Tree communities reshaped following the Chestnut Knob Wildfire in South Mountains State Park, North Carolina

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Abstract

Wildfire has been relatively rare in forests of the Southeastern United States since European colonizations and the transition to a fire suppression regime. In particular, the Piedmont region, which is characterized by diverse mixed hardwood forests, has been less studied than more fire-prone ecosystems such as longleaf pine savannas. Consequently, the effects of wildfire on forests in the Piedmont remain poorly understood. This study examines the impacts of the 2016 Chestnut Knob wildfire on tree abundance and composition at South Mountains State Park, North Carolina. We conducted tree surveys at 16 sites, comparing burned and unburned sites on slopes of differing aspects (North/East vs. South/West). Five years post-fire, burned sites exhibited a strong trend toward increased dominance of fire adapted species, regardless of slope aspect. On North/East slopes, surviving trees were disproportionately of large diameter, suggesting selective survival of mature, fire-tolerant individuals of moderately fire-adapted species, such as eastern white pine (*Pinus strobus*) and chestnut oak (*Quercus michauxii*) and the severe decline of red maple (*Acer rubrum*) and sourwood (*Oxydendrum arboreum*), which dominated unburned North/East sites. In contrast, South/West slopes sites, which experienced near-stand-replacement fires, were dominated by new growth of fire-adapted species, especially mountain pine and Virginia pine, and the virtual elimination of previously-dominant mountain laurel and sourwood. Given the high densities of young Virginia pine, management interventions, such as low-intensity prescribed burns, may be warranted to reduce competition and support the establishment and growth of a mountain pine-dominated community, with benefits to biodiversity and fire management. These findings contribute to our understanding of post-fire forest dynamics in the Southeastern United States, highlighting how wildfire can promote the recovery of fire-adapted species and forest types in historically fire-suppressed ecosystems.

Introduction

The history of fire in forests of the southeastern United States is complex, varied, and has changed in concert with changes in human cultures and activities over recent centuries (Brose et al., 2001; Flatley et al., 2013; Kuppinger & Rich, 2019; McEwan et al., 2014). Before European colonization of eastern North America, Indigenous peoples used low-intensity fire to manage forests to enhance gathering, agriculture, and hunting (Brose et al., 2001; Flatley et al., 2013). These activities created open understories and promoted the dominance of fire-adapted species such as oak (*Quercus*), American chestnut (*Castanea dentata*), and pines (*Pinus*) (Delcourt & Delcourt, 1997). The arrival of settler-colonial Europeans disrupted these Indigenous practices, replacing them with extractive practices such as widespread logging, land clearing for agriculture, and a concomitant increase in more severe stand-replacement fires (Brose et al., 2001). By the early 1900s, aggressive fire suppression policies further altered fire regimes (Spooner et al., 2021), leading to dense forests with high fuel loads and a decline of fire-adapted species (Delcourt and Delcourt, 1997). These modern conditions favor severe, stand-replacement wildfires when ignition occurs, with an expectation of increasing trends of wildfire occurrence, wildfire size, total burned hectares, and probability of large wildfires, specifically in the southeastern United States (Andela et al., 2017; Ingram et al., 2013; Donovan et al., 2023).

Although fire ecology in the modern fire regime has been extensively studied in fire-prone ecosystems such as longleaf pine (*Pinus palustris*) savannas (Frost, 1977; Rother et al. 2022), the heavily-forested Piedmont region of the southeastern United States has not received similar attention. Like most eastern forests, the Piedmont's mixed hardwood forests, which historically experienced natural fire, have experienced significant compositional changes due to fire suppression, characterized as "mesophication" of forests (Nowacki & Abrams, 2008). Specifically, fire-adapted and shade-intolerant species such as table mountain pine (*Pinus pungens)*, shortleaf pine (*Pinus echinata)*, and multiple oak species (*Quercus)* are in regional decline (Clabo & Clatterbuck, 2005; Guldin, 2019; Delcourt and Delcourt, 1997; Hale & Peterson, 2024) and are being replaced mesophytic fire-sensitive and shade-tolerant species (e.g., red maple, *Acer rubrum*), leading to dramatic changes in forest structure and ecology (Nowacki & Abrams, 2008; Lorimer, 1984; Lorimer et al., 1994). In sum, most unmanaged forests in the Piedmont are simultaneously less adapted to fire and more susceptible to severe effects of wildfire than in the past. Despite this novel vulnerability and context, relatively little is known about how modern forests in the Piedmont region respond to and recover from wildfire, when it occurs.

The Chestnut Knob Fire of 2016 presented a relatively rare opportunity to study the effects of wildfire in foothill forests of the southeastern US Piedmont. The fire burned approximately 2500 ha in South Mountains State Park in the Piedmont of North Carolina, USA in the autumn of 2016, during an unusually severe fire season in the region. The size, location, and severity of the fire combined to create conditions for a natural experiment on the effects of relatively severe wildfire on tree composition in an understudied region within the context of a history of fire suppression, forest mesophication, and rare, but increasing, wildfires. In this study, we compare tree composition after the Chestnut Knob fire across burned and unburned locations, with a focus on differences between ridge slopes of north/east and south/west aspects, which we expect to have different histories with respect to fire return interval and severity. Specifically, we assess changes in tree species abundance patterns as a result of the wildfire, the differential response of fire-adapted tree species, and how post-fire forest structure differs based on slope aspect. Because of the rarity of similar studies in the region, we aim to address gaps in knowledge of post-fire dynamics in modern forests in the foothill forests.

Methods

Chestnut Knob Fire

Intense drought in 2016 in the southeastern United States led to dry conditions in the southern Appalachian region, sparking numerous wildfires (Stiefel et al., 2021). In South Mountains State Park, the Chestnut Knob Fire burned approximately 2500 of the total 8500 acres of the park in November of 2016. Although much of the fire was of mild to moderate severity (Stiefel et al., 2021), ridgelines and south and west-facing slopes experienced conditions closer to stand-replacement fires. The fire was fully contained by the end of November, using existing or widened trails as firebreaks. In portions of the park, a clear distinction between burned and unburned areas is now evident across firebreaks (Fig. 1), often along ridgetops where park trails already existed.

Study Area

South Mountains State Park (SMSP) is in Burke Co, North Carolina, at the western border of the Piedmont ecoregion, separated from the higher Blue Ridge Mountains by the Catawba River Valley. SMSP ranges in elevation from 365–915 meters, and while not reaching the same elevations as the adjacent Blue Ridge Mountains (305–1830 m), tree biodiversity and forest composition within SMSP has similarities to the forests of the lower-elevation Appalachian Mountains.

Based on maps of the extent of the Chestnut Knob Fire, we identified 16 study sites (Fig. 2). Eight sites had a primary south/west aspect and others had a north/east aspect. Because these sites were chosen near ridgelines, sites with drastically different conditions or burn severities were in close proximity to each other (Fig. 1). This allowed us to investigate forests with similar environmental conditions, differing in some combination of aspect (south/west vs. north/east) and burn status (burned or unburned). Using a natural experimental approach and a space-for-time substitution, in this study we considered unburned sites on similar aspects as approximate controls for burned sites.

Data Collection and Analysis

At each of the 16 sites we established individual 100 m x 5 m tree survey transects that followed the slope contour at each site. We identified all trees and shrubs > 2 cm diameter at breast height (DBH) within the transect and measured DBH in cm. For ambiguous individuals, especially of young trees, we took pictures and recorded their location and characteristics for later identification by consultation with published field guides and online resources. Data used in this study were collected in the summers of 2021 and 2022 (4.5–5.5 years post-fire). We analyzed data in R and focused on descriptive statistics with 95% confidence intervals presented as mean [confidence interval]. Data is available by request by contacting the corresponding author.

Results

Overview

We identified 26 tree species across all sites. Across all sites the most abundant species were Virginia pine (*Pinus Virginiana*) with 161 individuals and table mountain pine (*Pinus pungens*) with 107 individuals, followed in decreasing order of abundance by chestnut oak (*Quercus Montana*), sourwood (*Oxydendrum arboreum*), white pine (*Pinus strobus)*, and red maple (*Acer rubrum*). We identified over 880 individual trees, with each 500 m^2 transect having an average of 59.2 trees > 2 cm DBH.

Tree abundance and species richness

Burned sites had lower average tree abundance than unburned sites on both slope aspects (Fig. 3A). This difference was most pronounced on NE slopes, where burned sites had an average of 30.33 individual trees compared to 46.0 trees at unburned NE sites. On SW slopes, abundance was higher overall and followed a similar pattern, with burned sites averaging 78.25 individual trees per site, compared to 86.5 trees at unburned SW sites.

In general, burned sites also had a lower tree species richness than their unburned counterparts within each aspect category (Fig. 3B). The lowest richness was at burned NE sites, with 6.67 species per site, compared to 7.67 species per site on unburned NE sites. On SW aspects, unburned sites also had greater tree species richness (10.6 species per site) than burned sites (8.0 species per site.

Mean tree diameter varied dramatically across burned and unburned sites (Fig. 3C). On NE aspects, burned sites had larger trees on average (23.27 cm DBH) compared to unburned sites (16.31 cm). In contrast, trees were larger on unburned SW sites (16.37 cm) than on burned SW sites (8.66 cm), which was consistent with our observations of regeneration following stand-replacement conditions on burned SW slopes.

Forest composition

North/east sites

We found clear differences in tree species composition across burned and unburned NE slopes. Unburned NE slopes exhibited communities consistent with fire suppression and mesophication, with sourwood (*Oxydendrum arboreum*) and mountain laurel (*Kalmia latifolia)*, as the most abundant species, followed red maple (*Acer rubrum*), chestnut oak (*Quercus montana*), and great rhododendron (*Rhododendron maximum)* (Fig. 6A).

In contrast, burned NE slopes were dominated by chestnut oak (*Quercus montana*; 33 individuals), white pine (*Pinus strobus*), and sourgum (*Nyssa sylvatica*), with lower densities of red maple (Fig. 6C). Overall, burned NE sites had lower species richness than unburned sites and were dominated by fire-adapted species with fewer individuals of mesophytic species (Fig. 6C).

South/west sites

Burned SW sites had more individuals present than other site types post-fire, and were dominated by Virginia pine (*Pinus virginiana*; 144 individuals across four sites), with many individuals of table mountain pine *(Pinus pungens*; 79 individuals*)* (Fig. 6D). In contrast, unburned SW sites were dominated by red maple and sourwood (Fig. 6B).

Together, these patterns are consistent with a shift from mesophytic hardwood dominance to fire-adapted oak and pine communities following wildfire, with stand-replacement regeneration on SW slopes and survival of large, fire-resistance trees on NE slopes.

Discussion

The Chestnut Knob Fire of 2016 resulted in changes to forest structure in burned forests at South Mountain State Park. Tree communities differed dramatically between burned and unburned slopes, and the exact nature of these differences were distinct between the two aspect categories. In sum, burned South/West slopes were dominated by small, dense regenerating pines, while burned North/East slopes were characterized by large fire-resistance and fire-adapted trees. Unburned North/East slopes showed signs of progressing mesophication. Here, we interpret the effects of the Chestnut Knob Fire on forests across the two slope aspects and discuss the implications of our results for forest ecology and management.

The Chestnut Knob Fire was of relatively low intensity and severity on North/East slopes, as evidenced by the large mean diameter of surviving trees (Fig. 3C) suggesting that very few mature trees were killed. Even for a fire during an extended drought, this is not unexpected based on interactions between microclimate and fire behavior (Cantlon, 1953, Parsons and DeBenedetti, 1979, Desta et al., 2004). Our results suggest that small diameter and fire-intolerant trees were disproportionately top-killed or killed outright, leading to a shift in forest composition away from a mesophytic ecosystem dominated by red maple and sourwood (Fig. 6A) to forest dominated by chestnut oak, a fire-adapted species, and white pine, which is fire resistant when mature (Fig. 6C). Although we lack pre-fire data, space-for-time comparison to unburned slopes, which had smaller average and more variable tree diameters, suggests that the 2016 fire primarily affected small-diameter trees on North/East slopes. As a result, mature, and therefore fire-resistant, trees remain, and the community has shifted toward fire-adapted species and fire-tolerant individuals, with less evidence of mesophication (Figs. 6A,C).

On South/West slopes, the Chestnut Knob fire also changed forest structure, but more dramatically, reflecting the near stand-replacement severity on xeric SW ridges compared to dry-mesic NE slopes. After the fire, tree communities on SW slopes were primarily composed of abundant (Fig. 3A) small diameter (Fig. 3C) new growth of *Pinus* saplings that colonized the slopes, vs. the mostly mature, fire-adapted or fire-resistant trees persistent on NE slopes. SW slopes are now characterized by a high densities of young Virginia Pine, a pioneer species, and a fire-adapted species with serotinous cones, Table Mountain Pine. Virginia Pine was present only in low abundances at unburned SW slopes, suggesting that the higher severity of the wildfire on SW ridges facilitated rapid colonization by this disturbance-adapted species.

Implications of forest community changes post-fire

In the context of South Mountains State Park and the southeastern US Piedmont, the effects of the Chestnut Knob Wildfire differed dramatically by slope aspect. Pre-existing differences between SW and NE slopes, presumably driven by microclimate, were magnified by variation in fire severity between the two slope aspect categories (Parsons and DiBenedetti, 1979).

On NE slopes, the Chestnut Knob fire appears to have achieved effects similar to those of prescribed fire in dry-mesic forests experiencing mesophication, leading to a partial reversal or “setting back” of mesophication. Given that our surveys occurred 4–6 years after the fire, the continued reduced presence of mesophytic species on burned NE slopes suggests short-term persistence of primarily dry-mesic forest conditions. However, in the absence of future management, mesophication is likely to resume as mesic species regenerate, re-colonize, and eventually regain the dominance seen on unburned slopes (Fig. 6A), consistent with positive-feedback processes such as mesophication (Alexander et al., 2021). Evidence in our surveys of resprouting red maple stems on burned NE slopes confirms both the low severity of the wildfire on NE slopes but also the first steps back toward mesophication.

The stand-reducing nature of the wildfire on xeric SW slopes contrasts sharply with the fire's more moderate management-scale effects on NE slopes. Mature trees did survive the Chestnut Knob fire on burned SW slopes, but over 70% of the trees in our post-fire survey data were less than 5 cm DBH, indicating the dominance by recent regeneration, overwhelmingly *Pinus* species. Densities of large trees > 20 cm DBH were reduced by almost 50% as compared to unburned slopes, whereas burned NE slopes showed little change in tree density (55 vs. 56 large trees across all burned and unburned transects; respectively). Although not complete stand replacement, on SW slopes the wildfire created conditions favorable for colonization by species adapted to post-fire environments, particularly Virginia Pine and Table Mountain Pine.

Over time, the pine-dominated stands on SW slopes may shift toward dominance by Table Mountain Pine due to the susceptibility of Virginia Pine to infection by bark beetles and its relatively low fire tolerance (Clabo & Clatterbuck, 2005). However, the current high abundance of Virginia Pine may allow it to outcompete Table Mountain Pine. Management interventions such as low-intensity prescribed fire or mechanical thinning may be needed to reduce competition and promote development of a fire-adapted pine community.

More broadly, our results suggest that wildfire in the Piedmont can promote shifts toward fire-adapted mixed forests, with specific outcomes determined in part by slope aspect. As climate change progresses, fire likelihood and severity are expected to increase (Ingram et al., 2013), suggesting that wildfire will play an increasingly important role in shaping southeastern forest ecosystems. Future research should continue to examine longer-term impacts of wildfire on tree community composition and the drivers of variability among sites.

Conclusion

Tree species composition following wildfire varies with slope aspect and burn severity. Burn severity was typically greater on South/West slopes, resulting in communities dominated by new growth, particularly Virginia Pine. In contrast, burned North/East sites were composed of larger mature trees and shifted toward fire-adapted species such as Chestnut Oak. Across both slope types, wildfire promoted increased abundance of fire-adapted species.

Given the high densities of young Virginia Pine on burned SW slopes, management actions such as low-intensity prescribed fire may be important for managing fuel loads, More generally, periodic fire may be necessary to maintain fire-adapted mixed oak-pine forests and prevent continued mesophication in Piedmont forests ecosystems of the southeastern United States.

Declarations

Clinical trial number

not applicable.

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Author Contribution

WG and KGS conceptualized the study and WG, RJA, EVS, CV, and KGS designed the study. All authors collected data. KEP, WG, EVS, RJA, CV, NZ, and KGS analyzed the data. WG, CV, and NZ produced early draft manuscripts and KEP and KGS wrote and revised the final manuscript.

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Data Availability

Data are available upon request by the authors.

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Figures

Figure 1

A panoramic view of burned (left) and unburned (right) slopes on a ridgeline at South Mountains State Park. The location of trails on ridges allowed for the juxtaposition of burned and unburned sites, on similar and different slope aspects. Photo by Kevin G. Smith in June, 2021.

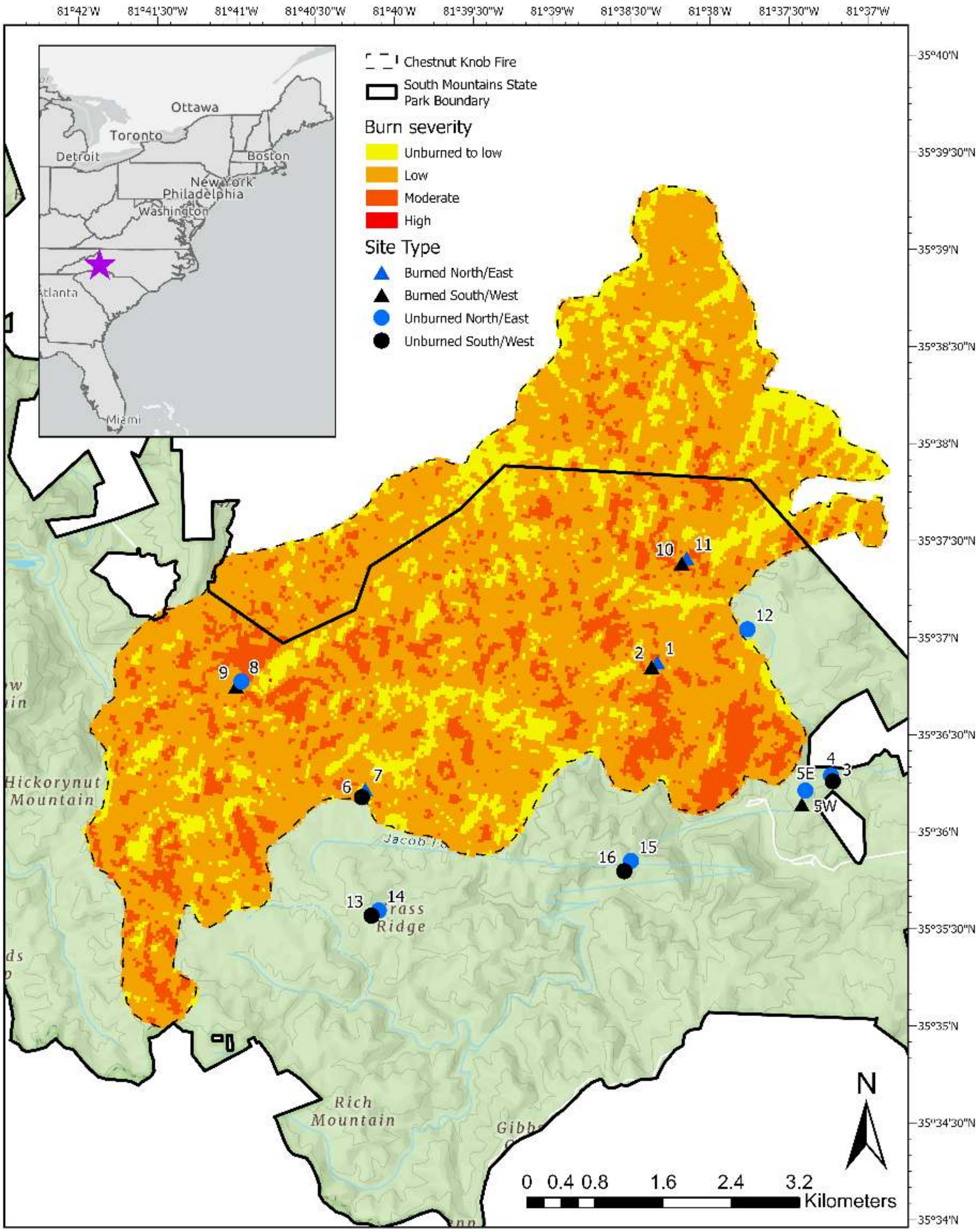

Figure 2

Map of field sites and the Chestnut Knob Fire burn severity. Numbers indicate sites and symbols indicate aspect and burn status of each site. Burn severity data is from the US Forest Service Monitoring Trends in Burn Severity Database. Note that site 5W is outside of the burn polygon, but is a burned site; there was a moderate to high severity spot fire not captured by remote sensing in this location. Additionally, site 8 is an unburned patch of mesic forest within the broader burned area; we saw no evidence of burn while surveying at this site.

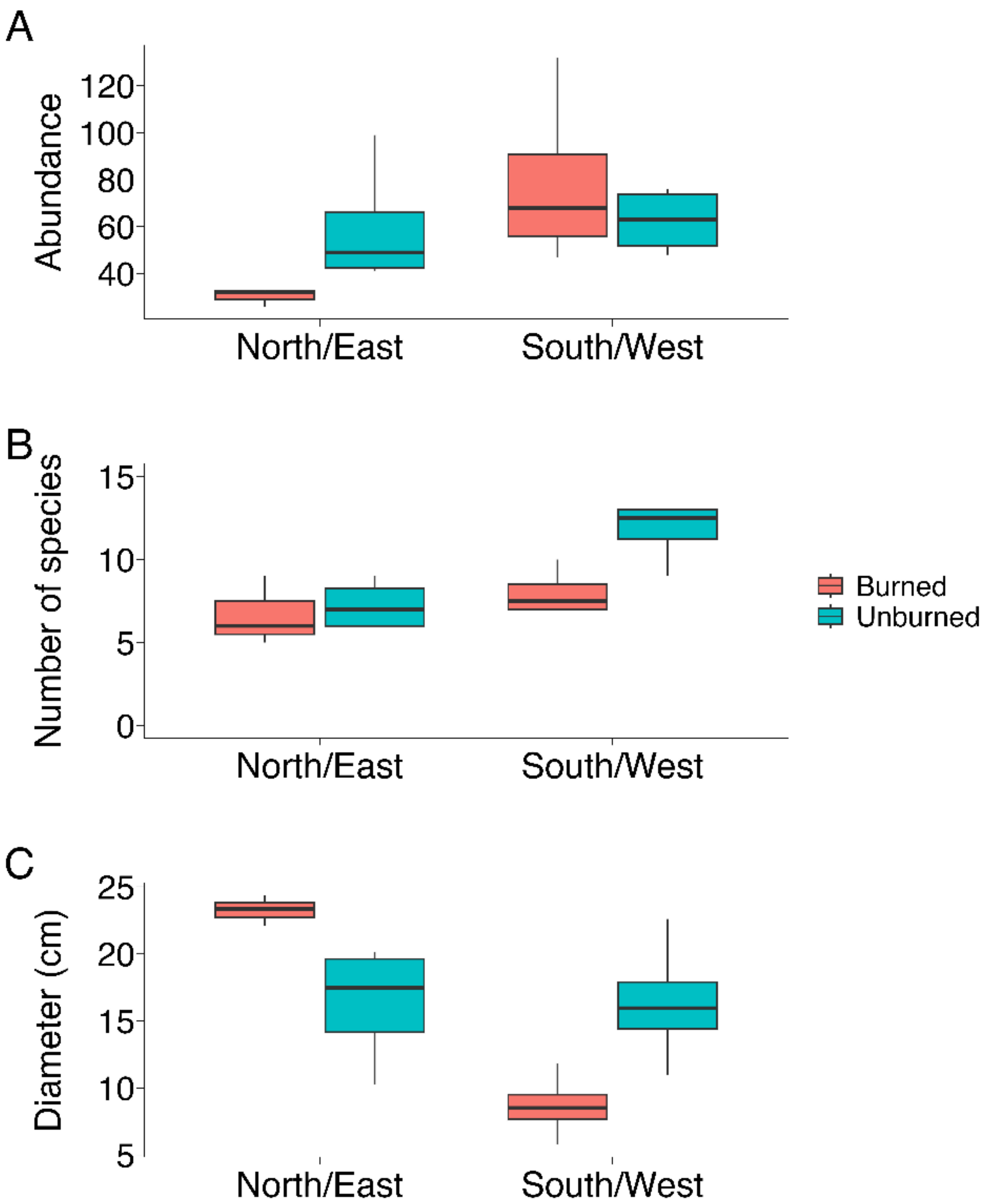

Figure 3

A) Comparison between tree abundance, aspect, and whether the site was burned or unburned by the Chestnut Knob Wildfire. B) Number of species present for NE and SW aspects, compared between burned and unburned sites. C) Comparison of average DBH in cm at each aspect by burn condition. All error bars are 95% CIs.

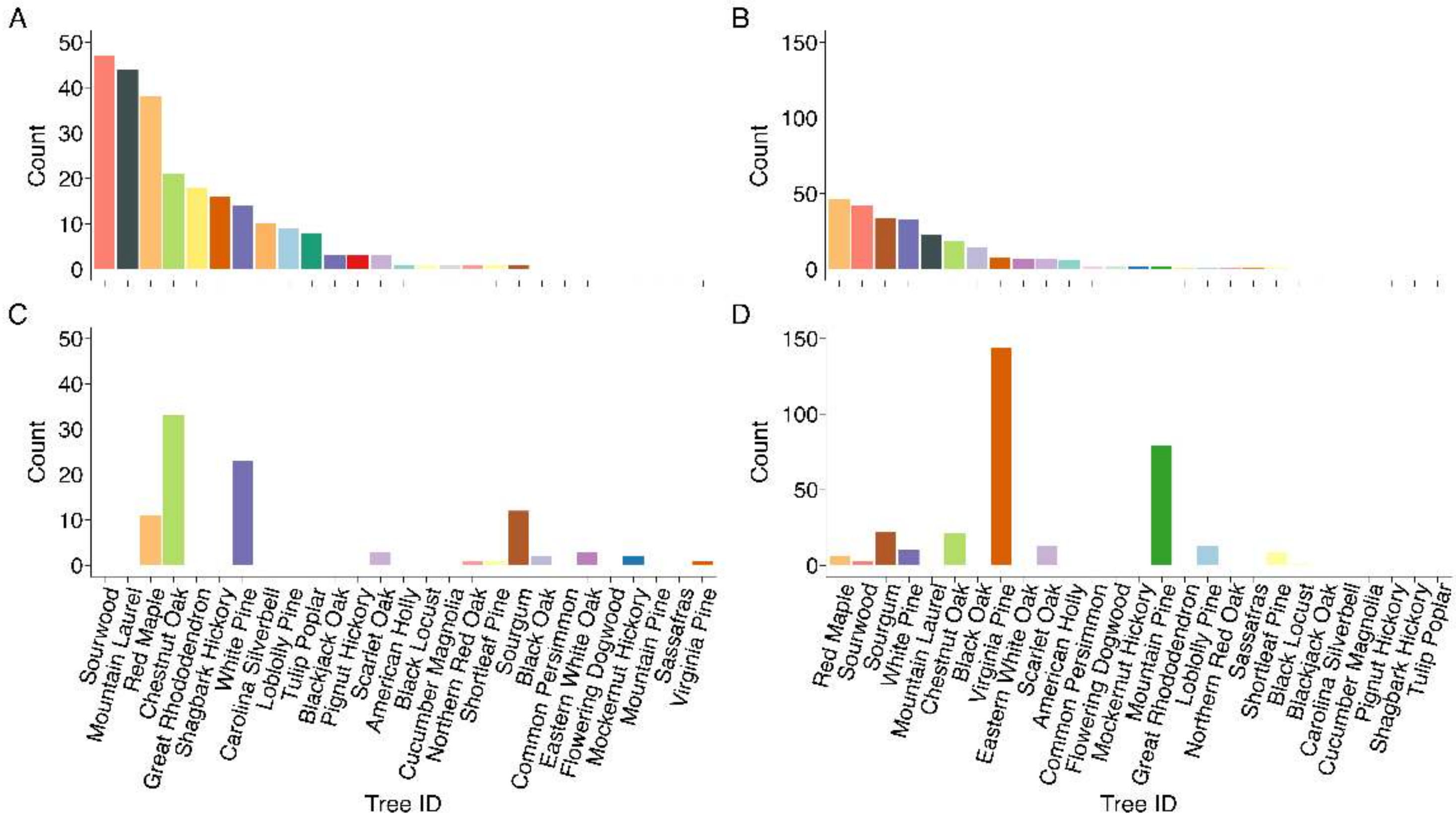

Figure 4

Figure 6. A) Species abundance distributions for all species on unburned North/East slopes. B) Species abundance distributions for all species on unburned South/West slopes. C) Species abundance distributions for all species on burned North/East slopes. D) Species abundance distributions for all species on burned South/West slopes. Tree species are presented in the same order across the two panels to enable comparison of compositional differences between burned and unburned sites.