FINAL REPORT

Firescapes in the mid-Atlantic: mismatches between social perceptions and prescribed fire use

JFSP PROJECT ID: 16-1-02-5

October 2020

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List of Abbreviations/Acronyms

BA – Basal Area
BoF – Bureau of Forestry
FVS – Forest Vegetation Simulator
DCNR – Department of Conservation and Natural Resources
PA - Pennsylvania
Penn State – The Pennsylvania State University
NJ – New Jersey
NJFFS – New Jersey Forest Fire Service
PGC – Pennsylvania Game Commission
U.S. – United States
WUI – Wildland Urban Interface

Keywords

Prescribed fire, controlled burning, prescribed fire policy, mid-Atlantic, Pennsylvania, New Jersey pinelands, restoration, mesophication, pitch pine, oak, FVS, pine-oak, *Quercus*, *Acer, Pinus*

Acknowledgements

We thank the Pennsylvania Game Commission, the Bureau of Forestry and the New Jersey Forest Fire Service for support of the trailhead surveys and help with organization of the focus group surveys. We particularly thank the participants in the workshops and focus groups for their time and interest in the research. We thank Cody Dems and Anthony Zhao who completed their M.S. research as part of this award on fire effects monitoring and forest simulation modeling, respectively. Each also contributed to field work, surveys, and focus groups. We also thank Zach Miller, who led the research on hunter versus non-hunter perceptions of prescribed burning and helped to guide the qualitative analyses. We thank Yau-Huo Shr for coding and analysis related to the cost-benefit analysis. We thank Pheonix Chan, Kathryn Giesa, Gregory Mitchell, Ellen Thurston, Hudson Wagner, and Nancy Weinheimer for help with conducting the trailhead interviews. Shawn Lehman, Paul Lupo, Todd Breininger, John Wakefield, Kenneth Clark, Michael Gallagher, Bernard Isaacson, William Zipse, Lane Gibbons, Lindsey Curtin, and Nikole Simmons provided field data and/or guidance with model parameterization. The Center for Landscape Dynamics in the Earth and Environmental Institute supported the project by supplying iPads for the surveys and helping with the logistics of the Pennsylvania manager workshops. We thank the Institutes of Energy and Environment at Penn State for the initial seed grant in support of this project. Human subjects research was approved through the Penn State Internal Review Board (#00002672).

Abstract

The social barriers and opportunities of prescribed fire management practices in the mid-Atlantic region are unknown. We hypothesized that there are mismatches between community perceptions of prescribed fire operations in the mid-Atlantic U.S. and the realities of its current and potential use in landscape management, but that these mismatches varied across the region between places with recent (Pennsylvania (PA)) and long-term (New Jersey (NJ)) active management programs. We used interdisciplinary, mixed-method approaches including trailhead surveys, focus groups, field measurements, simulation modeling, and environmental cost-benefit analysis. The goal was to triangulate the interactions among fire effects on ecosystems, community perceptions of benefits and concerns about prescribed fire, and manager perceptions of barriers and opportunities for putting managed fire safely back on the landscape.

Major results include:

- Field studies indicated that, in central PA, within five years post-fire, tree seedling density increased more than 72% while sapling density decreased by 90%, forest midstory density decreased by 46%, and overstory densities remained constant or decreased up to 12%. Not all tree species responded similarly and post-fire shifts in species relative abundance occurred in sapling and seedling size classes. Red maple and cherry species abundance decreased while sassafras, quaking aspen, black oak, and hickory species increased.
- Our simulations of fire regimes over the long-term at multiple intervals suggest that implementation of prescribed fire could be a feasible strategy to restore fire-adapted oak forests where management objectives are compatible with fire use. Moreover, several fire regimes maintain basal area (BA) of fire-adapted species and above average live C stocks providing flexibility to managers who seek to restore oak forests and maintain ecosystem services.
- Our focus groups with fire managers in PA and NJ identified barriers and opportunities for prescribed fire management in the region. Barriers and opportunities spanned levels of analysis including individuals, communities, and landscapes, indicating the need for multi-scalar coordination and planning for fire management across constituencies.
- Trailhead surveys with recreational users of forests identified substantial support for prescribed burning activities. When compared to results from our online survey of managers, we found that benefits and concerns around prescribed fire differed somewhat between forest users and managers, as well as between PA and NJ. Across both locations, forest users were moderately concerned about wildlife mortality and fire spread. There was greater concern for recreational access in PA and about smoke in NJ. While managers judged the most benefit for lowering wildfire risk, tick reduction was ranked highly, and was the top benefit selected by all forest users. The NJ forest users rated lower wildfire risk as more important than PA forest users.
- It is not known whether the burn rotations of prescribed fire in the area meet the perceived benefits (desired conditions) of forest users. To test this, we compared perceived user benefits based on structural features (increased visibility, hazard reduction, increased habitat quality) to actual conditions post-fire (based on modeled output from the Forest Vegetation Simulator (FVS)). Results show that current burn rotations in the region (approximately 10-20 years for PA and 2-5 years for NJ) would achieve the benefits that forest users judged to be important.

Overall, our project demonstrated the importance of evaluating the interactions among communities, managers, and ecosystems to understand the challenges and opportunities for prescribed fire management in the mid-Atlantic. Despite differences among perceived benefits and concerns among communities, our work demonstrates moderate to strong support by forest users for prescribed fire implementation and identifies pathways for communication between managers and communities, as well as among managers. Moreover, our field and modeling work indicates the effectiveness of current fire management practices. While more research is needed, our research sets the stage for successful integration of prescribed fire into mid-Atlantic forests more broadly to meet a variety of management goals.

Objectives

Our first research objective was to <u>assess community perceptions</u> about prescribed fire risk and impacts (**Objective 1**). *We hypothesized that public beliefs and perceptions about prescribed fire use are shaped by the level of experience or exposure to fire activity over time, as well as values shaped by forest use (e.g. hunting, recreational use).* We explored these perceptions using trailhead surveys in communities with different forest use and fire histories (NJ vs. PA).

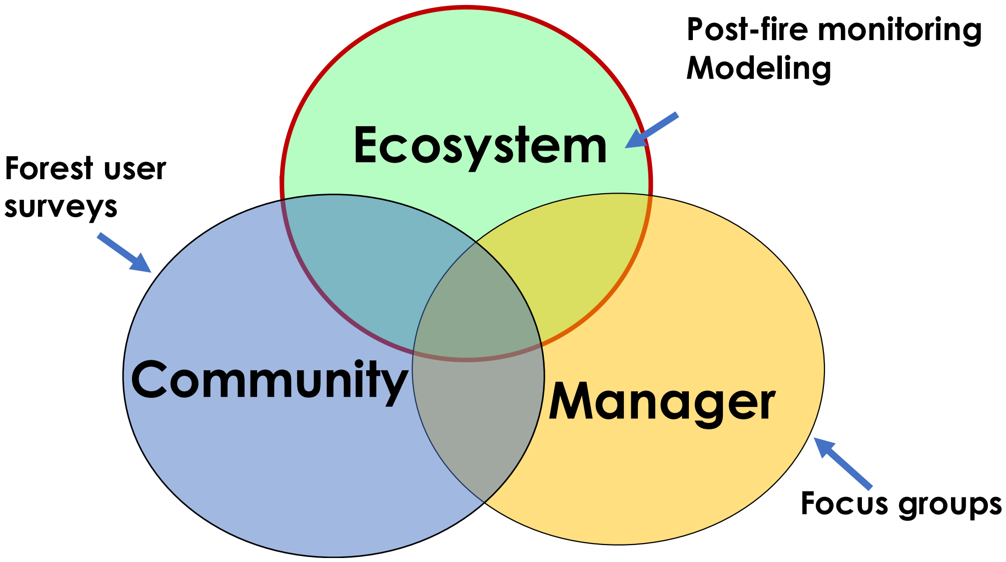

Figure 1. Venn diagram of the conceptual interaction between ecosystems, communities, and managers that we posit is necessary to understand, through a mixed-method approach, to adequately address prescribed fire management challenges in the mid-Atlantic.

Our second research objective was to <u>characterize the relative influence of manager perceptions and ecological outcomes on prescribed fire implementation</u> (**Objective 2**). *We hypothesized that opportunities for burning to meet ecological objectives, already limited in the Mid-Atlantic based on biophysical factors, are further limited by manager concerns about social implications of burning*. We explored this hypothesis through manager focus groups to identify barriers and opportunities around prescribed fire activity.

In addition to these original objectives, our project identified opportunities for science-based engagement with management decisions. Specifically, we explored fire effects in mixed oak-pine-aspen forests in central PA (**Objective 3**). We used field sampling to quantify the impact of single and repeated burns on forest structure and function for recent burns and compared them to continuous forest inventory data. *We hypothesized that, following one or two dormant season prescribed fires, there would be a pulse of seedling recruitment but a reduction of living sapling and canopy trees; and, that the abundance of fire-tolerant tree species would increase following prescribed fire due to superior survival and regeneration relative to fire-intolerant trees.*

To explore the long-term consequences of repeated and single burns on forest structure and carbon storage in PA and NJ (**Objective 4**), we used FVS modeling. Specifically, this research used simulation modeling to test how initial forest conditions, fire frequency, and duration of fire regimes influence long-term dominance of pines and oaks in mid-Atlantic forests. *We hypothesized that oak and pitch pine dominance, as measured by relative basal area (BA) would be facilitated by higher initial BA proportion, repeated burning over longer durations, and burning at medium fire frequency for oaks and at high fire frequency for pitch pine.*

Our final original objective was to quantify spatial and temporal mismatches between the social-ecological dimensions that motivate burn decisions and the social-ecological impacts of prescribed fire activity (**Objective 5**). *We hypothesized that (a) social and ecological benefits and drawbacks to burning are unevenly distributed across the mid-Atlantic and (b) impacts of burn activity will be most contested where either social or ecological goals are unmet.* We tested this hypothesis by using an environmental economics model to calculate optimal burning rotations that would maximum recreational benefits (characterized by user willingness to pay for post-fire forest attribute (visibility, hazard, habitat quality).

Background

Fire is a key disturbance process in temperate forest ecosystems that regulates plant successional dynamics, nutrient cycling, and wildlife habitat, generates spatial and temporal heterogeneity in vegetation and fuels, and contributes to maintenance of species diversity and biodiversity (Pausas and Keeley 2019; Bond and Keeley 2005; Turner 2010). However, concerns about wildfire risk and impacts on social, economic, and ecological costs are high many regions of the U.S. In 2018, fire suppression costs reached over $3.1 billion, compared to an average of $426 million between 1985 and 1999 (NIFC 2020). Costs are expected to increase in the future as the wildland fire seasons lengthen and the frequency of dangerous fires increases (Westerling et al. 2011; Fitch et al. 2018; Rogers et al. 2020), as evidenced by the dramatic 2020 wildfire season in the western U.S.

Prescribed fires are planned disturbances used to influence forest structure and composition with varying effects across regions (Ryan et al. 2013). There are increasing calls to expand prescribed fire as an overarching land management strategy and to focus science and policy on prescribed fire management as part of a comprehensive forest land management approach (Hiers et al. 2020). Prescribed fires are commonly implemented in the western and southeastern U.S., where fire-prone ecosystems dominate the landscape.

Although fire in forested ecosystems is a key natural disturbance and a valued management tool, little is known about social barriers and facilitators that influence prescribed fire implementation. In the western U.S., more is known about social acceptance of fire mitigation activities. In contrast, McCaffrey et al. (2013) reported that only 4% of social science studies about fire in the U.S. have occurred in the Northeast. This is despite the fact that the wildland urban interface (WUI) is pervasive in the area (Radeloff et al. 2018), and risks of fire from people, in addition to baseline risk from natural causes, can be high in some areas.

Changing prescribed fire use in the mid-Atlantic region

In the United States, prescribed fire research is particularly needed in eastern deciduous forests where its role is understudied relative to other regions (Varner et al. 2016) and fire is increasingly used for management purposes. For example, the Commonwealth of Pennsylvania passed the Prescribed Burning Practices Act in 2009 (PA House Bill 262) reducing the legal barriers placed on the use of prescribed fire within the state (PA General Assembly 2009). This policy change supports the desires of multiple land agencies to use prescribed fire to promote specific forest compositions for ecologic and economic benefit (Brose et al. 2008, PA General Assembly 2009). In the seven years following the legislation, the annual number of prescribed fires in PA increased from 56 to 222 and area burned increased from 1,107 to 7,532 hectares (PA DCNR 2015, National Interagency Fire Center 2017). This influx of prescribed fire is introducing disturbance to areas that have been fire-free for about 80 years (Klimkos 2017) and localized forest response has not been extensively studied.

Moreover, across the mid-Atlantic, prescribed fire use is motivated by numerous factors in addition to mitigation of fire risk, including ecosystem restoration for biodiversity and game habitat. The complexity and heterogeneity of governance structures and land ownership, the relative dearth of community programs, combined with the complexity of fire ecologies and fire management in the region, indicates the critical and timely importance of focusing on social studies in the mid-Atlantic, which may in fact differ from patterns elsewhere in the U.S.

The social exposure to fire and fire management are highly variable, spatially and temporally, with some areas having a relatively long history of prescribed burning activity (e.g., Pine Barrens) and other areas witnessing fire as an emergent landscape management tool. This heterogeneity is a product of recent relaxation of fire management regulations in some areas, where fire is now a ‘new’ management opportunity (e.g., PA) with little insight about public perceptions of its use, versus a long history of fire management and community awareness in others (e.g., NJ). The temporal and spatial heterogeneity in regulatory policies, land ownership and management partnerships, and social exposure to fire across the region provides a unique opportunity to test for barriers and facilitators of prescribed fire implementation.

As calls for prescribed fire grow, the mid-Atlantic region may exemplify challenges and opportunities of prescribed fire management more broadly for several key reasons: (1) a large human footprint (Radeloff et al. 2018), (2) a complex mosaic of forest types and fire histories (Abrams and Nowacki 2008), (3) heretofore unknown community “buy-in” to proactive fire management in some areas, (4) a finely grained land mosaic of ownership and governance jurisdictions, and (5) varying management objectives, from fire hazard mitigation to wildlife habitat management. Collectively, these factors provide a good model for understanding barriers and opportunities to broadened prescribed fire use. Managers in the region have been at the forefront of these issues, but no previous study has assessed manager perceptions about these barriers and opportunities.

Fire ecology in the mid-Atlantic region

Fire regimes in mixed oak forests in the mid-Atlantic region have changed dramatically since post-glacial forest composition stabilized about 4000 years ago (Delcourt and Delcourt 1997; Willard et al. 2005; Menking et al. 2012). During the Native American period, fires were moderately frequent (5-20 years) and then became much more frequent (3-10 years) in the Euro-American settlement period (Stambaugh et al. 2018). A period of infrequent fire has prevailed since the early 20th century when a policy of excluding fire was implemented (Brose et al. 2001; Stambaugh et al. 2018).

Over the past century, eastern oak (*Quercus* spp.) forests experienced a shift in species dominance (Abrams 2003) with limited regeneration of shade intolerant oak (Nowacki and Abrams 2008) and increases in shade tolerant red maple (*Acer rubrum* L.). Reduced oak dominance is a management concern due to declines in habitat quality (Brose et al. 2008, Dey 2014), timber market stability (Brose et al. 2008), and nutrient cycling (Alexander and Arthur 2010, Alexander and Arthur 2014). While multiple interacting factors are driving this recent forest change (McEwan et al 2011), research indicates that humans played a significant role in altering the type and extent of forest disturbance (Drummond and Loveland 2010) including landscape-scale forest clearing and homogenization of forest age (Dey 2014) as well as shifts in fire frequency (Stambaugh et al. 2018, Abrams and Nowacki 2019).

Oak dominance has been historically linked to recurring fire, and more recently to anthropogenic disturbance associated with mining, logging and other land uses (Abrams 2002, McEwan et al. 2007). Since the onset of fire suppression, oak regeneration has been limited and oaks are being replaced by more fire sensitive shade tolerant hardwoods, particularly maple (*Acer* spp.) (Hutchinson et al. 2008), and this compositional shift has altered surface fuel structure and litter moisture characteristics reducing flammability (Nowacki and Abrams 2008, Kreye et al. 2013, 2018, Dyer and Hutchinson 2019, Knott et al. 2019). Fire-adapted pines (*Pinus* spp.) including pitch pine (*P. rigida*), table mountain pine (*P.pungens*), and eastern white pine (*P. strobus*) often co-occur with oak depending on site conditions. As a group, these pines exhibit a range of traits associated with a capacity to survive low severity surface fire (thick bark) or regenerate after higher severity crown damaging fire (cone serotiny, epicormic and basal sprouting). Shifts in forest composition, and surface fuel flammability related to fire exclusion have raised concerns about future dominance by oak, how fire can used to restore fire-adapted species, and how fire may affect ecosystem services (Welch et al. 2000, Brose et al. 2013, Dey 2014, Vose and Elliott 2016, Lafon et al. 2017)

Prescribed fire is considered a tool to reinstate disturbance in eastern forests (Brose 2014), an idea that stems from research suggesting a historical relationship between frequent fire and oak dominance (Abrams 1998, Hutchinson et al. 2008). Following prescribed fire, top-killed or injured trees of certain species use below ground energy stores to re-sprout (Huddle and Pallardy 1999, Blankenship and Arthur 2006) and fire promotes seedling germination by exposing bare mineral soil through consumption of surface fuels (Graham and McCarthy 2006, Arthur et al. 2012). Additionally, fire promotes seedling growth with temporary increases in light availability due to canopy thinning (Alexander et al. 2008). However, the extent of tree death and regrowth is dependent on time of year (Huddle and Pallardy 1999, Knapp et al. 2009), number and frequency of fires (Arthur et al. 2017, Keyser et al. 2017), fire intensity (McGee et al. 1995), pre-fire management (Albrecht and McCarthy 2006, Schwilk et al. 2009), landscape position (Iverson et al. 2008, Arthur et al. 2015), and tree species (Fan et al. 2011, Keyser et al. 2018). Species in eastern forests have traits that influence their response to fire (Fan et al. 2011, Keeley et al. 2011, Pausas 2015). For example, many oak species have thicker bark, more flammable leaf litter, and greater below-ground energy stores than red maple, effectively increasing their survival and promoting fire where they are dominant (Abrams 2003, Kreye et al. 2013). Variation in species composition contributes to a feedback system where vegetation influences flammability and fire effects, and fire effects influence future vegetation (Mitchell et al. 2009, Tiribelli et al. 2018).

Figure 2. Fire managers in central PA planning a prescribed burn.

The effects of fire on forest structure and dynamics are diverse and tied to both short term variation in species response to individual fire characteristics (i.e. fire intensity), and longer term variation in fire regimes driven by climate and human activity (Nowacki and Abrams 2008, Taylor et al. 2016, Stambaugh et al. 2018). Changes in fire regimes (e.g. seasonal timing, return interval, extent, severity) can alter patterns of species dominance in fire-adapted forests and generate new fire-vegetation feedbacks that may amplify (Brose 2014, Lauvaux et al. 2016) or diminish (Nowacki and Abrams 2008, Hanberry 2013) future fire effects on forest structure, and forest ecosystem services (Martin et al. 2015, Johnstone et al. 2016, Hurteau et al. 2019). Fire regime change effects on vegetation and fuels can persist for decades, or even centuries, and may shift forest conditions to a new ecosystem states with reduced fire resilience and diminished ecosystem services (Adams 2013). Re-introducing fire into forests with highly altered fire regimes is one of several approaches that can be used to restore, maintain, and confer resilience to fire-adapted forests (Brose et. al 2001, Nowacki and Abrams 2008, North et al. 2015) though it is not without risks, and can impair ecosystem services (Varner et al. 2005, Ryan et al. 2013).

However, empirical studies of prescribed fire effects in eastern oak forests show variable outcomes that are related to the frequency, intensity, and season of burning (Hutchinson et al. 2005, 2012, Dey 2014, Brose et al. 2013, Keyser et al. 2019). Prescribed fire has had mixed success in promoting oak, especially with single or several short-interval, low-intensity burns in mature forests (Brose et al. 2006, Hutchinson et al. 2005, 2012). Outcomes from implementation of a prescribed fire regime in eastern mixed oak forests remain unclear due to a paucity of long-term studies. An exception is a six-decade long study of repeated prescribed burning in Missouri

Ozark oak-hickory forests (Knapp et al. 2015, 2017). Burning at four-year intervals reduced overstory density and canopy cover and favored white (*Quercus alba*) and post (*Q. stellate*) oak, over scarlet (*Q. coccinea*), Spanish (*Q. falcate*), and black (*Q. velutina*) oak, and hickories (*Carya* spp.) compared to annual burning or no fire. Low tree regeneration with frequent burning suggested that recruitment may be linked to the length of fire-free periods (Knapp et al. 2015, 2017). Additional investigation of the multi-decadal effects of different prescribed fire regimes is needed to improve our understanding of prescribed fire use as a restoration tool in mixed oak forests, and how prescribed fire regimes may influence ecosystem services (Varner et al. 2016).

An important ecosystem service provided by oak forests is carbon (C) storage and sequestration and U.S. forests are estimated to offset 12-19% of annual U.S. carbon dioxide emissions (EPA 2015) with much owed to forest biomass increases in the eastern US (EPA 2015; USGCRP 2018). Disturbances such as prescribed fire can increase both direct emissions through combustion and indirect emissions through decomposition of fire killed trees (Williams et al. 2016). Moreover, changes in forest structure with prescribed fire can reduce overall forest C storage (Hurteau and North 2009, Martin et al. 2015). Capacity for C storage remains an important consideration in increasing use of prescribed fire given the important role of eastern U.S. forests in mitigating anthropogenic emissions of carbon dioxide (Williams et al. 2016). Prescribed burning, however, has not been shown to negatively impact C uptake in forests (Chiang et al. 2008), and careful long-term management can increase and maintain forest C stability (Earles et al. 2014, Harris et al. 2019).

Firescapes of the mid-Atlantic

The firescape concept views fire science, policy, and management as part of a linked biophysical and human system (Smith et al. 2016). In this approach, natural resource management strategies must account for both social and ecological factors to be robust, resilient, and sustainable (Smith et al. 2016; Higuera et al. 2019; Fischer et al. 2016). We posit that the mid-Atlantic region represents an under-analyzed firescape. In the western U.S. and globally, concerns about wildfire risk are high and significant attention has been placed on creating social acceptance of prescribed fire to mitigate fire hazard. In the southeastern U.S., fire-dependent ecosystems are ubiquitous, and communities have a long history of living with and using prescribed fire in forest management. However, in the northeastern and mid-Atlantic U.S., wildfire is rare at a regional scale due to a wetter climate, lower fire hazard, and fire suppression (Abrams and Nowicki 2008). Thus, social 'memory' of fire is limited, except in localized areas. On the other hand, the wildland urban interface (WUI) is pervasive and larger than that in the western U.S., and land ownership units are tightly intertwined (Radeloff et al. 2018). The built landscape reflects a tight intermingling of public and private ownership, multiple levels of public governance, and extensive critical infrastructure. Recognizing these additional challenges is important understanding to help coordinate prescribed fire management at landscape scales.

Within the region, the social exposure to fire and fire management is variable. In contrast to Pennsylvania's recent policy change in 2009, the NJ Pine Barrens have had a relatively long history of prescribed burning activity. However, even in NJ, policy has shifted recently, creating more flexibility in using prescribed burning as a management tool (NJAC 7:27-2.1, 2018). Because of these policy changes, prescribed fire is becoming more common on the landscape to meet multiple management objectives including habitat restoration and fuels reduction. Land managers are interested in working with communities in their planning process around burning. Collectively, the region offers an opportunity to explore the social factors that managers perceive constrain or facilitate prescribed fire management.

Previous research conducted in the western U.S. has indicated that community acceptance is shaped by factors such as values, attitudes, or experience (Bright et al. 2007, McCaffrey et al. 2013, Mickler et al. 2013, Miller et al. 2020). Others have emphasized the importance of governance, social networks, or community archetypes to better understand community acceptance of fire management practices (Dickinson et al. 2015, Paveglio 2015, Qin et al. 2015). However, few studies (but see Schultz et al. 2019 for a western U.S. perspective) engage managers. A focus on perspectives of managers about fire management offers the opportunity to

Figure 3. Photos of forests in the mid-Atlantic managed using prescribed fire. Top left: remnant pitch pine stand in the Scotia Barrens, central PA. Top right: epicormic branching of pitch pine stands in the NJ Pine Barrens. Bottom left: Mature pitch pine stands in the NJ Pine Barrens. Bottom right: managed burn in mixed-oak stands in central PA.

understand how attitudes by the public are received by managers, with implications for decision-making.

Materials and Methods

Study Sites. Mixed oak forests in the Ridge and Valley physiographic province in eastern and central PA were the focus of our simulation experiments and prescribed fire effects research (**Figure 4**). This area is characterized by folded Paleozoic era sedimentary rocks with series of sandstone ridges and intervening shale and carbonate valleys. Elevation ranges from 130-770 m and mean annual temperature ranges from 8-13 °C depending on elevation. Annual average annual precipitation is ca. 1130 mm and is evenly distributed throughout the year. Forests in the Ridge and Valley are typically second growth and developed after a period of intense harvesting in the 19th century, particularly associated with the iron ore industry. Mixed oak forests in the 81-120 years old age class make up 65% of the forest cover in the ridge and valley (Reed and Kaye 2020). Forests are dominated by oaks including chestnut oak (*Q. prinus*), northern red oak (*Q. rubra*), white oak (*Q. alba*), scarlet oak (*Q. coccinea*) and black oak (*Q. velutina*) and oaks comprise >60% of the forest biomass in the region (Reed and Kaye 2020). Other common species include red maple (*A. rubrum*), black gum (*Nyssa sylvatica*), Sassafras (*Sassafras albidum*), and black cherry (*Prunus serotina*). Fire effects were studied on Pennsylvania State Game Lands 176 (SGL176) in the Ridge and Valley Physiographic Province of central PA (40.7°N, 77.9°W). SGL176 has a humid continental climate with 80-100 cm of annual precipitation and averages 9.4°C throughout the year (The Pennsylvania State Climatologist – calculated from State College data). SGL176 is about 400 m above sea level and is located in a valley floor "frost pocket" where cold air pools as it sinks from surrounding ridges (O'Neil 2006). Soils are well-drained, acidic sandy loams (USDA Web Soil Survey) and land use has varied over the past 200 years including eras of iron ore mining and charcoal production (O'Neil 2006, Abrams and Johnson 2014) as well as extensive logging and human-caused fires from these activities.

Fire Effects. Field measurements began the summer prior to the initial burn and the same protocols were repeated at various intervals for five to nine growing seasons (ending in 2018). All measurements were completed between May 1 and August 31 to measure growing season vegetation. Nested fixed area plots (12.6 m radius) were established within each burn unit using a systematic sampling design (mixed-oak, n=44; aspen-oak, n=10). Plots were located at least 60 m from unit boundaries and the number of plots in each burn unit was determined by unit size. To measure forest structure and composition change over time, all living trees > 5 cm tall were identified to species (to genus by some observers) and their DBH was recorded. When

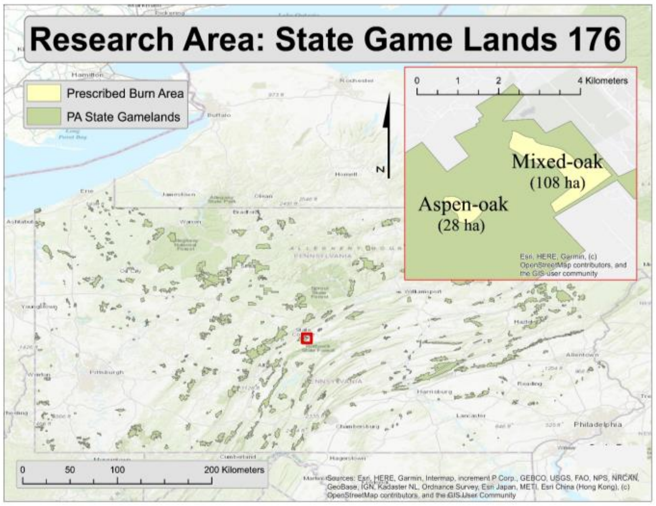

Figure 4. Study area for field monitoring of prescribed fire in central PA. Red circle highlights the Scotia Pine lands in central PA. Inset shows the aspen-oak and mixed-oak stands included in the study.

seedlings were of stump sprout origin (> 5.08 cm diameter stump present) only the three largest seedlings were recorded. Unburned forest plots were measured twice, in 2009 and 2014, using the PAGC's CFI protocols (Bureau of Wildlife Habitat Management 2013) and slightly larger vegetation plots (16.1 m radius) than those in the burn units.

Simulation Modeling. We used forest inventory data collected by the Pennsylvania Department of Conservation of Natural Resources Bureau of Forestry (DCNR BoF) and the Pennsylvania Game Commission (PGC) in our simulation study. Inventory plots are distributed across the region to provide resource data on forest growth, forest volume and structure, forest mortality, and forest change on state lands. We extracted inventory plots (n=1623) classified as oak, and oak-pine forest or woodlands for this study. Tree-level (stems >2.54 cm diameter at breast height, dbh) information included plot identification, species, dbh, height, status (live, dead), damage, and tree seedling counts by height class. Inventory plots were initially organized into groups based on their plot classification. Our modeling platform has a limitation of 3000 tree records for a stand (Dixon 2002) so initial groups of plots with more than 3000 records were divided into stands with approximately equal numbers of plots. Stands were then grouped for our analysis into forest types based on the proportional basal area (BA) of oaks (*Quercus* spp.), pines (*Pinus* spp.), and other species in a stand (**Table 1**). Of the original set of 54 stands, 10 were selected to simulate forest response to different fire regimes. Up to three stands from a forest type were selected representing low, intermediate or high BA proportions for pine, oak, or other species in that group. Forest response to prescribed fire regimes were simulated using the USDA Forest Vegetation Simulator (FVS). FVS is an individual tree, distance independent growth and yield model that simulates forest vegetation change to natural disturbance or other management scenarios (Dixon 2002). FVS is often used to evaluate the effects of different management practices-including prescribed and wildland fire on forest structure, and forest C stocks and emissions (e.g. Finney et al. 2007, Hurteau and North 2009, Buma et al. 2013) and is parameterized for different geographical regions. We used the Northeastern Variant (NE) of FVS for this study (Dixon and Keyser 2008). FVS has multiple extensions and we used The Fire and Fuels Extension (FFE) to simulate BA and forest C stocks and emissions (Rebain 2015). FVS is deterministic and does not provide information on the range of possible outcomes for a stand but relies instead on well-defined user specified initial conditions and allows for further calibration of the equations simulating forest processes-such as regeneration and tree mortality-to best reflect the geographic area of study.

Simulated fire regimes included unburned, single burn, and repeated burns at intervals of 5, 10, and 20 years over a 30 and 60-year period in each stand. Three replicates for each regime were implemented to incorporate stochastic variation in projected stand conditions using randomly selected radial growth rates by FVS (Dixon 2002). Fires were scheduled before spring green-up, the most common period for prescribed burning in the region. Weather conditions during simulated prescribed fires were drawn from burn plans and consultation with fire managers. For our burns, temperature and wind speed at 6 m (20 feet) were set to 18.3 °C (65 °F) and ~13 km hr^{-1} (8 mph), respectively, and fuel moisture was classified as dry. We identified initial fuel models (i.e. Scott and Burgan 2005) for each stand in consultation with prescribed fire managers. Fuel models (and weights) were TL6 (range, 70-80%) and SH4 (range, 20-30%) for all stands except the mixed species type, which was assigned TL3. Canopy fuel variables were calculated by FFE from tree lists using default values for each species (Rebain 2010). Automatic fuel model selection was invoked in FFE after fires based on projected stand conditions (Rebain 2010).

Table 1. Initial composition of oaks, pines, and other species for each forest type at the onset of the simulation period.

Forest Class	Oak BA (%)	Other Species BA (%)	Pine BA (%)	Total BA (m^2 ha^{-1})
Oak-Dominant	74.8	20.9	4.3	26.6
Mixed-Oak	59.3	38.9	1.8	27.5
Mixed-Species	42.7	56.3	0.9	26.2
Oak-Pine	61.1	23.4	15.5	27.5

To assess forest change overtime with each fire regime we calculated stand composition (%) of pines, oaks, and other species based on BA, and live above ground C stocks, and C emissions, at 10-year time steps using default FVS logic. We used default tree species mortality values in FFE in the simulations, except for pitch pine. Tree mortality for pitch pine was reduced to 20% of the default value to more accurately reflect pitch pine mortality to fire (Gallagher 2017). We also calculated the proportional abundance (BA) of the top four species at each time step and report these values for year 30 and 60 of the simulations.

Trailhead and Online Surveys. Forest user participants for this research were intercepted by university-trained researchers on public lands in both PA and NJ, and an online version of the survey was sent to fire managers in PA and NJ through an email listserve. In PA, visitors were intercepted in several park settings in Rothrock State Forest, Circleville Park, and State Game Lands 176 and 33. In NJ, visitors were intercepted in the Wharton State Forest at the Batsto Visitor Center, Atsion Recreation Area, and the Carranza Memorial. If a group was intercepted, the person with the most recent birthday was asked to participate in the research. Only visitors 18 years of age or older participated in the research. An electronic tablet was used to collect survey data. The survey instrument consisted of five relevant sections: participation in recreation activities, perceived costs of using prescribed fire, perceived benefits of using prescribed fire, perceived likelihood of outcomes related to using prescribed fire, and a discrete choice experiment to measure the value of forest attributes to park users. To measure participation in recreation activities, visitors were provided with a list of activities and asked, “Please check all the recreation activities you typically partake in during your visits to forested areas.” Activities listed included running, biking, off highway vehicle use, hunting specific game (e.g. deer, bear, small game), wildlife viewing, and variety of other common recreation activities. Perceived costs were measured by asking visitors, “Based on your understanding of prescribed burns, how would you rate your concern about the following effects?” and recording responses to several statements on a 5-point scale where 1=not at all concerned and 5=extremely concerned. Perceived benefits were measured by asking visitors, “How would you rate the importance of the following effects (benefits) of prescribed fire?” and recording responses on a 5-point scale where 1=not at all important and 5=extremely important. Perceived likelihood for both costs and benefits were measured by asking visitors how likely they thought either the costs or benefits would occur. Perceived likelihood responses were recorded on a 5-point scale from 1=not at all likely and 5=completely likely. The discrete choice experiment presents several scenarios with two forest sites which are different in terms of three forest attributes – fire hazard, habitat quality, and visibility – and required travel time to reach the sites. Respondents were asked to choose their preferred site to visit. Therefore, the values of the forest attributes can be assessed by evaluating the trade-off that the respondents made between (better) forest amenities and (more) time. The three forest attributes are selected based on their ecological importance in prescribed fire dynamics and also importance for recreational users. The full suvery instrument can be found in the final report supplemental material associated with this project.

Figure 5. Example photo from trailhead surveys conducted in central PA and the NJ Pinelands.

The samples were partitioned into various groups, including PA forest users, NJ forest users, managers, hunters, and non-hunters, to explore differences among groups. All the data were analyzed in IBM© SPSS© version 25 (IBM Corp., 2017). Independent t-tests, Friedman tests, and post-hoc pairwise comparisons were used to compare mean differences of costs, benefits, and likelihood of outcomes related to prescribed fire among the different groups. Kruskal-Wallis tests and post-hoc pairwise comparisons were used to compare the various aspects of concerns and benefits of prescribed fire.

Focus Groups. Focus groups made up of fire management officials in New Jersey and Pennsylvania were used to address manager perceptions of prescribed fire challenges and opportunities (Objective 2). Focus group participation was initiated over email with state and federal managers, facilitated by the Pennsylvania Prescribed Fire Council (PPFC) and the New Jersey Forest Fire Service (NJFFS). In NJ, we also convened a focus group with Firewise community members, identified by the NJFFS coordinator. Firewise USA communities are part of a program coordinated by the National Fire Protection Association that encourages neighborhood readiness against the threat of wildfire. Leaders within Firewise communities work closely with fire managers; as a result, they are familiar with perspectives within their communities and how that might influence proposed management.

A semi-structured guide was created for the focus groups that included a series of open-ended questions with follow-up probes to keep conversations consistent with the goals of the research as approved by Penn State's IRB. The Pennsylvania focus groups included 12 total participants, split into two groups, from state, federal, and private natural resource management agencies and organizations. The NJ focus groups included a total of 45 participants, split into four groups: three comprised of fire managers, and one comprised of Firewise community leaders. Fire managers in NJ were largely from the NJFFS with limited representation from other agencies and groups (i.e., National Park Service, Audubon Society). Each group was assigned a group leader and scribe from the research team. Discussions lasted at least one hour. All focus groups were digitally-recorded

Figure 6. Example photo from focus groups with fire managers.

and permission was obtained by participants prior to recording. Recordings were transcribed for further data analysis. We used open and axial coding schemes to analyze the focus group transcripts (Corbin & Strauss, 2008). First, the data was independently coded by two team members into themes that emerged from the data, such as "governance" or "experience" and then assigned as either a "barrier" or "opportunity." Quotes could fit multiple themes. To ensure robustness of the organization, example quotes were presented to the interdisciplinary research team (n=12 people) and outside researchers familiar with fire science but not our project. These individuals were asked to classify the quotes given a separate list of the full set of preliminary codes. Feedback from this process lead to re-categorization of some quotes among themes and rewording of several large categories (i.e., 'governance' changed to 'institutional capacity'). Using this final schematic, representative quotes related to barriers and opportunities were organized among themes and sorted into landscape, community and individual levels following the mental model approach of Harr et al. (2014).

Benefit Analysis. To identify the value of prescribed fire to forest users we model the optimal timing of prescribed fire management as a Faustmann rotation problem (Yoder 2004). However, instead of a landowner choosing a prescribed fire rotation that maximizes the net present value of timber production, our forest manager is choosing how often to use prescribed fires to maximize the net present value of the forest for recreational use. The value to forest visitors of one prescribed fire rotation, $Y(T)$, is:

$$Y(T) = e^{\delta T}\left(\int_0^T B(t)e^{-\delta t}dt\right) \tag{1}$$

where T is the time at which a prescribed fire is implemented and t is the time since the last prescribed fire, $B(t)$ is the net benefit of the forest in the t^{th} year after the last burn and $\int_0^T B(t)e^{-\delta t}dt$ is the stream of net benefits between fires, andδ is the discount rate.

The optimal prescribed fire rotation maximizes the present value of all future rotations is:

$$\max_{\mathrm{T}} PV(T) = \sum_{i=1}^{\infty} Y(T)e^{-i\delta T} = \frac{Y(T)}{e^{\delta T}-1}. \tag{2}$$

The solution to this problem is found when $\delta PV(T) = B(T)$, where δPV is the usual Faustmann rent term that represents the cost of delaying all future burns[1]and $B(T)$ is the benefit of waiting to

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[1] Typically, the Faustmann equation is $\delta PV(T) - \delta c = B(T)$, which includes a term for the cost of cutting trees or, in this case, burning in period T, δc. However, we assume that the costs to park visitors of actually performing a prescribed fire are negligible.

perform a prescribed fire in period T. To solve this equation, we model the recreational benefits of a forest as a function of time since a prescribed fire, $B(t)$. The recreational value of a forest after a prescribed fire depends on the value that visitors place on forest attributes and the dynamics of these attributes after a fire. That is, the dynamics of recreational values will be a product of the changes in forest attributes and the associated values of each forest attribute. We use a stated preference choice experiment survey to value forest attributes. We selected three attributes – fire hazard, habitat quality, and visibility – based on their ecological importance in prescribed fire dynamics and also their potential importance for recreational users. To convert the marginal utility of these attributes into dollars we also include an attribute for required travel time to reach the forest. We use a random utility model framework to estimate the values of forest attributes.

$$P_{ni}(v_{ni} > v_{nk}) = \int \left(\frac{e^{\beta_n Z_i - \lambda p_{ni}}}{\sum_k e^{\beta_n Z_k - \lambda p_{nk}}} \right) f(\beta_n)\, d\beta_n; \;\; \forall i \neq k \tag{3}$$

where $f(\beta)$ is the probability density distribution of β. We then calculate the recreational value to visitor n as a function of time after a prescribed fire t as

$$E\big(WTP_n(t)\big) = \frac{\Delta \boldsymbol{Z_t} \widehat{\beta_n}}{\hat{\lambda}} \tag{4}$$

where $\Delta \boldsymbol{Z_t} = \boldsymbol{Z_t} - \boldsymbol{Z_0}$ is the change in the matrix of forest attributes over time from the baseline scenario $t = 0$ in the year the fire occurs, $\widehat{\beta_n}$ are the estimated coefficients for these attributes, and $\hat{\lambda}$ is the estimated coefficient on the travel cost attribute. To estimate equation (4) as willingness to pay in dollars we need to convert time into money and to estimate the change in the forest attributes over time $\Delta \boldsymbol{Z_t}$.

Value of Time. Given the recent literature on the value of leisure time, following (Lloyd-Smith, Abbott, and Adamowicz 2018) we elicit respondents' willingness to give up leisure time for a monetary payment. Specifically, we ask respondents if they are willing to participate in an eight-hour focus group near their home on their day off work for monetary payments. We assume that respondents choose to participate in the focus group when doing so maximizes their utility. Define the utility of individual n choosing either to participate in the focus group $l = 1$ or not $l = 0$ for each of the choice situations m as

$$u_{nlm} = \alpha_p p_{lm} + \alpha_n x_{nlm} + \varepsilon_{nlm} = \alpha_p p_{lm} + (\alpha + \gamma W_n + \eta_n) x_{nlm} + \varepsilon_{nlm} \tag{5}$$

where $p_{1m} \in (50, 100, 200, 400, 700)$ is the payment for participating in the focus group $l = 1$ for each choice situation m, and $p_{0m} = 0 \; \forall m$, x_{nlm} is a matrix of attributes that affects the probability of participating in the focus group, W_n is a matrix of socio-demographic attributes, η_n is an individual specific random component, $(\alpha_p, \alpha, \gamma)$ are parameters to be estimated, and ε_{nlm} is a Type I Extreme Value error term. The probability of choosing to participate in the focus group is then

$$P_{nl}\big(u_{nlm} > u_{nqm}\big) = \int \left(\frac{e^{\alpha_p p_{lm} + \alpha_n x_{nlm}}}{\sum_q e^{\alpha_p p_{qm} + \alpha_n x_{nqm}}} \right) g(\alpha_n)\, d\alpha_n; \;\; \forall l \neq q \tag{6}$$

where $g(\alpha_n)$ is the probability density distribution of α_n. The value of time ($ per hour) can then be calculated as

$$VOT_n = \frac{\widehat{\alpha_n}}{\widehat{\alpha_p}} \times \frac{1}{8}\,. \tag{7}$$

We divide the VOT_n by eight because the focus group is said to be eight hours, and this gives us an hourly value of time. Thus, WTP in dollars will be

$$E\left(WTP_n(t)\right) = \frac{\Delta \boldsymbol{Z_t} \widehat{\beta_n}}{\hat{\lambda}} \cdot VOT_n. \tag{8}$$

To estimate the recreational value of forests after a prescribed fire, B(t), we estimated the willingness to pay (WTP) for forest attributes, the value of time to convert WTP estimate from distances to dollars, and the dynamics of forest attributes over time after a prescribed fire. To estimate the change in the forest attributes over time $\Delta \boldsymbol{Z_t}$ we used FVS modeling results, described above. Simulated flame length was used as our measure of fire hazard; canopy base height was used as our measure of visibility; habitat quality was measured using trees per acre (TPA) and basal area (BA). With an estimate of the function B(t), we are able to estimate the Faustmann equation to predict the optimal timing of prescribed fires to maximize recreational values. We ultimately used two methods to calculate the value of time – income-based value of time and individual-specific value of time (Lloyd-Smith et al. (2018). The individual-specific value of time was calculated using a mixed logit model to estimate the probability that a given respondent chooses to participate. From our choice experiment we estimated the value of these forest attributes at low, medium, and high levels and clustered FVS output into low, medium, and high groups into $k = 1, .. K$ groups with a k-means approach. Then, we estimate individual discount rates, δ (Coller and Williams 1999; Andersen et al. 2008; Harrison, Lau, and Williams 2002). We asked respondents to choose between two payment options across ten scenarios – one in which they would receive a sum of money in one month from today, and another in which they would receive a sum of money seven months from today. We estimate the discount rate to be 31% which is consistent with the findings in Harrison, Lau, and Williams (2002). Using the values that people place on the fire attributes and how these attributes change over time, we can predict the benefits to park visitors in dollars for the 60 years after a fire. We proceed by using TPA and basal area percentage as a measure of habitat quality. With estimates of the recreational benefits over time after a prescribed fire B(t) and the estimated discount rate δ, we can then solve to find T, the optimal timing of prescribed fires to maximize the recreational value of a forest.

Results and Discussion

Fire Effects

Forest structure. The largest structural changes following prescribed fire were observed in seedlings and saplings with lesser shifts in the midstory and overstory trees (**Figure 7**). Following a single prescribed fire (year 2010 in mixed-oak and 2014 in aspen-oak), both burn units had large increases in seedling density within two growing seasons. Seedling density in the aspen-oak unit increased by more than six-fold in the aspen-oak unit and by 72% in the mixed oak unit. Seedling densities ranged between 78,000-102,000 stems ha^{-1}. A second fire in the aspen-oak unit reduced seedling density, but density remained more than 100% higher than before fire. Prior to prescribed fire there were more sapling stems in both the aspen-oak (2,103 stems ha^{-1}) and mixed-oak (2,862 stems ha-1) units than the unburned sites (840 stems ha^{-1}). However, within two growing seasons post-fire, both burned units had fewer saplings than the unburned sites and between 50-92% fewer saplings than were initially present. In contrast, sapling density in unburned plots was steady over the measurement period. Sapling BA dropped 87-89% following a single burn while the unburned sites unchanged. Living midstory stem density and BA decreased in both burned units, but were not different from pre-fire measurements prior to the fifth growing season, at which point midstory stem density in both burned units decreased by 42-48%. Overstory stem density did not change in unburned sites (208 stems ha^{-1}), slightly but insignificantly increased in the aspen-oak unit (from 157 to 197 stems ha-1, $p = 0.25$), and decreased in the mixed-oak unit (249 to 218 stems ha^{-1}, $p <$

0.01). Most overstory reduction occurred prior to the sixth growing season (p = 0.02). Overstory BA increased over time in the burn units (from 21.1 to 22.1 m^2 ha^{-1} in the mixed-oak unit and from 9.0 to 12.7 m^2 ha^{-1} in the aspen-oak unit) and on unburned sites (from 21.2 to 22.8 m^2 ha^{-1}). Overstory BA in the aspen-oak unit increased 34% within two growing seasons after the first prescribed fire. Following a second fire and total of five growing seasons, aspen-oak overstory basal area was 40% more than prior to any fire.

Forest composition. The aspen-oak unit had the largest changes in relative density in all tree size classes, but most compositional change occurred in the seedling and sapling strata (**Figure 8a**).

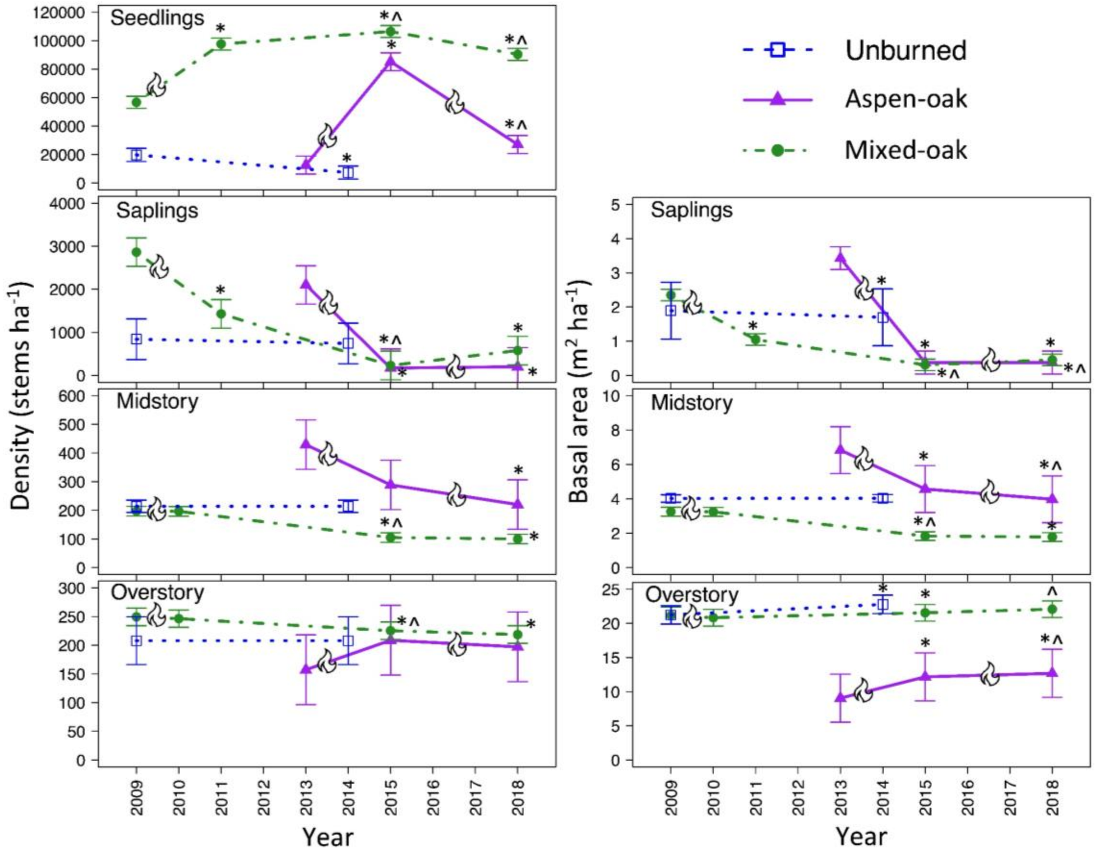


Figure 7. Change in forest structure (density and basal area of seedlings, saplings, midstory, and overstory vegetation) in unburned stands and following prescribed fire in aspen-oak, mixed-oak stands in central PA.

After two prescribed fires, relative red maple seedling density decreased 49% and black oak increased 29% becoming the dominant seedling species. Other seedling shifts in the aspen-oak unit include slight increases in northern red oak (+9%), white oak (+11%), and quaking aspen (+19) and decreases in cherry (-18%). The top four most abundant seedling species before the first fire were red maple, cherry, serviceberry, and white oak. After two fires, they were black oak, red maple, quaking aspen, and white oak. At the sapling level, white oak had the largest increase in relative density (+23%) and was the most abundant sapling in the aspen-oak unit after two fires. Additional increases occurred for black oak (+8%) and, after two fires, cherry was the only other tree present in the sapling layer. There were minor changes in relative density of midstory and overstory trees but the top four most abundant species in each size class did not change over the sample period. The most abundant midstory tree in the aspen-oak unit was cherry, followed by white oak, bigtooth aspen (*Populus grandidentata*), and red maple in that order. Overstory trees were dominated by bigtooth aspen followed by a mix of cherry, scarlet oak, and white oak. In comparison to the aspen-oak unit, seedling abundance by species in the mixed-oak unit barely changed (**Figure 8b**). Both before prescribed fire and eight years post-fire, the three most abundant seedling species were red maple, chestnut oak, and serviceberry. No species had a relative density change more than 9% at the seedling level. Sapling dominance in the mixed-oak unit shifted from red maple to sassafras. Minor increases in sapling abundance occurred for black oak (+6%) and hickory (+10%) with decreases measured in chestnut oak (-2%), scarlet oak (-3%), and white oak (-5%). Similar to the aspen-oak unit, the midstory and overstory trees in the mixed-oak unit showed little change in relative abundance. Both before and nine growing seasons after fire, the midstory was dominated by red maple, hickory, sassafras, and white oak. White oak dominated the overstory pre-fire but was second to red maple post-fire. Bigtooth aspen remained the third most abundant overstory tree and chestnut oak was replaced by black oak as the fourth most abundant.

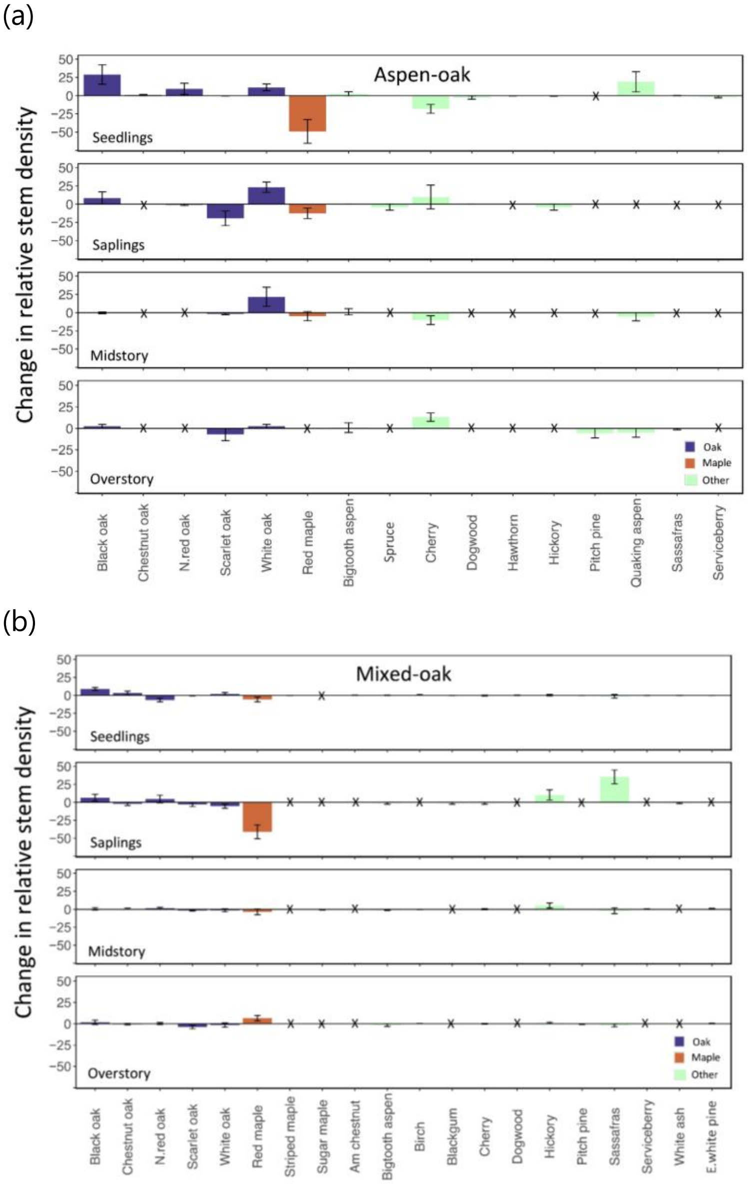


Figure 8. Changes in relative stem density among common tree species in aspen-oak (a) and mixed-oak (b) stands following prescribed fire in central PA.

Simulation modeling of fire regimes

Single burns had little effect on BA or dominant species composition while more frequent burning increased pine BA, especially when pine was initially abundant. Simulated fire regimes with longer intervals applied for longer periods maintained higher oak BA and reduced fire sensitive hardwoods. Average BA at the end of the 60-year simulation period was inversely related to fire frequency. Live tree C stocks increased over initial values with low fire frequencies. Live C stocks decreased with more frequent burning which also sharply increased cumulative C emissions.

Basal Area. At the start of the simulations, oaks were initially dominant in the oak-dominant, mixed-oak, and oak-pine forest classes and without fire oaks comprised 54-73% of BA at year 60 (**Figure 9**). Oaks were not initially dominant in the mixed-species class, and without burning they declined slightly by the end of the simulation. Temporal trends in BA of oak, pine, and other species for single burns were similar to unburned, except early in the simulation where there was a small increase in oak and pine and a decrease in other species. This initial shift had little long-term effect on BA proportions or average BA for these species groups by year 60.

Application of more than one fire led to compositional shifts and declines in BA. The magnitude of changes varied with fire return interval, duration of the fire regime, and initial stand conditions. With a 20-year fire interval, oaks increased to become the dominant species group, and other species decreased by year 60, even in the mixed-species class. In the oak-pine class, the proportion of pine surpassed that for other species by year 60, with smaller increases for pine in the other forest classes. Application of 5 and 10-year fire return intervals over 60 years strongly favored oak, and proportion of oak increased and ranged from 77-91% by year 60, with larger increases for the five-year interval, except in the oak-pine forest class. In the oak-pine class, oak decreased and pine reached nearly 50% of stand BA by year 60. In the other forest classes, proportional BA of pine more than doubled with a five-year burn interval, but still comprised only 10-15% of stand BA by year 60. Burning at 5-year or 10-year intervals for only the first half of the 60-year the simulation period produced different outcomes than applying fire for the full period. When fires were paused at year 30, oaks began to decline, other species began to increase and they attained proportions within 10%-15% of initial values by year 60.

Species Composition. Simulated fire regimes influenced the composition of the four most abundant species in a forest class. Oaks as a group were favored with a 10- to 20-year fire return interval applied over 60 years. Even without fire chestnut oak remained dominant in the oak-dominant forest class, but red maple increased by year 60. When present, pitch pine increased with the five-year return interval, applied over 60 years, while other hardwoods such as red maple decreased. Red maple also increased in mixed-oak forests without fire, and oak dominance was also highest in this type with the 10- to 20-year fire return intervals applied over 60 years. Red maple and other hardwoods decreased with fire application, and white pine increased with five- and 10-year fire return intervals. In the mixed-species class, non-oaks such as red maple, black, sassafras, and aspens were projected to increase without fire or with infrequent fire. Oak species such as red, chestnut, and black were favored with five- and 10-year fire return intervals in the mixed-species class and pitch pine also increased with short fire return intervals when present. In the oak-pine class, chestnut oak remained dominant without fire, and red maple was projected to increase, and sour gum (*Nyssa sylvatica*) dropped out of the top four species by year 60. With fire, pitch pine increased, particularly with short fire return intervals, and became nearly co-dominant with oaks by year 60 with burning at a five-year return interval.

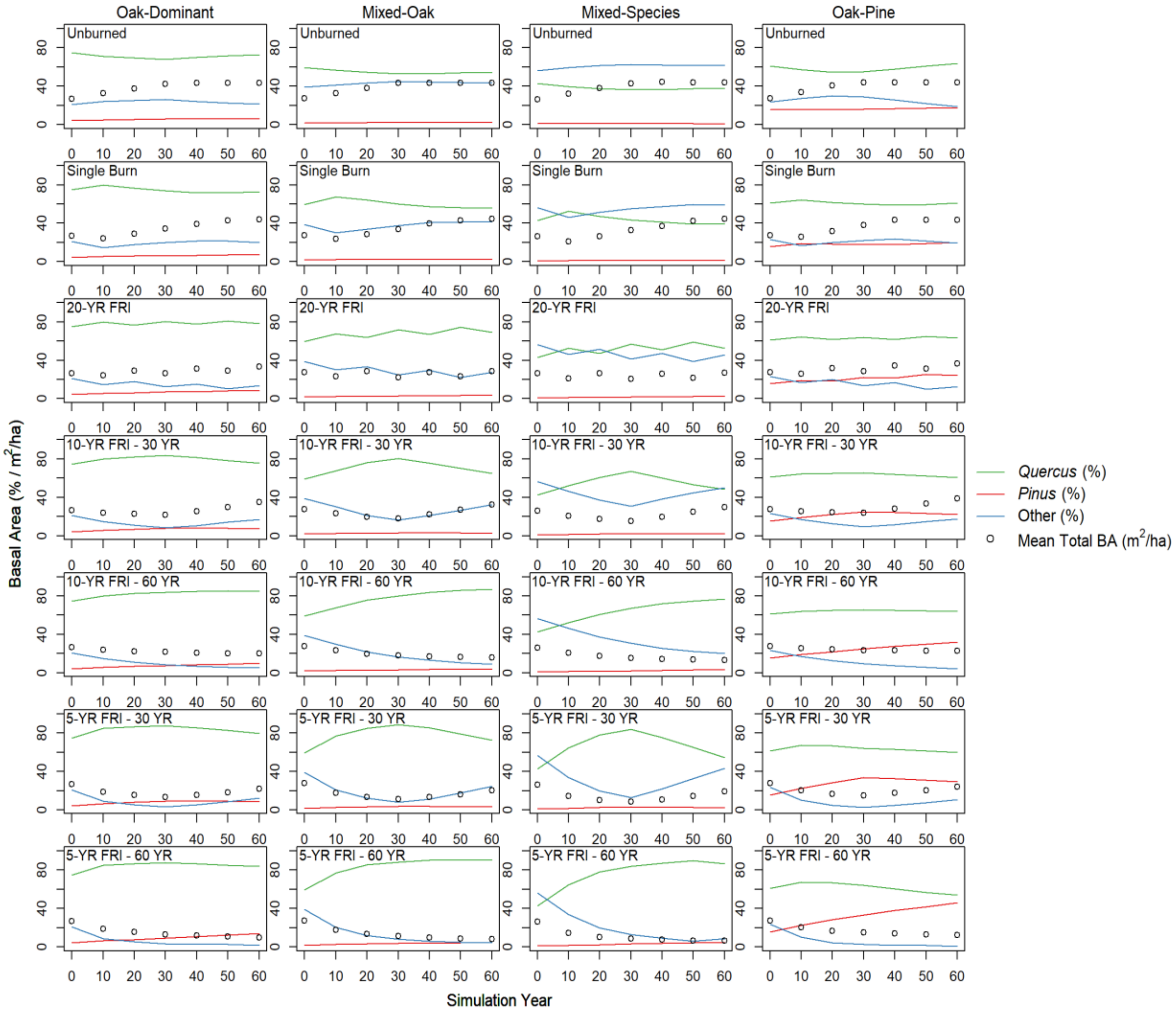


Figure 9. Proportional abundance (BA) of oak (Quercus), pine (Pinus), and other species to simulated fire regimes in Pennsylvania mixed oak forests. Fire regimes were unburned, burned once, and burned at intervals of 5, 10, and 20 years for a 30 of 60-year period.

Carbon stocks and emissions fromfFire. Projected total live aboveground C stocks were influenced by fire frequency and duration of fire regimes. When forests were not burned, average live C stocks increased by 160% from initial conditions in all forest classes, rapidly at first and then more gradually in later decades (**Table 2, Figure 10**). With a single burn treatment, live C stock increases were similar to those of the unburned forest, after an initial C loss due to the burn. With a 20-year fire interval increases in live C were small for the first 30 years but increased by 33-55% over initial pre-burn values at year 60, except in the mixed oak class. Live C stocks in the mixed-oak class were similar at the beginning and end of the simulation period. Burns at five-year return intervals caused a steady decline in live C stocks in all forest classes, and after 60 years live C stocks were 42-67% lower than initial values. With a 10-year fire return interval, live C in oak-pine and oak-dominant classes dropped below initial stock values, but then increased to within 10% of initial values by year 60. Live C values for the mixed-oak and mixed-species classes, in contrast, declined with the 10-year fire interval and were 29-33% below initial stock values after 60 years. Live C stock outcomes at year 60 for the five- and 10-year fire intervals differed when fire was only applied for the first 30 years. With the 10-year fire return interval and cessation of burning by year 30, live C stocks in all forest classes exceeded initial values by 12-61% by year 60. With the five-year fire return interval, live C stock recovery was lower than that for the 10-year interval, and 4-26% below initial values.

Table 2. Mean aboveground live carbon and standard deviation for each forest class at initial inventory, based on unweighted means among stands.

Forest Class	Total Aboveground Live C (Mg ha^{-1})	Standard Deviation
Oak-Dominant	78.3	24.7
Mixed-Oak	81.6	6.6
Mixed-Species	63.8	26.1
Oak-Pine	71.6	N/A

Cumulative C released from burning over the 60-year simulation period varied with the applied fire regime. Across all forest classes, the single burn treatment released the lowest cumulative C. Projected release with a 20-year regime was more than three-fold higher than the single burn release. Cumulative projected C release was highest with the five-year return interval and 7-9-fold

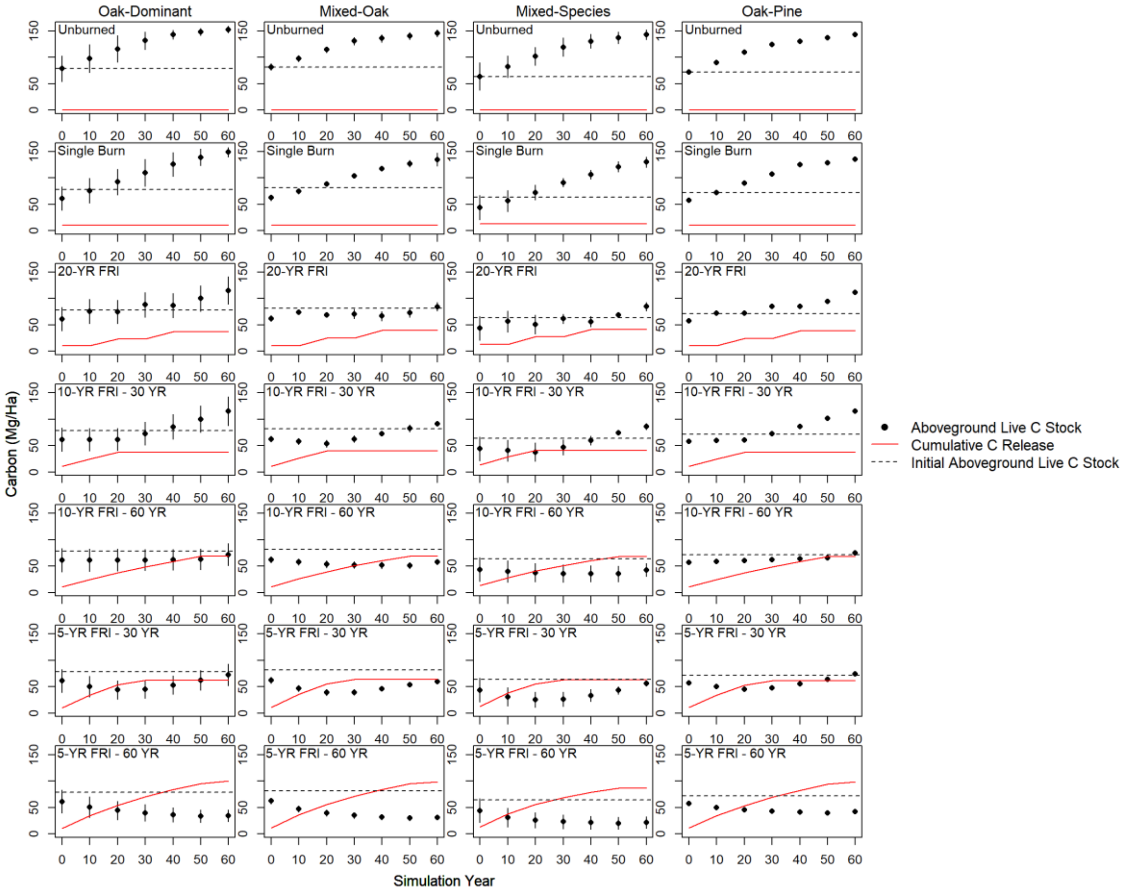


Figure 10. Aboveground live C stocks and cumulative C release to simulated fire regimes in Pennsylvania mixed oak forests. Fire regimes were unburned, burned once, and burned at intervals of 5, 10, and 20 years for a 30 or 60-year period.

higher than the single burn release and values for the 10-year return interval were lower than for the five-year burn interval. Cumulative C release was lower for when burning was stopped at year 30. With the shortened burning period, cumulative C emissions by year 60 for the five-year interval were reduced by 30-40%, and 40-46% for the ten-year fire interval across forest classes.

Intercept Surveys

Hunters vs. non-Hunters. About 58% of intercepted visitors agreed to participate in the research. Hunters comprised roughly 15% of the sample (*n*=79), with non-hunters making up the remaining 85% of the sample (*n*=452). Overall, hunters were less concerned with the perceived costs of prescribed fire than non-hunters for five of the six cost measures. There was no difference between hunters and non-hunters for the high cost of conducting burns. The importance of the benefits of prescribed fire was significantly different between hunters and non-hunters for two of six measures. Both “lower wildfire risk due to fuel reduction” and “increase of game species carrying capacity” were significantly more important for hunters. There were no differences in any other perceived benefits between hunters and non-hunters. Non-hunters expressed higher levels of perceived likelihood of costs from prescribed fire than hunters for four of the six costs measured. There were no differences between the groups for the perceived likelihood of costs of prescribed fire for the items “high cost of conducting burns” and “possible spread to private property.” For the likelihood of benefits, non-hunters indicated a significantly higher likelihood of benefits for two of the six items. Non-hunters indicated a significantly higher likelihood for the item “Less wildfire risk due to fuel reduction,” and hunters indicated a significantly higher likelihood for the item “Increase of game species carrying capacity”. All of these results can be found in more detail in our publication (Miller et al. 2020).

Trailhead surveys taken by recreational forest users showed that most respondents had moderate, strong, or very strong support of prescribed burning in both PA and NJ (**Figure 11**). There were slightly more respondents who replied that they were neutral in PA versus NJ, and slightly fewer

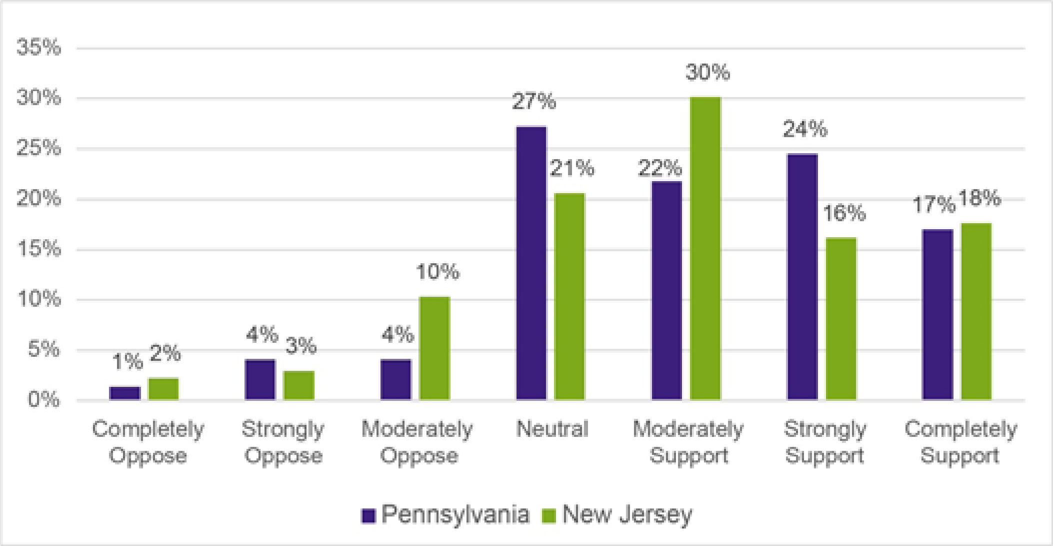


Figure 11. Results from trailhead survey of forest users in PA and NJ about their support of prescribed fire.

respondents who answered "strongly support" in NJ compared to PA. Very few respondents answered "completely oppose" or "strongly oppose" in both locations.

Users vs. Managers. Comparing NJ and PA forest users with managers, the survey revealed different levels of concern among prescribed burning outcomes (**Figure 12**). Forest users ranked wildlife mortality as the top concern, followed by fire spread. In contrast, managers ranked fire spread and smoke as the top two concerns, followed by wildlife mortality and cost. Among benefits, users ranked tick reduction as the top benefit from prescribed fire, followed by the protection of endangered species. Support for game species was ranked lowest (likely due to the fact that hunters comprised only a portion of the respondents). Among managers, lowering wildfire risk was the top benefit, followed by tick reduction.

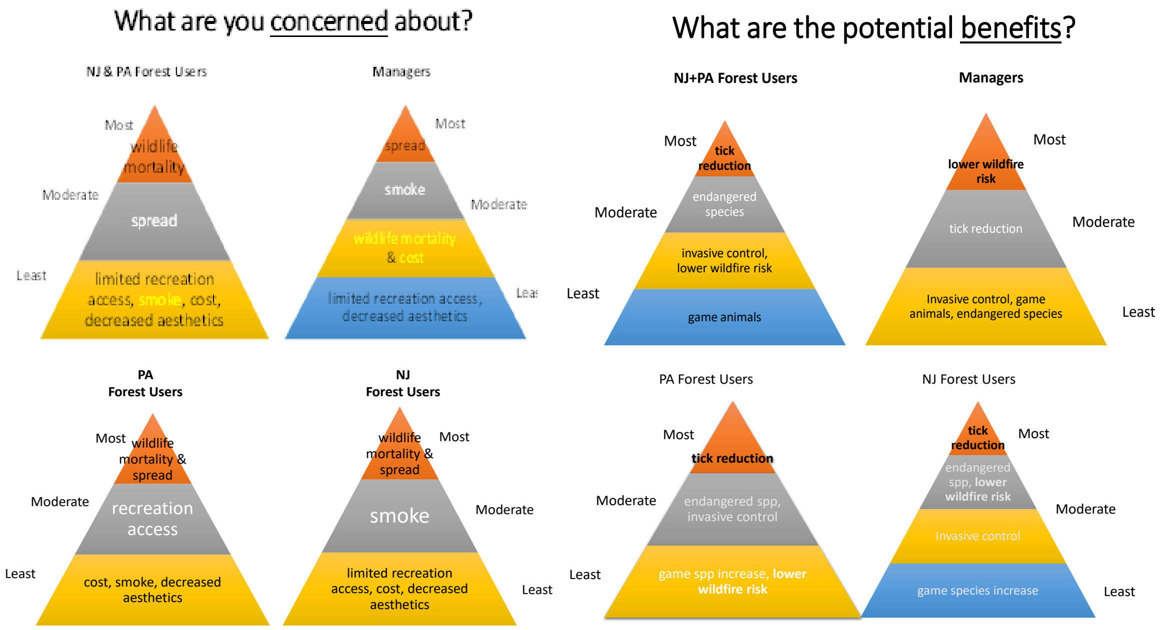


Figure 12. Survey results comparing perspectives of forest recreational users and managers about the top concerns and benefits (top) from prescribed burning, and among perspectives of forest recreational users in Pennsylvania (PA) and New Jersey (NJ) (bottom).

Pennsylvania Users vs. New Jersey Users. Among forest users, there were many similarities between respondents in PA and NJ (**Figure 12**). In both locations, users ranked wildlife mortality and fire spread as the most important concern. However, forest users in PA were secondarily most concerned about the loss of recreational benefits, whereas NJ forest users were moderately concerned about smoke. For prescribed fire benefits, forest users in PA and NJ both ranked potential tick reduction as their top perceived benefit. Endangered species were of moderate concern to both groups, in addition to the reduction of invasive species for forest users in PA and reduction in wildfire risk for forest users in NJ.

Focus groups

Barriers and Opportunities for Prescribed Fire Management

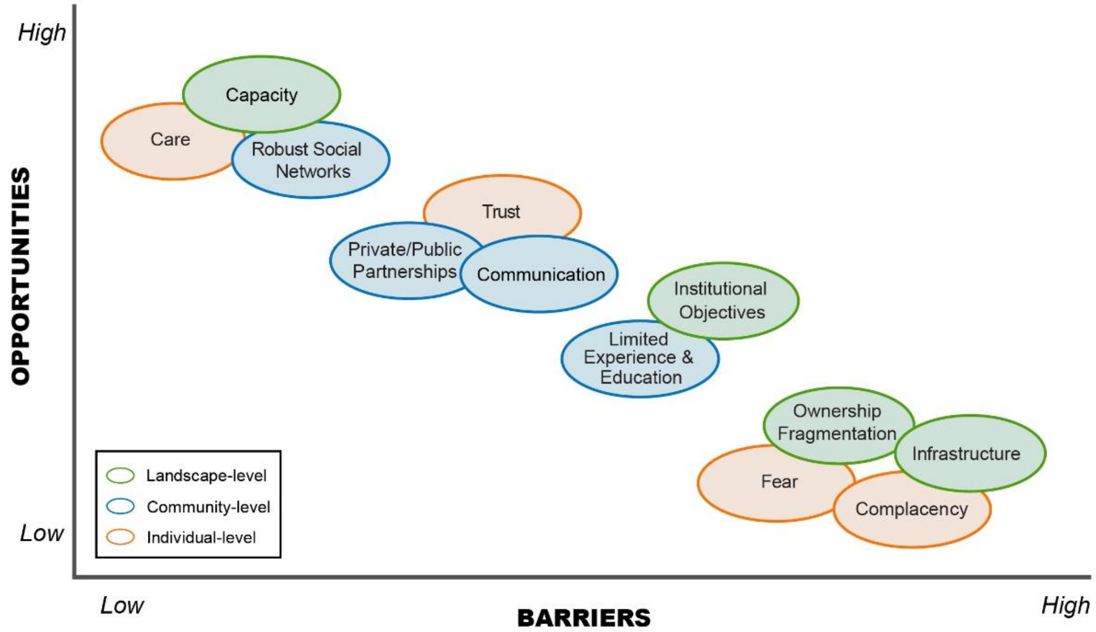
Our results show that barriers and opportunities of implementing prescribed fire vary at the landscape, community, and individual level (**Figure 13**).

Landscape-level. Managers expressed an interest in burning larger areas because "*governing larger tracts is better, easier, more cost effective and more time effective, in the long run,*" but are often constrained by fine-grained ownership mosaics and infrastructural constraints. Managers noted challenges of burning in areas with high human population and associated infrastructure common in the mid-Atlantic region. Said one: "*we have a lot of interface here. We have a bigger population compared to out West. So, we have a lot of people, roads, homes, developments, or businesses that we have to take into consideration when we burn…Everything has to be in place to be able to accommodate that population, to make sure the winds aren't affecting the smoke."*

Coordination of landscape-level planning that includes public and private lands is particularly important in the mid-Atlantic given the higher percentage of privately-owned land (Radeloff et al. 2018). In New Jersey, the NJFFS is responsible for putting out wildfire on both public and private land. One New Jersey fire manager stated that "*it is in our best interest to support* [private landowners]," because "*any burnt ground that they are accomplishing is going to help us as far as hazard reduction.*" While coordination among some private landowners, like cranberry farmers, is evident in New Jersey, managers in Pennsylvania reported a "*shortage of prescribed fire implementors to deliver fire on private lands*" as well as a lack of incentives for landowner participation, saying "*People don't realize that if somebody is going to come burn your land, it costs money. And now as soon as they hear that, they go 'Oh, okay. I am out.' A very small percentage of those people want to do it out of the goodness of their heart because they want to do the right thing*."

Managers also perceive persistent constraints in working with agencies that have different objectives. For example, managers note the challenges of implementing burns in narrow burn windows limited by weather conditions, while balancing the life history of species of concern that could be in the area: "*it narrows down your operational window to a small window if you can even do it in some cases*." In addition, the compliance challenges of coordinating burns with municipalities and agencies is a substantial barrier. One said, "*The whole planning process and notification process is a lot of times more difficult than actually doing the burn itself*." On the other hand, managers reported many opportunities or benefits for burning at the landscape level, including invasive species control, habitat restoration, endangered species protection, cultural landscape maintenance, game management (hunting), and wildfire risk management, with the balance of objectives varying across agencies and states. Many managers also report a desire to "*take an interdisciplinary approach*" to identify mutual benefits of burning across multiple objectives.

Community-level. Attitudes towards burning vary within and among communities, presenting challenges to managers. As one manager put it: "*There is just as many people that like it and think that it is the greatest thing in the world. And there is just as many people who hate it*." Reflecting on these challenges, one said: "*We are not marketing professionals. We are often tasked with developing some kind of communication mechanism to inform people or change people's minds,* *and we are not well-equipped in general to do that*.” Working with communities is exacerbated by high-levels of community turnover and lack of education and experience with fire. One manager summarized it simply as “*to me, fire risk is a lack of knowledge*.” A lack of social networks in communities with high turnover was mentioned frequently. A Firewise member lamented “*I mean you are getting a new group of people moving down here that aren’t used to it. And they want to have a say on what should be done now.”* In the face of these challenges, network brokers, individuals who facilitate and cheerlead manager-community relationships, are seen as pivotal for enhancing community buy-in. Numerous Firewise members reflected on the importance of these individuals, in this case a Firewise community liaison, for opportunities to build trust with communities: “*He called me immediately. Every time I asked for something, he has come right back to me. So that gives us the confidence to go on*.” Another reflected that the community liaison “*makes opportunities like this happen so that we are not out there by ourselves. If you look, there is a whole room of people. We all started as an individual community. None of us knew each other. But we have all started, as meetings go, to learn, and that’s where you build trust when you present*



Definitions

Institutional Objectives	Reasons for burning, such as hazard reduction or ecosystem restoration, which differ across agencies or jurisdictional regions.	Private/Public Partnerships	Cooperation among state or federal agencies and private landowners to meet burning objectives.	Trust	Trust betw. communities and managers is critical to successful burning programs, and is based on personal relationships & experience.
Capacity	The ability to meet burning objectives using available resources.	Social Networks	Community relationships that facilitate burning educational and outreach activities.	Care	Intentionality to support community and manager well-being.
Ownership Fragmentation	Tight intermingling of different land ownerships.	Communication	Communication that supports community education and awareness about burn management.	Fear	Concern related to geographical vulnerabilities to wildfire (communities) or stresses related to liability or injury (managers).
Infrastructure	The built environment around which burning must be managed to minimize harm.	Experience & Education	Knowledge of burn management in communities as a function of the amount of community turnover, i.e. higher turnover = less familiarity with local burning.	Complacency	Lack of experience with fire, or lack of perceived benefits or risks.

Figure 13. Comparison of multi-level (landscape, community, individual) barriers and opportunities identified by managers in mid-Atlantic firescapes.

the opportunities for people to get together to converse the problems, to figure it out."

<u>Individual level.</u> At the individual level, participants reflected on the palpable, personal challenges of working in communities that lacked buy-in. Said one manager: "*See, I got the angel and the devil. I listen to the phone calls from people that are going to sue me vs. the people that want to burn. I am kind of torn*." A Firewise community member reported fear about the "*one way in and one way out*" layout of the community, saying their community was "*in a cup*" surrounded by woods. Individual-level experience with wildfire or prescribed fire among the public was also seen as a barrier for support of prescribed fire activities, leading to complacency: "*I think when it comes to the public, they are very busy and many people are working. They have children. You know, some people have church activities. And if you say, where is wildfire on your list of things that you are afraid of, they would put it down as a zero or a one*." A long-time Firewise community resident reported that families that had *"been here for a long period of time know that fire is a problem, and know what we are doing is trying to address the problem,*" but that newer residents are less aware of fire's role in the ecosystem: "*if we knew you did controlled burning, we would have never moved here*." On the other hand, participants' comments reflected a deep sense of mutual care about each other, that seemed to buoy those fears: "*if we save one home or saved one firefighter from having to go to that home, it's worth it, for that firefighter's life*." In addition to mutual care, trust was seen as a key opportunity for manager-community relations, developed through relations among individuals through time, as in the case of the Firewise community liaison: "*The trust factor. There are three kinds of people in the world. People who make things happen. People who watch things happen, and people who wonder what happened. [He] makes things happen*." Among managers and Firewise community leaders, care and trust, combined with a firm understanding of fire's role in the forest, underlay sustainable opportunities for prescribed fire implementation.

Value of Prescribed Fire

Willingness to pay estimates for forest attributes (reduction in fire hazard, visibility, and habitat quality) are shown in **Figure 14**.

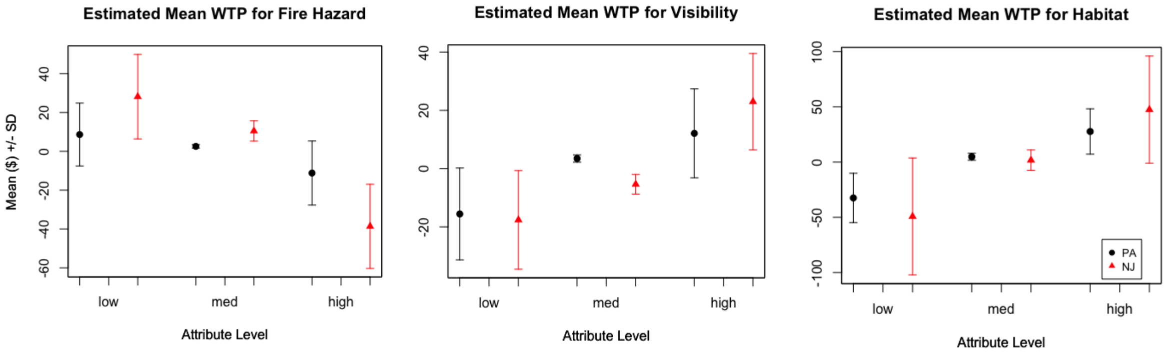


Figure 14. Estimated mean willingness to pay (WTP) for forest attributes.

In Pennsylvania, the present value of the recreational benefits of prescribed fire reaches an asymptote between 10-20 years and is maximized at 44 years for both TPA and BA (**Figure 15**). In New Jersey, the present value of the recreational benefits of prescribed fire is maximized at 2-year burn intervals for TPA and 4-year burn intervals for BA (**Figure 15**). This too is consistent with pine barrens which typically have a natural burn cycle of every 5-10 years.

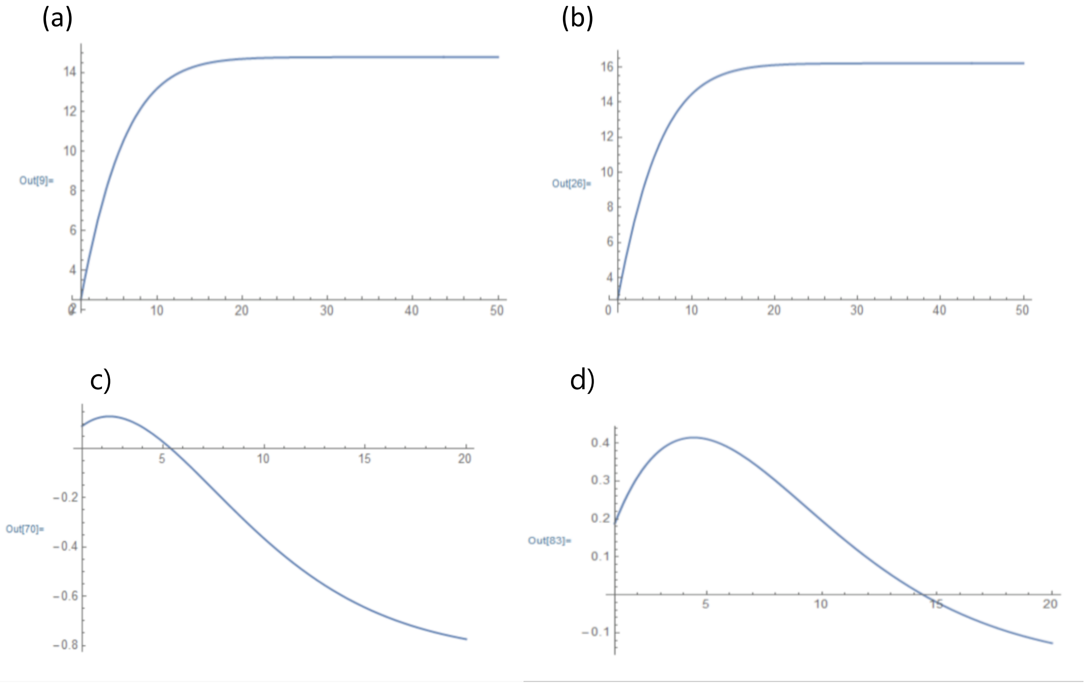


Figure 15. Peak benefit from prescribed burning in (a) Pennsylvania for Trees per Acre (TPA), (b) Pennsylvania, Basal Area (BA), (c) New Jersey, TPA, and (d) New Jersey (BA).

As shown in **Table 3** using prescribed fire every 15 years yields 86% of the maximum achievable benefits (using prescribed fire every 44 years), whereas burning every 20 years yields 99% of these maximum benefits. Therefore, waiting the additional 24 years to burn every 44 years instead of every 20 years only produces 1% more benefits to forest visitors. This is consistent with oak forests which typically have a natural burn cycle of every 30-50 years.

Table 3. Maximum benefits to forest users as a function of years between fires.

Years between prescribed fires	**% error from max benefits (TPA)**	**% error from max benefits (BA)**
5	60.6%	60.7%
10	13.4%	13.5%
15	3.3%	3.3%
20	0.75%	0.76%
25	0.16%	0.16%
30	0.028%	0.029%

Science Delivery Activities

Deliverable Type	**Delivery Dates**
Masters' thesis	Dems, C. M.S. 2019 Zhao, A. M.S. 2019
Refereed publication	Smithwick et al., under review by co-authors
Refereed publication	Miller et al. 2019 - published
Refereed publication	Zhao et al. under review by co-authors
Refereed publication	Zipp et al., under review by co-authors
Refereed publication	Dems et al. under review by co-authors
Refereed publication	Wu et al., drafted
Conference presentations	Numerous – see products
Workshop I	Combined with Focus Group activities (PA 2016)
Workshop II	Combined with Focus Group activities (NJ 2018)
Workshop III	Combined with MD TNC Fire Learning Network presentation and focus group (MD 2019)
Webinar & outreach activities	• NJ Fire Manager Annual Meeting Invited Seminar [2019] • MD Chapter of The Nature Conservancy Fire Learning Network Seminar [2019] • Videos and publication disseminated through @NorthAtlFireSci • Center for Private Forests Webinar [Feb 2020; ~100 participants] • Fire in Eastern Oak Forests Conference Plenary [Invited, 2019] • Pennsylvania Prescribed Fire Council Plenary [Invited; 2019] • Schlow Public Library presentation [Invited; 2019]
Website	WPSU produced outreach and teaching videos (see products); regular social media presence
Datasets	Ongoing (see Metadata section)
Video-story	Two, high quality video stories about community acceptance of burning (see products) – Fall 2019

Figure 16. Photo from NJ Fire Manager Annual Meeting in which results were shared back with managers (2019).

Conclusions and Implications for Management/Policy and Future Research

Prescribed fire is an effective tool for managing wildfire risk and supporting habitat restoration. However, sustainable prescribed fire management practices must grapple with challenges of complex land ownership patterns, growing interface between communities and forests, and variable acceptance by communities and individuals. Our research explored these dynamics in the understudied region of mid-Atlantic U.S. where barriers and opportunities for stewardship of firescapes were expected to be particularly complex. Based on community, manager, and Firewise leader perspectives, our results highlight both barriers and opportunities for prescribed fire management in the mid-Atlantic. We also identify both differences (mismatches) and similarities about these barriers and opportunities, both within the region (NJ vs. PA) and among stakeholders (community vs. manager)

First, our project showed that prescribed fire in central PA appeared to meet major habitat restoration objectives in terms of forest structure and species composition. Because our study was limited to a small number of sites, more research is needed to identify whether these outcomes are similar across the region. In addition, long-term monitoring will be important to ensure these outcomes remain persistent through stand succession. In lieu of opportunities for long-term monitoring, we used a simulation model to estimate the long-term impact of repeated burns on mid-Atlantic forest structure, species composition, and carbon storage. Our results showed that repeated burning over 60 years should meet management objectives (i.e., at least every 5 years in NJ and ~10-20 years in PA). Across most scenarios, C sequestration potential remained high, with the exception of scenarios to restore pitch pine ecosystem; these scenarios resulted in a tradeoff between stand conditions and C storage potential.

Our community surveys identified strong support for prescribed fire in the mid-Atlantic. However, the perceived benefits and concerns differed somewhat among recreational forest users in NJ and PA, among hunters and non-hunters, and between managers and communities. While concerns about wildlife were high among all respondents, community members ranked these concerns higher than concerns about smoke or fire spread, whereas fire spread was a top concern for managers. Smoke and fire spread concerns among forest users were highest in NJ versus in PA, where recreational access was the biggest concern. Potential reduction in ticks was uniformly seen as a potential benefit from prescribed fire, especially among forest users. Although there is some evidence to support this perception from studies in other areas, more empirical research is needed in the local region to corroborate this perception. Reduction of wildfire risk remained a top concern for managers. When modeling the willingness to pay for certain attributes of forests (habitat quality, visibility, hazard reduction), we found that burn rotations of ~5 years in NJ and 10-20 years in PA would maximize user benefits. These fire return intervals are consistent with the ecological results from the FVS modeling, suggesting that both social and ecological attributes are feasible under these management strategies.

Finally, our focus groups with managers identified multi-scalar barriers and opportunities for prescribed fire implementation in the mid-Atlantic, which may help prioritize strategies for broader prescribed fire use in the future. For example, our project showed that coordinating landscape fire management where privately-owned lands are widespread is a particular challenge. Addressing challenges around burning on private land in the mid-Atlantic may involve codifying best practices and standards, enhancing management capacity, ensuring liability protection, supporting educational programs and workshops, and developing cost-sharing and financial incentives. We also identified many opportunities for sustainable prescribed fire management. Of note was the mutual trust and care shown among managers and community members to cultivate community

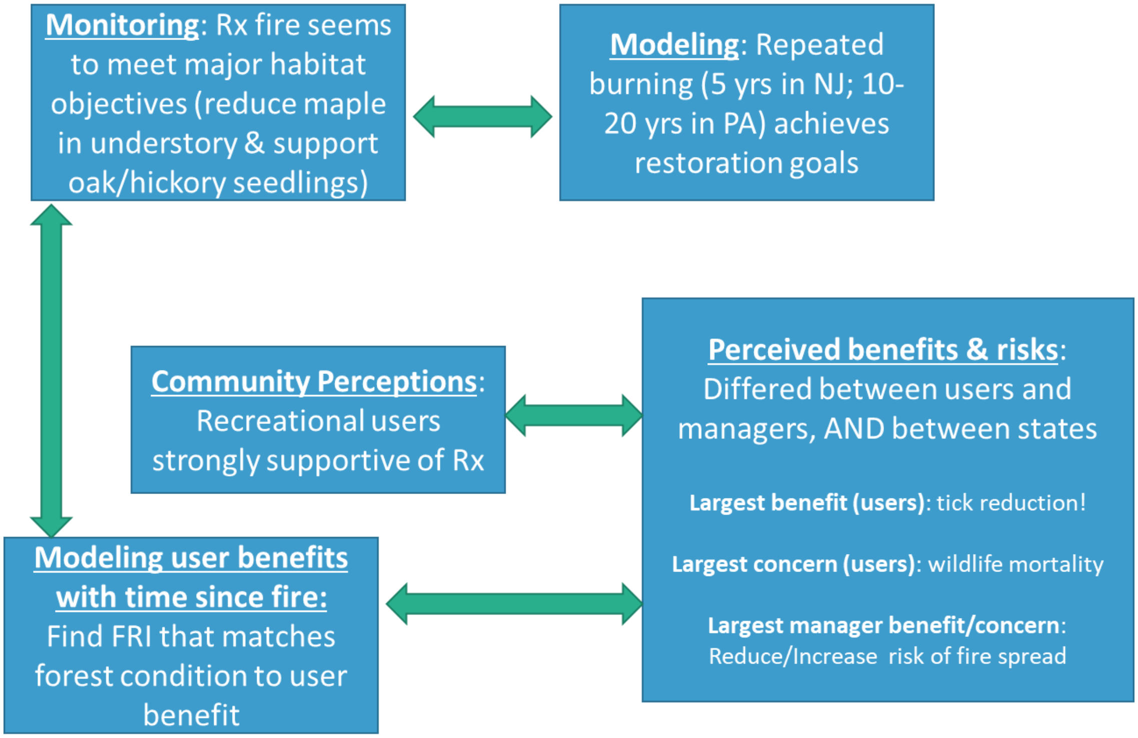


Figure 17. Summary of project results.

safety and well-being of the management community. In our case, this was enhanced by manager-community liaisons that acted as a network broker with Firewise community leaders.

Overall, we demonstrate the importance of qualitative research identifying management approaches to understanding and tracking social acceptance of prescribed burning. Alongside quantitative approaches for monitoring and assessment to ensure ecological objectives are being met, social science research is critical to fulfilling the need of developing resilient firescapes (McCaffrey et al. 2013, Smith et al. 2016).

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Appendix B: List of Completed/Planned Scientific/Technical Publication/Science Delivery Products

Graduate Theses

Dems, C. 2019. Igniting Change: Measuring Prescribed Fire Effects in a Central Pennsylvania Hardwood Forest. M.S. The Pennsylvania State University.

Zhao, A. 2019. Modeling Prescribed Fire Effects on Vegetation Dynamics in Mid-Atlantic Oak and Pitch Pine Forests. M.S. The Pennsylvania State University.

Articles

Miller ZD, Wu H, Zipp K, Dems CL, Smithwick EAH, Kaye M, Newman P, Zhao A, Taylor A. 2020. Hunter and non-hunter perceptions of costs, benefits and likelihood of outcomes of prescribed fire in the mid-Atlantic region. *Society & Natural Resources* 33 (10): 1321-1327.https://doi.org/10.1080/08941920.2020.1780359

Dems, C.L., Taylor AH, Smithwick EAH, Kreye J, Kaye MW. Altering forest structure and composition using prescribed fire: A case study in central Pennsylvania, USA, under review by co-authors.

Zhao, A, Taylor AH, Smithwick EAH, Kaye M, Harris L. The effects of simulated fire regimes on oak forest development and carbon stocks and emissions in Pennsylvania, U.S.A., under review by co-authors.

Zipp K, Shr Y-H, Smithwick EAH, Zhao A, Taylor AH, Kaye MW, Miller Z, Wu H, Newman P. Feeling the burn: the optimal timing of prescribed fires for recreational benefits, analysis completed, drafted.

Smithwick EAH, Taylor AH, Kaye MW, Zipp K, Wu H, Miller ZD, Shr Y-H, Zhao A, Dems C, Newman P. Manager perspectives: barriers and opportunities of prescribed fire in the mid-Atlantic, under review by co-authors.

Conference of symposium abstracts

2020	Smithwick EAH, Zipp K, Wu H, Kaye M, Taylor A, Miller Z, Dems C, Zhao A, Shr Y-H, Newman P. Firescapes of the mid-Atlantic. Center for Private Forests Webinar, February 11, 2020. [Invited]
2020	Smithwick EAH, Taylor A, Kreye J, Zipp K, Wu H, Newman P, Webber J, Battersby J, Bearer S. Barriers and opportunities for science-policy coordination in mid-Atlantic firescapes. North America Chapter of the International Association of Landscape Ecology Annual Meeting [Virtual], May 2020.
2019	Smithwick EAH, Zipp K, Wu H, Kaye M, Taylor A, Miller Z, Shr, Y-H, Zhao, A, Dems C, Newman P. Burning mismatches in firescapes of the mid-Atlantic. Annual meeting of the American Geophysical Union, San Francisco, California, (December 11, 2019), Accepted, National.

2019 Smithwick EAH, Zipp K, Wu H, Kaye M, Taylor A, Miller Z, Shr, Y-H, Zhao, A, Dems C, Newman P. Firescapes in the mid-Atlantic: mismatches between social perceptions and prescribed fire use. Pennsylvania Prescribed Fire Council, Gettysburg PA, February 6. [Invited Plenary]

2019 Smithwick, E. A. H., Zipp, K. Y., Wu, H., Kaye, M. W., Taylor, A. H., Miller, Z., Shr, Y.-H. (Iowa State University), Zhao, A.*, & Dems, C.* New Jersey Forest Fire Service – All Staff Meeting, Island Beach State Park, New Jersey, September 12, 2019, Invited. Regional.

2019 Smithwick, E. A. H., Zipp, K. Y., Wu, H., Kaye, M. W., Taylor, A. H., Miller, Z., Shr, Y.-H. (Iowa State University), Zhao, A.*, & Dems, C.* (September 11, 2019). "Firescapes in the mid-Atlantic: mismatches between social perceptions and managed fire use," Central Appalachians Fire Learning Network Workshop, Central Appalachians Fire Learning Network, McHenry, Maryland, 100 in attendance, Invited. Regional.

2019 Smithwick, E. A. H., Zipp, K. Y., Wu, H., Kaye, M. W., Taylor, A. H., Miller, Z., Shr, Y.-H. (Iowa State University), Zhao, A.*, & Dems, C.* (July 23, 2019). "Burning misMatches in Firescapes of the mid-Atlantic," The sixth Fire in Eastern Oak Forests Conference, Oak Woodlands & Forests Fire Consortium; Consortium of Appalachian Fire Managers and Scientists, State College, PA, 100 in attendance, peer-reviewed/refereed. Regional. [Invited Plenary]

2019 Dems, C., Kaye, M., Taylor, A., Smithwick, E.A.H, Lupo, P., & Maynard, E. (2019, March). *Prescribed fire in Pennsylvania forests*. Presented at the Pennsylvania Private Landowners Conference. State College, PA

2019 Dems, C., Kaye, M., Taylor, A., Smithwick, E.A.H, Lupo, P., & Maynard, E. (2019, February). Measuring eight years of forest response to prescribed fire in central Pennsylvania. Presented at the Pennsylvania Prescribed Fire Council Annual Meeting. Gettysburg, PA.

2019 Zhao, A., Taylor, A.H. Modeling Prescribed Fire Effects on Vegetation Dynamics in Pitch Pine and Mixed-Oak Forests Association of American Geographers, Washington D.C.

2019 Zhao, A. Modeling prescribed fire effects on vegetation dynamics in Pennsylvania mixed-oak forests. Pennsylvania Prescribed Fire Council Annual Meeting. Gettysburg, PA.

2018 Smithwick EAH, Zipp K, Wu H, Kate M, Taylor A, Newman P, Shr Y-H, Zhao A, Dems C, Miller, Z. Firescapes in the mid-Atlantic: Mismatches between social perceptions and prescribed fire use. The Nature Conservancy, MD Chapter, September 11, 2018. [Invited]

2018 Smithwick EAH, Zipp K, Wu H, Kate M, Taylor A, Newman P, Shr Y-H, Zhao A, Dems C, Thurston E. Firescapes in the mid-Atlantic: Mismatches between social perceptions and prescribed fire use. Association of American Geographers Annual Meeting, New Orleans, LA, April 11, 2018

2018 Smithwick EAH, Zipp K, Wu H, Kate M, Taylor A, Newman P, Shr Y-H, Zhao A, Dems C, Miller, Z. Firescapes in the mid-Atlantic: Mismatches between social perceptions and prescribed fire use. Eastern States Section of the Combustion Institute annual meeting, The Pennsylvania State University, March 4-7, 2018 [Invited Plenary]

2018 Smithwick EAH, Zipp K, Wu H, Kate M, Taylor A, Newman P, Shr Y-H, Zhao A, Dems C, Miller, Z. Firescapes in the mid-Atlantic: Mismatches between social perceptions and prescribed fire use. Pennsylvania Prescribed Fire Council annual meeting, Williamsport, PA, February 2018 [Invited/Cancelled due to weather]

2018 Zipp K and Shr Y-H. Feeling the burn: the optimal timing of prescribed fires for recreational benefits. EEEP seminar, October 24, 2018, The Pennsylvania State University, University Park, PA.

Presentations/webinars/other outreach/science delivery materials

- Schlow Library Research Unplugged Speaker Series, Oct 3, 2019. "Firescapes of the mid-Atlantic: A Promethean Promise." Penn State Office of Government and Community Relations and Schlow Library, State College, PA, 100 in attendance, Invited. Local.
- WPSU Outreach and teaching videos; provided to managers and distributed on North Atlantic Fire Science Exchange Learning Network twitter feed
    - https://vimeo.com/386811665/7fe48534d8
    - https://vimeo.com/user12944121/review/374158256/52dd899651

Appendix C: Metadata

Qualitative and quantitative data from focus groups and surveys is currently stored on a password protected data storage platform (Box at Penn State) and all project personnel with access to human subjects' data are authorized through Penn State's IRB for this project. Following the data management plan, our data will be archived through Penn State's DataCommons service and shared with the Forest Service R&D data archive to be shared with the scientific and management community. According to IRB protections, no personally identifiable information will be included. Transfer of data to DataCommons is underway and will be coordinated with publication of journal articles, but no later than 2 years following completion of the project.

Sampling protocols used to parameterize FVS modeling are included in the publicly available M.S. thesis of Anthony Zhao (Penn State). These include the data collection protocol from

- the Pennsylvania Department of Conservation and Natural Resources (DCNR) Bureau of Forestry Continuous Forest Inventory (CFI). Source: Commonwealth of Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry – Inventory Manual of Procedure for the 2003 State Forest Plan – Inventory of Biological Resources (Phase 3), June, 2003 (Revised March 9, 2006)
- the Pennsylvania Game Commission pre- and post-burn forest monitoring research. Source: Pennsylvania Game Commission – Prescribed Fire Monitoring Protocol.
- the Pennsylvania Game Commission pre- and post-burn forest monitoring research conducted in State Game Land 176 Unit 2. Source: SGL 176 Prescribed Burn Inventory – 2009 Pre-burn Inventory, August 2009.
- the New Jersey Forest Service state forest inventory. Source: Request for Proposal 16-X-24150 – For: State Forest Inventory, NJDEP, December 24, 2015.
- Forest Inventory and Analysis (FIA) Fact Sheets showing the data collection protocol corresponding to the U.S. Forest Service FIA Program. Source: FIA Fact Sheet Series, 2/3/05.

Additional FVS parameterization data (seedling height classes and corresponding reliability indices; tree species estimated survival rates are also included in Appendix C of the Zhao M.S. thesis.

Data from the FVS modeling results can also be found in Supplementary Appendix C of the Zhao MS thesis. These include:

Table 3 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.

Projected changes in relative BA for pines (Pinus spp.), oaks (Quercus spp.), and other species and total BA values (m2 ha-1) over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands.

Table 4 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.

Top four most dominant species in terms of BA, corresponding BA proportions relative to total stand BA, total stand BA (m2 ha-1), and standard deviation among experimental replicates at initial inventory, year 30, and year 60 for each stand, with different fire regime treatments. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species

Table 5 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.

Top four most abundant species in terms of density, corresponding density proportions relative to total stand density, total stand density (trees ha-1), and standard deviation among experimental replicates at initial inventory, year 30, and year 60 for each stand, with different fire regime treatments. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set.

Table 6 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx

Projected changes in total density values (trees ha-1) over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands.

Table 7 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.

Projected changes in quadratic mean diameter (QMD) for pines (Pinus spp.), oaks (Quercus spp.), and all species combined over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands.

Table 8 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.

Projected changes in relative BA for pines (Pinus spp.), oaks (Quercus spp.) and other species and total BA values (m2 ha-1) over 60 years, and standard deviation among experimental replicates, for each stand with different fire regime treatments.

Table 9 in ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx

Projected changes in quadratic mean diameter (QMD) for pines (Pinus spp.), oaks (Quercus spp.), and all species combined over 60 years, and standard deviation among experimental replicates, for each stand with different fire regime treatments.

Additional and original data from fire effects monitoring can be found in the publicly available M.S. thesis of C. Dems. These include prefire tree species composition, original fire prescription parameters, and fire weather information.