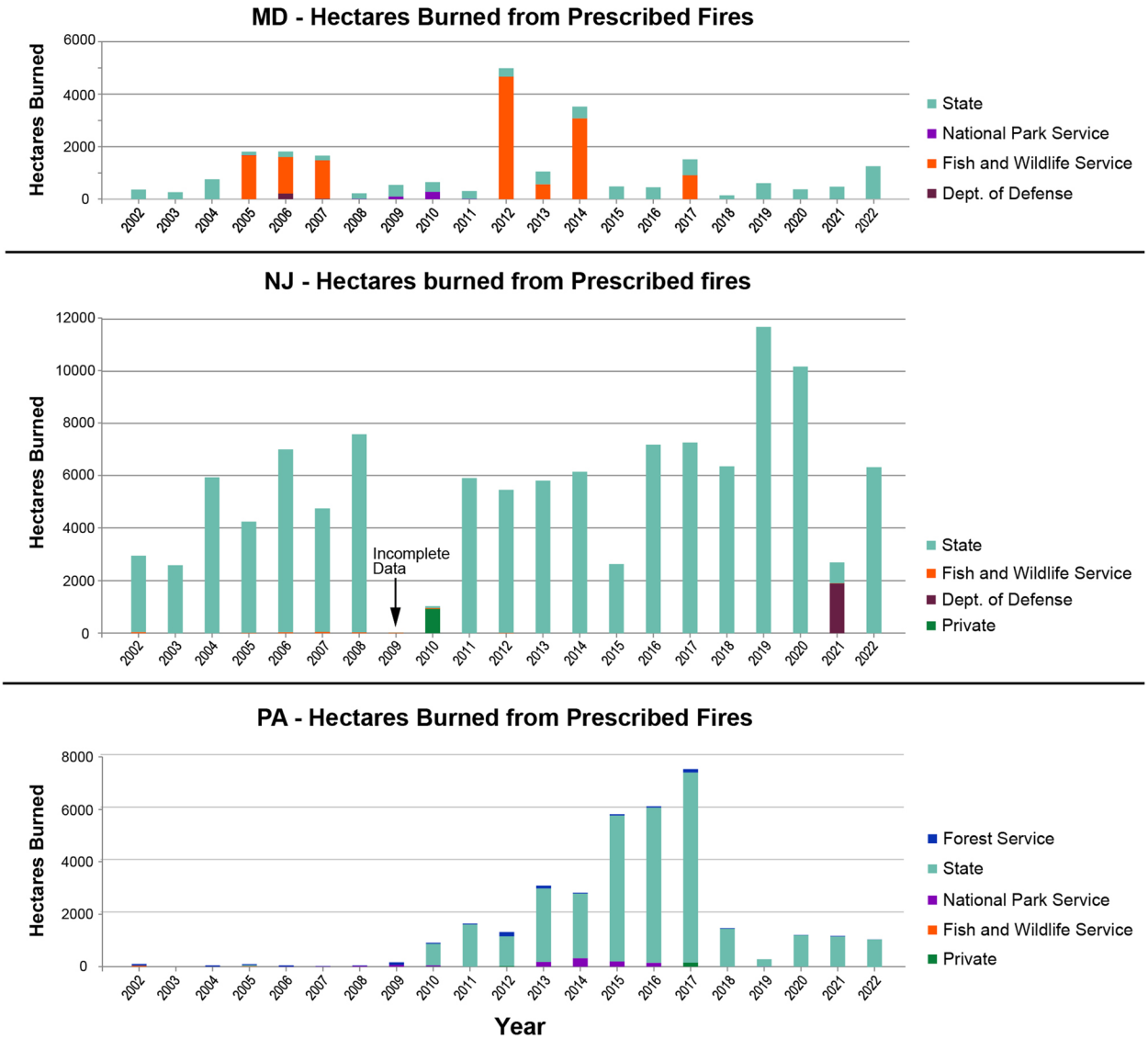

Fig. 2 Annual burned area. Annual hectares (ha) burned from prescribed fires in Maryland (top), New Jersey (middle), and Pennsylvania (bottom) between 2002 and 2022 across land ownerships. State (light green) refers to area managed by state agencies; other colors represent lands managed by federal agencies (orange or purple) or are privately owned (dark green)

Methods

Study area vegetation

Here we focus on prescribed burn management in the mid-Atlantic region that represents a gradient of fire-associated forest vegetation types (Fig. 3). At the northern extent, forest fire activity is limited by cooler and wetter climates and less flammable northern hardwood maple-beech-birch (*Acer* spp.–*Fagus* spp.–*Betula* spp.) forests. At the southern extent, a warmer climate, periodic droughts, and fire-adapted oak-pine (*Quercus* spp.–*Pinus* spp.) forests support higher fire activity. Across the region, variability in latitude, elevation, and climate leads to heterogeneous forest types and a range of fire activity from fire-adapted scrub oak-pitch pine forest (*Q. ilicifolia* Wangenh–*P. rigida* P. Mill) communities to xeric mixed oak-hickory forests (*Quercus* spp.–*Carya* spp.) to mesic northern hardwoods to marsh grasslands (e.g., *Spartina* spp.) in the eastern Maryland shore. Heterogeneity in forest type results in variable objectives and tactics for implementing prescribed burns based on species composition and seasonal climate patterns. A history of fire suppression, deer grazing, canopy defoliation and mortality by pests and pathogens, notably legacy effects from loss of American chestnut from chestnut blight, has markedly

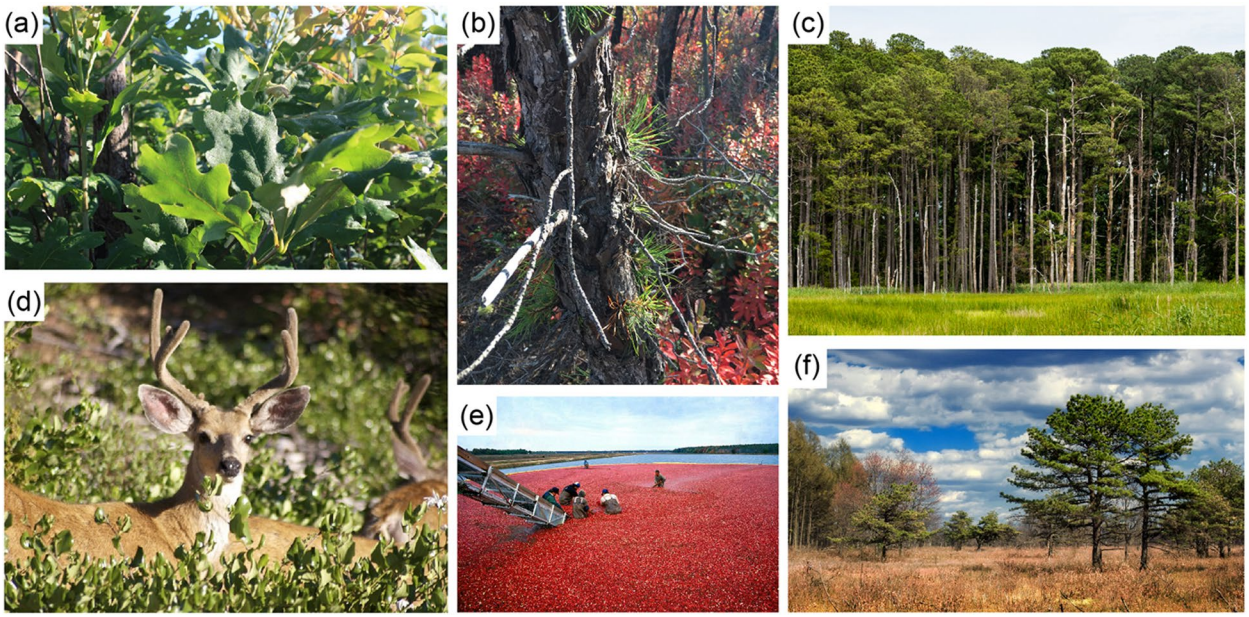

Fig. 3 Typical ecosystem characteristics. Study area of the mid-Atlantic includes oak (**a**) and pine (**b**, **c**) forested ecosystems of Pennsylvania, New Jersey, and Maryland and associated social drivers of prescribed fire management, including game management (**a**), cranberry farming (**e**), and ecosystem restoration (**f**). (Photo source: **a** and **b** Authors; **c** https://www.flickr.com/photos/chesbayprogram/48179938472/in/photostream/; **d** https://boudewijnhuijgens.getarchive.net/amp/media/deer-bucks-stag-animals-85bb0f; **e** https://picryl.com/media/cranberry-harvest-in-new-jersey-978660; **f** https://www.flickr.com/photos/nicholas_t/17155329217; **c**–**f** all under creative commons license)

changed the forest composition of the region, reducing the regeneration of oaks and other fire-tolerant species in favor of more mesic forest communities. Understory fuels include ericaceous shrubs (Mountain Laurel, *Kalmia latifolia* L.) and rhododendron (*Rhododendron* spp. L.), dense ferns (e.g., hay-scented fern, *Dennstaedtia punctilobula* Michx. and bracken fern, *Pteridium aquilinum* L.), as well as invasive plants such as Japanese barberry (*Berberis thunbergia*) and Japanese stiltgrass (*Microstegium vimineum*).

Focus group description

Use of focus groups is a commonly applied approach to involve community members in research on decision-making in natural resource management (O.Nyumba et al. 2018), including fire management (Weisshaupt et al. 2006). Here, we held three sets of focus group meetings in Pennsylvania, New Jersey, and Maryland from July 2018 to September 2019 to identify managers' perceived barriers and opportunities for prescribed fire use. These groups are hereafter referred to as the PA, NJ, or MD focus groups, although some participants were involved in managing fire in neighboring states. Focus group participation was initiated over email and facilitated by the Pennsylvania Prescribed Fire Council, the NJFFS, and the Central Appalachians Fire Learning Network managed by The Nature Conservancy.

A semi-structured protocol was developed and used that included a series of open-ended questions with follow-up probes, approved by the Institutional Review Board of The Pennsylvania State University (STUDY00002672). The Pennsylvania focus groups, held at The Pennsylvania State University, included 18 participants, split evenly into two groups, and included individuals from state, federal, and private natural resource management agencies in each group. Participants were recruited through purposive sampling by email to representatives from fire management agencies in the state, including the Pennsylvania Game Commission, the Bureau of Forestry, the Pennsylvania Prescribed Fire Council, and The Nature Conservancy. The New Jersey focus groups included 60 participants, split into four separate groups. The first three groups comprised fire managers, convened at Batsto Village, Hammonton, NJ, and one group, hosted at the NJ Forest Fire Service Division headquarters, comprised Firewise community leaders who worked closely with fire management personnel on implementing prescribed fires near their communities. Recruitment of New Jersey fire managers was through email, approved by the NJ State Parks and Forestry, and distributed to anyone who applied for a prescribed burn permit during the previous year in addition to all fire managers in the agency. New Jersey managers were mainly from the NJFFS but also included fire

professionals from the US Forest Service, National Park Service, and Audubon Society. Recruitment of Firewise community members was distributed by the prevention coordinator of the NJ State Parks and Forests to Firewise community contacts. The Maryland focus group was recruited voluntarily from participants attending a Potomac Headwaters and Central Appalachian Fire Learning Network meeting held in McHenry, Maryland, coordinated by The Nature Conservancy Maryland/D.C. chapter. Participants included 14 participants, split into two groups, from the Maryland Forest Service, West Virginia Division of Forestry, Nature Conservancy, Chesapeake Conservation Corps, AmeriCorps, and Sustainable Solutions, a natural resource management firm in West Virginia. Each focus group was assigned a group leader and scribe from the research team. The NJ and MD focus groups were video- and audio-recorded, whereas the PA focus groups were audio-recorded. Since demographic data like gender identity, age, racial identity, or ethnicity were not collected during the focus groups to preserve anonymity, we do not include them here.

Quantitative and qualitative data analysis

Recordings from each focus group were transcribed digitally, and open and axial coding schemes were used to analyze these transcripts (Corbin and Strauss 2014). An initial codebook was developed by two coders, each independently coding four of the eight transcripts and comparing findings. Through this, codes were found to fall into categories reflecting the level (individual, community, and landscape) of the perceived opportunity or barrier (Harr et al. 2014). Specifically, the individual-level referenced factors that influence how fire ecology and management is understood and perceived by individuals (non-managers), and this level is related to factors such as attitudes or beliefs towards burning. The community level referred to topics specific to the community within which fire management occurs, such as manager perceptions of the community turnover as residents move in and out. The landscape level referred to social and environmental drivers of fire management dynamics that operated beyond the scope or influence of specific communities and included factors such as the intermingling of fire management jurisdictions or land ownerships. Codes were then grouped into secondary thematic groups, such as "governance" or "experience," and finally assigned a tertiary categorization as either a "barrier" or "opportunity" within their broader categories. These code groups were tested by having the full interdisciplinary research team and two external researchers (familiar with fire science but not our project) perform an independent classification on example quotes from each category, which was then compared to the codebook for alignment. With feedback from this process, we recategorized certain quotes and reworded several broader categories (e.g., "governance" changed to "institutional capacity") for clarity.

Following this initial coding analysis, three additional coders applied the final four-level codebook (see Supplementary Table 1) to all transcripts using the qualitative coding software NVivo, each coding two to four (of the eight total) transcripts. Table 1 presents a summary of the final codebook. To accurately assess codes quantitatively, only one code was used for any given quote. To ensure consistency across coders, each coder independently coded a small section of text from one transcript, and the inter-rater reliability (IRR) metric of Kappa's coefficient (McDonald, Schoenebeck, and Forte 2019) was calculated in NVivo to gauge agreement. Coders used this testing process to clarify discrepancies in the interpretation of codes and refine code definitions. Three coding test rounds were conducted on the same subsample of transcripts until the average Kappa's coefficient across all fourth-level code groups and across all coders reached 0.84 overall using Nvivo's internal calculation process and averaging manually (see Supplementary Fig. 1 for final IRR metrics). While IRR metrics are often not reported, and there is no universal standard as to what is acceptable (O'Connor and Joffe 2020), a Kappa's coefficient over 0.81 overall is deemed "nearly perfect" agreement (Landis and Koch 1977). The coding structure used to calculate IRR metrics was edited and merged in the presentation of results to better interpret and visualize thematic analysis, although this did not affect the coding process.

Once coded, all code count data were visualized to better understand the prominence of certain themes and the proportion of barriers and opportunities across the community, individual, and landscape levels, as well as across the three focus groups. Further, all codes were qualitatively assessed to present key themes and associated quotes.

Methodological considerations

Since our focus groups were conducted, several changes to state-level policies and practices have occurred within the region. For example, New Jersey now recognizes that "proper application of prescribed burning is essential to the existence, continuation, restoration, and management of many plant and animal communities, and the resulting vegetative growth benefits rare, threatened, and endangered species, songbirds, and other game and nongame species" (NJ Rev Stat § 13:9–44.12 (2022)) (Justia 2022), which allows for significantly broader burn objectives for the NJFFS beyond fuels management and hazard reduction. Thus, manager perspectives described herein should be considered as a reflection of the historical context at

Table 1 Overview of levels and themes, including a description of the associated barriers and opportunities, that were used to organize the focus group coding. Only the first-, third-, and fourth-level codes are presented for brevity (see Supplementary Table 1 for the final codebook)

Level (1st)	Theme (3rd-level)	Barriers and opportunities (4th-level)	
		Barriers	**Opportunities**
Landscape	Institutional coordination	• Interference with tourism can limit when burns can occur. • Fire is often a lower priority over other more profitable activities. • Restrictions to prescribed fire due to potential risk may limit coordination across agencies • Fire managers face increased responsibilities due to increased land areas and management scope.	• Fire managers perceive growing convergence of institutional objectives. • Collaborations across agencies and landscapes are important. • Agencies have broadened institutional objectives. • Maintenance and preservation of cultural burning practices. • Fire can achieve invasive species management. • Fire contributes to landscape restoration. • Prescribed fire reduces fire hazard. • Prescribed fire enhances wildlife habitat.
	Institutional prioritization		• Agencies have a growing understanding of the appropriate prescribed fire return intervals for different ecosystems. • Agencies understand that fuel loadings vary spatially. • Fire managers have a growing understanding of weather-climate relationships. • Fire managers understand how prescribed fire can address multiple systemic threats.
	Burn management flexibility	• Policies that limit the flexibility of when, where, and how fire occurs. • Burn windows are limited by weather patterns and seasons.	• Policies that can increase the flexibility of when, where, and how fire can occur.
	Capacity and compliance	• Paperwork and lengthy reviews can make compliance more difficult. • Employee turnover within agencies is high. • The needs of fire managers within agencies are not necessarily met by institutional training.	• Managing fire across the state provides institutional opportunities for better management. • Fire is a cheaper alternative to other forms of management.
	Landscape mosaic	• Critical infrastructure can get in the way of operations. • The geography is so diverse that it is hard to find a generalized approach. • Different, closely spaced units limit flexibility.	• Agencies and personnel aspire to achieve landscape-level management because it is more cost-effective.
	Fire effects	• Fire agencies lack understanding of and research on how fire operations affect endangered species and other wildlife. • Fire managers and agencies lack expertise and technology for ongoing assessment of the impacts of prescribed fire.	

Table 1 (continued)

Level (1st)	Theme (3rd-level)	Barriers and opportunities (4th-level)	
		Barriers	**Opportunities**
Community	In-person community engagement	• The general barrier to offline fire communication and education.	• Offline communication, such as public forums, newspapers, demonstrations, etc. provides opportunity for community engagement
	Prescribed fire exposure		• Proximity to recent fires enhances community understanding of fire ecology and management.
	Online community engagement	• Managers may lose control of the message on online social media platforms. • Managers may lack expertise in implementing online communication and education.	• Social media/online communication and education can be utilized for timely messaging.
	Social networks	• Developing social networks is challenging.	• Network-broker can facilitate trusting relationships between local communities and managers through trust-building communication.
	Place attachment	• The expectations of what tourists and visitors should and do experience vary across communities. • Communities fear that fire will affect their "pristine" nature	• Appreciation for long fire histories deepens place attachment.
	Risk awareness	• Different communities have different levels of awareness about fire vulnerabilities.	
	Residents' turnover	• As communities turn over, the newer residents will have less knowledge and experience. • As communities turn over, this disrupts the community's sense of cohesion.	
	Extent of engagement	• Online and offline communication/education are limited regionally. • Increasing news coverage of mid-Atlantic fires can counter educational objectives. • Communication does not reach the public.	
Individual	Fire ecology understanding	• Lack of individuals/general public's understanding of fire ecology and management. • Individuals perceive the loss of ecosystem services because of fires.	• Individuals have a growing understanding of fire ecology and fire. • Individuals perceive increased ecosystem services from fires.
	Individual-manager relationship	• Individuals do not easily trust managers and government officials.	• Managers are concerned about risk and safety related to fires. • Managers can increase trust by continuing to engage in their communities.
	Attitudes and preferences	• Managers hear from communities that landscapes are ugly shortly after a burn. • Managers perceive that individuals are complacent about fire management. • Managers perceive that negative mindsets hinder attitudes about fire.	• Mechanical thinning in addition to fire can reduce negative impacts on viewshed.
	Fear or stress	• Managers perceive that residents fear home or property loss. • Managers perceive that residents fear life loss or injury from operations. • Managers perceive that residents fear smoke's negative health effects • Managers are concerned about being shamed by communities if something goes wrong. • Managers fear the physical risks of prescribed fire management	

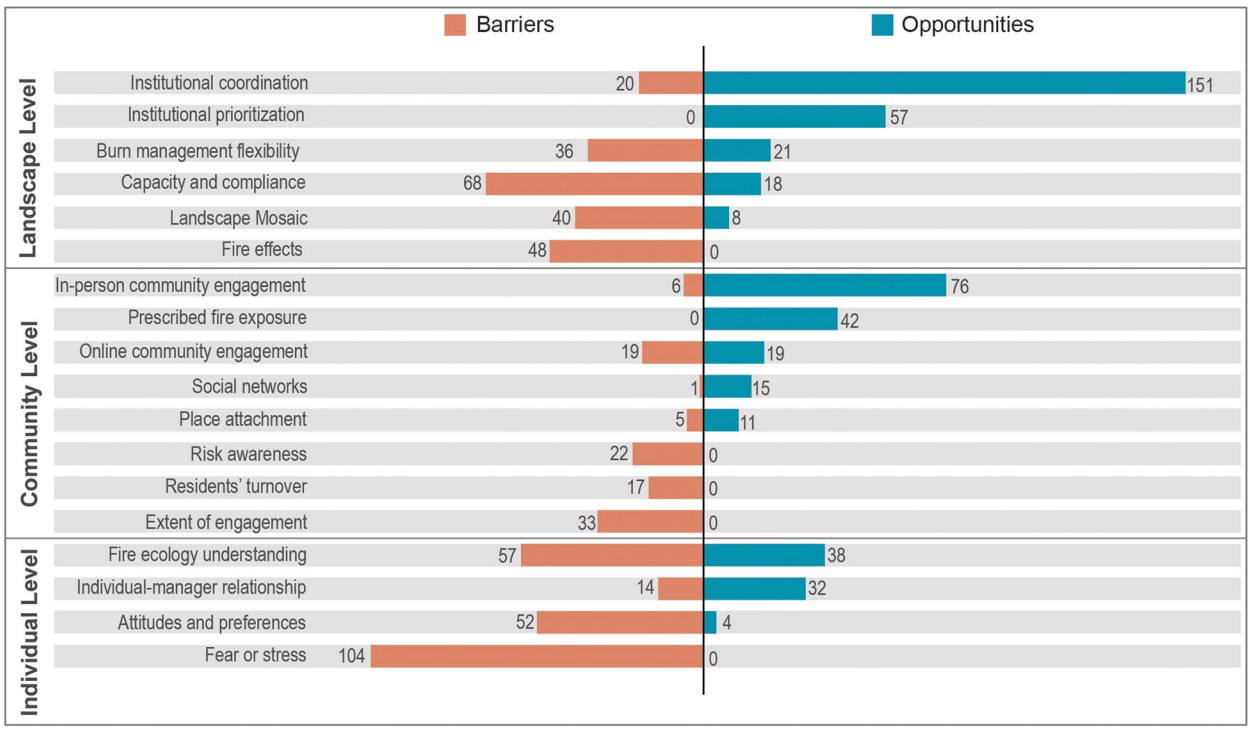

Fig. 4 Prevalence of coded barriers and opportunities. Prevalence of themes identified across focus groups, coded as barriers (orange) or opportunities (blue), and organized by the individual, community, and landscape level

the time and not necessarily reflective of current perspectives; that said, based on continued engagement with these management communities, we posit that the themes and specific barriers and opportunities remain relevant and timely. We also acknowledge that, given our emphasis on managers, our focus groups did not necessarily capture perspectives of additional key partners discussed herein, such as community members, many federal agencies, tribes, or other key decision-makers; we contextualize findings with respect to managers' perceptions of these actors, but it is important to note that their perspectives may differ from what is reported here. Finally, we note that our results are reflective of the specific code choices and thematic categories decided upon by the co-authors, which we partially account for through the use of both quantitative and qualitative data analysis to provide complementary avenues for data interpretation and synthesis.

Results

First, we present an overview of perceived barriers and opportunities through quantitative coding results. These findings indicate shared (across focus groups), multi-scalar (landscape, community, and individual) opportunities and barriers for prescribed fire management in the mid-Atlantic. Then, we provide more detail about identified themes across the three scalar levels using representative quotes focusing on (1) landscape-level institutional coordination, (2) community-level fire engagement and education, and (3) individual-level relationships. In the section that follows, we contextualize these findings in the broader fire management literature and conclude with recommendations and strategies for improvement.

Overview: perceived barriers and opportunities

Based on our focus group analysis, described above, we identified a total of eighteen themes related to manager perceptions of the barriers and opportunities for prescribed burning in the mid-Atlantic region. When these themes were organized by level, we identified six themes at the landscape level, eight themes at the community level, and four themes at the individual level (see Table 1). Visual assessment of coded barriers and opportunities across the landscape, community, and individual themes (Fig. 4) provided important insights into focus group responses.

First, within a theme, most managers reported both barriers and opportunities. For example, managers reported that burn windows (periods of time conducive for safe and effective fire behavior, with minimal wildlife and smoke impacts and within legal calendar dates) are narrow in the mid-Atlantic, reflecting the

general weather of the region (a barrier); but, managers also noted that if policies could be more flexible—burning under the best conditions, not just pre-determined calendar dates—prescribed fire management would be more effective (an opportunity). Throughout, managers had similar insights spanning barriers and opportunities, suggesting as a group they have a good understanding of how to develop strategies that would minimize barriers to prescribed fire implementation.

Second, the landscape level had the highest number of codes overall ($n=467$) compared to individual ($n=301$) and community ($n=266$) levels (Fig. 4). Moreover, across all themes and levels, the highest number of opportunities were coded at the landscape level ($n=255$) whereas the highest number of barriers were coded at the individual level ($n=227$). The ratio of opportunities to barriers was 1.20 at the landscape level, 1.58 at the community level, and 0.33 at the individual level. Across all themes and levels, institutional coordination across agencies or organizations ($n=151$) and in-person community engagement ($n=76$) were seen as the greatest opportunities by managers. Conversely, fear or stress held by managers themselves or heard from community members, e.g., related to smoke from burning causing health impacts, was the highest recorded barrier ($n=104$). The highest opportunity recorded at the community level was related to in-person community engagement ($n=76$), and the greatest barriers were the extent of engagement ($n=33$) and risk awareness ($n=22$).

Third, even though we expected to see differences emerge at the state level, given differences in prescribed fire histories and geographies, it is notable that these patterns were consistent across focus group locations (Fig. 5). In other words, managers shared approximately the same relative proportion of barriers and opportunities within each theme, independent of the location (state) that the manager represented (here grouped by focus group location as PA, NJ, or MD), suggesting that barriers and opportunities were shared among managers within the mid-Atlantic region despite different prescribed burning histories and policies at the state level (Fig. 5).

Landscape-level institutional coordination

Institutional coordination was defined to include many components of inter-agency barriers and objectives (see Supplementary Table 1 for specific levels, themes, and definitions). In sum, managers understood the ecological, historical, and cultural context of landscape-level prescribed fire management and the need for this coordination. For example, one manager from New Jersey said, "The Pinelands won't stay the Pinelands unless it has fire because the forest will turn into hardwood-oak something without the fire." Additionally, managers expressed

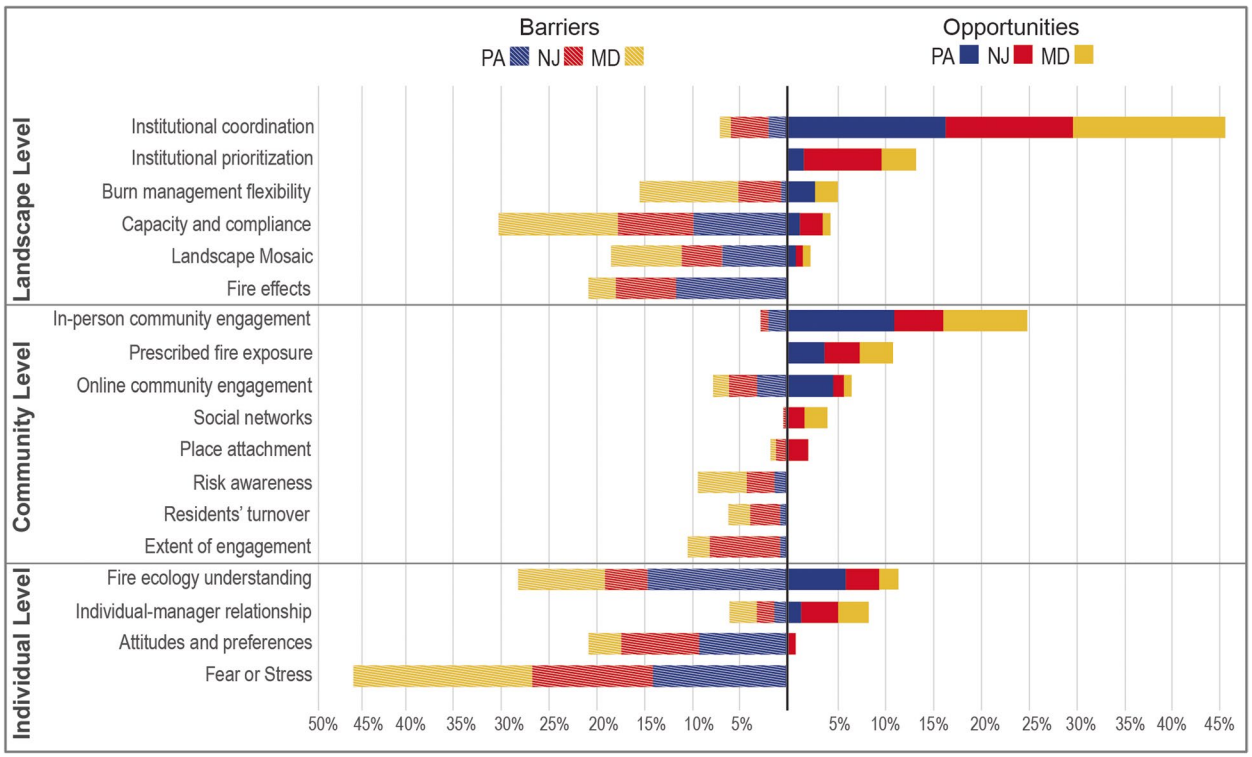

Fig. 5 Prevalence of coded barriers and opportunities by state. Prevalence of coded themes for each focus group, Pennsylvania (PA—blue), New Jersey (NJ—red), and Maryland (MD—yellow), organized as opportunities and barriers across individual, community, and landscape levels

an interest in burning larger areas because, "…Governing larger tracts is better, easier, more cost-effective and more time effective, in the long run." Despite this appreciation of landscape-level fire management, managers expressed that they were often constrained in managing at landscape scales by the fine-grained ownership mosaic of the mid-Atlantic region, exacerbated by burning in areas with a high human population and associated infrastructure. As one said, "We have a lot of interface here. We have a bigger population compared to out West. So, we have a lot of people, roads, homes, developments, or businesses that we have to take into consideration when we burn." Not only does the intermingling of land uses and infrastructure require increased coordination around burn management, but it also creates additional communication challenges due to greater visibility of fire effects, especially smoke and greater risks for public safety such as having, "……People showing up on your burn that don't know what's going on.").

In addition to the challenge of managing across complex, built landscapes of the mid-Atlantic, managers also reported challenges of coordinating across agencies or organizations with different priorities, such as habitat maintenance versus hazard reduction. Many managers recognized the opportunity of achieving multiple co-benefits through burning, including habitat maintenance (e.g., for deer and diverse bird species), controlling invasive species (e.g., Japanese barberry, Autumn olive (*Elaeagnus umbellata* Thunb.), sustaining fire-dependent forest species (e.g., Pitch pine or Broom's crowberry (*Corema conradii* (Torr.) Torr. ex Loud.), and potentially increasing carbon sequestration. On the other hand, for some managers, planning fire management around potential habitats of endangered species is a recent, and somewhat frustrating, change. One said, "For the last 60 years, for the last 80 years, it really hasn't bothered the eagles and the owls or anybody. But in the last five years, boy has it bothered them, to the point where we have to be careful of them." This comment reflects managers' frustrations about increasing regulations across multiple conservation or restoration objectives, which may not fully consider the role of burning.

Despite recognition of multiple co-benefits of prescribed fire and the desirability of management at landscape scales, managers reflected that both weather conditions and policies interact to limit landscape-level coordination. For example, at the time of our focus groups, policies limited burn windows to certain calendar dates that were anticipated to be conducive to prescribed burning and limit the potential of wildfire risk or harm to sensitive habitats. Indeed, optimal burn windows in the Eastern US only provide, "… A few days here and there in an area you can optimally burn." However, these narrow and precise dates may be an historical artefact in US state-level policies, and many managers discussed that effective fire management should be determined less by calendar days and more by the conditions needed to meet burn objectives, which may be shifting due to climate change.

Managers expressed an interest in taking, "an interdisciplinary approach" to identify ways to mitigate across differential management objectives. For example, managers from Maryland reported their agencies often have high-level objectives to promote climate resilience through forest management strategies, but that many site-level considerations, such as whether there are timber rattlesnakes in the area or if oak regeneration is a concern, need to be integrated into specific burn plans. While consultation and local problem-solving can work to integrate these objectives, this requires cross-agency coordination and flexibility which may or may not prioritize prescribed fire. Navigating this complexity across agencies and objectives is non-trivial, as one manager reflected, "How do you ensure that there is adequate workforce that is well trained in this very complex thing to do?" Another reflected, "The actual individuals who are charged with getting these objectives on the ground… and the conversations they can have" are the most important things to prioritize, fostered by partnerships among managers and between agencies.

Managers acknowledged there are substantial barriers to cross-agency, landscape-level collaboration. For example, navigating differing and sometimes conflicting cross-agency objectives or policy regulations can be stymied by the inherent risks associated with burning. In the context of using fire for wildlife management, one manager observed tensions between managing for individuals versus populations:

> *I think that it is hard to explain to some of the resource managers that you are playing with fire, and you are going to have a lot of benefits and you are going to have a lot of negative consequences. And you need to find that place where you are comfortable with whatever the results are because you are going to kill some things, you are going to promote some things. It depends on where the [area] wants to be, what they want to do in the long run.*

Another constraint to landscape-level coordination of prescribed fire is limited capacity. Managers discussed a major concern of being "task saturated" on top of being short-staffed. One manager explained, "You got this combination of a lack of available people to do it on a consistent basis due to funding. Then, the people that are working in the industry are task saturated." This manager continued to say that "I would love to be able to go out

and talk Firewise [referring to the municipal-level fire community educational programs] all day, but I am not getting paid for it. And so, that makes it a lower priority ultimately," suggesting that despite the recognition that community education and engagement are important in an effective prescribed fire program, it may not be prioritized within job descriptions. Given the limited burn windows, managers also expressed frustrations with maintaining regular crews because, "most of the time they'd just be sitting there" with limited work. Further, while many resources for monitoring exist, there remains a need to expand monitoring capacity. One manager described, "We just don't have the resources to throw in monitoring programs just willy-nilly that measure everything across all of the burn sites. We need to actually have monitoring or objective assessment practices for burning that are part of a competent professional's everyday workflow." Finally, managers also noted that agencies were constrained by other political or social factors when coordinating landscape-level implementation. For example, some expressed pressure to not burn in areas visible near roadways that were popular tourist routes.

Managers recognized that the legislation for prescribed fire management across these states is relatively new in some areas like Pennsylvania and evolving. One manager saw great potential for a more comprehensive fire management strategy to meet land management needs, saying, "We have a small example of what we are able to do. I say this to our crew almost every burn, and don't have all of the answers yet; I feel like we just learned to put fire on the ground safely and develop our crew experience. Now we have to figure out the rest of it." Moreover, managers repeatedly stressed the need for cross-agency collaborations across public and private lands to, "…get together and figure out what to do in the long run"—a common theme across focus groups. This begins by first understanding what different agencies' goals are and keeping them going "…another 100 years into the future." Across focus groups, managers desired that fire be used as a landscape management tool, despite the challenges of doing so in the heterogeneous landscapes of the mid-Atlantic but said it will be more and more crucial to do so as "…fire is not going away anytime soon."

Community level: opportunities for fire education and engagement

The most significant opportunity perceived by managers at the community level was managers' experiences with and plans for in-person community education programs. While they stressed there was limited agency capacity, managers repeatedly emphasized the importance of community education. For example, said one manager, "I think the more you educate the people, the more they are willing to accept anything from prescribed burns to mechanical clearing and so on. You have to get out to the people. Education to me starts from the top, and I'm talking about government officials, local officials, and down the line. When you educate the people, then your community becomes safer because you're able to do things to keep your community safe." Starting by integrating education about fire management into schools was described as an important step in this community education process, using existing programs like the junior firefighters or through volunteer fire companies. In addition, continuing education for managers was also framed as important, given the increasing need to "…put fire into more places under increasingly challenging conditions."

In addition to educational activities, managers also stressed the benefits of having direct engagement with burn operations, noting that when prescribed burn events go well, they can serve as an opportunity for providing education to other decision-makers and residents, helping the public understand the process more fully and directly witness the benefits. One manager said, "The perception beforehand is it is going to be a charred landscape, treeless, but especially when you are doing some of these spring burns in the early growing season, and you start having things green up, and they get out there and see it. Then they start understanding." Therein, investing in ways to help community members "see it themselves" was expressed as a top priority. One manager said of a recent fire, "The more education thatwe gave the homeowners, the more that they appreciated the work we were doing out there." Managers reported that people who witness a burn have, on occasion, gone from complaining about burning in one year to filing an application for a prescribed burn in the next.

However, challenges in coordinating these educational and exposure-oriented activities in communities were noted by managers. These included high community turnover, resulting in limited experience and familiarity with prescribed fire activities within some communities. A New Jersey member of a Firewise community commented on the challenge of continuously educating new residents on fires and forest management: "I mean you are getting a new group of people moving down here that aren't used to it. And they want to have a say on what should be done." In the Maryland focus group, the loss of a "cultural legacy" in burn management, particularly a loss of training and experience with burning in Appalachian regions of western Maryland, West Virginia, and Virginia, which was seen as a concern and contributed to the challenge of educating and working with communities. Regarding the changing attitudes toward prescribed fire, managers voiced the need to target outreach and education toward things they care about. One said,

"maybe the way to get to people's heart is just to show them a dead tick," and another noted the importance of engaging with hunters on the benefits of fire.

An overarching concern related to communication was related to social media, mentioning that, "We are not marketing professionals. We are often tasked with developing some kind of communication mechanism to inform people or change people's minds, and we are not well-equipped in general to do that." Relatedly, while social media can be a positive mechanism for messaging about burn plans and events, many managers were concerned about the social media not being under their control. As one commented, "It only takes one photo taken out of context or one misinterpreted action or whatever. Once it is out there, you can't take it back." Social media communication is not something that managers often do themselves without other support staff and, moreover, they feel ill-equipped to communicate well on online platforms to the general public. Further, the pressures of "instant gratification" through social media contribute to quick and fragmented news coverage of prescribed fires and wildfires. One manager described a situation where a wildfire that occurred during prescribed fire burning season was described over social media as "an escaped prescribed burn," spreading rumors and misinformation about their real fire management efforts; in this way, social media is seen as a "double-edged sword" to getting the word out quickly while also risking losing control of the broader message.

Individual level: the importance of interpersonal trust

At the individual level, interpersonal trust (Shindler et al. 2014) between individual managers and individuals living in communities affected by fire management activities was seen as a critical factor for the success of prescribed fire management programs. Developing trust with community members was critical to many managers, even if it takes more time and even if it must be done personally. Said one manager of this process of relationship-building, "We met with them. We walked the property. We explained what we were doing, why we were doing it. We talked about our credentials and our publications. And we knew then they became an ally."

Many focus groups discussed the importance of a manager liaison who acted as a network-broker to support relationship building between managers and members of communities. In the New Jersey focus groups, especially, where this personnel member worked closely with Firewise communities, the importance of this relationship was emphasized repeatedly. One Firewise community coordinator described their relationship with the agency's community liaison as, "…The trust factor. There are three kinds of people in the world: people who make things happen, people who watch things happen, and people who wonder what happened. He [a Firewise Community Liaison] makes things happen." Another described how someone "…returned my call while he was on vacation, and I was sold right then that he was committed… So, that gives us the confidence to go on." This strong sense of interpersonal trust was reciprocal, manifesting as care for each other's well-being. Firewise community leaders described their role in community education and preparedness as "If we saved one home or saved one firefighter from having to go to that home, it's worth it, for that firefighter's life."

Despite the importance of relationship building and the importance of talking with individuals, one manager reported that "Thebig challengeis not being trained in the social sciences," referring to the importance of working with people to achieve fire management objectives. Moreover, another suggested a lack of coordinated investment across management agencies in the social network that helps to maintain interpersonal relationships and collaborations: "We are not unique in this fire space at undervaluing and underinvesting in that backbone infrastructureof trust and community-buildingthat enables people to really collaborate in an authentic way."

In the absence of that collaboration, trust, and care, managers reported the pressures of meeting potentially untenable expectations of community members. Said one manager, "See, I got the angel and the devil. I listen to the phone calls from people that are going to sue me versus the people that want to burn. I am kind of torn." Said another: "Putting a wildfire out is one thing, that is stressful on its own. But when you are lighting a fire and are in charge of it, you are making it happen, everything comes together and is focused on you. It is stressful." In response to the risk of not building that trust, another manager said, "You could burn for ten years and have an awesome record, but it only takes that one burn."

While mistrust and lack of relationship-building were seen as a challenge, managers also raised concerns about individual-level complacency of community members. As one described, "I think when it comes to the public, they are very busy, and many people are working. They have children. You know, some people have church activities. And if you say, where is wildfire on your list of things that you are afraid of, they would put it down as a zero or a one." Perhaps because of a link between complacency and a lack of experience with fire, fire managers reported that individual attitudes toward fire are affected, noting that burning is often perceived as ugly in the short term. One manager summarized some of the complaints they hear from homeowners in the forest near their burn: "[Homeowners will say] 'I don't want to look at black trees. It is

going to look so ugly. I paid more money to have the forest right behind me.'".

Related, managers expressed an interest in having individuals better understand the role of fire management in landscape stewardship. Said one, "It would be nice if the public saw fire as just one of many tools professionals use to manage complicated ecosystems and recognize it as having a place, as a tool, to be used in that." One stated it this way: "To me, fire risk is a lack of knowledge." Another manager observed that the act of conducting burns could support greater awareness: "So, it might only be a two-acre burn, but if it makes 50 people start thinking about the benefits of prescribed burning, then you have accomplished something there." The long timescales needed to meet forest management objectives (e.g., up to 10 or 20 years in some areas) were also seen as a challenge in communication with community members. One manager said, "That is the hardest thing about my job, in general, is getting people to think in terms of on a forest management scale, whether its fire or timber or anything, you are thinking 10, 15, 20 years down the road or more."

Further, a general lack of understanding of the difference between wildfire and controlled burns makes communication less transparent. One manager stated broadly, "Pretty much what they see with fire is what they see on the news of western fire and giant fires. And they kind of associate that with what we are talking about when we say either wildfire here or prescribed or controlled burn. And I think there is just a general lack of knowledge, awareness." This general gap in knowledge creates confusion around when fire seasons are, and, more importantly, obfuscates the potential benefits of prescribed fire management. Managers pointed to this as part of a larger ethical question of "…your responsibility for a healthy ecosystem" as a landowner.

Finally, from the managers' perspective, smoke causes the greatest concern in gaining support for fire management activities. Given its known health risks, smoke was recognized by managers as a consistent source of worry and frustration for homeowners, especially for families with asthma. Although smoke mitigation and management remain top priorities with any burn plan, managers acknowledged that, "If we had to notify each and every homeowner before we get a burn, we would never get any burns." Thus, building interpersonal trust while understanding these potential risks was concerning to managers and a barrier to effective prescribed fire management.

Discussion

Using the mid-Atlantic region to understand manager perceptions reveals several lessons for prescribed fire management strategies more generally. Overarchingly, it is clear that prescribed fire management practices must grapple with challenges of complex land ownership patterns, growing interface between communities and forests, and variable acceptance by communities and individuals, which have been well studied in other locations and contexts (Loomis et al. 2001; McCaffrey 2006; Toman et al. 2014; Wu et al. 2022) and these factors remain important in the mid-Atlantic. However, our study also deepens insights into ways in which management strategies could be improved, with specific opportunities for integration into national strategy planning and to other geographic contexts globally, where more proactive, beneficial fire use strategies are called for within increasingly complex and dynamic socio-environmental firescapes.

Our work highlighted that managers experience barriers and opportunities that extend across scales and sectors that are acting simultaneously and interactively. This is important for several reasons. First, it suggests that landscape-level, community-level, or individual-level planning (Moritz et al. 2014; Schoennagel et al. 2017; DeMoulin et al. 2022) should be coordinated as part of a hierarchical system that enables knowledge of managers to be shared through vertical integration of policies and practices (Ziervogel et al. 2019). Previous work has demonstrated that nimble coordination of the wildland fire management system is needed to address a wide variety of local contexts and dynamics (Smith et al. 2016; Paveglio 2021; Huber-Stearns et al. 2022). Practically, these connections and opportunities for sharing could be enhanced, for example, by collaborative functions that span organizations such as convening meetings and agreements, collaborative funding support, or project planning (Huber-Stearns et al. 2022). Second, the opportunities and barriers at each level (landscape, community, individual) are not equal, with a need to consider scalar influence. For example, institutional coordination was a much more prevalent opportunity than opportunities identified at the community or individual level. Being able to identify these critical levers in the system will be critical to enhance prescribed fire management.

More specifically, our results highlight the importance of landscape-level coordination, particularly related to inter-agency collaboration, as the most prominent opportunity for prescribed fire management. Burn coordination is likely of high interest to managers in the mid-Atlantic due to the region's complex geographical and jurisdictional setting. Tight intermingling of land ownership and high levels of interface between natural and built-up areas, significant infrastructure, and a substantial proportion of private lands mean that, operationally, coordinating landscape fire management is a particular challenge in the region (Radeloff et al. 2018; Wilbur et al. 2021). Moreover, as in many parts of the northeastern US,

the jurisdictional and governance structure of the region is complex (e.g., the Pennsylvania Commonwealth alone has 67 counties and 2560 municipalities). In addition, the relatively small amount of federally managed lands in the eastern US (including the southeastern US) differentiates it from the western US and places additional land management burdens on state and local agencies, often with limited capacity. Moreover, fire management in the mid-Atlantic can be attributed to many objectives beyond hazard reduction, such as habitat conservation and restoration, with different agency leadership across these differential objectives. This is due to the fact that fire hazard is currently low in many parts of the region due to a history of mesophication (Nowacki and Abrams 2008) affecting fuels and the generally wetter and milder climate, compared to many other parts of the US. Due to this complicated geographic context, addressing national calls for coordination and collaboration may thus provide unique challenges to the mid-Atlantic. Given that state and local agencies or non-governmental organizations will likely be tasked with implementation, new approaches, such as cost-sharing and financial incentives between federal, state, and local agencies will be needed (Kreye et al. 2021).

Our research also highlighted an opportunity for improved prescribed fire implementation by attending to relationships among managers and community members that cultivate mutual trust and care (Rasch and McCaffrey 2019; Paveglio and Edgeley 2023). Shindler et al. (2014) refer to this as interpersonal trust, pertaining to the relationship between individuals. That an individual is trustworthy is due to many factors, such as ability or competence, goodwill, and integrity (Shindler et al. 2014). In our case, this was evidenced by the pivotal role of manager-community coordinators who prioritized meaningful connections with Firewise community leaders. Managers also noted that trust can be strengthened at the organization (agency) level (Shindler et al. 2014) through participatory processes that provide opportunities for community members and managers to bridge discussions and build capacity for fire management goals and planning (Huber-Stearns et al. 2021). However, unfamiliarity may hinder trust building in natural resource management (Emborg, Daniels, and Walker 2020) and this may be a particular challenge in the mid-Atlantic. Our focus groups included representatives from Firewise communities who work together with managers on community education and preparedness activities, but Firewise communities are not common in many regions of the mid-Atlantic, limiting opportunities for manager-community engagement. In the Western US, it has been shown that resident support for fire management activities can vary even within small geographic areas (Paveglio and Shriner-Beaton 2024) signaling the importance of trust-building activities that attend to local contexts and issues. Interestingly, novel strategies such as immersive experiences can provide opportunities for storytelling about fire management and have been shown to be effective in communication and sustainability education around fire management (Wallgrün et al. 2019; 2021; Steidle et al. 2023; Nasr-Azadani et al. 2023).

Recent attention has been placed on the importance of individual well-being in the context of wildland fire management, with due consideration to wildland firefighters and vulnerable populations threatened by the impacts of wildfire or smoke (Reid et al. 2016). Adding to this, our work highlights that managers on the front lines of burn operations and in key decision-making roles are also vulnerable to the stresses of prescribed fire management (Igboanugo et al. 2021; Koopmans et al. 2022; Granberg et al. 2023). Addressing the human toll of fire management is not unique to uncontrolled wildfire situations and applies to managed fires as well. Supporting managers in these positions may involve codifying best practices, standards, and management capacity surrounding liability protection and authorization of burns, addressing capacity gaps, and supporting educational programming and training for managers and within the communities they serve.

Despite our expectations that state-level differences would emerge depending on whether fire management practices have been absent until recently (e.g., Pennsylvania) or long-standing (e.g., New Jersey), managers held shared perceptions about opportunities and barriers for more effective prescribed fire implementation. Given similar training standards and educational resources for the training of wildland fire personnel nationally through the National Wildfire Coordinating Group, it may not be surprising that managers perceive common challenges and opportunities. Moreover, previous research has similarly shown more commonalities than differences in community perceptions of fire (McCaffrey et al. 2013; Schultz et al. 2019). Some differences across state lines did exist, however, such as the coordination of burning on private land. For example, in New Jersey, fire management is largely driven by concern over wildfire hazard, and, as a result, the state-wide agency (NJFFS) has been responsible for wildfire management on both public and private lands for at least 100 years. This strong relationship between private landowners (particularly industrial landowners such as cranberry farmers) and the NJFFS was evident in focus groups, presumably due to this explicit and long-standing mandate for public–private fire coordination. In contrast, managers in Pennsylvania, where fire hazard is lower, reported a lack of incentives for

private landowners to implement fire management on their lands, even when willing to do so, due to few training opportunities and limited capacity of trained personnel.

Results from our study have implications for regional and national coordination of fire policies and activities, such as described in the 2023 report from the Wildland Fire Mitigation and Management Commission (WFMMC 2023) and updates to the National Cohesive Wildland Fire Management Strategy (Wildland Fire Leadership Council 2023) that support the use of beneficial fire, including prescribed fire, to help address a broad set of wildland fire management issues. For example, our finding that managers see opportunities for landscape-level coordination of prescribed fire management affirms the recommendation of the WFMMC that prescribed fire support systems be as nimble as for wildfire response, and further suggests that prescribed fire be included in the development of joint offices for coordination of wildfire management data and operations. Other recommendations, such as enhanced risk reduction programming for mitigating wildfire risk in the built environment, would also have substantial implications for prescribed management operations in certain areas of the mid-Atlantic, given manager concern about the complex infrastructural setting of the region. Interestingly, the WFMMC also recognized the need for greater research to improve the well-being of firefighters, including mental, psychological, and emotional impacts, and our study clearly highlights the emotional toll on prescribed fire managers as well.

It is notable that the mid-Atlantic region is a region whose fire management policies are in a period of substantial change. To date, these changes have helped support prescribed fire efforts by broadening flexibility for managers in several key areas, such as meeting multiple burn objectives, broadening burn windows, and removing liability concerns. For example, the Pennsylvania Prescribed Burning Practices Act (Pennsylvania General Assembly 2009) removes civil or criminal penalty for damage or injury unless negligence is proven, assuming the prescribed burn plan follows approved standards and is conducted by a burn manager with relevant qualifications. Managers saw these changes as positive because they could reduce inter-agency conflicts and provide more opportunities to meet management objectives. Leveraging these recent management changes in the mid-Atlantic would be timely in support of the more proactive approach called for by the WFMMC (2023) to build effective prescribed fire policies and incentives to enhance landscape-level fire planning and workforce development, restore fire-adapted ecosystems where appropriate, and reduce wildfire hazard which may increase in the future (Kerr et al. 2018; Robbins et al. 2024).

Conclusions

Sustainable prescribed fire management practices must grapple with challenges of complex land ownership patterns, growing interface between communities and forests, and variable acceptance by communities and individuals. Our research explored these dynamics in the understudied mid-Atlantic, where barriers and opportunities for stewardship of firescapes were expected to be particularly complex. Overall, results affirm that the mid-Atlantic region would benefit from existing policy recommendations (e.g., Schultz et al. 2019; WFMMC 2023) that address interagency coordination, community engagement, and capacity building, and our results also highlight the importance of psychological and interpersonal factors (e.g., mental health effects and relationship building) of fire managers, themselves. Moving forward, national strategies to coordinate prescribed fire management must account for specific barriers and opportunities that may exist at a regional scale, such as the mid-Atlantic, where complex governance structures, varied fire management histories, and potential for risks may be different than in other regions. Given that managers perceived the greatest opportunity for effective prescribed fire management as the coordination of landscape-level burning, future research should examine the best means to coordinate cross-agency operations and trust-building through community engagement.

Supplementary Information

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Supplementary Material 1: Figure S1. Inter-rater reliability metrics across fourth level codes and across three coders.

Supplementary Material 2: Table S1. Overview of levels and themes, including a description of the associated barriers and opportunities that were used to organize the focus group coding.

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Authors' contributions

EAHS, HW, AT, MK, KZ, and PN conceptualized and designed the study; EAHS, HW, CD, KZ, and AZ collected data; EAHS, HW, KS, MA, RW, and CD analyzed the data; all authors contributed to the interpretation of the data and writing.

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Availability of data and materials
Supplementary Table 1 includes the codebook used in the data analysis. Focus group scripts and recordings are protected by the IRB and not shareable publicly to protect participant identity.

Declarations

Ethics approval and consent to participate
The research was approved by Penn State's Institutional Review Board (#00002672).

Competing interests
The authors declare that they have no competing interests.

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