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Awareness and Social Interactions Influence Natural Resource Professionals' Recommendations for Prescribed Fire Use

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ABSTRACT

Restoring fire in fire-adapted ecosystems is necessary to curtail woody plant expansion, enhance biodiversity, and reduce wildfire risks, yet prescribed fire is promoted less by federal agencies than other grassland conservation practices. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) is the primary federal agency responsible for the delivery of rangeland conservation incentives to private landowners in the Great Plains. The degree to which NRCS employees choose to offer technical guidance on prescribed fire and whether they encourage landowners to consider financial support is not well-understood and varies among states. Our study explored the extent to which *prescribed fire awareness* and *social interaction* factors influence NRCS employees' knowledge and comfort level regarding prescribed fire and the frequency with which they recommend this conservation practice. The results show that while *prescribed fire awareness* influences knowledge, it was not significantly associated with frequency of prescribed fire recommendations. Rather, *social interaction* factors were significantly related to recommendation frequency; these included priority of prescribed fire education in their jobs, positive interactions with landowners regarding prescribed fire, and how often they were asked to deal with brush management. An important implication is that while better knowledge about prescribed fire is necessary, it is not sufficient for more frequent prescribed fire recommendation by natural resource professionals. Instead of focusing primarily on technical proficiency, federal agencies tasked with expanding the application of prescribed fire as an ecosystem restoration and wildfire mitigation tool should focus more on building stronger social networks through, for example, providing greater support of existing and new prescribed burning associations. Our findings also have implications for a national unified policy that supports the application of prescribed fire on privately-owned rangelands because negative fire culture at the federal level has an erosive effect on agencies' willingness to assist landowners with prescribed fire applications.

Introduction

Grasslands and savannas are two of the world's most burned biome types but have lost approximately half of their global distribution over the last 125 years (Mishra and Young 2020; Scholtz and Twidwell 2022). Prior to the industrialized era, people thrived with fire for thousands of years in grasslands and savannas (Bond and Keeley 2005 Twidwell et al. 2021). These ecosystems were shaped by the widespread occurrence of purposeful human fire ignitions and corresponding interactions with herbivores (Staver et al. 2011; Scholtz et al., 2018; Wilcox et al. 2018). More recent efforts to suppress fire in these ecosystems represents one of the largest sources of change across the world's vegetation types. Only fragments of prescribed burning cultures exist today (Twidwell et al. 2021). Concomitantly, intact grasslands and savannas now represent a little over 20% of global vegetation, down from 40% prior to industrialized agriculture (Mishra and Young 2020).

Understanding the complex social and ecological factors driving modern applications of prescribed fire has become increas-

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ingly relevant as efforts expand to conserve remaining grasslands and savannas (Twidwell et al. 2019; Scholtz and Twidwell 2022). Calls have increased to restore fire as a fundamental ecological process in grasslands and savannas, to enhance heterogeneity and biodiversity in these ecosystems, and to contain the threat of encroaching woody species in order to mitigate elevated fuel loads and associated wildfire risks (Ryan et al. 2013; Donovan et al. 2017; Vaillant and Reinhardt 2017; Kolden 2019). Despite calls for increased adoption of prescribed fire in rangeland management, barriers to its application are widespread (Kreuter et al. 2008; Toledo et al. 2012; Wonkka et al. 2015; Clark et al. 2022).

Multiple administrative authorities are involved in the oversight of prescribed fire in the Great Plains, and typically involve state agency personnel and locally-elected officials (e.g., county commissioners and district court judges) (Hinojosa et al. 2020; McDaniel et al. 2021). These entities vary by state but are generally responsible for providing state or local administrative oversight, which can include prescribed burn permitting, establishing burn bans, establishing regulatory requirements for prescribed burning, and certification programs. Key gatekeepers to prescribed fire authorization in the southern Great Plains include the Oklahoma Forestry Services, Texas A&M Forest Service and local fire departments who oversee permissions and safety compliance. County commissioners enact burn bans in both states, and district court judges hear civil cases related to damages resulting from prescribed fire escapes and smoke-related accidents.

Receiving less scientific attention has been how federal agencies, such as the U.S. Department of Agriculture Natural Resources Conservation (NRCS), serve as gatekeepers to the application of prescribed fire. NRCS employees are primarily responsible for providing technical guidance and financial assistance to farmers and ranchers for the application of land conservation practices. Specifically, national NRCS policy makes prescribed burning available as a conservation management practice for all agricultural producers (NRCS 2019). It is programmatically available through the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), which provide cost deferment for prescribed burning on private lands. While thirty states currently have supplements or additions to national policy on prescribed fire, the availability of technical assistance and prescribed burning recommendations from the NRCS vary widely across states (Weir et al. 2015). In Texas and Oklahoma, NRCS employees engage with prescribed fire as a conservation practice standard by assisting with writing burn plans and offering financial assistance, primarily though Environmental Quality Incentives Program (EQIP) funding. In both states, landowners must develop detailed burn plans, notify local fire departments and forestry agencies, and comply with state and county laws, including adherence to burn bans and air quality regulations. However, the degree to which NRCS employees choose to discuss prescribed fire as a primary practice, and the factors that dictate how much technical guidance is provided for prescribed fire, influences landowner exposure to scientific information about the role of fire in rangelands and impact the number of landowners who are encouraged by NRCS employees to consider programs that incentivize prescribed fire as a conservation practice.

Land management decision-authorities, including federal entities like the NRCS, are often influenced more strongly by prevailing social norms, prior experience, and public opinion than analytical information about ecological or societal considerations for prescribed fire applications (Kreuter et al. 2019; Weir et al. 2019; Hoffman et al. 2021). This outcome should not be surprising; for example, most county commissioners and district judges were trained outside the natural resource profession, serve a public office, and are therefore more likely to include nonecological criteria in governance decisions (Hinojosa et al. 2020; McDaniel et al. 2021).

In the Great Plains, natural resource professionals serve a key facilitatory role for the application of prescribed fire and breaking down barriers to its broader adoption in rangeland conservation (Wilbur et al. 2021). The Great Plains is dominated by private landownership. Natural resource professionals are tasked with incentivizing private rural landowners to address resource management concerns by providing them with technical assistance for land use planning and recommending ecologically sound land management practices. Yet, prescribed fire is incentivized far less than other rangeland management practices (Limb et al. 2016; Scholtz et al. 2021), even though it is recognized as a critical tool for federal agencies to meet conservation priorities in rangelands (Wilbur et al. 2021). Some studies have demonstrated that knowledge gaps and public relations affect the degree to which natural resource professionals are likely to support the application of management practices, such as prescribed fire, that are part of their tool kit for improving private land management (Wilbur et al. 2021; Jeffries et al. 2023). However, no studies have been conducted to determine the extent to which social norms influence such professionals to recommend the adoption of prescribed fire by private landowners.

We conducted a study in the Southern Great Plains to better understand how complex factors of *prescribed fire awareness* and *social interaction* contribute to natural resource professionals' knowledge, comfort-level, and motivation to recommend prescribed fire as a conservation practice. The survey focused on employees of the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), which is the federal agency primarily tasked with the delivery of rangeland conservation incentives to private landowners. The NRCS' strategic goal is to foster the application of science-based tools, technologies, and information to improve natural resources through conservation planning and implementation (NRCS 2023). In some states that includes incentives related to prescribed fire, but the extent of NRCS involvement in prescribed burning varies widely among states. Therefore, this agency's employees were an ideal focal group for our study. Our broad hypothesis was that separate *social interaction* and *prescribed fire awareness* factors influence the frequency with which a federal natural resources employee recommends prescribed fire, as well as the knowledge and comfort level that an individual possesses about this conservation practice.

Methods

Study area

This study was conducted in the Southern Great Plains (SGP) of North America, which extend from Kansas through Oklahoma and Texas into Mexico. This investigation focused on the central portion of the SGP located in Oklahoma and Texas, which encompasses nearly 73 million acres of the ecoregion (Assal et al. 2015). Both states are comprised of more than 95% privately owned land and have experienced significant woody plant expansion (Wilcox et al. 2018; Donovan et al. 2020). Dominant land cover in the SGP historically consisted of semi-arid grassland and savannas, with shortgrass prairies in the west transitioning along the precipitation gradient to mixed prairies and tallgrass prairies in the east. However, 46-93% of formerly open grasslands in the SGP have been converted to other land uses or by woody plant encroachment (Scholtz and Twidwell 2022). Specifically, prolonged fire suppression, long-term and widespread overgrazing by livestock, and elevated atmospheric carbon dioxide concentrations that favor photosynthetically less efficient C3-type woody plants over C4-type herbaceous plants that evolved under declining carbon dioxide concentrations, have

resulted in large areas becoming dominated by woody plants, particularly *Juniperus* species, with a concomitant decline of native grasslands (McPherson et al. 1988; Fuhlendorf et al. 2018).

Study design and survey approach

The study consisted of a mail survey of NRCS employees in Oklahoma and Texas. Specifically, the survey sample consisted of all NRCS District Conservationists, Natural Resource Managers, Natural Resource Specialists, Rangeland Management Specialists, Range and Wildlife Conservationists, Resource Conservationists, and Soil Conservationists in these two states. This included 115 survey participants in Oklahoma and 299 survey participants in Texas, representing a survey sample size of 414 NRCS personnel in the two states. The survey was conducted using the multiphase mailing protocol recommended by Dillman et al. (2014). The survey was administered during July through September 2018. The four mailings included a pre-survey information letter (day 1), a survey questionnaire with cover letter and pre-paid return envelope (day 7), a reminder card (day 21), and a replacement questionnaire with another cover letter and pre-paid return envelope (day 42). Participation was voluntary and no survey participation incentives were provided. The survey was approved under IRB2017-0734M.

A total of 215 responses were received, including 59 from Oklahoma and 156 from Texas; this represents an overall response rate of 52%, with almost equal response rates for Oklahoma and Texas. Of the returned questionnaires, 136 (63%) were sufficiently complete to be usable for data analyses, representing a 33% useable response rate. The reasons for nearly 37% of the returned questionnaires being excluded from the data analysis is that respondents either did not respond to key questions or provided too few responses to meaningfully undertake multiple imputation. Due to the high response rate no follow-up nonresponse bias survey was conducted.

Data entry and analyses

Data were double entered into a spreadsheet using the response values provided by the survey participants for each of the relevant survey questions. We then used three regression models to explore the social and ecological knowledge that influence the frequency that survey respondents stated they recommend prescribed fire, the knowledge that they possesses about prescribed fire, and the level of comfort they have with prescribed fire. We used questionnaire answers relevant to the hypothesis as predictor variables in the three models and included demographic information as covariates. Where predictor variables or covariates exhibited collinearity, one of the collinear variables was removed and models with different removed collinear variables were compared using the Akaike Information Criterion (AIC) to determine the most parsimonious set of predictor variables. We used an ordinal logistic regression model to assess how often respondents recommended prescribed fire based on four frequency categories: never, rarely, occasionally, and frequently. We used linear regression models to assess the respondents' knowledge about prescribed fire, and their level of comfort with prescribed fire, because we provided Likert scale response options that ranged from 1 (very low) to 5 (very high). With five or more categories, the Likert scale can be treated as an ordinal approximation of a continuous variable with no negative consequences for analysis (Zumbo and Zimmerman 1993; Sullivan and Artino 2013). All statistical analyses were performed using R Statistical Software (version 4.3.3; R Foundation for Statistical Computing, Vienna, Austria).

Results

Participant demographics

Survey respondents averaged 55 years of age and were predominantly male (75% of those who answered this question) with most having an undergraduate degree. They had worked for the NRCS for an average of 16.5 years, ranging from 1 year to 43 years, and they had worked in their current location an average of 9.5 years, ranging from 0.5 years to 34 years.

Factors affecting frequency of prescribed fire recommendation

How often survey respondents recommended prescribed fire was unaffected by any of the *prescribed fire awareness* factors included in our study but was influenced instead by factors involving *social interactions* (Table 1). In the *social interactions* category, recommendations to use prescribed fire were positively related to the priority of prescribed fire education in their jobs, to positive interactions with landowners regarding prescribed fire, and to how often they were asked to deal with brush management (Table 1). Survey respondents were 3.12 times more likely to recommend prescribed fire at a higher level if interactions with landowners about prescribed fire were reported to be positive rather than negative (see odds ratio from Table 1, $P = 0.035$, and Fig. 1). There was complete separation in levels of responses for how often respondents were asked to deal with brush management and how often they recommended prescribed fire, so the odds ratios were not interpretable, but this was a significant explanatory variable ($P < 0.001$ to $P = 0.020$). The number of times survey respondents recommended prescribed fire for controlling brush was 0.58 times more likely to increase by one response category with every categorical increment in the prescribed fire education priority level in their job ($P = 0.010$), and 1.03 times more likely to go up a level for every categorical increment in the frequency that they recommended mechanical and chemical woody plant treatments ($P = 0.005$).

Level of knowledge of prescribed fire

In the model for survey respondents' self-rated level of knowledge about prescribed fire, both *prescribed fire awareness* and *social interaction* factors were also significant predictors (Table 2). In the *prescribed fire awareness* category, holding all other variables constant, respondents' knowledge of fire increased, on average, by 0.07 ($P = 0.009$) for each categorical increment in the perceived knowledge of others about prescribed fire (the combined knowledge scores of the general public, landowners, county commissioners, and district court judges; Fig. 2), and it increased by 0.54 ($P < 0.001$) for every categorical increment in their comfort level with prescribed fire. In the *social interactions* category, while the cubic term for how often personnel were asked to deal with brush management was a significant model variable, a likelihood ratio test of the full model compared to the model reduced by that variable showed this effect was not a significant variable ($\chi 2 = 1.56$, $P = 0.114$).

Level of comfort with prescribed fire

In the model pertaining to the respondents' level of comfort with prescribed fire, there were significant explanatory variables in the *prescribed fire awareness*, *social interactions* and control variable categories (Table 3). In the *prescribed fire awareness* category, holding all other variables constant, respondents' level of comfort with prescribed fire increased, on average, by 0.63 times ($P < 0.001$) with every categorical increment in their own knowledge

Table 1
Output for ordinal logistic regression modeling how often survey respondents recommend prescribed fire.

Predictors	Prescribed fire recommendations		
	Odds Ratios	*Conf. Int (95%)*	*P-Value*
0|1 = never to rarely	1673	1012-2766	**0.008**
1|2 = rarely to occasionally	20994	13489-32676	**0.001**
2|3 = occasionally to frequently	460197	29843-7096426	**<0.001**
Level of knowledge about prescribed fire—yourself	1.24	0.61-2.52	0.559
Level of knowledge about prescribed fire—others	0.88	0.71-1.08	0.219
Level of comfort with prescribed fire—yourself	1.96	1.01-3.88	0.052
Level of comfort with prescribed fire—others	1.05	0.88-1.26	0.605
Understand difference between prescribed fire and wildfire	1.44	0.82-2.53	0.206
Awareness of laws/regulations regarding burn bans	1.08	0.62-1.90	0.790
Priority of prescribed fire education in job	1.58	1.13-2.23	**0.010**
Interaction with landowners about prescribed fire (Neutral)	1.74	0.61-5.12	0.310
Interaction with landowners about prescribed fire (Positive)	4.12	1.13-15.41	**0.035**
Interaction with landowners about brush management (Neutral)	1.18	0.08-18.45	0.904
Interaction with landowners re. brush management (Positive)	0.18	0.02-1.83	0.145
How often asked to deal with brush management—linear	31.68[1]		**0.020**
How often asked to deal with brush management—quadratic	430.51[1]		**<0.001**
How often asked to deal with brush management—cubic	0.00[1]		**<0.001**
How often recommend mechanical and chemical treatment	2.03	1.26-3.34	**0.005**
Consider landowner liability in prescribed recommendation	0.95	0.57-1.58	0.844
Rank of livestock production	1.08	0.64-1.77	0.763
Rank of wildlife operation	0.80	0.51-1.24	0.325
Gender (Female)	0.67	0.27-1.68	0.397
Years of formal education	0.94	0.71-1.26	0.682
Observations / Degrees of freedom	136 / 113		
R^2 Nagelkerke	0.849		

Bold values are statistically significant probability values (<0.05) to highlight the most important variables.
[1] Complete separation yielded unreliable/uninterpretable estimates.

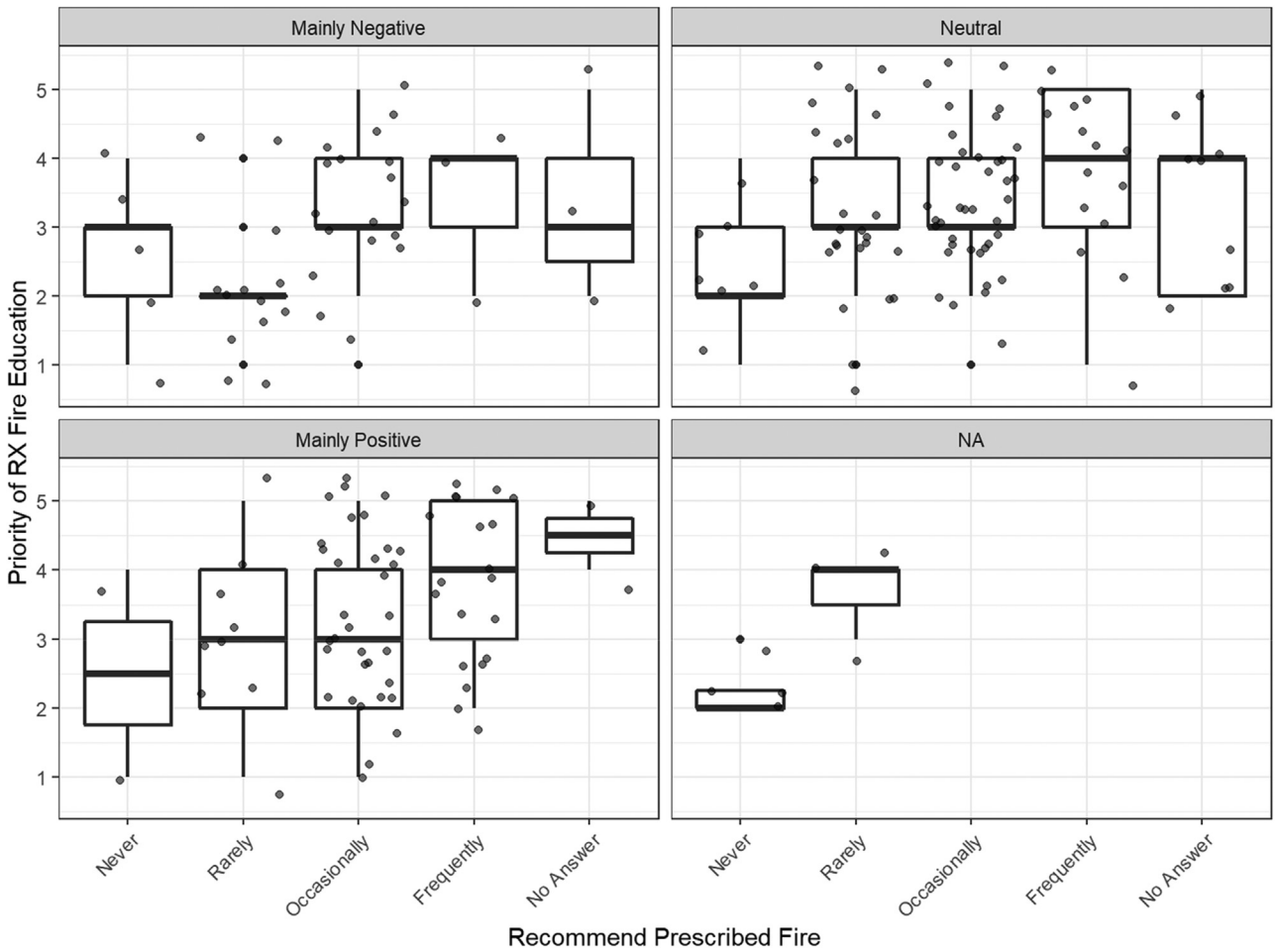

Figure 1. Boxplots showing median and interquartile range (boxes) and the range (whiskers) of responses for how often survey respondents recommend prescribed fire for brush management (x axis) by their rating for priority for prescribed fire education in their position (y axis). Each panel represents the response distribution for different categories of how they described their interactions with landowners about prescribed fire (positive, neutral, negative, or not applicable).

Table 2
Linear regression output modeling how survey respondents self-rate their level of knowledge about prescribed fire.

Predictors	Knowledge of Prescribed Fire		
	Estimates	*95% Conf. Int.*	*P-Value*
(Intercept)	−1.11	−2.60 to 0.38	0.142
Level of knowledge about prescribed fire—others	0.07	0.02-0.12	**0.009**
Level of comfort with prescribed fire—yourself	0.54	0.40-0.68	**<0.001**
Level of comfort with prescribed fire—others	−0.03	−0.08 to 0.01	0.178
Understand difference between prescribed fire and wildfire	0.05	−0.10 to 0.20	0.487
Awareness of laws/regulations regarding burn bans	0.02	−0.12 to 0.16	0.733
Priority of prescribed fire education in job	0.00	−0.08 to 0.09	0.911
Interaction with landowners about prescribed fire (Neutral)	0.04	−0.23 to 0.31	0.744
Interaction with landowners about prescribed fire (Positive)	0.02	−0.31 to 0.35	0.920
Interaction with landowners about brush management (Neutral)	−0.18	−0.90 to 0.55	0.631
Interaction with landowners about brush management (Positive)	−0.10	−0.73 to 0.52	0.741
How often asked to deal with brush management—linear	0.07	−0.76 to 0.89	0.876
How often asked to deal with brush management—quadratic	−0.82	−1.66 to 0.03	0.057
How often asked to deal with brush management—cubic	1.01	0.16-1.85	**0.020**
How often recommend mechanical and chemical treatment	−0.01	−0.13 to 0.11	0.856
Consider landowner liability in prescribed fire recommendation	0.05	−0.08 to 0.18	0.451
Rank of livestock production	0.05	−0.08 to 0.18	0.471
Rank of wildlife operation	0.07	−0.03 to 0.18	0.174
Gender (Female)	−0.04	−0.28 to 0.20	0.747
Years of formal education	0.05	−0.02 to 0.13	0.187
Observations / Degrees of freedom	136 / 116		
R^2 / R^2 adjusted	0.528 / 0.451		

Bold values are statistically significant probability values (<0.05) to highlight the most important variables.

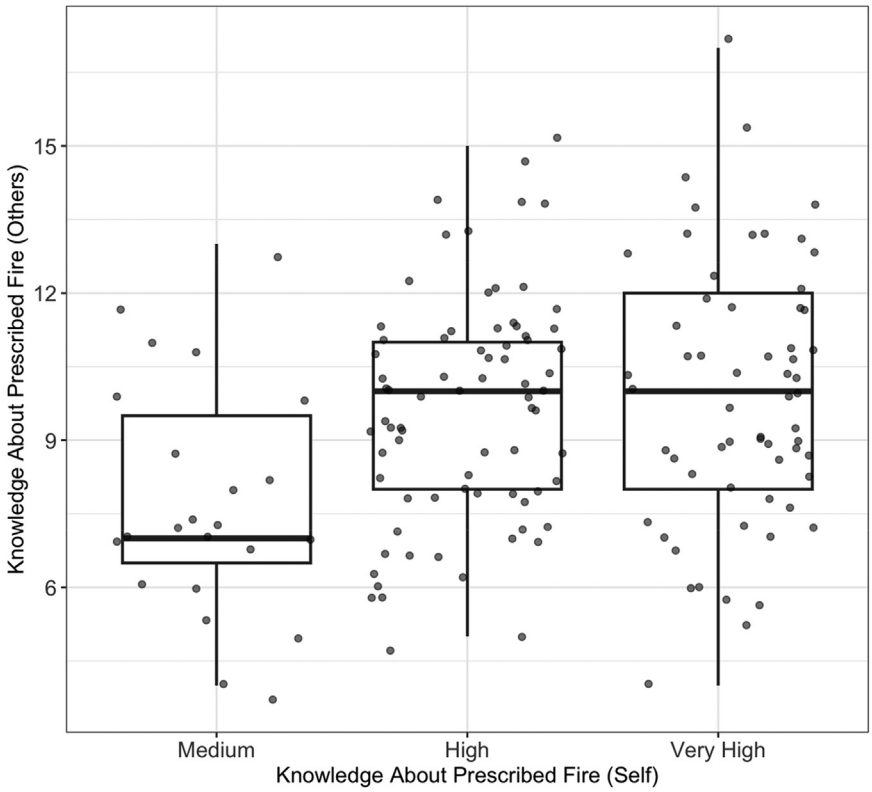

Figure 2. Boxplots showing median and interquartile range (boxes) and the range (whiskers) of responses for survey respondents rated their knowledge regarding prescribed fire (x axis) by their rating for knowledge of others (general public, landowners, county commissioners, and district court judges; y axis).

of prescribed fire ($P < 0.001$). By contrast, respondents' level of comfort with prescribed fire decreased very slightly (0.07 times, $P = 0.011$) with every categorical increment in others' knowledge of prescribed fire, but it increased slightly (by 0.06 times, $P = 0.023$) with every categorical increment in others' comfort level with prescribed fire; however, although these two contradictory effects were stastically significant, they were small enough to be negligible. Last in this explanatory variables category, respondents' level of comfort with prescribed fire increased by 0.27 times ($P < 0.001$) with every categorical increment in their awareness of laws and regulations regarding prescribed burning and burn bans.

In the *social interactions* category, the number of times respondents were asked to deal with brush management was also a significant variable, with their comfort level being negatively related with time spent on brush management ($\chi 2=6.32$, $P < 0.001$). While respondents who rarely spent time on brush management did not differ in comfort levels from those who never spent time on brush management (linear term, $P = 0.519$), respondents who

Table 3
Linear regression output modeling how survey respondents rate their level of comfort with prescribed fire.

Predictors	Comfort with Prescribed Fire		
	Estimates	*95% Conf. Int.*	*P-Value*
(Intercept)	2.10	0.53-3.67	**0.009**
Level of knowledge about prescribed fire—yourself	0.63	0.46-0.79	**<0.001**
Level of knowledge about prescribed fire—others	−0.07	−0.13 to −0.02	**0.011**
Level of comfort with prescribed fire—others	0.06	0.01-0.10	**0.023**
Understand difference prescribed vs. wildfire	0.04	−0.12 to 0.20	0.598
Awareness of laws/regulations regarding burn bans	0.27	0.13-0.41	**<0.001**
Priority of prescribed fire education in job	0.06	−0.03 to 0.15	0.194
Interaction with landowners about prescribed fire (Neutral)	0.02	−0.27 to 0.32	0.867
Interaction with landowners about prescribed fire (Positive)	0.14	−0.21 to 0.50	0.426
Interaction with landowners about brush management (Neutral)	−0.16	−0.94 to 0.63	0.693
Interaction with landowners about brush management (Positive)	−0.12	−0.79 to 0.55	0.717
How often asked to deal with brush management—linear	0.29	−0.59 to 1.17	0.519
How often asked to deal with brush management—quadratic	1.65	0.78-2.52	**<0.001**
How often asked to deal with brush management—cubic	−1.92	−2.78 to −1.06	**<0.001**
How often recommend mechanical and chemical treatment	−0.05	−0.18 to 0.08	0.446
Consider landowner liability in prescribed recommendation	−0.11	−0.24 to 0.03	0.123
Rank of livestock production	−0.14	−0.28 to −0.01	**0.041**
Rank of wildlife operation	−0.05	−0.17 to 0.06	0.382
Years of formal education	−0.04	−0.12 to 0.05	0.381
Gender (Female)	−0.23	−0.48 to 0.02	0.076
Observations / Degrees of freedom	136 / 116		
R^2 / R^2 adjusted	0.654 / 0.597		

Bold values are statistically significant probability values (<0.05) to highlight the most important variables.

spent time on brush management occasionally were 1.65 times more likely to be comfortable with prescribed fire than those who had never spent time on brush management (quadratic term, $P < 0.001$), while those who spent time on brush management frequently were 1.92 times less likely to be more comfortable with prescribed fire than those who never spent time on brush management (cubic term, $P < 0.001$). Lastly, one control variable was also stastically significant in the respondent comfort level model. Holding all other variables constant, the respondents' level of comfort with prescribed fire decreased by 0.14 times with each rank increment in the relative abundance of livestock production compared to other land uses in their area of operation ($P = 0.041$).

Discussion

Restoration of fire in fire-adapted ecosystems has been widely recognized as necessary to curtail woody plant expansion, enhance biodiversity, and reduce woody fuel loads that are exacerbating wildfires (Ryan et al. 2013; Donovan et al. 2017; Vaillant and Reinhardt 2017; Kolden 2019). Therefore, natural resource professionals tasked with increasing the adoption of conservation practices should prioritize the use of prescribed fire as a rangeland conservation practice (Wilbur et al. 2021). Unfortunately, the widespread use of prescribed fire on private lands in the Southern Great Plains has been shackled by liability concerns instead of being adopted as a biome priority (Weir et al. 2019). While the NRCS is the federal agency primarily responsible for the delivery of rangeland conservation incentives to private landowners (NRCS 2023), the extent to which it includes prescribed fire in its toolbox of initiatives varies widely among states. To address this quandary, our study explored the extent to which various factors influence natural resources professionals' (NRCS employees') knowledge and comfort level regarding prescribed fire and the frequency with which they recommend this conservation practice. Our survey revealed that both *prescribed fire awareness* and *social interaction* factors affected these three aspects of their engagement with prescribed fire.

Frequency of prescribed fire recommendation

We found that not a single factor associated with natural resources professionals' *prescribed fire awareness* was significantly related with their frequency of recommendation for the use of this land management tool. Rather, *social interaction* factors were the dominant driver of their frequency of prescribed fire recommendations. However, whereas the number of interactions with landowners about prescribed fire was positively associated with the frequency of respondents' recommendations to apply prescribed fire, the number of times they consulted with landowners about brush management was not consistently associated with such recommendations. Based on the finding that prescribed fire is economically likely the only feasible option for reducing woody plant cover at large scales (van Liew et al. 2012), the seeming discontinuity between woody cover and prescribed fire recommendation frequency seems contradictory. However, this finding corresponds with Stroman et al. (2020) who found no correlation between the desire of landowners in Texas and Oklahoma to reduce woody plants on their land and their willingness to apply prescribed fire because concerns over legal liability inhibit many landowners from applying this conservation tool regardless of its economic efficiency (Morton et al. 2010; Toledo et al. 2012). The availability of other management options, while often cost-prohibitive at scales sufficient to address woody plant encroachment, might also reduce the impetus to offer prescribed fire incentives. One implication of these findings is that natural resource professionals may prefer to keep fire at arm's length to avoid being blamed for an escaped fire that was tied to the objective of controlling brush expansion, especially in areas where they have more negative interactions with landowners. By contrast, they may have more positive interactions with landowners in areas that have a positive fire culture. In many instances, pro-fire cultures are associated with the presence of prescribed burn associations (PBAs), which tend to be more common in regions with a serious woody encroachment problem (Twidwell et al. 2013). Oklahoma currently has 22 PBAs under the umbrella of the Oklahoma Prescribed Burn Association, and Texas has at least 11 PBAs that are supported by the Prescribed Burn Alliance of Texas, and many others have been initiated throughout the Great Plains states and in Florida and California.

An important implication of these findings is that better knowledge about this management tool is necessary but not sufficient for more frequent prescribed fire recommendations by natural resource professionals. Instead of focusing only on technical proficiency, federal agencies tasked with facilitating land management

improvement should build stronger social networks in areas where prescribed fire acceptance is limited. Given the voluntary nature and strong local influence of rural landowner associations, notably PBAs, an important strategy for federal agencies, such as the NRCS, would be to more directly engage with and support the activities of existing PBAs and to encourage the establishment of new PBAs. These organizations engage landowners in expanding the use of prescribed fire on private land through training, shared fire management equipment, and shared labor on burn days, and have created more positive fire cultures among their members (Taylor 2005; Twidwell et al. 2013; Toledo et al. 2014). Practically, the NRCS could partner with PBAs in promoting the application of prescribed fire on private land by initiating direct communications with the leadership of PBAs, aiding in the development of burn plans, providing federal funding for fire management equipment, and contributing labor on burn days. Whereas differences in legal statutes regarding prescribed fire have been found to affect the frequency and extent of burning (Wonkka et al. 2015), regions with similar legal statues may differ in fire culture. For example, Stroman et al. (2020) found that landowners in Oklahoma have a stronger fire culture and were more likely to apply prescribed fire than their counterparts in Texas, both of which have simple negligence liability standards. Understanding the reasons for such differences and facilitating the creation of conditions that promote more positive fire cultures should be an important objective of national land management agencies. Additionally, they should recognize that land ownership fragmentation can lead to contrasting social ideologies about fire with newer landowners who tend to own smaller properties being more reluctant to burn (Kreuter et al. 2008).

Level of knowledge of prescribed fire

In contrast to frequency of recommendation, knowledge of prescribed fire was mainly associated with *prescribed fire awareness* factors. Specifically, respondents' prescribed fire knowledge was positively associated with their comfort level and their perception about prescribed fire knowledge of other people with whom they interacted. While federal natural resource professionals are reportedly aware that fire is a necessary part of healthy ecosystems (McCaffrey et al. 2008), we did not find any significant association between respondents' self-reported knowledge of prescribed fire and their awareness of laws and regulations regarding its use. The implication is that increasing knowledge about prescribed fire is necessary not only among federal natural resource professionals but importantly also among other stakeholders, including state and county officials, such as County Commissioners and District Court Judges, and landowners (Kreuter et al. 2008; Hinojosa et al. 2020; McDaniel et al. 2021).

Level of comfort with prescribed fire

Survey respondents' level of comfort with prescribed fire was affected by one control variable and several *prescribed fire awareness* and *social interaction* factors. Specifically, it was negatively associated with the livestock being a primary land use in their region, which is contrary to prescribed fire use patterns in the southern Great Plains where the majority of burns are conducted on working rangelands where livestock is a primary land use (Weir et al. 2015). By contrast, the survey respondents' comfort with it was positively associated with their awareness of prescribed fire laws and burn bans. Their comfort was also somewhat positively associated with others' comfort level with prescribed fire but somewhat negatively associated with others' knowledge of prescribed fire, but the effect size of both of these variables was small, indicating they may not be key social factors. Nevertheless, these results are consistent with Toledo et al. (2013) who found that social norms (i.e., landowners' perceived support from their community members) are an important determinant of the attitudes of landowners towards the use of prescribed burns to manage brush. In addition, while respondents' comfort level was also positively correlated with a moderate number of requests for brush management input, it was negatively associated with frequent requests for such input. Assuming that the amount of time spent on brush management might be a proxy for how severe the brush problem is in their area of operation, this finding indicates respondents were more comfortable with the use of prescribed fire when brush levels are moderate than when fire behavior may be less controllable due to high woody plant fuel loads. Natural resource professionals may also be uncomfortable in recommending the use of prescribed fire to manage brush because weather windows that adhere to NRCS safe burning specifications are unpredictable and may become increasingly restricted under projected higher temperatures when wildfire risk may be higher (Luo et al. 2013; Abatzoglou and Williams 2016; Twidwell et al. 2016). Rather, they may perceive economically less efficient chemical or mechanical brush management treatments to be safer and easier to implement within a specified timeframe.

Necessary measures for natural resource professionals to promote prescribed fire use

Collectively our findings have several implications for ensuring that federal professional natural resource managers are more knowledgeable about and comfortable with prescribed fire and, importantly, more willing to recommend it as a preferred rangeland restoration, woody plant management, and wildfire mitigation tool.

National unified policy supporting the use of prescribed fire on privately-owned rangelands: Wilbur et al. (2021) emphasized the need for a national unifying policy guiding prescribed fire use because negative fire culture at the federal level reduces natural resource professionals' comfort with prescribed fire and, therefore, has an erosive effect on agencies' willingness to assist landowners with prescribed fire applications. This is beginning to take shape with the redrafting of The National Cohesive Wildland Fire Management Strategy, the guiding document on wildfire management in the USA (NRCS 2019), and reports associated with redrafting from wildland fire leadership. It highlights three foci for effective fire management in the face of increasingly extreme fire behavior, increasing costs of fire suppression, and increasing risks to people and their communities (USDA/DOI 2014; WFMMC 2023). The Cohesive Strategy, a report from the Wildland Fire Mitigation and Management Commission, and a recent report to Congress from the Wildland Fire Leadership Council emphasize the need for an "all hands, all lands" approach to proactive fuels management, which will require more support for private landowners in the application of prescribed fire. Additionally, the recently proposed Prescribed Fire Act would make funds available and facilitate collaboration across jurisdictions for required prescribed burning. At the national level, NRCS policy makes prescribed burning available as a conservation management practice for all producers (NRCS 2019). It is programmatically available through the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), which provide cost deferment for prescribed burning on private lands. Recent national policy shifts reduced the level the Job Approval Authority needs to approve burn plans in order to enhance the capacity for burning with NRCS assistance. Despite national support for and encouragement of prescribed burning, state-level NRCS leadership has ultimate authority over what NRCS employees will be allowed to do regarding prescribed burning. Accordingly, the availability of technical assistance from the NRCS

and prescribed burning recommendations vary widely across states (Weir et al. 2015). NRCS personnel can both develop a burn plan and assist with burning on private lands in only 14 states (Maine, Pennsylvania, Maryland, Tennessee, Georgia, Florida, Arkansas, Illinois, North Dakota, Kansas, Oklahoma, New Mexico, Arizona and Nevada), despite calls at the national level within the NRCS and across wildland fire management leadership to increase private land burning (Weir 2020). Oklahoma is one of only a handful of states in which NRCS personnel are allowed to both develop burn plans and assist on private land fires in any capacity, including as a burn boss or crew leader (Weir 2020). In many of the 14 states where they are allowed to assist with fire, they are not allowed to conduct ignitions or be a burn boss/crew lead, and in Tennessee, Georgia, Arkansas, Illinois, North Dakota and Nevada they are allowed to only assist with training burns. In Texas, NRCS personnel can assist with burn plan preparation, and are only allowed to observe but not participate in prescribed fire (Weir 2020). In general, this is consistent with NRCS policy to provide technical guidance and financial support but not assist in implementation for other incentivized practices (e.g., brush management). However, the lack of experience in conducting prescribed fires has been noted in previous research as a factor contributing to lack of awareness by employees, and we would expect this to decrease agency recommendations for landowners to participate in prescribed fire incentives programs.

Other factors can also influence agency decisions to provide more technical assistance on prescribed burning. For example, pressure from the wildfire commission, tribal councils, and PBAs can move state programs to provide greater prescribed burning assistance. Recently, Missouri NRCS moved to shift its policy on prescribed burning to allow personnel to plan and assist private lands burners. This resulted from collaborations with Missouri Pheasants Forever, PBAs in the state, and others interested in enhancing private land burning in the state and coincides with a new prescribed burning statute being enacted in the state (RSMo Section 537.354; Wes Buchheit, personal communication).

Further confounding prescribed fire policy are differences in state statutes regarding escaped fire, which creates inefficiencies for federal support of prescribed fire application and inhibits federal natural resource professionals from assisting landowners due to liability concerns (Wilbur et al. 2021). Wonkka et al. (2015) found that conversion of prescribed fire liability standards from simple to gross negligence with codified regulations regarding burning was positively correlated with both prescribed fire frequency and area burned. For example, recently enacted legislation in California, SB 332 changed the state's liability standard for fire suppression costs from simple to a gross negligence, increasing protections for fire practitioners with approved burn plans, and SB 926 established a Prescribed Fire Pilot Fund that provides up to $2 million in coverage for qualifying projects led by burn bosses and cultural practitioners. (https://calcattlemen.org/2021/10/06/sb332/; https://legiscan.com/CA/text/SB926/id/2609473). Changing state statutes to gross negligence should be a national aspiration in order to increase the application of prescribed fire with federal support. In several states, NRCS policy shifted away from providing technical assistance on fires after lawsuits. This is likely less concerning to NRCS leadership in states where liability is limited via statue with gross negligence liability standards. It is crucial to address these issues collectively through scientific research, adaptive management strategies, and effective communication to reconcile the benefits of prescribed fire with potential challenges. This will require improved integration of science, policy, and management, and greater societal acceptance through education and public involvement in land-management issues, which is a key function of NRCS employees in this ecoregion.

Prescribed fire engagement and facilitation: Due to an ever-changing landowner demographic throughout the Southern Great Plains, conducting community workshops and public forums to educate landowners on the science of prescribed fire is a priority. These types of community education can highlight the differences between prescribed fires and wildfires in terms of emissions and air quality impacts. Implementing air quality monitoring programs during active prescribed fires to provide real-time data on particulate matter levels could elucidate the perceived risks associated with safe prescribed fire application further alleviating the concerns for liability and increase willingness to collaborate with the NRCS or other stakeholders (Wilbur et al. 2021). As air quality concerns grow and smoke regulations are enacted, public perception and liability inhibit the use of prescribed fire. This is exacerbated by historical wildfire incidents sparked by prescribed fires compounded by litigation and even criminal charges of "reckless burning" (Stringer 2024).

Physical engagement activities for training and application of prescribed fire are consistent with adult learning theory (Kreuter et al. 2008). Previous research focusing on the perspectives of county officials (District Court Judges and County Commissioners) in Texas and Oklahoma regarding prescribed fire concluded that participation in management burns would enhance their understanding of and comfort with this land management tool (Hinojosa et al. 2020; McDaniel 2021). Voluntary membership organizations, such as the PBAs of Texas and Oklahoma (and increasingly other Great Plains states), can enhance collaborative engagement by landowners, county and state officials, and federal natural resource professionals in broader application of this critically important rangeland management tool (Twidwell et al. 2013; Toledo et al. 2014).

Additionally, virtual engagement opportunities include online resources, webinars, and interactive tools explaining the science behind prescribed fire and its effects on air quality. Using visualizations and simulations to convey the controlled nature of prescribed burns and the subsequent dispersion of emissions, while leveraging social media platforms to share success stories and testimonials from communities where prescribed fires have been effectively used without compromising air quality standards, could reduce resistance, especially among new landowners. Even developing virtual reality experiences that allow users to explore the before- and after-effects of prescribed burns on grasslands, offering an immersive educational tool, may spur a positive conversation about prescribed fire between federal employees and landowners. By combining physical engagement initiatives with virtual outreach strategies, communities and stakeholders can foster a better understanding of the scientific basis for prescribed fire use, ultimately reducing resistance and promoting a more informed and supportive approach to prescribed fire management.

Implications

The application of prescribed fire on private rangelands has become more urgent for mitigating destruction from increasingly catastrophic wildfire. In the U.S., federal natural resource agencies, notably the NRCS tasked with prompting conservation practices on private land, play a critical role in expanding the use of land conservation practices including prescribed fire. While increased knowledge about prescribed fire and the associated laws and regulations are positively associated with comfort regarding this land management tool, our finding that social norms and interactions with landowners are fundamental to how often prescribed burning is recommended has important policy implications for federal agencies, such as the NRCS. Specifically, identifying ways to expand social networks should be a central feature of future national guid-

ance on prescribed fire. Prescribed burning associations provide an ideal mechanism for developing such networks with landowners and with state and county officials who deal with fire. These findings imply the need for a multifaceted approach for promoting prescribed fire by federal natural resources agencies that combines scientific knowledge, outreach, education, and financial incentives. By integrating these elements, federal natural resource agencies can collaborate with private landowners to be better equipped to apply prescribed fire on their land, leading to improved ecological outcomes and reduced wildfire risks under changing climate conditions.

Declaration of Competing Interest

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

CRediT authorship contribution statement

Urs P. Kreuter: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Carissa L. Wonkka:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis. **Dirac Twidwell:** Writing – review & editing, Writing – original draft, Visualization. **Morgan L. Treadwell:** Writing – review & editing, Writing – original draft, Visualization, Funding acquisition, Conceptualization. **N. Lee May:** Writing – review & editing, Data curation.

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