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Forest landowner values and perspectives of prescribed fire in the Northeast/Mid-Atlantic region of the United States

Arun Regmi[1*], Jesse K. Kreye[1] and Melissa M. Kreye[1]

Abstract

Background Fire is an important ecological process that shapes structures and compositions in many ecosystems worldwide. Changes in climate, land use, and long-term fire exclusion have altered historic fire regimes often leading to more intense and severe wildfires and loss of biodiversity. There is an increasing interest by resource managers to reintroduce fire in historically fire-dependent ecosystems while enhancing the provision of ecosystem services. Restoring fire, however, is complicated by a diverse mix of public and private land ownerships in regions like the Northeast/Mid-Atlantic US, where private lands make up the majority (~70%) but prescribed burning is less common. To help inform policies that promote prescribed burning on private lands, we conducted a regional survey of forest landowners regarding their perspectives and willingness to pay (WTP) for prescribed fire as a management tool. We also used spatial hotspot analysis to detect regional variations in landowner opinions.

Results Respondents had limited knowledge and experience with burning overall, but many also perceived fire as a low-risk tool and were trusting of burning professionals. Most landowners (64%) expressed interest in a variety of prescribed fire programs to help achieve management outcomes. Preferred outcomes include protecting forest health, controlling invasive species, and wildlife habitat. Also significant in explaining landowner choices were economic (e.g., cost of burning), governance (e.g., state coordination, cost-share assistance, and access to consultants), and demographic factors. According to two models, the mean WTP for the prescribed fire was \$10 ha^{-1} and \$40 ha^{-1} (\$4 ac^{-1} and \$16 ac^{-1}) but could be as high as \$220 ha^{-1} (\$89 ac^{-1}) for specific outcomes and programs. Spatial analysis revealed a north–south gradient in landowner opinions across the region, with opinions about burning more positive in the south. Pennsylvania landowners were unique within our study in that they placed the highest economic value on prescribed fire, despite having limited knowledge and experience.

Conclusions There is significant support by landowners to use prescribed fire to achieve management objectives on private lands in the Northeast/Mid-Atlantic region. Pennsylvania landowners, in particular, were strongly motivated to use prescribed fire; however, knowledge and experience are severely limited. Education, technical support, financial assistance, and access to professionals will be important for helping landowners use prescribed fire to achieve management objectives.

Keywords Private landowners, Forest management, Economic demand, Choice experiment hotspot analysis, Prescribed burning, Spatial autocorrelation, Willingness to pay

*Correspondence:
Arun Regmi
arun.regmi@psu.edu
Full list of author information is available at the end of the article

Resumen

Antecedentes El fuego es un proceso ecológico importante que modela la estructura y composición de muchos ecosistemas del mundo. Cambios en el clima, en el uso de la tierra y la exclusión del fuego por largos períodos, ha alterado los regímenes históricos de fuegos y los ha llevado a provocar incendios más intensos y severos y la consecuente pérdida de biodiversidad. Hay un interés creciente de los gestores de recursos por reintroducir el fuego en ecosistemas que históricamente dependieron de fuegos periódicos y aumentar de esa manera la provisión de servicios ecosistémicos. Sin embargo, restaurar el fuego es complicado, dada la mezcla diversa de propietarios de tierras públicos y privadas en regiones como en el Noreste y en la zona atlántica media de los EEUU (Northeast/Mid-Atlantic US), donde la mayoría de las propiedades (~ 70%) son privadas y las quemas prescriptas menos comunes. Para ayudar a establecer políticas que promuevan las quemas prescriptas en tierras privadas, condujimos un relevamiento regional de propietarios forestales para conocer sus perspectivas y voluntad de pagar (willingness to pay, WTP) por las quemas prescriptas, como una herramienta de manejo. Usamos también un análisis de puntos conflictivos para detectar variaciones en las opiniones de los propietarios de tierras.

Resultados Quienes respondieron al relevamiento tenían conocimientos y experiencias limitadas con las quemas en general, aunque muchos percibieron al fuego como una herramienta de bajo riesgo y confiaron en la experticia de los quemadores profesionales. La mayoría de los propietarios (64%) expresaron su interés en una variedad de programas de quemas prescriptas para alcanzar objetivos de manejo. Los objetivos de manejo preferidos incluyeron la protección de la sanidad del bosque, el control de especies invasoras, y el hábitat para la fauna. También significativos en explicar las preferencias de los propietarios fueron la cuestión económica (i.e. el costo de la quema), la gobernanza, (i.e. la coordinación por parte del estado, la asistencia en compartir los costos, y el acceso a los consultores), y los factores demográficos. De acuerdo a dos modelos, el costo medio para una quema prescripta fue de 10 dólares/ha, y de 40 dólares/ha (4 y 16 dólares por acre), pero puede llegar a tanto como 220 dólares /ha (89 dólares por acre) para programas y resultados especiales. Los análisis espaciales revelaron un gradiente de norte a sur en la opinión de los propietarios, con opiniones más positivas sobre las quemas prescriptas en el sur. Los propietarios de Pennsilvania fueron los únicos en nuestro estudio que dieron el valor más alto a las quemas prescriptas, a pesar su poco conocimiento y experiencia con esta herramienta.

Conclusiones Existe un apoyo significativo por parte de los propietarios en usar quemas prescriptas para conseguir objetivos de manejo en tierras privadas en la región del noreste y atlántica media de los EEUU (Northeast/Mid-Atlantic US). Los propietarios de tierras de Pennsilvania, en particular, fueron fuertemente motivados para usar quemas prescriptas; sin embargo, su conocimiento y experiencia en el tema son severamente limitados. La educación, el soporte técnico, la asistencia financiera, y el acceso a profesionales va a ser muy importante para ayudar a los propietarios a usar las quemas prescriptas para así lograr objetivos de manejo.

Background

Fire is a natural ecological process that has shaped landscapes and ecosystems around the world for millennia (Keeley et al. 2011). Humans have intentionally used fire for centuries to alter the landscape for hunting and agricultural purposes (Anderson 2006; Gillson et al. 2019; Díaz et al. 2023). Today, the use of prescribed fire or "controlled burning" is limited due to changes in land use, climate change, and strict fire suppression policies (Ryan et al. 2013; Prichard et al. 2017; Brando et al. 2019; Moura et al. 2019). Long-term fire exclusion in forests has led to several undesirable outcomes, including the loss of valuable fire-dependent tree species, high stand densities, and increased fuel loads (Nowacki and Abrams 2008; North et al. 2015; Fernandes et al. 2013). To reverse this trend, advocates are looking to re-introduce burning as a cost-effective way of restoring fire-resilient ecosystems and reducing wildfire hazard. Today, controlled burning is commonly used as a management tool in the United States (US) and many parts of the world (Fernandes et al. 2013, Ryan et al. 2013, Harper et al. 2018, Moura et al. 2019, Morgan et al. 2020). However, rates of adoption have been much slower in the Northeast/Mid-Atlantic region of the US, where fire has been long excluded and the reintroduction of fire may be more complicated (Lee et al. 2014; Melvin 2021).

Historically, the Northeast/Mid-Atlantic region contained a variety of fire-adapted ecosystems (e.g., oak forests, pitch pine). Centuries of fire exclusion led to the mesophication of these ecosystems and fire-tolerant species are now less likely to persist in the long term due to a lack of successful regeneration (Nowacki and Abrams 2008; Alexander et al. 2021). Re-introducing fire in these landscapes may help meet national wildfire policy goals of restoring and maintaining fire-resilient landscapes.

Establishing fire-adapted communities, or communities that intentionally live with fire, can also help deliver new economic and cultural benefits (Brose et al. 2014; Clark et al. 2014; Lee et al. 2014). Changes in legislation over the last decade have allowed prescribed burning to increase in the Northeast/Mid-Atlantic states (Melvin 2021). The enactment of the Prescribed Burning Practice Act in 2009 in Pennsylvania led to a tenfold increase in annual burned area from 1108 ha (2737 acres) in 2010 to 8863 ha (21,901 acres) in 2021, with over 60,703 ha (150,000 acres) burned in a decade (PA-DCNR 2022). Restoring fire is still complicated by a diverse mix of public and private land ownership (Ryan et al. 2013). Most burning in this region is conducted on public lands by federal, state, and some non-governmental agencies. Burning on private lands is less common, even though 70% of forests in this region are privately owned (Oswalt et al. 2019; Regmi et al. 2023). Forest landowner demand and preferences for using prescribed fire on their land have been recently explored in the Northeast/Mid-Atlantic region (Regmi et al. 2023).

The public in the Northeast/Mid-Atlantic region was found to be supportive of prescribed fire and demonstrated high trust in state agencies that implement burning (Wu et al. 2022). However, using prescribed fire on private lands in the region depends on both the willingness and abilities of the landowner (Regmi et al. 2023). Studies outside the Mid-Atlantic identified personal, societal, legal, institutional, and economic factors that constrain the acceptance and use of prescribed fire on private lands. For example, perceived risk of liability is often cited as a major impediment to landowner decisions about fire (Wonkka et al. 2015; Kreuter et al. 2019; Weir et al. 2019; Melvin 2021). Knowledge and past experiences can also shape landowner perceptions of risk (Yoder et al. 2004; Toledo et al. 2013; Twidwell et al. 2015; Kreuter et al. 2019). Trust in the person or institution responsible for implementing the burn has been found to influence the acceptability of prescribed fire (McCaffrey 2006; Regmi et al. 2023). Other functional barriers include issues such as property size, income, narrow burn windows, and lack of adequate personnel (Kreuter et al. 2008, Quinn-Davidson and Varner 2011, Melvin 2021). Policies that support landowner engagement and help address functional barriers will likely be critical for establishing a prescribed fire economy in this region.

To understand how prescribed fire policies may impact public welfare, non-market valuation research methods are commonly used. Many US studies focus on homeowner willingness to pay (WTP) for prescribed fire on public lands to reduce wildfire hazard (Loomis et al. 2002; Kaval et al. 2007; Walker et al. 2007; Loomis and Gonza´lez-Caba´n 2010). For example, residents of Colorado were willing to pay \$140 to \$796 per year for prescribed fire activities on public lands near their homes (Kaval et al. 2007; Walker et al. 2007). A more recent study found forest landowners in Mississippi were willing to pay an average of \$102.28 ha^{-1} (\$41.39 ac^{-1}) for prescribed fires that may help reduce wildfire hazard (Shrestha et al. 2021). Outside the US, Varela et al. (2014) used an economic choice experiment that revealed significant heterogeneity in public preferences for different fire prevention strategies in Mediterranean Europe, including prescribed fire. Mavsar et al. (2013) also found that residents preferred mechanical fuel treatment techniques over prescribed burning to reduce wildfire hazard.

Prescribed fire benefits extend beyond reduction in wildfire hazard and help bring about a variety of non-market goods and services through ecosystem management (Ryan et al. 2013; Waldrop and Goodrick 2012). Prescribed fire management in Australian tropical savannas provided a well-being value of US \$189 million per year to the indigenous people of the region (Sangha et al. 2021). To our knowledge, there have been no other studies that examine the value of prescribed burning to achieve more holistic management objectives, except for our most recent paper (Regmi et al. 2023). More economic research is needed to help address the market failures associated with ecosystem service provision and fire suppression. In this paper, we explore landowner intentions about using prescribed fire across a variety of economic, cultural, political, and geographical contexts. Specific parameters include knowledge, attitudes, and WTP for prescribed burning programs in the Northeast/Mid-Atlantic region of the US. Findings are expected to help policymakers design more targeted landowner assistance programs and advocate for policies that promote burning on private lands.

Methods and materials

Study sites

The study was conducted in four states across the Northeast/Mid-Atlantic region of the US: New York (NY), Pennsylvania (PA), Maryland (MD), and Virginia (VA) (Fig. 1). Fire history studies propose that mean fire return interval before 1850 was 8–12 years for most of the study area but was less frequent in northern portions of the study area (Guyette et al. 2012; Stolte 2012). Today, burning is more widely implemented in southern portions of the region. In 2022, more than 12,141 ha (30,000 acres) of forests were burned in VA, while only 4856 ha (12,000 acres) were burned in PA and 4452 ha (11,000 acres) in MD (NIFC 2022). Prescribed burning in NY is even rarer, where approx. 405 ha (1000 acres) were burned in

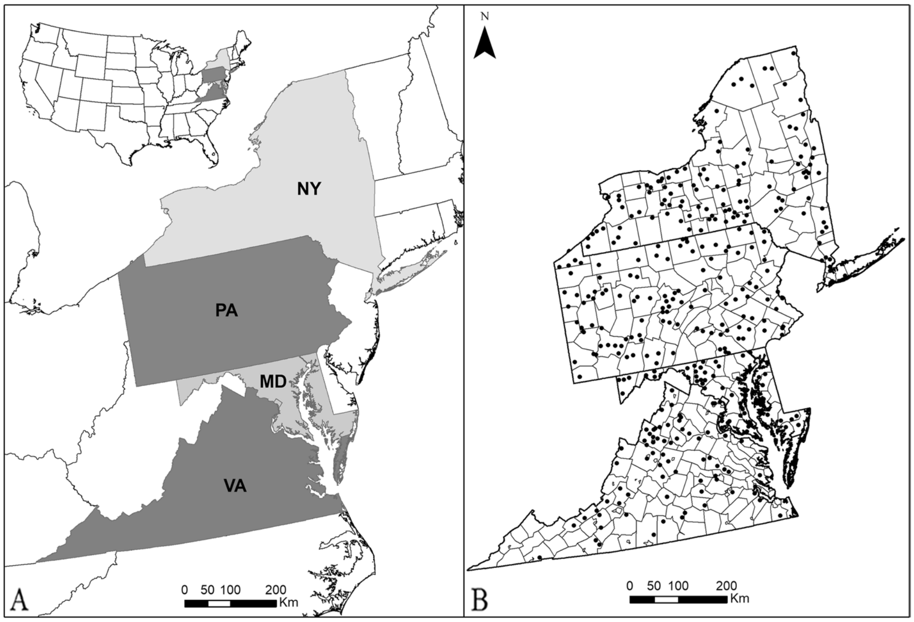


Fig. 1 **A** Study area location in the US Mid-Atlantic region (New York, Pennsylvania, Maryland, and Virginia) and (**B**) spatial distribution of survey responses

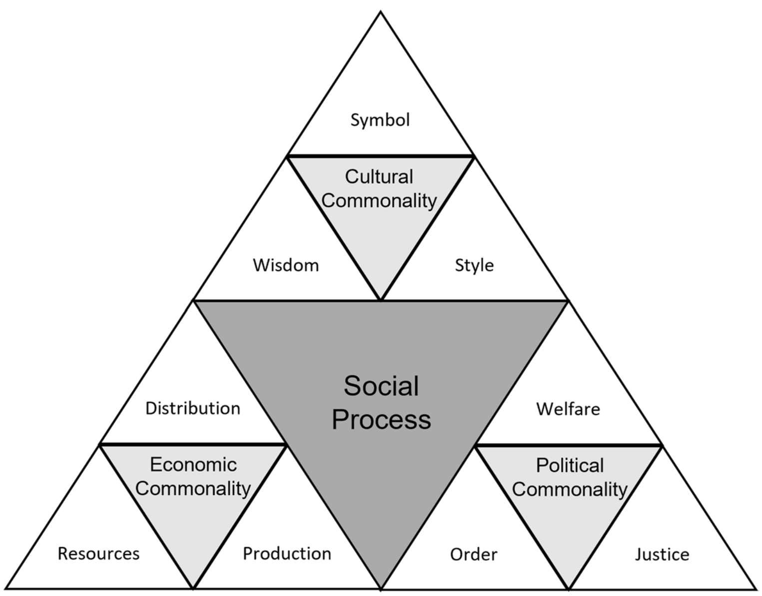


Fig. 2 Social process triangle

2022, but this is still an increase compared to past years (Melvin 2021). Ecological responses to fire exclusion and fire reintroduction in this region are expected to vary, due to several factors (e.g., pre-suppression fire frequency, ecosystem dependency on burning, the extent to which fire was excluded).

Theoretical approach

Social network theory endeavors to describe the processes by which society evolves (Lusher et al. 2013). The Social Process Triangle (SPT) is useful for assessing social conditions and the complex factors behind them to create strategies for addressing social issues in communities and organizations (Fig. 2). The SPT framework below depicts the inter-relatedness of social dynamics that may be associated with land management and prescribed fire.

Following this conceptual model, we expect that landowner willingness to use prescribed fire is likely a function of the political, cultural, and economic context in which decisions are made. Landowner perspectives of prescribed fire may also vary across the region due to heterogeneity in ownership objectives, legal provisions, and complex ecological and geographical conditions.

Political context

After a century of fire suppression, political officials in these states provided a legal framework for prescribed burning by passing a variety of acts and policies. The primary approach was to give civil and criminal liability protection to prescribed fire implementers who burn under certain standards (e.g., PA) or provide exclusions for prescribed burning where open burning is otherwise not legal (e.g., NY). Many of these acts were passed in 2009 in PA and NY and 2010 in MD. Virginia implemented a series of laws related to fire going back to 1998 which can be found in Articles 6 and 6.1 § 10.1–1150 to § 10.1–1150.6. The liability laws used in PA, MD, and VA are standard (i.e., simple negligence), but NY has a stricter liability standard (Melvin 2018). Prescribed fire councils, comprised of both public and private stakeholders with a vested interest in prescribed fire use and policy, have been established in PA and VA to help promote prescribed burning in their states (Melvin 2018). Even with liability laws in place, landowner reaction to these laws is not well understood, and burning on private lands can still be limited if political officials are risk-averse (Schultz et al. 2019).

Cultural context

Cultural values about prescribed fire are often a function of people's knowledge, beliefs, and attitudes. Despite its limited use, some landowners in this region may view prescribed fire as a useful tool for supporting cultural values about land management and achieving certain benefits such as hunting, resource gathering, and cultural heritage preservation (Schultz et al. 2019). Cultural values about fire and land stewardship can also be shaped by offerings of technical assistance and training programs in prescribed fire. Virginia already has an established system to conduct prescribed fire on private lands, including a landowner education program through Virginia Polytechnic Institute and State University (Virginia Tech) and a certified prescribed burn manager program operated by the Virginia Department of Forestry. They also have more fire professionals to conduct burning (e.g., burn bosses, and consultants), compared to the other states included in this study. In 2023, the Pennsylvania Prescribed Fire Council started to provide learn and burn opportunities for landowners in the state, but opportunities are still limited in PA as well as the other study states.

Economic context

Implementation costs for prescribed fire vary greatly across the US. In the southeastern US, where prescribed fire is more established, the average cost is around \$77 ha^{-1} (\$31 ac^{-1}) (Maggard 2021). The cost of burning in the Northeast/Mid-Atlantic states has not been formally documented; however, interviews with practitioners suggest that costs can range from \$99 to \$988 ha^{-1} (\$40 to \$400 ac^{-1}) or more depending on the total area burned and availability of trained personnel (Regmi et al. 2023). The limited number of trained burning professionals in this region could be one reason why costs are high (i.e., increased competition). At these prices, some landowners may need cost-share assistance to help achieve burning goals. High liability protection costs could also discourage landowner participation even when incentives are provided (Schultz et al. 2019).

Survey design

A multi-stage process was used to design, test, validate, and distribute a survey to private landowners across the Northeast/Mid-Atlantic US (Dillman et al. 2014). To help develop survey questions, semi-structured interviews were conducted with 25 participants representing diverse stakeholder groups including landowners. The final survey contained 68 questions and consisted of four sections: (1) information on land ownership and management objectives; (2) questions to measure knowledge, perceived risk, and trust; (3) choice experiment questions; and (4) landowner demographic questions. Survey pre-testing was conducted with more than 20 participants including forest landowners, state agency personnel, and other research professionals.

Attitude and knowledge scales

Five-point Likert scale questions (1 = strongly disagree, 5 = strongly agree) were used to measure respondents' knowledge and experience with prescribed fire, trust in prescribed fire implementers, and perceived risk of prescribed fire. Scaler statements were developed based on the psychometric tools produced in related studies (e.g., Blanchard and Ryan 2007, Elmore et al. 2009, Busam and Evans 2015).

Choice experiment design

A choice experiment technique was used to understand landowner motivations and WTP for prescribed

Table 1 Description of dependent and independent variables tested in mixed logistic regression models for the willingness to pay for using prescribed fire

Name	*Description*	*Coding*
Dependent variable		
Choice (WTP)	Willingness to enroll in a prescribed fire program?	Binary*: 1 = yes, 0 = no
Independent variables		
Program attributes (factors and levels used in choice experiment)		
Ecological outcomes (EO)	0. Promote oak regeneration	Reference level (– 1)[+]
	1. Improve wildlife habitat	1 = EO_1, and 0 if else
	2. Restore rare vegetation	1 = EO_2, and 0 if else
	3. Maintain forest health	1 = EO_3, and 0 if else
Management benefits (MB)	0. Reduce management costs	Reference level (– 1)
	1. Control invasive plant species	1 = MB_1, and 0 if else
	2. Reduce ticks that harm humans	1 = MB_2, and 0 if else
	3. Reduce tree/plant pests	1 = MB_3, and 0 if else
Support resources (SR)	0. Landowner training	Reference level (– 1)
	1. Prescribed fire associations	1 = SR_1, and 0 if else
	2. State agency coordination	1 = SR_2, and 0 if else
	3. Financial assistance: cost share	1 = SR_3, and 0 if else
Institutional factors (IF)	0. Reduce legal liability	Reference level (– 1)
	1. Access to qualified consultants	1 = IF_1, and 0 if else
	2. Access to qualified burn bosses	1 = IF_2, and 0 if else
	3. Relaxed standards	1 = IF_3, and 0 if else
Price	Cost of burning per ha (or per acre)	Categorical: \$49 (\$20), \$124 (\$50), \$309 (\$125), \$494 (\$200)
Psychological factors		
Trust	Trust in prescribed fire implementers (total score)	Continuous: 1 = low trust, 5 = high trust
Risk	Perceived risk of prescribed fire (total score)	Continuous: 1 = low risk, 5 = high risk
Landowner characteristics		
Assistance program	Past use of government assistance	Binary: 1 = previously enrolled in an assistance program, 0 if else
Pennsylvania	State of residence	Binary: 1 = Pennsylvania, 0 if else
Virginia	State of residence	Binary: 1 = Virginia, 0 if else
New York	State of residence	Binary: 1 = New York, 0 if else
Maryland	State of residence	Binary: 1 = Maryland, 0 if else
Income	Annual household income	Ranked categories: 1 = < \$20 k, 2 = \$20 k to < \$50 k, 3 = \$50 k to < \$80, 4 = \$80 k to < \$100 k, 5 = \$100 k to < \$150 k, 6 = \$150 k to < \$250, 7 = \$250 k & more
Age	Age of respondent (years)	Ranked: Categories: 1 = 18 to 24, 2 = 25 to 34, 3 = 35 to 44, 4 = 45 to 54, 5 = 55 to 64, 6 = 65 to 74, 7 = 75 or older

[*] Observations were recoded to 0 if the associated response on the 10-point confidence scale was ≤ 5. [+]Program attributes were effect coded

fire programs. This method is frequently used in environmental research to evaluate the monetary value of non-market goods and services (Hanley et al. 1998; Hensher et al. 2015). Respondents are asked to make decisions about a series of hypothetical management programs (often called a choice set) made up of a combination of attributes. This approach is based on random utility theory which provides the necessary link between a statistical model (i.e., observed landowner behavior) and an economic model of utility maximization (see Hanley et al. 1998).

A total of 16 choice sets were designed using the Taguchi orthogonal array (OA) (Cimbala 2014). Preliminary surveys, interviews, and focus group discussions revealed the need to rank a wide range of potential program options and benefits. The attributes and levels used in the choice experiment were designed to represent what landowners may consider when deciding to adopt fire as a new management tool (see Table 1). For example, preferences for levels describing ecological outcomes and management benefits are expected to be dependent on the respondent's management objectives. Preferences for support resources are expected to be dependent on the barriers to prescribed fire that a respondent considers important. Preferences for levels describing changes in institutional factors indicate potential barriers that could be controlled by policy. A price attribute was also included in the design to estimate a marginal WTP for the other attributes. Based on interviews and focus groups, the price of burning can be highly variable ranging from \$49 to \$988 ha^{-1} (\$20 to \$400 ac^{-1}). These values informed the prices stated in this study.

To reduce respondent fatigue, only 8 of the 16 choice sets were presented to each respondent at any given time. A 10-point certainty scale (1 = Extremely uncertain, 10 = Extremely certain) was included with each WTP question to help control hypothetical bias (see Appendix 1). A follow-up 5-point Likert scale question (see Table 4) was asked after all choice questions to understand reasons for not accepting any of the giving programs.

Data collection

Data was collected through a regional survey that utilized mixed modes of distribution, including mail and web, following Dillman et al. (2014). The primary method of data collection was through a push-to-web method that involved mailing survey invitation postcards to respondents with a secure web link or QR code to access the survey. This method collected 55% of the data. For those who preferred a mail survey, a questionnaire with a cover letter was mailed, and this method collected 25% of the data. The mailing addresses of private forest landowners were obtained through collaboration with various private organizations and state agencies, including the Centre of Private Forests in Pennsylvania, the Pennsylvania Bureau of Forestry, the New York Forest Owners Association, and the Maryland Tree Farm Program. Some organizations were only willing to distribute survey information via their list-serve rather than sharing members' names and addresses for direct mailers. In such a case, we created an opt-in method where respondents could sign up to participate in the survey through a link on the project website. This method was used to collect the remaining data (20%). A link to the project website was distributed via collaborators' organizational list serves, including the Virginia Landowner Education Program's newsletter listserv and the Virginia Prescribed Fire Council listserv. Respondents could either take the survey online or request a paper copy of the survey. The Qualtrics software was used to design and distribute the web survey. To improve response rates, follow-up communications, such as reminder postcards or emails, were sent to non-responders.

Data analysis

Responses to attitude scales were analyzed by calculating a mean response to individual statements and grand means for the whole set of statements. The grand means are reported as descriptive statistics, and the total score was used as a covariate in the model. The certainty score associated with each WTP question was used to address the potential hypothetical bias. Respondents who accepted the choice set at the proposed price and had a certainty score of ≤ 5 had their responses changed to reject the program (referred to "certainty correction" hereafter), because of their lack of certainty about the purchase (Vossler et al. 2003). Effect coding[1] was used to parameterize program attributes and avoid confounding the *Opt-Out* coefficient (Bech and Gyrd-Hansen 2005).

Mixed logistic regression models (see Train 2009, chapter 6) were used to establish a relationship between the dependent variable (i.e., willingness to enroll in a prescribed fire program at the offered price per ha or per acre) and the independent variables listed in Table 1. Sequential runs of the model were set to retain variables significant at $P < 0.01$, $P < 0.05$, and $P < 0.10$ levels. Model selection was also based on goodness-of-fit measures including the likelihood ratio test and McFadden's Pseudo R-squared (Rolfe 2000).

The part-worth value (PWV) per ha (or per acre) (also referred to as WTP or marginal utility) of each attribute can be estimated using the ratios of a choice attribute ($\beta_{\text{attribute}}$) and price coefficients (β_{price}) given by Hanemann (1984) in the simplified form (Eq. 1):

$$\text{WTP(orPWV)} = -1\left(\frac{\beta_{\text{attribute}}}{\beta_{\text{price}}}\right) \tag{1}$$

We used the Krinsky-Robb simulation method as introduced by Hole (2007)[2] to estimate WTP standard errors and the 95% confidence interval for each variable. Total WTP for different prescribed fire programs (i.e., different combinations of variables) can be estimated using the following equation (adopted from Rolfe et al. 2000).

$$\text{Overall willingness to pay value} = -\frac{1}{\beta_{\text{price}}}(\beta_1 x_1 + \cdots + \beta_i x_i) \tag{2}$$

where β_{price} is the coefficient for the price per ha (or per acre) variable, $\beta_{1\ldots}\beta_i$ represents the coefficients of program attributes, and x_i represents the value of desired features (e.g., trust score).

Benefit transfer analysis

Equation 2 was used to conduct a value transfer procedure that predicted an acceptable mean price for

[1] The effects coded variable for an attribute level is set equal to 1 when that level is present in the choice set, and equal to − 1 if the reference level is present in the choice set and equal to 0 otherwise.

[2] Hole (2007) introduced a STATA command "wtp" based on the simulation of variance and co-variance matrix.

prescribed fire for each county based on income level and state. Values were transferred to each county by matching the income levels in the calculation with the median household income level in each county. The median household income values for each county were obtained from 2010 US Census Bureau data.

Spatial data analysis

We examined spatial variability in landowner knowledge, trust, risk perception, and WTP across the study area to determine if regional-scale variability existed beyond just simple state boundaries. Geospatial analyses were conducted using ArcGIS 10.8.2 (Esri Inc. 2021). Survey responses were geocoded and converted into individual point data using respondent zip codes (Fig. 1B). Next, the point data was spatially joined with county shapefiles, and point observations were aggregated into a mean value for each county. The aggregated mean value was later used as input data for hotspot analysis. Although the sample size was not high, the spatial distribution of survey respondents was widespread across the study region and county-level spatial analysis allowed us to conduct an initial examination of potential regional variability.

The Global Moran's I (Cliff and Ord 1981) was used to detect spatial autocorrelation of landowner knowledge and experience with prescribed burning, trust in fire implementers, risk perceptions, and WTP for using prescribed fire as a management tool. The Global Moran's *I* statistic tests whether landowner opinions are randomly distributed among counties in the study area or if there is any spatial pattern (or clustering). The local Getis-Ord Gi* statistic was used to identify significant hot and cold spots ($\alpha = 0.05$) associated with respondent responses (Getis and Ord 1992; Allen 2016). This statistic determines whether the local cluster of counties is significantly different from all counties. To measure the local Getis-Ord Gi* statistic, a threshold distance was obtained using the incremental spatial autocorrelation method, rather than relying on ArcGIS's default setting. The resulting hot spots are relative measures and represent clusters of counties with above-average values also surrounded by neighboring counties with high values. Likewise, cold spots indicate clusters of counties with below-average values also surrounded by counties with low values. While sample sizes were small within counties, spatial autocorrelation was expected to reveal hot or cold spots at a regional scale.

Results

Of the 2051 respondents contacted, 27 surveys were undelivered and 482 surveys were returned (adjusted return rate of 24%). After excluding non-usable responses,[3] 430 responses were classified as usable for the analysis. Based on the total landowner population of the study area, the expected sample size was 385 with a 95% confidence interval and 5% margin of error. A summary of the respondent demographic profiles are presented in Appendix 2 (Table 5). Among respondents, most were male (85%) and ≥ 55 years of age (87%). Many landowners (55%) owned less than 40 ha (100 acres) of forest. Most respondents (63%) had annual household income levels ≥ $80,000. About 78% of respondents held either a bachelor's degree, or equivalent, or a higher level of education. Many respondents (59%) reported that they were members of a private landowner association, and 47% reported that they had enrolled in government assistance programs in the past.

Management objectives

Respondents owned and managed forests for a variety of reasons (see Appendix 2: Tables 6 and 7). Most management priorities pertained to cultural benefits such as recreation, aesthetics, and a sense of place and to enhancing natural heritage. Timber production and income generation were generally lower priorities. The most common management activities included invasive plant species control, habitat management, regeneration of desired tree species, and stand improvement. Few survey respondents (14%) had any burning experience. Those that did burn generally used smaller burns to manage warm-season grasses, reduce understory fuel loads, or improve deer browse.

Knowledge, perception and trust scales

The grand mean score on the knowledge scale was relatively low (1.86), indicating many respondents have limited experience or formal knowledge about prescribed fire (Table 2). Most (78%) respondents disagreed with statements describing knowledge and experiences with prescribed fire (Tables 2 and 4). The grand mean for risk perceptions was also low (2.20), indicating that most respondents do not consider prescribed fire as having significant potential for hazard or harm. Respondent concerns mostly related to potential harm to human health due to poor air quality resulting from smoke (25%) and potential harm to native plants and trees from fires (23%). Most respondents (75%) perceive prescribed fire and wildfire are not dangerous to public safety. The grand mean for trust was high (3.78), indicating most respondents generally trusted the people and organizations who implement prescribed fire. Expressions of trust were higher for professional fire implementors (e.g., state agencies and consultants, about 82% of respondents agreed) compared to trained landowners who implement prescribed fire (about 45% of respondents agreed) (Table 2).

[3] Non-usable surveys include incomplete surveys, responses from non-landowners (e.g., wildlife managers, biologists, government professionals, etc.), and landowners with less than 10-acre forests.

Table 2 Mean response to statements on the knowledge, risk and trust scales (1 = strongly disagree, 5 = strongly agree)

Measurement items	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	SD
Knowledge and experiences (n = 426)							
I know people who have used prescribed burning	40%	6%	12%	16%	26%	2.81	1.68
I have taken higher education classes on ecosystem management and prescribed burning	67%	8%	9%	9%	8%	1.83	1.34
I have taken a training course on ecosystem management and prescribed burning	70%	6%	7%	10%	7%	1.79	1.33
I have experience conducting a prescribed burn	72%	6%	8%	6%	7%	1.70	1.27
I have been trained to conduct a prescribed burn	75%	5%	7%	5%	7%	1.64	1.25
I have enough experience and qualifications to be a burn boss	82%	6%	8%	2%	3%	1.39	0.94
Grand mean						***1.86***	***1.30***
Risk perceptions (n = 429)							
Prescribed fire often harms human health (e.g., smoke)	20%	29%	26%	22%	3%	2.61	1.13
Prescribed fire could harm native plants and trees	23%	31%	23%	20%	3%	2.49	1.14
Prescribed fire can cause soil erosion	27%	34%	25%	12%	2%	2.28	1.04
Animals are unable to find safety during prescribed fires	27%	45%	16%	10%	3%	2.17	1.02
Prescribed fire harms wildlife and destroys their habitat	32%	37%	19%	10%	2%	2.14	1.06
Prescribed fire can reduce water quality	33%	33%	27%	6%	1%	2.08	0.95
Prescribed fire reduces aesthetic/recreational benefits important to me	36%	33%	19%	10%	2%	2.08	1.05
Prescribed fire typically causes damage to private property	39%	31%	21%	7%	2%	2.03	1.04
Prescribed fire and wildfires are equally dangerous to the public safety	47%	28%	12%	10%	3%	1.94	1.11
Grand mean						***2.20***	***1.06***
Trust in Implementors (n = 430)							
I trust that trained resource management professionals have the skills needed to conduct a burn safely	3%	5%	10%	37%	45%	4.17	0.98
I trust state agencies will do a good job setting the prescribed fire standards	4%	8%	13%	38%	37%	3.96	1.08
I trust state agencies to run programs that promote the use of prescribed fire on private lands	5%	8%	18%	32%	37%	3.89	1.14
I trust that trained landowners have the skills needed to conduct a burn safely	15%	16%	24%	34%	11%	3.10	1.24
Grand mean						***3.78***	***1.11***

Value of prescribed fire programs

Sixty-four percent of respondents were willing to enroll in at least one prescribed fire program. The mean certainty score was 7.55 (out of 10) indicating that most respondents were highly confident in expressing their choices for programs on offer (i.e., choice sets). After using the certainty correction to modify responses (> 5), only 48% were willing to enroll in at least one prescribed fire program. Virginia had the most respondents (58%) willing to enroll, followed by PA (57%), MD (45%), and NY (32%). Many respondents (39%) preferred the lowest cost program (\$49 ha^{-1} or \$20 ac^{-1}), but 15% of respondents were willing to pay up to \$494 ha^{-1} (\$200 ac^{-1}) for burning (Fig. 3).

A total of 3434 WTP observations were used in the model, of which 36% were "yes" votes and 64% were "no" votes. Two mixed logistic models were fitted with data, the first base model used original data without the certainty correction, and the second model used the data with the certainty correction. The Akaike Information Criterion (AIC) was used for final model selection and results are presented in Appendix 2 (Table 8). Variables positively correlated with program enrollment (i.e., WTP) included trust, assistance program, income, Pennsylvania, Virginia, wildlife habitat, forest health, controlling invasive, state coordination, cost-share, and access to consultants. Variables negatively correlated with enrollment included factors such as risk, age, price, rare vegetation, and prescribed fire associations.

The mean WTP for prescribed fire programs was estimated to be \$35.98 ha^{-1} and \$15.42 ha^{-1} (\$14.56 ac^{-1} and \$6.24 ac^{-1}) in models 1 and 2, respectively (Table 3). The mean is used to describe the average level of utility or satisfaction associated with adopting prescribed fire for any given landowner. The PWV of significant variables ranged from − \$127.36 to \$221.75 ha^{-1} (− \$51.54

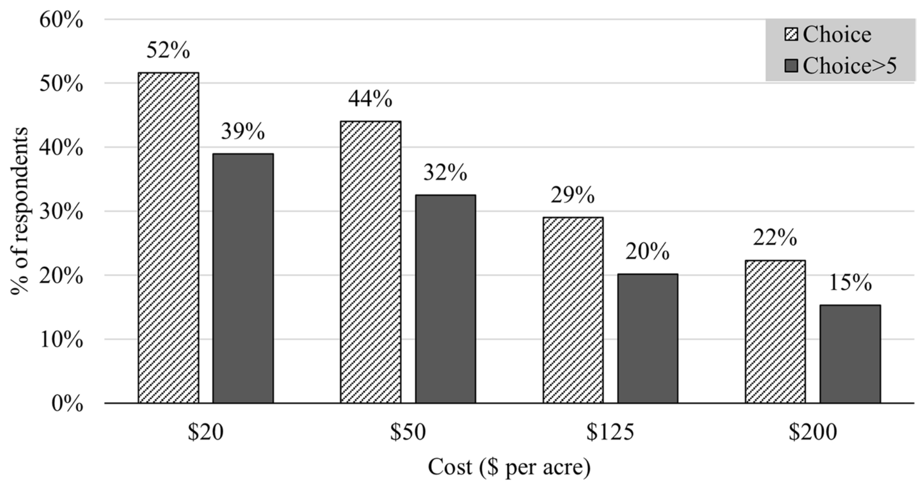


Fig. 3 Percent enrollment in proposed prescribed fire programs with four different price levels based on survey conducted in 2021–2022 across the Mid-Atlantic region, USA. Note: "choice" denotes survey responses without certainty correction, "choice > 5" denotes certainty corrected dataset (i.e., yes responses with certainty scores ≤ 5 were recoded "no"). [*Conversion factor from acre to hectare = 2.47*]

Table 3 Estimated willingness to pay (WTP) per acre values for significant variables obtained from the mixed logistic regressions, along with the 95% confidence intervals, based on the survey conducted in 2021–2022 across the Mid-Atlantic region, USA [*Note: Conversion factor to SI unit: one per acre = 2.47 per hectare, e.g., Trust $12.93 ac^{-1} = $31.95 ha^{-1} (2.47*$12.93)*]

Variables	Model 1 Original choice data		Model 2 Certainty corrected (choice > 5)	
	WTP ($/acre)	95% CI ($/acre)	WTP ($/acre)	95% CI ($/acre)
Trust	12.93	[6.85; 19.00]	9.99	[3.45; 16.53]
Perceived risk	− 6.79	[− 10.02; − 3.55]	− 8.02	[− 11.58; − 4.45]
Age category	− 45.63	[− 63.45; − 27.81]	− 51.54	[− 70.78; − 32.3]
Assistance program	62.56	[24.32; 100.79]	54.90	[14.18; 95.61]
Income category	11.29	[− 0.57; 23.15]	11.71	[− 0.99; 24.41]
Pennsylvania	38.87	[− 4.59; 82.33]	89.47	[42.4; 136.52]
Virginia	-	-	49.19	[− 1.39; 99.76]
Program attributes				
Wildlife habitat	9.99	[− 1.3; 21.27]	11.89	[− 0.31; 24.09]
Rare vegetation	− 18.05	[− 29.41; − 6.7]	− 20.06	[− 32.62; − 7.5]
Forest health/resilience	13.35	[2.52; 24.18]	13.73	[1.68; 25.77]
Control invasive	12.50	[3.03; 21.97]	-	-
Prescribed fire associations	− 14.95	[− 26.18; − 3.7]	-	-
State coordination	17.44	[6.45; 28.43]	-	-
Cost share	18.00	[7.06; 28.95]	19.18	[9.05; 29.32]
Access to consultants	7.89	[− 1.25; 17.03]	10.29	[0.2; 20.39]
Mean WTP	14.56	[12.92; 16.19]	6.24	[5.46; 7.02]

to $89.74 ac^{-1}). The PWV describes the average utility or satisfaction associated with an individual variable, relative to the other variables. Respondents who had enrolled in a government assistance program in the past were willing to pay $135.66 ha^{-1} ($54.90 ac^{-1}) more compared to respondents who had never been in an assistance program. Increasing trust by one level on the psychometric scale was associated with an increased WTP of $24.69 ha^{-1} ($9.99 ac^{-1}), whereas increasing the level of risk perception reduced the value of prescribed burn programs by $19.82 ha^{-1} ($8.02 ac^{-1}), on average. Landowners with higher income levels and who were younger were willing to pay an additional $28.94 and $127.36 ha^{-1} ($11.71 and $51.54 ac^{-1}) on average, respectively. More importantly, landowners from PA and VA were willing to pay an average of \$221.09 ha^{-1} and \$121.55 ha^{-1} (\$89.47 and \$49.19 ac^{-1}) more, respectively, compared to the other study states (NY and MD) (Table 3).

Variation in WTP was also explained by the presence of certain program attributes. The most valuable programs included those that helped with wildlife habitat management (\$29.38 ha^{-1} or \$11.89 ac^{-1}), forest health and resilience (\$33.93 ha^{-1} or \$13.73 ac^{-1}), offered cost-share benefits (\$47.39 ha^{-1} or \$19.18 ac^{-1}), and enhanced access to consultants (\$25.43 ha^{-1} or \$10.29 ac^{-1}) (model 2). Other valuable programs helped landowners coordinate with state agencies (\$43.10 ha^{-1} or \$17.44 ac^{-1}) and control invasive species (\$30.89 ha^{-1} or \$12.50 ac^{-1}) (model 1). Landowners expressed a lower preference for rare vegetation management and prescribed fire associations, which reduced the value of prescribed fire programs by an average of \$49.57 ha^{-1} (\$20.06 ac^{-1}) (model 2) and \$36.94 ha^{-1} (\$14.95 ac^{-1}) (model 1), respectively (Table 3).

Reasons for rejecting programs

Respondents who rejected choice sets were asked to report possible reasons behind the rejection. Most respondents either agreed (40%) or strongly agreed (30%) that they were concerned about liability risk from escape fire, and 32% agreed and 21% strongly agreed that burning costs were prohibitive (Table 4). One-third of respondents (34%) rejected programs because they were not interested in burning. Limited information about prescribed burning and weather conditions were not major reasons for rejecting the programs. Written responses for rejecting programs were air pollution, limited resources (e.g., burn boss), and topography.

Spatial variation in landowner perspectives

Of 257 counties within the study states, 164 counties (63%) provided survey responses for use in the spatial analysis. Survey responses ($n=430$) were geocoded and converted into individual point data using respondent zip codes. The average number of respondents per county before aggregation was 2.57 (min 1, max 17).

We rejected the null hypothesis of complete spatial randomness of the aggregated values for each county representing landowner knowledge and experiences of prescribed fire (Moran's $I=0.128$; $P<0.001$); perceived risk of prescribed fire (Moran's $I=0.054$; $P=0.020$) trust in prescribed fire implementors (Moran's $I=0.029$; $P=0.005$), choice to enroll in burn program (Moran's $I=0.066$; $P<0.001$); and prescribed fire use (Moran's $I=0.121$; $P<0.001$). This means the clustering of landowner opinions, when evaluated at a county level, is significantly correlated. The higher value of Moran's I for knowledge and prescribed fire use reflects a stronger autocorrelation compared to other variables.

Hot and cold spots on the map identify areas where higher and lower values were concentrated at 90%, 95%, and 99% levels of confidence (Figs. 4 and 5). Results indicate that knowledge and attitudes vary across the region, but strong opinions are also concentrated in some areas (Fig. 4). Cold spots for knowledge and trust were largely concentrated around central NY and northeastern PA (Fig. 4). Hot spots for knowledge occurred in southern VA and hotspots for trust were dispersed around both VA and MD. As expected, hotspots for risk were also located around areas with cold spots for knowledge and trust; however, the number of counties associated with risk was fewer compared to the number of counties associated with knowledge and trust.

The map in Fig. 4 (D) represents the combined hotspots for knowledge, trust, and perceived risk scales. The values for risk were reversed to make the interpretation consistent with the knowledge and trust values (i.e., positive or negative views of burning). Findings indicate that a few counties in central NY have overall strong negative views about prescribed fire and a few countries in southeastern VA have overall strong positive views about prescribed fire. Surrounding counties have more mixed opinions (e.g., high knowledge, low trust). The cold spot in NY also appears to cross the state boundary.

The maps in Fig. 5 show hot and cold spots associated with landowner experience using prescribed fire (A) and

Table 4 Percentage and mean response to statements on reasons for rejecting programs scales (1 = strongly disagree, 5 = strongly agree) (*n = 193*)

Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	SD
I am concerned about liability of escaped fire	11%	9%	9%	40%	30%	3.68	1.30
I found burning cost prohibitive	11%	12%	23%	32%	21%	3.40	1.26
I do not have sufficient information to recognize the value and benefits of prescribed fire	30%	17%	19%	20%	14%	2.70	1.43
I am not interested in burning	35%	15%	16%	16%	18%	2.66	1.53
Weather is not favorable for burning in my area	30%	15%	41%	9%	5%	2.44	1.16

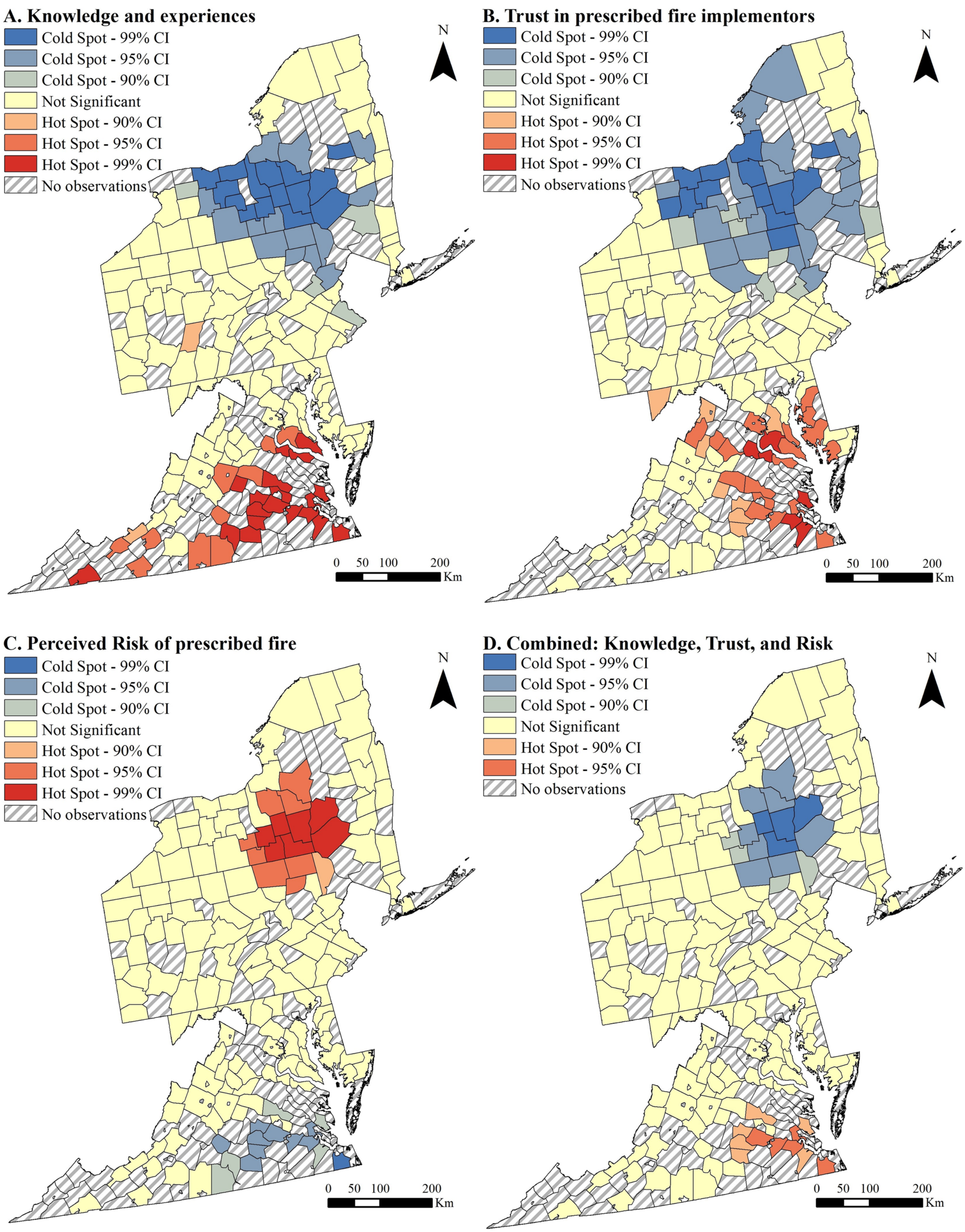


Fig. 4 Spatial clusters indicating hot and cold spots of landowner opinions corresponding to their knowledge of prescribed fire (**A**), trust in fire practitioners (**B**), perceived risk of prescribed fire (**C**), and (**D**) combined of knowledge, trust, and risk clusters. [In (**D**), risk values were reverse coded. Cold spots indicate counties with lower knowledge values, lower trust values, and higher risk values and vice versa for hot spots]

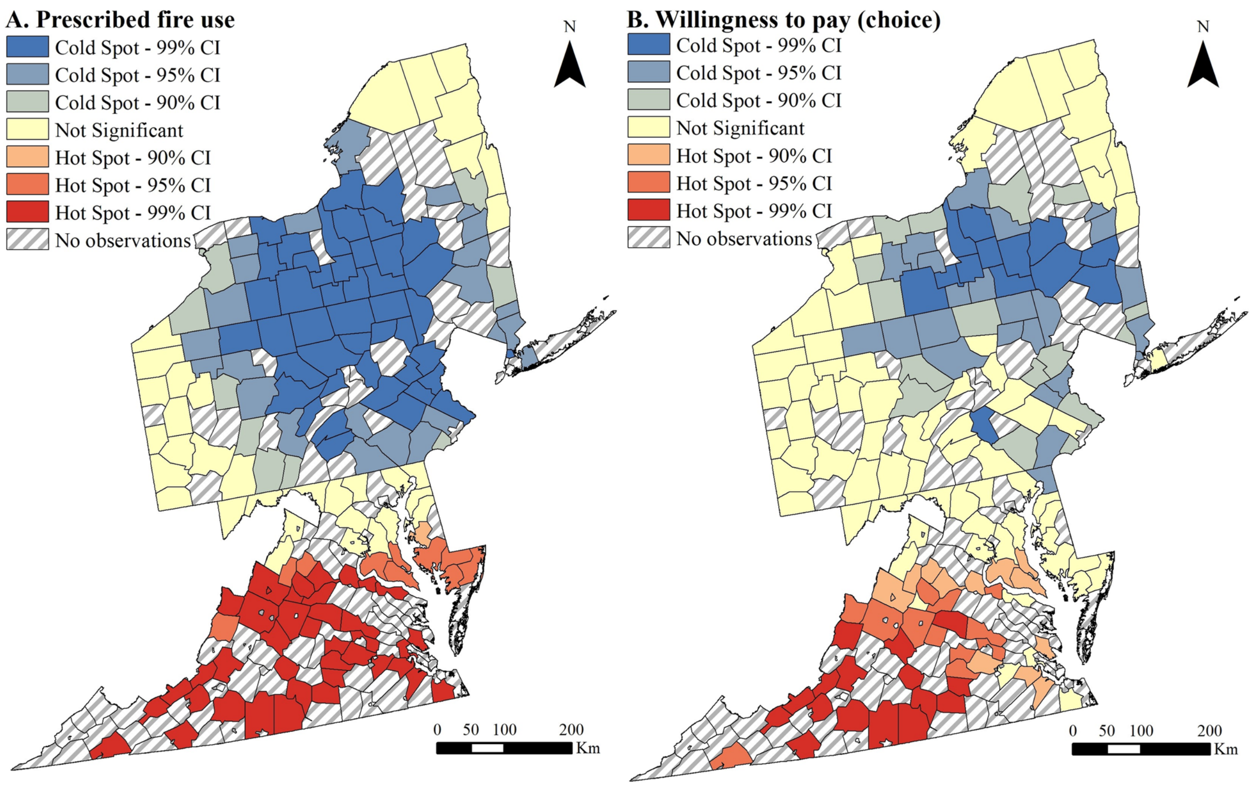


Fig. 5 Spatial clusters showing hot and cold spots of landowner responses to the use of prescribed fire (yes/no response) (**A**) and willingness to pay for burning (WTP choice: yes/no response) (**B**). Light or dark blue coated counties indicate cluster of no responses (cold spot) while light to dark red-shaded counties represents cluster of yes responses (hot spot)

the decision (yes or no) to pay for burning (B). Cold spots for landowner experience covered large areas of NY and PA while hot spots spanned across most of VA and counties in southern MD. Hot spots for landowners' WTP were largely concentrated in VA, and cold spots occurred in central NY and eastern PA.

Transferred willingness to pay value for counties

To estimate an acceptable mean price for prescribed fire in each county, a benefit transfer procedure was conducted using model 2 and adjusting the parameter for income. Estimated prices (min \$85.05 to max 336.80 ha^{-1} or \$34.42 to \$136.30 ac^{-1}) for each county are presented in a supplementary file. Figure 6 presents the range of acceptable prices for each county represented by cold and hot spots. Pennsylvania frequently contained counties with higher acceptable prices compared to all other study states. New York and the southern part of Maryland were cold spots indicating that these areas frequently contained counties with the lowest acceptable prices for prescribed fire.

Discussion

It is generally assumed that landowner knowledge and prior experience with burning underpins support for prescribed burning programs (Kreuter et al. 2008; Ascher et al. 2013; Toledo et al. 2013). In this study, landowners had a low level of knowledge about prescribed fire, likely due to a lack of exposure to burning practices. However, knowledge was not a significant predictor in the models. Low-risk perceptions and high trust in prescribed fire implementors indicate a favorable social condition required for promoting prescribed fire on private lands. The percentage (64%) of private landowner supportive of prescribed burning is consistent with the study conducted in West Virginia (Piatek and McGill 2010). Our estimated mean value of prescribed fire was lower than expected ($\leq$\$39.54 ha^{-1} or $\leq$\$16 ac^{-1}). This is likely due to variation across states and the incorporation of zero bid in the model. NY frequently rejected the programs on offer (i.e., choice sets), which lowered the mean WTP value for the region. Evidence of this can be found in the PWVs associated with VA and PA, indicating that prescribed fire in these states is more valuable.

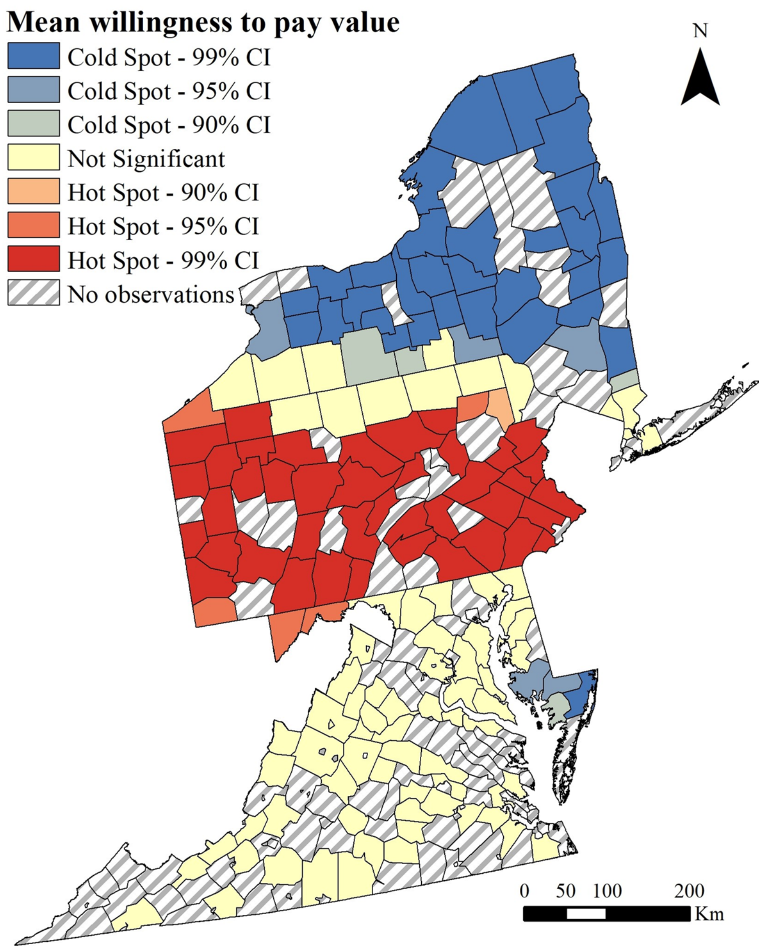


Fig. 6 Spatial cluster showing hot and cold spots of acceptable prices for prescribed burning in each county. Light or dark blue shaded counties indicate cluster of lower WTP values (cold spot) while light to dark red shaded counties represents cluster of higher WTP values (hot spot)

The cost of burning significantly influenced WTP. Low-cost programs were more favored with half of respondents citing cost as a barrier to accepting a program. A related report found actual costs for prescribed fire in PA could be as high as \$988 ha^{-1} (\$400 ac^{-1}) (Regmi et al. 2023). Since 15% of respondents were willing to pay up to \$494 ha^{-1} (\$200 ac^{-1}), it appears that demand for fire is somewhat elastic even when prices change. Including cost-share support in burn programs increased the value of prescribed burning by \$47 ha^{-1} (\$19 ac^{-1}), suggesting that landowners appreciate sharing management costs with government agencies.

Landowners preferred burn programs that offer ecological benefits such as improved forest health, control of invasive species, and improved wildlife habitat. They were willing to pay an additional \$25 to \$35 ha^{-1} (\$10 to \$14 ac^{-1}) for these benefits. Specific benefits such as enhancing rare vegetation were less favored indicating that prescribed fire is not viewed as a solution to all management problems. Landowners showed a strong preference for habitat management benefits from prescribed burning but not for enhancing oak regeneration. This was also reflected in top priority management objectives in landowner responses (see Appendix 2), similar to other surveys (e.g., National Woodland survey findings, Butler et al. 2021). Long-term fire suppression altered oak woodlands, shifting tree composition to closed-canopy forests, diminishing understory vegetation, and reducing wildlife habitat diversity in the region. (Nowacki and Abrams 2008; Alexander et al. 2021; Gallagher et al.

2022). Reintroducing frequent burning on these landscapes can restore oak ecosystems, stop mesophication, and create early successional habitats with increased forage production, aiding habitat management goals (Ratajczak et al. 2014; Dems et al. 2021). The linked benefits of burning for oak regeneration and wildlife habitat may mean that multiple benefits can be achieved through prescribed burning regardless of the motivation of landowners. This finding can be useful for resource managers to develop outreach education and expand burning activities on private lands to achieve wildlife-related benefits.

Governance factors were also key in explaining motivations for using fire. Landowners expressed a strong preference for burn programs that enable them to coordinate burning activities with state agencies, access expert consultants, and receive cost-share assistance. These activities involve the use of experts and government oversight, which is ideal since many private landowners in this region are inexperienced with prescribed burning. Expert involvement in burning activities valued between \$20 and \$42 ha^{-1} (\$8 to \$17 ac^{-1}), which is slightly more than the PWVs assigned to expected management benefits. These governance factors are critical in helping landowners in transitioning from mere motivation to actual fire application. This is because lack of adequate resources and qualified personnel are often cited as key constraints to a broader application of prescribed burning on private lands (Quinn-Davidson and Varner 2011, Kreuter et al. 2019; Schultz et al. 2019; Melvin 2021). Qualified consultants (e.g., certified burn managers) have the expertise and experience required to execute prescribed fire safely and effectively (Toledo et al. 2014).

Prescribed Burn Associations (PBA), where landowners partner to achieve burning, were ranked somewhat lower compared to other governance options, despite evidence of their effectiveness in promoting prescribed burning on private lands (Kreuter et al. 2008; Toledo et al. 2014; Weir et al. 2019). PBAs support landowners burning on their lands by providing necessary resources such as training, equipment, and networking with qualified landowners and burning professionals (e.g., consultants) (Toledo et al. 2014). The preference for qualified consultants over PBAs may suggest a lack of awareness regarding the benefits of PBAs, or cultural values about cooperative forms of management are not well established. The high demand for qualified burn personnel could also be a function of having few burning consultants available in this region and landowners generally lack experience using fire (Regmi et al. 2023). Landowners also preferred opportunities to coordinate with state agencies over PBAs, which is reasonable since state agencies have been facilitating burning for a long time in this region. Landowners also expressed higher trust in state agencies compared to trained landowners when it comes to implementing fire.

Expanding the prescribed fire economy is promising in VA and PA, but less so in NY. Landowners from VA and PA were willing to pay \$124 to \$222 ha^{-1} (\$50 to \$90 ac^{-1}) more than other states, reflecting their strong positive attitudes toward burning compared to those from other states. Certain categories of landowners were found to be more supportive than others. Respondents with prior involvement in landowner assistance programs (e.g., education, cost-share, and technical assistance) valued prescribed fire more than others, indicating that such programs could be used to promote the adoption of prescribed fire. Younger and wealthier landowners were willing to pay more compared to their counterparts. Strategically targeting fire management programs to these groups could increase the use of prescribed burning across the landscape.

Many landowners expressed concerns about liability, although the variable for reduced liability was not significant in regression models, aligning with findings from related landowner studies (Kobziar et al. 2015; Weir et al. 2019; Kreuter et al. 2019). Landowners may also vary in how they conceptualize liability protection, with some having different perceptions of risk and others lacking clarity on existing laws. State laws often shape liability protection for prescribed fire users (Wonkka et al. 2015). The formulation of these laws and the benefits for landowners are not uniform across states (Melvin 2021).

Spatial analysis showed that burn laws and associated liability protection may have only a moderate influence on landowner motivations to use prescribed fire. For example, the cold spot in central NY (indicating a strong resistance to using prescribed fire) extended into some counties in PA. The hot spot in southern VA (indicating strong support for prescribed fire) was only in the eastern region of the state, even though state laws apply evenly throughout the state. There is evidence, however, that burn laws could interfere with landowners actively putting fire on the ground (Yoder et al. 2004; Sun 2006). For example, despite high economic demand for burning on private lands in PA, more acres are burned in VA. This could be due to a lack of qualified professionals in PA who can meet state standards for obtaining liability protection when burning.

This explanation is supported by a study conducted in the southeastern US, which found that total burn acreage was higher in areas with reduced liability compared to areas with a simple negligence liability standard (Wonkka et al. 2015).

Landowner perspectives and cultural values toward prescribed fire varied considerably across state boundary and ecoregions with a general north–south gradient. Hotspotting revealed a zone in southeastern VA characterized by high knowledge and trust levels and low-risk perceptions. Conversely, a zone with low knowledge and trust, and higher risk perceptions was identified in Central NY and some northeastern PA counties. Compared to knowledge and trust, very few counties were identified as hot and cold spots for risk perceptions, suggesting that risk perception was not a great concern among landowners across the region.

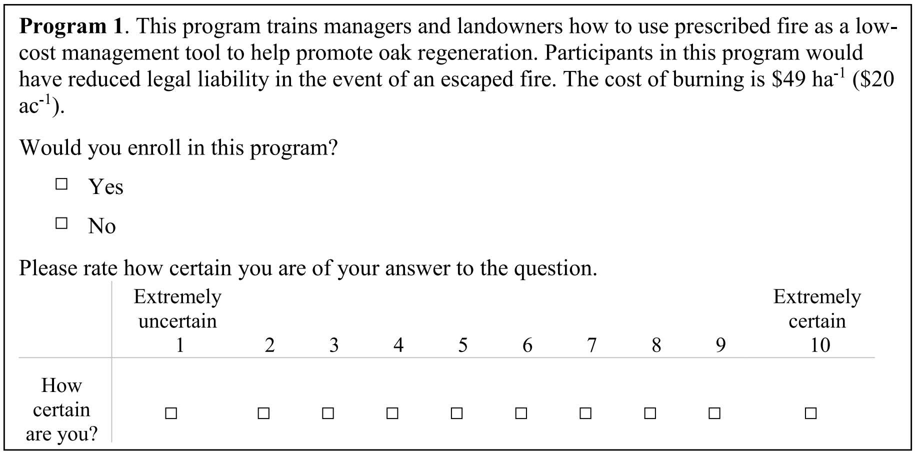
Hot and cold spot mapping revealed that counties in southeastern VA, where prescribed burning is already being used, are more likely to contain landowners who are willing to pay for the benefits of prescribed fire. This supports the assumption that past experiences with prescribed burning can impact how fire is valued (Kreuter et al. 2008). This pattern did not hold in central PA where most counties showed very little use of fire (dark blue), but this did not create a cold spot for WTP for fire. VA landowners were willing to pay less for prescribed fire compared to PA, despite greater experience with it, suggesting WTP values are not always reflective of knowledge and experience. In PA, landowners might overvalue prescribed fire due to limited experience with burning or high demand for burning with limited resources (e.g., burn consultants), whereas VA landowners may be more realistic about using fire due to their pro-fire culture and a more established prescribed fire economy. Applying fire could also be challenging in areas where mesophication has already occurred and long exclusion of fire can complicate prediction of long-term outcomes. Further study at finer spatial scales, and with greater sampling effort, could help to elucidate these questions at more localized economic scales.

The opt-in sampling methods and somewhat low response rate are limitations of this study as they could lead to nonresponse bias. In other words, respondents already inclined to support prescribed fire could have been more likely to take the survey. Nonetheless, this study provides a relevant examination of prescribed fire demand across a region where private land burning has not been widely used in the recent past, but where public land burning is increasing and demand for prescribed fire on private lands seems to be on the rise.

Conclusions

Study findings reveal a potential for the use of prescribed fire on private lands in the Northeast/Mid-Atlantic region, as many landowners expressed a strong desire for burning. Capturing landowner demand for prescribed fire can help establish a stronger prescribed fire economy in the Northeast/Mid-Atlantic region (i.e., jobs, infrastructure). Limited knowledge and experience with prescribed burning indicate a need for education and training programs in this region. Landowner opinions are spatially clustered and varied across state boundaries. Efforts to promote the use of prescribed burning as a management tool will need to consider these regional and local differences and tailor their approach accordingly. This could involve working closely with local landowners to understand their specific needs and concerns, as well as providing education and outreach to help support prescribed burning as a management tool, particularly in NY, that focuses on a more foundational understanding of fire and safety practices. Outside the hot and cold spot zones, educational programs may need to offer a mix of resources for those with different levels of experience and concerns. The lack of qualified professionals is one of the important barriers to burning on private lands in this region. Unlike the Southeast, where burning on private lands is often done by landowners and non-professionals, technical and financial assistance programs in the Northeast/Mid-Atlantic region should look for ways to support the employment of professionals in applying fire on private lands. Efforts on building the capacity of fire implementors by providing applicable education and training will be important to increase private land burning. Liability concerns among landowners related to escaped fire suggest a need for educational programs to improve understanding of liability protection options in their state. Educational programs should also help landowners understand the realities of using fire in places where fire has been long excluded. Future research should include feasibility studies for liability protection and technical resources for landowners. As forest landowners become more familiar with prescribed fire, their willingness to pay may change. To meet ecological restoration goals at the landscape scale, restoring fire in this region will ultimately benefit from private landowner participation given the dominance of private forestlands. The economic, social, and political context of private land burning needs to be well-understood to support large-scale restoration goals.

Appendix 1



Program 1. This program trains managers and landowners how to use prescribed fire as a low-cost management tool to help promote oak regeneration. Participants in this program would have reduced legal liability in the event of an escaped fire. The cost of burning is \$49 ha^{-1} (\$20 ac^{-1}).

Would you enroll in this program?

☐ Yes

☐ No

Please rate how certain you are of your answer to the question.

	Extremely uncertain 1	2	3	4	5	6	7	8	9	Extremely certain 10
How certain are you?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Fig. 7 A sample of a discrete choice experiment question with a confidence scale to measure a forest owner's willingness to pay for prescribed fire

Appendix 2

Table 5 Summary of demographic profiles of respondents based on the survey conducted in 2021–2022 across the Mid-Atlantic region, USA

Characteristics	Count	Percent (%)
Gender		
Male	363	85
Age		
25–34 years	2	1
35–44 years	18	5
45–54 years	30	7
55–64 years	97	22
65–74 years	184	43
75 years and above	97	22
Acres owned		
25–122 ha (10–49 acres)	120	29
123–245 ha (50–99 acres)	110	26
247–493 ha (100–199 acres)	97	23
494–1233 ha (200–499 acres)	74	17
1234 ha or above (≥ 500 acres)	22	5
Annual household income		
Less than \$20,000	11	3
\$20,000–\$49,999	49	12
\$50,000–\$79,999	88	22
\$80,000–\$99,999	65	16
\$100,000–\$149,999	80	20
\$150,000–\$ 249,999	75	19
\$250,000 and more	31	8
Education		
Less than high school	6	1
High school	43	10
Associates degree	48	11
Bachelor's degree	148	35
Graduate degree	183	43
Assistance program (yes)	203	47
Association member (yes)	252	59

Table 6 Forest management objectives ($n = 430$)

Rank	Objectives	Mean	Std. Dev.	Freq.	Percent (%)
1	Enhance wildlife populations	0.85	0.36	364	85
2	Recreational hunting	0.73	0.45	313	73
3	Timber production	0.68	0.47	291	68
4	Recreation in general (e.g., hiking, bird watching)	0.66	0.47	283	66
5	Aesthetics, sense of place	0.66	0.48	282	66
6	Preserve or enhance natural heritage	0.65	0.48	279	65
7	Personal privacy, seclusion	0.60	0.49	260	60
8	Carbon sequestration	0.36	0.48	155	36
9	Environmental education/outreach	0.23	0.42	99	23

Rank	Objectives	Mean	Std. Dev.	Freq.	Percent (%)
10	Cultivate and collect non-timber forest products (e.g., maple syrup, mushrooms)	0.20	0.40	86	20

Table 7 Forest management activities ($n = 430$)

Rank	Activities	Mean	Std. Dev.	Freq.	Percent (%)
1	Thinning/stand improvement	0.72	0.45	310	72
2	Control invasive plan species	0.70	0.46	299	70
3	Habitat management	0.63	0.48	269	63
4	Harvesting/timber sales	0.62	0.49	268	62
5	Recreation management	0.57	0.50	246	57
6	Planting native species	0.45	0.50	194	45
7	Food plots	0.39	0.49	168	39
8	Erosion/sediment control	0.38	0.49	165	38
9	Control tree regeneration	0.35	0.48	152	35

Table 8 Estimates of mixed logistic models of factors affecting landowner willingness to pay for prescribed fire programs in the Mid-Atlantic region, USA, based on the survey conducted in 2021–2022 ($n = 3434$)

Variables	Model 1 Original choice data		Model 2 Certainty corrected (choice > = 6)	
	Coeff	**se**	**Coeff**	**se**
Trust	0.235***	(0.056)	0.174***	(0.058)
Perceived risk	−0.124***	(0.030)	−0.139***	(0.031)
Age category	−0.831***	(0.164)	−0.896***	(0.167)
Assistant program	1.139***	(0.353)	0.954***	(0.359)
Income category	0.206*	(0.110)	0.203*	(0.112)
Pennsylvania	0.708*	(0.403)	1.555***	(0.413)
Virginia	0.504	(0.436)	0.855*	(0.447)
Program attributes				
Price	−0.0182***	(0.001)	−0.0174***	(0.001)
Wildlife habitat	0.182*	(0.104)	0.207*	(0.108)
Rare vegetation	−0.329***	(0.105)	−0.349***	(0.111)
Forest health/resilience	0.243**	(0.101)	0.239**	(0.107)
Control invasive	0.227***	(0.088)		
Prescribed fire associations	−0.272***	(0.105)		
State coordination	0.317***	(0.102)		
Cost share	0.328***	(0.101)	0.333***	(0.089)
Access to consultants	0.144*	(0.085)	0.179**	(0.089)
Constant	2.102	(1.622)	2.201	(1.662)
Insig2u	2.243	(0.130)	2.201	(0.138)
Sigma_u	3.0698	(0.199)	3.006	(0.207)
Pseudo-R^2	0.19		0.18	
AIC	2744		2454	

Standard errors in parentheses. *$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-024-00258-y.

Supplementary Material 1.

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Authors' contributions

AR: conceptualization, methodology, data curation and analysis, investigation, writing—original draft, writing—review and editing, funding acquisition. MMK and JKK: conceptualization, methodology, investigation, supervision, project administration, funding acquisition, writing—review and editing.

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Availability of data and materials

Data will be made available on request.

Declarations

Ethics approval and consent to participate

The study has been approved by the Institutional Review Board (IRB).

Consent for publication

All figures and tables were created by the authors and all authors give their consent to publish.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Ecosystem Science & Management, Pennsylvania State University, University Park, PA 16802, USA.

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References

Alexander, H.D., C. Siegert, J.S. Brewer, J.K. Kreye, M.A. Lashley, J.K. McDaniel, A.K. Paulson, H.J. Renninger, and J.M. Varner. 2021. Mesophication of oak landscapes: Evidence, knowledge gaps, and future research. *BioScience* 71 (5): 531–542.

Allen, D.W. 2016. *GIS tutorial 2: Spatial analysis workbook*. Redlands, California: ESRI press.

Anderson, M.K. 2006. *The use of fire by Native Americans in California. Fire in California's ecosystems*. Berkeley, California, USA: University of California Press.

Ascher, T.J., R.S. Wilson, and E. Toman. 2013. The importance of affect, perceived risk and perceived benefit in understanding support for fuels management among wildland–urban interface residents. *International Journal of Wildland Fire* 22 (3): 267–276.

Bech, M., and D. Gyrd-Hansen. 2005. Effects coding in discrete choice experiments. *Health Economics* 14 (10): 1079–1083.

Blanchard, B., and R.L. Ryan. 2007. Managing the wildland-urban interface in the northeast: Perceptions of fire risk and hazard reduction strategies. *Northern Journal of Applied Forestry* 24 (3): 203–208.

Brando, P.M., L. Paolucci, C.C. Ummenhofer, E.M. Ordway, H. Hartmann, M.E. Cattau, L. Rattis, V. Medjibe, M.T. Coe, and J. Balch. 2019. Droughts, wildfires, and forest carbon cycling: A pantropical synthesis. *Annual Review of Earth and Planetary Sciences* 47 (1): 555–581.

Brose, P.H., D.C. Rey, and T.A. Waldrop. 2014. *The fire—oak literature of eastern North America: Synthesis and guidelines. Gen. Tech. Rep. NRS-135*, 1–98. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

Busam, J., and J. Evans. 2015. Prescribed burning perceptions among private landowners: An annotated bibliography of relevant literature. North Carolina State University Fire Communications. URL. https://research.cnr.ncsu.edu/blogs/southeast-fire-update/files/2015/08/Prescribed-Burning-Perceptions-Among-Private-Landowners.pdf.

Butler, B.J., S.M. Butler, J. Caputo, J. Dias, A. Robillard, and E.M. Sass. 2018. *Family forest ownerships of the United States, 2018: Results from the USDA Forest Service, national woodland owner survey. Gen. Tech. Rep. NRS-199*, 52. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station.

Cimbala, J.M., 2014. *Taguchi orthogonal arrays*. *Pennsylvania State University*, pp.1–3. Retrieved from: https://www.me.psu.edu/cimbala/me345/Lectures/Taguchi_orthogonal_arrays.pdf

Clark, K.L., N. Skowronski, H. Renninger, and R. Scheller. 2014. Climate change and fire management in the mid-Atlantic region. *Forest Ecology and Management* 327: 306–315.

Cliff, A.D., and J.K. Ord. 1981. *Spatial processes: Models & applications*. Taylor & Francis.

Dems, C.L., A.H. Taylor, E.A. Smithwick, J.K. Kreye, and M.W. Kaye. 2021. Prescribed fire alters structure and composition of a mid-Atlantic oak forest up to eight years after burning. *Fire Ecology* 17: 1–13.

Díaz, S.C., L.C. Quezada, L.J. Álvarez, J. Loján-Córdova, and V. Carrión-Paladines. 2023. Indigenous use of the fire in the paramo ecosystem of southern Ecuador: A case study using remote sensing methods and ancestral knowledge of the Kichwa Saraguro people. *Fire Ecology* 19: 5.

Dillman, D.A., J.D. Smyth, and L.M. Christian. 2014. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. Hoboken, New Jersey: John Wiley & Sons Inc.

Elmore, R.D., T.G. Bidwell, and J.R. Weir. 2009. Perceptions of Oklahoma residents to prescribed fire. *In Proceedings of the 24th Tall Timbers Fire Ecology Conference: The Future of Prescribed Fire: Public Awareness, Health, and Safety*. Tallahassee: Tall Timbers Research Station.

Esri Inc. 2021. ArcGIS (Version 10.8.2). Esri Inc. https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview.

Fernandes, P.M., G.M. Davies, D. Ascoli, C. Fernández, F. Moreira, E. Rigolot, C.R. Stoof, J.A. Vega, and D. 2013. Prescribed burning in southern Europe: Developing fire management in a dynamic landscape. *Frontiers in Ecology and the Environment* 11 (1): 4–14.

Gallagher, M.R., J.K. Kreye, E.T. Machtinger, A. Everland, N. Schmidt, and N.S. Skowronski. 2022. Can restoration of fire-dependent ecosystems reduce ticks and tick-borne disease prevalence in the eastern United States? *Ecological Applications* 32 (7): 2637.

Getis, A., and J.K. Ord. 1992. The analysis of spatial association by use of distance statistics. *Geographical Analysis* 24 (3): 189–206.

Gillson, L., C. Whitlock, and G. Humphrey. 2019. Resilience and fire management in the Anthropocene. *Ecology and Society* 24 (3): 14.

Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. 2012. Predicting fire frequency with chemistry and climate. *Ecosystems* 15: 322–335.

Hanemann, W.M. 1984. Welfare evaluations in contingent valuation experiments with discrete responses. *American Journal of Agricultural Economics* 66 (3): 332–341. https://doi.org/10.2307/1240800.

Hanley, N., R.E. Wright, and V. Adamowicz. 1998. Using choice experiments to value the environment. *Environmental and Resource Economics* 11 (3–4): 413–428.

Harper, A.R., S.H. Doerr, C. Santin, C.A. Froyd, and P. Sinnadurai. 2018. Prescribed fire and its impacts on ecosystem services in the UK. *Science of the Total Environment* 624: 691–703.

Hensher, D.A., J.M. Rose, and J.M., and W.H. Greene. 2015. *Applied choice analysis*, 2nd ed. Cambridge: Cambridge University Press.

Hole, A.R. 2007. Fitting mixed logit models by using maximum simulated likelihood. *The Stata Journal* 7 (3): 388–401.

Kaval, P., J. Loomis, and A. Seidl. 2007. Willingness-to-pay for prescribed fire in the Colorado (USA) wildland urban interface. *Forest Policy and Economics* 9 (8): 928–937. https://doi.org/10.1016/j.forpol.2006.08.003.

Keeley, J.E., W.J. Bond, R.A. Bradstock, J.G. Pausas, and P.W. Rundel. 2011. *Fire in Mediterranean ecosystems: Ecology, evolution, and management*. Cambridge University Press.

Kobziar, L.N., D. Godwin, L. Taylor, and A.C. Watts. 2015. Perspectives on trends, effectiveness, and impediments to prescribed burning in the southern U.S. *Forests* 6: 561–580.

Kreuter, U.P., D.A. Stroman, C.L. Wonkka, J. Weir, A.A. Abney, and J.K. Hoffman. 2019. Landowner perceptions of legal liability for using prescribed fire in the Southern Plains. *United States. Rangeland Ecology & Management* 72 (6): 959–967.

Kreuter, U.P., J.B. Woodard, C.A. Taylor, and W.R. Teague. 2008. Perceptions of Texas landowners regarding fire and its use. *Rangeland Ecology & Management* 61 (4): 456–464.

Lee, D.C., T.M. Quigley, S. Norman, W. Christie, J. Fox, K. Rogers, and M. Hutchins. 2014. *2014*. US Department of the Interior, Washington, D.C.: National Cohesive Wildland Fire Management Strategy.

Loomis, J., and A. González-Cabán. 2010. Forest service use of nonmarket valuation in fire economics: Past, present, and future. *Journal of Forestry* 108 (8): 389–396. https://doi.org/10.1093/jof/108.8.389.

Loomis, J.B., L.S. Bair, and A. González-Cabán. 2002. Language-related differences in a contingent valuation study: English versus Spanish. *American Journal of Agricultural Economics* 84 (4): 1091–1102. https://doi.org/10.1111/1467-8276.00370.

Lusher, D., J. Koskinen, and G. Robins. 2013. *Exponential random graph models for social networks: Theory, methods, and applications*. Cambridge University Press.

Maggard, A. 2021. *Costs & trends of southern forestry practices, 2020 FOR- 2115*. Alabama Cooperative Extension System (ACES): Auburn AL USA.

Mavsar, R., A.G. Cabán, and E. Varela. 2013. The state of development of fire management decision support systems in America and Europe. *Forest Policy and Economics* 29: 45–55.

McCaffrey, S.M. 2006. Prescribed fire: What influences public approval? In *Fire in eastern oak forests: delivering science to land managers, proceedings of a conference; 2005 November 15–17; Columbus, OH. Gen. Tech. Rep. NRS-P-1*., ed. B. Matthew, 192–198. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

Melvin, M.A. 2018. *2018 National Prescribed Fire Use Survey Report. Technical Report 03–18*. Coalition of Prescribed Fire Councils, Inc. and National Association of State Foresters. p 29. Retrieved from: https://www.stateforesters.org/wp-content/uploads/2018/12/2018-Prescribed-Fire-Use-Survey-Report-1.pdf

Melvin, M.A. 2021. 2021 National prescribed fire use survey report. Technical report 01–22. Prescribed Fire Councils and the National Association of State Foresters. p20. Online retrieved at: https://www.stateforesters.org/wp-content/uploads/2023/01/2021-National-Rx-Fire-Use-Report_FINAL.pdf.

Morgan, G.W., K.G. Tolhurst, M.W. Poynter, N. Cooper, T. McGuffog, R. Ryan, M.A. Wouters, N. Stephens, P. Black, D. Sheehan, and P. Leeson. 2020. Prescribed burning in south-eastern Australia: History and future directions. *Australian Forestry* 83 (1): 4–28.

Moura, L.C., A.O. Scariot, I.B. Schmidt, R. Beatty, and J. Russell-Smith. 2019. The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: Impacts, consequences, new directions. *Journal of Environmental Management* 232: 600–606.

NIFC. 2022. National Year-to-Date Report on Fires and Acres Burned by State and Agency, National Interagency Fire Center (NIFC). Accessed on 12/14/2022 URL: https://gacc.nifc.gov/sacc/predictive/intelligence/NationalYTDbyStateandAgency.pdf.

North, M.P., S.L. Stephens, B.M. Collins, J.K. Agee, G. Aplet, J.F. Franklin, and P.Z. Fulé. 2015. Reform forest fire management. *Science* 349 (6254): 1280–1281.

Nowacki, Gregory J., and M.D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. *BioScience* 58 (2): 123–138.

Oswalt, S.N., W.B. Smith, P.D. Miles, and S.A. Pugh. 2019. *Forest resources of the United States, 2017: A technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97*, 97. Washington, DC: US Department of Agriculture, Forest Service, Washington Office.

PA-DCNR. 2022. Pennsylvania Historical Prescribed Fire Data 2010–2022. Pennsylvania Department of Conservation and Natural Resources (PA-DCNR). Online retrieved at: http://elibrary.dcnr.pa.gov/GetDocument?docId=3580726&DocName=Historical%20Prescribed%20Fire%20Data%202020.pdf.
Piatek, K.B., and D.W. McGill. 2010. Perceptions of private forest owners in West Virginia on the use of prescribed fire in forestry. *Small-Scale Forestry* 9 (2): 227–241.
Prichard, S.J., C.S. Stevens-Rumann, and P.F. Hessburg. 2017. Tamm Review: Shifting global fire regimes: Lessons from reburns and research needs. *Forest Ecology and Management* 396: 217–233.
Quinn-Davidson, L.N., and J.M. Varner. 2011. Impediments to prescribed fire across agency, landscape and manager: An example from northern California. *International Journal of Wildland Fire* 21 (3): 210–218.
Ratajczak, Z., J.B. Nippert, J.M. Briggs, and J. Blair. 2014. Fire dynamics distinguish grasslands, shrublands and woodlands as alternative attractors in the Central Great Plains of North America. *Journal of Ecology.* 102: 1374–1385.
Regmi, A., M.M. Kreye, and J.K. Kreye. 2023. Forest landowner demand for prescribed fire as an ecological management tool in Pennsylvania, USA. *Forest Policy and Economics* 148: 102902.
Rolfe, J., J. Bennett, and J. Louviere. 2000. Choice modelling and its potential application to tropical rainforest preservation. *Ecological Economics* 35 (2): 289–302.
Ryan, K.C., E.E. Knapp, and J.M. Varner. 2013. Prescribed fire in North American forests and woodlands: History, current practice, and challenges. *Frontiers in Ecology and the Environment* 11 (1): 15–24.
Sangha, K.K., J. Evans, A. Edwards, J. Russell-Smith, R. Fisher, C. Yates, and R. Costanza. 2021. Assessing the value of ecosystem services delivered by prescribed fire management in Australian tropical savannas. *Ecosystem Services* 51: 101343.
Schultz, C.A., S.M. McCaffrey, and H.R. Huber-Stearns. 2019. Policy barriers and opportunities for prescribed fire application in the western United States. *International Journal of Wildland Fire* 28 (11): 874–884.
Shrestha, A., R.K. Grala, S.C. Grado, S.D. Roberts, J.S. Gordon, and R.K. Adhikari. 2021. Nonindustrial private forest landowner willingness to pay for prescribed burning to lower wildfire hazards. *Forest Policy and Economics* 127: 102451.
Stolte, K.W. 2012. *State of Mid-Atlantic region forests in 2000-Summary Report. Gen. Tech. Rep. SRS–163*. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station. 37 (163): 1–37.
Sun, C. 2006. State statutory reforms and retention of prescribed fire liability laws on US forest land. *Forest Policy and Economics* 9 (4): 392–402.
Toledo, D., U.P. Kreuter, M.G. Sorice, and C.A. Taylor Jr. 2014. The role of prescribed burn associations in the application of prescribed fires in rangeland ecosystems. *Journal of Environmental Management* 132: 323–328.
Toledo, D., M.G. Sorice, and U.P. Kreuter. 2013. Social and ecological factors influencing attitudes toward the application of high-intensity prescribed burns to restore fire adapted grassland ecosystems. *Ecology and Society* 18 (4): 9.
Train, K.E. 2009. *Discrete choice methods with simulation*. Cambridge University Press.
Twidwell, D., C.L. Wonkka, M.T. Sindelar, and J.R. Weir. 2015. First approximations of prescribed fire risks relative to other management techniques used on private lands. *PLoS ONE* 10 (10): 0140410.
Varela, E., J.B. Jacobsen, and M. Soliño. 2014. Understanding the heterogeneity of social preferences for fire prevention management. *Ecological Economics* 106: 91–104.
Vossler, C.A., R.G. Ethier, G.L. Poe, and M.P. Welsh. 2003. Payment certainty in discrete choice contingent valuation responses: Results from a field validity test. *Southern Economic Journal* 69 (4): 886–902.
Waldrop, T.A., and S.L. Goodrick. 2012. Introduction to prescribed fires in Southern ecosystems. Science Update SRS-054. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station. 1–80. https://www.srs.fs.usda.gov/pubs/su/su_srs054.pdf.
Walker, S.H., D.B. Rideout, J.B. Loomis, and R. Reich. 2007. Comparing the value of fuel treatment options in northern Colorado's urban and wildland–urban interface areas. *Forest Policy and Economics* 9 (6): 694–703. https://doi.org/10.1016/j.forpol.2006.06.001.
Weir, J.R., U.P. Kreuter, C.L. Wonkka, D. Twidwell, D.A. Stroman, M. Russell, and C.A. Taylor. 2019. Liability and prescribed fire: Perception and reality. *Rangeland Ecology & Management* 72 (3): 533–538.
Wonkka, C.L., W.E. Rogers, and U.P. Kreuter. 2015. Legal barriers to effective ecosystem management: Exploring linkages between liability, regulations, and prescribed fire. *Ecological Applications* 25 (8): 2382–2393.
Wu, H., Z.D. Miller, R. Wang, K.Y. Zipp, P. Newman, Y.H. Shr, C.L. Dems, A. Taylor, M.W. Kaye, and E.A. Smithwick. 2022. Public and manager perceptions about prescribed fire in the Mid-Atlantic, United States. *Journal of Environmental Management* 322: 116100.
Yoder, J., D. Engle, and S. Fuhlendorf. 2004. Liability, incentives, and prescribed fire for ecosystem management. *Frontiers in Ecology and the Environment* 2 (7): 361–366.

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